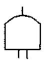
ATTACHMENT A. DETERMINATION OF INTEGRITY AND CONTINUITY OF SERVICE OBJECTIVES USING THE RISK TREE METHOD

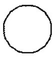
1. The risk tree method is a graphical method of expressing the logical relationship between a particular failure condition and the causes or failures leading to this condition. It is an application of fault tree analysis being used in the aerospace industry.

1.1 The method employs a set of logic symbols to show the relationship between the various causes of failure. The following symbols are used in this guidance material.


The "AND" gate describes the logical operation whereby the coexistence of all input events is required to produce the output event.


The "OR" gate defines a situation whereby the output event will exist if one or more of the input events exist.


The rectangle identifies an event that results from the combination of fault or failure events through the input logic gate.


The circle describes a primary failure event that requires no further development. Frequency and mode of failure of items so identified are derived from empirical data.

1.2 The method gives a visual representation of sequences and combinations of events leading to the top failure event. The method can also be used to determine the probability of the top event occurring, provided that the probabilities of the individual events are known or can be estimated. In the case of simple fault trees probabilities can be directly calculated, but care must be taken if the primary failure events are not independent, i.e. if failure events are common to more than one path.

1.3 In this guidance material the acceptable probability of the top level event occurring is determined by the risk allocation and the fault tree is used to further partition the risk into integrity and continuity of service risks. Therefore, the term "risk tree" is used rather than "fault tree".

2. A generic risk tree for aircraft landing operations is given in Figure A-1. The top event for this tree is taken to be the loss of the aircraft due to a failure of the non-aircraft guidance system. The causes of this event are either an integrity failure of the primary non-aircraft guidance equipment or a continuity of service (COS) failure of the non-aircraft guidance system (i.e. both the primary system and any secondary system used to support a discontinued approach/missed approach). The primary non-aircraft guidance system is considered to have a number of elements, 1 to N, for example azimuth, elevation and DME/P in the case of MLS. The secondary guidance system may be an alternative non-aircraft system, or in some cases an aircraft navigation system such as an inertial reference system.

2.1 The following probabilities can be defined:

P_a = Probability of aircraft loss due to a failure of the non-aircraft guidance system.

P_b = Probability of aircraft loss due to primary guidance integrity failure.

P_c = Probability of aircraft loss due to COS failure.

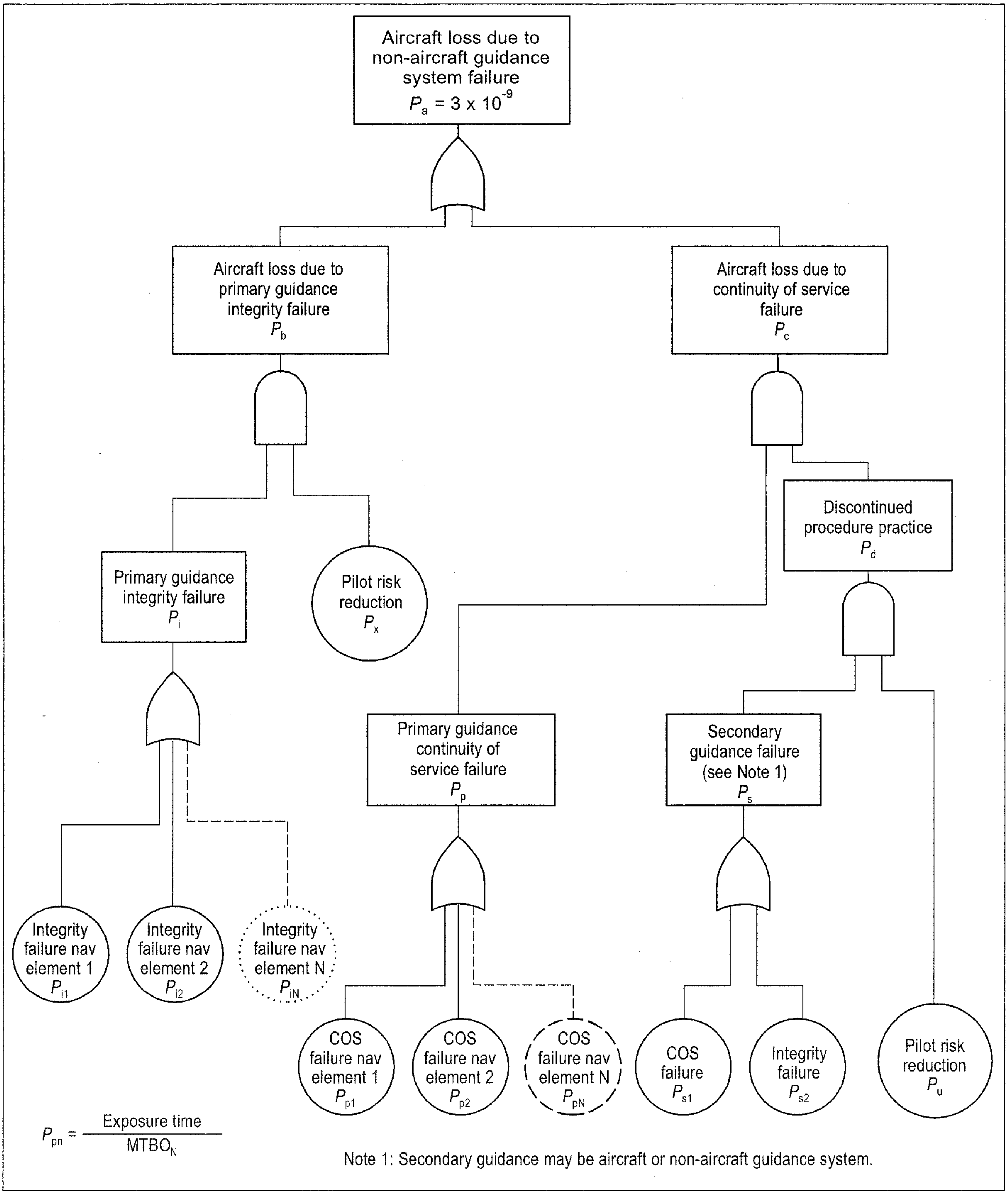


Figure A-1. Generic risk tree

P_x = Probability that the pilot is unable to detect and intervene successfully following a primary guidance integrity failure. This risk reduction factor is only relevant in those cases where an integrity failure of the guidance system may be detected by the pilot, e.g. at decision height in a Category I ILS approach.

P_p = Probability of primary guidance COS failure.

P_d = Probability of aircraft loss during a discontinued approach/missed approach procedure.

P_i = Probability of primary guidance integrity failure.

P_{iN} = Probability of integrity failure in Nav element N.

P_{pN} = Probability of COS failure in Nav element N.

P_s = Probability of aircraft loss during a discontinued approach/missed approach with secondary guidance.

P_{s1} = Probability of secondary guidance COS failure.

P_{s2} = Probability of secondary guidance integrity failure.

P_u = Probability that the pilot is unable to intervene successfully following primary guidance COS failure with no secondary guidance available.

Where:

$$P_a = P_b + P_c$$

$$P_b = P_i \times P_x$$

$$P_i = P_{i1} + P_{i2} + \ldots P_{iN}$$

$$P_c = P_p \times P_d$$

$$P_p = P_{p1} + P_{p2} + \ldots P_{pN}$$

$$P_d = P_s \times P_u$$

$$P_s = P_{s1} + P_{s2}$$

2.2 The acceptable probability of the top event, P_a, can be determined by partitioning the global risk factor for the approach and landing operation to the various classes of accident. Using this method an acceptable value for P_a of 3×10^{-9} has been determined. This is consistent with the smallest probability that can be assigned to each ground navigation element, which is 1×10^{-9} (normally divided equally between integrity and COS failures).

2.3 The risk analysis above assumes no equipment design errors.

3. *Example of the use of the risk tree — MLS Category III basic operations (Figure A-2).*

3.1 In this case there are only two navigation elements involved (e.g. azimuth and elevation). It is assumed that no secondary guidance is available following a COS failure of the primary guidance, the normal procedure being to maintain heading and climb.

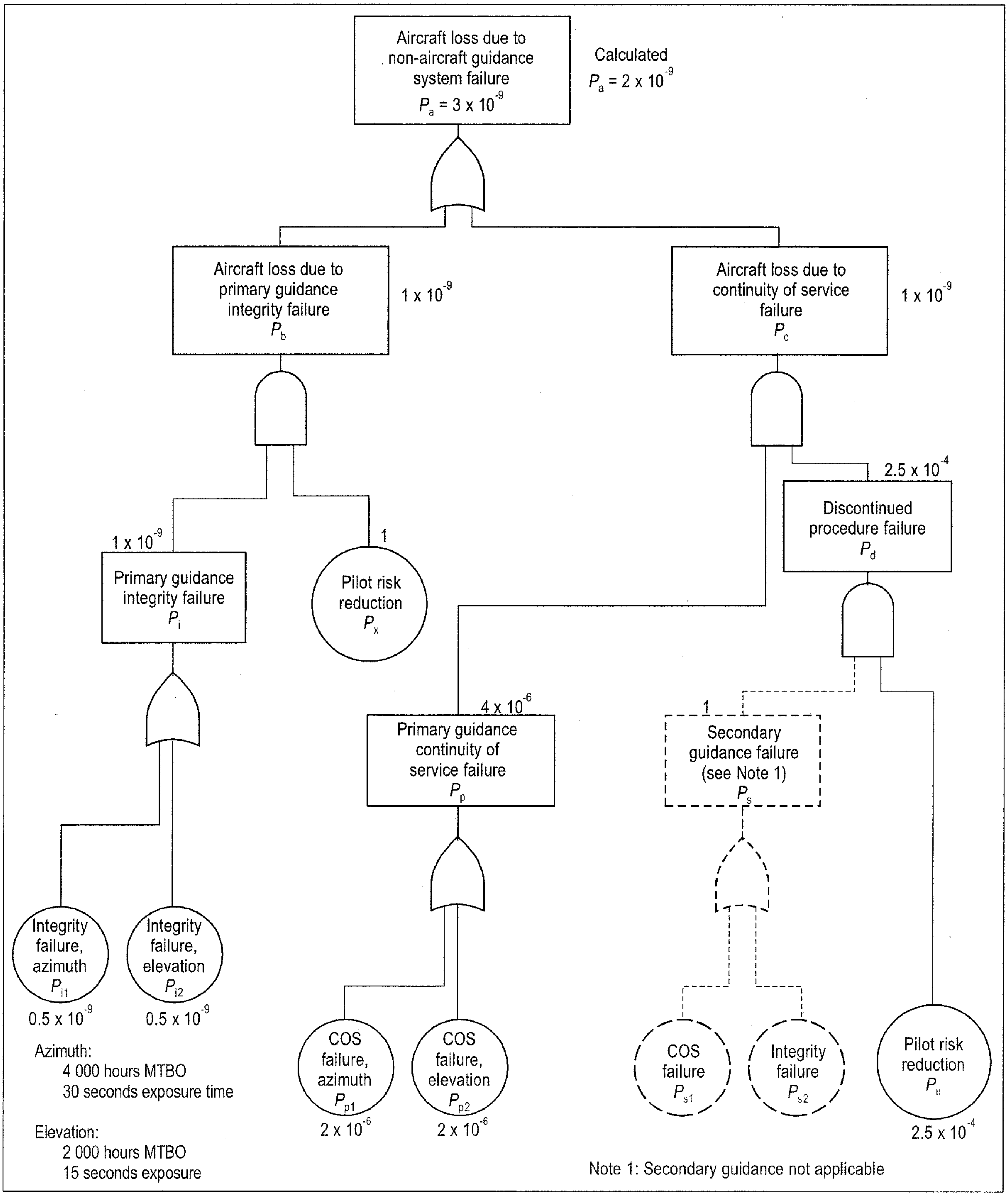


Figure A-2. MLS Category III landing risk tree

$P_{i1} = P_{i2} = 0.5 \times 10^{-9}$

$P_{p1} = P_{p2} = 2 \times 10^{-6}$

Note.— These figures are from Attachment G, Table G-15, Level 4 and assume exposure times of 30 and 15 seconds, and MTBOs of 4 000 and 2 000 hours for the azimuth and elevation elements respectively.

$P_s = 1.0$

Note.— Since there is no guided discontinued approach/missed approach procedure using secondary guidance, the probability of an accident during the procedure is taken to be 1.

$P_x = 1.0$

Note.— It is assumed in this example that in a Category III operation the pilot is unable to intervene in the event of an integrity failure in the ground system. The risk reduction factor is therefore equal to 1.

$P_u = 2.5 \text{ x } 10^{-4}$

Note.— The pilot risk reduction factor is estimated at 1 in 4 000 based on a study of accidents to aircraft conducting approaches to land using ground guidance systems. This is the risk reduction factor assumed due to pilot intervention following a continuity of service failure.

Therefore:

$P_i = 1 \times 10^{-9}$

$P_p = 4 \times 10^{-6}$

$P_d = 2.5 \times 10^{-4}$

$P_c = 4 \times 10^{-6} \times 2.5 \times 10^{-4} = 1 \times 10^{-9}$

$P_b = 1 \times 10^{-9} \times 1$

and:

calculated $P_a = 2 \times 10^{-9}$.

3.2 There is therefore a margin of 1×10^{-9} on the generic requirement.

4. *Application of the risk tree to an MLS/RNAV approach in an obstacle rich environment (Figure A-3).*

4.1 In this case there are three navigation elements (i.e. azimuth, elevation and DME/P) and all are assumed to meet the integrity and COS requirements for Level 4 azimuth equipment; i.e integrity = $1 - 0.5 \times 10^{-9}$ and MTBO = 4 000 hours.

$P_{i1} = P_{i2} = P_{i3} = 0.5 \times 10^{-9}$

$P_x = 1.0$

Note.— It is assumed that the pilot is unable to intervene in the event of an integrity failure in the ground system.

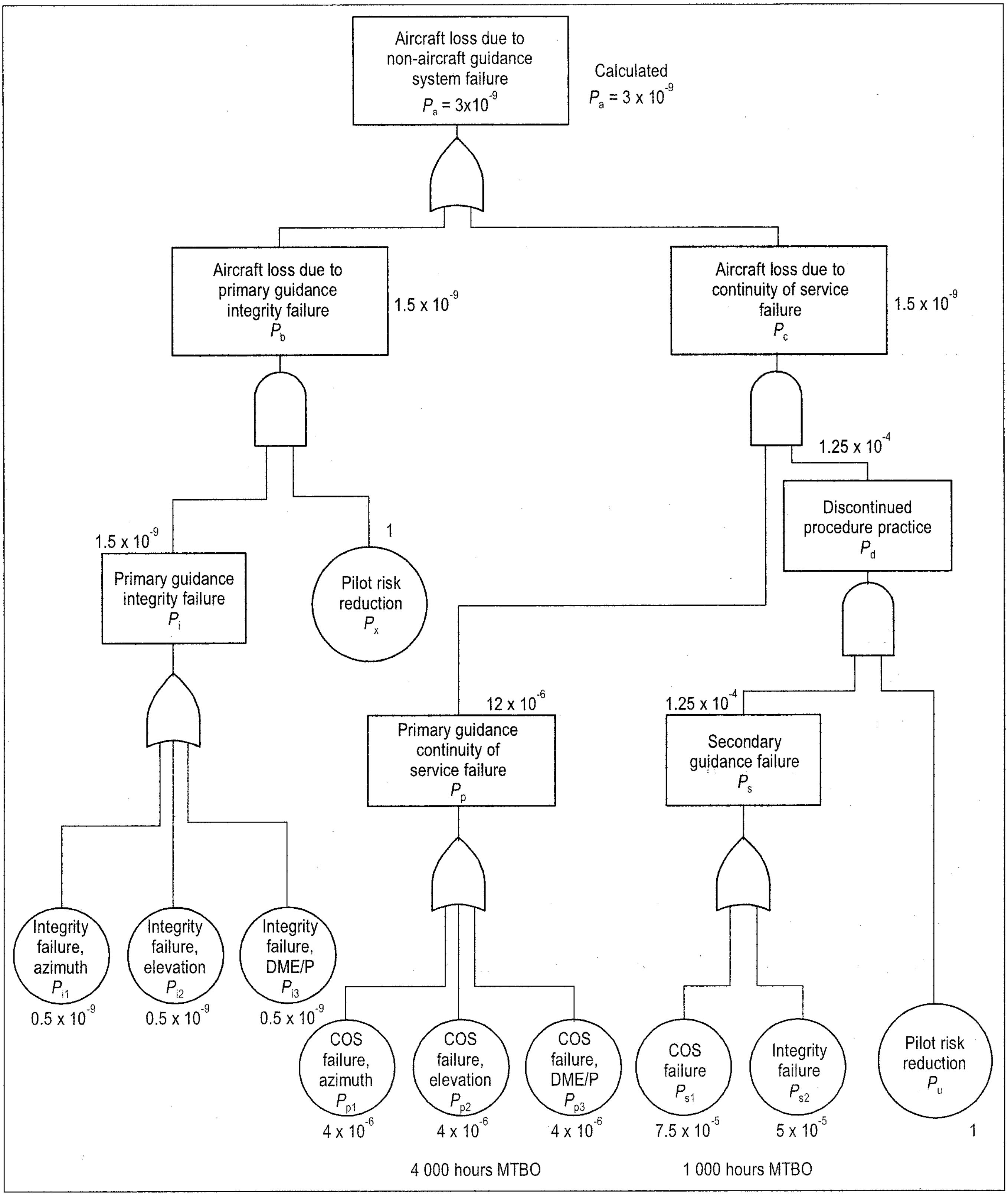


Figure A-3. MLS/RNAV obstacle rich risk tree

$P_{p1} = P_{p2} = P_{p3} = 4 \times 10^{-6}$

Note.— This assumes an obstacle exposure time (OET) of 60 seconds, and an MTBO of 4 000 for all ground elements.

$P_u = 1.0$

Note.— It is assumed that an unguided discontinued approach/missed approach procedure is unacceptable. The probability of an accident during such a procedure is therefore taken to be 1.

4.2 In the case of an MLS/RNAV procedure in an obstacle rich environment, it is assumed that secondary guidance will be essential to execute a safe discontinued approach/missed approach procedure during the period of exposure to the obstacles.

$P_{s1} = 7.5 \times 10^{-5}$

Note.— This is the probability of a COS failure of the secondary guidance ground equipment. It is assumed here that the secondary guidance system has a MTBO of 1 000 hours and that the exposure time is 270 seconds. The exposure time to a failure of the secondary guidance is dependent on the point in the procedure at which the availability of secondary guidance is confirmed. Assuming that this would be prior to the commencement of the MLS/RNAV procedure, and that the pilot would not be required to reconfirm the availability of secondary guidance before commencing the critical obstacle rich part of the procedure, the exposure time could be several minutes.

$P_{s2} = 5 \times 10^{-5}$

Note.— This is the integrity required by the secondary guidance system.

Therefore:

$P_i = 1.5 \times 10^{-9}$

$P_b = 1.5 \times 10^{-9}$

$P_p = 12 \times 10^{-6}$

$P_s = 7.5 \times 10^{-5} + 5 \times 10^{-5} = 1.25 \times 10^{-4}$

$P_d = 1.25 \times 10^{-4}$

$P_c = 12 \times 10^{-6} \times 1.25 \times 10^{-4} = 1.5 \times 10^{-9}$

and:

calculated $P_a = 3 \times 10^{-9}$, as required.

Note.— For obstacle exposure times greater than 60 seconds, it will be necessary to either increase the MTBOs of the primary guidance or to increase the risk reduction factor due to the secondary guidance. For example, if the exposure time is increased to 90 seconds, the MTBOs of the primary guidance must be increased to 6 000 hours or the MTBO of the secondary guidance increased to 2 250 hours. There are clearly trade-offs between the reliability of the primary guidance, the exposure time, and the reliability and integrity of the secondary guidance. The risk tree method can be used to examine individual MLS/RNAV procedures and determine the appropriate reliability and integrity requirements for the primary and secondary guidance.

ATTACHMENT B. STRATEGY FOR INTRODUCTION AND APPLICATION OF NON-VISUAL AIDS TO APPROACH AND LANDING

(see Chapter 2, 2.1)

1. Introduction

1.1 Various elements have an influence on all weather operations in terms of safety, efficiency and flexibility. The evolution of new techniques requires a flexible approach to the concept of all weather operations to obtain full benefits of technical development. To create this flexibility a strategy enables, through identification of its objectives and thoughts behind the strategy, incorporation of new technical developments or ideas into this strategy. The strategy does not assume a rapid transition to a single globally established system or selection of systems to support approach and landing operations.

1.2 The strategy addresses the application of non-visual aids to approach and landing with vertical guidance (APV) and precision approach and landing operations.

2. Objectives of strategy

The strategy must:

a) maintain at least the current safety level of all weather operations;

b) retain at least the existing level or planned improved level of service;

c) maintain global interoperability;

d) provide regional flexibility based on coordinated regional planning;

e) be applicable until at least the year 2020; and

f) take account of economic, operational and technical issues.

3. Considerations

3.1 General

The following considerations are based on the assumption that the operational requirement and the required commitment are available and the required effort is applied.

3.2 ILS-related considerations

a) There is a risk that ILS Category II or III operations cannot be safely sustained at specific locations;

b) Annex 10, Volume I, Chapter 3, 3.1.4 contains interference immunity performance standards for ILS receivers;

c) expansion of ILS is limited by channel availability (40 channels);

d) many aging ILS ground installations will need to be replaced; and

e) in most areas of the world, ILS can be maintained in the foreseeable future.

3.3 MLS-related considerations

a) MLS Category I is operational;

b) Category II capable ground equipment is certified. Ground and airborne Category IIIB equipment certification is in progress and is scheduled to be completed in the 2004-2005 time frame; and

c) MLS implementation is planned at specific locations to improve runway utilization in low visibility conditions.

3.4 GNSS-related considerations

a) Standards and Recommended Practices (SARPs) are in place for GNSS with augmentation to support APV and Category I precision approach;

b) SARPs for ground-based regional augmentation system (GRAS) for APV operations are under development;

c) GNSS with satellite-based augmentation system (SBAS) for APV operations is operational in some regions of the world;

d) GNSS with ground-based augmentation system (GBAS) for Category I precision approach operations is expected to be operational by 2006;

e) it is not expected that an internationally accepted GNSS with augmentation as required may be available for Category II and III operations before the 2010-2015 time frame;

f) technical and operational issues associated with GNSS approach, landing and departure operations must be solved in a timely manner; and

g) institutional issues associated with GNSS approach, landing and departure operations must be solved in a timely manner.

3.5 Multi-modal airborne approach and landing capability considerations

To enable this strategy, a multi-modal airborne approach and landing capability is necessary and is expected to be available.

3.6 Other considerations

a) There is an increasing demand for Category II and III operations;

b) GNSS can potentially offer unique operational benefits for low-visibility operations, including new procedures, flexible siting requirements and provision of airport surface guidance;

c) only the three standard systems (ILS, MLS and GNSS with augmentation as required) are considered to play a major role in supporting all weather operations. The use of head-up displays in conjunction with enhanced and/or synthetic vision systems may provide operational benefits;

d) a consequence of the global strategy is that there will not be a rapid transition from ILS to new systems such as GNSS or MLS. It is therefore essential for the implementation of the strategy that the radio frequency spectrum used by all of these systems be adequately protected;

e) to the extent practical, a transition directly from ILS to GNSS is preferable. In some States, however, it may not be possible to make this transition without losing the current level of Category II or III operations;

f) as long as some users of a given runway continue to rely on ILS, the potential operational benefits resulting from the introduction of new landing systems may be limited by the constraints of mixed-system operations;

g) APV operations may be conducted using GNSS with augmentation as required or barometric vertical guidance, and GNSS with ABAS or DME/DME RNAV lateral guidance; and

h) APV operations provide enhanced safety and generally lower operational minima as compared to non-precision approaches.

4. Strategy

Based on the considerations above, the need to consult aircraft operators and international organizations, and to ensure safety, efficiency and cost-effectiveness of the proposed solutions, the global strategy is to:

a) continue ILS operations to the highest level of service as long as operationally acceptable and economically beneficial so as to ensure that airport access is not denied to aircraft solely equipped with ILS;

b) implement MLS where operationally required and economically beneficial;

c) implement GNSS with augmentation (i.e. ABAS, SBAS, GBAS) as required for APV and Category I operations where operationally required and economically beneficial, while ensuring that the issues associated with ionospheric propagation in the equatorial regions are duly addressed and resolved;

d) promote the development and use of a multi-modal airborne approach and landing capability;

e) promote the use of APV operations, particularly those using GNSS vertical guidance, to enhance safety and accessibility;

f) identify and resolve operational and technical feasibility issues for GNSS with ground-based augmentation system (GBAS) to support Category II and III operations. Implement GNSS for Category II and III operations where operationally required and economically beneficial; and

g) enable each region to develop an implementation strategy for these systems in line with the global strategy.

ATTACHMENT C. INFORMATION AND MATERIAL FOR GUIDANCE IN THE APPLICATION OF THE STANDARDS AND RECOMMENDED PRACTICES FOR ILS, VOR, PAR, 75 MHz MARKER BEACONS (EN-ROUTE), NDB AND DME

1. Introduction

The material in this Attachment is intended for guidance and clarification purposes and is not to be considered as part of the specifications or as part of the Standards and Recommended Practices contained in Volume I.

For the clarity of understanding of the text that follows and to facilitate the ready exchange of thoughts on closely associated concepts, the following definitions are included.

Definitions relating to the Instrument Landing System (ILS)

Note.— The terms given here are in most cases capable of use either without prefix or in association with the prefixes "nominal" and "indicated". Such usages are intended to convey the following meanings:

The prefix "nominal": *the design characteristics of an element or concept.*

No prefix: *the achieved characteristics of an element or concept.*

The prefix "indicated": *the achieved characteristics of an element or concept, as indicated on a receiver (i.e. including the errors of the receiving installation).*

Localizer system	ILS glide path system

Slant course line. The line formed at the intersection of the course surface and the plane of the nominal ILS glide path.

	False ILS glide path. Those loci of points in the vertical plane containing the runway centre line at which the DDM is zero, other than that locus of points forming the ILS glide path.

Displacement error. The angular or linear displacement of any point of zero DDM with respect to the nominal course line or the nominal ILS glide path respectively.

Linearity sector. A sector containing the course line or ILS glide path, within a course sector or an ILS glide path sector, respectively, in which the increment of DDM per unit of displacement remains substantially constant.

Low DDM zone. A zone outside a course sector or an ILS glide path sector in which the DDM is less than the minimum value specified for the zone.

Note.— The minimum values of DDM related to such zones are specified in Chapter 3, 3.1.3.7 and 3.1.5.6.

Plane of the nominal ILS glide path. A plane perpendicular to the vertical plane of the runway centre line extended and containing the nominal ILS glide path.

Localizer system	ILS glide path system
Indicated course line. The locus of points in any horizontal plane at which the receiver indicator deflection is zero.	***Indicated ILS glide path.*** The locus of points in the vertical plane containing the runway centre line at which the receiver indicator deflection is zero.

Indicated slant course line. The line formed at the intersection of the indicated course surface and the plane of the nominal ILS glide path.

	Indicated ILS glide path angle. The angle above the horizontal plane of the indicated ILS glide path.
Indicated course sector. A sector in any horizontal plane containing the indicated course line in which the receiver indicator deflection remains within full-scale values.	***Indicated ILS glide path sector.*** The sector containing the indicated ILS glide path in which the receiver indicator deflection remains within full-scale values.
Localizer course bend. A course bend is an aberration of the localizer course line with respect to its nominal position.	***ILS glide path bend.*** An ILS glide path bend is an aberration of the ILS glide path with respect to its nominal position.

Incremental sensitivity. The increment of receiver indicator current per unit change of receiver antenna displacement from the nominal course line or nominal ILS glide path.

Flat zone. A zone within an indicated course sector or an indicated ILS glide path sector in which the slope of the sector characteristic curve is zero.

Reversal zone. A zone within an indicated course sector or an indicated ILS glide path sector in which the slope of the sector characteristic curve is negative.

2. Material concerning ILS installations

2.1 Operational objectives, design and maintenance objectives, and definition of course structure for Facility Performance Categories

2.1.1 The Facility Performance Categories defined in Chapter 3, 3.1.1 have operational objectives as follows:

Category I operation: A precision instrument approach and landing with a decision height not lower than 60 m (200 ft) and with either a visibility not less than 800 m or a runway visual range not less than 550 m.

Category II operation: A precision instrument approach and landing with a decision height lower than 60 m (200 ft) but not lower than 30 m (100 ft), and a runway visual range not less than 350 m.

Category IIIA operation: A precision instrument approach and landing with:

a) a decision height lower than 30 m (100 ft), or no decision height; and

b) a runway visual range not less than 200 m.

Category IIIB operation: A precision instrument approach and landing with:

a) a decision height lower than 15 m (50 ft), or no decision height; and

b) a runway visual range less than 200 m but not less than 50 m.

Category IIIC operation: A precision instrument approach and landing with no decision height and no runway visual range limitations.

2.1.2 Relevant to these objectives will be the type of aircraft using the ILS and the capabilities of the aircraft flight guidance system(s). Modern aircraft fitted with equipment of appropriate design are assumed in these objectives. In practice, however, operational capabilities may extend beyond the specific objectives given at 2.1.1.

2.1.2.1 The availability of fail-passive and fail-operational flight guidance systems in conjunction with an ILS ground system which provides adequate guidance with an appropriate level of continuity of service and integrity for the particular case can permit the attainment of operational objectives which do not coincide with those described at 2.1.1.

2.1.2.2 For modern aircraft fitted with automatic approach and landing systems the routine use of such systems is being encouraged by aircraft operating agencies in conditions where the progress of the approach can be visually monitored by the flight crew. For example, such operations may be conducted on Facility Performance Category I — ILS where the guidance quality and coverage exceeds basic requirements given at Chapter 3, 3.1.3.4.1 and extends down to the runway.

2.1.2.3 In order to fully exploit the potential benefits of modern aircraft automatic flight control systems there is a related need for a method of describing ground based ILS more completely than can be achieved by reference solely to the Facility Performance Category. This is achieved by the ILS classification system using the three designated characters. It provides a description of those performance aspects which are required to be known from an operations viewpoint in order to decide the operational applications which a specific ILS could support.

2.1.2.4 The ILS classification scheme provides a means to make known the additional capabilities that may be available from a particular ILS ground facility, beyond those associated with the facilities defined in Chapter 3, 3.1.1. These additional capabilities can be exploited in order to permit operational use according to 2.1.2.1 and 2.1.2.2 to be approved down to and below the values stated in the operational objectives described in 2.1.

2.1.2.5 An example of the classification system is presented in 2.14.3.

2.1.3 Guidance material relating to airborne equipment tolerances appropriate to the attainment of the objectives of ILS Operational Performance Categories I and II are given in 2.2.4 and 2.2.5. In the case of Category II operations utilizing appropriate ILS facilities, it may be feasible to allow operations by aircraft with low approach speeds and adequate demonstrable manoeuvrability fitted with airborne equipment having tolerances less stringent than those specified for Category II.

Note.— The following guidance material is intended to assist States when they are evaluating the acceptability of ILS localizer courses and glide paths having bends. Although, by definition, course bends and glide path bends are related to the nominal positions of the localizer course and glide path respectively, the evaluation of high frequency aberrations is based *on the deviations from the mean course or path. The material in 2.1.6 and Figure C-2 regarding the evaluation of bends indicates how the bends relate to the mean position of the course and path. Aircraft recordings will normally be in this form.*

2.1.4 *Course bends.* Localizer course bends should be evaluated in terms of the course structure specified in Chapter 3, 3.1.3.4. With regard to landing and rollout in Category III conditions, this course structure is based on the desire to provide adequate guidance for manual and/or automatic operations along the runway in low visibility conditions. With regard to Category I performance in the approach phase, this course structure is based on the desire to restrict aircraft deviations, due to course bends (95 per cent probability basis) at the 30 m (100 ft) height, to lateral displacement of less than 10 m (30 ft). With regard to Categories II and III performance in the approach phase, this course structure is based on the desire to restrict aircraft deviations due to course bends (95 per cent probability basis) in the region between ILS Point B and the ILS reference datum (Category II facilities) or Point D (Category III facilities), to less than 2 degrees of roll and pitch attitude and to lateral displacement of less than 5 m (15 ft).

Note 1.— Course bends are unacceptable when they preclude an aircraft under normal conditions from reaching the decision height in a stable attitude and at a position, within acceptable limits of displacement from the course line, from which a safe landing can be effected. Automatic and semi-automatic coupling is affected to a greater degree than manual coupling by the presence of bends. Excessive control activity after the aircraft has settled on an approach may preclude it from satisfactorily completing an approach or landing. Additionally, when automatic coupling is used, there may be an operational requirement to continue the approach below the decision height. Aircraft guidance can be satisfied if the specification for course structure in Chapter 3, 3.1.3.4, is met.

Note 2.— Bends or other irregularities that are not acceptable will normally be ascertained by flight tests in stable air conditions requiring precision flight check techniques.

2.1.5 *ILS glide path bends.* Bends should be evaluated in terms of the ILS glide path structure specified in Chapter 3, 3.1.5.4. With regard to Category I performance, this glide path structure is based on the desire to restrict aircraft deviations due to glide path bends (95 per cent probability basis) at the 30 m (100 ft) height, to vertical displacements of less than 3 m (10 ft). With regard to Categories II and III performance, this glide path structure is based on the desire to restrict aircraft deviations due to path bends (95 per cent probability basis) at the 15 m (50 ft) height, to less than 2 degrees of roll and pitch attitude and to vertical displacements of less than 1.2 m (4 ft).

Note 1.— Path bends are unacceptable when they preclude an aircraft under normal conditions from reaching the decision height in a stable attitude and at a position, within acceptable limits of displacement from the ILS glide path, from which a safe landing can be effected. Automatic and semi-automatic coupling is affected to a greater degree than manual coupling by the presence of bends. Additionally, when automatic coupling is used, there may be an operational requirement to continue the approach below the decision height. Aircraft guidance can be satisfied if the specification for ILS glide path structure in Chapter 3, 3.1.4.4, is met.

Note 2.— Bends or other irregularities that are not acceptable will normally be ascertained by precision flight tests, supplemented as necessary by special ground measurements.

2.1.6 *Application of localizer course/glide path bend amplitude Standard.* In applying the specification for localizer course structure (Chapter 3, 3.1.3.4) and ILS glide path structure (Chapter 3, 3.1.5.4), the following criteria should be employed:

— Figure C-1 shows the relationship between the maximum (95 per cent probability) localizer course/glide path bend amplitudes and distances from the runway threshold that have been specified for Categories II and III performance.

— If the bend amplitudes are to be evaluated in any region of the approach, the flight recordings, corrected for aircraft angular position error, should be analysed for a time interval of plus or minus 20 seconds about the midpoint of the region to be evaluated. The foregoing is based on an aircraft ground speed of 195 km/h (105 knots) plus or minus 9 km/h (5 knots).

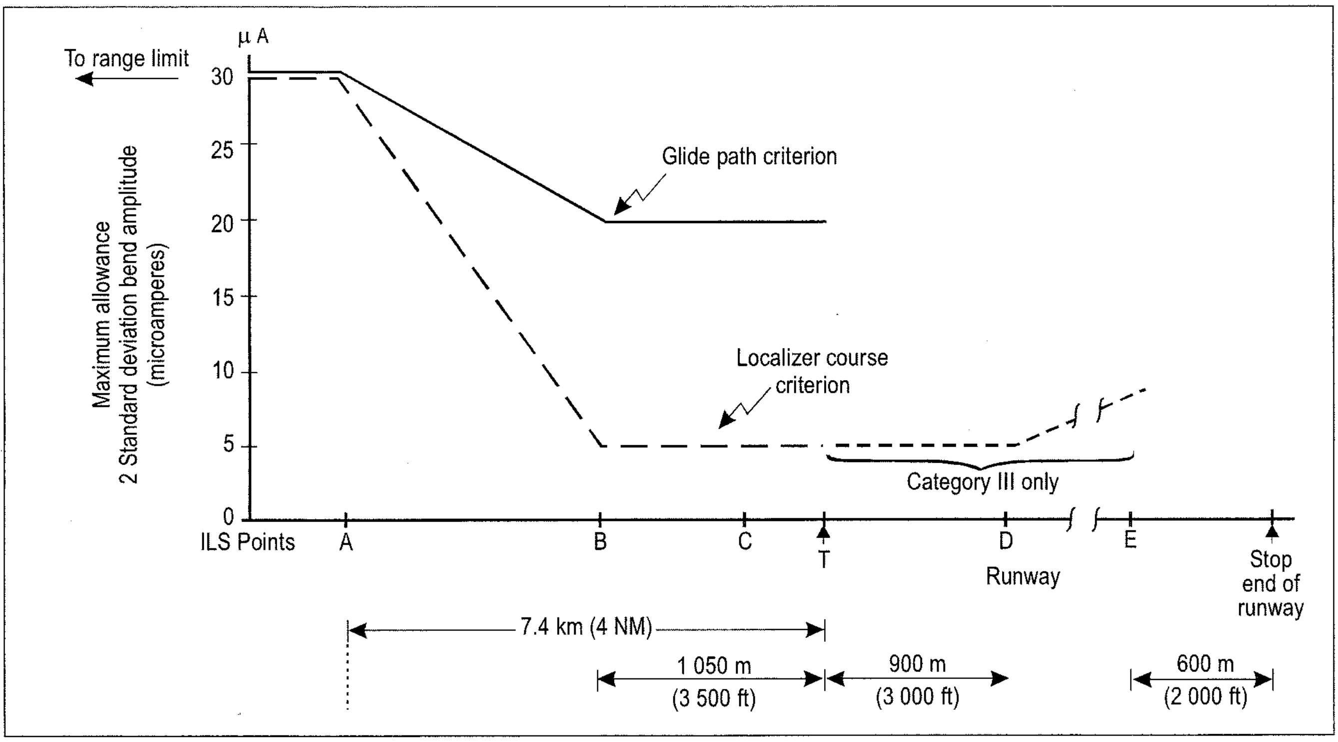
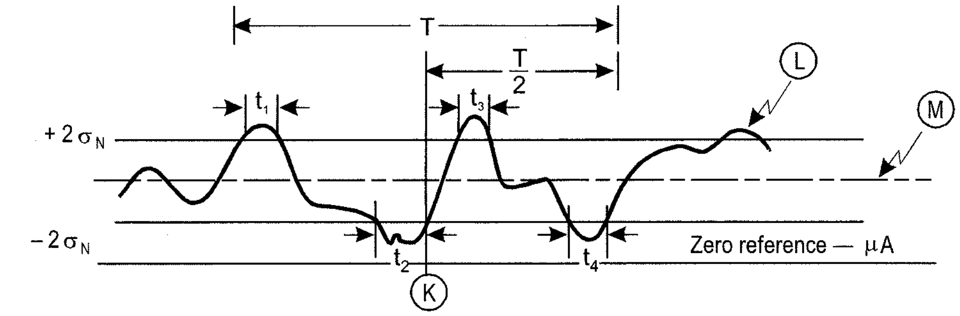


Figure C-1. Categories II and III localizer course and glide path maximum bend amplitude criteria



(L) = Theodolite corrected sample of course/path bends (microamperes)

(M) = Mean value of course/path bends (microamperes)

T = Region to be evaluated (± 20 seconds wide)

$\pm 2\sigma_N$ = Maximum bend amplitude specification at point (K) (microamperes)

$t_1, t_2, t_3, \ldots$ = Time intervals that noise exceeds allowable $2\sigma_N$ value.
For the facility to be acceptable in this region:

$$100 \frac{[T - (t_1 + t_2 + t_3 \ldots)]}{T} \geqslant 95\%$$

Figure C-2. Evaluation of course/path bend amplitude

The 95 per cent maximum amplitude specification is the allowable percentage of total time interval in which the course/path bend amplitude must be less than the amount specified in Figure C-1 for the region being evaluated. Figure C-2 presents a typical example of the method that can be employed to evaluate the course/path bend amplitude at a particular facility. If the sum of the time intervals t_1, t_2, t_3, where the given specification is exceeded, is equal to or less than 5 per cent of the total time T, the region that is being evaluated is acceptable. Therefore:

$$100 \; \frac{T - [(t_1 + t_2 + ...)]}{T} \geq 95\%$$

Analysis of ILS glide path bends should be made using as a datum the mean glide path and not the downward extended straight line. The extent of curvature is governed by the offset displacement of the ground equipment glide path antenna system, the distance of this antenna system from the threshold, and the relative heights of the ground along the final approach route and at the glide path site (see 2.4).

2.1.7 Owing to the complex frequency components present in the ILS beam bend structures, measured values of beam bends are dependent on the frequency response of the airborne receiving and recording equipment. It is intended that beam bend measurements be obtained by using a total time constant (in seconds) for the receiver DDM output circuits and associated recording equipment of $92.6/V$, where V is the velocity in km/h of the aircraft or ground vehicle as appropriate.

2.1.8 *Monitor systems.* Available evidence indicates that performance stability within the limits defined in Chapter 3, 3.1.3.6, 3.1.3.7 and 3.1.5.6, i.e. well within the monitor limit, can readily be achieved.

The choice of monitor limits is based on judgement, backed by knowledge of the safety requirements for the category of operation. However, the specifications of such monitoring limits do not indicate the magnitude of the normal day-to-day variations in performance which result from setting-up errors and equipment drift. It is necessary to investigate and take corrective action if the day-to-day performance frequently drifts beyond the limits specified in Chapter 3, 3.1.3.6, 3.1.3.7 and 3.1.5.6. The causes of such drifts should be eliminated:

a) to reduce greatly the possibility of critical signal parameters hovering near the specified monitor limits;

b) to ensure a high continuity of ILS service.

Following are some general guidelines for the design, operation and maintenance of monitor systems to meet the requirements in Chapter 3, 3.1.3.11 and 3.1.5.7.

1) Great care should be exercised to ensure that monitor systems respond to all those variations of the ground facility which adversely affect the operation of the airborne system during ILS approach.

2) Monitor systems should not react to local conditions which do not affect the navigational information as seen by airborne systems.

3) Drifts of the monitor system equipment should not appreciably reduce or increase the monitoring limits specified.

4) Special care must be taken in the design and operation of the monitor system with the aim of ensuring that the navigational components will be removed or radiation cease in the event of a failure of the monitor system itself.

5) Some monitors rely on devices which sample the signal in the vicinity of the transmitter antenna system. Experience has shown that such monitor systems require special attention in the following aspects:

a) where large-aperture antenna systems are used, it is often not possible to place the monitor sensors in such a position that the phase relationship observed in the far field on the course exists at the sensing point. Nevertheless, the monitor system should also detect antenna and associated feeder system changes which significantly affect the course in the far field;

b) changes in effective ground level caused by snow, flooding, etc., may affect glide path monitor systems, and the actual course in space differently, particularly when reliance is placed on the ground plane to form the desired glide path pattern;

c) attention should be paid to other causes which may disturb the monitor sensing of the radiated signal, such as icing and birds;

d) in a system where monitoring signals are used in a feedback loop to correct variations of the corresponding equipment, special care should be taken that extraneous influence and changes in the monitor system itself do not cause course or ILS glide path variations outside the specified limits without alarming the monitor.

6) One possible form of monitor is an integral monitor in which the contribution of each transmitting antenna element to the far-field course signal is measured at the antenna system. Experience has shown that such monitoring systems, properly designed, can give a close correlation between the monitor indication and the radiated signal in the far field. This type of monitor, in certain circumstances, overcomes the problem outlined in 5) a), b) and c).

It will be realized that the DDM measured at any one point in space is a function of displacement sensitivity and the position of the course line or ILS glide path. This should be taken into account in the design and operation of monitor systems.

2.1.9 *Radiation by ILS localizers not in operational use.* Severe interference with operational ILS localizer signals has been experienced in aircraft carrying out approaches to low levels at runways equipped with localizer facilities serving the reciprocal direction to the approach. Interference in aircraft overflying this localizer antenna system is caused by cross modulation due to signals radiated from the reciprocal approach localizer. Such interference, in the case of low level operations, could seriously affect approach or landing, and may prejudice safety. Chapter 3, 3.1.2.7, 3.1.2.7.1 and 3.1.2.7.2 specify the conditions under which radiation by localizers not in operational use may be permitted.

2.1.10 *ILS multipath interference due to large reflecting objects and movements on the ground*

2.1.10.1 The occurrence of interference to ILS signals is dependent on the total environment around the ILS antennas, and the antenna characteristics. Any large reflecting objects, including vehicles or fixed objects such as structures within the radiated signal coverage, will potentially cause multipath interference to the ILS course and path structure. The location and size of the reflecting fixed objects and structures in conjunction with the directional qualities of the antennas will determine the static course or path structure quality whether Category I, II or III. Movable objects can degrade this structure to the extent that it becomes unacceptable. The areas within which this degradable interference is possible need to be defined and recognized. For the purposes of developing protective zoning criteria, these areas can be divided into two types, i.e. critical areas and sensitive areas:

a) the ILS critical area is an area of defined dimensions about the localizer and glide path antennas where vehicles, including aircraft, are excluded during all ILS operations. The critical area is protected because the presence of vehicles and/or aircraft inside its boundaries will cause unacceptable disturbance to the ILS signal-in-space;

b) the ILS sensitive area is an area extending beyond the critical area where the parking and/or movement of vehicles, including aircraft, is controlled to prevent the possibility of unacceptable interference to the ILS signal during ILS operations. The sensitive area is protected against interference caused by large moving objects outside the critical area but still normally within the airfield boundary.

Note 1.— The objective of defining critical and sensitive areas is to afford adequate protection to the ILS. The manner in which the terminology is applied may vary between States. In some States, the term "critical area" is also used to describe the area that is referred to herein as the sensitive area.

Note 2.— It is expected that at sites, where ILS and MLS are to be collocated, the MLS might be located within ILS critical areas in accordance with guidance material in Attachment G, Section 4.1.

2.1.10.2 Typical examples of critical and sensitive areas that need to be protected are shown in Figures C-3A, C-3B, C-4A and C-4B. To protect the critical area, it is necessary to normally prohibit all entry of vehicles and the taxiing or parking of aircraft within this area during all ILS operations. The critical area determined for each localizer and glide path should be clearly designated. Suitable signal devices may need to be provided at taxiways and roadways which penetrate the critical area to restrict the entry of vehicles and aircraft. With respect to sensitive areas, it may be necessary to exclude some or all moving traffic depending on interference potential and category of operation. It would be advisable to have the aerodrome boundaries include all the sensitive areas so that adequate control can be exercised over all moving traffic to prevent unacceptable interference to the ILS signals. If these areas fall outside the aerodrome boundaries, it is essential that the cooperation of appropriate authorities be obtained to ensure adequate control. Operational procedures need to be developed for the protection of sensitive areas.

2.1.10.3 The size of the sensitive area depends on a number of factors including the type of ILS antenna, the topography, and the size and orientation of man-made objects, including large aircraft and vehicles. Modern designs of localizer and glide path antennas can be very effective in reducing the disturbance possibilities and hence the extent of the sensitive areas. Because of the greater potential of the larger types of aircraft for disturbing ILS signals, the sensitive areas for these aircraft extend a considerable distance beyond the critical areas. The problem is aggravated by increased traffic density on the ground.

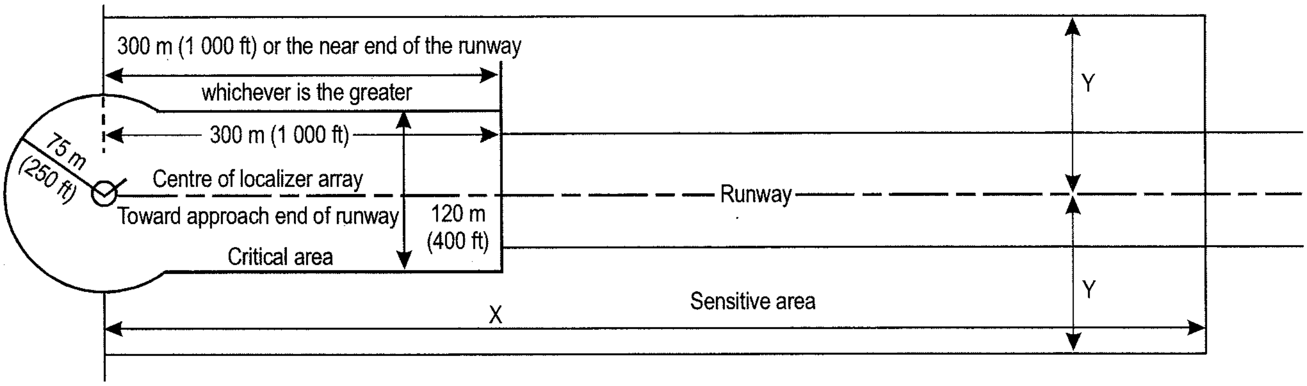
2.1.10.3.1 In the case of the localizer, any large objects illuminated by the main directional radiation of the antenna must be considered as possible sources of unacceptable signal interference. This will include aircraft on the runway and on some taxiways. The dimensions of the sensitive areas required to protect Category I, II and III operations will vary, the largest being required for Category III. Only the least disturbance can be tolerated for Category III, but an out-of-tolerance course along the runway surface would have no effect on Category I or II operations. If the course structure is already marginal due to static multipath effects, less additional interference will cause an unacceptable signal. In such cases a larger-size sensitive area may have to be recognized.

2.1.10.3.2 In the case of the glide path, experience has shown that any object penetrating a surface above the reflection plane of the glide path antenna and within azimuth coverage of the antenna must be considered as a source of signal interference. The angle of the surface above the horizontal plane of the antenna is dependent on the type of glide path antenna array in use at the time. Very large aircraft, when parked or taxiing within several thousand feet of the glide path antenna and directly between it and the approach path, will usually cause serious disturbance to the glide path signal. On the other hand, the effect of small aircraft beyond a few hundred feet of the glide path antenna has been shown to be negligible.

2.1.10.3.3 Experience has shown that the major features affecting the reflection and diffraction of the ILS signal to produce multipath interference are the height and orientation of the vertical surfaces of aircraft and vehicles. The maximum height of vertical surface likely to be encountered must be established, together with the "worst case" orientation. This is because certain orientations can cause out-of-tolerance localizer or glide path deviations at greater distances than parallel or perpendicular orientations.

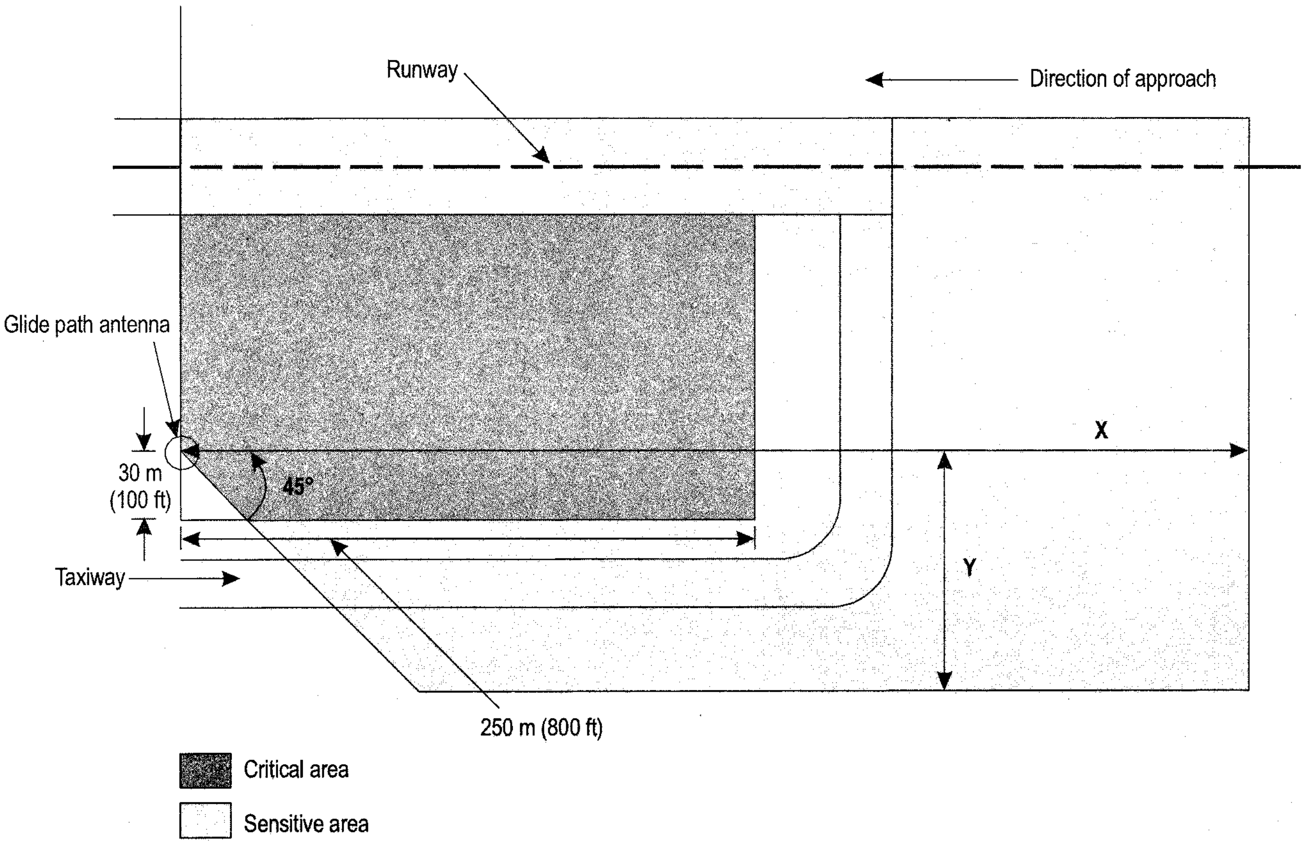
2.1.10.4 Computer or model techniques can be employed to calculate the probable location, magnitude and duration of ILS disturbances caused by objects, whether by structures or by aircraft of various sizes and orientation at different locations. Issues involved with these techniques include the following:

a) computerized mathematical models are in general use and are applied by personnel with a wide variety of experience levels. However, engineering knowledge of and judgement about the appropriate assumptions and limitations are required when applying such models to specific multipath environments. ILS performance information relative to this subject should normally be made available by the ILS equipment manufacturer;



		Example 1	*Example 2*	*Example 3*
Aircraft type		B-747	B-747	B-727
Localizer antenna aperture		Typically 27 m (90 ft) (Directional dual frequency, 14 elements)	Typically 16 m (50 ft) (Semi-directional, 8 elements)	Typically 16 m (50 ft) (Semi-directional, 8 elements)
Sensitive area (X, Y)				
Category I	X	600 m (2 000 ft)	600 m (2 000 ft)	300 m (1 000 ft)
	Y	60 m (200 ft)	110 m (350 ft)	60 m (200 ft)
Category II	X	1 220 m (4 000 ft)	2 750 m (9 000 ft)	300 m (1 000 ft)
	Y	90 m (300 ft)	210 m (700 ft)	60 m (200 ft)
Category III	X	2 750 m (9 000 ft)	2 750 m (9 000 ft)	300 m (1 000 ft)
	Y	90 m (300 ft)	210 m (700 ft)	60 m (200 ft)

Figure C-3A. Typical localizer critical and sensitive areas dimension variations for a 3 000 m (10 000 ft) runway



		Example 1	*Example 2*	*Example 3*
Aircraft type		B-747	B-727	small & medium*
Category I	X	915 m (3 000 ft)	730 m (2 400 ft)	250 m (800 ft)
	Y	60 m (200 ft)	30 m (100 ft)	30 m (100 ft)
Category II/III	X	975 m (3 200 ft)	825 m (2 700 ft)	250 m (800 ft)
	Y	90 m (300 ft)	60 m (200 ft)	30 m (100 ft)

* Small and medium aircraft here are considered as those having both a length less than 18 m (60 ft) and a height less than 6 m (20 ft).

Note.— In some cases the sensitive areas may be extended beyond the opposite side of the runway.

Figure C-3B. Typical glide path critical and sensitive areas dimension variations

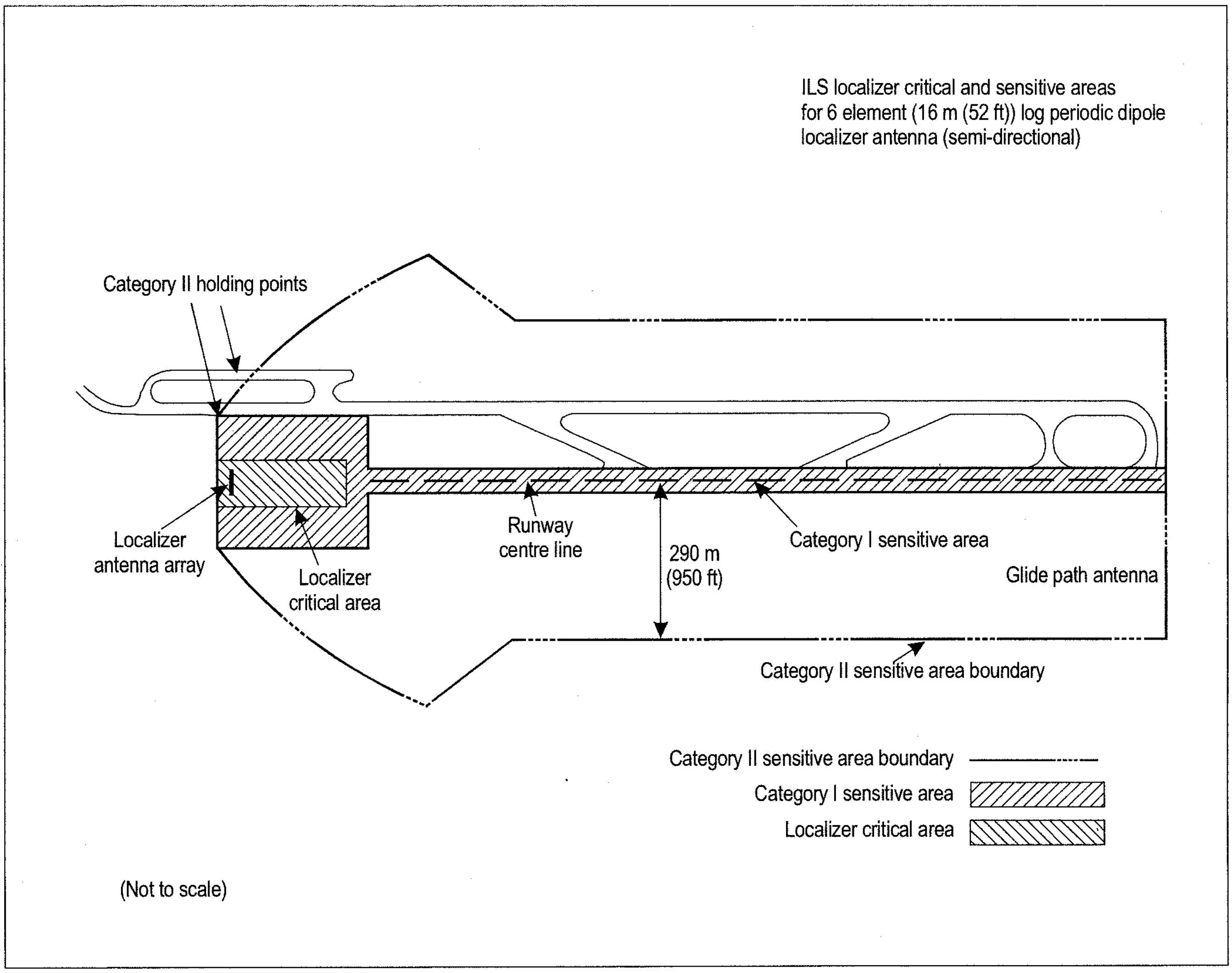


Figure C-4A. Example of critical and sensitive area application at specific sites with B-747 aircraft interference

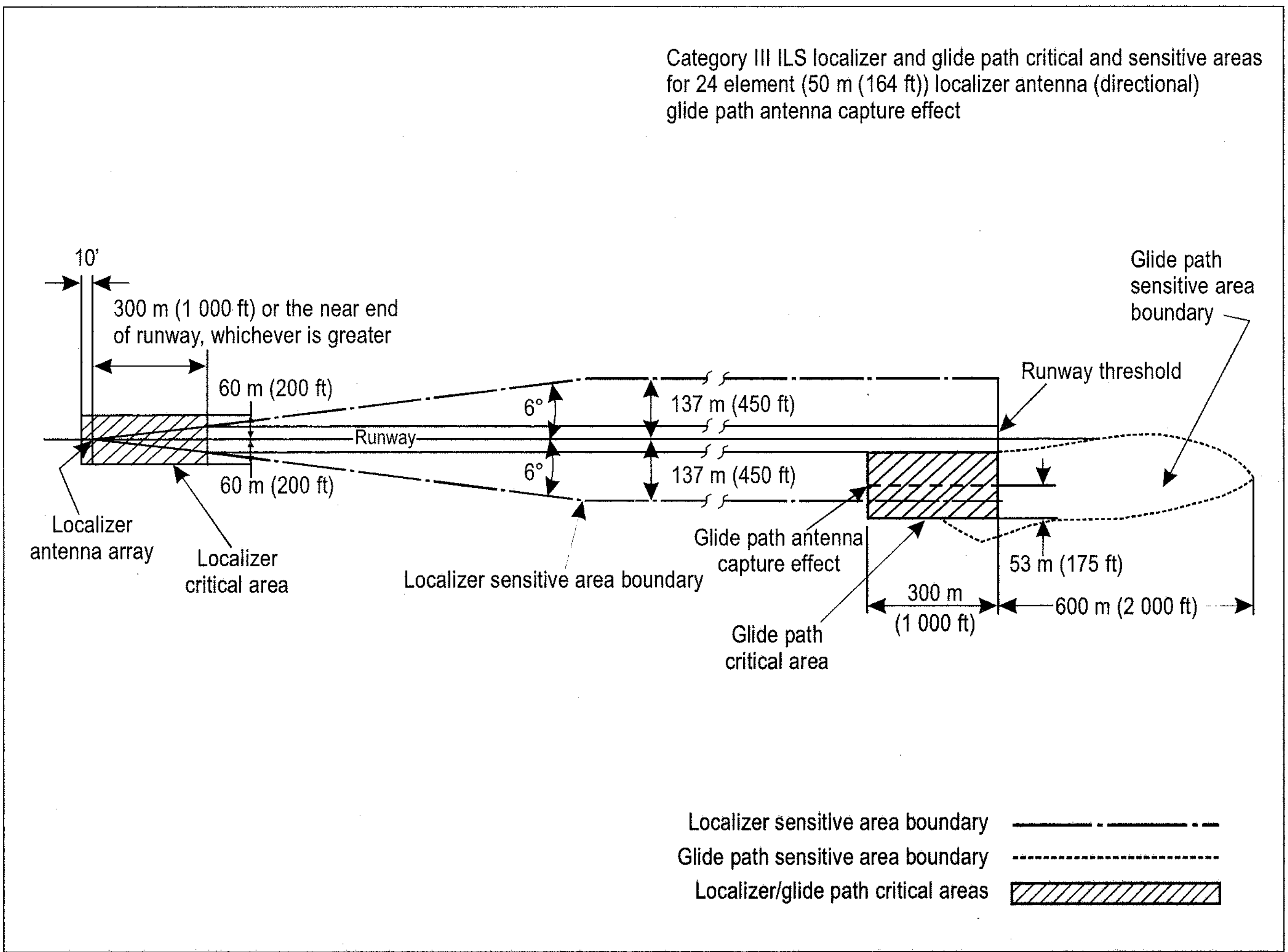


Figure C-4B. Example of critical and sensitive area application at specific sites with B-747 aircraft interference

b) where an ILS has been installed and found satisfactory, computers and simulation techniques can be employed to predict the probable extent of ILS disturbance which may arise as a result of proposed new construction. Wherever possible, the results of such computer-aided simulation should be validated by direct comparison with actual flight measurements of the results of new construction; and

c) taking into account the maximum allowable multipath degradation of the signal due to aircraft on the ground, the corresponding minimum sensitive area limits can be determined. Models have been used to determine the critical and sensitive areas in Figures C-3A, C-3B, C-4A and C-4B, by taking into account the maximum allowable multipath degradation of ILS signals due to aircraft on the ground. The factors that affect the size and shape of the critical and sensitive areas include: aircraft types likely to cause interference, antenna aperture and type (log periodic dipole/dipole, etc.), type of clearance signals (single/dual frequency), category of operations proposed, runway length, and static bends caused by existing structures. Such use of models should involve their validation, which includes spot check comparison of computed results with actual field demonstration data on parked aircraft interference to the ILS signal.

2.1.10.5 Control of critical areas and the designation of sensitive areas on the airport proper may still not be sufficient to protect an ILS from multipath effects caused by large, fixed ground structures. This is particularly significant when considering the size of new buildings being erected for larger new aircraft and other purposes. Structures outside the boundaries of the airport may also cause difficulty to the ILS course quality, even though they meet restrictions with regard to obstruction heights.

2.1.10.5.1 Should the environment of an airport in terms of large fixed objects such as tall buildings cause the structure of the localizer and/or glide path to be near the tolerance limits for the category of operation, much larger sensitive areas may need to be established. This is because the effect of moving objects, which the sensitive areas are designed to protect the ILS against, has to be added to the static beam bends caused by fixed objects. However, direct addition of the maximum bend amplitudes is not considered appropriate and a root sum square combination is felt to be more realistic. Examples are as follows:

a) localizer course bends due to static objects equals plus or minus 1½μA. Limit plus or minus 5μA. Therefore allowance for moving objects to define localizer sensitive area is

$$\sqrt{5^2 - 1.5^2} = 4.77\mu A$$

b) localizer course bends due to static objects equals plus or minus 4μA. Limit plus or minus 5μA. Therefore allowance for moving objects to define localizer sensitive area is

$$\sqrt{5^2 - 4^2} = 3\mu A$$

In case b) the sensitive area would be larger, thus keeping interfering objects further away from the runway so that they produce 3μA or less distortion of the localizer beam. The same principle is applied to the glide path sensitive area.

2.1.11 *Guidance on operational aspects of improving the performance of the ILS localizer in respect to bends*

2.1.11.1 *Introduction.* Owing to site effects at certain locations, it is not always possible to produce with simple standard ILS installations localizer courses that are sufficiently free from troublesome bends or irregularities. At such installations, it will often be possible to reduce bends and irregularities in the localizer course to a satisfactory extent by various methods, most of which require acceptance of some deviation from the specification for ILS set forth in this Annex, together with possible penalties from an operational aspect.

2.1.11.2 *Methods of effecting improvement.* In general, improvements in localizer courses from the aspect of bends or irregularities may be effected by restriction of radiation in particular directions so as to avoid or minimize reflection from objects that give rise to the bends. In the majority of instances where special treatment is required, this may be achieved by screens placed and designed to reduce the radiation in the direction of the object. Where reflecting objects are numerous or of large dimensions, however, it may be necessary to restrict almost all the radiation from the localizer to a narrow sector centred on the course line. Each method introduces certain disadvantages which should be weighed for the individual installation in the light of the specific operational application to be made of the installation and the following considerations.

2.1.11.3 *Disadvantages of methods of effecting improvements mentioned above*

2.1.11.3.1 The use of screens limiting radiation in selected directions will, in general, give rise to a reduction of the clearance between the two modulation signals of the ILS in some other direction, with the consequence that the ILS indicator needle may move towards the centre when the aircraft is passing through areas in that direction. It is considered however that, in general, such deviations are not operationally significant or may be overcome by suitable procedures. In certain applications including the use of screens or reflectors to reinforce signals in the course sector, the use of screens or reflectors will modify the range and characteristics of the back course of the localizer. Here again, it is considered that the effects are unlikely to be operationally significant unless operational use is being made of the back course. In this latter case, it may be necessary to provide an additional facility to supplement or replace the back course.

2.1.11.3.2 Where it is necessary to limit radiation from the localizer over a wide sector and confine most of it to a sector centred on the front course of the localizer in order to reduce bends sufficiently, the disadvantages will, in general, be as follows:

a) Orientation information from the localizer in the sector in which radiation is limited will no longer be available or will be unreliable.

b) It will not be practicable to carry out a preliminary check of the performance of the aircraft receiver through the flag system until the aircraft is within the sector centred on the course line.

c) In the area outside the sector centred on the course line, sufficient radiation may occur in particular directions to operate the ILS indicator in the aircraft in an erratic manner, giving rise to false indications.

d) The loss of the back course.

2.1.11.3.3 In respect to a), it is considered that orientation information is necessary but that practice has shown that such information is preferably obtained in any event from an auxiliary aid such as a locator. Such an auxiliary aid would be necessary if radiation from the localizer is confined to a narrow sector centred on the course line. In respect to b), it is considered that the loss of a receiver check prior to entry into the sector centred on the course line could be operationally accepted.

2.1.11.3.4 The disadvantage indicated in c) may, in some instances, be a serious drawback. In general, it is considered that acceptance of this disadvantage will depend on the extent to which false indications will occur at a particular site and on the procedures established or specified for the use of the ILS installation. In practice, it is possible to establish procedures so that no use is made of the localizer signals until the aircraft is able to check that it is in the usable sector. Experience has shown at one installation in operational use that, procedurally, no difficulty has arisen through the existence of erratic indications in the off-course sector. It is considered that the question of whether or not the off-course signal characteristics due to reduction of radiation in a narrow sector may be accepted operationally is a matter for individual assessment at each location concerned.

2.1.11.3.5 The loss of the back course indicated in d) may have several disadvantages. At some locations, the back course serves a useful function through intersection with other aids for facilitating procedures in the area concerned. Also, the back course often provides a useful aid in missed approach procedures and can often be used to simplify approach for landing when conditions require that the landing direction be opposite to the direction for which the ILS is primarily installed. Loss of the back course will, in general, require the provision of a substitute aid or aids, and the principal disadvantage in suppressing the back course may be considered in terms of the additional expense of a substitute aid or aids.

2.1.11.4 *Extent to which sector centred on course line may be narrowed.* It is considered that a radiation sector 10 degrees each side of the localizer course line would be the minimum sector that could be accepted operationally. It is desirable that the characteristics of the signal from the localizer be identical with those specified in Chapter 3 within the region in the immediate vicinity (region from DDMs 0.155 to zero) of the course line and approximate closely to them out to 10 degrees, so that the indications of the ILS indicator and the signals fed to a coupling device, if used, will correspond to the standard ILS throughout any manoeuvres necessary in the transition from the approach to the localizer to establishment on course line.

It should be realized, however, that for an increased runway length, the localizer course sector wherein proportional guidance is provided will be narrower as a result of adjusting the localizer to the sensitivity specified in Chapter 3, 3.1.3.7.1. Although a proportional guidance signal is provided on each side of the course line up to a level of 0.180 DDM, the level above 0.150 DDM may not be usable by the automatic airborne system during the intercept manoeuvre unless that system is armed within the sector in which a minimum of 0.180 DDM is provided (e.g. plus or minus 10 degrees). It is advantageous to permit the localizer capture mode of the automatic airborne system to be armed at off-course angles greater than 10 degrees; consequently it is desirable to maintain a minimum DDM of 0.180 through a wider sector than plus or minus 10 degrees wherever practical.

2.1.11.5 *Further possibilities.* If the disadvantages arising from the use of the restricted coverage and modified signal characteristics discussed in 2.1.11.3 are unacceptable, possibilities exist through the use of two radio frequency carriers to provide the coverage and signal characteristics that would maintain the essential information provided by a standard ILS in the suppressed sector while, at the same time, maintaining in the regions about the course sector the objective of the restricted coverage system. It may be necessary to employ this more elaborate system at aerodromes with high multipath environments. Additional guidance on two radio frequency carrier coverage is provided in 2.7.

2.2 ILS airborne receiving equipment

Note.— The specified tolerances are those considered necessary to achieve the operational objective and include allowances, where appropriate, for:

a) variation of relevant ground system parameters within the limits defined in Chapter 3, 3.1;

b) variation of aircraft environment;

c) measurement error; and

d) deterioration in service between maintenance periods.

The words "receiving equipment", as used in this section, include the receiver itself, the antenna(s) and the necessary interconnections in the aircraft.

2.2.1 *General*

2.2.1.1 In order to ensure consistent and reliable operation, the output characteristics of the receiver in respect of course line (centring) and course width (deflection) should be maintained to a degree of accuracy appropriate to the operational objective. Attention is directed towards the need to take into account the variable conditions that may affect such accuracy.

2.2.1.2 Furthermore, in order to ensure that a constant course width is realized by all users of the ILS system, it is necessary to standardize the overall gain of the localizer receiver. Similar considerations apply in the case of the glide path receiver.

2.2.2 *Localizer receiver audio gain adjustment*

2.2.2.1 The audio gain of the receiver should be such that, with a radio frequency input of 1 000 microvolts modulated 20 per cent by a 90 Hz tone and 20 per cent by a 150 Hz tone, a zero indication is achieved and that, upon a simultaneous increase in one component of 4.65 per cent (i.e. to 24.65 per cent) and a decrease in the other component of 4.65 per cent (i.e. to 15.35 per cent), there is a proportional deflection of 3/5 of the full course width indication but not less than 9.5 mm along its scale. This gain adjustment is to be made with the normal power supply voltage encountered under airborne operating conditions.

2.2.3 *Localizer receiving equipment centring tolerance*

2.2.3.1 To obtain the operational objectives associated with ILS Performance Categories I, II and III and to ensure the safe operation of aircraft within the obstacle clearance surfaces, the centring error of the receiving equipment, operating within all the likely aircraft environmental conditions and receiving a zero signal (DDM) within the limits of the ground equipment radio frequency modulation characteristics and identification tolerances, as specified in Chapter 3, 3.1.3, and with an RF field strength of 90 microvolts per metre (minus 107 dBW/m^2), should not exceed the following limits with a 68 per cent probability:

Category I: 4.66 per cent of the full course width indication (0.0072 DDM)

Category II: 2.33 per cent of the full course width indication (0.0036 DDM)

Category III: 1.66 per cent of the full course width indication (0.00258 DDM)

Note.— These operational requirements are also to be met at larger field strengths up to the maximum field strength likely to be encountered in operational service.

2.2.4 *Localizer course displacement sensitivity (deflection) tolerance*

2.2.4.1 When the receiver audio gain has been adjusted in accordance with 2.2.2, and with an increase in one modulation tone of the audio frequency input signal of 4.65 per cent with respect to the nominal value (i.e. 24.65 per cent) and a simultaneous decrease of the other component by 4.65 per cent with respect to the nominal value (i.e. 15.35 per cent), the indicated deflection signal should not vary more than plus or minus 0.019 DDM from the nominal value at a signal strength of 90 microvolts per metre (minus 107 dBW/m^2) up to the maximum field strength likely to be encountered in operational service.

Note.— See 2.2.5 in respect to signal levels.

2.2.5 *Localizer receiving system minimum signal level sensitivity*

2.2.5.1 The sensitivity of the localizer receiving equipment should be such that in a high percentage of cases, the receiver indicates a usable signal and a substantially steady indication in the presence of the minimum field strength specified in Chapter 3, 3.1.3.3.2 (40 microvolts per metre or minus 114 dBW/m^2).

Note 1.— The maximum signal level likely to be encountered under 2.2.3 and 2.2.4 is 500 microvolts. Signal levels on the order of 5 000 microvolts may be encountered in the near vicinity of the transmitter (e.g. when flying over the localizer during a missed approach, or when the localizer is used for rollout or take-off guidance).

Note 2.— The two levels of sensitivity addressed in 2.2.4 and 2.2.5 ensure:

a) a high quality output such as is necessary for approach purposes; and

b) an output of lesser quality adequate for operational usage of the facility in other parts of the coverage volume.

Note 3.— The proper operation of the localizer receiving system in the presence of the specified minimum field strength is to occur independently of the orientation of the aircraft longitudinal axis in the horizontal plane when the aircraft is exposed to roll angles of 20 degrees and pitch angles of 10 degrees.

2.2.6 *Localizer course displacement linearity*

2.2.6.1 The receiver output course displacement signal should be a substantially linear function of the DDM of the receiver input signal. For any input over the range of plus or minus 0.155 DDM, and for any RF signal level likely to be encountered in operational service, the displacement sensitivity should not depart from the nominal DDM/deflection ratio defined in 2.2.2 by more than plus or minus 20 per cent. Also for an input signal of plus or minus 0.165 DDM or greater, the output must be greater than full course displacement.

Note.— See 2.2.5 in respect to signal levels.

2.2.7 *Localizer receiver bandwidth*

2.2.7.1 The receiver bandwidth should be such as to provide for the reception of channels having the characteristics defined in Chapter 3, 3.1.3.2.1 after taking suitable account of appropriate receiver tolerances.

2.2.8 *Localizer receiver susceptibility to VOR and localizer signals*

2.2.8.1 The receiver design should provide correct operation in the following environment:

a) the desired signal exceeds an undesired co-channel by 20 dB or more;

b) an undesired signal, 50 kHz removed from the desired signal, exceeds the desired signal by up to 34 dB. (During bench testing of the receiver, in this first adjacent channel case, the undesired signal is varied over the frequency range of the combined ground station (plus or minus 9 kHz) and receiver frequency tolerance.);

c) an undesired signal, 100 kHz removed from the desired signal, exceeds the desired signal by up to 46 dB;

d) an undesired signal, 150 kHz or further removed from the desired signal, exceeds the desired signal by up to 50 dB.

Note 1.— It is recognized that not all receivers currently meet requirement b); however, all future equipment shall be designed to meet this requirement.

Note 2.— In some States, a smaller ground station tolerance is used.

2.2.9 *Immunity performance of ILS localizer receiving systems to interference from VHF FM broadcast signals*

2.2.9.1 With reference to Note 2 of 3.1.4.2, Chapter 3, the immunity performance defined there must be measured against an agreed measure of degradation of the receiving system's normal performance, and in the presence of, and under standard conditions for the input wanted signal. This is necessary to ensure that the testing of receiving equipment on the bench can be performed to a repeatable set of conditions and results and to facilitate their subsequent approval. Tests have shown that FM interference signals may affect both course guidance and flag current, and their effects vary depending on the

DDM of the wanted signal which is applied. Additional information can be found in ITU Recommendation ITU-R IS.1140, *Test procedures for measuring receiver characteristics used for determining compatibility between the sound-broadcasting service in the band of about 87–108 MHz and the aeronautical services in the band 108–118 MHz.*

2.2.9.2 Commonly agreed methodology and formulae should be used to assess potential incompatibilities to receivers meeting the general interference immunity criteria specified in Chapter 3, 3.1.4. The formulae provide clarification of immunity interference performance of spurious emission (type A1) interference, out-of-band channel (type A2) interference, two-signal and three-signal third order (type B1) interference, and overload/desensitization (type B2) interference. Additional information can be found in ITU Recommendation ITU-R IS.1009-1, *Compatibility between the sound-broadcasting service in the band of about 87–108 MHz and the aeronautical services in the band 108–137 MHz.*

2.2.9.3 The frequency planning criteria given in Recommendation ITU-R IS.1009-1 does not take account of the potential for two-signal and three-signal fifth order (type B1) intermodulation products. Measurements have determined that fifth order intermodulation products created in receiver by FM stations might degrade the performance of ILS receivers conforming to specifications in Chapter 3, 3.1.4. Fifth order intermodulation products can occur without a third order intermodulation product occurring on the same ILS frequency. In the planning of frequencies, and in the assessment of protection from FM broadcast interference, consideration needs to be given to two-signal and three-signal fifth order intermodulation products generated within ILS receivers by FM broadcast stations.

2.2.10 *Glide path receiver audio gain adjustment*

2.2.10.1 The audio gain of the receiver should be such that, with a radio frequency input of 600 microvolts modulated 40 per cent by a 90 Hz tone and 40 per cent by a 150 Hz tone, a zero indication is achieved and that, upon a simultaneous increase in one component of 5.25 per cent (i.e. to 45.25 per cent) and a decrease in the other component of 5.25 per cent (i.e. to 34.75 per cent), there is a proportional deflection of 3/5 of full course width indication but not less than 9.5 mm along its scale. This gain adjustment is to be made with the normal power supply voltage encountered under airborne operational conditions.

2.2.11 *Glide path receiving equipment centring tolerance*

2.2.11.1 To obtain the operational objectives associated with ILS Performance Categories I, II and III and to ensure the safe operation of aircraft within the obstacle clearance surfaces, the centring error of the receiving equipment, operating within all likely aircraft environmental conditions and receiving a zero signal (DDM) within the limits of the ground equipment radio frequency modulation characteristics and identification tolerances, as specified in Chapter 3, 3.1.5, and with an RF field strength of 400 microvolts per metre (minus 95 dBW/m^2), should not exceed the following limits with a 68 per cent probability:

Category I: 5.33 per cent of the full course width indication (0.0093 DDM)

Category II: 3.33 per cent of the full course width indication (0.0058 DDM)

Category III: 3.33 per cent of the full course width indication (0.0058 DDM)

Note.— These operational requirements are also to be met at larger field strengths up to the maximum field strength likely to be encountered in operational service.

2.2.12 *Glide path course displacement sensitivity (deflection) tolerance*

2.2.12.1 When the receiver audio gain has been adjusted in accordance with 2.2.10, and with an increase in one modulation tone of the radio frequency input signal of 5.25 per cent (i.e. to 45.25 per cent) and a simultaneous decrease of the other component of 5.25 per cent (i.e. to 34.75 per cent), the displacement signal should not vary more than plus or minus 0.016 DDM from the nominal value at a signal strength of 400 microvolts per metre (minus 95 dBW/m^2) up to the maximum field strength likely to be encountered in operational service.

Note.— See 2.2.13 in respect to signal levels.

2.2.13 *Glide path receiving system minimum signal level sensitivity*

2.2.13.1 The sensitivity of the glide path receiving system should be such that, in a high percentage of cases, the receiver should indicate a usable signal and a substantially steady indication in the presence of the minimum field strength specified in Chapter 3, 3.1.5.3.2 (400 microvolts per metre or minus 95 dBW/m^2).

Note 1.— The maximum signal level likely to be encountered under 2.2.11 and 2.2.12 is 2 500 microvolts. This signal level occurs when the aircraft is at the runway threshold.

Note 2.— The two levels of sensitivity addressed in 2.2.12 and 2.2.13 ensure:

a) a high quality output such as is necessary for approach purposes; and

b) an output of lesser quality adequate for operational usage of the facility in other parts of the coverage volume.

Note 3.— The proper operation of the glide path receiving system in the presence of the specified minimum field strength should occur also if the aircraft longitudinal axis is varied plus or minus 10 degrees in the horizontal plane together with 20 degrees roll about the localizer course line and also plus or minus 10 degrees pitch in the vertical plane about the horizontal plane.

2.2.14 *Glide path displacement linearity*

2.2.14.1 The receiver output glide path displacement signal should be a substantially linear function of the DDM of the receiver input signal. For any input over the range plus or minus 0.175 DDM, and for any RF signal strength likely to be encountered in operational service, the displacement sensitivity should not depart from the nominal DDM/deflection ratio defined in 2.2.10 by more than plus or minus 20 per cent. For an input signal of 0.185 DDM or greater, the output must be greater than full course displacement.

Note.— See 2.2.13 with respect to signal levels.

2.2.15 *Glide path receiver bandwidth*

2.2.15.1 The receiver bandwidth should be such as to provide for the reception of channels having the characteristics defined in Chapter 3, 3.1.5.2.1 after taking suitable account of appropriate receiver tolerances.

2.2.16 *Glide path receiver susceptibility to glide path signal*

2.2.16.1 The receiver design should provide correct operation in the following environment:

a) the desired signal exceeds an undesired co-channel signal by 20 dB or more;

b) an undesired glide path signal, 150 kHz removed from the desired signal, exceeds the desired signal by up to 20 dB. (During bench testing of the receiver, in this first adjacent channel case, the undesired signal is varied over the frequency range of the combined ground station (plus or minus 17 kHz) and receiver frequency tolerance.);

c) an undesired glide path signal, 300 kHz or further removed from the desired signal, exceeds the desired signal by up to 40 dB.

Note 1.— It is recognized that not all receivers currently meet requirement b); however, all future equipment shall be designed to meet this requirement.

Note 2.— In some States, a smaller ground station tolerance is used.

2.2.17 *Localizer and glide path receiver effect from vertical polarization*

2.2.17.1 Over the localizer and glide path frequency bands, respectively, the reception of vertically polarized signals from the forward direction with respect to the localizer and glide path antenna should be at least 10 dB below the reception of horizontally polarized signals from the same direction.

2.2.18 *Localizer and glide path receiver spurious response*

2.2.18.1 The response (indicator deflection) of the localizer receiver to a 150 Hz 30 per cent modulated RF signal at 110 MHz should be greater than the response to a similarly modulated but 60 dB greater amplitude RF signal varied over 90 kHz to 107.8 MHz and 112.2 MHz to 1 500 MHz. The response of the glide path receiver to a 150 Hz 30 per cent modulated RF signal at 332.0 MHz should be greater than the response to a similarly modulated but 60 dB greater amplitude RF signal varied over 90 kHz to 329.0 MHz and 335.3 MHz to 1 500 MHz.

2.3 Malfunctioning alarm in ILS airborne equipment

2.3.1. Ideally, a receiver alarm system such as a visual mechanical flag should warn a pilot of any unacceptable malfunctioning conditions which might arise within either the ground or airborne equipments. The extent to which such an ideal may be satisfied is specified below.

2.3.2 The alarm system is actuated by the sum of two modulation depths and, therefore, the removal of the ILS course modulation components from the radiated carrier should result in the actuation of the alarm.

2.3.3 The alarm system should indicate to the pilot and to any other airborne system which may be utilizing the localizer and glide path data, the existence of any of the following conditions:

a) the absence of any RF signal as well as the absence of simultaneous 90 Hz and 150 Hz modulation;

b) the percentage modulation of either the 90 Hz or 150 Hz signal reduction to zero with the other maintained at its normal 20 per cent and 40 per cent modulation respectively for the localizer and glide path;

Note.— It is expected that the localizer alarm occur when either the 90 Hz or 150 Hz modulation is reduced to 10 per cent with the other maintained at its normal 20 per cent. It is expected that the glide path alarm occur when either the 90 Hz or 150 Hz modulation is reduced to 20 per cent with the other maintained at its normal 40 per cent.

c) the receiver off-course indication 50 per cent or less of that specified when setting the receiver audio gain adjustment (see 2.2.2 and 2.2.10).

2.3.3.1 The alarm indication should be easily discernible and visible under all normal flight deck conditions. If a flag is used, it should be as large as practicable commensurate with the display.

2.4 Guidance for the siting, elevation, adjustment and coverage of glide path equipment

2.4.1 The ILS reference datum and the ILS glide path angle setting are the primary factors influencing the longitudinal location of the ILS glide path equipment with respect to the threshold.

2.4.2 The lateral placement of the glide path antenna system with respect to the runway centre line is normally not less than 120 m (400 ft). In deciding the lateral placement of the glide path antenna, account should be taken of the appropriate provisions of Annex 14 with regard to obstacle clearance surfaces and objects on strips for runways.

2.4.3 In selecting the ILS glide path antenna location and glide path angle, the aim should be to place the ILS reference datum as close as possible to the appropriate nominal value. The actual selection of the ILS glide path antenna location and glide path angle are governed by a number of factors, including:

a) acceptable rates of descent and/or approach speeds for the type of operations envisaged at the particular aerodrome;

b) the position of obstacles in the final approach area, the aerodrome sector and the missed approach area, and the resulting obstacle clearance limits;

c) technical siting problems.

2.4.4 The selection of the antenna location and the angle, and the resulting ILS reference datum height, will also be affected by:

a) the runway length available;

b) the operating limits envisaged.

Where the application of the foregoing criteria permits, the preferred angle of the ILS glide path would be 3 degrees.

2.4.5 An ILS reference datum and glide path should then be selected, having regard to the foregoing criteria, and the ability of the site to provide the clearance required by the *Procedures for Air Navigation Services — Aircraft Operations* (PANS-OPS, Doc 8168) should be determined by calculation and confirmed, where possible, by flight test.

2.4.6 Where the selected ILS reference datum, the ILS glide path angle and the other relevant equipment characteristics do not provide the required clearances, the following alternative course of action should be investigated:

a) removal of the offending obstacle;

b) selection of an alternative height for the ILS reference datum, taking into account the criteria indicated in 2.4.3 and 2.4.5;

c) selection of an alternative acceptable ILS glide path angle;

d) variation of the obstacle clearance limit to cater for the offending obstacle.

2.4.7 To enable more effective use of land adjacent to Category III — ILS glide path sites and to reduce siting requirements and sensitive areas at these sites, it is desirable that the signals forming the horizontal radiation pattern from the Category III — ILS glide path antenna system be reduced to as low a value as practicable outside the azimuth coverage limits specified in Chapter 3, 3.1.5.3. Another acceptable method is to rotate in azimuth the glide path antennas away from multipath sources thus reducing the amount of radiated signals at specific angles while still maintaining the azimuth coverage limits.

2.4.8 *ILS glide path curvature.* In many cases the ILS glide path is formed as a conic surface originating at the glide path aerial system. Owing to the lateral placement of the origin of this conic surface from the runway centre line, the locus of the glide path in the vertical plane along the runway centre line is a hyperbola. Curvature of the glide path occurs in the threshold region and progressively increases until touchdown.

2.4.9 Relationship between siting of glide path antenna and glide path threshold crossing height. The longitudinal position of the glide path antenna should be selected so as to meet the recommendation made in Chapter 3, 3.1.5.1.4, in respect to the height of the ILS reference datum above the runway threshold. The height of the ILS reference datum above the runway threshold is then a function of the longitudinal position of the glide path antenna, of the longitudinal slope of the glide path reflection plane and of the position of the runway threshold in respect to the glide path reflection plane. This situation is described pictorially in Figure C-5. The longitudinal position of the glide path antenna is then calculated as follows:

$$D = \frac{H + Y}{\tan(\theta + \alpha)}$$

where

D = the horizontal distance between O and P;

H = the nominal threshold crossing height;

Y = the vertical height of the runway threshold above P';

θ = the nominal ILS glide path angle;

α = the longitudinal downslope of the glide path reflection plane.

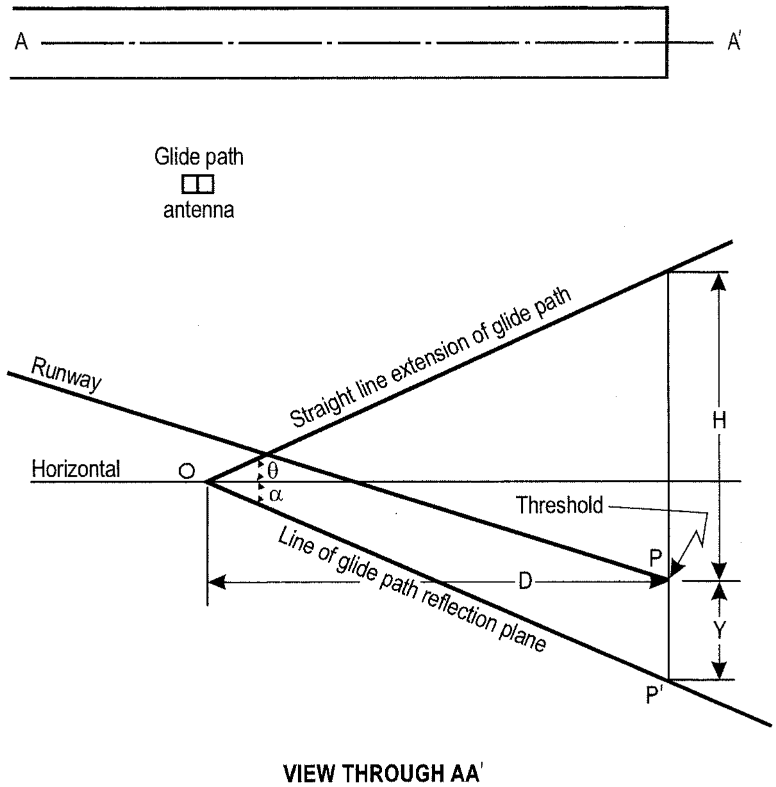
Note.— In the above formula α is to be taken as positive in the case of a downslope from the antenna towards the threshold. Y *is taken as positive if the threshold is above the reflection plane intersection line.*

2.4.10 The foregoing guidance material in respect of the longitudinal placement to the glide path antenna in relation to the runway threshold, which takes into account the fact that the runway may not be in the glide path reflection plane, and that the glide path reflection plane may be sloped, is based on geometrical abstractions. The material implicitly assumes that the glide path locus in the vertical plane, containing the runway centre line, is a perfect hyperbola; consequently, the glide path extension is implicitly assumed as the asymptote to this hyperbola.

2.4.11 In fact, however, the glide path is often quite irregular. The mean ILS glide path angle can be ascertained only by flight tests; the mean observed position of that part of the glide path between ILS Points A and B being represented as a straight line, and the ILS glide path angle being the angle measured between that straight line and its vertical projection on the horizontal plane.

2.4.12 It is important to recognize that the effect of glide path irregularities if averaged within the region between the middle marker and the threshold will likely tend to project a reference datum which is actually different from the ILS reference datum. This reference datum, defined here as the achieved ILS reference datum, is considered to be of important operational significance. The achieved ILS reference datum can only be ascertained by flight check, i.e. the mean observed position of that portion of the glide path typically between points 1 830 m (6 000 ft) and 300 m (1 000 ft) from the threshold being represented as a straight line and extended to touchdown. The point at which this extended straight line meets the line drawn vertically through the threshold at the runway centre line is the achieved ILS reference datum.

Note.— Further guidance on the measurement of the glide path angle and the achieved ILS reference datum is given in Doc 8071.



Note.— The line OP' represents the intersection of the glide path reflection plane and the vertical plane through AA'.

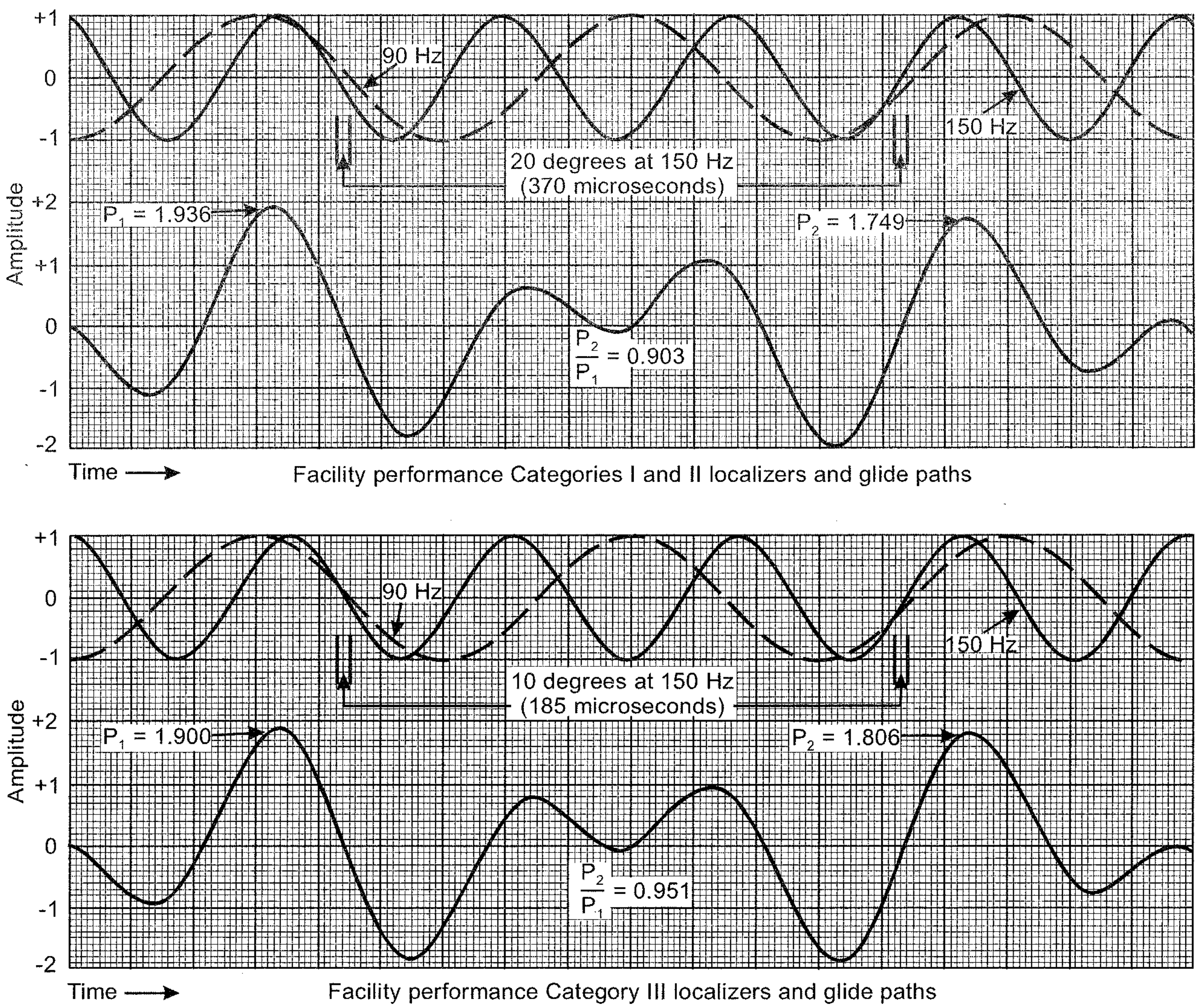
Figure C-5. Glide path siting for sloping runway

2.4.13 Chapter 3, 3.1.5.3.1 indicates the glide path coverage to be provided to allow satisfactory operation of a typical aircraft installation. The operational procedures promulgated for a facility must be compatible with the lower limit of this coverage. It is usual for descents to be made to the intercept altitude and for the approach to continue at this altitude until a fly-down signal is received. In certain circumstances a cross-check of position may not be available at this point. Automatic flight control systems will normally start the descent whenever a fly-up signal has decreased to less than about 10 microamperes.

2.4.14 The objective is, therefore, to provide a fly-up signal prior to intercepting the glide path. Although under normal conditions, approach procedures will be accomplished in such a way that glide path signals will not be used below 0.45 θ, or beyond 18.5 km (10 NM) from the runway, it is desirable that misleading guidance information should not be radiated in this area. Where procedures are such that the glide path guidance may be used below 0.45 θ, adequate precautions must be taken to guard against the radiation of misleading guidance information below 0.45 θ, under both normal conditions and during a malfunction, thus preventing the final descent being initiated at an incorrect point on the approach. Some precautions which can be employed to guard against the radiation of misleading guidance include the radiation of a supplementary clearance signal such as provided for in Chapter 3, 3.1.5.2.1, the provision of a separate clearance monitor and appropriate ground inspection and setting-up procedures.

2.4.15 To achieve satisfactory monitor protection against below-path out-of-tolerance DDM, depending on the antenna system used, the displacement sensitivity monitor as required in Chapter 3, 3.1.5.7.1 e) may not be adequate to serve also as a clearance monitor. In some systems, e.g. those using multi-element arrays without supplementary clearance, a slight deterioration of certain antenna signals can cause serious degradation of the clearance with no change or only insignificant changes within the glide path sector as seen by the deviation sensitivity monitor. It is important to ensure that monitor alarm is achieved for any or all possible deteriorated antenna and radiated signal conditions, which may lead to a reduction of clearance to 0.175 DDM or less in the below-path clearance coverage.

2.5 Diagrams (Figures C-6 to C-12 illustrate certain of the Standards contained in Chapter 3)



The accompanying graphs illustrate a method that can be used to measure the relative phase relationship between the 90 Hz and 150 Hz tones. The upper portion of each graph shows the individual waveforms and their relationship at the limit of phase differences allowed by Chapter 3, 3.1.3.5.3.3 and 3.1.5.5.3. The lower portion shows the combined waveforms as would be seen on an oscilloscope. By taking the ratio of P_1 and P_2, which gives a value equal to or less than unity, it is possible to determine if the phasing is within tolerance. For Categories I and II ILS the ratio should be greater than 0.903 and for Category III the ratio should be greater than 0.951.

Figure C-6. ILS wave forms illustrating relative audio phasing of the 90 Hz and 150 Hz tones

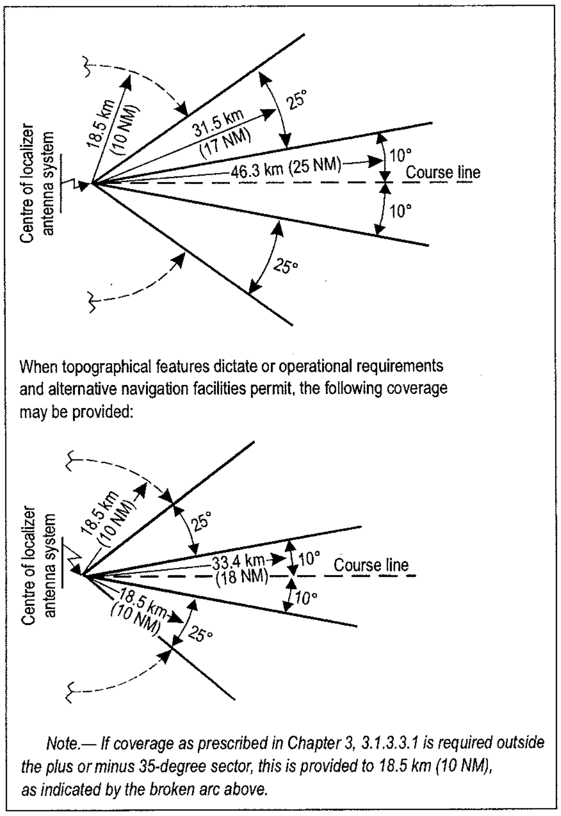


Figure C-7. Localizer coverage with respect to azimuth

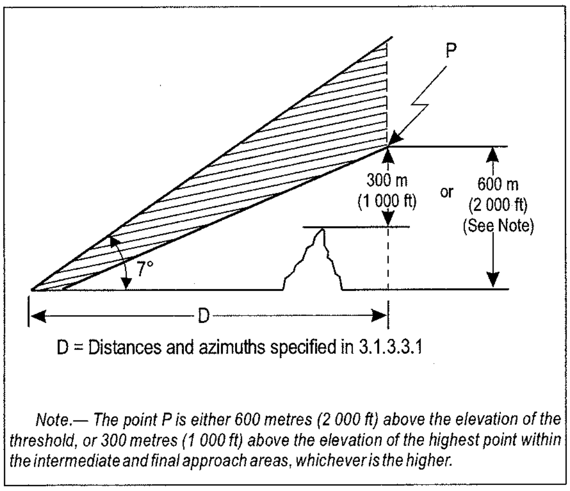


Figure C-8. Localizer coverage with respect to elevation

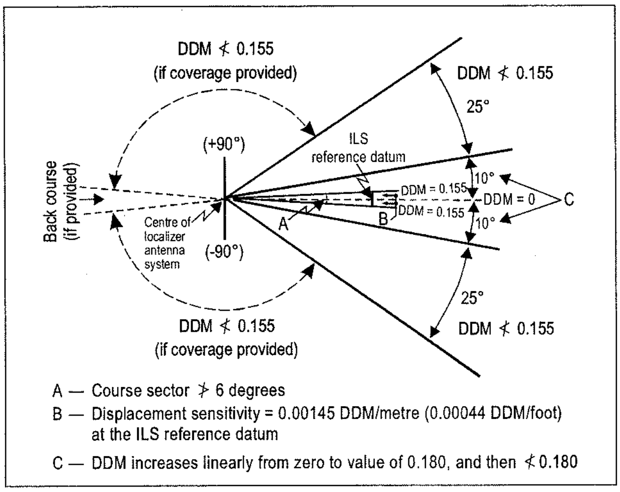


Figure C-9. Difference in depth of modulation and displacement sensitivity

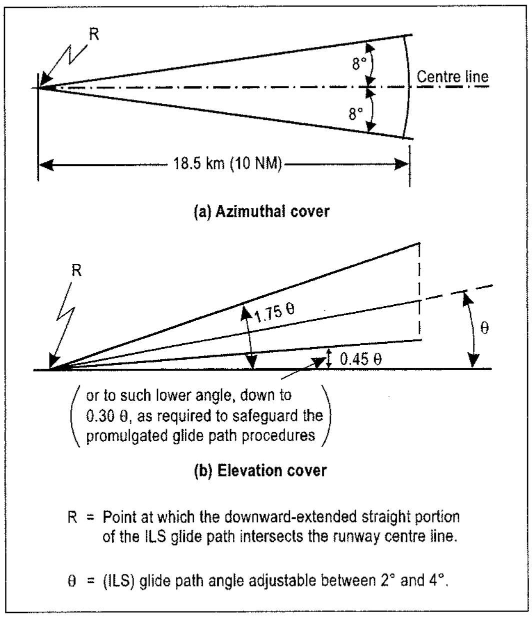
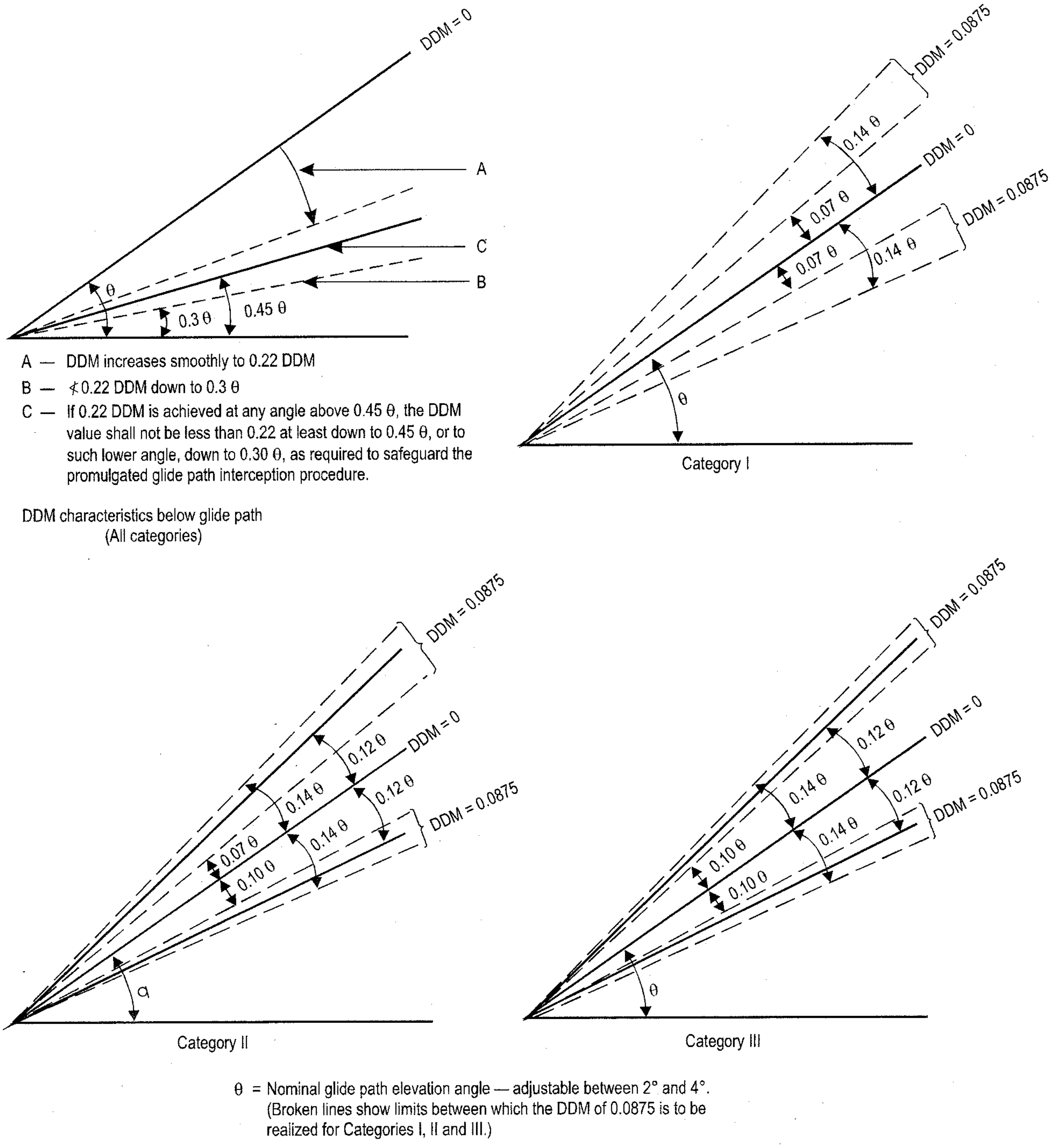
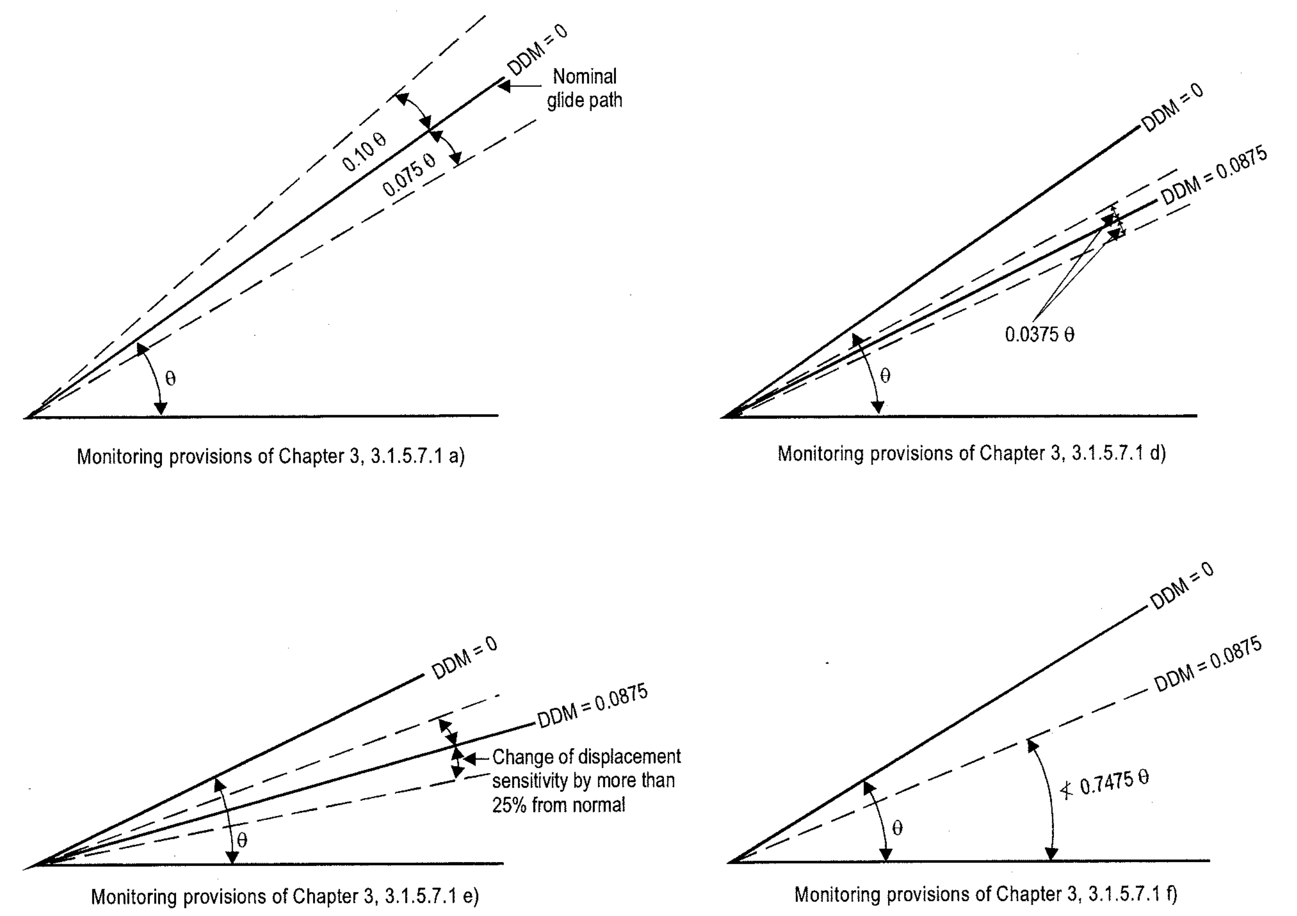


Figure C-10. Glide path coverage



Note.— Figure C-11 depicts the tolerances for the radiated space pattern specified in Chapter 3, 3.1.5.6; however, this space pattern should not be interpreted as being representative of any one particular ground equipment. In this connection, it should be noted that there are several known types of ILS glide path ground equipment having different characteristics but which can satisfy the requirements of Chapter 3, 3.1.5.6. Therefore, wherever there is a requirement to know the tolerances applicable to a specific equipment, reference should be made to the manufacturer's technical data rather than the ICAO systems specification.

Figure C-11. Glide path — difference in depth of modulation



Note.— The broken lines represent the permissible limits of deviation before monitoring action is required.

Figure C-12. Glide path monitoring provisions

2.6 Deployment of ILS frequencies

2.6.1 In using the figures listed in Table C-1, it must be noted that these are related to ensuring freedom from interference to a point at the protection height and at the limit of service distance of the ILS in the direction of the front beam. If there is an operational requirement for back beam use, the criteria would also be applied to a similar point in the back beam direction. Frequency planning will therefore need to take into account the localizer azimuthal alignment. It is to be noted that the criteria must be applied in respect of each localizer installation, in the sense that while of two localizers, the first may not cause interference to the use of the second, nevertheless the second may cause interference to the use of the first.

2.6.2 The figures listed in Table C-1 are based on providing an environment within which the airborne receivers can operate correctly.

Table C-1. Required distance separations

	Frequency separation	Minimum separation between second facility and the protection point of the first facility km (NM)		
		List A	List B	List C
Localizer	Co-channel	148 (80)	148 (80)	148 (80)
	50 kHz	—	37 (20)	9 (5)
	100 kHz	65 (35)	9 (5)	0
	150 kHz	—	0	0
	200 kHz	11 (6)	0	0
Glide path	Co-channel	93 (50)	93 (50)	93 (50)
	150 kHz	—	20 (11)	2 (1)
	300 kHz	46 (25)	2 (1)	0
	450 kHz	—	0	0
	600 kHz	9 (5)	0	0

List A refers to the use of localizer receivers designed for 200 kHz channel spacing coupled with glide path receivers designed for 600 kHz channel spacing and applicable only in regions where the density of facilities is low.

List B refers to the use of localizer receivers designed for 100 kHz channel spacing coupled with glide path receivers designed for 300 kHz channel spacing.

List C refers to the use of localizer receivers designed for 50 kHz channel spacing coupled with glide path receivers designed for 150 kHz channel spacing.

Note 1.— The above figures are based on the assumption of protection points for the localizer at 46 km (25 NM) distance and 1 900 m (6 250 ft) height and for the ILS glide path at 18.5 km (10 NM) distance and 760 m (2 500 ft) height.

Note 2.— States, in applying the separations shown in the table, have to recognize the necessity to site the ILS and VOR facilities in a manner which will preclude the possibility of airborne receiver error due to overloading by high unwanted signal levels when the aircraft is in the initial and final approach phases.

Note 3.— States, in applying the separations shown in the table, have to recognize the necessity to site the ILS glide path facilities in a manner which will preclude the possibility of erroneous glide path indications due to reception of adjacent channel signals when the desired signal ceases to radiate for any reason while the aircraft is in the final approach phase.

2.6.2.1 *ILS localizer receivers*

2.6.2.1.1 In order to protect receivers designed for 50 kHz channel spacing, minimum separations are chosen in order to provide the following minimum signal ratios within the service volume:

a) the desired signal exceeds an undesired co-channel signal by 20 dB or more;

b) an undesired signal, 50 kHz removed from the desired signal, exceeds the desired signal by up to 34 dB;

c) an undesired signal, 100 kHz removed from the desired signal, exceeds the desired signal by up to 46 dB;

d) an undesired signal, 150 kHz or further removed from the desired signal, exceeds the desired signal by up to 50 dB.

2.6.2.1.2 In order to protect receivers designed for 100 kHz channel spacing, minimum separations are chosen in order to provide the following minimum signal ratios within the service volume:

a) the desired signal exceeds an undesired co-channel signal by 20 dB or more;

b) an undesired signal, 50 kHz removed from the desired signal, exceeds the desired signal by up to 7 dB;

c) an undesired signal, 100 kHz removed from the desired signal, exceeds the desired signal by up to 46 dB;

d) an undesired signal, 150 kHz or further removed from the desired signal, exceeds the desired signal by up to 50 dB.

2.6.2.2 *ILS glide path receivers*

2.6.2.2.1 In order to protect receivers designed for 150 kHz spacing, minimum separations are chosen in order to provide the following minimum signal ratios within the service volume:

a) a desired signal exceeds an undesired co-channel signal by 20 dB or more;

b) an undesired glide path signal, 150 kHz removed from the desired signal, exceeds the desired signal by up to 20 dB;

c) an undesired glide path signal, 300 kHz or further removed from the desired signal, exceeds the desired signal by up to 40 dB.

2.6.2.2.2 In order to protect receivers designed for 300 kHz spacing, minimum separations are chosen in order to provide the following minimum signal ratios within the service volume:

a) a desired signal exceeds an undesired co-channel signal by 20 dB or more;

b) an undesired glide path signal, 150 kHz removed from the desired signal, does not exceed the desired signal (0 dB signal ratio);

c) an undesired glide path signal, 300 kHz removed from the desired signal, exceeds the desired signal by up to 20 dB;

d) an undesired glide path signal, 450 kHz or further removed from the desired signal, exceeds the desired signal by up to 40 dB.

2.6.3 The calculations are based on the assumption that the protection afforded to the wanted signal against interference from the unwanted signal is 20 dB. This corresponds to a disturbance of not more than 15 microamperes at the limit of the service distance of ILS.

2.6.4 In so far as the wanted and unwanted carriers may produce a heterodyne note, the protection ratio ensures that the instrumentation is not affected. However, in cases where a voice facility is used, the heterodyne note may interfere with this facility.

2.6.5 In general, when international use of ILS systems is confined to the pairings listed in Chapter 3, 3.1.6.1.1, the criteria are such that, provided they are met for the localizer element, the glide path element is automatically covered. At certain congested locations, where it is necessary to make assignments in both the first ten and the second ten sequence pairings, it may be necessary to select certain pairings out of sequence in order to meet the minimum geographical separation in 2.6.6.

Example: Referring to Chapter 3, 3.1.6.1.1, it will be noted that ILS Sequence Number 2 pairs the localizer frequency of 109.9 MHz with glide path frequency 333.8 MHz. Sequence Numbers 12 and 19, however, although providing wide frequency separation from Sequence Number 2 in the case of the localizers, assign frequencies of 334.1 MHz and 333.5 MHz, respectively, for the glide paths, both being first adjacent channels (300 kHz spacing) to the Sequence Number 2 glide path channel. If selection of ILS channels is confined to either the first ten or the second ten pairings, then the minimum glide path frequency separation will be 600 kHz.

2.6.6 *Table of required distance separations* [See Table C-1.]

2.6.7 The application of the figures given in Table C-1 will only be correct within the limitations set by the assumptions which include that facilities are essentially non-directional in character, that they have similar radiated powers, that the field strength is approximately proportional to the angle of elevation for angles up to 10 degrees, and that the aircraft antenna is essentially omnidirectional in character. If more precise determination of separation distances is required in areas of frequency congestion, this may be determined for each facility from appropriate propagation curves, taking into account the particular directivity factors, radiated power characteristics and the operational requirements as to coverage. Where reduced separation distances are determined by taking into account directivity, etc., flight measurements at the ILS protection point and at all points on the approach path should be made wherever possible to ensure that a protection ratio of at least 20 dB is achieved in practice.

2.7 Localizers and glide paths achieving coverage with two radio frequency carriers

2.7.1 Localizer coverage may be achieved by using two composite radiation field patterns on different carrier frequencies spaced within the localizer frequency channel. One field pattern gives accurate course and displacement indications within the front course sector; the other field pattern provides ILS indications outside the front course sector to meet the coverage requirements in Chapter 3, 3.1.3.3 and 3.1.3.7. Discrimination between signals is obtained in airborne receivers by the stronger signal capturing the receiver. Effectiveness of capture depends on the type of detector used but, in general, if the ratio of the two signals is of the order of 10 dB or more, the smaller signal does not cause significantly large errors in demodulated output. For optimum performance within the front course sector, the following guidance material should be applied in the operation of two carrier frequency localizer systems.

2.7.2 The localizer should be designed and maintained so that the ratio of the two radiated signals-in-space within the front course sector does not fall below 10 dB. Particular attention should be directed to the vertical lobe structure produced by the two antenna systems which may be different in height and separated in distance, thus resulting in changes in ratio of signal strengths during approach.

2.7.3 Due to the 6 dB allowance for the receiver pass-band filter ripple, localizer receiver response variations can occur as the clearance frequency is displaced from the course frequency. To minimize this effect, particularly for Category III operations, the course-to-clearance signal ratio needs to be increased from 10 dB to 16 dB.

2.7.4 To minimize further the risk of errors if the ratio of the two radiated signals falls below 10 dB within the front course sector, the difference in alignment of the radiation field patterns of the two signals should be kept as minimal as practicable.

2.7.5 Glide paths which employ two carriers are used to form a composite radiation field pattern on the same radio frequency channel. Special configurations of antennas and the distribution of antenna currents and phasing may permit siting of glide path facilities at locations with particular terrain conditions which may otherwise cause difficulty to a single-frequency system. At such sites, an improvement is obtained by reducing the low angle radiation. The second carrier is employed to provide coverage in the region below the glide path.

2.8 Integrity and continuity of service — ILS ground equipment

2.8.1 *Introduction*

2.8.1.1 This material is intended to provide clarification of the integrity and continuity of service objectives of ILS localizer and glide path ground equipment and to provide guidance on engineering design and system characteristics of this equipment. The integrity and continuity of service must of necessity be known from an operational viewpoint in order to decide the operational application which an ILS could support.

2.8.1.2 It is generally accepted, irrespective of the operational objective, that the average rate of a fatal accident during landing, due to failures or shortcomings in the whole system, comprising the ground equipment, the aircraft and the pilot, should not exceed 1×10^{-7}. This criterion is frequently referred to as the global risk factor.

2.8.1.3 In the case of Category I operations, responsibility for assuring that the above objective is not exceeded is vested more or less completely in the pilot. In Category III operations, the same objective is required but must now be inherent in the whole system. In this context it is of the utmost importance to endeavour to achieve the highest level of integrity and continuity of service of the ground equipment. Integrity is needed to ensure that an aircraft on approach will have a low probability of receiving false guidance; continuity of service is needed to ensure that an aircraft in the final stages of approach will have a low probability of being deprived of a guidance signal.

2.8.1.4 It is seen that various operational requirements correspond to varied objectives of integrity and continuity of service. Paragraph 2.14 identifies and describes four levels of integrity and continuity of service.

2.8.2 *Guidance material concerning the achievement and retention of integrity and continuity of service levels*

2.8.2.1 An integrity failure can occur if radiation of a signal which is outside specified tolerances is either unrecognized by the monitoring equipment or the control circuits fail to remove the faulty signal. Such a failure might constitute a hazard if it results in a gross error.

2.8.2.2 Clearly not all integrity failures are hazardous in all phases of the approach. For example, during the critical stages of the approach, undetected failures producing gross errors in course width or course line shifts are of special significance whereas an undetected change of modulation depth, or loss of localizer and glide slope clearance and localizer identification would not necessarily produce a hazardous situation. The criterion in assessing which failure modes are relevant must however include all those deleterious fault conditions which are not unquestionably obvious to the automatic flight system or pilot.

2.8.2.3 It is especially important that monitors be designed to provide fail-safe operation through compliance with the Standards of Chapter 3, 3.1.3.11.4 and 3.1.5.7.4. This often requires a rigorous design analysis. Monitor failures otherwise may permit the radiation of erroneous signals. Some of the possible conditions which might constitute a hazard in Operational Performance Categories II and III are:

a) an undetected shift of course line significantly outside the monitor limits for localizer and glide path;

b) an undetected fault that significantly changes the course width and glide path sensitivity;

c) an undetected fault causing slow cyclic movements of the course, producing apparent course bends as seen by the approaching aircraft significantly exceeding in amplitude the figures specified in Chapter 3, 3.1.3.4.2 for the localizer and Chapter 3, 3.1.5.4.2 for the glide path between ILS points "B" and "T".

2.8.2.4 The highest order of protection is required against the risk of undetected failures in the monitoring and associated control system. This would be achieved by careful design to reduce the probability of such occurrences to a low level and by carrying out maintenance checks on the monitor system performance at intervals which are determined by the design analysis. Such an analysis can be used to calculate the level of integrity of the system in any one landing. The following formula applies to certain types of ILS and provides an example of the determination of system integrity, I, from a calculation of the probability of transmission of undetected erroneous radiation, P.

(1) $$I = 1 - P$$

$$P = \frac{T_1 T_2}{\alpha_1 \alpha_2 M_1 M_2} \text{ when } T_1 < T_2$$

where

I = integrity

P = the probability of a concurrent failure in transmitter and monitor systems resulting in erroneous undetected radiation

M_1 = transmitter MTBF

M_2 = MTBF of the monitoring and associated control system

$\frac{1}{\alpha_1}$ = ratio of the rate of failure in the transmitter resulting in the radiation of an erroneous signal to the rate of all transmitter failures

$\frac{1}{\alpha_2}$ = ratio of the rate of failure in the monitoring and associated control system resulting in inability to detect an erroneous signal to the rate of all monitoring and associated control system failures

T_1 = period of time (in hours) between transmitter checks

T_2 = period of time (in hours) between checks on the monitoring and associated control system

When $T_1 \geq T_2$ the monitor system check may also be considered a transmitter check. In this case, therefore $T_1 = T_2$ and the formula would be:

(2) $$P = \frac{T_2^2}{\alpha_1 \alpha_2 M_1 M_2}$$

2.8.2.5 With regard to integrity, since the probability of occurrence of an unsafe failure within the monitoring or control equipment is extremely remote, to establish the required integrity level with a high degree of confidence would necessitate an evaluation period many times that needed to establish the equipment MTBF. Such a protracted period is unacceptable and therefore the required integrity level can only be predicted by rigorous design analysis of the equipment.

2.8.2.6 The MTBF and continuity of service of equipment is governed by basic construction and operating environment. Equipment design should employ the most suitable engineering techniques, materials and components, and rigorous inspection should be applied during manufacture. It is essential to ensure that equipment is operated within the environmental conditions specified by the manufacturer. The manufacturer is required to provide the details of the design to enable the MTBF and continuity of service to be calculated. It is expected that the equipment MTBF is confirmed by evaluation in an operational environment to take account of the impact of operational factors, i.e. airport environment, inclement weather conditions, power availability, quality and frequency of maintenance. For integrity and continuity of service Levels 2, 3 or 4 the evaluation period should be sufficient to determine achievement of the required level with a high degree of confidence. The following considerations apply:

a) the minimum acceptable confidence level is 60 per cent. Depending on the service level of the ILS, this may result in different evaluation periods. To assess the influence of the airport environment, a minimal evaluation period of one year is typically required for a new type of installation at that particular airport. It may be possible to reduce this period in cases where the operating environment is well controlled and similar to other proven installations. Subsequent installation of the same type of equipment under similar operational and environmental conditions may follow different evaluation periods. Typically, these minimal periods for subsequent installations are for Level 2, 1 600 hours, for Level 3, 3 200 hours and for Level 4, at least 6 400 hours. Where several identical systems are being operated under similar conditions, it may be possible to base the assessment on the cumulative operating hours of all the systems. This will result in a reduced evaluation period; and

b) during the evaluation period, it should be decided for each outage if it is caused by a design failure or if it is caused by a failure of a component due to its normal failure rate. Design failures are, for instance, operating components beyond their specification (overheating, overcurrent, overvoltage, etc. conditions). These design failures should be dealt with such that the operating condition is brought back to the normal operating condition of the component or that the component is replaced with a part suitable for the operating conditions. If the design failure is treated in this way, the evaluation may continue and this outage is not counted, assuming that there is a high probability that this design failure will not occur again. The same applies to outages due to any causes which can be mitigated by permanent changes to the operating conditions.

2.8.2.7 Continuity of service performance may also be demonstrated by means of MTBO (mean time between outages) where an outage is defined as any unanticipated cessation of signal-in-space. It is calculated by dividing the total facility up-time by the number of operational failures. MTBF and MTBO are not always equivalent, as not all equipment failures will necessarily result in an outage, e.g. an event such as a failure of a transmitter resulting in the immediate transfer to a standby transmitter. The minimum MTBO values expected for the continuity of service in 2.14 have been derived from several years of operational experience of many systems. To determine whether the performance record of an individual ILS system justifies its assignment to Levels 2, 3 or 4 requires a judicious consideration of such factors as:

a) the performance record and experience of system use established over a suitable period of time (see 2.8.2.6);

b) the average achieved MTBO established for this type of ILS; and

c) the trend of the failure rates.

An assigned designation should not be subject to frequent change. A suitable method to assess the behaviour of a particular installation is to keep the records and calculate the average MTBO over the last five to eight failures of the equipment. A typical record of this method is given in Figures C-12A and C-12B.

2.8.2.8 During the equipment evaluation, and subsequent to its introduction into operational service, records should be maintained of all equipment failures or outages to confirm retention of the desired continuity of service.

2.8.2.9 The following configuration is an example of a redundant equipment arrangement that is likely to meet the objectives for integrity and continuity of service Levels 3 or 4. The localizer facility consists of two continuously operating transmitters, one connected to the antenna and the standby connected to a dummy load. With these transmitters is associated a monitor system performing the following functions:

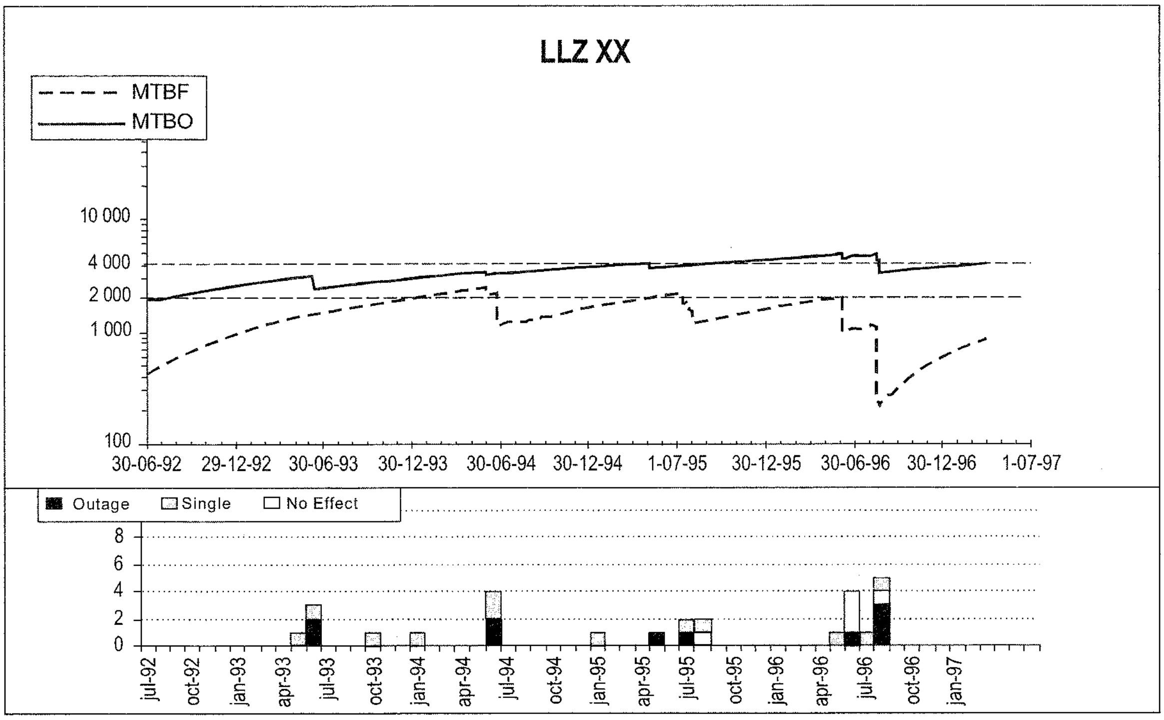


Figure C-12A. Example of a localizer outage record

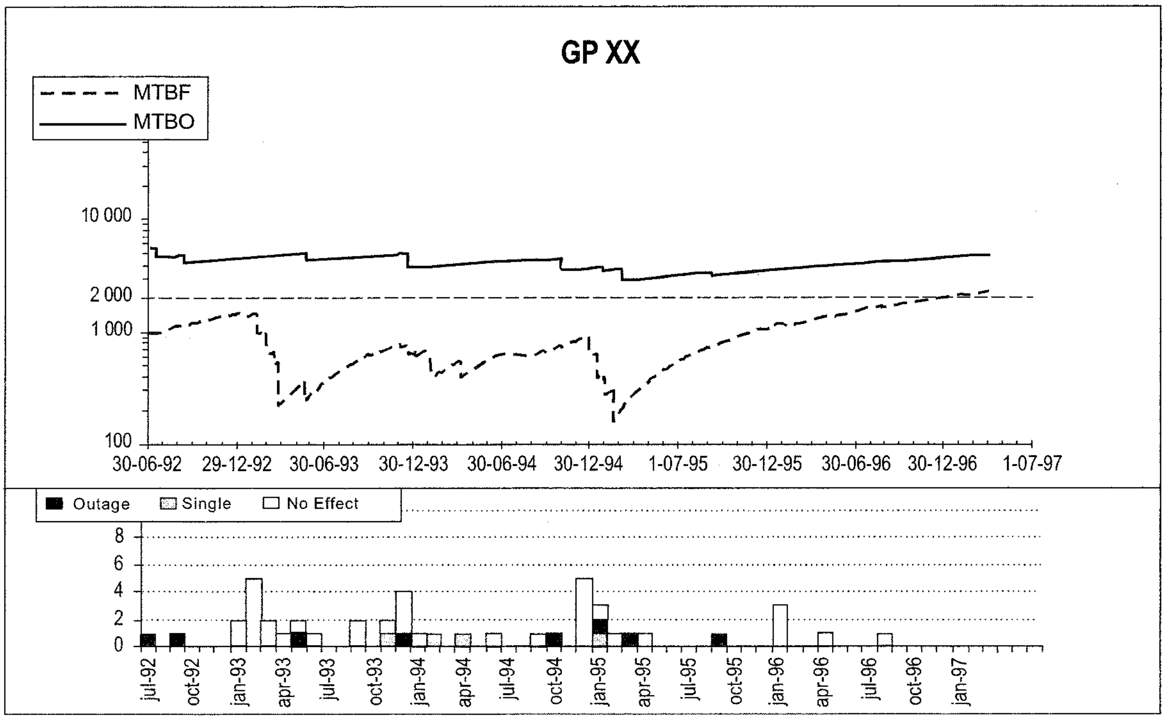


Figure C-12B. Example of a glide path outage record

a) monitoring of operation within the specified limits of the main transmitter and antenna system by means of majority voting among redundant monitors;

b) monitoring the standby equipment.

2.8.2.9.1 Whenever the monitor system rejects one of the equipments the facility continuity of service level will be reduced because the probability of cessation of signal consequent on failure of other equipment will be increased. This change of performance must be automatically indicated at remote locations.

2.8.2.9.2 An identical monitoring arrangement to the localizer is used for the glide path facility.

2.8.2.9.3 To reduce mutual interference between the main and standby transmitters any stray radiation from the latter is at least 50 dB below the carrier level of the main transmitter measured at the antenna system.

2.8.2.9.4 In the above example, the equipment would include provision to facilitate monitoring system checks at intervals specified by the manufacturer, consequent to the design analysis, to ensure attainment of the required integrity level. Such checks, which can be manual or automatic, provide the means to verify correct operation of the monitoring system including the control circuitry and changeover switching system. The advantage of adopting an automatic monitor integrity test is that no interruption to the operational service provided by the localizer or glide path is necessary. It is important when using this technique to ensure that the total duration of the check cycle is short enough not to exceed the total period specified in Chapter 3, 3.1.3.11.3 or 3.1.5.7.3.

2.8.2.9.5 Interruption of facility operation due to primary power failures is avoided by the provision of suitable standby supplies, such as batteries or "no-break" generators. Under these conditions, the facility should be capable of continuing in operation over the period when an aircraft may be in the critical stages of the approach. Therefore the standby supply should have adequate capacity to sustain service for at least two minutes.

2.8.2.9.6 Warnings of failures of critical parts of the system, such as the failure of the primary power supply, must be given at the designated control points.

2.8.2.10 In order to reduce failure of equipment that may be operating near its monitor tolerance limits, it is useful for the monitor system to include provision to generate a pre-alarm warning signal to the designated control point when the monitored parameters reach a limit equal to a value in the order of 75 per cent of the monitor alarm limit.

2.8.2.11 Protection of the integrity of the signal-in-space against degradation which can arise from extraneous radio interference falling within the ILS frequency band or from re-radiation of ILS signals must also be considered. Measures to prevent the latter by critical and sensitive area protection are given in general terms at 2.1.10. With regard to radio interference it may be necessary to confirm periodically that the level of interference does not constitute a hazard.

2.8.2.12 A far field monitor can provide additional protection by providing a warning against the extremely remote probability of the radiation of false information from a localizer facility, as indicated in 2.8.5.

2.8.2.13 In general, monitoring equipment design is based on the principle of continuously monitoring the radiated signals-in-space at specific points within the coverage volume to ensure their compliance with the Standards specified at Chapter 3, 3.1.3.11 and 3.1.5.7. Although such monitoring provides to some extent an indication that the signal-in-space at all other points in the coverage volume is similarly within tolerance, this is largely inferred. It is essential therefore to carry out rigorous flight and ground inspections at periodic intervals to ensure the integrity of the signal-in-space throughout the coverage volume.

2.8.2.14 An equipment arrangement similar to that at 2.8.2.9, but with no transmitter redundancy, and the application of the provisions outlined in 2.8.2.11, 2.8.2.12 and 2.8.2.13, would normally be expected to achieve the objectives for integrity and continuity of service Level 2.

2.8.2.15 An analysis of the factors involved in different types of operations allows the determination of desired values for the integrity, expressed in terms of the probability in any one landing, to be determined from the allowable global risk factor criterion. See 2.14.2 c).

2.8.3 The stringent requirement for integrity and high continuity of service essential for Category III operations requires the use of ILS Facility Performance Category III equipment having adequate assurance against failures. A failure is taken to be performance outside the monitor system tolerances specified in Chapter 3, 3.1.3.11 for Category III localizers and 3.1.5.7 for Category III glide paths. Reliability of ground equipment operation must be very high, so as to ensure that safety during the critical phase of approach and landing is not impaired by a ground equipment failure when the aircraft is at such a height or attitude that it is unable to take safe corrective action. A high probability of performance within the specified limits has to be ensured. Facility reliability in terms of mean time between failures (MTBF) clearly has to be related on a system basis to the probability of failure which may affect any characteristic of the total signal-in-space. The system must ensure the highest degree of protection against failure of the monitors to detect a failure in performance of the ground equipment. It is suggested that States endeavour to achieve reliability with as large a margin as is technically and economically reasonable.

2.8.3.1 The following configuration is an example of a redundant arrangement suitable for Category III operations. The localizer facility consists of two continuously operating transmitters, one connected to an antenna load. With these transmitters is associated a monitor system performing the following functions:

a) monitoring of operation within the specified limits of the main transmitter and antenna system by means of a majority voting among redundant monitors;

b) monitoring of the standby equipment.

2.8.3.1.1 Whenever the monitor system rejects one of the equipments the facility will no longer have Category III status because the probability of cessation of signal consequent on failure of other equipment will be too high. This reversion to a lower category is automatically indicated at remote locations.

2.8.3.1.2 An identical monitoring arrangement is used for the glide path facility.

2.8.3.1.3 To reduce mutual interference between the main and standby transmitters, any stray radiation from the latter should be at least 50 dB below the carrier level of the main transmitter measured at the antenna system.

2.8.3.2 The highest order of protection is required against the consequence of undetected monitor system failures. This should be achieved by careful design to reduce the probability of such occurrences to a low level and by carrying out maintenance checks on the monitor system performance at intervals which are determined by the design analysis.

2.8.4 Additional guidance material applicable to Categories II and III — ILS localizer and glide path ground equipment is given below.

2.8.4.1 Reliability of equipment is governed by basic construction and operating environment. Equipment design should employ the most suitable engineering techniques, materials and components, and rigorous inspection should be applied in manufacture. Equipment should be operated in environmental conditions appropriate to the manufacturers' design criteria. It is expected that the equipment reliability be established by evaluation before introduction into Categories II and III service. Design analysis should verify the predicted performance of the equipment.

2.8.5 Guidance relating to localizer far field monitors is given below.

2.8.5.1 Far field monitors are provided to monitor course alignment but may also be used to monitor course sensitivity. A far field monitor operates independently from integral and near field monitors. Its primary purpose is to protect against the risk of erroneous setting-up of the localizer, or faults in the near field or integral monitors. In addition, the far field monitor system will enhance the ability of the combined monitor system to respond to the effects of physical modification of the radiating elements or variations in the ground reflection characteristics. Moreover, multipath effects and runway area disturbances not seen by near field and integral monitors, and some occurrences of radio interferences may be substantially monitored by using a far field monitoring system built around a suitable receiver(s), installed under the approach path.

2.8.5.2 A far field monitor is generally considered essential for Category III operations, while for Category II it is generally considered to be desirable. Also for Category I installations, a far field monitor has proved to be a valuable tool to supplement the conventional monitor system.

2.8.5.3 The signal received by the far field monitor will suffer short-term interference effects caused by aircraft movements on or in the vicinity of the runway and experience has shown that it is not practical to use the far field monitor as an executive monitor. When used as a passive monitor, means must be adopted to minimize such temporary interference effects and to reduce the occurrence of nuisance downgrade indications; some methods of achieving this are covered in 2.8.5.4. The response of the far field monitor to interference effects offers the possibility of indicating to the air traffic control point when temporary disturbance of the localizer signal is present. However, experience has shown that disturbances due to aircraft movements may be present along the runway, including the touchdown zone, and not always be observed at the far field monitor. It must not be assumed, therefore, that a far field monitor can provide comprehensive surveillance of aircraft movements on the runway.

2.8.5.3.1 Additional possible applications of the far field monitor are as follows:

a) it can be a useful maintenance aid to verify course and/or course deviation sensitivity in lieu of a portable far field monitor;

b) it may be used to provide a continuous recording of far field signal performance showing the quality of the far field signal and the extent of signal disturbance.

2.8.5.4 Possible methods of reducing the occurrence of nuisance downgrade indications include:

a) incorporation of a time delay within the system adjustable from 30 to 240 seconds;

b) the use of a validation technique to ensure that only indications not affected by transitory disturbances are transmitted to the control system;

c) use of low pass filtering.

2.8.5.5 A typical far field monitor consists of an antenna, VHF receiver and associated monitoring units which provide indications of DDM, modulation sum, and RF signal level. The receiving antenna is usually of a directional type to minimize unwanted interference and should be at the greatest height compatible with obstacle clearance limits. For course line monitoring, the antenna is usually positioned along the extended runway centre line. Where it is desired to also monitor displacement sensitivity, an additional receiver and monitor are installed with antenna suitably positioned to one side of the extended runway centre line. Some systems utilize a number of spatially separated antennas.

2.9 Localizer and glide path displacement sensitivities

2.9.1 Although certain localizer and glide path alignment and displacement sensitivities are specified in relation to the ILS reference datum, it is not intended to imply that measurement of these parameters must be made at this datum.

2.9.2 Localizer monitor system limits and adjustment and maintenance limits given in Chapter 3, 3.1.3.7 and 3.1.3.11 are stated as percentage changes of displacement sensitivity. This concept, which replaces specifications of angular width in earlier editions, has been introduced because the response of aircraft guidance systems is directly related to displacement sensitivity. It will be noted that angular width is inversely proportional to displacement sensitivity.

2.10 Siting of ILS markers

2.10.1 Considerations of interference between inner and middle markers, and the minimum operationally acceptable time interval between inner and middle marker light indications, will limit the maximum height marked by the inner marker to a height on the ILS glide path of the order of 37 m (120 ft) above threshold for markers sited within present tolerances in Annex 10. A study of the individual site will determine the maximum height which can be marked, noting that with a typical airborne marker receiver a separation period of the order of 3 seconds at an aircraft speed of 140 kt between middle and inner marker light indications is the minimum operationally acceptable time interval.

2.10.2 In the case of ILS installations serving closely spaced parallel runways, e.g. 500 m (1 650 ft) apart, special measures are needed to ensure satisfactory operation of the marker beacons. Some States have found it practical to employ a common outer marker for both ILS installations. However, special provisions, e.g. modified field patterns, are needed in the case of the middle markers if mutual interference is to be avoided, and especially in cases where the thresholds are displaced longitudinally from one another.

2.11 Use of DME as an alternative to ILS marker beacons

2.11.1 When DME is used as an alternative to ILS marker beacons, the DME should be located on the airport so that the zero range indication will be a point near the runway. If the DME associated with ILS uses a zero range offset, this facility has to be excluded from RNAV solutions.

2.11.2 In order to reduce the triangulation error, the DME should be sited to ensure a small angle (e.g. less than 20 degrees) between the approach path and the direction to the DME at the points where the distance information is required.

2.11.3 The use of DME as an alternative to the middle marker beacon assumes a DME system accuracy of 0.37 km (0.2 NM) or better and a resolution of the airborne indication such as to allow this accuracy to be attained.

2.11.4 While it is not specifically required that DME be frequency paired with the localizer when it is used as an alternative for the outer marker, frequency pairing is preferred wherever DME is used with ILS to simplify pilot operation and to enable aircraft with two ILS receivers to use both receivers on the ILS channel.

2.11.5 When the DME is frequency paired with the localizer, the DME transponder identification should be obtained by the "associated" signal from the frequency-paired localizer.

2.12 The use of supplementary sources of orientation guidance in association with ILS

2.12.1 Aircraft beginning an ILS approach may be assisted by guidance information provided by other ground referenced facilities such as VORs, surveillance radar or, where these facilities cannot be provided, by a locator beacon.

2.12.2 When not provided by existing terminal or en-route facilities, a VOR, suitably sited, will provide efficient transition to the ILS. To achieve this purpose the VOR may be sited on the localizer course or at a position some distance from the localizer course provided that a radial will intersect the localizer course at an angle which will allow smooth transitions in the case of auto coupling. The distance between the VOR site and the desired point of interception must be recognized when determining the accuracy of the interception and the airspace available to provide for tracking errors.

2.12.3 Where it is impracticable to provide a suitably sited VOR, a compass locator or an NDB can assist transition to the ILS. The facility should be sited on the localizer course at a suitable distance from the threshold to provide for optimum transition.

2.13 The use of Facility Performance Category I — ILS for automatic approaches and landings in visibility conditions permitting visual monitoring of the operation by the pilot

2.13.1 Facility Performance Category I — ILS installations of suitable quality can be used, in combination with aircraft flight control systems of types not relying solely on the guidance information derived from the ILS sensors, for automatic approaches and automatic landings in visibility conditions permitting visual monitoring of the operation by the pilot.

2.13.2 To assist aircraft operating agencies with the initial appraisal of the suitability of individual ILS installations for such operations, provider States are encouraged to promulgate:

a) the differences in any respect from Chapter 3, 3.1;

b) the extent of compliance with the provisions in Chapter 3, 3.1.3.4 and 3.1.5.4, regarding localizer and glide path beam structure; and

c) the height of the ILS reference datum above the threshold.

2.13.3 To avoid interference which might prevent the completion of an automatic approach and landing, it is necessary that local arrangements be made to protect, to the extent practicable, the ILS critical and sensitive areas.

2.13.4 Where two separate ILS facilities serve opposite ends of a single runway, an interlock should ensure that only the localizer serving the approach direction in use should radiate.

2.14 ILS classification — supplementary ILS description method with objective to facilitate operational utilization

2.14.1 The classification system given below, in conjunction with the current facility performance categories, is intended to provide a more comprehensive method of describing an ILS.

2.14.2 The ILS classification is defined by using three characters as follows:

a) I, II or III: this character indicates conformance to Facility Performance Category in Chapter 3, 3.1.3 and 3.1.5.

b) A, B, C, T, D or E: this character defines the ILS points to which the localizer structure conforms to the course structure given at Chapter 3, 3.1.3.4.2, except the letter T, which designates the runway threshold. The points are defined in Chapter 3, 3.1.1.

c) 1, 2, 3 or 4: this number indicates the level of integrity and continuity of service given in Table C-2.

Note.— In relation to specific ILS operations it is intended that the level of integrity and continuity of service would typically be associated as follows:

1) Level 2 is the performance objective for ILS equipment used to support low visibility operations when ILS guidance for position information in the landing phase is supplemented by visual cues. This level is a recommended objective for equipment supporting Category I operations;

2) Level 3 is the performance objective for ILS equipment used to support operations which place a high degree of reliance on ILS guidance for positioning through touchdown. This level is a required objective for equipment supporting Category II and IIIA operations; and

Table C-2. Integrity and continuity of service objectives

Level	Localizer or glide path		
	Integrity	Continuity of service	MTBO (hours)
1		Not demonstrated, or less than required for Level 2	
2	$1 - 10^{-7}$ in any one landing	$1 - 4 \times 10^{-6}$ in any period of 15 seconds	1 000
3	$1 - 0.5 \times 10^{-9}$ in any one landing	$1 - 2 \times 10^{-6}$ in any period of 15 seconds	2 000
4	$1 - 0.5 \times 10^{-9}$ in any one landing	$1 - 2 \times 10^{-6}$ in any period of 30 seconds (localizer) 15 seconds (glide path)	4 000 (localizer) 2 000 (glide path)

Note.— For currently installed systems, in the event that the Level 2 integrity value is not available or cannot be readily calculated, it is necessary to at least perform a detailed analysis of the integrity to assure proper monitor fail-safe operation.

3) Level 4 is the performance objective for ILS equipment used to support operations which place a high degree of reliance on ILS guidance throughout touchdown and rollout. This level basically relates to the needs of the full range of Category III operations.

2.14.3 As an example, a Facility Performance Category II — ILS which meets the localizer course structure criteria appropriate to a Facility Performance Category III — ILS down to ILS point "D" and conforms to the integrity and continuity of service objectives of Level 3 would be described as class II/D/3.

2.14.4 ILS classes are appropriate only to the ground ILS element. Consideration of operational categories must also include additional factors such as operator capability, critical and sensitive area protection, procedural criteria and ancillary aids, such as transmissometers and lights.

2.15 ILS carrier frequency and phase modulation

2.15.1 In addition to the desired 90 Hz and 150 Hz AM modulation of the ILS RF carriers, undesired frequency modulation (FM) and/or phase modulation (PM) may exist. This undesired modulation can cause centring errors in ILS receivers due to slope detection by ripple in the intermediate frequency (IF) filter pass-band.

2.15.2 For this to occur, the translated RF carrier frequency must fall on an IF frequency where the pass-band has a high slope. The slope converts the undesired 90 Hz and 150 Hz frequency changes to AM of the same frequencies. Similarly, any difference in FM deviation between the undesired 90 Hz and 150 Hz components is converted to DDM, which in turn produces an offset in the receiver. The mechanism is identical for PM as for FM, since PM causes a change in frequency equal to the change in phase (radians) multiplied by the modulating frequency.

2.15.3 The effect of the undesired FM and/or PM is summed by vector addition to the desired AM. The detected FM is either in phase or anti-phase with the AM according to whether the pass-band slope at the carrier's IF is positive or negative. The detected PM is in quadrature with the AM, and may also be positive or negative according to the pass-band slope.

2.15.4 Undesired FM and/or PM from frequencies other than 90 Hz and 150 Hz, but which pass through the 90 Hz and 150 Hz tone filters of the receiver, can also cause changes to the desired 90 Hz and 150 Hz AM modulation of the ILS RF carrier, resulting in a DDM offset error in the receiver. Thus, it is essential that when measuring undesired FM and PM levels, audio band-pass filters with a pass-band at least as wide as that of the tone filters of ILS receivers be used. These filters are typically inserted in commercial modulation meter test equipment between the demodulation and metering circuits, to ensure that only spectral components of interest to ILS applications are measured. To standardize such measurements, the filter characteristics are recommended as shown below:

Frequency (Hz)	*90 Hz band-pass filter attenuation, dB*	*150 Hz band-pass filter attenuation, dB*
≤45	−10	−16
85	−0.5	(no specification)
90	0	−14
95	−0.5	(no specification)
142	(no specification)	−0.5
150	−14	0
158	(no specification)	−0.5
≥300	−16	−10

2.15.5 The preferred maximum limits, as shown below, are derived from ILS receiver centring error limits specified in EUROCAE documents ED-46B and ED-47B, based on the worst-case-to-date observed correlation between undesired modulation levels and centring errors:

Facility type	*90 Hz peak deviation, FM Hz/PM radians (Note 1)*	*150 Hz peak deviation, FM Hz/PM radians (Note 2)*	*Deviation difference, Hz (Note 3)*
Localizer, Cat I	135/1.5	135/0.9	45
Localizer, Cat II	60/0.66	60/0.4	20
Localizer, Cat III	45/0.5	45/0.3	15
Glide path, Cat I	150/1.66	150/1.0	50
Glide path, Cat II or III	90/1.0	90/0.6	30

Note 1.— This column applies to the peak frequency or phase deviation as measured with the 90 Hz tone filter specified in 2.15.4.

Note 2.— This column applies to the peak frequency or phase deviation as measured with the 150 Hz tone filter specified in 2.15.4.

Note 3.— This column applies to the difference in peak frequency deviation between the separate measurements of the undesired 90 Hz FM (or equivalent PM) and the 150 Hz FM (or equivalent PM) obtained with the filters specified in the table in 2.15.4. The equivalent deviation for 90 Hz and 150 Hz measured PM values is calculated by multiplying each peak PM measurement in radians by its corresponding modulating frequency in Hz.

3. Material concerning VOR

3.1 Guidance relating to VOR effective radiated power (ERP) and coverage

3.1.1 The field strength specified at Chapter 3, 3.3.4.2, is based on the following consideration:

Airborne receiver sensitivity	−117 dBW
Transmission line loss, mismatch loss, antenna polar pattern variation with respect to an isotropic antenna	+7 dBW
Power required at antenna	−110 dBW

The power required of minus 100 dBW is obtained at 118 MHz with a power density of minus 107 dBW/m^2; minus 107 dBW/m^2 is equivalent to 90 microvolts per metre, i.e. plus 39 dB referenced to 1 microvolt per metre.

Note.— The power density for the case of an isotropic antenna may be computed in the following manner:

$$P_d = P_a - 10 \log \frac{\lambda^2}{4\pi}$$

where

P_d = *power density in dBW/m^2;*

P_a = *power at receiving point in dBW;*

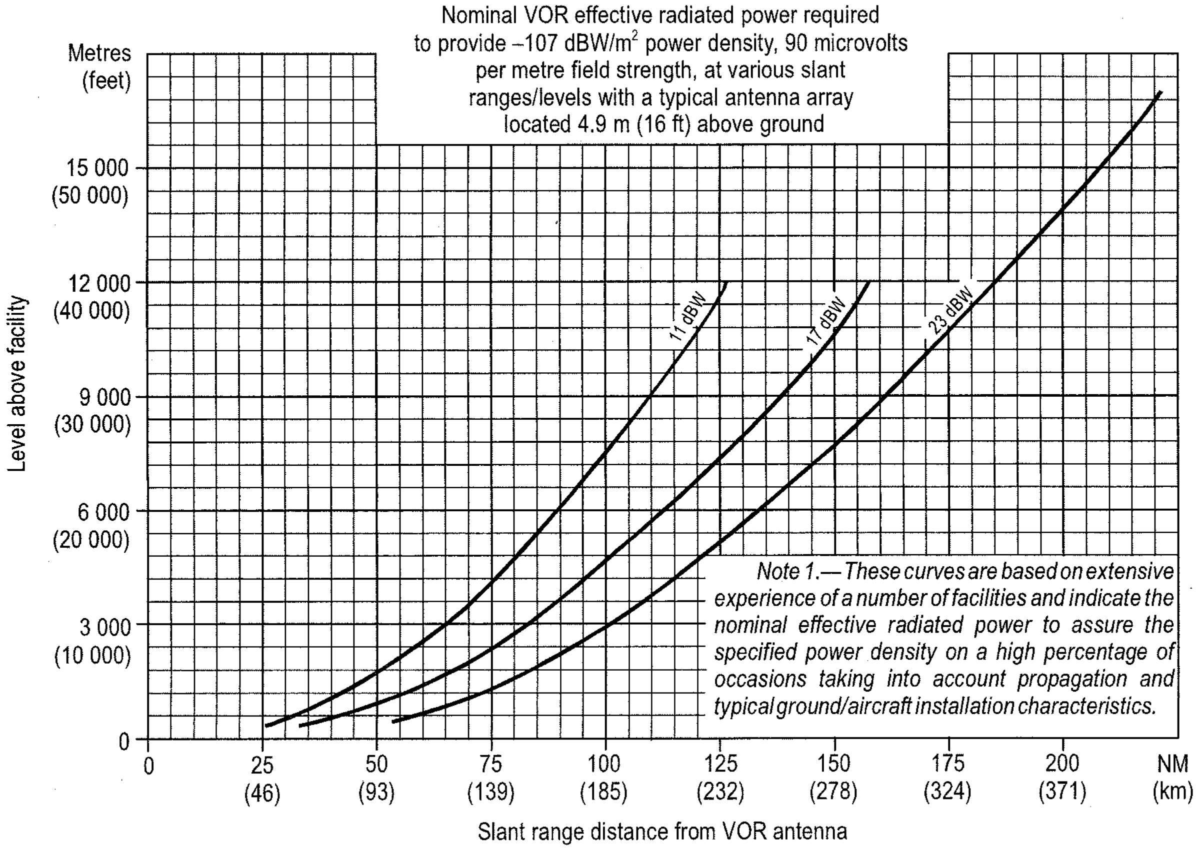
λ = *wavelength in metres.*

3.1.2 Nominal values of the necessary ERP to achieve a field strength of 90 microvolts per metre (minus 107 dBW/m^2) are given at Figure C-13. For coverage under difficult terrain and siting conditions, it may be necessary to make appropriate increases in the effective radiated power. Conversely, practical experience has shown that under favourable siting conditions, and under the less pessimistic conditions often found in actual service, satisfactory system operation is achieved with a lower ERP.

Note.— The nominal effective radiated powers, expressed as a function of level and range, are based upon consideration of basic theoretical data from various sources (such as ITU-R and NBS) modified empirically to reflect typical operational experience.

3.1.3 The use of Figure C-13 is illustrated by the following examples. In order to achieve the necessary field strength at 342 km (185 NM)/12 000 m (40 000 ft), 300 km (162 NM)/12 000 m (40 000 ft), and 166.5 km (90 NM)/6 000 m (20 000 ft), nominal effective radiated powers of plus 23 dBW, plus 17 dBW and plus 11 dBW respectively are required.

3.1.4 In order to facilitate frequency and equipment planning, wherever practicable, ERP categories corresponding to plus 23 dBW, plus 17 dBW and plus 11 dBW should be employed. These ERP values should be indicated during regional planning activities.



Note 2.— These curves display coverage versus power only. For frequency planning guidance, refer to 3.4 of Attachment C.

Figure C-13

3.1.5 A VOR having an ERP of plus 23 dBW approximates to a VOR previously referred to in Annex 10 as Category A (transmitter power 200 W). Possible relationships between ERP and transmitter output powers are illustrated by the following examples:

	Example I	*Example II*
Transmitter power	+23 dBW	+18 dBW
Ground transmission line loss	–2 dB	–1 dB
Antenna gain relative to an isotropic antenna	+2 dB	+6 dB
ERP	+23 dBW	+23 dBW

Similarly, a VOR having an ERP of plus 17 dBW approximates to a VOR previously referred to in Annex 10 as Category B (transmitter power 50 W). Possible relationships between ERP and transmitter output powers are illustrated by the following examples:

	Example I	*Example II*
Transmitter power	+17 dBW	+10 dBW
Ground transmission line loss	–2 dB	–1 dB
Antenna gain relative to an isotropic antenna	+2 dB	+8 dB
ERP	+17 dBW	+17 dBW

3.1.6 It is recognized that the above ERP categories may achieve a greater coverage than is necessary for some operational requirements. A suitable lesser coverage might be achieved by a VOR facility having an ERP of approximately plus 11 dBW as follows:

	Example I	*Example II*
Transmitter power	+11 dBW	+7 dBW
Ground transmission line loss	–2 dB	–1 dB
Antenna gain relative to an isotropic antenna	+2 dB	+5 dB
ERP	+11 dBW	+11 dBW

3.2 Guidance in respect of siting of VOR

3.2.1 The site should be on the highest ground in the vicinity to obtain the greatest line-of-sight coverage and should be level or should slope away from the station (at a downgrade not exceeding 4 per cent) to a distance of at least 300 m (1 000 ft) and preferably to 600 m (2 000 ft) from the station. The site contours should be circular with respect to the antenna array to a radius of at least 300 m (1 000 ft). The site should be as far removed from wire lines and fences as possible. The height of wire lines and fences should not subtend a vertical angle of more than 1.5 degrees or extend more than 0.5 degree above the horizontal as measured from the antenna array. These limits may be increased by 50 per cent for fences or lines which are essentially radial to the antenna array or which subtend a horizontal angle of no more than 10 degrees. Single trees of moderate size, up to 9 m (30 ft) in height, may be tolerated beyond 150 m (500 ft). No groups of trees should subtend a vertical angle greater than 2 degrees or be situated within 300 m (1 000 ft) of the station. Provisions should be made for clearing trees to 600 m (2 000 ft) if it should prove necessary. No structures should subtend a vertical angle greater than 1.2 degrees or be situated within 150 m (500 ft) of the station. Wooden structures with negligible metallic content and with little prospect of future metallic additions may subtend vertical angles up to 2.5 degrees.

3.2.2 In mountainous terrain, a mountain-top site will often be preferable. The site should be on the highest accessible hilltop or mountain, the top of which should be graded flat to a radius of at least 45 m (150 ft). On such sites, the antenna system should be installed approximately a half wavelength above ground level in the centre of the graded area and the transmitter building should be beyond the graded area, far enough down the slope to be below optical line of sight from the antenna array. No ground, trees, power lines, buildings, etc. between 45 m (150 ft) and 360 m (1 200 ft) should be within optical line of sight of the antenna array.

3.3 Determination of the effect of "polarization error" on VOR accuracy

3.3.1 As it is not possible to specify as yet the maximum permissible value of the vertically polarized component of the radiation from the VOR, certain flight tests are necessary to determine the effect on the bearing indication accuracy due to the presence of the "polarization errors".

3.3.2 Three methods are available to determine the effects of "polarization errors":

a) 30-degree wing rock;

b) flying 8 tracks over a ground checkpoint;

c) flying a circle at 30-degree bank.

The first of these methods is designed to measure the polarization errors which occur when an aircraft rolls while flying a given VOR radial. The second method measures the polarization error for eight different aircraft headings when the aircraft is not banked. The third method measures the polarization errors, for all aircraft headings, with the aircraft banked at 30 degrees. The flight tests are as follows:

3.3.3 *30-degree wing rock.* The aircraft is flown on a constant heading towards the VOR station and is banked slowly from plus 30 degrees to minus 30 degrees. The course deviation indicator current is recorded and converted into degrees of course displacement.

3.3.4 *Eight tracks over a ground checkpoint.* The aircraft is flown over a specific ground checkpoint on eight different headings displaced by 45 degrees. The course deviation indicator current is recorded and the recording is marked when the aircraft is over the checkpoint. The indicated bearing on each heading is compared with the indicated bearing when the aircraft is heading towards the VOR station and is over the checkpoint.

3.3.5 *Circular flight with 30-degree bank.* The aircraft is first headed towards the VOR station over a ground checkpoint. From this point, it is flown in a circle at constant 30-degree bank. The course deviation indicator current is recorded while the aircraft is flying this circle and converted into degrees of error from the bearing indicated at the beginning of the procedure when the aircraft is over the checkpoint. The change of bearing of the aircraft with respect to the VOR station must be subtracted from the course deviation error. The resultant, after receiver error has been eliminated, is assumed to be polarization error.

3.3.6 The polarization tests may conveniently be conducted at an altitude of 300 m (1 000 ft). Flight tests in 3.3.4 and 3.3.5 may be employed with respect to a checkpoint which is approximately 33.4 km (18 NM) from the VOR.

3.4 Criteria for geographical separation of VOR type facilities

3.4.1 In using the figures listed in Table C-3, it must be noted that these are derived from the agreed formulae in respect of specific altitudes. In application of the figures, regional meetings would only afford protection to the extent of the operationally required altitude and distance and, by use of the formulae, criteria can be calculated for any distance or altitude.

3.4.2 The figures listed are calculated on the assumption that the effective adjacent channel rejection of the airborne receiver is better than 60 dB down at the next assignable channel.

3.4.3 The calculations are based on the assumption that the protection against interference afforded to the wanted signal from the unwanted signal is 20 dB, corresponding to a bearing error of less than 1 degree due to the unwanted signal.

3.4.4 It is recognized that, in the case of adjacent channel operation, there is a small region in the vicinity of a VOR facility, in which interference may be caused to an aircraft using another VOR facility. However, the width of this region is so small that the duration of the interference would be negligible and, in any case, it is probable that the aircraft would change its usage from one facility to the other.

Table C-3. Values of geographical separation distances for co-channel operation

		VOR facilities of equal effective radiated power		VOR facilities which differ in effective radiated power by 6 dB				VOR facilities which differ in effective radiated power by 12 dB			
		Minimum geo-graphical separation between facilities is $2D_1 + \frac{20}{S}$ *if* $D_1 > D_2$ or $2D_2 + \frac{20}{S}$ *if* $D_2 > D_1$		Minimum geographical separation between facilities is $2D_1 + \frac{20-K}{S}$ *if* $D_1 > D_2 + \frac{K}{S}$ or $2D_2 + \frac{20+K}{S}$ *if* $D_1 < D_2 + \frac{K}{S}$				Minimum geographical separation between facilities is $2D_1 + \frac{20-K}{S}$ *if* $D_1 > D_2 + \frac{K}{S}$ or $2D_2 + \frac{20+K}{S}$ *if* $D_1 < D_2 + \frac{K}{S}$			
Altitude m (ft)	S dB/km (NM)	K dB	$\frac{20}{S}$ km (NM)	K dB	$\frac{K}{S}$ km (NM)	$\frac{20-K}{S}$ km (NM)	$\frac{20+K}{S}$ km (NM)	K dB	$\frac{K}{S}$ km (NM)	$\frac{20-K}{S}$ km (NM)	$\frac{20+K}{S}$ km (NM)
1	2	3	4	5	6	7	8	9	10	11	12
1 200 (4 000)	0.32 (0.60)	0	61 (33)	6	19 (10)	43 (23)	80 (43)	12	37 (20)	24 (13)	98 (53)
3 000 (10 000)	0.23 (0.43)	0	87 (47)	6	26 (14)	61 (33)	113 (61)	12	52 (28)	35 (19)	137 (74)
4 500 (15 000)	0.18 (0.34)	0	109 (59)	6	33 (18)	76 (41)	143 (77)	12	67 (36)	44 (24)	174 (94)
6 000 (20 000)	0.15 (0.29)	0	128 (69)	6	39 (21)	89 (48)	167 (90)	12	78 (42)	52 (28)	206 (110)
7 500 (25 000)	0.13 (0.25)	0	148 (80)	6	44 (24)	104 (56)	193 (104)	12	89 (48)	59 (32)	237 (128)
9 000 (30 000)	0.12 (0.23)	0	161 (87)	6	48 (26)	113 (61)	209 (113)	12	96 (52)	65 (35)	258 (139)
12 000 (40 000)	0.10 (0.19)	0	195 (105)	6	59 (32)	135 (73)	254 (137)	12	119 (64)	78 (42)	311 (168)
18 000 (60 000)	0.09 (0.17)	0	219 (118)	6	65 (35)	154 (83)	284 (153)	12	130 (70)	87 (47)	348 (188)

Note.— S, K and the sign of K are defined in 3.4.5.

3.4.5 The agreed formulae for calculating the geographical separations are as follows (nautical miles may be substituted for kilometres):

A — *minimum geographical separation (co-channel):*

either $2\,D_1 + \frac{20-K}{S}$ km

where $D_1 > D_2 + \frac{K}{S}$

or $2\,D_2 + \frac{20+K}{S}$ km

where $D_1 < D_2 + \frac{K}{S}$

B — *geographical separation (adjacent channel):*

collocation case

$$< \frac{40-K}{S}$$

non-collocated case

$$> 2D_1 - \frac{40+K}{S}\ km$$

where $D_1 > D_2 + \frac{K}{S}$

or $2D_2 - \frac{40-K}{S}\ km$

where $D_1 < D_2 + \frac{K}{S}$

C — *geographical separation (adjacent channel)*
(receivers designed for 100 kHz channel spacing in a 50 kHz channel spacing environment)

If receivers having an effective adjacent channel rejection of no better than 26 dB are used (e.g. a 100 kHz receiver used in a 50 kHz environment), a figure of 6 should be substituted for the figure of 40 in the above adjacent channel formulae. In this instance, the geographical collocation formula should not be used as the protection afforded may be marginal.

This leads to the following formula:

$$> 2D_1 + \frac{6+K}{S}\ km$$

where $D_1 > D_2 + \frac{K}{S}$

or $2D_2 - \frac{6-K}{S}\ km$

where $D_1 < D_2 + \frac{K}{S}$

In the above formulae:

D_1, D_2 = service distances required of the two facilities (km).

K = the ratio (dB) by which the effective radiated power of the facility providing D_1 coverage exceeds that of the facility providing D_2 coverage.

Note.— If the facility providing D_2 is of higher effective radiated power, then "K" will have a negative value.

S = slope of the curve showing field strength against distance for constant altitude (dB/km).

3.4.6 The figures listed in Table C-3 are based on providing an environment within which the airborne receivers can operate correctly.

3.4.6.1 In order to protect VOR receivers designed for 50 kHz channel spacing, minimum separations are chosen in order to provide the following minimum signal ratios within the service volume:

a) the desired signal exceeds an undesired co-channel signal by 20 dB or more;

b) an undesired signal, 50 kHz removed from the desired signal, exceeds the desired signal by up to 34 dB;

c) an undesired signal, 100 kHz removed from the desired signal, exceeds the desired signal by up to 46 dB;

d) an undesired signal, 150 kHz or further removed from the desired signal, exceeds the desired signal by up to 50 dB.

3.4.6.2 In order to protect VOR receivers designed for 100 kHz channel spacing, minimum separations are chosen in order to provide the following minimum signal ratios within the service volume:

a) the desired signal exceeds an undesired co-channel signal by 20 dB or more;

b) an undesired signal, 50 kHz removed from the desired signal, exceeds the desired signal by up to 7 dB;

c) an undesired signal, 100 kHz removed from the desired signal, exceeds the desired signal by up to 46 dB;

d) an undesired signal, 150 kHz or further removed from the desired signal, exceeds the desired signal by up to 50 dB.

3.4.7 Use of the figures given in 3.4.6 or other figures appropriate to other service distances and altitudes implies recognition of the basic assumptions made in this substitution of an approximate method of calculating separation, and the application of the figures will only be correct within the limitations set by those assumptions. The assumptions include that the change of field strength with distance (Factor "S") at various altitudes of reception is only valid for angles of elevation at the VOR of up to about 5 degrees, but above the radio line of sight. If more precise determination of separation distances is required in areas of frequency congestion, this may be determined for each facility from appropriate propagation curves.

3.4.8 The deployment of 50 kHz channel spacing requires conformity with Chapter 3, 3.3.2.2 and 3.3.5.7 and Annex 10, Volume V, Chapter 4, 4.2.4. Where, due to special circumstances it is essential during the initial conversion period from 100 kHz channel spacing to 50 kHz channel spacing to take account of nearby VOR facilities that do not conform with Chapter 3, 3.3.2.2 and 3.3.5.7 and Annex 10, Volume V, Chapter 4, 4.2.4, greater geographical separation between these and the new facilities utilizing 50 kHz channel spacing will be required to ensure a bearing error of less than one degree due to the unwanted signal. On the assumption that the sideband levels of the 9 960 Hz harmonic of the radiated signal of such facilities do not exceed the following levels:

9 960 Hz	0 dB reference
2nd harmonic	–20 dB
3rd harmonic	–30 dB
4th harmonic and above	–40 dB

the separation formulae at 3.4.5 should be applied as follows:

a) where only receivers designed for 50 kHz channel spacing need to be protected, the value of 40 should be replaced by 20 in the formula at B — non-collocated case;

b) where it is necessary to protect receivers designed for 100 kHz channel spacing, the co-channel formula at A — co-channel case, should be applied for the range of altitudes for which protection is required.

3.4.9 When DME/N facilities and VOR facilities are intended to operate in association with each other, as outlined in Chapter 3, 3.5.3.3.5, and have a common service volume, both the co-channel and adjacent channel geographical separation distances required by the DME are satisfied by the separation distances of the VOR as computed in this section, provided the distance between VOR and DME does not exceed 600 m (2 000 ft). However, if DME/W facilities are employed, the first adjacent channel minimum separation for the DME/W facilities should be equal to the co-channel separation specified for the VOR. The second adjacent channel minimum separation for DME/W facilities should equal the first adjacent channel separation specified for VOR. A potential interference situation may also occur with the implementation of DME "Y" channels since interference between two DME ground stations spaced 63 MHz apart could occur when transmitting and receiving on the same frequency (e.g. transmissions from channel 17 Y could interfere with reception on channels 80 X and 80 Y). To obviate any ground receiver desensitization due to this interference, a minimum ground separation distance of 18.5 km (10 NM) between facilities is necessary.

3.5 Criteria for geographical separation of VOR/ILS facilities

3.5.1 In using the figures of 3.5.3.1 and 3.5.3.2, it is to be borne in mind that the following assumptions have been made:

a) that the localizer receiver characteristic is as shown in 2.6.2, and the VOR receiver characteristic as shown in 3.4.2;

b) that the protection ratio for the ILS system and the VOR system is 20 dB as in 2.6.3 and 3.4.3, respectively;

c) that the protection point for ILS is at a service distance of 46.25 km (25 NM) measured along the line of use, and at an altitude of 1 900 m (6 250 ft).

Note.— With the advent of highly directional ILS localizer antenna arrays, the most critical protection point will not be along the extended runway centre line. Directive antennas result in critical protection points at maximum distance, either plus or minus 10 degrees or plus or minus 35 degrees off the runway centre line. Protection of these points should be examined during the frequency assignment process.

3.5.2 Although international VOR and ILS facilities will not appear on the same frequency, it may occur that an international VOR facility may share temporarily the same frequency as, and on a comparable basis with, a national ILS facility. For this reason, guidance is given as to the geographical separation required not only for a VOR and an ILS facility separated by 50 kHz or 100 kHz, but also for co-channel usage.

3.5.3 Because of the differing characteristics of use of the two equipments, the criteria for minimum geographical separation of VOR/ILS to avoid harmful interference are stated separately for each facility where relevant.

3.5.3.1 *Co-channel case*

a) Protection of the ILS system requires that a VOR having an ERP of 17 dBW (50 W) be at least 148 km (80 NM) from the ILS protection point.

b) On the assumption that a VOR having an ERP of 17 dBW (50 W) is to be protected to a service distance of 46.25 km (25 NM) and an altitude of 3 000 m (10 000 ft), protection of the VOR system requires that the ILS be at least 148 km (80 NM) from the VOR.

c) If protection of the VOR is required to, say, 92.5 km (50 NM) and 6 000 m (20 000 ft), the ILS is to be at least 250 km (135 NM) from the VOR.

3.5.3.2 *Adjacent channel case.* Protection of the VOR system is effectively obtained without geographical separation of the facilities. However, in the case of:

a) a localizer receiver designed for 100 kHz channel spacing and used in an area where navaid assignments are spaced at 100 kHz, the protection of the ILS system requires that a VOR having an ERP of 17 dBW (50 W) be at least 9.3 km (5 NM) from the ILS protection point;

b) a localizer receiver designed for 100 kHz channel spacing and used in an area where assignments are spaced at 50 kHz, the protection of the ILS system requires that a VOR having an ERP of 17 dBW (50 W) be at least 79.6 km (43 NM) from the ILS protection point.

3.5.4 Use of the figures given in 3.5.3 or other figures appropriate to other service distances and altitudes implies recognition of the basic assumptions made in this substitution of an approximate method of calculating separation, and the application of the figures will only be correct within the limitations set by those assumptions. If more precise determination of separation distances is required in areas of frequency congestion, this may be determined for each facility from appropriate propagation curves.

3.5.5 Protection of the ILS system from VOR interference is necessary where a VOR facility is located near an ILS approach path. In such circumstances, to avoid disturbance of the ILS receiver output due to possible cross modulation effects, suitable frequency separation between the ILS and VOR channel frequencies should be used. The frequency separation will be dependent upon the ratio of the VOR and ILS field densities, and the characteristics of the airborne installation.

3.6 Receiving function

3.6.1 *Sensitivity.* After due allowance has been made for aircraft feeder mismatch, attenuation loss and antenna polar diagram variation, the sensitivity of the receiving function should be such as to provide on a high percentage of occasions the accuracy of output specified in 3.6.2, with a signal having a field strength of 90 microvolts per metre or minus 107 dBW/m^2.

3.6.2 *Accuracy.* The error contribution of the airborne installation should not exceed plus or minus 3 degrees with a 95 per cent probability.

Note 1.— The assessment of the error contribution of the receiver will need to take account of:

1) the tolerance of the modulation components of the ground VOR facility as defined in Chapter 3, 3.3.5;

2) variation in signal level and carrier frequency of the ground VOR facility;

3) the effects of unwanted VOR and ILS signals.

Note 2.— The airborne VOR installation is not considered to include any special elements which may be provided for the processing of VOR information in the aircraft and which may introduce errors of their own (e.g. radio magnetic indicator (RMI).).

3.6.3 *Flag alarm operation.* Ideally, the flag alarm should warn a pilot of any unacceptable malfunctioning conditions which might arise within either the ground or airborne equipments. The extent to which such an ideal might be satisfied is specified below.

3.6.3.1 The flag alarm movement is actuated by the sum of two currents which are derived from the 30 Hz and 9 960 Hz elements of the VOR bearing component signal and, therefore, the removal of these elements from the radiated carrier results in the appearance of the flags. Since the VOR ground monitor interrupts the bearing components when any unacceptable condition prevails on the ground, there will be an immediate indication within an aircraft when the system is unusable.

3.6.3.2 The flag alarm movement current is also dependent upon the AGC characteristics of the airborne equipment and any subsequent gain following the receiver's second detector. Thus, if with a correctly adjusted airborne receiver the flag is just out of view when receiving a VOR signal conforming to the modulation characteristics specified in Chapter 3, 3.3.5, the flags will again become visible in the event of a decrease in the receiver's overall gain characteristics.

Note.— Certain types of receivers employ warning indications other than mechanical flags to perform the functions described here.

3.6.4 *VOR receiver susceptibility to VOR and localizer signals*

3.6.4.1 The receiver design should provide correct operation in the following environment:

a) the desired signal exceeds an undesired co-channel signal by 20 dB or more;

b) an undesired signal, 50 kHz removed from the desired signal, exceeds the desired signal by up to 34 dB (during bench testing of the receiver, in this first adjacent channel case, the undesired signal is varied over the frequency range of the combined ground station (plus or minus 9 kHz) and receiver frequency tolerance);

c) an undesired signal, 100 kHz removed from the desired signal, exceeds the desired signal by up to 46 dB;

d) an undesired signal, 150 kHz or further removed from the desired signal, exceeds the desired signal by up to 50 dB.

Note 1.— It is recognized that not all receivers currently meet requirement b); however, all future equipments are designed to meet this requirement.

Note 2.— In some States, a smaller ground station tolerance is used.

3.6.5 *Immunity performance of VOR receiving systems to interference from VHF FM broadcast signals*

3.6.5.1 With reference to the Note of 3.3.8, Chapter 3, the immunity performance defined there must be measured against an agreed measure of degradation of the receiving system's normal performance, and in the presence of, and under standard conditions for the input wanted signal. This is necessary to ensure that the testing of receiving equipment on the bench can be performed to a repeatable set of conditions and results and to facilitate their subsequent approval. Tests have shown that FM interference signals may affect both course guidance and flag current, and their effects vary depending on the DDM of the wanted signal which is applied. Additional information can be found in ITU Recommendation ITU-R IS.1140, *Text procedures for measuring receiver characteristics used for determining compatibility between the sound-broadcasting service in the band of about 87–108 MHz and the aeronautical services in the band 108–118 MHz.*

3.6.5.2 Commonly agreed formulae should be used to assess potential incompatibilities to receivers meeting the general interference immunity criteria specified in Chapter 3, 3.3.8. The formulae provide clarification of immunity interference performance of spurious emission (type A1) interference, out-of-band channel (type A2) interference, two-signal and three-signal third order (type B1) interference, and overload/desensitization (type B2) interference. Additional information can be found in ITU Recommendation ITU-R IS.1009-1, *Compatibility between the sound-broadcasting service in the band of about 87–108 MHz and the aeronautical services in the band 108–137 MHz.*

3.6.5.3 The frequency planning criteria given in Recommendation ITU-R IS.1009-1 do not take account of the potential for two-signal and three-signal fifth order intermodulation products. Measurements have determined that fifth order intermodulation products created in the receiver by FM stations might degrade the performance of VOR receivers conforming to specifications in Chapter 3, 3.3.8. Fifth order intermodulation products can occur without a third order intermodulation product occurring on the same VOR frequency. In the planning of frequencies, and in the assessment of protection from FM broadcast interference, consideration needs to be given to two-signal and three-signal fifth order intermodulation products generated within VOR receivers by FM broadcast stations.

3.7 VOR system accuracy

Note.— Guidance material on the determination of VOR system performance values is also contained in Annex 11, Attachment A.

3.7.1 *Purpose.* The following guidance material is intended to assist in the use of VOR systems. It is not intended to represent lateral separation standards or minimum obstacle clearances, although it may of course provide a starting point in their determination. The setting of separation standards or minimum obstacle clearances will necessarily take account of many factors not covered by the following material.

3.7.1.1 There is, however, a need to indicate a system use accuracy figure for the guidance of States planning VOR systems.

3.7.2 *Explanation of terms.* The following terms are used with the meanings indicated:

a) *VOR radial signal error.* The difference between the nominal magnetic bearing to a point of measurement from the VOR ground station and the bearing indicated by the VOR signal at that same point. The VOR radial signal error is made up of certain stable elements, such as course displacement error and most site and terrain effect errors, and certain random variable errors. The VOR radial signal error is associated with the ground station only and excludes other error factors, such as airborne equipment errors and pilotage element.

b) *VOR radial variability error.* That part of the VOR radial signal error which can be expected to vary about the essentially constant remainder. The radial variability error is the sum of the variable errors.

c) *VOR radial displacement error.* That part of the VOR radial signal error which is stable and may be considered as fixed for long periods of time.

d) *VOR airborne equipment error.* That error attributable to the inability of the equipment in the aircraft to translate correctly the bearing information contained in the radial signal. This error includes the contributions of the airborne receiver and the instrumentation used to present the information to the pilot.

e) *VOR aggregate error*. The difference between the magnetic bearing to a point of measurement from the VOR ground station and the bearing indicated by airborne VOR equipment of stated accuracy. More simply put, this is the error in the information presented to the pilot, taking into account not only the ground station and propagation path errors, but also the error contributed by the airborne VOR receiver and its instrumentation. The entire VOR radial signal error, both fixed and variable, is used.

f) *VOR pilotage element*. The error in the use of VOR navigation attributable to the fact that the pilot cannot or does not keep the aircraft precisely at the centre of the VOR radial or bearing indicated by the equipment.

g) *VOR system use error*. The square root of the sum of the squares (RSS) of VOR aggregate error and the pilotage element. This combination may be used to determine the probability of an aircraft remaining within specified limits when using VOR.

3.7.3 *Calculation of VOR system use accuracy*

3.7.3.1 The VOR system use accuracy is derived by considering the following error elements:

a) *VOR radial signal error* (Eg). This element consists of the radial displacement error and the radial variability error. It is determined by considering such factors as fixed radial displacement, monitoring, polarization effects, terrain effects and environment changes.

b) *VOR airborne equipment error* (Ea). This element embraces all factors in the airborne VOR system which introduces errors (errors resulting from the use of compass information in some VOR displays are not included).

c) *VOR pilotage element* (Ep). The value taken for this element is that used in PANS-OPS (Doc 8168) for pilot tolerance.

Note.— A measurement error also exists, but in a generalized discussion of errors may be considered to be absorbed in the other error values.

3.7.3.2 Since the errors in a), b), and c), when considered on a system basis (not any one radial) are independent variables, they may be combined on a root-sum-square method (RSS) when the same probability level is given to each element. For the purpose of this material, each element is considered to have a 95 per cent probability.

Therefore, the following formulae are derived:

$$\text{VOR aggregate error} = \sqrt{Eg^2 + Ea^2}$$

$$\text{VOR system use error} = \sqrt{Eg^2 + Ea^2 + Ep^2}$$

3.7.3.3 The following examples will derive only the VOR system use error but calculations can also be made to determine VOR aggregate error, if desired. By use of these formulae, the impact on the system of improvement or degradation of one of more error elements can be assessed.

Note.— All figures for VOR radial signal error are related to radials for which no restrictions are published.

3.7.3.4 Subject to the qualifications indicated in 3.7.1, it is considered that a VOR system use accuracy of plus or minus 5 degrees on a 95 per cent probability basis is a suitable figure for use by States planning the application of the VOR system (see, however, 3.7.3.5). This figure corresponds to the following component errors:

VOR radial signal error:

plus or minus 3° (95 per cent probability), a value readily achieved in practice.

VOR airborne equipment error:

plus or minus 3° (95 per cent probability), system characteristics value (see 3.6.2).

VOR pilotage element:

plus or minus 2.5° (95 per cent probability), in accordance with PANS-OPS (see also 3.7.3.8).

3.7.3.5 While the figure of plus or minus 5 degrees on a 95 per cent probability basis is a useful figure based on broad practical experience and used by many States, it must be noted that this figure may be achieved only if the error elements which make it up remain within certain tolerances. It is clear that, if the errors attributable to the VOR system elements are larger than the amounts noted, the resulting VOR system use error will also be larger. Conversely, where any or all of the VOR system error elements are smaller than those used in the above computation, the resulting VOR system use error will also be smaller.

3.7.3.6 The following examples, also derived from practical experience, provide additional planning guidance for States:

A.— *VOR radial signal error:*

plus or minus 3.5° (95 per cent probability), used by some States as the total ground system error.

VOR airborne equipment error:

plus or minus 4.2° (95 per cent probability), recognized in some States as the minimum performance figure for some classes of operations.

VOR pilotage element:

plus or minus 2.5° (95 per cent probability), in accordance with PANS-OPS (see also 3.7.3.8).

Calculated VOR system use accuracy:

plus or minus 6° (95 per cent probability).

B. — *VOR radial signal error:*

plus or minus 1.7° (95 per cent probability), based on extensive flight measurements conducted in one State on a large number of VORs.

VOR airborne equipment error:

plus or minus 2.7° (95 per cent probability), achieved in many airline operations.

VOR pilotage element:

plus or minus 2.5° (95 per cent probability), in accordance with PANS-OPS (see also 3.7.3.8).

Calculated VOR system use accuracy:

plus or minus 4° (95 per cent probability).

3.7.3.7 More realistic application of the VOR system may be achieved by assessing the errors as they actually exist in particular circumstances, rather than by using all-embracing generalizations which may give unduly optimistic or pessimistic results. In individual applications, it may be possible to utilize a system use accuracy value less than plus or minus 5 degrees if one or more of the error elements are smaller than the values used to compute the plus or minus 5 degrees. Conversely, a system use accuracy value greater than plus or minus 5 degrees will be necessary where it is known that radials are of poor quality or significant site errors exist, or for other reasons. However, in addition to this advice a warning is also essential regarding the use of lower values of individual elements in the system (for example, the radial signal error) on the assumption that an overall improvement in system accuracy will occur. There is considerable evidence that this may not be the case in some circumstances and that lower system accuracy values should not be applied without other confirmation (e.g. by radar observation) that an actual improvement in overall performance is being achieved.

3.7.3.8 It is to be noted that in angular systems such as the VOR, the pilotage element error, expressed in angular terms, will be greater as the aircraft nears the point source. Thus, while ground system and airborne error contributions, expressed in angular terms, are for all practical purposes constant at all ranges, it is necessary when considering the overall system use accuracy figures to take into account the larger pilotage element error occurring when the aircraft is near the VOR. However, these larger pilotage element errors do not result in large lateral deviations from course when near the facility.

3.8 Changeover points for VORs

Guidance on the establishment of changeover points on ATS routes defined by VORs is contained in Annex 11, Attachment A.

4. Precision approach radar system

Figures C-14 to C-18 illustrate certain of the Standards contained in Chapter 3, 3.2.

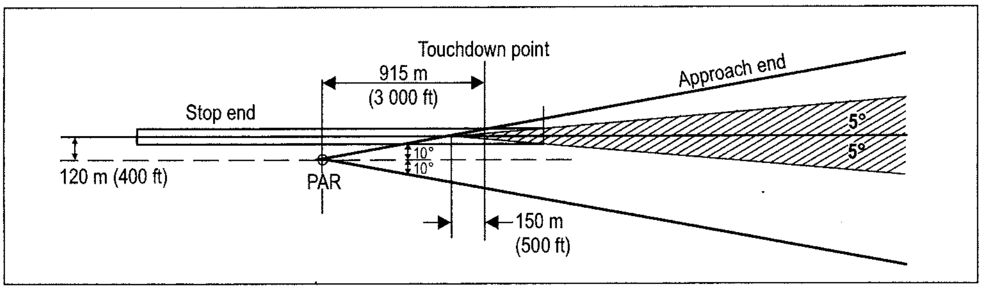


Figure C-14. Minimum set-back of PAR with respect to touchdown for offset of 120 m (400 ft) when aligned to scan plus or minus 10 degrees on QDR of runway

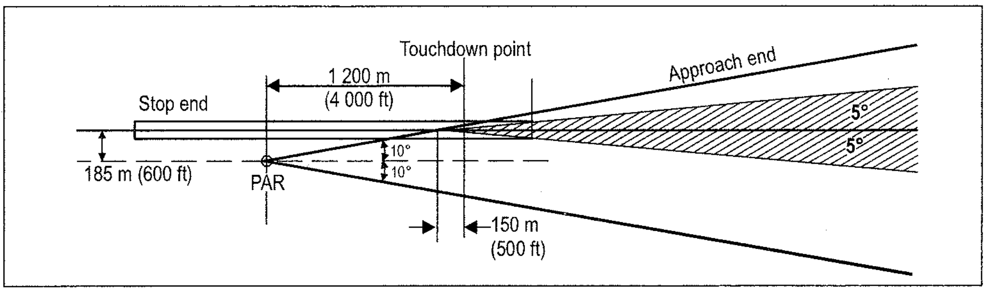


Figure C-15. Minimum set-back of PAR with respect to touchdown for offset of 185 m (600 ft) when aligned to scan plus or minus 10 degrees on QDR of runway

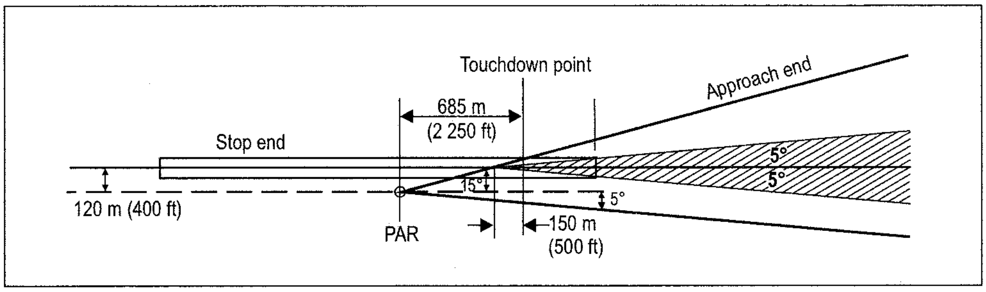


Figure C-16. Minimum set-back of PAR with respect to touchdown for offset of 120 m (400 ft) when aligned to scan 5 degrees and 15 degrees on QDR of runway

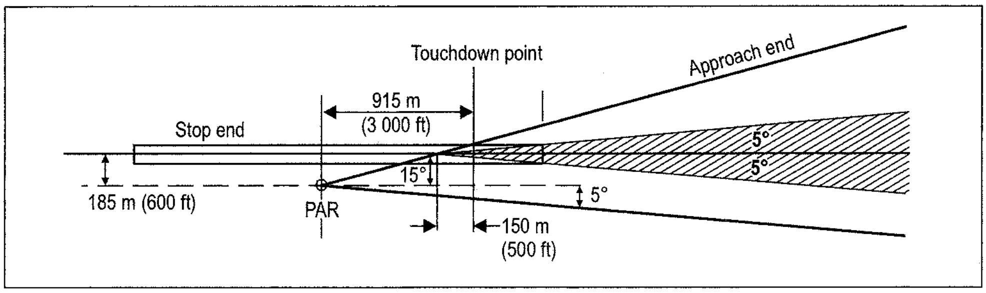


Figure C-17. Minimum set-back of PAR with respect to touchdown for offset of 185 m (600 ft) when aligned to scan 5 degrees and 15 degrees on QDR of runway

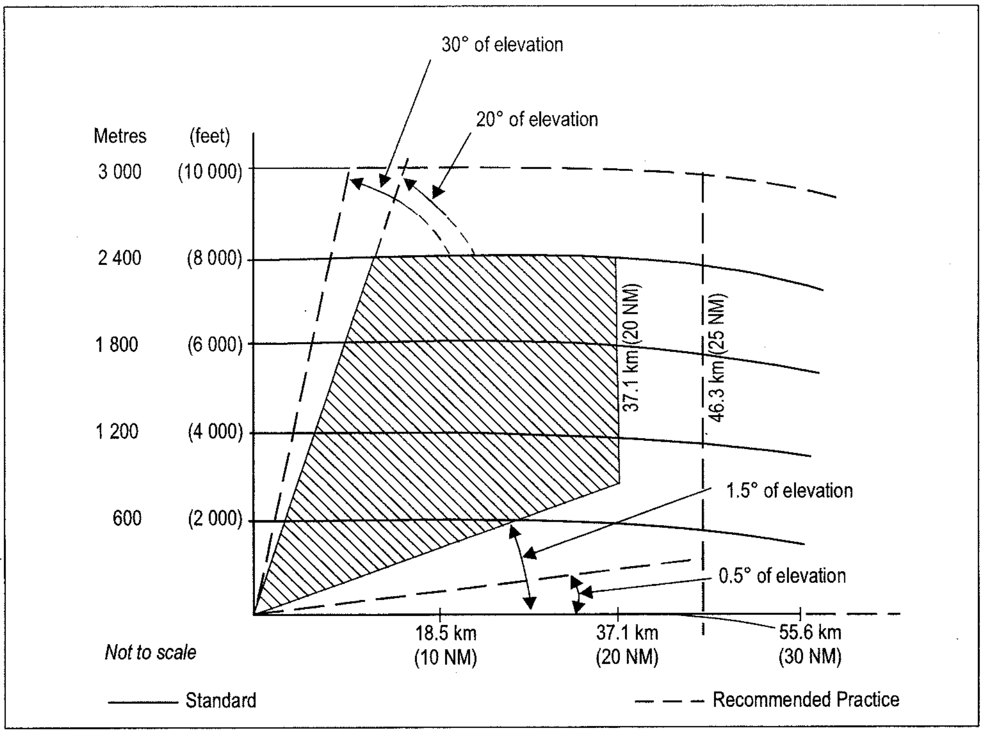


Figure C-18. SRE of precision approach radar system — vertical coverage on a 15 m^2 echoing area aircraft

5. Specification for 75 MHz marker beacons (en-route)

5.1 Marker beacon antenna arrays

5.1.1 *General.* The following describes types of marker antenna arrays that are frequently used in current practice. These types are the simplest forms meeting normal requirements; in special cases, arrays having a better performance (see Note to 5.1.4) may be required.

5.1.2 *Z marker beacons*

a) *Radiating system.* A radiating system consisting of two horizontal dipole arrays crossed at right angles, each comprising two co-linear half-wave radiating elements with centres spaced approximately a half wavelength apart and mounted one-quarter wavelength above the counterpoise. The currents in the dipoles and their respective elements are adjusted so that:

1) the current in one set of dipole arrays relative to that in the other set is equal but differs in time phase by 90 degrees;

2) the currents in the radiating elements of a particular dipole array are equal and in time phase.

b) *Counterpoise.* A square counterpoise with minimum dimensions of 9 m × 9 m, usually elevated about 1.8 m (6 ft) above the ground and, if fabricated from wire mesh, with the dimension of the mesh not exceeding 7.5 cm × 7.5 cm.

5.1.3 *Fan marker beacons for use only at low altitudes (low power fan marker beacons).* A radiating system capable of providing the field strengths indicated in Chapter 3, 3.1.7.3.2.

5.1.4 *Fan marker beacons for general use (high power fan marker beacons)*

a) *Radiating system.* A radiating system consisting of four horizontal co-linear half-wave (approximate) radiating elements mounted approximately one-quarter wavelength above the counterpoise. The current in each of the antenna elements should be in phase and should have a current ratio of 1:3:3:1.

Note.— The current distribution between elements and their height above the counterpoise may be altered to provide patterns for specific operational requirements. Improved vertical patterns for certain operational needs may be achieved by adjusting the height of the dipole arrays above the counterpoise to a value of one-quarter wavelength or greater, but less than a half wavelength.

b) *Counterpoise.* A rectangular counterpoise with minimum dimensions of 6 m × 12 m, usually elevated about 1.8 m (6 ft) above the ground and, if fabricated from wire mesh, with the dimension of the mesh not exceeding 7.5 cm × 7.5 cm.

5.2 Identification coding for fan marker beacons associated with a four-course radio range

5.2.1 Fan marker beacons located on the legs of a four-course radio range do not normally require an identification signal relating to a particular geographic location, but only a signal that will indicate the leg with which they are associated.

5.2.2 In the case of a four-course radio range having not more than one marker on any leg, it is current practice to identify a marker by a single dash if on the leg bearing true north or nearest to north in a clockwise direction (east), and to identify a marker on other legs by two, three or four dashes according to whether the leg with which it is associated is the second, third or fourth leg from north in a clockwise direction. Where more than one fan marker beacon is associated with one leg of a four-course radio range, the marker nearest to the station is identified by dashes only, the next nearest by two dots preceding the dashes, and the third by three dots preceding the dashes, and so on.

Note.— In certain special circumstances, the above coding system may lead to ambiguities due to two markers associated with the legs of different but overlapping radio ranges being geographically close together. In such cases, it is desirable to use a distinctive identification coding with one of the marker beacons.

6. Material concerning NDB

6.1 Guidance material on NDB field strength requirements in latitudes between 30°N and 30°S

6.1.1 In order to obtain a satisfactory service within the rated coverage of an NDB located in latitudes between 30°N and 30°S, a minimum value of field strength of 120 microvolts per metre would be required, except where practical experience in the operation of NDBs over several years has revealed that a minimum field strength of 70 microvolts per metre would be adequate to meet all the operational needs. In some specific areas, field strength values considerably in excess of 120 microvolts per metre would be required. Such areas are:

a) Indonesia and Papua New Guinea, Myanmar, Malay Peninsula, Thailand, Lao People's Democratic Republic, Democratic Kampuchea, Viet Nam and Northern Australia;

b) Caribbean and northern parts of South America;

c) Central and South Central Africa.

6.1.2 The field strength of 120 microvolts per metre is based upon practical experience to date and is a compromise between what is technically desirable and what it is economically possible to provide.

6.2 Guidance material on meaning and application of rated and effective coverage

6.2.1 *Rated coverage*

6.2.1.1 The rated coverage as defined in Chapter 3, 3.4.1, is a means of designating actual NDB performance, in a measurable way, which is dependent on the frequency, the radiated power, and the conductivity of the path between the NDB and a point on the boundary where the minimum value of field strength is specified.

6.2.1.2 The rated coverage has been found to be a useful means of facilitating regional planning and, in some instances, may be related to effective coverage.

6.2.1.3 The application of rated coverage to frequency planning is governed by the following criteria:

6.2.1.3.1 Frequencies should be deployed having regard to the rated coverage of the NDBs concerned, so that the ratio of the signal strength of any NDB at the boundary of its rated coverage to the total field strength due to co-channel stations and adjacent channel stations (with an appropriate allowance for the selectivity characteristics of a typical airborne receiver) is not less than 15 dB by day.

6.2.1.3.2 The figures set forth in Attachment B to Volume V of Annex 10 should be applied, as appropriate, in determining the allowance to be made for the attenuation of adjacent channel signals.

6.2.1.4 It follows from the application of rated coverage to frequency deployment planning that, unless otherwise specified, protection against harmful interference can only be ensured within the rated coverage of an NDB and, then, only if the radiated power of the NDBs is adjusted to provide within reasonably close limits the field strength required at the limit of the rated coverage. In areas where the density of NDBs is high, any NDB providing a signal at the limit of its rated coverage materially in excess of that agreed in the region concerned will give rise, in general, to harmful interference within the rated coverages of cochannel or adjacent channel NDBs in the area concerned, and will limit the number of NDBs which can be installed in the region within the available spectrum. It is important, therefore, that increases in radiated power beyond that necessary to provide the rated coverage, particularly at night when sky wave propagation may give rise to interference over long distances, should not be made without coordination with the authorities of the other stations likely to be affected (see Chapter 3, 3.4.3).

6.2.1.5 Frequency planning is considerably facilitated if a common value of minimum field strength within the desired coverage is used.

6.2.1.6 Extensive experience has shown that in relatively low noise level areas, such as Europe, the figure of 70 microvolts per metre is satisfactory.

6.2.1.6.1 Experience has also shown that the figure of 120 microvolts per metre is generally satisfactory for higher noise level areas but will be inadequate in areas of very high noise. In such areas, the information given in 6.3 may be used for general guidance.

6.2.2 *Relationship to effective coverage*

6.2.2.1 Rated coverage may have a close correlation to effective coverage under the following conditions:

a) when the minimum field strength within the rated coverage is such that, for most of the time, it exceeds the field strength due to atmospheric and other noise sufficiently to ensure that the latter will not distort the information presented in the aircraft to the extent that it is unusable;

b) when the ratio of the strength of the wanted signal to that of interfering signals exceeds the minimum required value at all points within the coverage, in order to ensure that interfering signals will also not distort the information presented in the aircraft to the extent that it is unusable.

6.2.2.2 Since, normally, the lowest signal within the coverage will occur at its boundary, these conditions imply that at the boundary the field strength should be such that its ratio to atmospheric noise levels would ensure usable indications in the aircraft for most of the time and that, in respect of the boundary value, overall planning should ensure that the ratio of its value to that of interfering signals exceeds the required value for most of the time.

6.2.2.3 Although the value of 70 microvolts per metre used for frequency deployment has been found successful in Europe (i.e. north of 30° latitude) in giving coverage values which closely approximate to effective coverage most of the time, experience is too limited to prove the suitability of the 120 microvolts per metre value for general application in areas of high noise. It is to be expected that rated coverages in high noise based on a boundary value of 120 microvolts per metre will, on many occasions, be substantially greater than the effective coverage achieved. In such areas, in order to secure a better correlation between rated coverage and an average of the achieved effective coverage, it may be advisable to choose a boundary value based more closely on the proportionality of noise in that area to the noise in areas where a boundary value has been satisfactorily established (e.g. Europe), or to determine an appropriate value from a statistical examination of achieved effective coverages in respect of an NDB in the area of known performance.

6.2.2.4 It is important to appreciate, however, that minimum values of field strength based on a simple comparison of noise levels in different areas may be insufficient, because factors such as the frequency of occurrence of noise, its character and effect on the airborne receiver and the nature of the air operation involved may all modify ratios determined in this way.

6.2.2.5 Values of diurnal and seasonal noise in various parts of the world have been published in Report 322 of the former CCIR of the ITU.

6.2.2.5.1 Correlation of these values to actual local conditions and the derivation of required signal-to-noise ratios for effective operational use of ADF equipment is not yet fully established.

6.2.3 *Effective coverage*

6.2.3.1 Effective coverage as defined in Chapter 3, 3.4.1, is the area surrounding an NDB, within which useful information to the operator concerned can be obtained at a particular time. It is, therefore, a measure of NDB performance under prevailing conditions.

6.2.3.2 The effective coverage is limited by the ratio of the strength of the steady (non-fading) signal received from the NDB to the total noise intercepted by the ADF receiver. When this ratio falls below a limiting value, useful bearings cannot be obtained. It should also be noted that the effective coverage of an NDB may in some cases be limited to the range of the usable identification signal.

6.2.3.3 The strength of signal received from the NDB is governed by:

a) the power supplied to the antenna of the NDB;

b) the radiation efficiency of the antenna, which varies according to the height of the antenna and other characteristics of the radiating system;

c) the conductivity of the path between the NDB and the receiver, which may vary considerably as between one site and another, and is always less over land than over seawater;

d) the operating radio frequency.

6.2.3.4 The noise admitted by the receiver depends on:

a) the bandwidth of the receiver;

b) the level of atmospheric noise, which varies according to the geographical area concerned, with the time of day and the season of the year, and which may reach very high levels during local thunderstorms;

c) the level of the interference produced by other radio emissions on the same or on adjacent frequencies, which is governed to a large extent by the NDB density in the area concerned and the effectiveness of regional planning;

d) the level of noise due to electrical noise in the aircraft or to industrial noise (generated by electric motors, etc.), when the coverage of the NDB extends over industrial areas.

6.2.3.4.1 It has to be noted that the effect of noise depends on characteristics of the ADF receiver and the associated equipment, and also on the nature of the noise (e.g. steady noise, impulsive noise).

6.2.3.5 A further factor which limits the effective coverage of an NDB is present at night when interaction occurs between components of the signal which are propagated respectively in the horizontal plane (ground wave propagation) and by reflection from the ionosphere (sky wave propagation). When there is interaction between these components, which arrive at the ADF receiver with a difference of phase, bearing errors are introduced (night effect).

6.2.3.6 It will thus be seen that the effective coverage of an NDB depends on so many factors, some of which are variable, that it is impossible to specify the effective coverage of an NDB in any simple manner. The effective coverage of any NDB, in fact, varies according to the time of day and the season of the year.

6.2.3.6.1 Hence any attempt to specify an effective coverage, which would be obtainable at any time throughout the day or throughout the year, would result either in a figure for coverage which would be so small (since this would be the coverage obtained under the worst conditions of atmospheric noise, etc.) as to give quite a misleading picture of the effectiveness of the NDB, or would involve such high power and costly antenna systems (to provide the required coverage under the worst conditions), that the installation of such an NDB would usually be precluded by considerations of initial and operating costs. No specific formula can be given in determining what rated coverage would be equivalent to a desired effective coverage and the relation must be assessed regionally.

6.2.3.7 Those concerned with the operational aspects of NDB coverage will normally consider requirements in terms of a desired operational coverage and, in regional planning, it will usually be necessary to interpret such requirements in terms of a rated coverage from which may be derived the essential characteristics of the NDB required and which will also define the area to be protected against harmful interference. No specific formula can be given in determining what rated coverage would be equivalent to a desired operational coverage and the relation must be assessed regionally.

6.2.3.8 Some States have recorded data on NDBs and their effective coverage; and collection of similar information would be a practical way of obtaining an assessment of effective coverage in terms of rated coverage of facilities in a given area. This information would also be useful for future regional planning. In order to reduce the number of factors involved in assessing effective coverage, it would be desirable to establish criteria for determining the limit of useful coverage in terms of the reaction of the bearing indicator. The data referred to previously, together with measurements of actual field strength within the coverage of the NDB, would also permit determination of the effectiveness of existing installations and provide a guide to improvements that may be necessary to achieve a desired effective coverage.

6.3 Coverage of NDBs

6.3.1 *Introduction*

6.3.1.1 The following studies have been based on the latest propagation and noise data available to the ITU. They are included in this Attachment as general guidance in respect of NDB planning. Attention is called particularly to the assumptions made.

6.3.1.2 When applying the material, the validity of the assumptions in respect of the particular conditions under consideration should be carefully examined and, in particular, it should be noted that the assumed signal-to-noise ratios require considerable further study before they can be accepted as representative of the ratios limiting useful reception.

6.3.2 *Assumptions*

1. Operating frequency — 300 kHz.
   Reference is made, however, where appropriate, to frequencies of 200 kHz and 400 kHz.

2. a) Average soil conductivity:
   ($\sigma = 10^{-13}$ e.m.u.)

   b) Average seawater conductivity:
   ($\sigma = 4.10^{-11}$ e.m.u.)

3. The level of atmospheric noise (RMS) which is likely to prevail: 1) by day, 2) by night, over land masses, within the belts of latitude mentioned. [The values of expected noise have been derived from Recommendation ITU-R P.372-6 and have been taken as the average noise by day and by night during equinox periods, i.e. the values which are likely to be exceeded 20–25 per cent of the year.]

4. Input powers to the antenna of the NDB of:

   a) 5 kW
   b) 1 kW
   c) 500 W
   d) 100 W
   e) 50 W
   f) 10 W

5. The following average values of radiation efficiencies of antennas, i.e. the ratio of:

$$\left[\frac{\text{Radiated power}}{\text{Input power to antenna}}\right]$$

	Input power to antenna	*Radiation efficiency of antenna*
a)	5 kW	20% (–7 dB)
b)	5 kW	10% (–10 dB)
c)	1 kW	8% (–11 dB)
d)	500 W	5% (–13 dB)
e)	100 W	3% (–15 dB)
f)	50 W	2% (–17 dB)
g)	10 W	1% (–20 dB)
h)	10 W	0.3% (–25 dB)

i) The figure for a) is included because it is possible to realize this efficiency by the use of a more elaborate antenna system than is usually employed.

ii) The figure for h) is included because many low power NDBs use very inefficient antennas.

6. An admittance band of the ADF receiver of 6 kHz.

7. Required ratios of signal-(median) to-noise (RMS) of:

a) 15 dB by day;

b) 15 dB by night.

6.3.3 *Results of studies*

A.— *Minimum field strengths required at the boundary of the rated coverage:*

Latitude	*By day for 15 dB S/N ratio*	*By night for 15 dB S/N ratio*
5°N – 5°S	320 μV/m (+50 dB)	900 μV/m (+59 dB)
5° – 15°N&S	85 μV/m (+39 dB)	700 μV/m (+57 dB)
15° – 25°N&S	40 μV/m (+32 dB)	320 μV/m (+50 dB)
25° – 35°N&S	18★μV/m (+25 dB)	120 μV/m (+42 dB)
>35°N&S	18★μV/m (+25 dB)	50 μV/m (+35 dB)

A star shown against a figure indicates that a higher value of field strength — probably 2 or 3 times the values shown (plus 6 to plus 10 dB) — may be necessary in the presence of high aircraft noise and/or industrial noise.

B.— *Coverage of NDBs (expressed in terms of the radius of a circle, in kilometres, with the NDB at the centre) which may be expected under the assumptions made:*

1) By *day*, over *land*, and for *15 dB S/N ratio* at the boundary of the coverage:

	Input power to antenna			
Latitude	*(a) 5 kW*	*(b) 5 kW*	*(c) 1 kW*	*(d) 500 W*
5°N – 5°S	320	300	170	120
5° – 15°N&S	510	470	320	250
15° – 25°N&S	>600	600	450	350
25° – 35°N&S	>600★	>600★	600★	500★
>35°N&S	>600★	>600★	>600★	500★

	Input power to antenna			
Latitude	*(e) 100 W*	*(f) 50 W*	*(g) 10 W*	*(h) 10 W*
5°N – 5°S	50	30	10	<10
5° – 15°N&S	150	90	40	10
15° – 25°N&S	220	160	70	45
25° – 35°N&S	330★	250★	130★	80★
>35°N&S	330★	250★	130★	100★

2) By *night*, over *land*, and for *15 dB S/N ratio* at the boundary of the coverage:

	Input power to antenna			
	(a)	*(b)*	*(c)*	*(d)*
Latitude	*5 kW*	*5 kW*	*1 kW*	*500 W*
5°N – 5°S	190	150	85	50
5° – 15°N&S	210	180	110	70
15° – 25°N&S	320	300	170	120
25° – 35°N&S	390	390	280	200
>35°N&S	390	390	390	310

	Input power to antenna			
	(e)	*(f)*	*(g)*	*(h)*
Latitude	*100 W*	*50 W*	*10 W*	*10 W*
5°N – 5°S	20	<10	<10	<10
5° – 15°N&S	25	15	<10	<10
15° – 25°N&S	50	30	10	<10
25° – 35°N&S	100	70	25	15
>35°N&S	180	120	50	30

6.3.3.1 In all of the above tables, it has to be noted that:

a) the distances are given in kilometres, in accordance with ITU practice;

b) the figures in the final columns, with the heading 10 W, are calculated on the assumption that the low power NDB uses a very inefficient antenna (see 6.3.2, assumption 5 h));

c) a star shown against a figure indicates that the coverage may be limited by aircraft and industrial noises.

6.3.3.2 It has also to be noted that:

a) if a frequency of 200 kHz were used in place of 300 kHz, this would not appreciably affect the coverage of low power short range NDBs, but the coverage of the higher power, longer range beacons (for example, those with a range of 150 km or more) would be increased, as compared with those shown in the tables, by about 20 per cent;

b) if a frequency of 400 kHz were used in place of 300 kHz this would not appreciably affect the coverage of low power short range NDBs, but the coverage of the higher power, longer range beacons (for example, those with a range of 150 km or more) would be decreased, as compared with those shown in the tables, by about 25 per cent;

c) use of an ADF receiver with a narrower band would, other things being equal, provide wider coverage for the same radiated power of the NDB or, for the same coverage, an improved effective signal-to-noise ratio.

For example, if an admittance band of 1 kHz instead of 6 kHz were used, the coverage might be increased by as much as 30 per cent for the same radiated power or, alternatively, the effective signal-to-noise ratio might be increased by as much as 8 dB;

d) if a sector of the coverage of an NDB is over seawater, a greater coverage may be expected within that sector due to:

1) better ground wave propagation over seawater than over land;

2) the noise level, which is highest over land, often drops fairly steeply with increasing distance from the land. It might be assumed, therefore, that the distances shown in the tables could be increased by about 30 per cent by day, and by about 20 per cent by night, when the path is over seawater;

e) if, however, the beacon is sited on an island remote from land masses (for example, in mid-Pacific or mid-Atlantic, but not in the Caribbean), the coverage of the beacon is likely to be much greater, particularly in tropical latitudes, than is indicated in the tables; and in such cases figures for coverage similar to those shown for latitudes more than 35°N and S may be assumed for all latitudes, due to the much lower level of atmospheric noise which prevails in mid-ocean as compared with that experienced over, or in proximity to, land masses.

6.3.4 Limitation of coverage of a beacon at night due to "night effect".

a) The distances, at night, at which the ground wave and sky wave components of the received field are likely to be equal are as follows:

Frequency	*Over land*	*Over sea*
200 kHz	500 km	550 km
300 kHz	390 km	520 km
400 kHz	310 km	500 km

b) The distances, at night, at which the ground wave component of the received field is likely to exceed the sky wave component by 10 dB are as follows:

Frequency	*Over land*	*Over sea*
200 kHz	300 km	320 km
300 kHz	230 km	300 km
400 kHz	200 km	280 km

c) It is, therefore, unlikely that reliable bearings can be obtained, at night, due to interaction of the two components of the received field, at much greater distances than those shown in 6.3.4 b). *These distances are independent of the power of the NDB.*

d) It has to be noted, moreover, that, while with overland paths of good conductivity, night effect will only be serious at somewhat greater distances than those indicated over paths of poor conductivity, night effect may become pronounced at much shorter ranges. This will also depend to some extent upon the characteristics of the radiation system.

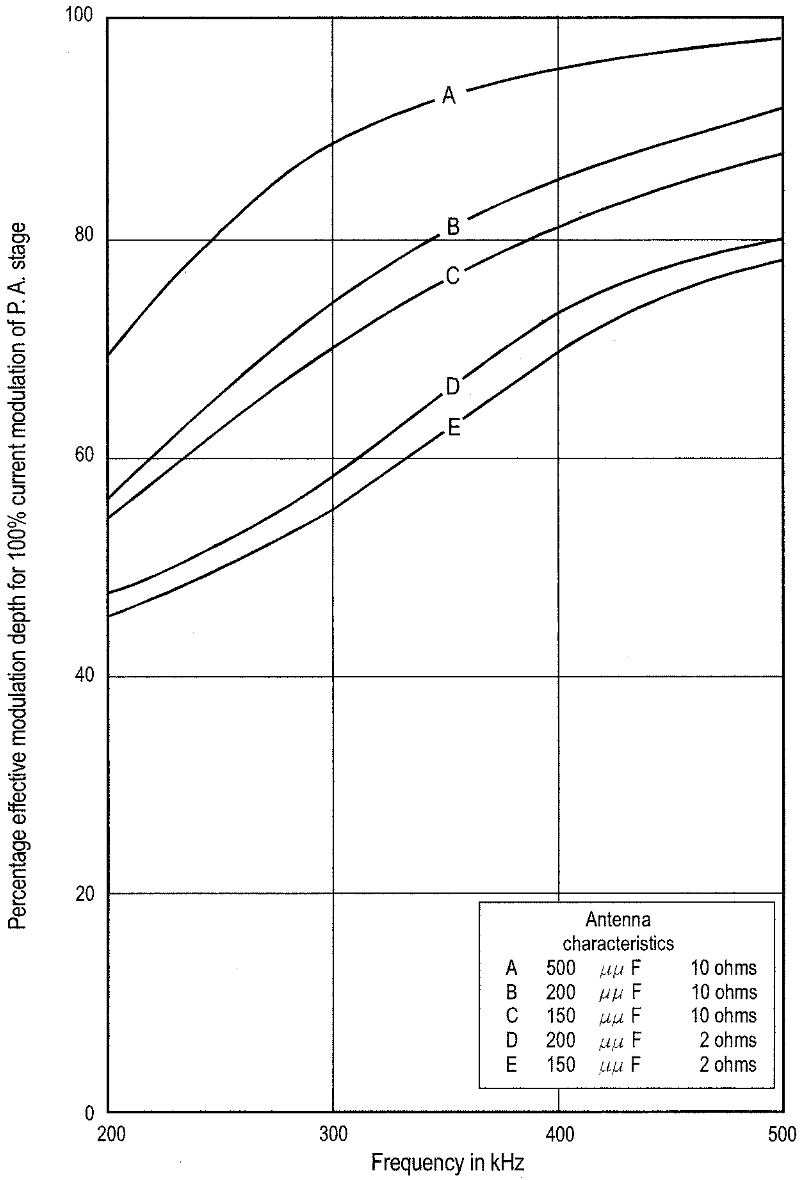
6.4 Considerations affecting operations of NDBs

6.4.1 *Depth of modulation*

6.4.1.1 In specifying that the depth of modulation should be maintained as near to 95 per cent as is practicable, it must be noted that, at the frequencies used for NDBs, the small antennas generally in use can affect the effective modulation depth of the NDB system due to attenuation of the sidebands.

6.4.1.2 At this order of frequency, the antennas are normally only a small fraction of a wavelength long; they are therefore highly reactive and tend to have a high Q.

6.4.1.3 The effect is illustrated in Figure C-19, which was compiled from measurements made by one State. The modulating frequency in these measurements was 1 020 Hz. If a lower modulating frequency were used, the effect would be less.



Note.— The modulating frequency in these measurements was 1 020 Hz.

Figure C-19. The effect of antenna Q on the depth of modulation of the radiated signal

6.4.1.4 In order to reduce the attenuation, attempts should be made to reduce the Q of the antenna. This can be done in two ways, by increasing either its capacity or resistance.

6.4.1.5 Inserting additional resistance in an antenna wastes power, whereas increasing the capacity does not. Additionally, the effect of increasing the capacity is to reduce the voltage across the system and hence to reduce the insulation problems.

6.4.1.6 For these reasons, it is considered desirable to increase antenna capacity by the use of a top load as, for example, in the so-called umbrella top capacity.

6.4.2 *Earth systems*

Frequency planning is done on the assumption that the field strength will be maintained at the correct value. If the earth resistance is high (i.e. an insufficient earth system), not only will the radiation efficiency be low but the power radiated will be sensitive to changes in climatic conditions and other factors affecting the earth loss. In all cases, the earth system needs to be the best possible, taking into account all local circumstances.

6.5 Considerations affecting the choice of the modulating frequency for NON/A2A NDBs

Recognition of the fact that modern narrow band ADF receivers have improved selectivity characteristics requires consideration of the fact that, in so far as attenuation of the audio sidebands by these receivers results in a reduction of the effective depth of modulation of the signal, the distance at which satisfactory identification is obtained is consequently reduced. In such circumstances, it is considered that 400 Hz would provide a better identification service than 1 020 Hz. There is some evidence, however, that under conditions of high atmospheric noise, the higher frequency of 1 020 Hz may provide a more easily readable signal.

6.6 Guidance material on the testing of NDBs

6.6.1 In the following paragraphs an indication is given of the desirable periodicity for various tests. These figures are intended as only general guidance, it being recognized that many local circumstances will influence a State in establishing its test programmes.

6.6.1.1 *Carrier frequency*

6.6.1.1.1 The carrier frequency should periodically be tested against an accurate standard to ensure that the tolerance specified in Chapter 3, 3.4.4.2, is maintained. A standard such as a crystal controlled frequency meter having an accuracy of 0.001 per cent of the operating frequency is recommended for this purpose.

6.6.1.1.2 This test of carrier frequency stability should be carried out:

a) at least semi-annually for crystal controlled transmitters;

b) at least once a month for non-crystal controlled transmitters.

6.6.1.1.3 If practicable, tests at shorter intervals should be made.

6.6.1.2 *Frequency of the modulating tone*

6.6.1.2.1 The identification frequency requirements are specified in Chapter 3, 3.4.5.4. An audio signal generator calibrated to an accuracy of 0.5 per cent or better at the specified frequency is recommended as a calibration standard.

6.6.1.2.2 This test should be made at least once a month.

6.6.1.3 *Ground wave field strength*

6.6.1.3.1 It is recommended that remote field strength measurements be made using a field strength indicator set capable of checking that the power radiated from an NDB is in accordance with Chapter 3, 3.4.3.

6.6.1.3.2 This test should be carried out at least once a month.

6.6.1.4 *Modulation depth*

6.6.1.4.1 Chapter 3, 3.4.6.2, requires that the depth of modulation of the carrier frequency should be maintained as near to 95 per cent as practicable. Use of an oscilloscope capable of operation at the transmitting frequency of the NDB is recommended for this purpose.

6.6.1.4.2 This test, using an oscilloscope, should be made at least every three months. Additionally, rough checks of modulation depth may be made frequently by using a calibrated diodevoltmeter, but these are not a satisfactory substitute for the test using the oscilloscope.

6.6.1.4.3 Unwanted audio frequency modulation should be measured at least every three months to ensure that it does not exceed the limits of Chapter 3, 3.4.6.5. An oscilloscope is also recommended for this test.

6.6.1.5 *Fall of carrier power with modulation*

6.6.1.5.1 When modulation is applied, the carrier power should not decrease by more than the amount specified in Chapter 3, 3.4.6.4. A recommended method of ensuring this is to use, at a suitable remote site, a calibrated communication receiver having a continuous wave IF crystal filter as an indicator of transmitter field strength and having sufficient selectivity to reject the audio sidebands.

6.6.1.5.2 An alternative but probably less accurate method of determining the fall of carrier power would be a comparison of the current fed into the antenna when the transmitter is modulated with that when it is not modulated.

6.6.1.5.3 This test should be done at least once a month.

7. Material concerning DME

7.1 Guidance material concerning both DME/N and DME/P

7.1.1 *System efficiency*

7.1.1.1 System efficiency is the combined effect of down-link garble, ground transponder dead time, up-link garble, and interrogator signal processor efficiency. Since each of these efficiency components are statistically independent, they can be computed individually and then combined to yield the system efficiency. The effect of a single component is defined as the percentage ratio of valid replies processed by the interrogator in response to its own interrogations assuming all other components are not present. The system efficiency is then the product of the individual components.

7.1.1.2 In computing system efficiency, the number of missing replies as well as the accuracy of the range measurement made with the received replies should be considered. Missing replies may result from signal interference due to garble or from interrogations being received at the transponder during a dead time period. Replies which contain significant errors large enough to be rejected by the interrogator signal processing also should be treated as missing replies when computing the efficiency component.

7.1.1.3 The interference rate due to garble is dependent upon the channel assignment plan, traffic loading, and the ground transponder and interrogator receiver bandwidths. Because the FA mode has a wider receiver bandwidth than the IA mode, it is more susceptible to interference. These factors were accommodated in the DME/P system definition and normally do not require special consideration by the operating authority.

7.1.2 *Down-link garble*

Down-link garble occurs when valid interrogations at the ground transponder are interfered with by coincident interrogations from other aircraft and results in loss of signal or errors in time-of-arrival measurement. This undesired air-to-ground loading is a function of the number of interrogating aircraft in the vicinity of the serving transponder and the corresponding distribution of interrogation frequencies and signal amplitudes received at the transponder.

Note.— Transponder to transponder garbling is controlled by the channel assignment authorities.

7.1.3 *Up-link garble*

Up-link garble occurs when valid replies at the interrogator are interfered with by other transponders and results in loss of signal or errors in pulse time-of-arrival measurement. The garble can be interference from any transponder whose frequency is within the bandwidth of the interrogator, including those on the same frequency, but with different pulse coding. This undesired ground-to-air loading is a function of the number of transponders in the vicinity of the interrogator and the corresponding distribution of reply frequencies and signal amplitudes received at the interrogator.

7.1.4 *Interrogator processor efficiency*

The interrogator signal processor efficiency is the ratio of the number of replies processed by the interrogator to the number of interrogations in the absence of garble and transponder dead time effects. This efficiency depends on the reply pulse threshold level and the receiver noise level.

7.1.5 *Relationship between aircraft served and transmission rate*

7.1.5.1 Specification of the maximum transponder transmission rate establishes the maximum average transmitter power level. Chapter 3, 3.5.4.1.5.5 recommends that the transponder have a transmission rate capability of 2 700 pulse pairs per second if 100 aircraft are to be served. This represents typical transponder loading arising from 100 aircraft. To determine the actual transmission rate capability that should be accommodated at a given facility during peak traffic conditions requires that the maximum number of interrogators be estimated. To compute the interrogation loading on the transponder, the following should be considered:

a) the number of aircraft that constitutes the peak traffic load;

b) the number of interrogators in use on each aircraft;

c) the distribution of operating modes of the interrogators in use (e.g. search, initial approach, final approach, ground test);

d) the appropriate pulse repetition frequency as given in Chapter 3, 3.5.3.4.

7.1.5.2 Given the interrogation loading which results from the peak traffic as well as the reply efficiency of the transponder in the presence of this load, the resulting reply rate can be computed, thereby establishing the required transmitter capability. This reply rate is the level that, when exceeded, results in a reduction in receiver sensitivity (as specified in Chapter 3, 3.5.4.2.4) in order to maintain the reply rate at or below this maximum level.

7.1.6 *Siting of DME associated with ILS or MLS*

7.1.6.1 The DME should, where possible, provide to the pilot an indicated zero range at touchdown in order to satisfy current operational requirements.

7.1.6.2 The optimum site for a DME transponder is dependent upon a number of technical and operational factors. DME/N may be installed with ILS or MLS where operational requirements permit. DME/P, which provides higher accuracy and coverage throughout the entire runway region, is required to support the more flexible and advanced operations that are available with MLS.

7.1.6.3 In the case of DME/N, the provision of zero range indication may be achieved by siting the transponder as close as possible to the point at which zero range indication is required. Alternatively, the transponder time delay can be adjusted to permit aircraft interrogators to indicate zero range at a specified distance from the DME antenna. When the indicated DME zero range has a reference other than the DME antenna, consideration should be given to publishing this information.

7.1.6.4 In the case of DME/P, in order to meet accuracy and coverage requirements, particularly in the runway region, it is recommended that the DME/P be sited as closely as possible to the MLS azimuth facility, consistent with obstacle clearance criteria. For aircraft equipped with a full MLS capability, the desired zero range indication can then be obtained by utilizing MLS basic data. Note that the DME/P transponder time delay must not be adjusted for this purpose.

7.1.6.5 It is desirable that all users obtain indicated zero range at touchdown irrespective of the airborne equipment fitted. This would necessitate location of the DME/P abeam the runway at the touchdown point. In this case accuracy requirements for DME/P would not be met on the runway. It must be noted that MLS Basic Data Word 3 only permits the coding of DME/P coordinates within certain limits.

7.1.6.6 If an MLS/DME/P and an ILS/DME/N serve the same runway, an aircraft equipped with a minimum MLS capability can have a zero range indication at the MLS approach azimuth site when operating on MLS and a zero range indication at the touchdown point when operating on ILS. As this is considered to be operationally unacceptable, specifically from an ATC point of view, and if ILS/MLS/DME frequency tripling to prevent the relocation of the DME/N is not possible, the implementation of DME/P is to be postponed until the DME/N is withdrawn.

7.1.6.7 The nominal location of the zero range indication provided by a DME/N interrogator needs to be published.

7.1.6.8 In considering DME sites, it is also necessary to take into account technical factors such as runway length, profile, local terrain and transponder antenna height to assure adequate signal levels in the vicinity of threshold and along the runway. Care is also to be taken that where distance information is required in the runway region, the selected site is not likely to cause the interrogator to lose track due to excessive rate of change of velocity.

7.1.7 *Geographical separation criteria*

In order to allow consideration of actual antenna designs, equipment characteristics, and service volumes, the signal ratios needed to assure interference-free operation of the various facilities operating on DME channels are provided in 7.1.8, 7.1.9 and 7.1.10. Given these ratios, the geographical separations of facilities may be readily evaluated by accounting for power losses over the propagation paths.

7.1.8 *Desired to undesired (D/U) signal ratios at the airborne receiver*

7.1.8.1 Table C-4 indicates the necessary D/U signal ratios needed to protect the desired transponder reply signal at an airborne receiver from the various co-frequency/adjacent frequency, same code/different code, undesired transponder reply signal combinations that may exist. For initial assignments, the D/U ratios necessary to protect airborne equipment with 6-microsecond decoder rejection should be used. In making an assignment, each facility must be treated as the desired source with the other acting as the undesired. If both satisfy their unique D/U requirement, then the channel assignment may be made.

Table C-4. Protection ratio D/U (dB)

Type of assignment	A	B
Co-frequency:		
Same pulse code	8	8
Different pulse code	8	–42
First adjacent frequency:		
Same pulse code	$-(P_u - 1)$	–42
Different pulse code	$-(P_u + 7)$	–75
Second adjacent frequency:		
Same pulse code	$-(P_u + 19)$	–75
Different pulse code	$-(P_u + 27)$	–75

Note 1.— The D/U ratios in column A protect those DME/N interrogators operating on X or Y channels. Column A applies to decoder rejection of 6 microseconds.

Note 2.— The D/U ratios in column B protect those DME/N or DME/P interrogators utilizing discrimination in conformance with 3.5.5.3.4.2 and 3.5.5.3.4.3 of Chapter 3 and providing a decoder rejection conforming to 3.5.5.3.5 of Chapter 3.

Note 3.— P_u is the peak effective radiated power of the undesired signal in dBW.

Note 4.— The frequency protection requirement is dependent upon the antenna patterns of the desired and undesired facility and the ERP of the undesired facility.

Note 5.— In assessing adjacent channel protection, the magnitude of D/U ratio in column A should not exceed the magnitude of the value in column B.

7.1.8.2 Accordingly, DME channel assignments depend upon the following:

a) *For co-channel assignments:* This condition occurs when both the desired and undesired signals operate on a channel (W, X, Y or Z) that is co-frequency, same code. The D/U signal ratio should be at least 8 dB throughout the service volume.

b) *For co-frequency, different code assignments:* This condition occurs when one facility operates on an X channel with the other on a W channel. A similar Y channel and a Z channel combination also applies.

c) *For first adjacent frequency, same code assignments:* This condition occurs when both the desired and undesired facilities are of W, X, Y or Z type.

d) *For first adjacent frequency, different code assignments:* This condition occurs when one facility operates on an X channel with the other on a W channel, but with a frequency offset of 1 MHz between transponder reply frequencies. A similar Y channel and a Z channel combination also applies.

e) *For second adjacent frequency, same or different code assignments:* The second adjacent frequency combinations generally need not be frequency protected. However, special attention should be given to Note 4 of Table C-4, especially if the undesired facility is a DME/P transponder.

7.1.9 *Special considerations for DME Y and Z channel assignments*

Assignment of a Y or Z channel whose reply frequency is 63 MHz removed from the reply frequency of another channel (either a W, X, Y or Z channel) or vice versa requires a distance separation of at least 28 km (15 NM) between facilities.

7.1.10 *Special considerations for DME W or Z channel assignments*

Assignment of a W or Z channel whose reply frequency is 63 MHz removed from the reply frequency of a Y channel or vice versa requires a distance separation of at least equal to the service volume range of the Y channel facility plus 28 km (15 NM).

7.1.11 *Special considerations for making pulse spectrum measurements*

The effective radiated power contained in the 0.5 MHz measurement frequency band specified in 3.5.4.1.3 e) can be calculated by integrating the power spectral density in the frequency domain or equivalently by integrating the instantaneous power per unit time in the time domain using the appropriate analogue or digital signal processing techniques. If the integration is performed in the frequency domain then the resolution bandwidth of the spectrum analyser must be commensurate with the 5 per cent duration interval of the DME pulse. If the integration is performed in the time domain at the output of a 0.5 MHz five pole (or more) filter then the time sample rate must be commensurate with the pulse spectrum width.

7.1.12 *Special considerations for DME/P associated with ILS*

7.1.12.1 For those runways where it is intended to install DME associated with ILS and where early MLS/RNAV operations are planned, installation of DME/P is preferred.

7.1.12.2 When it is intended to use the DME/P ranging information throughout the terminal area, interrogation pulse pairs with the correct spacing and nominal frequency must trigger the transponder if the peak power density at the transponder antenna is at least minus 93 dBW/m^2. This sensitivity level is based on the values contained in Chapter 3, 3.5.4.2.3.1 and it is applied to DME/P IA mode, where at this level DME/P IA mode is intended to comply with DME/N reply efficiency and at least DME/N accuracy.

7.2 Guidance material concerning DME/N only

7.2.1 *Effective radiated power (ERP) of DME/N facilities*

7.2.1.1 The power density figure prescribed in 3.5.4.1.5.1 of Chapter 3 is on the following assumptions:

Airborne receiver sensitivity	−112 dBW
Airborne transmission line loss	+3 dB
Airborne polar pattern loss relative to an isotopic antenna	+4 dB
Necessary power at antenna	−105 dBW

Minus 105 dBW at the antenna corresponds to minus 83 dBW/m^2 at the mid-band frequency.

Note.— The power density for the case of an isotropic antenna may be computed in the following manner:

$$P_d = P_a - 10 \log \frac{\lambda^2}{4\pi}$$

where P_d = *power density in dBW/m*^{2}*;*

P_a = *power at receiving point in dBW;*

λ = *wavelength in metres.*

7.2.1.2 Nominal values of the necessary ERP to achieve a power density of minus 83 dBW/m^2 are given in Figure C-20. For coverage under difficult terrain and siting conditions it may be necessary to make appropriate increases in the ERP. Conversely, under favourable siting conditions, the stated power density may be achieved with a lower ERP.

7.2.1.3 The use of Figure C-20 is illustrated by the following examples. In order to achieve the necessary nominal power density at slant range/levels of 342 km (185 NM)/12 000 m (40 000 ft), 263 km (142 NM)/12 000 m (40 000 ft) and 135 km (73 NM)/6 000 m (20 000 ft), ERPs of the order of plus 42 dBW, plus 36 dBW and plus 30 dBW respectively would be required.

7.3 Guidance material concerning DME/P only

7.3.1 *DME/P system description*

7.3.1.1 The DME/P is an integral element of the microwave landing system described in Chapter 3, 3.11. The DME/P signal format defines two operating modes, initial approach (IA) and final approach (FA). The IA mode is compatible and interoperable with DME/N and is designed to provide improved accuracies for the initial stages of approach and landing. The FA mode provides substantially improved accuracy in the final approach area. Both modes are combined into a single DME/P ground facility and the system characteristics are such that DME/N and DME/P functions can be combined in a single interrogator. The IA and FA modes are identified by pulse codes which are specified in Chapter 3, 3.5.4.4. In the MLS approach sector, the DME/P coverage is at least 41 km (22 NM) from the ground transponder. It is intended that the interrogator does not operate in the FA mode at ranges greater than 13 km (7 NM) from the transponder site, although the transition from the IA mode may begin at 15 km (8 NM) from the transponder. These figures were selected on the assumption that the transponder is installed beyond the stop end of the runway at a distance of approximately 3 600 m (2 NM) from the threshold.

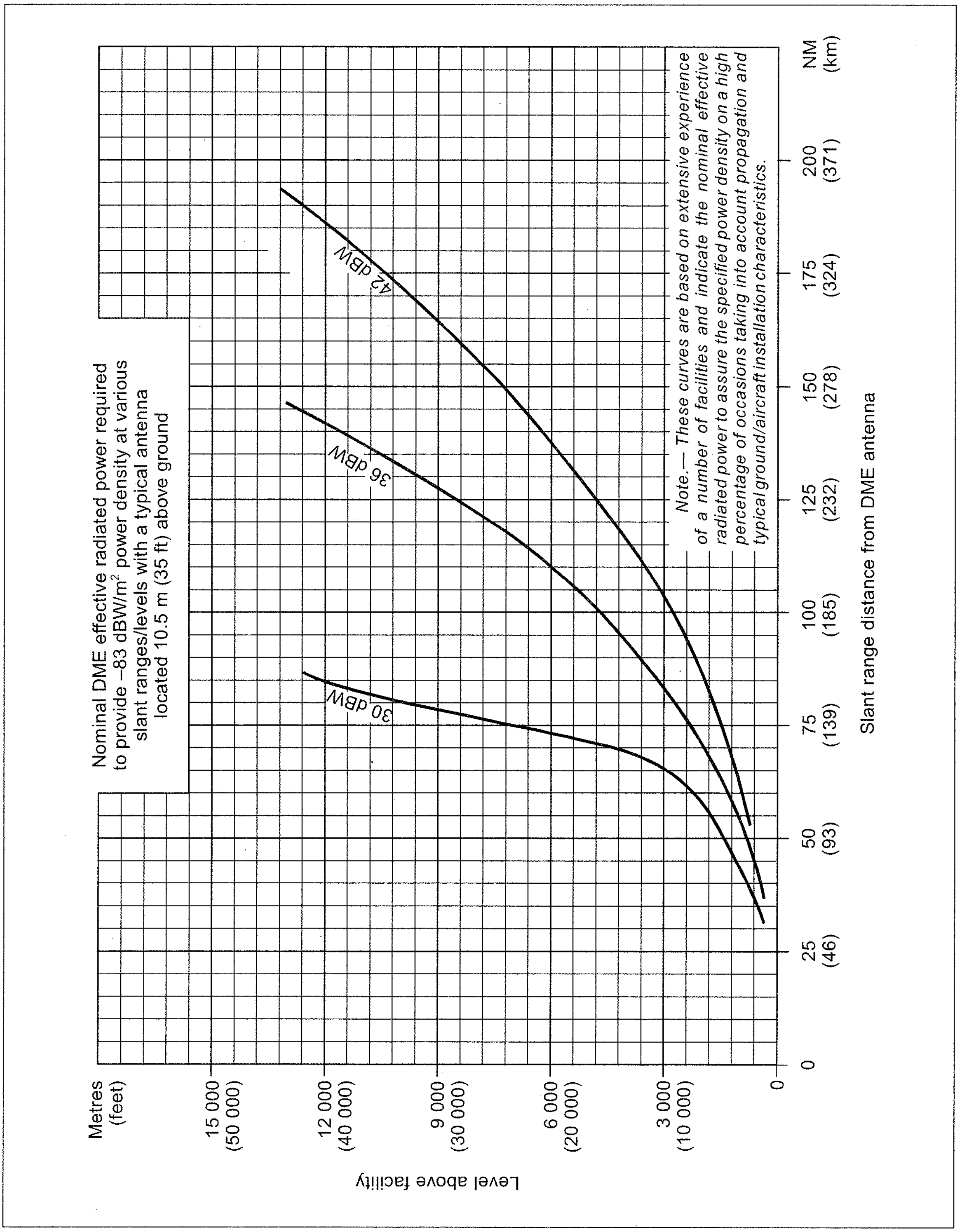

Nominal DME effective radiated power required to provide –83 dBW/m2 power density at various slant ranges/levels with a typical antenna located 10.5 m (35 ft) above ground
Note.— These curves are based on extensive experience of a number of facilities and indicate the nominal effective radiated power to assure the specified power density on a high percentage of occasions taking into account propagation and typical ground/aircraft installation characteristics.
42 dBW
36 dBW
30 dBW
Metres (feet)
15 000 (50 000)
12 000 (40 000)
9 000 (30 000)
6 000 (20 000)
3 000 (10 000)
0
Level above facility
NM (km)
0
25 (46)
50 (93)
75 (139)
100 (185)
125 (232)
150 (278)
175 (324)
200 (371)
Slant range distance from DME antenna

Figure C-20

7.3.1.2 A major potential cause of accuracy degradation encountered in the final phases of the approach and landing operation is multipath (signal reflection) interference. DME/P FA mode minimizes these effects by using wideband signal processing of pulses having fast rise time leading edges, and by measuring the time of arrival at a low point on the received pulse where it has not been significantly corrupted by multipath. This is in contrast to the slower rise time pulses and higher thresholding at the 50 per cent level used in DME/N.

7.3.1.3 Because the FA mode is used at ranges less than 13 km (7 NM), the transmitter can provide an adequate signal level to meet the required accuracy without the fast rise time pulse violating the transponder pulse spectrum requirements. Use of the 50 per cent threshold and a narrow receiver bandwidth in the IA mode permits an adequate but less demanding performance to the coverage limits. The transponder determines the interrogation mode in use by the interrogation code in order to time the reply delay from the proper measurement reference. The IA mode is interoperable with DME/N permitting a DME/N interrogator to be used with a DME/P transponder to obtain at least the accuracy with a DME/N transponder. Similarly, a DME/P interrogator may be used with a DME/N transponder.

7.3.2 *DME/P system accuracy requirements*

7.3.2.1 *DME/P accuracy requirements*

7.3.2.1.1 When considering the DME/P accuracy requirement, the operations that can be performed in the service volume of the final approach mode tend to fall into one of two groups. This has led to two accuracy standards being defined for the final approach mode:

a) *accuracy standard 1:* this is the least demanding and is designed to cater for most CTOL operations;

b) *accuracy standard 2:* this gives improved accuracy that may be necessary for VTOL and STOL operations, CTOL flare manoeuvres using MLS flare elevation guidance and CTOL high-speed turnoffs.

7.3.2.1.2 Table C-5 shows applications of DME and typical accuracy requirements. This will assist in selecting the appropriate accuracy standard to meet the operational requirement. The calculations are based on a distance of 1 768 m (5 800 ft) between the DME antenna and the runway threshold. The following paragraphs refer to Table C-5.

7.3.2.1.3 It is intended that the DME/P accuracy approximately corresponds to the azimuth function PFE at a distance of 37 km (20 NM) from the MLS reference datum both along the extended runway centre line and at an azimuth angle of 40 degrees. Also the DME/N error at the limits of MLS coverage is consistent with the 0.37 km (0.2 NM) system accuracy in Chapter 3, 3.5.3.1.3.3. The CMN is the linear equivalent of the plus or minus 0.1 degree CMN specified for the azimuth angle function.

7.3.2.1.4 PFE corresponds to azimuth angular error; CMN is approximately the linear equivalent of the plus or minus 0.1 degree CMN specified for the azimuth angle system.

7.3.2.1.5 The plus or minus 30 m PFE corresponds to a plus or minus 1.5 m vertical error for a 3-degree elevation angle.

7.3.2.1.6 Flare initiation begins in the vicinity of the MLS approach reference datum; MLS elevation and DME/P provide vertical guidance for automatic landing when the terrain in front of the runway threshold is uneven.

7.3.2.1.7 Sensitivity modification or autopilot gain scheduling requirements are not strongly dependent on accuracy.

Table C-5.

Function	Typical distance from the threshold	PFE (95% probability)	CMN (95% probability)
Approach (7.3.2.1.3)			
— extended runway centre line	37 km (20 NM)	±250 m (±820 ft)	±68 m (±223 ft)
— at 40° azimuth	37 km (20 NM)	±375 m (±1 230 ft)	±68 m (±223 ft)
Approach (7.3.2.1.4)			
— extended runway centre line	9 km (5 NM)	±85 m (±279 ft)	±34 m (±111 ft)
— at 40° azimuth	9 km (5 NM)	±127 m (±417 ft)	±34 m (±111 ft)
Marker replacement			
— outer marker	9 km (5 NM)	±800 m (±2 625 ft)	not applicable
— middle marker	1 060 m (0.57 NM)	±400 m (±1 312 ft)	not applicable
30 m decision height determination (100 ft) (7.3.2.1.5)			
— 3° glide path (CTOL)	556 m (0.3 NM)	±30 m (±100 ft)	not applicable
— 6° glide path (STOL)	556 m (0.3 NM)	±15 m (±50 ft)	not applicable
Flare initiation over uneven terrain (7.3.2.1.6)			
— 3° glide path (CTOL)	0	±30 m (±100 ft)	±18 m (±60 ft)
— 6° glide path (STOL)	0	±12 m (±40 ft)	±12 m (±40 ft)
Sensitivity modifications (7.3.2.1.7) (autopilot gain scheduling)	37 km (20 NM) to 0	±250 m (±820 ft)	not applicable
Flare manoeuvre with MLS flare elevation (7.3.2.1.8)			
— CTOL	0	±30 m (±100 ft)	±12 m (±40 ft)
— STOL	0	±12 m (±40 ft)	±12 m (±40 ft)
Long flare alert (7.3.2.1.9)	Runway region	±30 m (±100 ft)	not applicable
CTOL high speed roll-out/turnoffs (7.3.2.1.10)	Runway region	±12 m (±40 ft)	±30 m (±100 ft)
Departure climb and missed approach	0 to 9 km (5 NM)	±100 m (±328 ft)	±68 m (±223 ft)
VTOL approaches (7.3.2.1.11)	925 m (0.5 NM) to 0	±12 m (±40 ft)	±12 m (±40 ft)
Coordinate translations (7.3.2.1.12)	—	±12 m to ±30 m (±40 ft to ±100 ft)	±12 m (±40 ft)

7.3.2.1.8 It is intended that this specification applies when vertical guidance and sink rate for automatic landing are derived from the MLS flare elevation and the DME/P.

Note.— Although the standard has been developed to provide for MLS flare elevation function, this function is not implemented and is not intended for future implementation.

7.3.2.1.9 It indicates to the pilot if the aircraft is landing beyond the touchdown region.

7.3.2.1.10 The roll-out accuracy requirement reflects system growth potential. In this application the roll-out PFE would be dictated by the possible need to optimize roll-out deceleration and turnoff so as to decrease runway utilization time.

7.3.2.1.11 It is intended to assure the pilot that the aircraft is over the landing pad before descending.

7.3.2.1.12 It may be desirable to translate the MLS coordinates from one origin to another when the antennas are not installed in accordance with Chapter 3, 3.11.5.2.6 or 3.11.5.3.5. The figures in the table are typical of a VTOL application; actual values will depend on the geometry of the installation.

7.3.3 *DME/P error budgets*

Example error budgets for DME/P accuracy standards 1 and 2 are shown in Table C-6. If the specified error components are not individually exceeded in practice, it can be expected that the overall system performance, as specified in 3.5.3.1.3.4, will be achieved. A garbling contribution to the system error is computed by taking the root sum square (RSS) of the errors obtained in the specified down-link environment with those obtained in the specified up-link environment and removing, on an RSS basis, the error obtained in a non-garbling environment.

Table C-6. Example of DME/P error budget

		FA mode Standard 1		FA mode Standard 2		IA mode	
Error source	Error component	PFE m (ft)	CMN m (ft)	PFE m (ft)	CMN m (ft)	PFE m (ft)	CMN m (ft)
Instrumentation	Transponder	±10 (±33)	±8 (±26)	±5 (±16)	±5 (±16)	±15 (±50)	±10 (±33)
	Interrogator	±15 (±50)	±10 (±33)	±7 (±23)	±7 (±23)	±30 (±100)	±15 (±50)
Site related	Down-link specular multipath	±10 (±33)	±8 (±26)	±3 (±10)	±3 (±10)	±37 (±121)	±20 (±66)
	Up-link specular multipath	±10 (±33)	±8 (±26)	±3 (±10)	±3 (±10)	±37 (±121)	±20 (±66)
	Non-specular (diffuse) multipath	±3 (±10)	±3 (±10)	±3 (±10)	±3 (±10)	±3 (±10)	±3 (±10)
	Garble	±6 (±20)	±6 (±20)	±6 (±20)	±6 (±20)	±6 (±20)	±6 (±20)

Note 1.— The figures for "non-specular multipath" and for "garble" are the totals of the up-link and down-link components.

Note 2.— PFE contains both bias and time varying components. In the above table the time varying components and most site related errors are assumed to be essentially statistically independent. The bias components may not conform to any particular statistical distribution.

In considering these error budgets, caution is to be exercised when combining the individual components in any particular mathematical manner.

Note 3.— The transmitter wave form is assumed to have a 1 200 nanosecond rise time.

7.3.4 *System implementation*

7.3.4.1 While the DME/P may be implemented in various ways, the instrumental and propagation errors assumed are typical of those obtainable with equipment designs which provide internal time delay drift compensation and which establish timing reference points by thresholding on the leading edge of the first pulse of a pulse pair using the following techniques:

a) *IA mode.* A conventional technique which thresholds at the 50 per cent amplitude point;

b) *FA mode.* A delay-attenuate-and-compare (DAC) technique which thresholds between the 5 per cent and 30 per cent amplitude points.

7.3.4.2 Accuracy standard 1 can be achieved using a delay of 100 nanoseconds and an attenuation of 5 to 6 dB. It is also required that the threshold amplitude point of both the delayed pulse and the attenuated pulse lie within the partial rise time region.

7.3.4.3 The example above does not preclude time of arrival measurement techniques other than the DAC from being used, but it is necessary in any case that threshold measurements take place during the pulse partial rise time.

7.3.5 *DME/P interrogator signal processing*

7.3.5.1 *During acquisition*

a) The interrogator acquires and validates the signal within 2 seconds before transitioning to track mode even in the presence of squitter and random pulse pairs from adjacent channels, which result in a 50 per cent system efficiency.

b) After loss of the acquired signal in either the IA or FA mode, the interrogator provides a warning output within 1 second, during which time the guidance information continues to be displayed. After loss of signal, the interrogator returns to the search condition in the IA mode in order to re-establish track.

7.3.5.2 *During track*

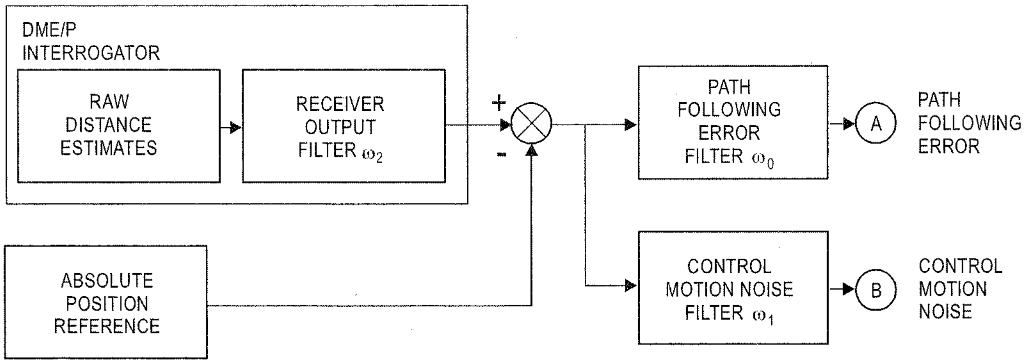
When track is established, the receiver output consists of valid guidance information before removing the warning. The validation process continues to operate as long as the interrogator is in track. The interrogator remains in track as long as the system efficiency is 50 per cent or greater. While in track, the receiver provides protection against short duration, large amplitude erroneous signals.

7.3.5.3 *Range date filter*

The accuracy specifications in Chapter 3, 3.5.3.1.3.4, as well as the error budgets discussed in 7.3.3, assume that the higher frequency noise contributions are limited by a low pass filter with a corner frequency of qw as specified in Figure C-21. Depending upon the user's application, additional filtering for noise reduction can be used provided that the induced phase delay and amplitude variation do not adversely affect the aircraft flight control system's dynamic response. The following sections recommend additional features which should be incorporated into the data filter.

7.3.5.4 *Velocity memory*

The data filter may require a velocity memory in order to achieve the specified accuracies in Chapter 3, 3.5.3.1.3.4 with a system efficiency of 50 per cent. It should be noted that low system efficiencies can occur in the IA mode during identification transmissions.



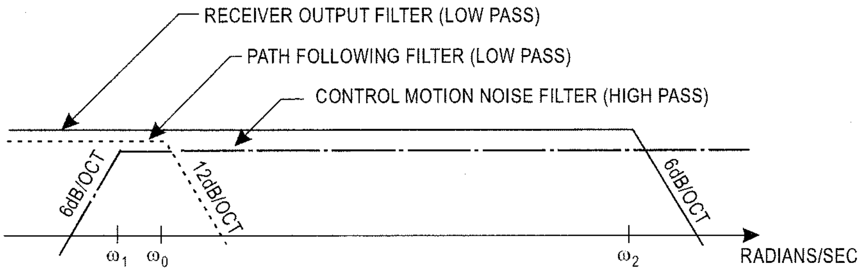
GUIDANCE FUNCTION	CORNER FREQUENCIES (RADIANS/SEC)		
	ω_0	ω_1	ω_2^*
DME/P	1.5	0.5	10

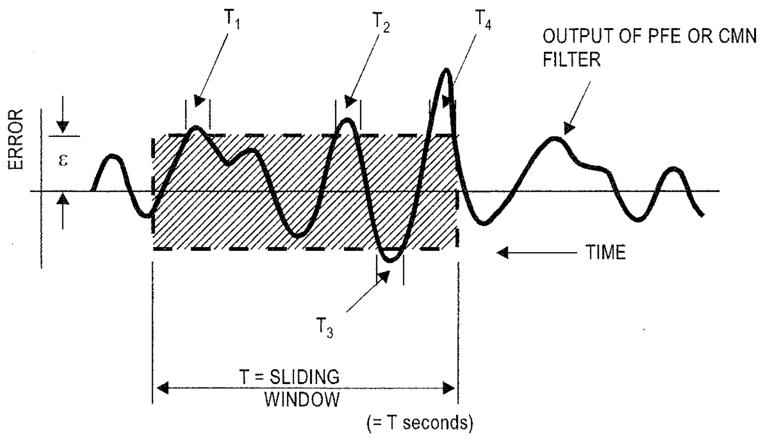
* This corner frequency may be less than 10 rad/sec for some applications.

RECEIVER OUTPUT FILTER $\frac{\omega_2}{S + \omega_2}$

PATH FOLLOWING FILTER $\frac{\omega_n^2}{S^2 + 2\zeta\,\omega_n S + \omega_n^2}$ $\zeta = 1; \omega_0 = .64\,\omega_n$

CONTROL MOTION NOISE FILTER $\frac{S}{S + \omega_1}$





	IA MODE	FA MODE
T	40 sec	10 sec

DME/P measurement methodology: ε is the error specification; T region to be evaluated; T_1, T_2, T_3 ... time intervals that error exceeds specifications. For the equipment to be acceptable in this region, the following inequality should be true:

$(T_1 + T_2 + T_3 + ...) / T \leq 0.05.$

Figure C-21

7.3.5.5 *Outlier rejection*

Range estimates which are significantly different from previous filtered range estimates, because they cannot be the result of aircraft motion, should be assumed to be in error. Such data should be rejected at the input to the data filter.

7.3.6 *DME/P error measurement methods*

7.3.6.1 *System errors*

7.3.6.1.1 The DME/P system accuracies are specified in Chapter 3, 3.5.4.1.3.4 in terms of path following error (PFE) and control motion noise (CMN). These parameters describe the interaction of the DME/P guidance signal with the aircraft in terms directly related to aircraft position errors and flight control system design.

7.3.6.1.2 For the purposes of determining compliance with the accuracy standard, the PFE and CMN components are evaluated over any T second interval (where T = 40 seconds in the IA mode and 10 seconds in the FA mode) of the flight error record taken within the DME/P coverage limits. The 95 per cent probability requirement is interpreted to be satisfied if the PFE and CMN components do not exceed the specified error limits for a total period that is more than 5 per cent of the evaluation time interval. This is illustrated in Figure C-21. To evaluate the PFE and CMN components of the DME/P guidance data, the true aircraft position, as determined by a suitable position reference, is subtracted from the guidance data to form an error signal. This error signal is then filtered by the PFE and CMN filters, where the outputs provide suitable estimates of the PFE and CMN components, respectively. These filters are defined in Figure C-21.

7.3.6.1.3 These filters can be utilized to determine the transponder instrumentation error components specified in Chapter 3, 3.5.4.5.3 and 3.5.4.5.4. Similarly, the interrogator instrumentation error components, specified in Chapter 3, 3.5.5.4, can be determined.

7.3.7 *Multipath effects*

7.3.7.1 Under the multipath conditions likely to exist, the accuracy specifications of the DME/P assume that the performance is not degraded beyond a certain limit and that this degradation is equally applied to both interrogator and transponder receiver.

7.3.7.2 To ensure that the equipment is working according to the specifications, the following should apply to FA mode operation of the system:

a) if a signal of sufficient power to make thermal noise contributions insignificant is applied to the receivers, a second signal delayed between 0 and 350 nanoseconds with respect to the first, with an amplitude 3 dB or more below the first and with a scalloping frequency between 0.05 and 200 Hz should not produce errors in the receiver output of more than plus or minus 100 nanoseconds (15 m);

b) for delays more than 350 nanoseconds the error contribution will be reduced considerably. A typical value will be plus or minus 7 nanoseconds (1 m).

7.3.7.3 The airborne DME antenna should be located so as to preclude antenna gain reductions in the forward direction with the aircraft in the landing configuration. Any such antenna gain reductions could enhance the multipath error component when the aircraft is on approach and landing phases when highest DME accuracies are required.

7.3.8 *DME/P power budget*

7.3.8.1 Tables C-7 and C-8 are an example of CTOL air-to-ground and ground-to-air power budgets. The permitted peak ERP value is based on a pulse shape which meets the spectral constraints in Chapter 3, 3.5.4.1.3 e).

Table C-7. CTOL ground-to-air power budget

Power budget items	41 km (22 NM)	13 km (7 NM)	Ref. datum	Roll-out
Peak effective radiated power, dBm	55	55	55	55
Ground multipath loss, dB	–5	–3	–4	–17
Antenna pattern loss, dB	–4	–2	–5	–5
Path loss, dB	–125	–115	–107	–103
Monitor loss, dB	–1	–1	–1	–1
Polarization and rain loss, dB	–1	–1	0	0
Received signal at aircraft, dBm	–81	–67	–62	–71
Power density at aircraft, dBW/m^2	–89	–75	–70	–79
Aircraft antenna gain, dB	0	0	0	0
Aircraft cable loss, dB	–4	–4	–4	–4
Received signal at interrogator, dBm	–85	–71	–66	–75
Receiver noise video, dBm				
(Noise factor (NF) = 9 dB)				
IF BW: 3.5 MHz		–103	–103	–103
IF BW: 0.8 MHz	–109			
Signal-to-noise ratio (video), dB	24	32	37	28

Table C-8. CTOL air-to-ground power budget

Power budget items	41 km (22 NM)	13 km (7 NM)	Ref. datum	Roll-out
Interrogator transmitter power, dBm	57	57	57	57
Aircraft antenna gain, dB	0	0	0	0
Aircraft cable loss, dB	–4	–4	–4	–4
Peak effective radiated power, dBm	53	53	53	53
Ground multipath loss, dB	–5	–3	–4	–17
Path loss, dB	–125	–115	–107	–103
Polarization and rain loss, dB	–1	–1	0	0
Received signal at transponder antenna, dBm	–78	–66	–58	–67
Ground antenna gain, dB	8	8	8	8
Pattern loss, dB	–4	–2	–5	–5
Cable loss, dB	–3	–3	–3	–3
Received signal at transponder, dBm	–77	–63	–58	–67
Receiver noise video, dBm				
(Noise factor (NF) = 9 dB)				
IF BW: 3.5 MHz		–106	–106	–106
IF BW: 0.8 MHz	–112			
Signal-to-noise ratio (video), dB	35	43	48	39

7.3.8.2 In the power budget calculations, it is assumed that the aircraft antenna is not shielded by the aircraft structure including the landing gear when extended.

7.3.8.3 The video power signal-to-noise ratio is related to the IF power signal-to-noise ratio in the following manner:

$$S/N\ (\text{video}) = S/N\ (\text{IF}) + 10 \log \frac{\text{IF noise bandwidth}}{\text{video noise bandwidth}}$$

Note 1.— The distances are measured from the transponder antenna.

Note 2.— Frequency dependent parameters were calculated for 1 088 MHz.

7.3.9 *DME/P monitor time delay measurement*

The required time delay measurement can be accomplished by measuring the output of a PFE filter and making a control decision within 1 second. However, since the transponder PFE is a slowly varying error component, an equivalent measurement is to average the unfiltered time delay samples for 1 second.

8. Material concerning power supply switch-over times

8.1 Power supply switch-over times for ground-based radio aids used in the vicinity of aerodromes

The power supply switch-over times for radio navigation aids and ground elements of communications systems are dependent on the type of runway and aircraft operations to be supported. Table C-9 indicates representative switch-over times which may be met by power supply systems currently available.

Table C-9. Power supply switch-over times for ground-based radio aids used at aerodromes

Type of runway	Aids requiring power	Maximum switch-over times (seconds)
Instrument approach	SRE	15
	VOR	15
	NDB	15
	D/F facility	15
Precision approach, Category I	ILS localizer	10
	ILS glide path	10
	ILS middle marker	10
	ILS outer marker	10
	PAR	10
Precision approach, Category II	ILS localizer	0
	ILS glide path	0
	ILS inner marker	1
	ILS middle marker	1
	ILS outer marker	10
Precision approach, Category III	(same as Category II)	

ATTACHMENT D. INFORMATION AND MATERIAL FOR GUIDANCE IN THE APPLICATION OF THE GNSS STANDARDS AND RECOMMENDED PRACTICES

1. Definitions

Bi-binary. Bi-binary is known as "Manchester Encoding". It is sometimes referred to as "Differential Manchester Encoding". Using this system, it is the transition of the edge that determines the bit.

Chip. A single digital bit of the output of a pseudo-random bit sequence.

Gold code. A class of unique codes used by GPS, which exhibit bounded cross-correlation and off-peak auto-correlation values.

Selective availability (SA). A set of techniques for denying the full accuracy and selecting the level of positioning, velocity and time accuracy of GPS available to users of the standard positioning service signal.

Note.— GPS SA was discontinued at midnight on 1 May 2000.

2. General

Standards and Recommended Practices for GNSS contain provisions for the elements identified in Chapter 3, 3.7.2.2.

Note.— Except where specifically annotated, GBAS guidance material applies to GRAS.

3. Navigation system performance requirements

3.1 Introduction

3.1.1 Navigation system performance requirements are defined in the *Manual on Required Navigation Performance (RNP)* (Doc 9613) for a single aircraft and for the total system which includes the signal-in-space, the airborne equipment and the ability of the aircraft to fly the desired trajectory. These total system requirements were used as a starting point to derive GNSS signal-in-space performance requirements. In the case of GNSS, degraded configurations which may affect multiple aircraft are to be considered. Therefore, certain signal-in-space performance requirements are more stringent to take into account multiple aircraft use of the system.

3.1.2 Two types of approach and landing operations with vertical guidance (APV), APV-I and APV-II, use vertical guidance relative to a glide path, but the facility or navigation system may not satisfy all of the requirements associated with precision approach. These operations combine the lateral performance equal to that of an ILS Category I localizer with different levels of vertical guidance. Both APV-I and APV-II provide access benefits relative to a non-precision approach, and the service that is provided depends on the operational requirements and the SBAS infrastructure. APV-I and APV-II exceed the requirements (lateral and vertical) for current RNAV approaches using barometric altimetry, and the relevant on-board equipment will therefore be suitable for the conduct of barometric VNAV APV and RNAV non-precision approaches.

3.2 Accuracy

3.2.1 GNSS position error is the difference between the estimated position and the actual position. For an estimated position at a specific location, the probability should be at least 95 per cent that the position error is within the accuracy requirement.

3.2.2 Stationary, ground-based systems such as VOR and ILS have relatively repeatable error characteristics, so that performance can be measured for a short period of time (e.g. during flight inspection) and it is assumed that the system accuracy does not change after the test. However, GNSS errors change over time. The orbiting of satellites and the error characteristics of GNSS result in position errors that can change over a period of hours. In addition, the accuracy itself (the error bound with 95 per cent probability) changes due to different satellite geometries. Since it is not possible to continually measure system accuracy, the implementation of GNSS demands increased reliance on analysis and characterization of errors. Assessment based on measurements within a sliding time window is not suitable for GNSS.

3.2.3 The error for many GNSS architectures changes slowly over time, due to filtering in the augmentation systems and in the user receiver. This results in a small number of independent samples in periods of several minutes. This issue is very important for precision approach applications, because it implies that there is a 5 per cent probability that the position error can exceed the required accuracy for an entire approach. However, due to the changing accuracy described in 3.2.2, this probability is usually much lower.

3.2.4 The 95 per cent accuracy requirement is defined to ensure pilot acceptance, since it represents the errors that will typically be experienced. The GNSS accuracy requirement is to be met for the worst-case geometry under which the system is declared to be available. Statistical or probabilistic credit is not taken for the underlying probability of particular ranging signal geometry.

3.2.5 Therefore, GNSS accuracy is specified as a probability for each and every sample, rather than as a percentage of samples in a particular measurement interval. For a large set of independent samples, at least 95 per cent of the samples should be within the accuracy requirements in Chapter 3, Table 3.7.2.4-1. Data is scaled to the worst-case geometry in order to eliminate the variability in system accuracy that is caused by the geometry of the orbiting satellites.

3.2.6 An example of how this concept can be applied is the use of GPS to support performance required for non-precision approach operations. Assume that the system is intended to support non-precision approaches when the horizontal dilution of precision (HDOP) is less than or equal to 6. To demonstrate this performance, samples should be taken over a long period of time (e.g. 24 hours). The measured position error g for each sample i is denoted g_i. This error is scaled to the worst-case geometry as $6 \times g_i$/HDOP. Ninety-five per cent of the scaled errors must be less than 220 m for the system to comply with the non-precision accuracy requirement under worst-case geometry conditions. The total number of samples collected must be sufficient for the result to be statistically representative, taking into account the decorrelation time of the errors.

3.2.7 A range of vertical accuracy values is specified for Category I precision approach operations which bounds the different values that may support an equivalent operation to ILS. A number of values have been derived by different groups, using different interpretations of the ILS standards. The lowest value from these derivations was adopted as a conservative value for GNSS; this is the minimum value given for the range. Because this value is conservative, and because GNSS error characteristics are different from ILS, it may be possible to achieve Category I operations using larger values of accuracy and alert limits within the range. The larger values would result in increased availability for the operation. The maximum value in the range has been proposed as a suitable value, subject to validation.

3.2.8 Specific alert limits have been defined for each augmentation system. For GBAS, technical provision has been made to broadcast the alert limit to aircraft. GBAS standards require the alert limit of 10 m. For SBAS, technical provisions have been made to standardize the alert limit through an updateable database (see *Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System (GPS/WAAS) Airborne Equipment* (RTCA/DO-229C)).

3.2.9 The GPS SPS position error (Chapter 3, 3.7.3.1.1.1) accounts for the contribution of the space and control segment to position errors (satellite clock and ephemeris errors) only; it does not include the contributions of ionospheric and tropospheric delay model errors, errors due to multipath effects, and receiver measurement noise errors (Attachment D, 4.1.2). These errors are addressed in the receiver standards. The user positioning error at the output of ABAS-capable equipment is mainly driven by the GNSS receiver used.

3.2.9.1 For Basic GNSS receivers, the receiver qualification standards require demonstration of user positioning accuracy in the presence of interference and a model of selective availability (SA) to be less than 100 m (95 per cent of time) horizontally and 156 m (95 per cent of time) vertically. The receiver standards do not require that a Basic GNSS receiver applies the ionospheric correction described in Appendix B, 3.1.2.4.

Note.— The term "Basic GNSS receiver" designates the GNSS avionics that at least meet the requirements for a GPS receiver as outlined in Annex 10, Volume I and the specifications of RTCA/DO-208 as amended by United States Federal Aviation Administration (FAA) TSO-C129A, or EUROCAE ED-72A (or equivalent).

3.2.9.2 Since the discontinuation of SA, the representative user positioning accuracy of GPS has been conservatively estimated to be as shown in Table D-0. The numbers provided assume that the worst two satellites of a nominal 24 GPS satellite constellation are out of service. In addition, a 7 m (1 σ) ionospheric delay model error, a 0.25 m (1 σ) residual tropospheric delay error, and a 0.80 m (1 σ) receiver noise error are assumed. After discontinuation of SA (Attachment D, 1.), the dominant pseudo-range error for users of the GPS Standard Positioning Service is the ionospheric error that remains after application of the ionospheric corrections. This error is also highly variable and depends on conditions such as user geomagnetic latitude, level of solar activity (i.e. point of the solar cycle that applies), level of ionospheric activity (i.e. whether there is a magnetic storm, or not), elevation angle of the pseudo-range measurement, season of the year, and time of day. The ionospheric delay model error assumption reflected in Table D-0 is generally conservative; however, conditions can be found under which the assumed 7 m (1 σ) error during solar maximum would be inadequate.

Table D-0. GPS user positioning accuracy

	GPS user positioning accuracy 95% of time, global average
Horizontal position error	33 m (108 ft)
Vertical position error	73 m (240 ft)

3.2.10 SBAS and GBAS receivers will be more accurate, and their accuracy will be characterized in real time by the receiver using standard error models, as described in Chapter 3, 3.5, for SBAS and Chapter 3, 3.6, for GBAS.

Note 1.— The term "SBAS receiver" designates the GNSS avionics that at least meet the requirements for an SBAS receiver as outlined in Annex 10, Volume I and the specifications of RTCA/DO-229C, as amended by United States FAA TSO-C145A/TSO-C146A (or equivalent).

Note 2.— The term "GBAS receiver" designates the GNSS avionics that at least meet the requirements for a GBAS receiver as outlined in Annex 10, Volume I and the specifications of RTCA/DO-253A, as amended by United States FAA TSO-C161 and TSO-C162 (or equivalent).

3.3 Integrity and time-to-alert

3.3.1 Integrity is a measure of the trust that can be placed in the correctness of the information supplied by the total system. Integrity includes the ability of a system to provide timely and valid warnings to the user (alerts) when the system must not be used for the intended operation (or phase of flight).

3.3.2 To ensure that the position error is acceptable, an alert limit is defined that represents the largest position error allowable for a safe operation. The position error cannot exceed this alert limit without annunciation. This is analogous to ILS in that the system can degrade so that the error is larger than the 95th percentile but within the monitor limit.

3.3.3 The integrity requirement of the navigation system for a single aircraft to support en-route, terminal, initial approach, non-precision approach and departure is assumed to be $1 - 1 \times 10^{-5}$ per hour.

3.3.4 For satellite-based navigation systems, the signal-in-space in the en-route environment simultaneously serves a large number of aircraft over a large area, and the impact of a system integrity failure on the air traffic management system will be greater than with traditional navigation aids. The performance requirements in Chapter 3, Table 3.7.2.4-1, are therefore more demanding.

3.3.5 For precision approach operations, integrity requirements for GNSS signal-in-space requirements of Chapter 3, Table 3.7.2.4-1, were selected to be consistent with ILS requirements.

3.4 Continuity of service

3.4.1 Continuity of service of a system is the capability of the system to perform its function without unscheduled interruptions during the intended operation.

3.4.2 *En-route*

3.4.2.1 For en-route operations, continuity of service relates to the capability of the navigation system to provide a navigation output with the specified accuracy and integrity throughout the intended operation, assuming that it was available at the start of the operation. The occurrence of navigation system alerts, either due to rare fault-free performance or to failures, constitute continuity failures. Since the durations of these operations are variable, the continuity requirement is specified as a probability on a per-hour basis.

3.4.2.2 The navigation system continuity requirement for a single aircraft is $1 - 1 \times 10^{-4}$ per hour. However, for satellite-based systems, the signal-in-space may serve a large number of aircraft over a large area. The continuity requirements in Chapter 3, Table 3.7.2.4-1, represent reliability requirements for the GNSS signal-in-space, i.e. they derive mean time between outage (MTBO) requirements for the GNSS elements.

3.4.2.3 A range of values is given in Chapter 3, Table 3.7.2.4-1, for the signal-in-space continuity requirement for en-route operations. The lower value is the minimum continuity for which a system is considered to be practical. It is appropriate for areas with low traffic density and airspace complexity. In such areas, the impact of a navigation system failure is limited to a small number of aircraft, and there is, therefore, no need to increase the continuity requirement significantly beyond the single aircraft requirement ($1 - 1 \times 10^{-4}$ per hour). The highest value given (i.e. $1 - 1 \times 10^{-8}$ per hour) is suitable for areas with high traffic density and airspace complexity, where a failure will affect a large number of aircraft. This value is appropriate for navigation systems where there is a high degree of reliance on the system for navigation and possibly for dependent surveillance. The value is sufficiently high for the scenario based on a low probability of a system failure during the life of the system. Intermediate values of continuity (e.g. $1 - 1 \times 10^{-6}$ per hour) are considered to be appropriate for areas of high traffic density and complexity where there is a high degree of reliance on the navigation system but in which mitigation for navigation system failures is possible. Such mitigation may be through the use of alternative navigation means or the use of ATC surveillance and intervention to maintain separation standards. The values of continuity performance are determined by airspace needs to support navigation where GNSS has either replaced the existing navigation aid infrastructure or where no infrastructure previously existed.

3.4.3 *Approach and landing*

3.4.3.1 For approach and landing operations, continuity of service relates to the capability of the navigation system to provide a navigation output with the specified accuracy and integrity during the approach, assuming that it was available at the start of the operation. The occurrence of navigation system alerts, either due to rare fault-free performance or to failures, constitute continuity failures. In this case, the continuity requirement is stated as a probability for a short exposure time.

3.4.3.2 The continuity requirements for approach and landing operations represent only the allocation of the requirement between the aircraft receiver and the non-aircraft elements of the system. In this case, no increase in the requirement is considered necessary to deal with multiple aircraft use of the system. The continuity value is normally related only to the risk associated with a missed approach and each aircraft can be considered to be independent. However, in some cases, it may be necessary to increase the continuity values since a system failure has to be correlated between both runways (e.g. the use of a common system for approaches to closely-spaced parallel runways).

3.5 Availability

3.5.1 The availability of GNSS is characterized by the portion of time the system is to be used for navigation during which reliable navigation information is presented to the crew, autopilot, or other system managing the flight of the aircraft.

3.5.2 When establishing the availability requirements for GNSS, the desired level of service to be supported should be considered. If the satellite navigation service is intended to replace an existing en-route navigation aid infrastructure, the availability of the GNSS should be commensurate with the availability provided by the existing infrastructure. An assessment of the operational impact of a degradation in service should be conducted.

3.5.3 Where GNSS availability is low, it is still possible to use the satellite navigation service by restricting the navigation operating times to those periods when it is predicted to be available. This is possible in the case of GNSS since unavailability due to insufficient satellite geometry is repeatable. Under such restrictions, there remains only a continuity risk associated with the failure of necessary system components between the time the prediction is made and the time the operation is conducted.

3.5.4 *En-route*

3.5.4.1 Specific availability requirements for an area or operation should be based upon:

a) traffic density and complexity;

b) alternate navigation aids;

c) primary/secondary surveillance coverage;

d) air traffic and pilot procedures; and

e) duration of outages.

3.5.4.2 For this reason, the GNSS SARPs specify a range of values for availability requirements. The requirements support GNSS sole-means operations in airspace with various levels of traffic and complexity. The lower end of the range is only sufficient for providing sole means of navigation in a low traffic density and complexity airspace.

3.5.4.3 While augmentations can reduce the dependency of the GNSS on a particular core element, they do not provide usable service without the core elements. The requirement for the availability of a particular augmentation in an area should account for potential degradation in the GNSS core elements (i.e. the minimum constellation of core elements (number and diversity of satellites) that is expected). Operational procedures should be developed in case such a degraded configuration occurs.

3.5.5 *Approach*

3.5.5.1 Specific requirements for an area should be based upon:

a) traffic density and complexity;

b) procedures for filing and conducting an approach to an alternate airport;

c) navigation system to be used for an alternate airport;

d) air traffic and pilot procedures;

e) duration of outages; and

f) geographic extent of outages.

3.5.5.2 When developing operating procedures for GNSS approach systems, the duration of an outage and its impact on the alternate airport should be considered. Although GNSS outages can occur which affect many approaches, the approach service can be restored without any maintenance because of the orbiting of the satellites.

3.5.6 *Determining GNSS availability*

The availability of GNSS is complicated by the movement of satellites relative to a coverage area under consideration and the potentially long time needed to restore a satellite in the event of a failure. Accurately measuring the availability would require many years to allow for a measurement period longer than the MTBF and repair times. The availability of GNSS should be determined through design, analysis and modelling, rather than measurement. The availability model should account for the ionospheric, tropospheric and receiver error models used by the receiver to verify integrity (e.g. HPL, LPL and VPL calculations). The availability specified in Chapter 3, 3.7.2.4, applies to the design availability.

Note.— Additional guidance material pertaining to reliability and availability of radio communications and navigation aids is contained in Attachment F.

4. GNSS core elements

4.1 GPS

Note.— Additional information concerning GPS can be found in the Global Positioning System Standard Positioning Service — Performance Standard, *October 2001, and Interface Control Document (ICD)-GPS-200C.*

4.1.1 The performance standard is based upon the assumption that a representative standard positioning service (SPS) receiver is used. A representative receiver has the following characteristics: designed in accordance with ICD-GPS-200C; uses a 5-degree masking angle; accomplishes satellite position and geometric range computations in the most current realization of the World Geodetic System 1984 (WGS-84) Earth-Centred, Earth-Fixed (ECEF) coordinate system; generates a position and time solution from data broadcast by all satellites in view; compensates for dynamic Doppler shift effects on nominal SPS ranging signal carrier phase and C/A code measurements; excludes GPS unhealthy satellites from the position solution; uses up-to-date and internally consistent ephemeris and clock data for all satellites it is using in its position solution; and loses track in the event that a GPS satellite stops transmitting C/A code. The time transfer accuracy applies to a stationary receiver operating at a surveyed location. A 12-channel receiver will meet performance requirements specified in Chapter 3, 3.7.3.1.1.1 and 3.7.3.1.2. A receiver that is able to track four satellites only (Appendix B, 3.1.3.1.2) will not get the full accuracy and availability performance.

4.1.2 *Accuracy.* The accuracy is measured with a representative receiver and a measurement interval of 24 hours for any point within the coverage area. The positioning and timing accuracy are for the signal-in-space (SIS) only and do not include such error sources as: ionosphere, troposphere, interference, receiver noise or multipath. The accuracy is derived based on the worst two of 24 satellites being removed from the constellation and a 6-metre constellation RMS SIS user range error (URE).

4.1.3 *Range domain accuracy.* Range domain accuracy is conditioned by the satellite indicating a healthy status and transmitting C/A code and does not account for satellite failures outside of the normal operating characteristics. Range domain accuracy limits can be exceeded during satellite failures or anomalies while uploading data to the satellite. Exceedance of the range error limit constitutes a major service failure as described in 4.1.6. The range rate error limit is the maximum for any satellite measured over any 3-second interval for any point within the coverage area. The range acceleration error limit is the maximum for any satellite measured over any 3-second interval for any point within the coverage area. The root-mean-square range error accuracy is the average of the RMS URE of all satellites over any 24-hour interval for any point within the coverage area. Under nominal conditions, all satellites are maintained to the same standards, so it is appropriate for availability modelling purposes to assume that all satellites have a 6-metre RMS SIS URE. The standards are restricted to range domain errors allocated to space and control segments.

4.1.4 *Availability.* Availability is the percentage of time over any 24-hour interval that the predicted 95 per cent positioning error (due to space and control segment errors) is less than its threshold, for any point within the coverage area. It is based on a 36-metre horizontal 95 per cent threshold; a 77-metre vertical 95 per cent threshold; using a representative receiver; and operating within the coverage area over any 24-hour interval. The service availability assumes the worst combination of two satellites out of service.

4.1.4.1 *Relationship to augmentation availability.* The availability of ABAS, GBAS and SBAS does not directly relate to the GPS availability defined in Chapter 3, 3.7.3.1.2. States and operators must evaluate the availability of the augmented system by comparing the augmented performance to the requirements. Availability analysis is based on an assumed satellite constellation and the probability of having a given number of satellites. Twenty-four operational satellites are available on orbit with 0.95 probability (averaged over any day), where a satellite is defined to be operational if it is capable of, but is not necessarily transmitting, a usable ranging signal. At least 21 satellites in the 24 nominal plane/slot positions must be set healthy and must be transmitting a navigation signal with 0.98 probability (yearly averaged).

4.1.5 *Reliability.* Reliability is the percentage of time over a specified time interval that the instantaneous SPS SIS URE is maintained within the range error limit, at any given point within the coverage area, for all healthy GPS satellites. The reliability standard is based on a measurement interval of one year and the average of daily values within the coverage area. The single point average reliability assumes that the total service failure time of 18 hours will be over that particular point (3 failures each lasting 6 hours).

4.1.6 *Major service failure.* A major service failure is defined to be a condition over a time interval during which a healthy GPS satellite's ranging signal error (excluding atmospheric and receiver errors) exceeds the range error limit. As defined in Chapter 3, 3.7.3.1.1.3 a), the range error limit is the larger of:

a) 30 m; or

b) 4.42 times the URA, not to exceed 150 m.

4.1.7 *Coverage.* The SPS supports the terrestrial coverage area, which is from the surface of the earth up to an altitude of 3 000 km.

4.2 GLONASS

Note.— Additional information concerning GLONASS can be found in the GLONASS Interface Control Document *published by Scientific Coordination Information Center, Russian Federation Ministry of Defence, Moscow.*

4.2.1 *Satellite selection.* The performance standard definitions are based upon the assumption that the channel of standard accuracy (CSA) receiver will select satellites based on the minimum PDOP every 5 minutes, or whenever a satellite used in the position solution sets below the mask angle.

4.2.2 *Accuracy.* Accuracy is conditioned by coverage, availability and reliability standards, and a measurement interval of 24 hours for any point on the earth.

4.2.3 *Time transfer accuracy.* Time transfer accuracy is conditioned by coverage, availability and reliability standards and a measurement interval of 24 hours for any point on the earth. It is based upon the GLONASS CSA receiver time as computed using the output of the position solution. Time transfer accuracy is defined with respect to Universal Coordinated Time as maintained by the National Time Service of Russia (UTC(SU)).

4.2.4 *Availability.* Availability is conditioned by coverage and a typical 24-hour interval (defined using an averaging period of 60 days) averaged over the earth.

4.2.5 *Reliability.* Reliability is conditioned by coverage, service availability, 200 m not to exceed predictable horizontal reliability threshold, a maximum of 18 hours of major service failure behaviour over the sample interval, and a measurement interval of one year, average of daily values over the earth.

4.2.5.1 *Major service failure.* A major service failure is defined as a departure from the normal ranging signal characteristics in a manner that can cause a reliability or availability service failure. Specifically, a major service failure is defined as a departure from the normal ranging signal characteristics in one of the following ways:

a) a statistical departure from nominal system ranging accuracy that causes the CSA instantaneous ranging error to exceed 70 m; or

b) a fault in a CSA ranging signal, navigation message structure or navigation message content that impacts the CSA receiver's minimum ranging signal reception or processing capabilities.

4.2.6 *Coverage.* Coverage is conditioned by the probability of four or more satellites in view over any 24-hour interval averaged over the earth, a PDOP of 6 or less from four satellites, a 5-degree mask angle, and a constellation of twenty-four operational satellites as defined in the almanac.

4.2.7 *GLONASS time.* GLONASS time is generated based on GLONASS Central Synchronizer time. Daily instability of the Central Synchronizer hydrogen clock is not worse than 5×10^{-14}. The difference between GLONASS time and UTC(SU) is within 1 millisecond. The navigation message contains the requisite data to relate GLONASS time to UTC(SU) within 0.7 microsecond.

4.2.7.1 *Transformation of GLONASS-M current data information into common form.* A satellite navigation message contains current data information in N_T parameter. It could be transformed into the common form by the following algorithm:

a) Current year number J in the four-year interval is calculated:

If $1 \leq N_T \leq 366$; $J = 1$;
If $367 \leq N_T \leq 731$; $J = 2$;
If $732 \leq N_T \leq 1096$; $J = 3$;
If $1097 \leq N_T \leq 1461$; $J = 4$.

b) Current year in common form is calculated by the following formula:

$$Y = 1996 + 4\,(N_4 - 1) + (J - 1).$$

c) Current day and month (dd/mm) are extracted from the reference table stored in user equipment ROM. The table interrelates N_T parameter and common form dates.

4.2.8 *GLONASS coordinate system.* The GLONASS coordinate system is PZ-90 as described in *Parameters of Earth, 1990 (PZ-90)*, published by the Topographic Service, Russian Federation Ministry of Defence, Moscow.

4.2.8.1 PZ-90 parameters include fundamental geodetic constants, dimensions of the common terrestrial ellipsoid, the characteristics of the gravitational field of the earth, and the elements of the Krasovsky ellipsoid (coordinate system 1942) orientation relative to the common terrestrial ellipsoid.

4.2.8.2 By definition, the coordinate system PZ-90 is a geocentric Cartesian space system whose origin is located at the centre of the earth's body. The Z-axis is directed to the Conventional Terrestrial Pole as recommended by the International Earth Rotation Service. The X-axis is directed to the point of intersection of the earth's equatorial plane and zero meridian established by the Bureau International de l'Heure. The Y-axis completes the right-handed coordinate system.

4.3 Dilution of precision

Dilution of precision (DOP) factors express how ranging accuracy is scaled by a geometry effect to yield position accuracy. The optimal geometry (i.e. the lowest DOP values) for four satellites is achieved when three satellites are equally spaced on the horizon, at minimum elevation angle, and one satellite is directly overhead. The geometry can be said to "dilute" the range domain accuracy by the DOP factor.

4.4 GNSS receiver

4.4.1 The failures caused by the receiver can have two consequences on navigation system performance which are the interruption of the information provided to the user or the output of misleading information. Neither of these events are accounted for in the signal-in-space requirement.

4.4.2 The nominal error of the GNSS aircraft element is determined by receiver noise, interference, and multipath and tropospheric model residual errors. Specific receiver noise requirements for both the SBAS airborne receiver and the GBAS airborne receiver include the effect of any interference below the protection mask specified in Appendix B, 3.7. The required performance has been demonstrated by receivers that apply narrow correlator spacing or code smoothing techniques.

5. Aircraft-based augmentation system (ABAS)

5.1 ABAS augments and/or integrates the information obtained from GNSS elements with information available on board the aircraft in order to ensure operation according to the values specified in Chapter 3, 3.7.2.4.

5.2 ABAS includes processing schemes that provide:

a) integrity monitoring for the position solution using redundant information (e.g. multiple range measurements). The monitoring scheme generally consists of two functions: fault detection and fault exclusion. The goal of fault detection is to detect the presence of a positioning failure. Upon detection, proper fault exclusion determines and excludes the source of the failure (without necessarily identifying the individual source causing the problem), thereby allowing GNSS navigation to continue without interruption. There are two general classes of integrity monitoring: receiver autonomous integrity monitoring (RAIM), which uses GNSS information exclusively, and aircraft autonomous integrity monitoring (AAIM), which uses information from additional on-board sensors (e.g. barometric altimeter, clock and inertial navigation system (INS));

b) continuity aiding for the position solution using information of alternative sources, such as INS, barometric altimetry and external clocks;

c) availability aiding for the position solution (analogous to the continuity aiding); and

d) accuracy aiding through estimation of remaining errors in determined ranges.

5.3 Non-GNSS information can be integrated with GNSS information in two ways:

a) integrated within the GNSS solution algorithm (an example is the modelling of altimetry data as an additional satellite measurement); and

b) external to the basic GNSS position calculation (an example is a comparison of the altimetry data for consistency with the vertical GNSS solution with a flag raised whenever the comparison fails).

5.4 Each scheme has specific advantages and disadvantages, and it is not possible to present a description of all potential integration options with specific numerical values of the achieved performance. The same applies to the situation when several GNSS elements are combined (e.g. GPS and GLONASS).

6. Satellite-based augmentation system (SBAS)

6.1 An SBAS is made up of three distinct elements:

a) the ground infrastructure;

b) the SBAS satellites; and

c) the SBAS airborne receiver.

6.1.1 The ground infrastructure includes the monitoring and processing stations that receive the data from the navigation satellites and compute integrity, corrections and ranging data which form the SBAS signal-in-space. The SBAS satellites relay the data relayed from the ground infrastructure to the SBAS airborne receivers that determine position and time information using core satellite constellation(s) and SBAS satellites. The SBAS airborne receivers acquire the ranging and correction data and apply these data to determine the integrity and improve the accuracy of the derived position.

6.1.2 The SBAS ground network measures the pseudo-range between the ranging source and an SBAS receiver at the known locations and provides separate corrections for ranging source ephemeris errors, clock errors and ionospheric errors. The user applies a tropospheric delay model.

6.1.3 The ranging source ephemeris error and slow moving clock error are the primary bases for the long-term correction. The ranging source clock error is adjusted for the long-term correction and tropospheric error and is the primary basis for the fast correction. The ionospheric errors among many ranging sources are combined into vertical ionospheric errors at predetermined ionospheric grid points. These errors are the primary bases for ionospheric corrections.

6.2 SBAS coverage area and service areas

6.2.1 It is important to distinguish between the coverage area and service areas for an SBAS. A coverage area comprises one or more service areas, each capable of supporting operations based on some or all of the SBAS functions defined in Chapter 3, 3.7.3.4.2. These functions can be related to the operations that are supported as follows:

a) *Ranging*: SBAS provides a ranging source for use with other augmentation(s) (ABAS, GBAS or other SBAS);

b) *Satellite status and basic differential corrections*: SBAS provides en-route, terminal, and non-precision approach service. Different operations (e.g. RNP types) may be supported in different service areas;

c) *Precise differential corrections*: SBAS provides APV and precision approach service (i.e. APV-I, APV-II and precision approach may be supported in different service areas).

6.2.2 Figure D-1* shows the initial coverage areas and approximated initial service areas for three SBASs: the Wide Area Augmentation System (WAAS), the European Geo-stationary Navigation Overlay Service (EGNOS) and the Multifunction Transport Satellite (MTSAT) Satellite-based Augmentation System (MSAS).

6.2.3 An SBAS may provide accurate and reliable service outside the defined service area(s). The ranging, satellite status and basic differential corrections functions are usable throughout the entire coverage area. The performance of these functions may be technically adequate to support en-route, terminal and non-precision approach operations by providing monitoring and integrity data for core satellite constellations and/or SBAS satellites. The only potential for integrity to be compromised is if there is a satellite ephemeris error that cannot be observed by the SBAS ground network while it creates an unacceptable error outside the service area. For alert limits of 0.3 NM specified for non-precision approach and greater, this is very unlikely.

6.2.4 Each State is responsible for defining SBAS service areas and approving SBAS-based operations within its airspace. In some cases, States will field SBAS ground infrastructure linked to an existing SBAS. This would be required to achieve APV or precision approach performance. In other cases, States may simply approve service areas and SBAS-based operations using available SBAS signals. In either case, each State is responsible for ensuring that SBAS meets the requirements of Chapter 3, 3.7.2.4, within its airspace, and that appropriate operational status reporting and NOTAMs are provided for its airspace.

6.2.5 Before approving SBAS-based operations, a State must determine that the proposed operations are adequately supported by one or more SBASs. This determination should focus on the practicality of using SBAS signals, taking into account the relative location of the SBAS ground network. This could involve working with the State(s) or organization(s) responsible for operating the SBASs. For an airspace located relatively far from an SBAS ground network, the number of visible satellites for which that SBAS provides status and basic corrections would be reduced. Since SBAS receivers are able to use data from two SBASs simultaneously, and to use autonomous fault detection and exclusion when necessary, availability may still be sufficient for approval of operations.

6.2.6 Before publishing procedures based on SBAS signals, a State is expected to provide a status monitoring and NOTAM system. To determine the effect of a system element failure on service, a mathematical service volume model is to be used. The State can either obtain the model from the SBAS operator or develop its own model. Using the current and forecast status data of the basic system elements, and the locations where the State has approved operations, the model would identify airspace and airports where service outages are expected, and it could be used to originate NOTAMs. The system element status data (current and forecast) required for the model could be obtained via a bilateral arrangement with the SBAS service provider, or via connection to a real time "broadcast" of the data if the SBAS service provider chooses to provide data in this way.

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* All figures are located at the end of the attachment.

6.2.7 Participating States or regions will coordinate through ICAO to ensure that SBAS provides seamless global coverage, taking into account that aircraft equipped to use the signal could suffer operational restrictions in the event that a State or region does not approve the use of one or more of the SBAS signals in its airspace. In such an event, the pilot may have to deselect GNSS altogether since the aircraft equipment may not allow deselection of all SBAS or a particular SBAS.

6.2.8 As the SBAS geostationary orbit satellite coverages (footprints) overlap, there will be interface issues among the SBASs. As a minimum, the SBAS airborne receivers must be able to operate within the coverage of any SBAS. It is possible for an SBAS provider to monitor and send integrity and correction data for a geostationary orbit satellite that belongs to another SBAS service provider. This improves availability by adding ranging sources. This improvement does not require any interconnection between SBAS systems and should be accomplished by all SBAS service providers.

6.2.9 Other levels of integration can be implemented using a unique connection between the SBAS networks (e.g. separate satellite communication). In this case, SBASs can exchange either raw satellite measurements from one or more reference stations or processed data (corrections or integrity data) from their master stations. This information can be used to improve system robustness and accuracy through data averaging, or integrity through a cross check mechanism. Availability will also be improved within the service areas, and the technical performance will meet the GNSS SARPs throughout the entire coverage (i.e. monitoring of satellites ephemeris would be improved). Finally, SBAS control and status data could be exchanged to improve system maintenance.

6.3 Integrity

6.3.1 The provisions for integrity are complex, as some attributes are determined within the SBAS ground network and transmitted in the signal-in-space, while other attributes are determined within the SBAS equipment on the aircraft. For the satellite status and basic corrections functions, an error uncertainty for the ephemeris and clock corrections is determined by the SBAS ground network. This uncertainty is modelled by the variance of a zero-mean, normal distribution that describes the user differential range error (UDRE) for each ranging source after application of fast and long-term corrections and excluding atmospheric effects and receiver errors.

6.3.2 For the precise differential function, an error uncertainty for the ionospheric correction is determined. This uncertainty is modelled by the variance of a zero-mean, normal distribution that describes the L1 residual user ionospheric range error (UIRE) for each ranging source after application of ionospheric corrections. This variance is determined from an ionospheric model using the broadcast grid ionospheric vertical error (GIVE).

6.3.3 There is a finite probability that an SBAS receiver would not receive an SBAS message. In order to continue navigation in that case, the SBAS broadcasts degradation parameters in the signal-in-space. These parameters are used in a number of mathematical models that characterize the additional residual error from both basic and precise differential corrections induced by using old but active data. These models are used to modify the UDRE variance and the UIRE variance as appropriate.

6.3.4 The individual error uncertainties described above are used by the receiver to compute an error model of the navigation solution. This is done by projecting the pseudo-range error models to the position domain. The horizontal protection level (HPL) provides a bound on the horizontal position error with a probability derived from the integrity requirement. Similarly, the vertical protection level (VPL) provides a bound on the vertical position. If the computed HPL exceeds the horizontal alert limit (HAL) for a particular operation, SBAS integrity is not adequate to support that operation. The same is true for precision approach and APV operations, if the VPL exceeds the vertical alert limit (VAL).

6.3.5 One of the most challenging tasks for an SBAS provider is to determine UDRE and GIVE variances so that the protection level integrity requirements are met without having an impact on availability. The performance of an individual SBAS depends on the network configuration, geographical extent and density, the type and quality of measurements used and the algorithms used to process the data. General methods for determining the model variance are described in Section 14.

6.3.6 *Residual clock and ephemeris error (σ_{UDRE}).* The residual clock error is well characterized by a zero-mean, normal distribution since there are many receivers that contribute to this error. The residual ephemeris error depends upon the user location. For the precise differential function, the SBAS provider will ensure that the residual error for all users within a defined service area is reflected in the σ_{UDRE}. For the basic differential function, the residual ephemeris error should be evaluated and may be determined to be negligible.

6.3.7 *Vertical ionospheric error (σ_{GIVE}).* The residual ionospheric error is well represented by a zero-mean, normal distribution since there are many receivers that contribute to the ionospheric estimate. Errors come from the measurement noise, the ionospheric model and the spatial decorrelation of the ionosphere. The position error caused by ionospheric error is mitigated by the positive correlation of the ionosphere itself. In addition, the residual ionospheric error distribution has truncated tails, i.e. the ionosphere cannot create a negative delay, and has a maximum delay.

6.3.8 *Aircraft element errors.* The combined multipath and receiver contribution is bounded as described in Section 14. This error can be divided into multipath and receiver contribution as defined in Appendix B, 3.6.5.5.1, and the standard model for multipath may be used. The receiver contribution can be taken from the accuracy requirement (Appendix B, 3.5.8.2 and 3.5.8.4.1) and extrapolated to typical signal conditions. Specifically, the aircraft can be assumed to have $\sigma^2_{air} = \sigma^2_{receiver} + \sigma^2_{multipath}$, where it is assumed that $\sigma_{receiver}$ is defined by the RMS_{pr_air} specified for GBAS Airborne Accuracy Designator A equipment, and $\sigma_{multipath}$ is defined in Appendix B, 3.6.5.5.1. The aircraft contribution to multipath includes the effects of reflections from the aircraft itself. Multipath errors resulting from reflections from other objects are not included. If experience indicates that these errors are not negligible, they must be accounted for operationally.

6.3.9 *Tropospheric error.* The receiver must use a model to correct for tropospheric effects. The residual error of the model is constrained by the maximum bias and variance defined in Appendix B, 3.5.8.4.2 and 3.5.8.4.3. The effects of this mean must be accounted for by the ground subsystem. The airborne user applies a specified model for the residual tropospheric error (σ_{tropo}).

6.4 RF characteristics

6.4.1 *SBAS pseudo-random noise (PRN) codes.* RTCA/DO-229C, Appendix A, provides two methods for SBAS PRN code generation.

6.4.2 *SBAS network time.* SBAS network time is a time reference maintained by SBAS for the purpose of defining corrections. When using corrections, the user's solution for time is relative to the SBAS network time rather than core satellite constellation system time. If corrections are not applied, the position solution will be relative to a composite core satellite constellation/SBAS network time depending on the satellites used and the resulting accuracy will be affected by the difference among them.

6.4.3 *SBAS convolutional encoding.* Information on the convolutional coding and decoding of SBAS messages can be found in RTCA/DO-229C, Appendix A.

6.4.4 *Message timing.* The users' convolutional decoders will introduce a fixed delay that depends on their respective algorithms (usually 5 constraint lengths, or 35 bits), for which they must compensate to determine SBAS network time (SNT) from the received signal.

6.5 SBAS data characteristics

6.5.1 *SBAS messages.* Due to the limited bandwidth, SBAS data is encoded in messages that are designed to minimize the required data throughput. RTCA/DO-229C, Appendix A, provides detailed specifications for SBAS messages.

6.5.2 *Data broadcast intervals.* The maximum broadcast intervals between SBAS messages are specified in Appendix B, Table B-54. These intervals are such that a user entering the SBAS service broadcast area is able to output a corrected position along with SBAS-provided integrity information in a reasonable time. For en-route, terminal and NPA operations, all needed data will be received within 2 minutes, whereas for precision approach operations, it will take a maximum of 5 minutes. The maximum intervals between broadcasts do not warrant a particular level of accuracy performance as defined in Chapter 3, Table 3.7.2.4-1. In order to ensure a given accuracy performance, each service provider will adopt a set of broadcast intervals taking into account different parameters such as the type of constellations (e.g. GPS with SA, GPS without SA) or the ionospheric activity.

6.5.2.1 For fast corrections, Table B-54 allows the maximum broadcast interval to be 60 seconds. Table B-56 gives data time-out intervals for the various data messages with reference to Table B-57 which shows the fast corrections time-out intervals as a function of the fast correction degradation factor indicator (ai_i). However, if the service provider chose 60 seconds for the fast corrections broadcast interval and the ai_i was 15, the user, due to data time-out prior to the next broadcast, would not have current fast corrections for 42 seconds of every minute for NPA and APV-I and for 48 seconds of every minute for APV-II and PA. In order to ensure that the aircraft element processes valid fast corrections without such interruptions, the maximum broadcast interval for fast corrections has to be set at a value that is one third of the NPA and APV-I time-out interval for fast corrections and one-half of the APV-II and PA time-out interval for fast corrections as determined by ai_i.

Note.— Maximum fast corrections broadcast intervals for each ai_i can be found in RTCA/DO-229C, Table A-8.

6.5.3 *Time-to-alert.* Figure D-2 provides explanatory material for the allocation of the total time-to-alert defined in Chapter 3, Table 3.7.2.4-1. The time-to-alert requirements in Appendix B, 3.5.7.3.1, 3.5.7.4.1 and 3.5.7.5.1 (corresponding to the GNSS satellite status, basic differential correction and precise differential correction functions, respectively) include both the ground and space allocations shown in Figure D-2.

6.5.4 *Tropospheric function.* Because tropospheric refraction is a local phenomenon, users will compute their own tropospheric delay corrections. A tropospheric delay estimate for precision approach is described in RTCA/DO-229C, although other models can be used.

6.5.5 *Multipath considerations.* Multipath is one of the largest contributors to positioning errors for SBAS affecting both ground and airborne elements. For SBAS ground elements, emphasis should be placed on reducing or mitigating the effects of multipath as much as possible so that the signal-in-space uncertainties will be small. Many mitigation techniques have been studied from both theoretical and experimental perspectives. The best approach for implementing SBAS reference stations with minimal multipath errors is to:

a) ensure that an antenna with multipath reduction features is chosen;

b) consider the use of ground plane techniques;

c) ensure that the antenna is placed in a location with low multipath effects; and

d) use multipath-reducing receiver hardware and processing techniques.

6.5.6 *GLONASS issue of data.* Since the existing GLONASS design does not provide a uniquely defined identifier for sets of ephemeris and clock data, SBAS will use a specific mechanism to avoid any ambiguity in the application of the broadcast corrections. This mechanism is explained in Figure D-3. The definitions of the latency time and validity interval along with the associated coding requirements can be found in Appendix B, section 3.5.4. The user can apply the long-term corrections received only if the set of GLONASS ephemeris and clock data used on board have been received within the validity interval.

6.6 SBAS final approach segment (FAS) data block

6.6.1 The SBAS final approach segment (FAS) data block for a particular approach procedure is as shown in Table D-1. It is the same as the GBAS FAS data block defined in Appendix B, section 3.6.4.5, with the exception that the SBAS FAS data block also contains the HAL and VAL to be used for the approach procedure as described in 6.3.4.

6.6.2 FAS data blocks for SBAS and some GBAS approaches are held within a common on-board database supporting both SBAS and GBAS. Within this database, channel assignments must be unique for each approach and coordinated with civil authorities. States are responsible for providing the FAS data for incorporation into the database. The FAS block for a particular approach procedure is described in Appendix B, 3.6.4.5.1 and Table B-66.

Table D-1. SBAS FAS data block

Data content	Bits used	Range of values	Resolution
Operation type	4	0 to 15	1
SBAS provider ID	4	0 to 15	1
Airport ID	32	–	–
Runway number (Note 1)	6	0 to 36	1
Runway letter	2	–	–
Approach performance designator	3	0 to 7	1
Route indicator	5	–	–
Reference path data selector	8	0 to 48	1
Reference path identifier	32	–	–
LTP/FTP latitude	32	± 90.0°	0.0005 arcsec
LTP/FTP longitude	32	± 180.0°	0.0005 arcsec
LTP/FTP height	16	–512.0 to 6 041.5 m	0.1 m
ΔFPAP latitude	24	± 1.0°	0.0005 arcsec
ΔFPAP longitude	24	± 1.0°	0.0005 arcsec
Approach threshold crossing height (TCH) (Note 2)	15	0 to 1 638.35 m (0 to 3 276.7 ft)	0.05 m (0.1 ft)
Approach TCH units selector	1	–	–
Glide path angle (GPA)	16	0 to 90.0°	0.01°
Course width at threshold (Note 1)	8	80.0 to 143.75 m	0.25 m
ΔLength offset	8	0 to 2 032 m	8 m
Horizontal alert limit (HAL)	8	0 to 50.8 m	0.2 m
Vertical alert limit (VAL) (Note 3)	8	0 to 50.8 m	0.2 m
Final approach segment CRC	32	–	–

Note 1.— When the runway number is set to 00, then the course width field is ignored and the course width is 38 m.

Note 2.— Information can be provided in either feet or metres as indicated by the approach TCH unit sector.

Note 3.— VAL of 0 indicates that the vertical deviations are not to be used (i.e. a lateral guidance only approach).

7. Ground-based augmentation system (GBAS) and ground-based regional augmentation system (GRAS)

Note.— In this section, except where specifically annotated, reference to approach with vertical guidance (APV) means APV-I and APV-II.

7.1 System description

7.1.1 GBAS consists of ground and aircraft elements. A GBAS ground subsystem typically includes a single active VDB transmitter and broadcast antenna, referred to as a broadcast station, and multiple reference receivers. A GBAS ground subsystem may include multiple VDB transmitters and antennas that share a single common GBAS identification (GBAS ID) and frequency as well as broadcast identical data. The GBAS ground subsystem can support all the aircraft subsystems within its coverage providing the aircraft with approach data, corrections and integrity information for GNSS satellites in view. All international aircraft supporting APV should maintain approach data within a database on board the aircraft. The Type 4 message must be broadcast when the ground subsystem supports Category I precision approaches. The Type 4 message must also be broadcast when the ground subsystem supports APV approaches if the approach data is not required by the State to be maintained in the on-board database.

Note.— Allocation of performance requirements between the GBAS subsystems and allocation methodology can be found in RTCA/DO-245, Minimum Aviation System Performance Standards for the Global Positioning System/Local Area Augmentation System (GPS/LAAS). Minimum Operational Performance Standards for GRAS airborne equipment are under development by RTCA.

7.1.2 GBAS ground subsystems provide two services: the approach service and the GBAS positioning service. The approach service provides deviation guidance for FASs in Category I precision approach, APV, and NPA within the operational coverage area. The GBAS positioning service provides horizontal position information to support RNAV operations within the service area. The two services are also distinguished by different performance requirements associated with the particular operations supported (see Table 3.7.2.4-1) including different integrity requirements as discussed in 7.5.1.

7.1.3 A primary distinguishing feature for GBAS ground subsystem configurations is whether additional ephemeris error position bound parameters are broadcast. This feature is required for the positioning service, but is optional for approach services. If the additional ephemeris error position bound parameters are not broadcast, the ground subsystem is responsible for assuring the integrity of ranging source ephemeris data without reliance on the aircraft calculating and applying the ephemeris bound as discussed in 7.5.9.

7.1.4 *GBAS.* There are multiple configurations possible of GBAS ground subsystems conforming to the GNSS Standards, such as:

a) configuration that supports Category I precision approach only;

b) a configuration that supports Category I precision approach and APV, and also broadcasts the additional ephemeris error position bound parameters;

c) a configuration that supports Category I precision approach, APV, and the GBAS positioning service, while also broadcasting the ephemeris error position bound parameters referred to in b); and

d) a configuration that supports APV and the GBAS positioning service, and is used within a GRAS.

7.1.5 From a user perspective, a GRAS ground subsystem consists of one or more GBAS ground subsystems (as described in 7.1.1 through 7.1.4), each with a unique GBAS identification, providing the positioning service and APV where required. By using multiple GBAS broadcast stations, and by broadcasting the Type 101 message, GRAS is able to support en-route operations via the GBAS positioning service, while also supporting terminal, departure, and APV operations over a larger coverage region than that typically supported by GBAS. In some GRAS applications, the corrections broadcast in the Type 101 message may be computed using data obtained from a network of reference receivers distributed in the coverage region. This permits detection and mitigation of measurement errors and receiver faults.

7.1.6 All broadcast stations of a GBAS ground subsystem broadcast identical data with the same GBAS identification on a common frequency. The airborne receiver need not and cannot distinguish between messages received from different broadcast stations of the same GBAS ground subsystem. When within coverage of two such broadcast stations, the receiver will receive and process duplicate copies of messages in different time division multiple access (TDMA) time slots.

7.1.7 Interoperability of the GBAS ground and aircraft elements compatible with RTCA/DO-253A is addressed in Appendix B, 3.6.8.1. GBAS receivers compliant with RTCA/DO-253A will not be compatible with GRAS ground subsystems broadcasting Type 101 messages. However, GRAS and GBAS receivers compliant with RTCA GRAS MOPS, will be compatible with GBAS ground subsystems. SARPs-compliant GBAS receivers may not be able to decode the FAS data correctly for APV transmitted from GBAS ground subsystems. These receivers will apply the FASLAL and FASVAL as if conducting a Category I precision approach. Relevant operational restrictions have to apply to ensure the safety of the operation.

7.1.8 The GBAS VDB transmits with either horizontal or elliptical polarization (GBAS/H or GBAS/E). This allows service providers to tailor the broadcast to their operational requirements and user community.

7.1.9 The majority of aircraft will be equipped with a horizontally-polarized VDB receiving antenna, which can be used to receive the VDB from both GBAS/H and GBAS/E equipment. A subset of aircraft will be equipped with a vertically-polarized antenna due to installation limitations or economic considerations. These aircraft are not compatible with GBAS/H equipment and are, therefore, limited to GBAS-based operations supported by GBAS/E.

7.1.10 GBAS service providers must publish the signal polarization (GBAS/H or GBAS/E), for each GBAS facility in the aeronautical information publication (AIP). Aircraft operators that use vertically polarized receiving antenna will have to take this information into account when managing flight operations, including flight planning and contingency procedures.

7.2 RF characteristics

7.2.1 *Frequency and time slot planning*

7.2.1.1 *Performance factors*

7.2.1.1.1 The geographical separation between a candidate GBAS station and existing VOR or GBAS installations must consider the following factors:

a) the coverage volume, minimum field strength and effective radiated power (ERP) of the candidate GBAS including the GBAS positioning service, if provided. The minimum requirements for coverage and field strength are found in Chapter 3, 3.7.3.5.3 and 3.7.3.5.4.4, respectively. The ERP is determined from these requirements;

b) the coverage volume, minimum field strength and ERP of the surrounding VOR and GBAS stations including the GBAS positioning service, if provided. Specifications for coverage and field strength for VOR are found in Chapter 3, 3.3, and respective guidance material is provided in Attachment C;

c) the performance of VDB receivers, including co-channel and adjacent channel rejection, and immunity to desensitization and intermodulation products from FM broadcast signals. These requirements are found in Appendix B, 3.6.8.2.2;

d) the performance of VOR receivers, including co-channel and adjacent channel rejection of VDB signals. Since existing VOR receivers were not specifically designed to reject VDB transmissions, desired-to-undesired (D/U) signal ratios for co-channel and adjacent channel rejection of the VDB were determined empirically. Table D-2 summarizes the assumed signal ratios based upon empirical performance of numerous VOR receivers designed for 50 kHz channel spacing;

e) for areas/regions of frequency congestion, a precise determination of separation may be required using the appropriate criteria.

7.2.1.1.2 The nominal link budget for VDB is shown in Table D-3. The figures in the table assume a receiver height of 3 000 m (10 000 ft) MSL and a transmit antenna designed to suppress ground illumination in order to limit the fading losses to a maximum of 10 dB at coverage edge. In the case of GBAS/E equipment, the 10 dB also includes any effects of signal loss due to interference between the horizontal and vertical components.

7.2.1.2 *FM immunity*

7.2.1.2.1 Once a candidate frequency is identified for which the GBAS and VOR separation criteria are satisfied, compatibility with FM transmissions must be determined. This is to be accomplished using the methodology applied when determining FM compatibility with VOR. If FM broadcast violates this criterion, an alternative candidate frequency has to be considered.

Table D-2. Assumed $[D/U]_{required}$ signal ratios to protect VOR from GBAS VDB

Frequency offset	$[D/U]_{required}$ ratio to protect VOR receivers (dB)
Co-channel	26
$\lvert f_{VOR} - f_{VDB} \rvert = 25$ kHz	0
$\lvert f_{VOR} - f_{VDB} \rvert = 50$ kHz	–34
$\lvert f_{VOR} - f_{VDB} \rvert = 75$ kHz	–46
$\lvert f_{VOR} - f_{VDB} \rvert = 100$ kHz	–65

Table D-3. Nominal VDB link budget

VDB link elements	Vertical component link budget at coverage edge	Horizontal component link budget at coverage edge
Required receiver sensitivity (dBm)	–87	–87
Maximum aircraft implementation loss (dB)	11	15
Power level after aircraft antenna (dBm)	–76	–72
Operating margin (dB)	3	3
Fade margin (dB)	10	10
Free space path loss (dB) at 43 km (23 NM)	106	106
Nominal effective radiated power (dBm)	43	47

7.2.1.2.2 The desensitization is not applied for FM carriers above 107.7 MHz and VDB channels at 108.050 MHz because the off-channel component of such high-level emissions from FM stations above 107.7 MHz will interfere with GBAS VDB operations on 108.025 and 108.050 MHz, hence those assignments will be precluded except for special assignments in geographic areas where the number of FM broadcast stations in operation is small and would unlikely generate interference in the VDB receiver.

7.2.1.2.3 The FM intermodulation immunity requirements are not applied to a VDB channel operating below 108.1 MHz, hence assignments below 108.1 MHz will be precluded except for special assignments in geographic areas where the number of FM broadcast stations in operation is small and would unlikely generate intermodulation products in the VDB receiver.

7.2.1.3 *Geographic separation methodologies*

7.2.1.3.1 The methodologies below may be used to determine the required GBAS-to-GBAS and GBAS-to-VOR geographical separation. They rely on preserving the minimum desired-to-undesired signal ratio. $[D/U]_{required}$ is defined as the signal ratio intended to protect the desired signal from co-channel or adjacent channel interference from an undesired transmission. $[D/U]_{required}$ values required for protection of a GBAS receiver from undesired GBAS or VOR signals are defined in Appendix B, 3.6.8.2.2.5 and 3.6.8.2.2.6. $[D/U]_{required}$ values intended for protection of a VOR receiver from GBAS VDB transmissions as shown in Table D-2 are not defined in SARPs and represent the assumed values based on test results.

7.2.1.3.2 Geographic separation is constrained by preserving $[D/U]_{required}$ at the edge of the desired signal coverage where the desired signal power is derived from the minimum field strength requirements in Chapter 3. This desired signal level, converted to dBm, is denoted $P_{D,min}$. The allowed signal power of the undesired signal ($P_{U,allowed}$) is:

$$P_{Uallowed}(dBm) = (P_{D,min}\ (dBm) - [D/U]_{required}\ (dB))$$

The undesired signal power P_U converted to dBm is:

$$P_U(dBm) = (Tx_U\ (dBm) - L\ (dB))$$

where

Tx_U is the effective radiated power of the undesired transmitter; and

L is the transmission loss of the undesired transmitter, including free-space path loss, atmospheric and ground effects. This loss depends upon the distance between the undesired transmitter and the edge of the desired signal coverage.

To ensure $D/U_{required}$ is satisfied, $P_u \leq D_{Uallowed}$. The constraint for assigning a channel is therefore:

$$L(dB) \geq ([D/U]_{required}\ (dB) + Tx_U(dBm) - P_{D,min}\ (dBm))$$

7.2.1.3.3 The transmission loss can be obtained from standard propagation models published in ITU-R Recommendation P.528-2 or from free-space attenuation until the radio horizon and then a constant 0.5 dB/NM attenuation factor. These two methodologies result in slightly different geographical separation for co-channel and first adjacent channels, and identical separation as soon as the second adjacent channel is considered. The free-space propagation approximation is applied in this guidance material.

7.2.1.4 *Example of GBAS/GBAS geographical separation criteria*

7.2.1.4.1 For GBAS VDB co-channel transmissions assigned to the same time slot, the parameters for horizontal polarization are:

D/U = 26 dB (Appendix B, 3.6.8.2.2.5.1);

$P_{D,min}$ = –72 dBm (equivalent to 215 microvolts per metre, Chapter 3, 3.7.3.5.4.4); and

Tx_U = 47 dBm (example link budget, Table D-3);

so

$$L \geq (47 + 26 - (-72)) = 145 \text{ dB}.$$

7.2.1.4.2 The geographic separation for co-channel, co-slot GBAS VDB assignments is obtained by determining the distance at which the transmission loss equals 145 dB for receiver altitude of 3 000 m (10 000 ft) above that of the GBAS VDB transmitter antenna. This distance is 318 km (172 NM) using the free-space attenuation approximation and assuming a negligible transmitter antenna height. The minimum required geographical separation can then be determined by adding this distance to the nominal distance between the edge of coverage and the GBAS transmitter 43 km (23 NM). This results in a co-channel, co-slot reuse distance of 361 km (195 NM).

7.2.1.5 *Guidelines on GBAS/GBAS geographical separation criteria.* Using the methodology described above, typical geographic separation criteria can be defined for GBAS to GBAS and GBAS to VOR. The resulting GBAS/GBAS minimum required geographical separation criteria are summarized in Table D-4.

Note.— Geographical separation criteria between the GBAS transmitters providing the GBAS positioning service are under development. A conservative value corresponding to the radiohorizon may be used as an interim value for separation between co-frequency, adjacent time slot transmitters to ensure time slots do not overlap.

7.2.1.6 *Guidelines on GBAS/VOR geographical separation criteria.* The GBAS/VOR minimum geographical separation criteria are summarized in Table D-5 based upon the same methodology and the nominal VOR coverage volumes in Attachment C.

Note 1.— When determining the geographical separation between VOR and GBAS, VOR as the desired signal is generally the constraining case due to the greater protected altitude of the VOR coverage region.

Note 2.— Reduced geographical separation requirements can be obtained using standard propagation models defined in ITU-R Recommendation P.528-2.

Table D-4. Typical GBAS/GBAS frequency assignment criteria

Channel of undesired VDB in the same time slots	Path loss (dB)	Minimum required geographical separation for Tx_U = 47 dBm and $P_{D,min}$ = –72 dBm in km (NM)
Cochannel	145	361 (195)
1st adjacent channel (±25 kHz)	101	67 (36)
2nd adjacent channel (±50 kHz)	76	44 (24)
3rd adjacent channel (±75 kHz)	73	No restriction
4th adjacent channel (±100 kHz)	73	No restriction

Note.— No geographic transmitter restrictions are expected between co-frequency, adjacent time slots provided the undesired VDB transmitting antenna is located at least 200 m from areas where the desired signal is at minimum field strength.

Table D-5. Minimum required geographical separation for a VOR coverage (12 000 m (40 000 ft) level)

Channel of undesired GBAS VDB	Path loss (dB)	VOR coverage radius		
		342 km (185 NM)	300 km (162 NM)	167 km (90 NM)
Co-channel	152	892 km (481 NM)	850 km (458 NM)	717 km (386 NM)
$\lvert f_{Desired} - f_{Undesired} \rvert$ = 25 kHz	126	774 km (418 NM)	732 km (395 NM)	599 km (323 NM)
$\lvert f_{Desired} - f_{Undesired} \rvert$ = 50 kHz	92	351 km (189 NM)	309 km (166 NM)	176 km (94 NM)
$\lvert f_{Desired} - f_{Undesired} \rvert$ = 75 kHz	80	344 km (186 NM)	302 km (163 NM)	169 km (91 NM)
$\lvert f_{Desired} - f_{Undesired} \rvert$ = 100 kHz	61	No restriction	No restriction	No restriction

Note.— Calculations are based on reference frequency of 112 MHz and assume GBAS Tx_U *= 47 dBm and VOR* $P_{D,min}$ *= –79 dBm.*

7.2.2 The geographical separation criteria for GBAS/ILS and GBAS/VHF communications are under development.

7.2.3 *Compatibility with ILS.* Until compatibility criteria are developed for GBAS VDB and ILS, VDB cannot be assigned to channels below 112.025 MHz. If there is an ILS with a high assigned frequency at the same airport as a VDB with a frequency near 112 MHz, it is necessary to consider ILS and VDB compatibility. Considerations for assignment of VDB channels include the frequency separation between the ILS and the VDB, the distance separation between the ILS coverage area and the VDB, the VDB and ILS field strengths, and the VDB and ILS sensitivity. For GBAS equipment with transmitter power of up to 150 W (GBAS/E, 100 W for horizontal component and 50 W for vertical component) or 100 W (GBAS/H), the 16th channel (and beyond) will be below –106 dBm at a distance of 200 m from the VDB transmitter, including allowing for a +5 dB positive reflection. This –106 dBm figure assumes a –86 dBm localizer signal at the ILS receiver input and a minimum 20 dB signal-to-noise ratio.

7.2.4 *Compatibility with VHF communications.* For GBAS VDB assignments above 116.400 MHz, it is necessary to consider VHF communications and GBAS VDB compatibility. Considerations for assignment of these VDB channels include the frequency separation between the VHF communication and the VDB, the distance separation between the transmitters and coverage areas, the field strengths, the polarization of the VDB signal, and the VDB and VHF sensitivity. Both aircraft and ground VHF communication equipment are to be considered. For GBAS/E equipment with a transmitter maximum power of up to 150 W (100 W for horizontal component and 50 W for vertical component), the 64th channel (and beyond) will be below –120 dBm at a distance of 200 m from the VDB transmitter including allowing for a +5 dB positive reflection. For GBAS/H equipment with a transmitter maximum power of 100 W, the 32nd channel (and beyond) will be below –120 dBm at a distance of 200 m from the VDB transmitter including allowing for a +5 dB positive reflection, and a 10 dB polarization isolation. It must be noted that due to differences in the VDB and VDL transmitter masks, separate analysis must be performed to ensure VDL does not interfere with the VDB.

7.2.5 For a GBAS ground subsystem that only transmits a horizontally-polarized signal, the requirement to achieve the power associated with the minimum sensitivity is directly satisfied through the field strength requirement. For a GBAS ground subsystem that transmits an elliptically-polarized component, the ideal phase offset between HPOL and VPOL components is 90 degrees. In order to ensure that an appropriate received power is maintained throughout the GBAS coverage volume during normal aircraft manoeuvres, transmitting equipment should be designed to radiate HPOL and VPOL signal components with an RF phase offset of 90 degrees. This phase offset should be consistent over time and environmental conditions. Deviations from the nominal 90 degrees must be accounted for in the system design and link budget, so that any fading due to polarization loss does not jeopardize the minimum receiver sensitivity. System qualification and flight inspection procedures will take into account an allowable variation in phase offset consistent with maintaining the appropriate signal level throughout the GBAS coverage volume. One method of ensuring both horizontal and vertical field strength is to use a single VDB antenna that transmits an elliptically-polarized signal, and flight inspect the effective field strength of the vertical and horizontal signals in the coverage volume.

7.3 Coverage

7.3.1 The GBAS coverage to support approach services is depicted in Figure D-4. When the additional ephemeris error position bound parameters are broadcast, differential corrections may only be used within the Maximum Use Distance (D_{max}) defined in the Type 2 message. Where practical, it is operationally advantageous to provide valid guidance along the visual segment of an approach.

7.3.2 The coverage required to support the GBAS positioning service is dependent upon the specific operations intended. The optimal coverage for this service is intended to be omnidirectional in order to support operations using the GBAS positioning service that are performed outside of the precision approach coverage volume. Each State is responsible for defining a service area for the GBAS positioning service and ensuring that the requirements of Chapter 3, 3.7.2.4 are satisfied. When making this determination, the characteristics of the fault-free GNSS receiver should be considered, including the reversion to ABAS-based integrity in the event of loss of GBAS positioning service.

7.3.3 The limit on the use of the GBAS positioning service information is given by the Maximum Use Distance (D_{max}), which defines the range within which the required integrity is assured and differential corrections can be used for either the positioning service or precision approach. D_{max} however does not delineate the coverage area where field strength requirements specified in Chapter 3, 3.7.3.5.4.4 are met nor matches this area. Accordingly, operations based on the GBAS positioning service can be predicated only in the coverage area(s) (where the field strength requirements are satisfied) within the D_{max} range.

7.3.4 As the desired coverage area of a GBAS positioning service may be greater than that which can be provided by a single GBAS broadcast station, a network of GBAS broadcast stations can be used to provide the coverage. These stations can broadcast on a single frequency and use different time slots (8 available) in neighbouring stations to avoid interference or they can broadcast on different frequencies. Figure D-4A details how the use of different time slots will allow a single frequency to be used without interference subject to guard time considerations noted under Table B-59. For a network based on different VHF frequencies, guidance material in 7.17 should be considered.

7.4 Data structure

A bit scrambler/descrambler is shown in Figure D-5.

Note.— Additional information on the data structure of the VHF data broadcast is given in RTCA/DO-246B, GNSS Based Precision Approach Local Area Augmentation System (LAAS)—Signal-in-Space Interface Control Document (ICD).

7.5 Integrity

7.5.1 Different levels of integrity are specified for precision approach operations and operations based on the GBAS positioning service. The signal-in-space integrity risk for Category I is 2×10^{-7} per approach. GBAS ground subsystems that are also intended to support other operations through the use of the GBAS positioning service have to also meet the signal-in-space integrity risk requirement specified for terminal area operations, which is 1×10^{-7}/hour (Chapter 3, Table 3.7.2.4-1). Therefore additional measures are necessary to support these more stringent requirements for positioning service. The signal-in-space integrity risk is allocated between the ground subsystem integrity risk and the protection level integrity risk. The ground subsystem integrity risk allocation covers failures in the ground subsystem as well as core constellation and SBAS failures such as signal quality failures and ephemeris failures. The protection level integrity risk allocation covers rare fault-free performance risks and the case of failures in one of the reference receiver measurements. In both cases the protection level equations ensure that the effects of the satellite geometry used by the aircraft receiver are taken into account. This is described in more detail in the following paragraphs.

7.5.2 The GBAS ground subsystem defines a corrected pseudo-range error uncertainty for the error relative to the GBAS reference point (σ_{pr_gnd}) and the errors resulting from vertical (σ_{tropo}) and horizontal (σ_{iono}) spatial decorrelation. These uncertainties are modelled by the variances of zero-mean, normal distributions which describe these errors for each ranging source.

7.5.3 The individual error uncertainties described above are used by the receiver to compute an error model of the navigation solution. This is done by projecting the pseudo-range error models to the position domain. General methods for determining that the model variance is adequate to guarantee the protection level integrity risk are described in Section 14. The lateral protection level (LPL) provides a bound on the lateral position error with a probability derived from the integrity requirement. Similarly, the vertical protection level (VPL) provides a bound on the vertical position. For Category I precision approach and APV, if the computed LPL exceeds the lateral alert limit (LAL) or the VPL exceeds the vertical alert limit (VAL), integrity is not adequate to support the operation. For the positioning service the alert limits are not defined in the standards, with only the horizontal protection level and ephemeris error position bounds required to be computed and applied. The alert limits will be determined based on the operation being conducted. The aircraft will apply the computed protection level and ephemeris bounds by verifying they are smaller than the alert limits. Two protection levels are defined, one to address the condition when all reference receivers are fault-free (H_0 – Normal Measurement Conditions), and one to address the condition when one of the reference receivers contains failed measurements (H_1 – Faulted Measurement Conditions). Additionally an ephemeris error position bound provides a bound on the position error due to failures in ranging source ephemeris. For Category I precision approach and APV, a lateral error bound (LEB) and a vertical error bound (VEB) are defined. For the positioning service a horizontal ephemeris error bound (HEB) is defined.

7.5.4 *Ground system contribution to corrected pseudo-range error (σ_{pr_gnd}).* Error sources that contribute to this error include receiver noise, multipath, and errors in the calibration of the antenna phase centre. Receiver noise has a zero-mean, normally distributed error, while the multipath and antenna phase centre calibration can result in a small mean error.

7.5.5 *Residual tropospheric errors.* Tropospheric parameters are broadcast in Type 2 messages to model the effects of the troposphere, when the aircraft is at a different height than the GBAS reference point. This error can be well-characterized by a zero-mean, normal distribution.

7.5.6 *Residual ionospheric errors.* An ionospheric parameter is broadcast in Type 2 messages to model the effects of the ionosphere between the GBAS reference point and the aircraft. This error can be well-characterized by a zero-mean, normal distribution.

7.5.7 *Aircraft receiver contribution to corrected pseudo-range error.* The receiver contribution is bounded as described in Section 14. The maximum contribution, used for analysis by the GBAS provider, can be taken from the accuracy requirement, where it is assumed that $\sigma_{receiver}$ equals RMS_{pr_air} for GBAS Airborne Accuracy Designator A equipment.

7.5.8 *Airframe multipath error.* The error contribution from airframe multipath is defined in Appendix B, 3.6.5.5.1. Multipath errors resulting from reflections from other objects are not included. If experience indicates that these errors are not negligible, they must be accounted for operationally or through inflation of the parameters broadcast by the ground (e.g. σ_{pr_gnd}).

7.5.9 *Ephemeris error uncertainty.* Pseudo-range errors resulting from ephemeris errors (defined as a discrepancy between the true satellite position and the satellite position determined from the broadcast data) are spatially decorrelated and will therefore be different for receivers in different locations. When users are relatively close to the GBAS reference point, the residual differential error due to ephemeris errors will be small and both the corrections and uncertainty parameters σ_{pr_gnd} sent by the ground subsystem will be valid to correct the raw measurements and compute the protection levels. For users further away from the GBAS reference point, protection against ephemeris failures can be ensured in two different ways:

a) the ground subsystem does not transmit the additional ephemeris error position bound parameters. In this case, the ground subsystem is responsible for assuring integrity in case of satellite ephemeris failures without reliance on the aircraft calculating and applying the ephemeris bound. This may impose a restriction on the distance between the GBAS reference point and the decision altitude/height depending upon the ground subsystem means of detecting ranging source ephemeris failures. One means of detection is to use satellite integrity information broadcast by SBAS; and

b) the ground subsystem transmits the additional ephemeris error position bound parameters which enable the airborne receiver to compute an ephemeris error bound. These parameters are: coefficients used in the ephemeris error position bound equations ($K_{md\_e\_()}$, where the subscript () means either "GPS", "GLONASS", "POS, GPS" or "POS, GLONASS"), the maximum use distance for the differential corrections (D_{max}), and the ephemeris decorrelation parameters (P). The ephemeris decorrelation parameter (P) in the Type 1 or Type 101 message characterizes the residual error as a function of distance between the GBAS reference point and the aircraft. The value of P is expressed in m/m. The values of P are determined by the ground subsystem for each satellite. One of the main factors influencing the values of P is the ground subsystem monitor design. The quality of the ground monitor will be characterized by the smallest ephemeris error (or minimum detectable error (MDE)) that it can detect. The relationship between the P parameter and the MDE for a particular satellite can be approximated by $P_i = MDE_i/R_i$ where R_i is the smallest of the predicted ranges from the ground subsystem reference receiver antenna(s) for the period of validity of P_i. Being dependent on satellite geometry, the P parameters values are slowly varying. However, it is not a requirement for the ground subsystem to dynamically vary P. Static P parameters could be sent if they properly ensure integrity. In this latter case, the availability would be slightly degraded. Generally, as MDE becomes smaller, overall GBAS availability improves.

7.5.10 *Ephemeris error/failure monitoring.* There are several types of monitoring approaches for detecting ephemeris errors/failures. They include:

a) *Long baseline.* This requires the ground subsystem to use receivers separated by large distances to detect ephemeris errors that are not observable by a single receiver. Longer baselines translate to better performance in MDE;

b) *SBAS.* Since SBAS augmentation provides monitoring of satellite performance, including ephemeris data, integrity information broadcast by SBAS can be used as an indication of ephemeris validity. SBAS uses ground subsystem receivers installed over very long baselines, therefore this provides optimum performance for ephemeris monitoring and thus achieves small MDEs; and

c) *Ephemeris data monitoring.* This approach involves comparing the broadcast ephemeris over consecutive satellite orbits. There is an assumption that the only threat of failure is due to a failure in ephemeris upload from the constellation ground control network. Failures due to uncommanded satellite manoeuvres must be sufficiently improbable to ensure that this approach provides the required integrity.

7.5.10.1 The monitor design (for example, its achieved MDE) is to be based upon the integrity risk requirements and the failure model the monitor is intended to protect against. A bound on the GPS ephemeris failure rate can be determined from the reliability requirements defined in Chapter 3, 3.7.3.1.3, since such an ephemeris error would constitute a major service failure.

7.5.10.2 The GLONASS control segment monitors the ephemeris and time parameters, and in case of any abnormal situation it starts to input the new and correct navigation message. The ephemeris and time parameter failures do not exceed 70 m of range errors. The failure rate of GLONASS satellite including the ephemeris and time parameter failures does not exceed 4×10^{-5} per satellite per hour.

7.5.11 A typical GBAS ground subsystem processes measurements from 2 to 4 reference receivers installed in the immediate vicinity of the reference point. The aircraft receiver is protected against a large error or fault condition in a single reference receiver by computing and applying the B parameters from the Type 1 or Type 101 message to compare data from the various reference receivers. Alternative system architectures with sufficiently high redundancy in reference receiver measurements may employ processing algorithms capable of identifying a large error or fault in one of the receivers. This may apply for a GRAS network with receivers distributed over a wide area and with sufficient density of ionospheric pierce points to separate receiver errors from ionospheric effects. The integrity can then be achieved using only the protection levels for normal measurement conditions (VPL_{H0} and LPL_{H0}), with appropriate values for K_{ffmd} and σ_{pr_gnd}. This can be achieved using the Type 101 message with the B parameters excluded.

7.6 Continuity of service

7.6.1 *Ground continuity and integrity designator.* The ground continuity and integrity designator (GCID) provides a classification of GBAS ground subsystems. The ground subsystem meets the requirements of Category I precision approach or APV when GCID is set to 1. GCID 2, 3 and 4 are intended to support future operations with requirements that are more stringent than Category I operations. The GCID is intended to be an indication of ground subsystem status to be used when an aircraft selects an approach. It is not intended to replace or supplement an instantaneous integrity indication communicated in a Type 1 or Type 101 message. GCID does not provide any indication of the ground subsystem capability to support the GBAS positioning service.

7.6.2 *Ground subsystem continuity of service.* GBAS ground subsystems are required to meet the continuity specified in Appendix B to Chapter 3, 3.6.7.1.3 in order to support Category I precision approach and APV. GBAS ground subsystems that are also intended to support other operations through the use of the GBAS positioning service should support the minimum continuity required for terminal area operations, which is $1-10^{-4}$/hour (Chapter 3, Table 3.7.2.4-1). When the Category I precision approach or APV required continuity ($1-3.3 \times 10^{-6}$/15 seconds) is converted to a per hour value it does not meet the $1-10^{-4}$/hour minimum continuity requirement. Therefore, additional measures are necessary to meet the continuity required for other operations. One method of showing compliance with this requirement is to assume that airborne implementation uses both GBAS and ABAS to provide redundancy and that ABAS provides sufficient accuracy for the intended operation.

7.7 GBAS channel selection

7.7.1 Channel numbers are used in GBAS to facilitate an interface between aircraft equipment and the signal-in-space that is consistent with interfaces for ILS and MLS. The cockpit integration and crew interface for GBAS may be based on entry of the 5-digit channel number. An interface based on approach selection through a flight management function similar to current practice with ILS is also possible. The GBAS channel number may be stored in an on-board navigation database as part of a named approach. The approach may be selected by name and the channel number can automatically be provided to the equipment that must select the appropriate GBAS approach data from the broadcast data. Similarly, the use of the GBAS positioning service may be based on the selection of a 5-digit channel number. This facilitates conducting operations other than the approaches defined by the FAS data. To facilitate frequency tuning, the GBAS channel numbers for neighbouring GBAS ground subsystems supporting positioning service may be provided in the Type 2 message additional data block 2.

7.7.2 A channel number in the range from 20 001 to 39 999 is assigned when the FAS data are broadcast in the Type 4 message. A channel number in the range from 40 000 to 99 999 is assigned when the FAS data associated with an APV are obtained from the on-board database.

7.8 Reference path data selector and reference station data selector

A mapping scheme provides a unique assignment of a channel number to each GBAS approach. The channel number consists of five numeric characters in the range 20 001 to 39 999. The channel number enables the GBAS airborne subsystem to tune to the correct frequency and select the final approach segment (FAS) data block that defines the desired approach. The correct FAS data block is selected by the reference path data selector (RPDS), which is included as part of the FAS definition data in a Type 4 message. Table D-6 shows examples of the relationship between the channel number, frequency and RPDS. The same mapping scheme applies to selection of the positioning service through the reference station data selector (RSDS). The RSDS is broadcast in the Type 2 message and allows the selection of a unique GBAS ground subsystem that provides the positioning service. For GBAS ground subsystems that do not provide the positioning service and broadcast the additional ephemeris data, the RSDS is coded with a value of 255. All RPDS and RSDS broadcast by a ground subsystem must be unique on the broadcast frequency within radio range of the signal. The RSDS value must not be the same as any of the broadcast RPDS values.

Table D-6. Channel assignment examples

Channel number (N)	Frequency in MHz (F)	Reference path data selector (RPDS) or Reference station data selector (RSDS)
20 001	108.025	0
20 002	108.05	0
20 003	108.075	0
....	....	....
20 397	117.925	0
20 398	117.95	0
20 412 (Note)	108.025	1
20 413	108.05	1
....	....	....

Note.— Channels between 20 398 and 20 412 are not assignable because the channel algorithm maps them to frequencies outside the range of 108.025 MHz and 117.950 MHz. A similar "gap" in the channel assignments occurs at each RPDS transition.

7.9 Assignment of RPDS and RSDS by service provider

RPDS and RSDS assignments are to be controlled to avoid duplicate use of channel numbers within the protection region for the data broadcast frequency. Therefore, the GBAS service provider has to ensure that an RPDS and RSDS are assigned only once on a given frequency within radio range of a particular GBAS ground subsystem. Assignments of RPDS and RSDS are to be managed along with assignments of frequency and time slots for the VHF data broadcast.

7.10 GBAS identification

The GBAS identification (ID) is used to uniquely identify a GBAS ground subsystem broadcasting on a given frequency within the coverage region of the GBAS. The aircraft will navigate using data broadcast from one or more GBAS broadcast stations of a single GBAS ground subsystem (as identified by a common GBAS identification).

7.11 Final approach segment (FAS) path

7.11.1 FAS path is a line in space defined by the landing threshold point/fictitious threshold point (LTP/FTP), flight path alignment point (FPAP), threshold crossing height (TCH) and glide path angle (GPA). These parameters are determined from data provided in a FAS data block within a Type 4 message or in the on-board database. The relationship between these parameters and the FAS path is illustrated in Figure D-6.

7.11.1.1 FAS data blocks for SBAS and some GBAS approaches are held within a common onboard database supporting both SBAS and GBAS. States are responsible for providing the FAS data to support APV procedures when the Type 4 message is not broadcast. These data comprise the parameters contained within the FAS block, the RSDS, and associated broadcast frequency. The FAS block for a particular approach procedure is described in Appendix B, 3.6.4.5.1 and Table B-66.

7.11.2 *FAS path definition*

7.11.2.1 *Lateral orientation.* The LTP/FTP is typically at or near the runway threshold. However, to satisfy operational needs or physical constraints, the LTP/FTP may not be at the threshold. The FPAP is used in conjunction with the LTP/FTP to define the lateral reference plane for the approach. For a straight-in approach aligned with the runway, the FPAP will be at or beyond the stop end of the runway. The FPAP is not placed before the stop end of the runway.

7.11.2.2 *ΔLength offset.* The Δlength offset defines the distance from the end of the runway to the FPAP. This parameter is provided to enable the aircraft equipment to compute the distance to the end of the runway. If the Δlength offset is not set to appropriately indicate the end of the runway relative to the FPAP, the service provider should ensure the parameter is coded as "not provided".

7.11.2.3 *Vertical orientation.* Local vertical for the approach is defined as normal to the WGS-84 ellipsoid at the LTP/FTP and may differ significantly from the local gravity vector. The local level plane for the approach is defined as a plane perpendicular to the local vertical passing through the LTP/FTP (i.e. tangent to the ellipsoid at the LTP/FTP). The datum crossing point (DCP) is a point at a height defined by TCH above the LTP/FTP. The FAS path is defined as a line with an angle (defined by the GPA) relative to the local level plane passing through the DCP. The GPIP is the point where the final approach path intercepts the local level plane. The GPIP may actually be above or below the runway surface depending on the curvature of the runway.

7.11.3 *"ILS look-alike" deviation computations.* For compatibility with existing aircraft designs, it is desirable for aircraft equipment to output guidance information in the form of deviations relative to a desired flight path defined by the FAS path. The Type 4 message includes parameters that support the computation of deviations that are consistent with ILS requirements.

7.11.3.1 *Lateral deviation definition.* Figure D-6 illustrates the relationship between the FPAP and the origin of the lateral angular deviations. The course width parameter and FPAP are used to define the origin and sensitivity of the lateral deviations. By adjusting the location of the FPAP and the value of the course width, the course width and sensitivity of a GBAS can be set to the desired values. They may be set to match the course width and sensitivity of an existing ILS. This may be necessary, for example, for compatibility with existing visual landing aids.

7.11.3.1.1 *Lateral deviation reference.* The lateral deviation reference plane is the plane that includes the LTP/FTP, FPAP and a vector normal to the WGS-84 ellipsoid at the LTP/FTP. The rectilinear lateral deviation is the distance of the computed aircraft position from the lateral deviation reference plane. The angular lateral deviation is a corresponding angular displacement referenced to the GBAS azimuth reference point (GARP). The GARP is defined to be beyond the FPAP along the procedure centre line by a fixed offset value of 305 m (1 000 ft).

7.11.3.1.2 *Lateral displacement sensitivity.* The lateral displacement sensitivity is determined by the aircraft equipment from the course width provided in the FAS data block. The service provider is responsible for setting the course width parameter to a value that results in the appropriate angle for full scale deflection (i.e. 0.155 DDM or 150 μA) taking into account any operational constraints.

7.11.3.2 *Vertical deviations.* Vertical deviations are computed by the aircraft equipment with respect to a GBAS elevation reference point (GERP). The GERP may be at the GPIP or laterally offset from the GPIP by a fixed GERP offset value of 150 m. Use of the offset GERP allows the glide path deviations to produce the same hyperbolic effects that are normal characteristics of ILS and MLS (below 200 ft). The decision to offset the GERP or not is made by the aircraft equipment in accordance with requirements driven by compatibility with existing aircraft systems. Service providers should be aware that users may compute vertical deviations using a GERP which is placed at either location. Sensitivity of vertical deviations is set automatically in the aircraft equipment as a function of the GPA. The relationship between GPA and the vertical deviation sensitivity is equivalent to the glide path displacement sensitivity provided by ILS.

7.11.4 *Approaches not aligned with the runway.* Some operations may require the definition of a FAS path that is not aligned with the runway centre line as illustrated in Figure D-7. For approaches not aligned with the runway, the LTP/FTP may or may not lie on the extended runway centre line. For this type of approach Δlength offset is not meaningful and should be set to "not provided".

7.11.5 *SBAS service provider.* A common format is used for FAS data blocks to be used by both GBAS and SBAS. The SBAS service provider ID field identifies which SBAS system(s) may be used by an aircraft that is using the FAS data during an approach. The GBAS service provider may inhibit use of the FAS data in conjunction with any SBAS service. For precision approaches based on GBAS this field is not used, and it can be ignored by aircraft GBAS equipment.

7.11.6 *Approach identifier.* The service provider is responsible for assigning the approach identifier for each approach. The approach identification should be unique within a large geographical area. Approach identifications for multiple runways at a given airport should be chosen to reduce the potential for confusion and misidentification. The approach identification should appear on the published charts that describe the approach.

7.12 Airport siting considerations

7.12.1 The installation of a GBAS ground subsystem involves special considerations in choosing prospective sites for the reference receiver antennas and the VDB antenna(s). In planning antenna siting, Annex 14 obstacle limitation requirements must be met.

7.12.2 *Locating reference receiver antennas.* The site should be selected in an area free of obstructions, so as to permit the reception of satellite signals at elevation angles as low as possible. In general, anything masking GNSS satellites at elevation angles higher than 5 degrees will degrade system availability.

7.12.2.1 The antennas for the reference receivers should be designed and sited to limit multipath signals that interfere with the desired signal. Mounting antennas close to a ground plane reduces long-delay multipath resulting from reflections below the antenna. Mounting height should be sufficient to prevent the antenna being covered by snow, or being interfered with by maintenance personnel or ground traffic. The antenna should be sited so that any metal structures, such as air vents, pipes and other antennas are outside the near-field effects of the antenna.

7.12.2.2 Besides the magnitude of the multipath error at each reference receiver antenna location, the degree of correlation must also be considered. Reference receiver antennas should be located in places that provide independent multipath environments.

7.12.2.3 The installation of each antenna should include a mounting that will not flex in winds or under ice loads. Reference receiver antennas should be located in an area where access is controlled. Traffic may contribute to error due to multipath or obstruct view of satellites from the antennas.

7.12.3 *Locating the VDB antenna.* The VDB antenna should be located so that an unobstructed line-of-sight exists from the antenna to any point within the coverage volume for each supported FAS. Consideration should also be given to ensuring the minimum transmitter-to-receiver separation so that the maximum field strength is not exceeded. In order to provide the required coverage for multiple FASs at a given airport, and in order to allow flexibility in VBD antenna siting, the actual coverage volume around the transmitter antenna may need to be considerably larger than that required for a single FAS. The ability to provide this coverage is dependent on the VDB antenna location with respect to the runway and the height of the VDB antenna. Generally speaking, increased antenna height may be needed to provide adequate signal strength to users at low altitudes, but may also result in unacceptable multipath nulls within the desired coverage volume. A suitable antenna height trade-off must be made based on analysis, to ensure the signal strength requirements are met within the entire volume. Consideration should also be given to the effect of terrain features and buildings on the multipath environment.

7.12.4 *Use of multiple transmit antennas to improve VDB coverage.* For some GBAS installations, constraints on antenna location, local terrain or obstacles may result in ground multipath and/or signal blockage that make it difficult to provide the specified field strength at all points within the coverage area. Some GBAS ground facilities may make use of one or more additional antenna systems, sited to provide signal path diversity such that collectively they meet the coverage requirements.

7.12.4.1 Whenever multiple antenna systems are used, the antenna sequence and message scheduling must be arranged to provide broadcasts at all points within the coverage area that adhere to the specified minimum and maximum data broadcast rates and field strengths, without exceeding the receiver's ability to adapt to transmission-to-transmission variations in signal strength in a given slot. To avoid receiver processing issues concerning lost or duplicated messages, all transmissions of the Type 1 or Type 101 message, or linked pair of Type 1 or Type 101 messages for a given measurement type within a single frame need to provide identical data content.

7.12.4.2 One example of the use of multiple antennas is a facility with two antennas installed at the same location but at different heights above the ground plane. The heights of the antennas are chosen so that the pattern from one antenna fills the nulls in the pattern of the other antenna that result from reflections from the ground plane. The GBAS ground subsystem alternates broadcasts between the two antennas, using one or two assigned slots of each frame for each antenna. Type 1 or Type 101 messages are broadcast once per frame, per antenna. This allows for reception of one or two Type 1 or Type 101 messages per frame, depending on whether the user is located within the null of one of the antenna patterns. Type 2 and 4 messages are broadcast from the first antenna in one frame, then from the second antenna in the next frame. This allows for reception of one each of the Type 2 and 4 messages per one or two frames, depending on the user location.

7.13 Definition of lateral and vertical alert limits

7.13.1 The lateral and vertical alert limits for Category I precision approach are computed as defined in Appendix B, Tables B-68 and B-69. In these computations the parameters D and H have the meaning shown in Figure D-8.

7.13.2 The vertical alert limit for Category I precision approach is scaled from a height of 60 m (200 ft) above the LTP/FTP. For a procedure designed with a decision height of more than 60 m (200 ft), the VAL at that decision height will be larger than the broadcast FASVAL.

7.13.3 The lateral and vertical alert limits for APV procedures associated with channel numbers 40 001 to 99 999 are computed in the same manner as for APV procedures using SBAS as given in Attachment D, 3.2.8.

7.14 Monitoring and maintenance actions

7.14.1 Specific monitoring requirements or built-in tests may be necessary and should be determined by individual States. Since the VDB signal is critical to the operation of the GBAS broadcast station, any failure of the VDB to successfully transmit a usable signal within the assigned slots and over the entire coverage area is to be corrected as soon as possible. Therefore, it is recommended that the following conditions be used as a guide for implementing a VDB monitor:

a) *Power.* A significant drop in power is to be detected within 3 seconds.

b) *Loss of message type.* The failure to transmit any scheduled message type(s). This could be based on the failure to transmit a unique message type in succession, or a combination of different message types.

c) *Loss of all message types.* The failure to transmit any message type for a period equal to or greater than 3 seconds will be detected.

7.14.2 Upon detection of a failure, and in the absence of a backup transmitter, termination of the VDB service should be considered if the signal cannot be used reliably within the coverage area to the extent that aircraft operations could be significantly impacted. Appropriate actions in operational procedures are to be considered to mitigate the event of the signal being removed from service. These would include dispatching maintenance specialists to service the GBAS VDB or special ATC procedures. Additionally, maintenance actions should be taken when possible for all built-in test failures to prevent loss of GBAS service.

7.15 Examples of VDB messages

7.15.1 Examples of the coding of VDB messages are provided in Tables D-7 through D-10. The examples illustrate the coding of the various application parameters, including the cyclic redundancy check (CRC) and forward error correction (FEC) parameters, and the results of bit scrambling and D8PSK symbol coding. The engineering values for the message parameters in these tables illustrate the message coding process, but are not necessarily representative of realistic values.

7.15.2 Table D-7 provides an example of a Type 1 VDB message. The additional message flag field is coded to indicate that this is the first of two Type 1 messages to be broadcast within the same frame. This is done for illustration purposes; a second Type 1 message is not typically required, except to allow broadcast of more ranging source corrections than can be accommodated in a single message.

7.15.3 Table D-7A provides an example of a Type 101 VDB message. The additional message flag field is coded to indicate that this is the first of two Type 101 messages to be broadcast within the same frame. This is done for illustration purposes; a second Type 101 message is not typically required, except to allow broadcast of more ranging source corrections than can be accommodated in a single message.

7.15.4 Table D-8 provides examples of a Type 1 VDB message and a Type 2 VDB message coded within a single burst (i.e. two messages to be broadcast within a single transmission slot). The additional message flag field of the Type 1 message is coded to indicate that it is the second of two Type 1 messages to be broadcast within the same frame. The Type 2 message includes additional data block 1. Table D-8A provides an example of Type 1 and Type 2 messages with additional data blocks 1 and 2.

7.15.5 Table D-9 provides an example of a Type 4 message containing two FAS data blocks.

7.15.6 Table D-10 provides an example of a Type 5 message. In this example, source availability durations common to all approaches are provided for two ranging sources. Additionally, source availability durations for two individual approaches are provided: the first approach has two impacted ranging sources and the second approach has one impacted ranging source. The Type 2 message includes additional data block 1.

7.16 GBAS survey accuracy

The standards for the survey accuracy for NAVAIDs are contained in Annex 14 — *Aerodromes*. In addition, the *Manual of the World Geodetic System 1984 (WGS-84)* (Doc 9674) provides guidance on the establishment of a network of survey control stations at each aerodrome and how to use the network to establish WGS-84 coordinates. Until specific requirements are developed for GBAS, the Annex 14 survey accuracy requirements for NAVAIDs located at the aerodrome apply to GBAS. The recommendation contained in Appendix B to Chapter 3, 3.6.7.2.3.4, for the survey accuracy of the GBAS reference point is intended to further reduce the error in the WGS-84 position calculated by an airborne user of the GBAS positioning service to a value smaller than that established by the requirements of Appendix B to Chapter 3, 3.6.7.2.4.1 and 3.6.7.2.4.2, in the GBAS standards and to enhance survey accuracy compared to that specified in Annex 14. The integrity of all aeronautical data used for GBAS is to be consistent with the integrity requirements in Chapter 3, Table 3.7.2.4-1.

7.17 Type 2 message additional data block 2

Type 2 message additional data block 2 data may be used in GRAS to enable the GRAS airborne subsystem to switch between GBAS broadcast stations, particularly if the GBAS broadcast stations utilize different frequencies. Additional data block 2 identifies the channel numbers and locations of the GBAS broadcast station currently being received and other adjacent or nearby GBAS broadcast stations.

Table D-7. Example of a Type 1 VDB message

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
BURST DATA CONTENT					
Power ramp-up and settling	15				000 0000 0000 0000
Synchronization and ambiguity resolution	48				0100 0111 1101 1111 1000 1100 0111 0110 0000 0111 1001 0000
SCRAMBLED DATA					
Station slot identifier (SSID)	3	—	—	E	100
Transmission length (bits)	17	0 to 1 824 bits	1 bit	536	000 0000 1000 0110 00
Training sequence FEC	5	—	—	—	0000 1
APPLICATION DATA MESSAGE BLOCK					
Message Block (Type 1 message)					
Message Block Header					
Message block identifier	8	—	—	Normal	1010 1010
GBAS ID	24	—	—	BELL	0000 1000 0101 0011 0000 1100
Message type identifier	8	1 to 8	1	1	0000 0001
Message length	8	10 to 222 bytes	1 byte	61	0011 1101
Message (Type 1 example)					
Modified Z-count	14	0 to 1 199.9 s	0.1 s	100 s	00 0011 1110 1000
Additional message flag	2	0 to 3	1	1st of pair	01
Number of measurements	5	0 to 18	1	4	0 0100
Measurement type	3	0 to 7	1	C/A L1	000
Ephemeris Decorrelation Parameter (P)	8	0 to 1.275 $\times 10^{-3}$m/m	5×10^{-6}m/m	1×10^{-4}	0001 0100
Ephemeris CRC	16	—	—	—	0000 0000 0000 0000
Source availability duration	8	0 to 2 540 s	10 s	Not provided	1111 1111
Measurement Block 1					
Ranging source ID	8	1 to 255	1	2	0000 0010
Issue of data (IOD)	8	0 to 255	1	255	1111 1111
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m	+1.0 m	0000 0000 0110 0100
Range rate correction (RRC)	16	±32.767 m	0.001 m/s	–0.2 m/s	1111 1111 0011 1000
σ_{pr_gnd}	8	0 to 5.08 m	0.02 m	0.98 m	0011 0001
B_1	8	±6.35 m	0.05 m	+0.10 m	0000 0010
B_2	8	±6.35 m	0.05 m	+0.15 m	0000 0011
B_3	8	±6.35 m	0.05 m	–0.25 m	1111 1011
B_4	8	±6.35 m	0.05 m	Not used	1000 0000
Measurement Block 2					
Ranging source ID	8	1 to 255	1	4	0000 0100
Issue of data (IOD)	8	0 to 255	1	126	0111 1110
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m	–1.0 m	1111 1111 1001 1100
Range rate correction (RRC)	16	±32.767 m	0.001 m/s	+0.2 m/s	0000 0000 1100 1000
σ_{pr_gnd}	8	0 to 5.08 m	0.02 m	0.34 m	0001 0001
B_1	8	±6.35 m	0.05 m	+0.20 m	0000 0100
B_2	8	±6.35 m	0.05 m	+0.30 m	0000 0110
B_3	8	±6.35 m	0.05 m	–0.50 m	1111 0110
B_4	8	±6.35 m	0.05 m	Not used	1000 0000

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
Measurement Block 3					
Ranging source ID	8	1 to 255	1	12	0000 1100
Issue of data (IOD)	8	0 to 255	1	222	1101 1110
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m	+1.11 m	0000 0000 0110 1111
Range rate correction (RRC)	16	±32.767 m	0.001 m/s	–0.2 m/s	1111 1111 0011 1000
σ_{pr_gnd}	8	0 to 5.08 m	0.02 m	1.02 m	0011 0011
B_1	8	±6.35 m	0.05 m	+0.10 m	0000 0010
B_2	8	±6.35 m	0.05 m	+0.25 m	0000 0101
B_3	8	±6.35 m	0.05 m	–0.25 m	1111 1011
B_4	8	±6.35 m	0.05 m	Not used	1000 0000
Measurement Block 4					
Ranging source ID	8	1 to 255	1	23	0001 0111
Issue of data (IOD)	8	0 to 255	1	80	0101 0000
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m	–2.41 m	1111 1111 0000 1111
Range rate correction (RRC)	16	±32.767 m	0.001 m/s	–0.96 m/s	1111 1100 0100 0000
σ_{pr_gnd}	8	0 to 5.08 m	0.02 m	0.16 m	0000 1000
B_1	8	±6.35 m	0.05 m	+0.20 m	0000 0100
B_2	8	±6.35 m	0.05 m	+0.30 m	0000 0110
B_3	8	±6.35 m	0.05 m	–0.50 m	1111 0110
B_4	8	±6.35 m	0.05 m	Not used	1000 0000
Message Block CRC	32	—	—	—	1100 0010 1111 0011 0000 1011 1100 1010
APPLICATION FEC	48	—	—	—	0110 0011 1110 1001 1110 0000 1110 1101 0010 1001 0111 0101
Input to the bit scrambling (Note 2)	0 46 10 10 55 30 CA 10 80 BC 17 C2 20 28 00 00 FF 40 FF 26 00 1C FF 8C 40 C0 DF 01 20 7E 39 FF 13 00 88 20 60 6F 01 30 7B F6 00 1C FF CC 40 A0 DF 01 E8 0A F0 FF 02 3F 10 20 60 6F 01 53 D0 CF 43 AE 94 B7 07 97 C6				
Output from the bit scrambling (Note 3)	0 60 27 98 1F 2F D2 3B 5F 26 C2 1B 12 F4 46 D0 09 81 B6 25 1C 18 D0 7C 2A 7F B9 55 A8 B0 27 17 3A 60 EB 5F 1B 3B A5 FE 0A E1 43 D7 FA D7 B3 7A 65 D8 4E D7 79 D2 E1 AD 95 E6 6D 67 12 B3 EA 4F 1A 51 B6 1C 81 F2 31				
Fill bits	0 to 2	—	—	0	
Power ramp-down	9	—	—	—	000 000 000
D8PSK Symbols (Note 4)	00000035 11204546 31650100 12707716 71645524 74035772 26234621 45311123 22460075 52232477 16617052 04750422 07724363 40733535 05120746 45741125 22545252 73171513 51047466 13171745 10622642 17157064 67345046 36541025 07135576 55745512 222				

Notes.—

1. *The rightmost bit is the LSB of the binary parameter value and is the first bit transmitted or sent to the bit scrambler. All data fields are sent in the order specified in the table.*
2. *This field is coded in hexadecimal with the first bit to be sent to the bit scrambler as its MSB. The first character represents a single bit.*
3. *In this example fill bits are not scrambled.*
4. *This field represents the phase, in units of π/4 (e.g. a value of 5 represents a phase of 5 π/4 radians), relative to the phase of the first symbol.*

Table D-7A. Example of a Type 101 VDB message

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
BURST DATA CONTENT					
Power ramp-up and settling	15				000 0000 0000 0000
Synchronization and ambiguity resolution	48				0100 0111 1101 1111 1000 1100 0111 0110 0000 0111 1001 0000
SCRAMBLED DATA					
Station slot identifier (SSID)	3			E	100
Transmission length (bits)	17	0 to 1824 bits	1 bit	416	00000000110100000
Training sequence FEC	5				11011
APPLICATION DATA MESSAGE BLOCK					
Message Block (Type 101 message)					
Message Block Header					
Message block identifier	8			Normal	1010 1010
GBAS ID	24			ERWN	00010101 00100101 11001110
Message type identifier	8	1 to 8,101	1	101	0110 0101
Message length	8	10 to 222 bytes	1 byte	46	0010 1110
Message (Type 101 example)					
Modified Z-count	14	0 to 1199.9 s	0.1 s	100 s	00 0011 1110 1000
Additional message flag	2	0 to 3	1	1st of pair	01
Number of measurements	5	0 to 18	1	4	0 0100
Measurement type	3	0 to 7	1	C/A L1	000
Ephemeris Decorrelation Parameter (P)	8	0 to 1.275 × 10^{-3}m/m	5 × 10^{-6}m/m	0.115 × 10^{-3}m/m	0001 0111
Ephemeris CRC	16			0	0000 0000 0000 0000
Source availability duration	8	0 to 2540 s	10 s	Not provided	1111 1111
Number of B parameters	1	0 to 1	1	0	0
Spare	7			0	000 0000
Measurement Block 1					
Ranging source ID	8	1 to 255	1	2	0000 0010
Issue of data (IOD)	8	0 to 255	1	255	1111 1111
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m	+3.56 m	0000 0001 0110 0100
Range rate correction (RRC)	16	±32.767 m/s	0.001 m/s	-0.011 m/s	1111 1111 1111 0101
σ_{pr_gnd}	8	0 to 50.8 m	0.2 m	9.8 m	0011 0001
Measurement Block 2					
Ranging source ID	8	1 to 255	1	4	0000 0100
Issue of data (IOD)	8	0 to 255	1	126	0111 1110
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m	-1.0 m	1111 1111 1001 1100
Range rate correction (RRC)	16	±32.767 m/s	0.001 m/s	+0.002 m/s	0000 0000 0000 0010
σ_{pr_gnd}	8	0 to 50.8 m	0.2 m	3.4 m	0001 0001
Measurement Block 3					
Ranging source ID	8	1 to 255	1	12	0000 1100
Issue of data (IOD)	8	0 to 255	1	222	1101 1110
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m	+4.11 m	0000 0001 1001 1011
Range rate correction (RRC)	16	±32.767 m/s	0.001 m/s	-0.029 m/s	1111 1111 1110 0011
σ_{pr_gnd}	8	0 to 50.8 m	0.2 m	10.2 m	0011 0011

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
Measurement Block 4					
Ranging source ID	8	1 to 255	1	23	0001 0111
Issue of data (IOD)	8	0 to 255	1	80	0101 0000
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m	-2.41 m	1111 1111 0000 1111
Range rate correction (RRC)	16	±32.767 m/s	0.001 m/s	-0.096 m/s	1111 1111 1010 0000
σ_{pr_gnd}	8	0 to 50.8 m	0.2 m	1.6 m	0000 1000
Message Block CRC	32				1000 1000 1001 1111 0111 1000 0000 0100
APPLICATION FEC	48				1100 1100 1110 0110 1111 0110 1100 1110 1101 0110 0110 0010
Input to the bit scrambling (Note 2)	0 41 60 1B 55 73 A4 A8 A6 74 17 C2 20 E8 00 00 FF 00 40 FF 26 80 AF FF 8C 20 7E 39 FF 40 00 88 30 7B D9 80 C7 FF CC E8 0A F0 FF 05 FF 10 20 1E F9 11 46 6B 73 6F 67 33				
Output from the bit scrambling (Note 3)	0 67 57 93 1F 6C BC 83 79 EE C2 1B 12 34 46 D0 09 C1 09 FC 3A 84 80 0F E6 9F 18 6D 77 8E 1E 60 19 1B BA FF BC AB 68 26 7B E7 BC CE FA 0B D3 C4 43 C8 E0 B6 FA 42 84 A1				
Fill bits	0 to 2			0	
Power ramp-down	9				000 000 000
D8PSK Symbols (Note 4)	00000035 11204546 31650105 06345463 57026113 51374661 15123376 12066670 44776307 04225000 02735027 73373152 13230100 04706272 74137202 47724524 12715704 15442724 01101677 44571303 66447212 222				

Notes.—

1. *The rightmost bit is the LSB of the binary parameter value and is the first bit transmitted or sent to the bit scrambler. All data fields are sent in the order specified in the table.*
2. *This field is coded in hexadecimal with the first bit to be sent to the bit scrambler as its MSB. The first character represents a single bit.*
3. *In this example, fill bits are not scrambled.*
4. *This field represents the phase, in units of π/4 (e.g. a value of 5 represents a phase of 5π/4 radians), relative to the phase of the first symbol.*

Table D-8. Example of Type 1 and Type 2 VDB messages in a single burst

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
BURST DATA CONTENT					
Power ramp-up and settling	15				000 0000 0000 0000
Synchronization and ambiguity resolution	48				0100 0111 1101 1111 1000 1100 0111 0110 0000 0111 1001 0000
SCRAMBLED DATA					
Station slot identifier (SSID)	3	—	—	E	10 0
Transmission length (bits)	17	0 to 1 824 bits	1 bit	544	000 0000 1000 1000 00
Training sequence FEC	5	—	—	—	0000 0
APPLICATION DATA					
Message Block 1 (Type 1 message)					
Message Block Header					
Message block identifier	8	—	—	Normal	1010 1010
GBAS ID	24	—	—	BELL	0000 1000 0101 0011 0000 1100
Message type identifier	8	1 to 8	1	1	0000 0001
Message length	8	10 to 222 bytes	1 byte	28	0001 1100
Message (Type 1 example)					
Modified Z-count	14	0 to 1 199.9 s	0.1 s	100 s	00 0011 1110 1000
Additional message flag	2	0 to 3	1	2nd of pair	11
Number of measurements	5	0 to 18	1	1	0 0001
Measurement type	3	0 to 7	1	C/A L1	000
Ephemeris Decorrelation Parameter (P)	8	0 to 1.275 × 10^{-3} m/m	5 × 10^{-6} m/m	0 (SBAS)	0000 0000
Ephemeris CRC	16	—	—	0	0000 0000 0000 0000
Source availability duration	8	0 to 2 540 s	10 s	Not provided	1111 1111
Measurement Block 1					
Ranging source ID	8	1 to 255	1	122	0111 1010
Issue of data (IOD)	8	0 to 255	1	2	0000 0010
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m	+1.0 m	0000 0000 0110 0100
Range rate correction (RRC)	16	±32.767 m	0.001 m/s	–0.2 m/s	1111 1111 0011 1000
σ_{pr_gnd}	8	0 to 5.08 m	0.02 m	1.96 m	0110 0010
B_1	8	±6.35 m	0.05 m	+0.10 m	0000 0010
B_2	8	±6.35 m	0.05 m	+0.15 m	0000 0011
B_3	8	±6.35 m	0.05 m	–0.25 m	1111 1011
B_4	8	±6.35 m	0.05 m	Not used	1000 0000
Message Block 1 CRC	32	—	—	—	1011 0101 1101 0000 1011 1100 0101 0010
Message Block 2 (Type 2 message)					
Message Block Header					
Message block identifier	8	—	—	Normal	1010 1010
GBAS ID	24	—	—	BELL	0000 1000 0101 0011 0000 1100
Message type identifier	8	1 to 8	1	2	0000 0010
Message length	8	10 to 222 bytes	1 byte	34	0010 0010
Message (Type 2 example)					
GBAS reference receivers	2	2 to 4	1	3	01
Ground accuracy designator letter	2	—	—	B	01
Spare	1	—	—	0	0

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
GBAS continuity/integrity designator	3	0 to 7	1	1	001
Local magnetic variation	11	±180°	0.25°	58° E	000 1110 1000
Spare	5	—	—	0	0000 0
$\sigma_{vert\_iono\_gradient}$	8	0 to 25.5 × 10^{-6} m/m	0.1 × 10^{-6} m/m	0	0000 0000
Refractivity index	8	16 to 781	3	379	1111 1001
Scale height	8	0 to 25 500 m	100 m	100 m	0000 0001
Refractivity uncertainty	8	0 to 255	1	20	0001 0100
Latitude	32	±90.0°	0.0005 arcsec	45°40'32" N	0001 0011 1001 1010 0001 0001 0000 0000
Longitude	32	±180.0°	0.0005 arcsec	93°25'13"W	1101 0111 1110 1000 1000 1010 1011 0000
Ellipsoid height	24	±83 886.07 m	0.01 m	892.55 m	0000 0001 0101 1100 1010 0111
Additional Data Block 1					
Reference Station Data Selector	8	0 to 48	1	5	0000 0101
Maximum Use Distance (D_{max})	8	2 to 510 km	2 km	50 km	0001 1001
$K_{md\_e\_POS,GPS}$	8	0 to 12.75	0.05	6	0111 1000
$K_{md\_e,GPS}$	8	0 to 12.75	0.05	5	0110 0100
$K_{md\_e\_POS,GLONASS}$	8	0 to 12.75	0.05	0	0000 0000
$K_{md\_e,GLONASS}$	8	0 to 12.75	0.05	0	0000 0000
Message Block 2 CRC	32	—	—	—	0101 1101 0111 0110 0010 0011 0001 1110
Application FEC	48				1110 1000 0100 0101 0011 1011 0011 1011 0100 0001 0101 0010
Input to the bit scrambling (Note 2)	0 41 10 00 55 30 CA 10 80 38 17 C3 80 00 00 00 FF 5E 40 26 00 1C FF 46 40 C0 DF 01 4A 3D 0B AD 55 30 CA 10 40 44 A4 17 00 00 9F 80 28 00 88 59 C8 0D 51 17 EB E5 3A 80 A0 98 1E 26 00 00 78 C4 6E BA 4A 82 DC DC A2 17				
Output from the bit scrambling (Note 3)	0 67 27 88 1F 2F D2 3B 5F A2 C2 1A B2 DC 46 D0 09 9F 09 25 1C 18 D0 B6 2A 7F B9 55 C2 F3 15 45 7C 50 A9 6F 3B 10 00 D9 71 17 DC 4B 2D 1B 7B 83 72 D4 F7 CA 62 C8 D9 12 25 5E 13 2E 13 E0 42 44 37 45 68 29 5A B9 55 65				
Fill bits	0 to 2	—	—	1	0
Power ramp-down	9	—	—	—	000 000 000
D8PSK Symbols (Note 4)	00000035 11204546 31650105 67443352 35201160 30501336 62023576 12066670 74007653 30010255 31031274 26172772 76236442 41177201 35131033 33421734 42751235 60342057 66270254 17431214 03421036 70316613 46567433 66547730 34732201 40607506 014444				

Notes.—

1. *The rightmost bit is the LSB of the binary parameter value and is the first bit transmitted or sent to the bit scrambler. All data fields are sent in the order specified in the table.*
2. *This field is coded in hexadecimal with the first bit to be sent to the bit scrambler as its MSB. The first character represents a single bit.*
3. *In this example fill bits are not scrambled.*
4. *This field represents the phase, in units of π/4 (e.g. a value of 5 represents a phase of 5 π/4 radians), relative to the phase of the first symbol.*

Table D-8A. Example of Type 1 and Type 2 VDB messages with additional data blocks 1 and 2

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
BURST DATA CONTENT					
Power ramp-up and settling	15				000 0000 0000 0000
Synchronization and ambiguity resolution	48				0100 0111 1101 1111 1000 1100 0111 0110 0000 0111 1001 0000
SCRAMBLED DATA					
Station slot identifier (SSID)	3			E	100
Transmission length (bits)	17	0 to 1824 bits	1 bit	592	00000001001010000
Training sequence FEC	5				10110
APPLICATION DATA					
Message Block 1 (Type 1 message)					
Message Block Header					
Message block identifier	8			Normal	1010 1010
GBAS ID	24			ERWN	00010101 00100101 11001110
Message type identifier	8	1 to 8	1	1	0000 0001
Message length	8	10 to 222 bytes	1 byte	28	0001 1100
Message (Type 1 example)					
Modified Z-count	14	0 to 1199.9 s	0.1 s	100 s	00 0011 1110 1000
Additional message flag	2	0 to 3	1	2nd of pair	11
Number of measurements	5	0 to 18	1	1	0 0001
Measurement type	3	0 to 7	1	C/A L1	000
Ephemeris Decorrelation Parameter (P)	8	0 to 1.275×10^{-3} m/m	5×10^{-6} m/m	0 (SBAS)	0000 0000
Ephemeris CRC	16			0	0000 0000 0000 0000
Source availability duration	8	0 to 2540 s	10 s	Not provided	1111 1111
Measurement Block 1					
Ranging source ID	8	1 to 255	1	122	0111 1010
Issue of data (IOD)	8	0 to 255	1	2	0000 0010
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m	+2.09 m	0000 0000 1101 0001
Range rate correction (RRC)	16	±32.767 m/s	0.001 m/s	-0.2 m/s	1111 1111 0011 1000
σ_{pr_gnd}	8	0 to 5.08 m	0.02 m	1.96 m	0110 0010
B1	8	±6.35 m	0.05 m	+0.10 m	0000 0010
B2	8	±6.35 m	0.05 m	+0.15 m	0000 0011
B3	8	±6.35 m	0.05 m	–0.25 m	1111 1011
B4	8	±6.35 m	0.05 m	Not used	1000 0000
Message Block 1 CRC	32				00110010 10100100 11001011 00110000
Message Block 2 (Type 2 message)					
Message Block Header					
Message block identifier	8			Normal	1010 1010
GBAS ID	24			ERWN	00010101 00100101 11001110
Message type identifier	8	1 to 8	1	2	0000 0010
Message length	8	10 to 222 bytes	1 byte	40	0010 1000
Message (Type 2 example)					
GBAS reference receivers	2	2 to 4	1	3	01
Ground accuracy designator letter	2			B	01
Spare	1			0	0

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
GBAS continuity/integrity designator	3	0 to 7	1	1	001
Local magnetic variation	11	±180°	0.25°	58° E	000 1110 1000
Spare	5			0	0000 0
$\sigma_{vert\_iono\_gradient}$	8	0 to 25.5 × 10^{-6}m/m	0.1 × 10^{-6}m/m	0	0000 0000
Refractivity index	8	16 to 781	3	379	1111 1001
Scale height	8	0 to 25 500 m	100 m	100 m	0000 0001
Refractivity uncertainty	8	0 to 255	1	20	0001 0100
Latitude	32	±90.0°	0.0005 arcsec	45°40'32" N	0001 0011 1001 1010 0001 0001 0000 0000
Longitude	32	±180.0°	0.0005 arcsec	93°25'13" W	1101 0111 1110 1000 1000 1010 1011 0000
Ellipsoid height	24	±83 886.07 m	0.01 m	892.55 m	0000 0001 0101 1100 1010 0111
Additional Data Block 1					
Reference Station Data Selector	8	0 to 48	1	5	0000 0101
Maximum Use Distance (Dmax)	8	2 to 510 km	2 km	50 km	0001 1001
$K_{md\_e\_POS,GPS}$	8	0 to 12.75	0.05	6	0111 1000
$K_{md\_e,GPS}$	8	0 to 12.75	0.05	5	0110 0100
$K_{md\_e\_POS,GLONASS}$	8	0 to 12.75	0.05	0	0000 0000
$K_{md\_e,GLONASS}$	8	0 to 12.75	0.05	0	0000 0000
Additional Data Blocks					
Additional Data Block Length	8	2 to 255	1	6	0000 0110
Additional Data Block Number	8	2 to 255	1	2	0000 0010
Additional Data Block 2					
Channel Number	16	20001 to 39999	1	25001	0110 0001 1010 1001
ΔLatitude	8	±25.4°	0.2°	5.2	0001 1010
ΔLongitude	8	±25.4°	0.2°	−3.4	1110 1111
Message Block 2 CRC	32				11100000 01110010 00011101 00100100
Application FEC	48				1110 0010 0101 1100 0000 1111 1010 1011 0011 0100 0100 0000
Input to the bit scrambling (Note 2)		0 42 90 0D 55 73 A4 A8 80 38 17 C3 80 00 00 00 FF 5E 40 8B 00 1C FF 46 40 C0 DF 01 0C D3 25 4C 55 73 A4 A8 40 14 A4 17 00 00 9F 80 28 00 88 59 C8 0D 51 17 EB E5 3A 80 A0 98 1E 26 00 00 60 40 95 86 58 F7 24 B8 4E 07 02 2C D5 F0 3A 47			
Output from the bit scrambling (Note 3)		0 64 A7 85 1F 6C BC 83 5F A2 C2 1A B2 DC 46 D0 09 9F 09 88 1C 18 D0 B6 2A 7F B9 55 84 1D 3B A4 7C 13 C7 D7 3B 40 00 D9 71 17 DC 4B 2D 1B 7B 83 72 D4 F7 CA 62 C8 D9 12 25 5E 13 2E 13 E0 5A C0 CC 79 7A 5C A2 DD B9 75 B6 95 64 52 78 3F			
Fill bits	0 to 2			1	0
Power ramp-down	9				000 000 000
D8PSK Symbols (Note 4)		00000035 11204546 31650107 56336574 60137224 74145772 26467132 56422234 30443700 05565722 06506741 73647332 27242654 63345227 31575333 33421734 42751235 60342057 66270254 17431214 03421036 70316613 46567433 62077121 37275607 55315167 17135031 34423411 274444			

Notes.—

1. *The rightmost bit is the LSB of the binary parameter value and is the first bit transmitted or sent to the bit scrambler. All data fields are sent in the order specified in the table.*
2. *This field is coded in hexadecimal with the first bit to be sent to the bit scrambler as its MSB. The first character represents a single bit.*
3. *In this example, fill bits are not scrambled.*
4. *This field represents the phase, in units of π/4 (e.g. a value of 5 represents a phase of 5π/4 radians), relative to the phase of the first symbol.*

Table D-9. Example of a Type 4 message

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
BURST DATA CONTENT					
Power ramp-up and settling	15				000 0000 0000 0000
Synchronization and ambiguity resolution	48				010 0011 1110 1111 1100 0110 0011 1011 0000 0011 1100 1000 0
SCRAMBLED DATA					
Station slot identifier (SSID)	3	—	—	D	01 1
Transmission length (bits)	17	0 to 1 824 bits	1 bit	784	000 0000 1100 0100 00
Training sequence FEC	5	—	—	—	0000 0
APPLICATION DATA MESSAGE BLOCK					
Message Block (Type 4 message)					
Message Block Header					
Message block identifier	8	—	—	Normal	1010 1010
GBAS ID	24	—	—	CMJ	0000 1100 1101 0010 1010 0000
Message type identifier	8	1 to 8	1	4	0000 0100
Message length	8	10 to 222 bytes	1 byte	92	0101 1100
Message (Type 4 example)					
FAS Data Set 1					
Data set length	8	2 to 212	1 byte	41	0010 1001
FAS Data Block 1					
Operation type	4	0 to 15	1	0	0000
SBAS service provider	4	0 to 15	1	15	1111
Airport ID	32	—	—	LFBO	0000 1100 0000 0110 0000 0010 0000 1111
Runway number	6	0 to 36	1	15	00 1111
Runway letter	2	—	—	R	01
Approach performance designator	3	0 to 7	1	CAT 1	001
Route indicator	5	—	—	C	0001 1
Reference path data selector (RPDS)	8	0 to 48	1	3	0000 0011
Reference path identifier	32	—	—	GTBS	0000 0111 0001 0100 0000 0010 0001 0011
LTP/FTP latitude	32	±90.0°	0.0005 arcsec	43.6441075°N	0001 0010 1011 1010 1110 0010 1000 0110
LTP/FTP longitude	32	±180.0°	0.0005 arcsec	1.345940°E	0000 0000 1001 0011 1101 1110 1001 0000
LTP/FTP height	16	–512.0 to 6 041.5 m	0.1 m	197.3	0001 1011 1011 0101
ΔFPAP latitude	24	±1°	0.0005 arcsec	–0.025145°	1111 1101 0011 1100 1100 1100
ΔFPAP longitude	24	±1°	0.0005 arcsec	0.026175°	0000 0010 1110 0000 0010 1100
Approach threshold crossing height (TCH)	15	0 to 1 638.35 m (0 to 3 276.7 ft)	0.05 m (0.1 ft)	17.05 m	000 0001 0101 0101
Approach TCH units selector	1	0 = ft; 1 = m	—	metres	1
Glide path angle (GPA)	16	0 to 90°	0.01°	3°	0000 0001 0010 1100
Course width	8	80.0 to 143.75 m	0.25 m	105	0110 0100
ΔLength offset	8	0 to 2 032 m	8 m	0	0000 0000
FAS Data Block 1 CRC	32	—	—	—	1010 0010 1010 0101 1010 1000 0100 1101
FASVAL/Approach status	8	0 to 25.4	0.1 m	10	0110 0100
FASLAL/Approach status	8	0 to 50.8	0.2 m	40	1100 1000
FAS Data Set 2					
Data set length	8	2 to 212	1 byte	41	0010 1001

FAS Data Block 2					
Operation type	4	0 to 15	1	0	0000
SBAS service provider	4	0 to 15	1	01	0001
Airport ID	32	—	—	LFBO	0000 1100 0000 0110 0000 0010 0000 1111
Runway number	6	0 to 36	1	33	10 0001
Runway letter	2	—	—	R	01
Approach performance designator	3	0 to 7	1	CAT 1	001
Route indicator	5	—	—	A	0000 1
Reference path data selector (RPDS)	8	0 to 48	1	21	0001 0101
Reference path identifier	32	—	—	GTN	0000 0111 0001 0100 0000 1110 0010 0000
LTP/FTP latitude	32	±90.0°	0.0005 arcsec	43.6156350°N	0001 0010 1011 0111 1100 0001 1011 1100
LTP/FTP longitude	32	±180.0°	0.0005 arcsec	1.3802350°E	0000 0000 1001 0111 1010 0011 0001 1100
LTP/FTP height	16	–512.0 to 6 041.5 m	0.1 m	200.2 m	0001 1011 1101 0010
ΔFPAP latitude	24	±1°	0.0005 arcsec	0.02172375°	0000 0010 0110 0010 1111 1011
ΔFPAP longitude	24	±1°	0.0005 arcsec	–0.0226050°	1111 1101 1000 0100 0011 1100
Approach threshold crossing height (TCH)	15	0 to 1 638.35 m (0 to 3 276.7 ft)	0.05 m (0.1 ft)	15.25 m	000 0001 0011 0001
Approach TCH units selector	1	0 = ft; 1 = m	—	metres	1
Glide path angle (GPA)	16	0 to 90°	0.01°	3.01°	0000 0001 0010 1101
Course width	8	80.0 to 143.75 m	0.25 m	105	0110 0100
ΔLength offset	8	0 to 2 032 m	8 m	0	0000 0000
FAS data block 2 CRC	32	—	—	—	1010 1111 0100 1101 1010 0000 1101 0111
FASVAL/Approach status	8	0 to 25.4	0.1 m	10	0110 0100
FASLAL /Approach status	8	0 to 50.8	0.2 m	40	1100 1000
Message Block CRC	32	—	—	—	0101 0111 0000 0011 1111 1110 1001 1011
APPLICATION FEC	48	—	—	—	0001 1011 1001 0001 0010 1010 1011 1100 0010 0101 1000 0101
Input to the bit scrambling (Note 2)	1 82 30 00 55 05 4B 30 20 3A 94 0F F0 40 60 30 F2 98 C0 C8 40 28 E0 61 47 5D 48 09 7B C9 00 AD D8 33 3C BF 34 07 40 AA 81 34 80 26 00 B2 15 A5 45 26 13 94 08 F0 40 60 30 86 90 A8 04 70 28 E0 3D 83 ED 48 38 C5 E9 00 4B D8 DF 46 40 3C 21 BF 8C 81 B4 80 26 00 EB 05 B2 F5 26 13 D9 7F C0 EA A1 A4 3D 54 89 D8				
Output from the bit scrambling (Note 3)	1 A4 07 88 1F 1A 53 1B FF A0 41 D6 C2 9C 26 E0 04 59 89 CB 5C 2C CF 91 2D E2 2E 5D F3 07 1E 45 F1 53 5F C0 4F 53 E4 64 F0 23 C3 ED 05 A9 E6 7F FF FF B5 49 81 DD A3 F2 B5 40 9D A0 17 90 12 60 64 7C CF E3 BE A0 1E 72 FF 61 6E E4 02 44 D9 1E D2 FD 63 D1 12 C3 5A 00 0E F8 89 FE 4C 12 0C 78 4F 9D 55 08 16 F6				
Fill bits	0 to 2	—	—	1	0
Power ramp down	9	—	—	—	000 000 000
D8PSK Symbols (Note 4)	0000003511204546316504322300771662170713052556673176724345377776157763461661570543615214576405133401677 5214231304443061301150266774341755603276241630527536540015247051420322575333462555437707605652760631444 6243163101353722250120760407526435103457714077770415665273600122324007402031443362754444				

Notes.—

1. *The rightmost bit is the LSB of the binary parameter value and is the first bit transmitted or sent to the bit scrambler. All data fields are sent in the order specified in the table.*
2. *This field is coded in hexadecimal with the first bit to be sent to the bit scrambler as its MSB. The first character represents a single bit.*
3. *In this example, fill bits are not scrambled.*
4. *This field represents the phase, in units of π/4 (e.g. a value of 5 represents a phase of 5π/4 radians), relative to the phase of the first symbol.*

Table D-10. Example of a Type 5 message

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
BURST DATA CONTENT					
Power ramp-up and settling	15				000 0000 0000 0000
Synchronization and ambiguity resolution	48				0100 0111 1101 1111 1000 1100 0111 0110 0000 0111 1001 0000
SCRAMBLED DATA					
Station slot identifier (SSID)	3	—	—	D	01 1
Transmission length (bits)	17	0 to 1 824 bits	1 bit	272	000 0000 0100 0100 00
Training sequence FEC	5	—	—	—	0001 1
APPLICATION DATA MESSAGE BLOCK					
Message Block (Type 5 message)					
Message Block Header					
Message block identifier	8	—	—	Normal	1010 1010
GBAS ID	24	—	—	CMJ	0000 1100 1101 0010 1010 0000
Message type identifier	8	1 to 8	1	5	0000 0101
Message length	8	10 to 222 bytes	1 byte	28	0001 1100
Message (Type 5 example)					
Modified Z-count	14	0 to 1 199.9 s	0.1 s	100 s	00 0011 1110 1000
Spare	2	—	—	—	00
Number of impacted sources (N)	8	0 to 31	1	2	0000 0010
First impacted source					
Ranging source ID	8	1 to 255	1	4	0000 0100
Source availability sense	1	—	—	Will cease	0
Source availability duration	7	0 to 1 270 s	10 s	50 s	0000 101
Second impacted source					
Ranging source ID	8	1 to 255	1	3	0000 0011
Source availability sense	1	—	—	Will start	1
Source availability duration	7	0 to 1 270 s	10 s	200 s	0010 100
Number of obstructed approaches (A)	8	0 to 255	1	2	0000 0010
First obstructed approach					
Reference path data selector (RPDS)	8	0 to 48	1	21	0001 0101
Number of impacted sources for first obstructed approach (N_A)	8	1 to 31	1	2	0000 0010
First impacted ranging source of first obstructed approach					
Ranging source ID	8	1 to 255	1	12	0000 1100
Source availability sense	1	—	—	Will cease	0
Source availability duration	7	0 to 1 270 s	10 s	250 s	0011 001
Second impacted ranging source of first obstructed approach					
Ranging source ID	8	1 to 255	1	14	0000 1110
Source availability sense	1	—	—	Will cease	0
Source availability duration	7	0 to 1 270 s	10 s	1 000 s	1100 100
Second obstructed approach					
Reference path data selector (RPDS)	8	0 to 48	1	14	0000 1110
Number of impacted sources for second obstructed approach (N_A)	8	1 to 31	1	1	0000 0001

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
First impacted ranging source of second obstructed approach					
Ranging source ID	8	1 to 255	1	12	0000 1100
Source availability sense	1	—	—	Will cease	0
Source availability duration	7	0 to 1 270 s	10 s	220 s	0010 110
Message Block CRC	32	—	—	—	1101 1011 0010 1111 0001 0010 0000 1001
APPLICATION FEC	48	—	—	—	0011 1110 1011 1010 0001 1110 0101 0110 1100 1011 0101 1011
Input to the bit scrambling (Note 2)	1 82 20 18 55 05 4B 30 A0 38 17 C0 40 20 50 C0 94 40 A8 40 30 4C 70 13 70 80 30 34 90 48 F4 DB DA D3 6A 78 5D 7C				
Output from the bit scrambling	1 A4 17 90 1F 1A 53 1B 7F A2 C2 19 72 FC 16 10 62 81 E1 43 2C 48 5F E3 1A 3F 56 60 18 86 EA 33 F3 B3 09 07 26 28				
Fill bits	0 to 2	—	—	0	
Power ramp-down	9				000 000 000
D8PSK Symbols (Note 3)	0000003511204546316504322056660551067602416124477363463220700103224006601332124166231163643777110173115 74302323445146644444				

Notes.—

1. *The rightmost bit is the LSB of the binary parameter value and is the first bit transmitted or sent to the bit scrambler. All data fields are sent in the order specified in the table.*
2. *This field is coded in hexadecimal with the first bit to be sent to the bit scrambler as its MSB. The first character represents a single bit.*
3. *Symbols are represented by their differential phase with respect to the first symbol of the message, in units of $\pi/4$ (e.g. a value of 5 represents a phase of $5\pi/4$ radians) relative to the first symbol.*

7.18 Type 101 message

Type 101 message is an alternative to Type 1 message developed to fit the specific needs of GRAS systems. The primary difference in the contents and application of these two message types is two-fold: (a) Type 101 message has a larger available range for σpr_gnd values and (b) ground subsystem time-to-alert is larger for a system broadcasting Type 101 messages. The first condition would typically occur in a system where a broadcast station covers a large area, such that decorrelation errors increase the upper limit of the pseudo-range correction errors. The second condition may be typical for systems where a central master station processes data from multiple receivers dispersed over a large area.

8. Signal quality monitor (SQM) design

8.1 The objective of the signal quality monitor (SQM) is to detect satellite signal anomalies in order to prevent aircraft receivers from using misleading information (MI). MI is an undetected aircraft pseudo-range differential error greater than the maximum error (MERR) that can be tolerated. These large pseudo-range errors are due to C/A code correlation peak distortion caused by satellite payload failures. If the reference receiver used to create the differential corrections and the aircraft receiver have different measurement mechanizations (i.e. receiver bandwidth and tracking loop correlator spacing), the signal distortion affects them differently. The SQM must protect the aircraft receiver in cases when mechanizations are not similar. SQM performance is further defined by the probability of detecting a satellite failure and the probability of incorrectly annunciating a satellite failure.

8.2 The signal effects that might cause a GBAS or SBAS to output MI can be categorized into three different effects on the correlation function as follows:

a) *Dead zones:* If the correlation function loses its peak, the receiver's discriminator function will include a flat spot or dead zone. If the reference receiver and aircraft receiver settle in different portions of this dead zone, MI can result.

b) *False peaks:* If the reference receiver and aircraft receiver lock to different peaks, MI could exist.

c) *Distortions:* If the correlation peak is misshapen, an aircraft that uses a correlator spacing other than the one used by the reference receivers may experience MI.

8.3 The threat model proposed for use in assessment of SQM has three parts that can create the three correlation peak pathologies listed above.

8.4 Threat Model A consists of the normal C/A code signal except that all the positive chips have a falling edge that leads or lags relative to the correct end-time for that chip. This threat model is associated with a failure in the navigation data unit (NDU), the digital partition of a GPS or GLONASS satellite.

8.4.1 Threat Model A for GPS has a single parameter Δ, which is the lead ($\Delta < 0$) or lag ($\Delta > 0$) expressed in fractions of a chip. The range for this parameter is $-0.12 \leq \Delta \leq 0.12$. Threat Model A for GLONASS has a single parameter Δ, which is the lead ($\Delta < 0$) or lag ($\Delta > 0$) expressed in fractions of a chip. The range for this parameter is $-0.11 \leq \Delta \leq 0.11$.

8.4.2 Within this range, threat Model A generates the dead zones described above. (Waveforms with lead need not be tested, because their correlation functions are simply advances of the correlation functions for lag; hence, the MI threat is identical.)

8.5 Threat Model B introduces amplitude modulation and models degradations in the analog section of the GPS or GLONASS satellite. More specifically, it consists of the output from a second order system when the nominal C/A code baseband signal is the input. Threat Model B assumes that the degraded satellite subsystem can be described as a linear system dominated by a pair of complex conjugate poles. These poles are located at $\sigma \pm j2\pi f_d$, where σ is the damping factor in nepers/second and f_d is the resonant frequency with units of cycles/second.

8.5.1 The unit step response of a second order system is given by:

$$e(t) = \begin{Bmatrix} 0 & t \leq 0 \\ 1 - \exp(-\sigma t)\left[\cos \omega_d t + \dfrac{\sigma}{\omega_d} \sin \omega_d t\right] & t \geq 0 \end{Bmatrix}$$

where $\omega_d = 2\pi f_d$.

8.5.2 Threat Model B for GPS corresponding to second order anomalies uses the following ranges for the parameters Δ, f_d and σ:

$$\Delta = 0;\ 4 \leq f_d \leq 17;\ \text{and}\ 0.8 \leq \sigma \leq 8.8.$$

Threat Model B for GLONASS corresponding to second order anomalies uses the following ranges for the parameters defined above:

$$\Delta = 0;\ 10 \leq f_d \leq 20;\ \text{and}\ 2 \leq \sigma \leq 8.$$

8.5.3 Within these parameter ranges, threat Model B generates distortions of the correlation peak as well as false peaks.

8.6 Threat Model C introduces both lead/lag and amplitude modulation. Specifically, it consists of outputs from a second order system when the C/A code signal at the input suffers from lead or lag. This waveform is a combination of the two effects described above.

8.6.1 Threat Model C for GPS includes parameters Δ, f_d and σ with the following ranges:

$$-0.12 \leq \Delta \leq 0.12;\ 7.3 \leq f_d \leq 13;\ \text{and}\ 0.8 \leq \sigma \leq 8.8.$$

Threat Model C for GLONASS includes parameters Δ, f_d and σ with the following ranges:

$$-0.11 \leq \Delta \leq 0.11;\ 10 \leq f_d \leq 20;\ \text{and}\ 2 \leq \sigma \leq 8.$$

8.6.2 Within these parameter ranges, threat Model C generates dead zones, distortions of the correlation peak and false peaks.

8.7 Unlike GPS and GLONASS, the SBAS signal is commissioned and controlled by the service provider. Moreover, the service provider also monitors the quality of the signal from the SBAS. To this end, the threat model will be specified and published by the service provider for each SBAS satellite. The SBAS SQM will be designed to protect all avionics that comply with Table D-12. Publication of the threat model is required for those cases where a service provider chooses to allow the SBAS ranging signal from a neighbouring service provider to be used for precision approach by SBAS or GBAS. In these cases, the service provider will monitor the SBAS ranging signal from the neighbouring satellite.

8.8 In order to analyse the performance of a particular monitor design, the monitor limit must be defined and set to protect individual satellite pseudo-range error relative to the protection level, with an allocation of the ground subsystem integrity risk. The maximum tolerable error (denoted as MERR) for each ranging source *i* can be defined in GBAS as:

$$\text{MERR} = K_{ffmd}\sigma_{pr\_gnd,i}\ \text{and}$$

$$\text{MERR}=K_{V,PA}\sqrt{\sigma_{i,UDRE}^2 + \min\left\{\sigma_{i,UIRE}^2\right\}}$$

for SBAS APV and precision approach where min $\left\{\sigma^2_{i,UIRE}\right\}$ is the minimum possible value for any user. MERR is evaluated at the output of a fault-free user receiver and varies with satellite elevation angle and ground subsystem performance.

8.9 The SQM is designed to limit the UDRE to values below the MERR in the case of a satellite anomaly. Typically, the SQM measures various correlation peak values and generates spacing and ratio metrics that characterize correlation peak distortion. Figure D-9 illustrates typical points at the top of a fault-free, unfiltered correlation peak.

8.9.1 A correlator pair is used for tracking. All other correlator values are measured with respect to this tracking pair.

8.9.2 Two types of test metrics are formed: early-minus-late metrics (D) that are indicative of tracking errors caused by peak distortion, and amplitude ratio metrics (R) that measure slope and are indicative of peak flatness or close-in, multiple peaks.

8.9.3 It is necessary that the SQM has a precorrelation bandwidth that is sufficiently wide to measure the narrow spacing metrics, so as not to cause significant peak distortion itself and not to mask the anomalies caused by the satellite failure. Typically, the SQM receiver must have a precorrelation bandwidth of at least 16 MHz for GPS and at least 15 MHz for GLONASS.

8.9.4 The test metrics are smoothed using low-pass digital filters. The time constant of these filters are to be shorter than those used jointly (and standardized at 100 seconds) by the reference receivers for deriving differential corrections and by the aircraft receiver for smoothing pseudo-range measurements (using carrier smoothing). The smooth metrics are then compared to thresholds. If any one of the thresholds is exceeded, an alarm is generated for that satellite.

8.9.5 The thresholds used to derive performance are defined as minimum detectable errors (MDEs) and minimum detectable ratios (MDRs). Fault-free false detection probability and missed detection probability are used to derive MDEs and MDRs. The noise in metrics (D) and (R), as denoted $\sigma_{D,test}$ and $\sigma_{R,test}$ below, is dominated by multipath errors. Note that the metric test can also have a mean value (μ_{test}) caused by SQM receiver filter distortion. Threshold tests must also account for the mean values.

8.9.6 The MDE and MDR values used in the SQM performance simulations are calculated based on the following equations:

$$MDE = (K_{ffd} + K_{md})\,\sigma_{D,test} \text{ and}$$
$$MDR = (K_{ffd} + K_{md})\,\sigma_{R,test}$$

where

$K_{ffd} = 5.26$ is a typical fault-free detection multiplier representing a false detection probability of 1.5×10^{-7} per test;

$K_{md} = 3.09$ is a typical missed detection multiplier representing a missed detection probability of 10^{-3} per test;

$\sigma_{D,test}$ is the standard deviation of measured values of difference test metric D; and

$\sigma_{R,test}$ is the standard deviation of measured values of ratio test metric R.

8.9.7 If multiple independent SQM receivers are used to detect the failures, the sigma values can be reduced by the square root of the number of independent monitors.

8.9.8 A failure is declared if

$$| D,test - \mu_{D,test} | \geq MDE \text{ or}$$
$$| R,test - \mu_{R,test} | \geq MDR$$

for any of the tests performed, where $\mu_{X,test}$ is the mean value of the test X that accounts for fault-free SQM receiver filter distortion, as well as correlation peak distortion peculiar to the specific C/A code PRN. (Not all C/A code correlation peaks have the same slope. In a simulation environment, however, this PRN distortion can be ignored, and a perfect correlation peak can be used, except for simulated filter distortion.)

8.10 The standard deviations of the test statistics, $\sigma_{D,test}$ and $\sigma_{R,test}$ can be determined via data collection on a multicorrelator receiver in the expected operating environment. The data collection receiver utilizes a single tracking pair of correlators and additional correlation function measurement points which are slaved to this tracking pair, as illustrated in Figure D-9. Data is collected and smoothed for all available measurement points in order to compute the metrics. The standard deviation of these metrics define $\sigma_{D,test}$. It is also possible to compute these one sigma test statistics if a multipath model of the installation environment is available.

8.10.1 The resulting $\sigma_{D,test}$ is highly dependent on the multipath environment in which the data are collected. The deviation due to multipath can be an order of magnitude greater than that which would result from noise even at minimum carrier-to-noise level. This aspect illustrates the importance of the antenna design and siting criteria which are the primary factors in determining the level of multipath that will enter the receiver. Reducing multipath will significantly decrease the resulting MDEs and thus improve the SQM capabilities.

8.10.2 Mean values $\mu_{D,test}$ and $\mu_{R,test}$, on the other hand, are determined in a relatively error-free environment, such as through the use of GPS and GLONASS signal simulator as input. These mean values model the nominal SQM receiver's filter distortion of the autocorrelation peak, including the effects of distortion due to adjacent minor autocorrelation peaks. The mean values can differ for the various PRNs based on these properties.

8.11 In order for the ground monitor to protect users against the different threat models described above, it is necessary to assume that aircraft receivers have specific characteristics. If no such constraints were assumed, the complexity of the ground monitor would be unnecessarily high. Evolution in the technology may lead to improved detection capability in the aircraft receiver and may alleviate the current constraints.

8.11.1 For double-delta correlators, the aircraft receiver tracks the strongest correlation peak over the full code sequence for every ranging source used in the navigation solution.

8.11.2 For double-delta correlators, the precorrelation filter rolls off by at least 30 dB per octave in the transition band.

8.11.3 The following parameters are used to describe the tracking performance specific to each type of satellite:

a) the instantaneous correlator spacing is defined as the spacing between a particular set of early and late samples of the correlation function;

b) the average correlator spacing is defined as a one-second average of the instantaneous correlator spacing. The average applies over any one-second time frame;

c) the discriminator Δ is based upon an average of early-minus-late samples with spacings inside the specified range, or is of the type $\Delta = 2\Delta_{d1} - \Delta_{2d1}$, with both d_1 and $2d_1$ in the specified range. Either a coherent or non-coherent discriminator is used;

d) the differential group delay applies to the entire aircraft system prior to the correlator, including the antenna. The differential group delay is defined as:

$$\left|\frac{d\phi}{d\omega}(f_c)-\frac{d\phi}{d\omega}(f)\right|$$

where

f_c is the precorrelation band pass filter centre frequency;

f is any frequency within the 3dB bandwidth of the precorrelation filter;

ϕ is the combined phase response of precorrelation band pass filter and antenna; and

ω is equal to $2\pi f$.

8.11.4 For aircraft receivers using early-late correlators and tracking GPS satellites, the precorrelation bandwidth of the installation, the correlator spacing and the differential group delay are within the ranges defined in Table D-11.

8.11.5 For aircraft receivers using early-late correlators and tracking GLONASS satellites, the precorrelation bandwidth of the installation, the correlator spacing, and the differential group delay are within the ranges as defined in Table D-12.

8.11.6 For aircraft receivers using double-delta correlators and tracking GPS satellites, the precorrelation bandwidth of the installation, the correlator spacing and the differential group delay are within the ranges defined in Table D-13.

8.11.7 For aircraft receivers using the early-late or double-delta correlators and tracking SBAS satellites, the precorrelation bandwidth of the installation, the correlator spacing and the differential group delay are within the ranges defined in Table D-14.

9. Status monitoring and NOTAM

9.1 System status

9.1.1 Degradation of GBAS usually has local effects and affects mainly approach operations. System degradation of GBAS is to be distributed as approach-related information.

9.1.2 Degradation of core satellite constellation(s) or SBAS usually has not only local effects, but additional consequences for a wider area, and may directly affect en-route operations. System degradation of these elements is to be distributed as area-related information. An example is a satellite failure.

9.1.3 Degradation of GRAS may have local effects and/or wide area effects. Therefore, if the degradation has only local effects, GRAS system degradation information is to be distributed in accordance with 9.1.1. If the degradation has wide area effects, GRAS system degradation information is to be distributed in accordance with 9.1.2.

9.1.4 Information is to be distributed to indicate the inability of GNSS to support a defined operation. For example, GPS/SBAS may not support a precision approach operation on a particular approach. This information can be generated automatically or manually based upon models of system performance.

Table D-11. GPS tracking constraints for early-late correlators

Region	3 dB precorrelation bandwidth, BW	Average correlator spacing (chips)	Instantaneous correlator spacing (chips)	Differential group delay
1	2 < BW ≤ 7 MHz	0.045 – 1.1	0.04 – 1.2	≤ 600 ns
2	7 < BW ≤ 16 MHz	0.045 – 0.21	0.04 – 0.235	≤ 150 ns
3	16 < BW ≤ 20 MHz	0.045 – 0.12	0.04 – 0.15	≤ 150 ns
4	20 < BW ≤ 24 MHz	0.08 – 0.12	0.07 – 0.13	≤ 150 ns

Table D-12. GLONASS tracking constraints for early-late correlators

Region	3 dB precorrelation bandwidth, BW	Average correlator spacing range (chips)	Instantaneous correlator spacing range (chips)	Differential group delay
1	7 < BW ≤ 9 MHz	0.05 – 1.0	0.045 – 1.1	≤100 ns
2	9 < BW ≤ 15 MHz	0.05 – 0.2	0.045 – 0.22	≤ 100 ns
3	15 < BW ≤ 18 MHz	0.05 – 0.1	0.045 – 0.11	≤ 100 ns

Table D-13. GPS tracking constraints for double-delta correlators

Region	3 dB precorrelation bandwidth, BW	Average correlator spacing range (chips)	Instantaneous correlator spacing range (chips)	Differential group delay
1	2 < BW ≤ 7 MHz	0.045 – 0.6	0.04 – 0.65	≤ 600 ns
2	7 < BW ≤ 14 MHz	0.045 – 0.24	0.04 – 0.26	≤ 150 ns
3	14 < BW ≤ 16 MHz	0.07 – 0.24	0.04 – 0.26	≤ 150 ns

Table D-14. SBAS ranging function tracking constraints

Region	3 dB precorrelation bandwidth, BW	Average correlator spacing (chips)	Instantaneous correlator spacing (chips)	Differential group delay
1	2 < BW ≤ 7 MHz	0.045 – 1.1	0.04 – 1.2	≤ 600 ns
2	7 < BW ≤ 20 MHz	0.045 – 1.1	0.04 – 1.2	≤ 150 ns

9.2 Information on type of degradation

The following information is to be distributed:

a) non-availability of service;

b) downgrade of service, if applicable; and

c) time and expected duration of degradation.

9.3 Timing of notification

For scheduled events, notification should be given to the NOTAM authority at least 72 hours prior to the event. For unscheduled events, notification to the NOTAM authority should be given within 15 minutes. Notification should be given for events of 15-minute, or longer, duration.

10. Interference

10.1 Potential for interference

Satellite radio navigation systems such as GPS and GLONASS feature relatively weak received signal power, meaning that an interference signal could cause loss of service. In order to maintain service, it will be necessary to ensure that the maximum interference levels specified in the SARPs are not exceeded.

10.2 Specification of the interference threshold at the antenna port

The indications of the interference threshold levels are referenced to the antenna port. In this context, the term "antenna port" means the interface between the antenna and the GNSS receiver where the satellite signal power corresponds to the nominal minimum received signal power of −164.5 dBW for GPS and −165.5 dBW for GLONASS. Due to the reduced distance from potential interference sources, GNSS receivers that are used for the approach phase of flight must have a higher interference threshold than receivers that are only used for en-route navigation.

10.3 In-band interference sources

A potential source of in-band harmful interference is Fixed Service operation in certain States. There is a primary allocation to the fixed service for point-to-point microwave links in certain States in the frequency band used by GPS and GLONASS.

10.4 Out-of-band interference sources

Potential sources of out-of-band interference include harmonics and spurious emissions of aeronautical VHF and UHF transmitters. Out-of-band noise, discrete spurious products and intermodulation products from radio and TV broadcasts can also cause interference problems.

10.5 Aircraft generated sources

10.5.1 The potential for harmful interference to GPS and GLONASS on an aircraft depends on the type of aircraft, its size and the transmitting equipment installed. The GNSS antenna location should take into account the possibility of on-board interference (mainly SATCOM).

10.5.2 GNSS receivers that are used on board aircraft with SATCOM equipment must have a higher interference threshold in the frequency range between 1 610 MHz and 1 626.5 MHz than receivers on board aircraft without SATCOM equipment. Therefore, specifications for the interference threshold discriminate between both cases.

Note.— Limits for radiated SATCOM aircraft earth stations are given in Annex 10, Volume III, Part I, Chapter 4, 4.2.3.5.

10.5.3 The principal mitigation techniques for on-board interference include shielding, filtering, receiver design techniques, and, especially on larger aircraft, physical separation of antennas, transmitters and cabling. Receiver design techniques include the use of adaptive filters and interference cancellation techniques that mitigate against narrow in-band interference. Antenna design techniques include adaptive null steering antennas that reduce the antenna gain in the direction of interference sources without reducing the signal power from satellites.

10.6 Integrity in the presence of interference

The requirement that SBAS and GBAS receivers do not output misleading information in the presence of interference is intended to prevent the output of misleading information under unintentional interference scenarios that could arise. It is not intended to specifically address intentional interference. While it is impossible to completely verify this requirement through testing, an acceptable means of compliance can be found in the appropriate receiver Minimum Operational Performance Standards published by RTCA and EUROCAE.

11. Recording of GNSS parameters

11.1 In order to be able to conduct post-incident/accident investigations (Chapter 2, 2.4.3), it is necessary to record GNSS information both for the augmentation system and for the appropriate GNSS core system constellation used for the operation. The parameters to be recorded are dependent on the type of operation, augmentation system and core elements used. All parameters available to users within a given service area should be recorded at representative locations in the service area.

11.2 The objective is not to provide independent assurance that the GNSS is functioning correctly, nor is it to provide another level of system monitoring for anomalous performance or input data for a NOTAM process. The recording system need not be independent of the GNSS service and may be delegated to other States or entities. In order to enable future reconstruction of position, velocity and time indications provided by specific GNSS configurations, it is recommended to log data continuously, generally at a 1 Hz rate.

11.3 For GNSS core systems the following monitored items should be recorded for all satellites in view:

a) observed satellite carrier-to-noise density (C/N_0);

b) observed satellite raw pseudo-range code and carrier phase measurements;

c) broadcast satellite navigation messages, for all satellites in view; and

d) relevant recording receiver status information.

11.4 For SBAS the following monitored items should be recorded for all geostationary satellites in view in addition to the GNSS core system monitored items listed above:

a) observed geostationary satellite carrier-to-noise density (C/N_0);

b) observed geostationary satellite raw pseudo-range code and carrier phase measurements;

c) broadcast SBAS data messages; and

d) relevant receiver status information.

11.5 For GBAS the following monitored items should be recorded in addition to the GNSS core system and SBAS monitored items listed above (where appropriate):

a) VDB power level;

b) VDB status information; and

c) broadcast GBAS data messages.

12. GNSS performance assessment

The data described in Section 11 may also support periodic confirmation of GNSS performance in the service area.

13. GNSS and database

Note.— Provisions relating to aeronautical data are contained in Annex 11, Chapter 2, and Annex 15, Chapter 3.

13.1 The database is to be current with respect to the effective AIRAC cycle, which generally means that a current database be loaded into the system approximately every 28 days. Operating with out-of-date navigation databases has to be avoided.

13.2 In certain situations, operations using an expired database can be conducted safely by implementing a process and/or using procedures to ensure that the required data is correct. These processes and/or procedures need prior approval by the State.

13.2.1 These procedures should be based on one of the following methods:

a) require the crew to check, prior to the operation, critical database information against current published information. (This method increases workload and would not be practical for all applications.); or

b) waive the requirement for a current database and frequent checks by the crew of the database information. This waiver can only be applied to very specific cases where aircraft are operated in a strictly limited geographical area and where that area is controlled by a single regulatory agency or multiple agencies that coordinate this process; or

c) use another approved method that ensures an equivalent level of safety.

14. Modelling of residual errors

14.1 Application of the integrity requirements for SBAS and GBAS requires that a model distribution be used to characterize the error characteristics in the pseudo-range. The HPL/LPL and VPL models (see 7.5.3) are constructed based on models of the individual error components (in the pseudo-range domain) that are independent, zero-mean, normal distributions. The relationship between this model and the true error distribution must be defined.

14.2 One method of ensuring that the protection level risk requirements are met is to define the model variance (σ^2), such that the cumulative error distribution satisfies the conditions:

$$\int_{y}^{\infty} f(x)dx \leq Q\left(\frac{y}{\sigma}\right) \text{ for all } \left(\frac{y}{\sigma}\right) \geq 0 \text{ and}$$

$$\int_{-\infty}^{-y} f(x)dx \leq Q\left(\frac{y}{\sigma}\right) \text{ for all } \left(\frac{y}{\sigma}\right) \geq 0 \text{ and}$$

where

$f(x) =$ probability density function of the residual aircraft pseudo-range error; and

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_{x}^{\infty} e^{-\frac{t^2}{2}} dt.$$

14.3 This method can be directly applied when the error components have zero-mean, symmetrical and unimodal probability density functions. This is the case for the receiver contribution to corrected pseudo-range error, since the aircraft element is not subjected to low-frequency residual multipath errors.

14.4 This method can be extended to address non-zero-mean, residual errors by inflating the model variance to compensate for the possible effect of the mean in the position domain.

14.5 Verification of the pseudo-range error models must consider a number of factors including:

a) the nature of the error components;

b) the sample size required for confidence in the data collection and estimation of each distribution;

c) the correlation time of the errors; and

d) the sensitivity of each distribution to geographic location and time.

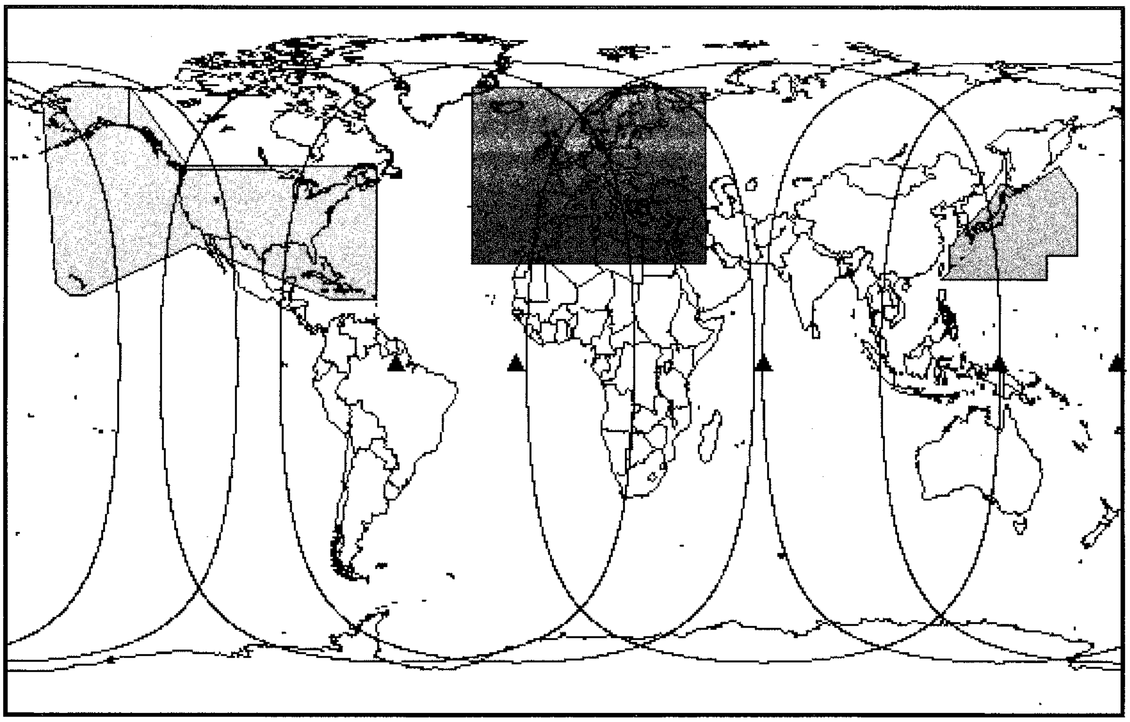
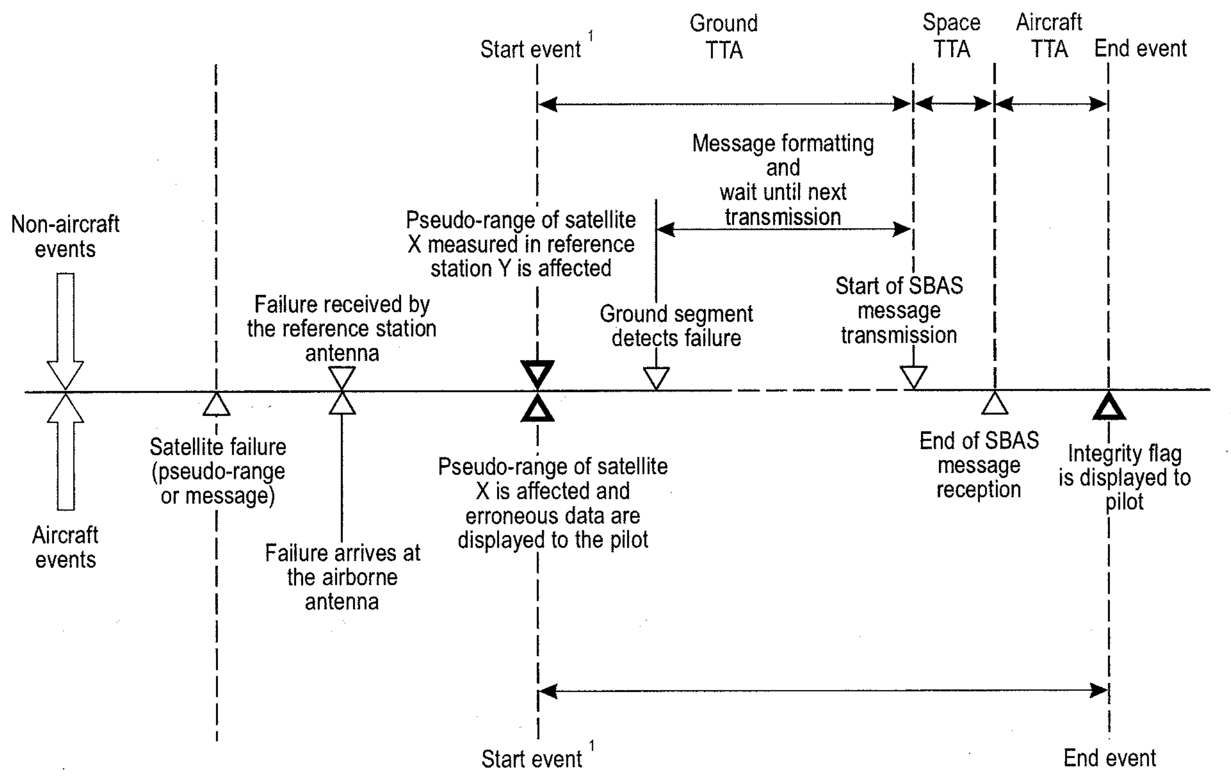


Figure D-1. Initial SBAS coverage areas and service areas



[1] Both events are considered as simultaneous. This is not strictly the case because of difference of performance between specific receivers. There is a slight difference due to receiver processing between the time the pseudo-range measurement is affected and the erroneous data are displayed. For practical reasons, this is not reflected in this diagram.

Figure D-2. SBAS time-to-alert

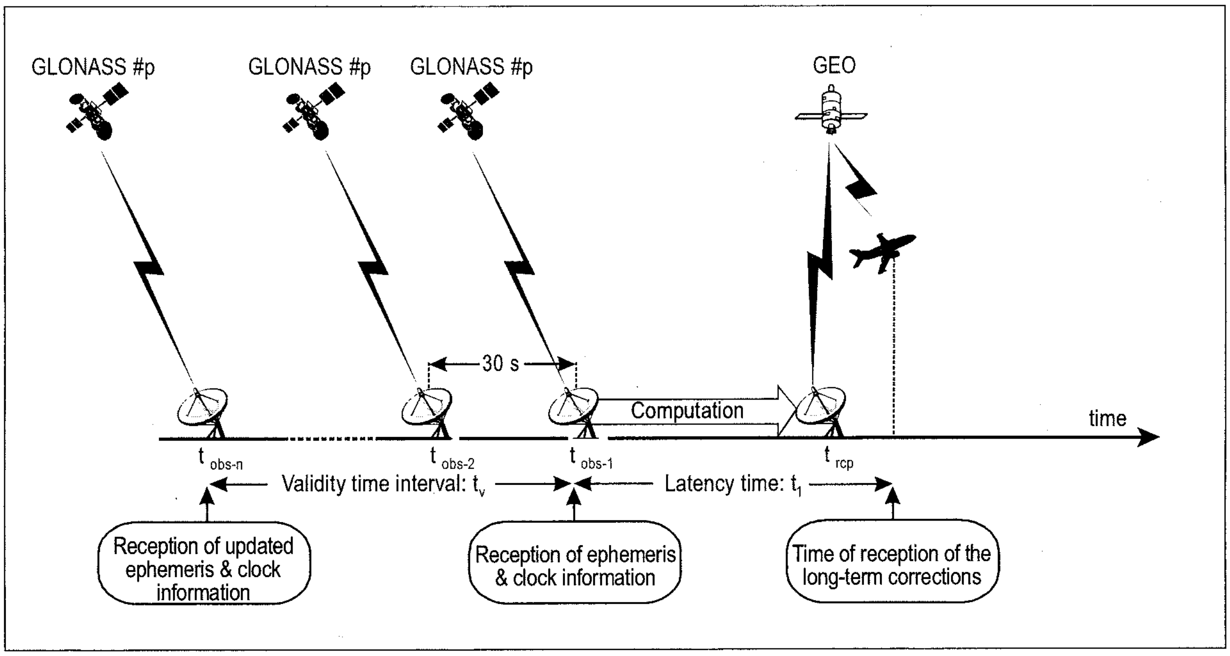
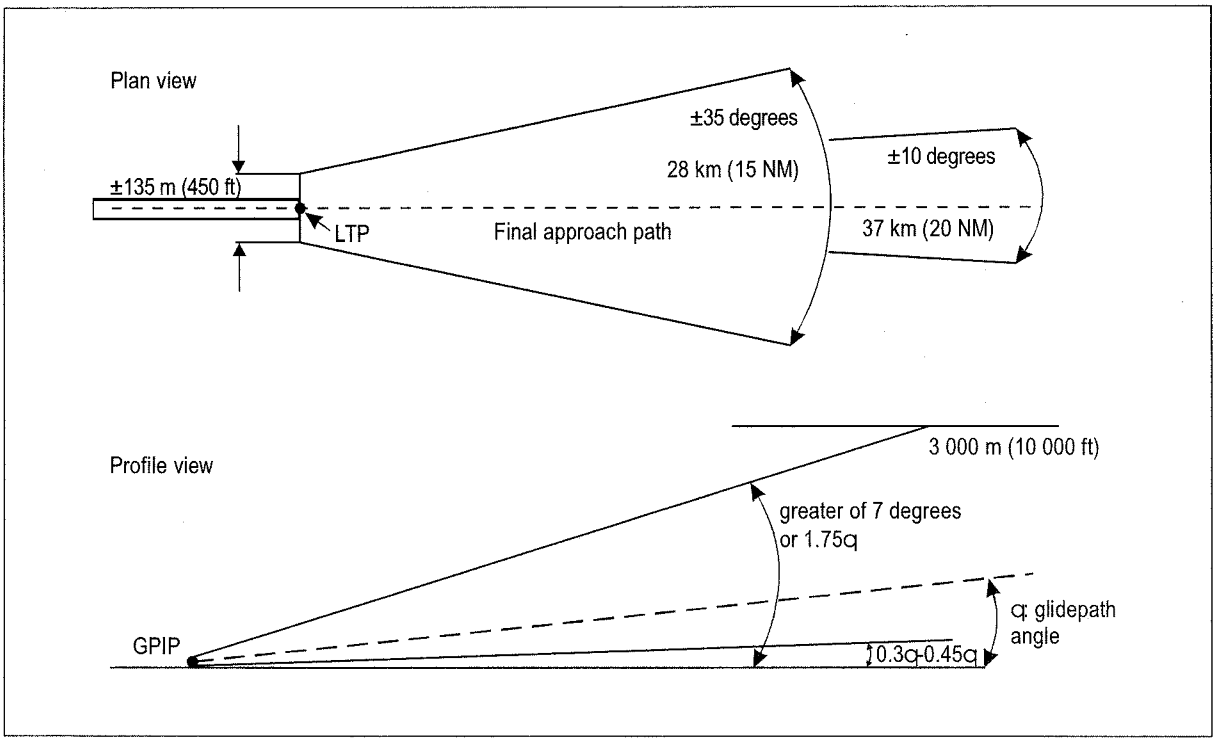


Figure D-3. GLONASS time



GPIP — glide path intersection point
LTP — landing threshold point

Figure D-4. Minimum GBAS coverage

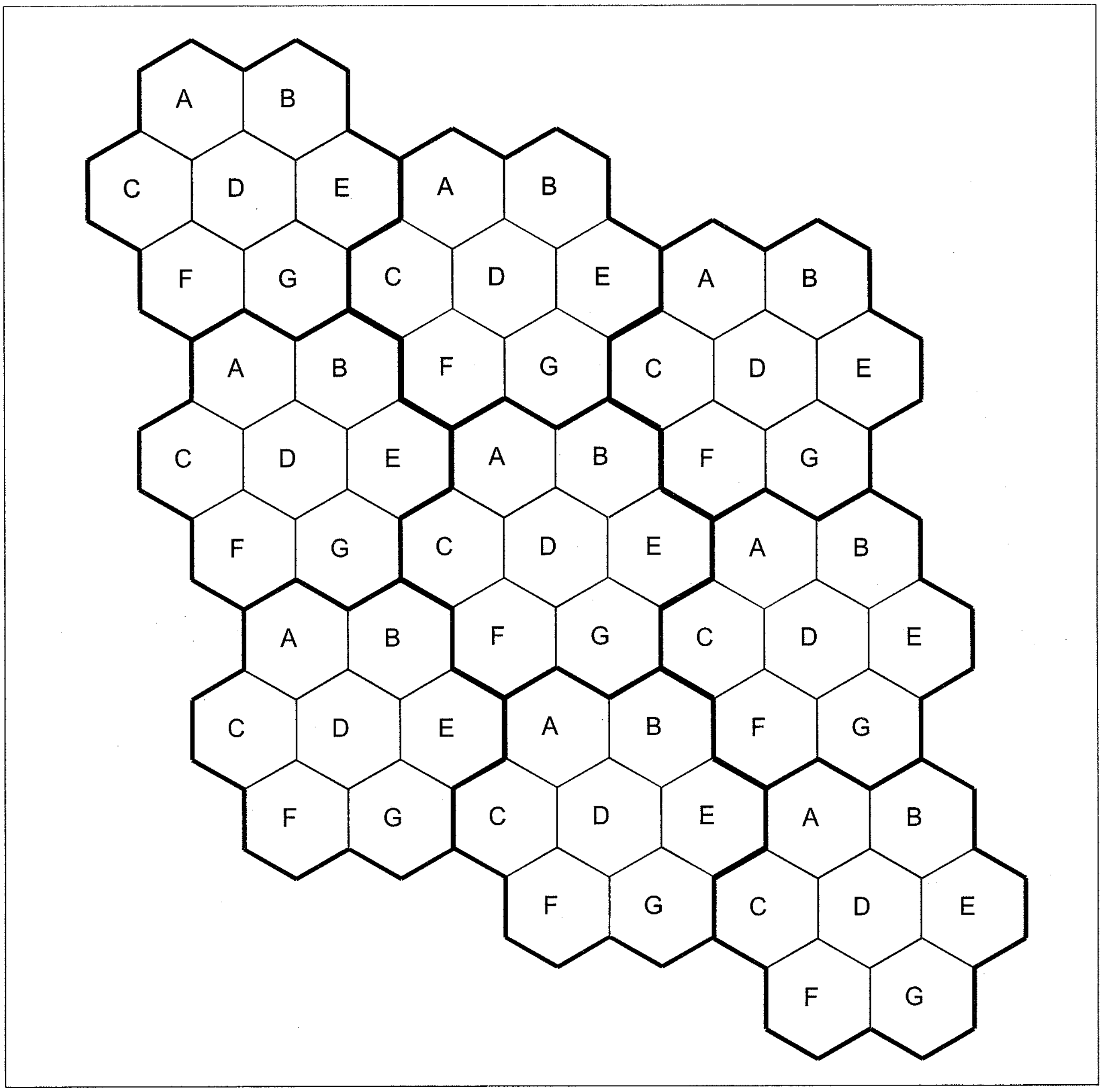


Figure D-4A. Single frequency GRAS VHF networking using multiple time slots

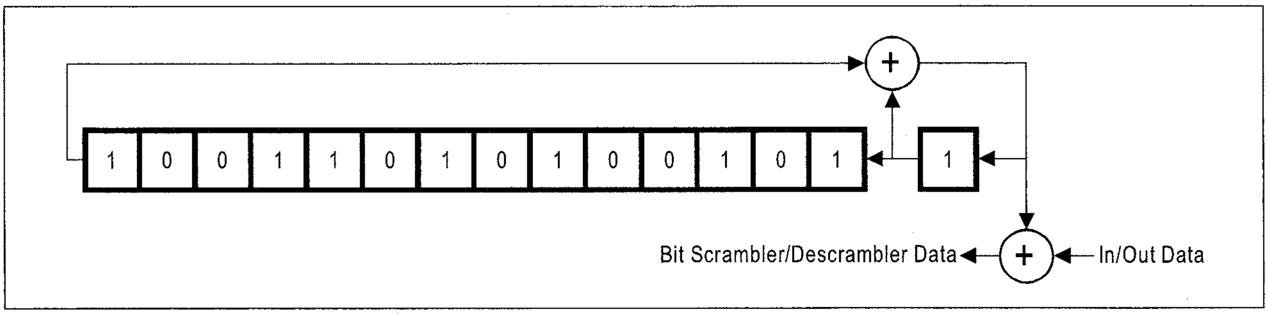
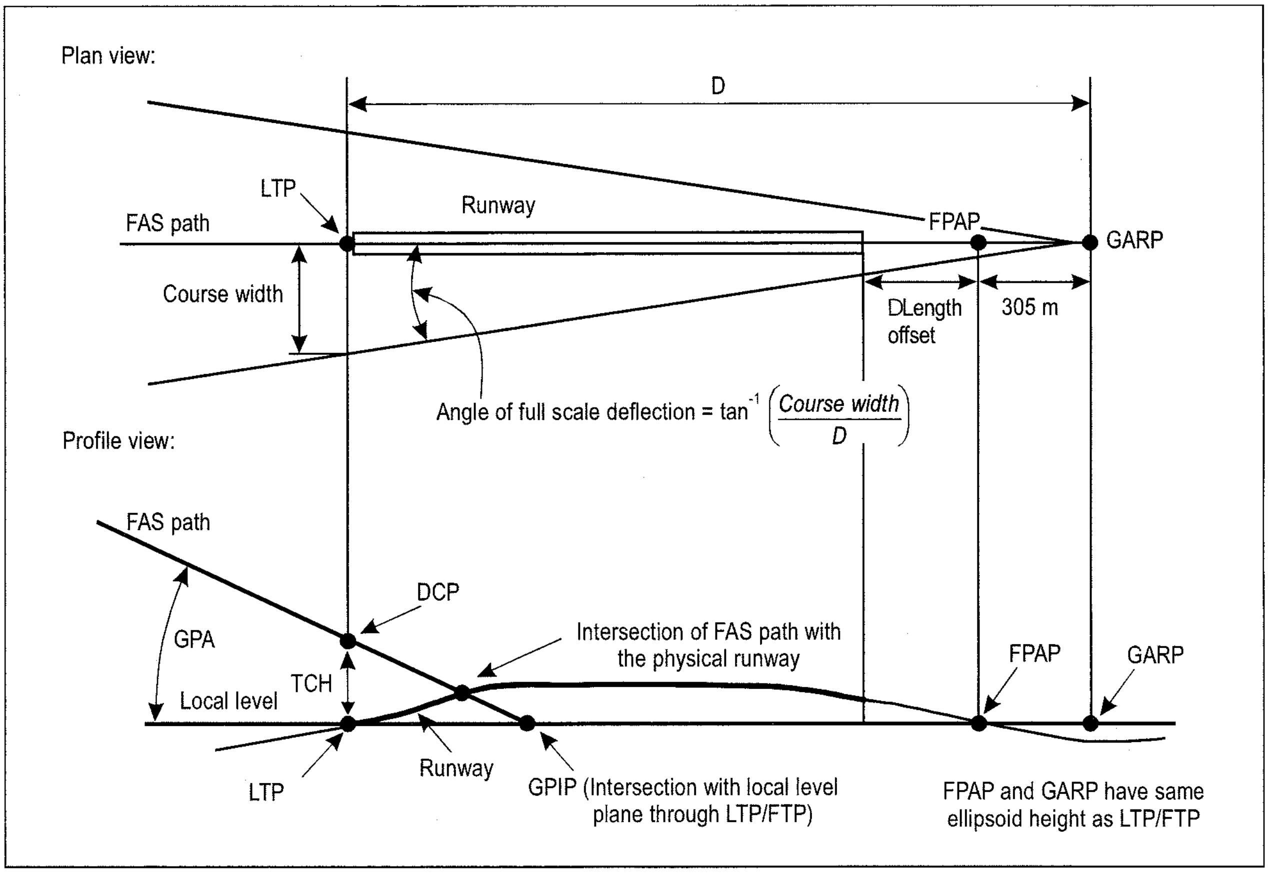
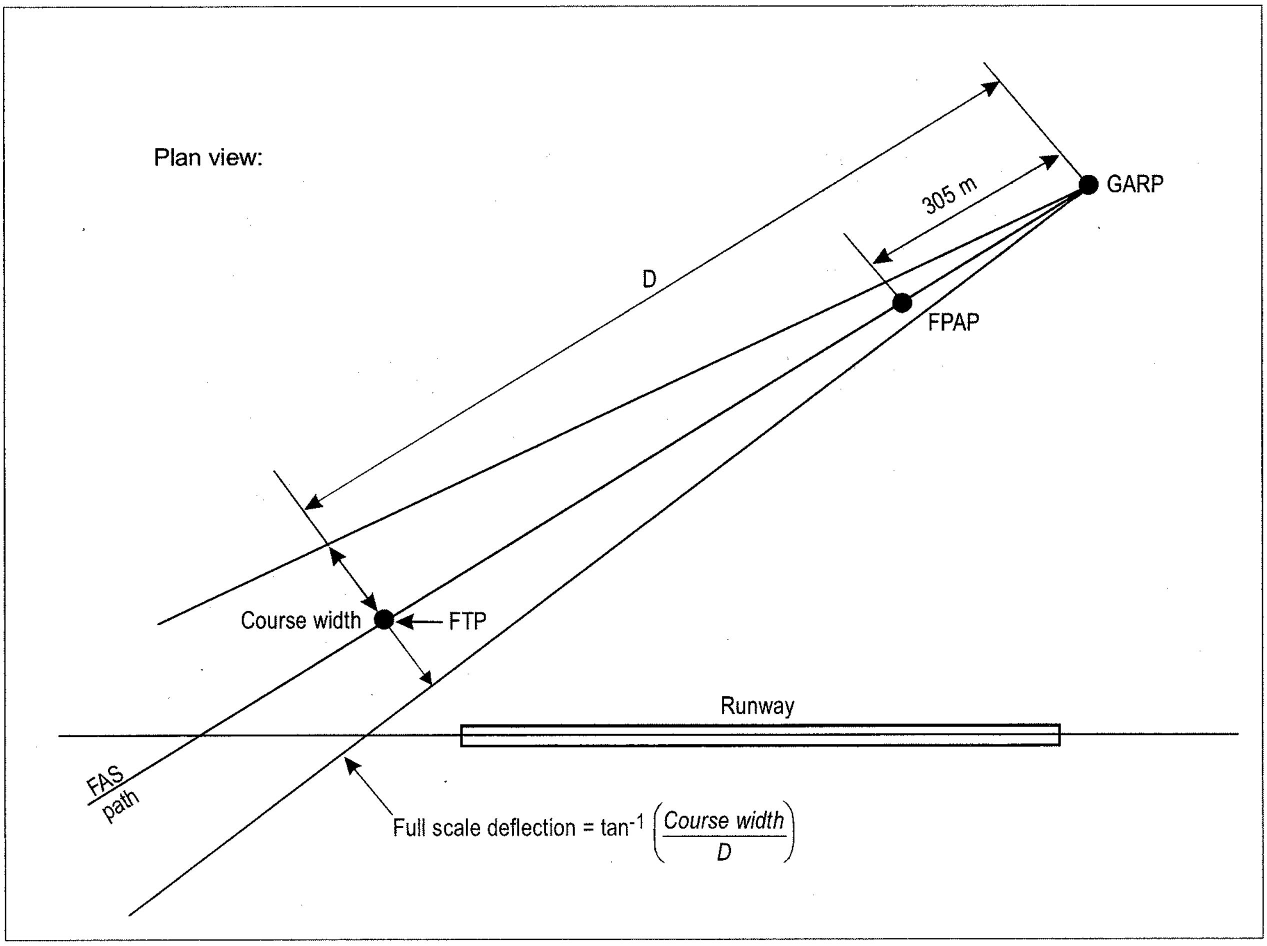


Figure D-5. Bit scrambler/descrambler



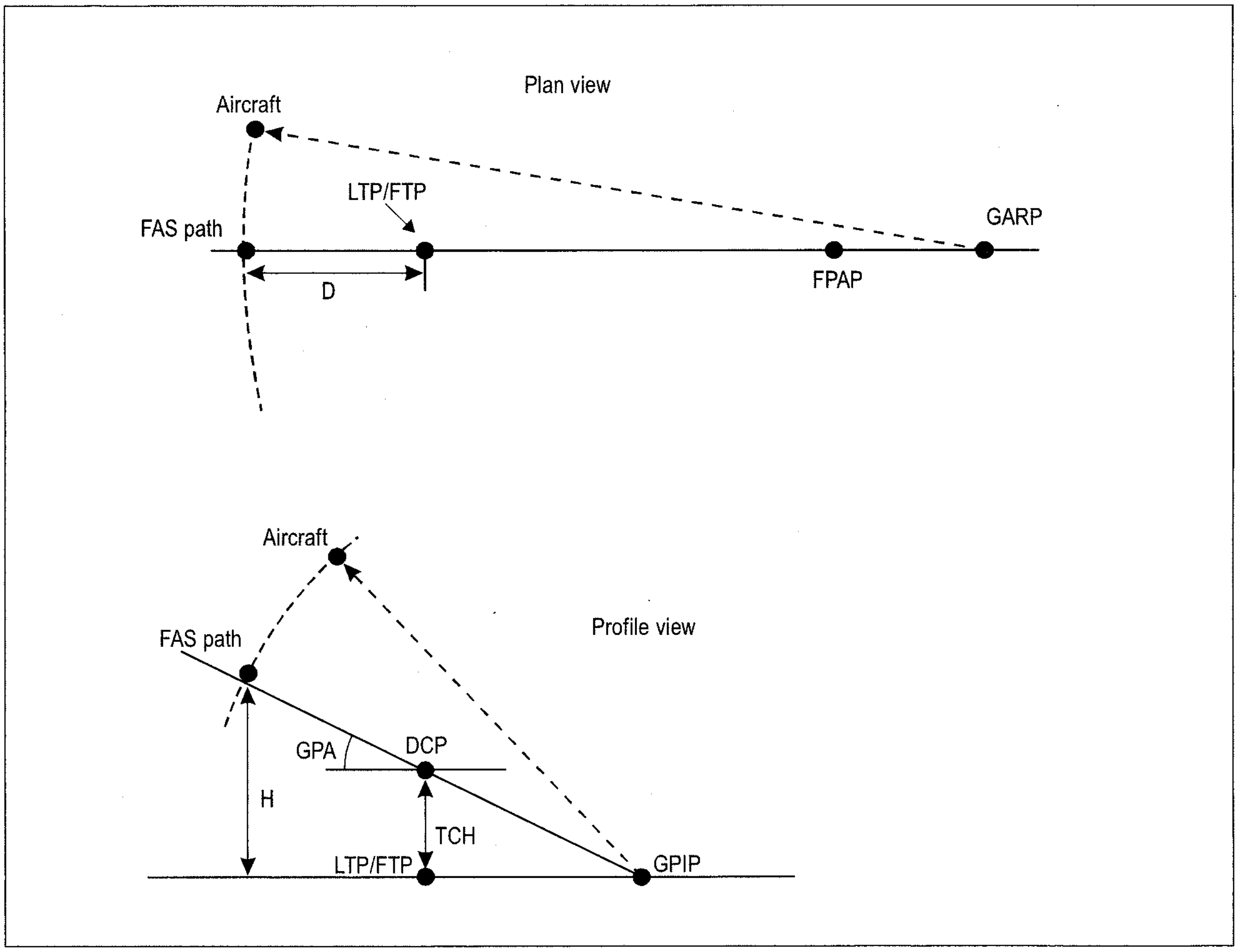
DCP — datum crossing point
FAS — final approach segment
FPAP — flight path alignment point
FTP — fictitious threshold point (see Figure D-7)
GARP — GBAS azimuth reference point
GPA — glide path angle
GPIP — glide path intersection point
LTP — landing threshold point
TCH — threshold crossing height

Figure D-6. FAS path definition



FAS — final approach segment
FPAP — flight path alignment point
FTP — fictitious threshold point
GARP — GBAS azimuth reference point

Figure D-7. FAS path definition for approaches not aligned with the runway



DCP — datum crossing point
FAS — final approach segment
FPAP — flight path alignment point
FTP — fictitious threshold point (see Figure D-7)
GARP — GBAS azimuth reference point
GPA — glide path angle
GPIP — glide path intersection point
LTP — landing threshold point
TCH — threshold crossing height

Figure D-8. Definition of D and H parameters in alert limit computations

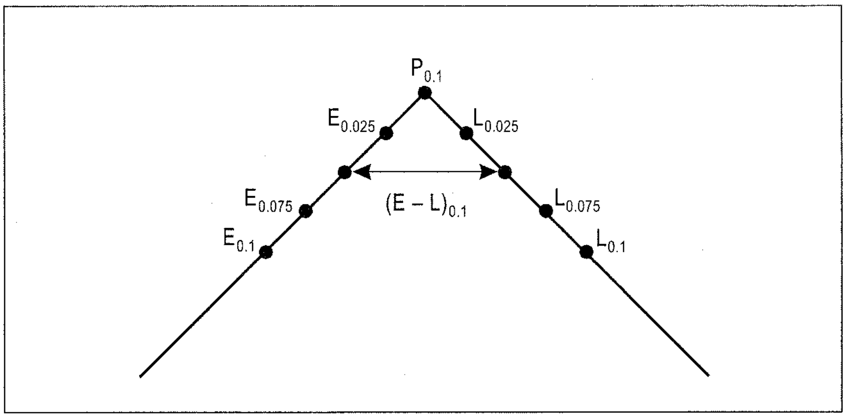


Figure D-9. "Close-in" correlation peak and measured correlator values

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ATTACHMENT E. GUIDANCE MATERIAL ON THE PRE-FLIGHT CHECKING OF VOR AIRBORNE EQUIPMENT

1. Specification for a VOR airborne equipment test facility (VOT)

1.1 Introduction

For the guidance of States wishing to provide a test signal for the pre-flight checking of VOR airborne equipment, suggested characteristics for a VOR airborne equipment test facility (VOT) are given hereafter.

1.2 General

1.2.1 The VOT must be designed to provide signals that will permit satisfactory operation of a typical VOR aircraft installation in those areas of the aerodrome where pre-flight checking is convenient and desirable.

1.2.2 The VOT must be constructed and adjusted so that the VOR bearing indicator in the aircraft will indicate zero degrees "FROM" when the receiver has not departed from calibration. This indication remains constant irrespective of the aircraft's angular position with respect to the VOT within the intended coverage.

1.2.3 In view of the manner in which use is made of a VOT, there is no fundamental need for its duplication at any one site.

1.2.4 The VOT is required to radiate a radio frequency carrier with which are associated two separate 30 Hz modulations. The characteristics of these modulations should be identical with the reference phase and variable phase signals associated with VOR. The phases of these modulations should be independent of azimuth and should be coincident with each other at all times.

1.3 Radio frequency

The VOT should operate in the band 108 to 117.975 MHz on an appropriate VOR channel selected so as not to interfere with any VHF navigation or communication services. The highest assignable frequency is 117.95 MHz. The frequency tolerance of the radio frequency carrier should be plus or minus 0.005 per cent, except as specified in Chapter 3, 3.3.2.2 and 3.3.2.3.

1.4 Polarization and accuracy

1.4.1 The emission from the VOT should be horizontally polarized.

1.4.2 The accuracy of the "bearing" information conveyed by the radiation from the VOT should be plus or minus 1 degree.

Note.— Since the two modulations on the radio frequency carrier are in phase coincidence at all times, the vestigial vertically polarized energy will have no effect on the accuracy of the facility.

1.5 Coverage

1.5.1 Coverage requirements, and hence the power which must be radiated, will necessarily depend to a considerable extent on local circumstances. For some installations, a small fraction of 1 W will suffice while in other cases, particularly if two or more closely adjacent aerodromes are to be served by a single test facility, several watts of radio frequency energy may need to be emitted.

1.5.2 Where there is a need to protect co-channel VORs, VOTs and ILS localizers from VOT interference, the radio emission must be limited to that required to provide satisfactory operation and to ensure that interference with other co-channel assignments does not occur.

1.6 Modulation

1.6.1 The radio frequency carrier as observed at any point in space should be amplitude modulated by two signals as follows:

a) a subcarrier of 9 960 Hz of constant amplitude, frequency modulated at 30 Hz and having a deviation ratio of 16 plus or minus 1 (i.e. 15 to 17);

b) 30 Hz.

1.6.2 The depth of modulation due to the 9 960 Hz and the 30 Hz signals should be within the limits of 28 per cent for each component.

1.6.3 The signal which frequency modulates the 9 960 Hz subcarrier and the signal which amplitude modulates the radio frequency carrier should both be maintained at 30 Hz within plus or minus 1 per cent.

1.6.4 The frequency of the 9 960 Hz subcarrier should be maintained within plus or minus 1 per cent.

1.6.5 The percentage of amplitude modulation on the 9 960 Hz subcarrier present at the output of the transmitter should not be greater than 5 per cent.

1.7 Identification

1.7.1 The VOT should transmit a 1 020 Hz identification signal. The identification code for a VOT installation should be selected by the competent authority so as to be unmistakably distinctive as to the test function and, if necessary, as to the location.

Note.— In one State, when the VOT coverage is confined to a single aerodrome, the identification consists of a continuous series of dots.

1.7.2 The depth to which the radio frequency carrier is modulated by the identification signal should be approximately 10 per cent.

1.8 Monitoring

1.8.1 Basically, there is no need for continuous automatic monitoring of VOT provided the relative phase of the AM and FM 30 Hz components are mechanically locked and facilities exist for periodic inspection and remote supervision of the state of the VOT.

1.8.2 Provision of automatic monitoring can double the cost of a VOT installation and, consequently, many competent authorities are likely to employ only remote supervision at a control point. However, where, in the light of the operational use to be made of a VOT, a State decides to provide automatic monitoring, the monitor should transmit a warning to a control point and cause a cessation of transmission if either of the following deviations from established conditions arises:

a) a change in excess of 1 degree at the monitor site of the "bearing" information transmitted by the VOT;

b) a reduction of 50 per cent in the signal level of the 9 960 Hz or 30 Hz signals at the monitor.

Failure of the monitor should automatically cause a cessation of transmission.

2. Selection and use of VOR aerodrome check-points

2.1 General

2.1.1 When a VOR is suitably located in relationship to an aerodrome, the pre-flight checking of an aircraft VOR installation can be facilitated by the provision of suitably calibrated and marked check-points at convenient parts of the aerodrome.

2.1.2 In view of the wide variation in circumstances encountered, it is not practicable to establish any standard requirements or practices for the selection of VOR aerodrome check-points. However, States wishing to provide this facility should be guided by the following considerations in selecting the points to be used.

2.2 Siting requirements for check-points

2.2.1 The signal strength of the nearby VOR has to be sufficient to ensure satisfactory operation of a typical aircraft VOR installation. In particular, full flag action (no flag showing) must be ensured.

2.2.2 The check-points should, within the limits of operating convenience, be located away from buildings or other reflecting objects (fixed or moving) which are likely to degrade the accuracy or stability of the VOR signal.

2.2.3 The observed VOR bearing at any selected point should ideally be within plus or minus 1.5 degrees of the bearing accurately determined by survey or chart plotting.

Note.— The figure of plus or minus 1.5 degrees has no direct operational significance in that the observed bearing becomes the published bearing; however, where a larger difference is observed, there is some possibility of poor stability.

2.2.4 The VOR information at a selected point should be used operationally only if found to be consistently within plus or minus 2 degrees of the published bearing. The stability of the VOR information at a selected point should be checked periodically with a calibrated receiver to ensure that the plus or minus 2-degree tolerance is satisfied, irrespective of the orientation of the VOR receiving antenna.

Note.— The tolerance of plus or minus 2 degrees relates to the consistency of the information at the selected point and includes a small tolerance for the accuracy of the calibrated VOR receiver used in checking the point. The 2-degree figure does not relate to any figure for acceptance or rejection of an aircraft VOR installation, this being a matter for determination by Administrations and users in the light of the operation to be performed.

2.2.5 Check-points which can satisfy the foregoing requirements should be selected in consultation with the operators concerned. Provision of check-points in holding bays, at runway ends and in maintenance and loading areas, is usually desirable.

2.3 Marking of VOR check-points

Each VOR check-point must be distinctively marked. This marking must include the VOR bearing which a pilot would observe on the aircraft instrument if the VOR installation were operating correctly.

2.4 Use of VOR check-points

The accuracy with which a pilot must position the aircraft with respect to a check-point will depend on the distance from the VOR station. In cases where the VOR is relatively close to a check-point, particular care must be taken to place the aircraft's VOR receiving antenna directly over the check-point.

ATTACHMENT F. GUIDANCE MATERIAL CONCERNING RELIABILITY AND AVAILABILITY OF RADIOCOMMUNICATIONS AND NAVIGATION AIDS

1. Introduction and fundamental concepts

This Attachment is intended to provide guidance material which Member States may find helpful in providing the degree of facility reliability and availability consistent with their operational requirement.

The material in this Attachment is intended for guidance and clarification purposes, and is not to be considered as part of the Standards and Recommended Practices contained in this Annex.

1.1 Definitions

Facility availability. The ratio of actual operating time to specified operating time.

Facility failure. Any unanticipated occurrence which gives rise to an operationally significant period during which a facility does not provide service within the specified tolerances.

Facility reliability. The probability that the ground installation operates within the specified tolerances.

Note.— This definition refers to the probability that the facility will operate for a specified period of time.

Mean time between failures (MTBF). The actual operating time of a facility divided by the total number of failures of the facility during that period of time.

Note.— The operating time is in general chosen so as to include at least five, and preferably more, facility failures in order to give a reasonable measure of confidence in the figure derived.

Signal reliability. The probability that a signal-in-space of specified characteristics is available to the aircraft.

Note.— This definition refers to the probability that the signal is present for a specified period of time.

1.2 Facility reliability

1.2.1 Reliability is achieved by a combination of factors. These factors are variable and may be individually adjusted for an integrated approach that is optimum for, and consistent with, the needs and conditions of a particular environment. For example, one may compensate to some extent for low reliability by providing increased maintenance staffing and/or equipment redundancy. Similarly, low levels of skill among maintenance personnel may be offset by providing equipment of high reliability.

1.2.2 The following formula expresses facility reliability as a percentage:

$$R = 100\, e^{-t/m}$$

where:

R = reliability (probability that the facility will be operative within the specified tolerances for a time t, also referred to as probability of survival, P_s);

e = base of natural logarithms;

t = time period of interest;

m = mean time between facility failures.

It may be seen that reliability increases as mean time between failures (MTBF) increases. For a high degree of reliability, and for operationally significant values of t, we must have a large MTBF; thus, MTBF is another more convenient way of expressing reliability.

1.2.3 Experimental evidence indicates that the above formula is true for the majority of electronic equipments where the failures follow a Poisson distribution. It will not be applicable during the early life of an equipment when there is a relatively large number of premature failures of individual components; neither will it be true when the equipment is nearing the end of its useful life.

1.2.4 At many facility types utilizing conventional equipment, MTBF values of 1 000 hours or more have been consistently achieved. To indicate the significance of a 1 000-hour MTBF, the corresponding 24-hour reliability is approximately 97.5 per cent (i.e. the likelihood of facility failure during a 24-hour period is about 2.5 per cent).

1.2.5 Figure F-1 shows the probability of facility survival, P_s, after a time period, t, for various values of MTBF.

Note.— It is significant that the probability of surviving a period of time equal to the MTBF is only 0.37 (37 per cent); thus, it is not assumed that the MTBF is a failure-free period.

1.2.6 It may be seen that adjustment of MTBF will produce the desired degree of reliability. Factors which affect MTBF and hence facility reliability are:

a) inherent equipment reliability;

b) degree and type of redundancy;

c) reliability of the serving utilities such as power and telephone or control lines;

d) degree and quality of maintenance;

e) environmental factors such as temperature and humidity.

1.3 Facility availability

1.3.1 Availability, as a percentage, may be expressed in terms of the ratio of actual operating time divided by specified operating time taken over a long period. Symbolically,

$$A = \frac{\text{Actual time operating (100)}}{\text{Specified operating time}}$$

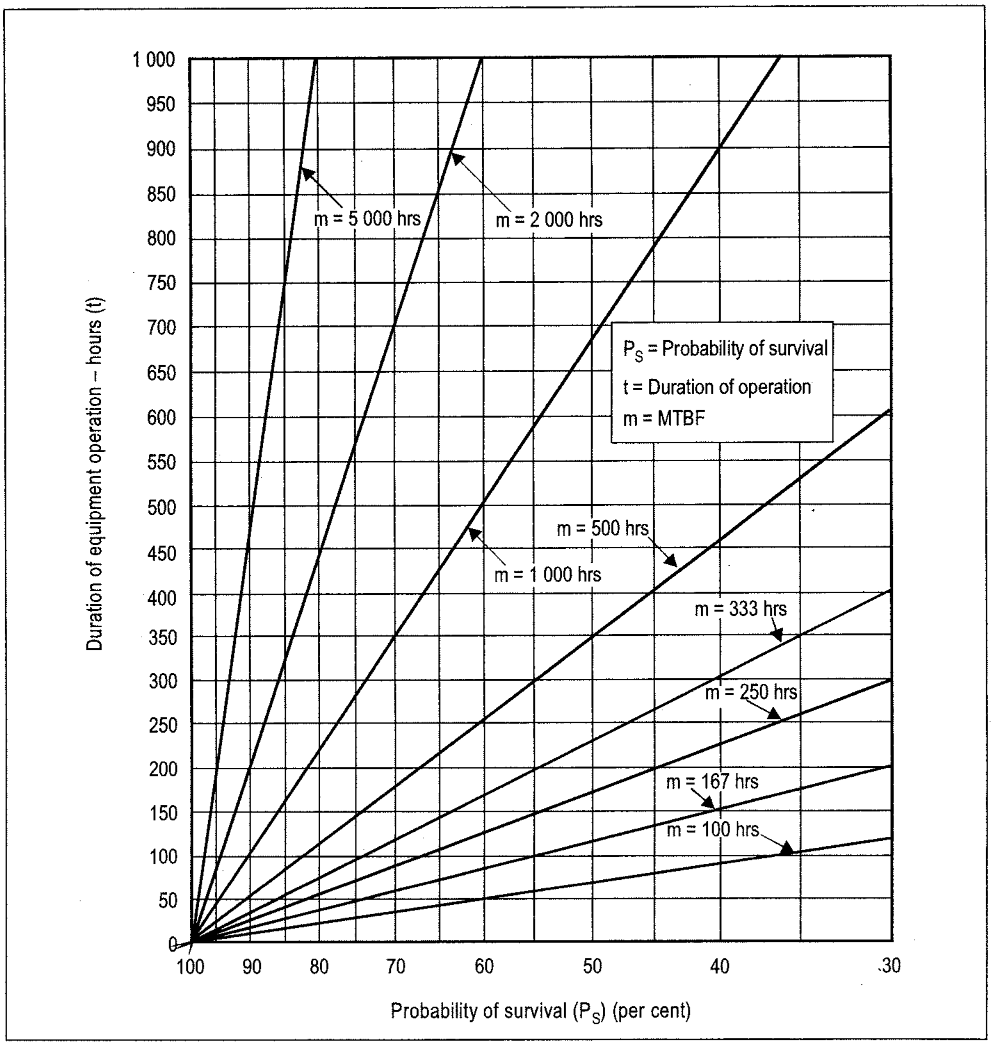


Figure F-1. Plot of $P_s = 100\ e^{-t/m}$

For example, if a facility was operating normally for a total of 700 hours during a 720-hour month, the availability for that month would be 97.2 per cent.

1.3.2 Factors important in providing a high degree of facility availability are:

a) facility reliability;

b) quick response of maintenance personnel to failures;

c) adequate training of maintenance personnel;

d) equipment designs providing good component accessibility and maintainability;

e) efficient logistic support;

f) provision of adequate test equipment;

g) standby equipment and/or utilities.

2. Practical aspects of reliability and availability

2.1 Measurement of reliability and availability

2.1.1 *Reliability.* The value that is obtained for MTBF in practice must of necessity be an estimate since the measurement will have to be made over a finite period of time. Measurement of MTBF over finite periods of time will enable Administrations to determine variations in the reliability of their facilities.

2.1.2 *Availability.* This is also important in that it provides an indication of the degree to which a facility (or group of facilities) is available to the users. Availability is directly related to the efficiency achieved in restoring facilities to normal service.

2.1.3 The basic quantities and manner of their measurement are indicated in Figure F-2. This figure is not intended to represent a typical situation which would normally involve a larger number of inoperative periods during the specified operating time. It should also be recognized that to obtain the most meaningful values for reliability and availability the specified operating time over which measurements are made should be as long as practicable.

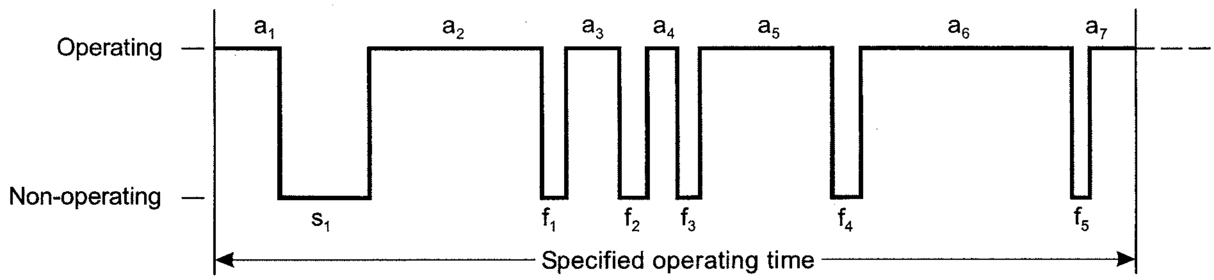


Figure F-2. Evaluation of facility availability and reliability

2.1.4 Using the quantities illustrated in Figure F-2, which includes one scheduled shutdown period and five failure periods, one may calculate mean time between failures (MTBF) and availability (A) as follows:

Let:

$a_1 + a_2 + a_3 + a_4 + a_5 + a_6 + a_7$	=	5 540	hours
s_1	=	20	hours
f_1	=	2½	hours
f_2	=	6¼	hours
f_3	=	3¾	hours
f_4	=	5	hours
f_5	=	2½	hours
Specified operating time	=	5 580	hours

$$\text{MTBF} = \frac{\text{Actual operating time}}{\text{Number of failures}}$$

$$= \frac{\sum_{i=1}^{7} a_1}{5}$$

$$= \frac{5\,540}{5} = 1\,108 \text{ hours}$$

$$A = \frac{\text{Actual operating time} \times 100}{\text{Specified operating time}}$$

$$= \frac{\sum_{i=1}^{7} a_i \times 100}{\sum_{i=1}^{7} a_i + s_1 + \sum_{i=1}^{5} f_i}$$

$$= \frac{5\,540}{5\,580} \times 100 = 99.3 \text{ per cent}$$

ATTACHMENT G. INFORMATION AND MATERIAL FOR GUIDANCE IN THE APPLICATION OF THE MLS STANDARDS AND RECOMMENDED PRACTICES

1. Definitions
(see also Chapter 3, 3.11.1)

Dynamic side-lobe level. The level that is exceeded 3 per cent of the time by the scanning antenna far field radiation pattern exclusive of the main beam as measured at the function scan rate using a 26 kHz beam envelope video filter. The 3 per cent level is determined by the ratio of the side-lobe duration which exceeds the specified level to the total scan duration.

Effective side-lobe level. That level of scanning beam side lobe which in a specified multipath environment results in a particular guidance angle error.

MLS point D. A point 2.5 m (8 ft) above the runway centre line and 900 m (3 000 ft) from the threshold in the direction of the azimuth antenna.

MLS point E. A point 2.5 m (8 ft) above the runway centre line and 600 m (2 000 ft) from the stop end of the runway in the direction of the threshold.

Standard receiver. The airborne receiver model assumed in partitioning the MLS error budgets. The salient characteristics are: (1) signal processing based on the measurement of beam centres; (2) negligible centring error; (3) control motion noise (CMN) less than or equal to the values contained in Chapter 3, 3.11.6.1.1.2; (4) a 26 kHz bandwidth 2-pole low pass beam envelope filter; and (5) angle data output filtering by a single pole, low pass filter with a corner frequency of 10 radians per second.

2. Signal-in-space characteristics — angle and data functions

2.1 Signal format organization

2.1.1 The signal format is based on time-division multiplexing wherein each angle guidance function is transmitted in sequence and all are transmitted on the same radio frequency. The angle information is derived by measuring the time difference between the successive passes of highly directive, unmodulated fan beams. Functions may be transmitted in any order. Recommended time slots are provided for the approach azimuth, approach elevation, flare, and back azimuth angle functions. Preceding each scanning beam and data transmission is a preamble which is radiated throughout the coverage volume by a sector antenna. The preamble identifies the next scan function and also synchronizes the airborne receiver signal processing circuits and logic.

2.1.2 In addition to the angle scan function, there are basic and auxiliary data functions, each with its own preamble, which are also transmitted from the sector antennas. The preamble permits each function to be recognized and processed independently. Consequently, functions can be added to or deleted from the ground configurations without affecting the operation of the receiver. The codes used in the preamble and data functions are modulated by differential phase shift keying (DPSK).

2.1.2.1 *DPSK data signal characteristics.* The DPSK data are transmitted by differential phase modulation of the radio frequency carrier with relative phase states of 0 or 180 degrees. The DPSK data signal has the following characteristics:

data rate — 15.625 kHz
bit length — 64 microseconds
logic "0" — no phase transition
logic "1" — phase transition

2.1.3 Examples of the angle function organization and timing are shown in Figures G-1 and G-2.* Details and definitions of the data items shown in Figure G-1 are given in Chapter 3, 3.11.4.8.

2.1.4 The sequences of angle guidance and data transmissions shown in Figures G-3A, G-3B and G-3C have been demonstrated to provide sufficient freedom from synchronous interference.

2.1.4.1 The structure of these sequences is intended to provide sufficient randomization to preclude synchronous interference such as may be caused by propeller rotation effects.

2.1.4.2 The sequence pair shown in Figure G-3A accommodates the transmission of all functions. Any function not required may be deleted so long as the remaining functions are transmitted in the designated time positions.

2.1.4.3 The sequence pair shown in Figure G-3B accommodates the high rate approach azimuth function. Any function not required may be deleted so long as the remaining functions are transmitted in the designated time positions.

2.1.4.4 Figure G-3C shows the complete time multiplex transmission cycle which may be composed of the sequence pairs from Figure G-3A or from Figure G-3B. The open time periods between sequences can be used for the transmission of auxiliary data words as indicated. Basic data words also may be transmitted in any open time period.

2.1.4.5 Sufficient time is available in the cycle shown for the transmission of the basic data and the auxiliary data defined in words A1-A4, B1-B39, B40-B45 and B55, provided that data are also transmitted during unused time slots or slots devoted for data words within the sequences.

2.1.4.6 More efficient sequences may be designed by adjusting the timing within the sequences and the inter-sequence gaps to allow the transmission of additional auxiliary data words. Such sequences must be designed to provide equivalent freedom from synchronous interference as the sequences shown in Figures G-3A, G-3B and G-3C. Frequency domain analysis techniques may be utilized to demonstrate that alternative sequences are sufficiently randomized.

2.2 Angle guidance parameters

2.2.1 The angle guidance parameters that define the MLS angle measurement process are specified in Chapter 3, 3.11.4.5. Two additional parameters that are useful in visualizing the operation of the system are the midscan time (T_m) and the pause time. They may be derived from the Chapter 3 specifications and are shown for reference in the following table.

* All figures are located at the end of the Attachment.

Signal format midscan and pause times
(see Figure G-2)

Function	*Midscan[1] time, T_m (μs)*	*Pause time (μs)*
Approach azimuth	7 972	600
High rate approach azimuth	5 972	600
Back azimuth	5 972	600
Approach elevation	2 518	400
Flare elevation	2 368	800

1 Measured from the receiver reference time (see Appendix A, Table A-1).

2.2.2 *Function timing accuracy.* Because of the inaccuracy in the determination of the reference time of the Barker code, and because the transmitter circuits smooth the phase or amplitude during phase transitions of the DPSK modulation, it is not possible to determine the timing of the signal with an accuracy better than 2 microseconds from the signal-in-space. It is therefore necessary to measure the timing accuracy specified in Chapter 3, 3.11.4.3.4 on the ground equipment. Suitable test points should be provided in the ground equipment.

2.3 Azimuth guidance functions

2.3.1 *Scanning conventions.* Figure G-4 shows the approach azimuth and back azimuth scanning conventions.

2.3.2 *Coverage requirements.* Figures G-5 and G-6 illustrate the azimuth coverage requirements specified in Chapter 3, 3.11.5.2.2.

2.3.2.1 When the approach or back azimuth antenna sites are necessarily offset from the runway centre line, the following factors should be considered:

a) coverage requirements throughout the runway region;

b) accuracy requirements at the applicable reference datum;

c) approach azimuth to back azimuth transition; and

d) potential disturbances due to moving vehicles, aircraft or airport structures.

2.3.2.2 An offset azimuth antenna is normally adjusted such that the zero-degree azimuth is either parallel to the runway centre line or intersects the centre line extended at an operationally preferred point for the intended application. The alignment of the zero-degree azimuth with respect to the runway centre line is transmitted on the auxiliary data.

2.3.3 *High rate approach azimuth.* Where the approach proportional guidance sector is plus or minus 40 degrees or less, it is possible to use a higher scanning rate for the azimuth function. The high rate approach azimuth function is available to offset the increase in CMN caused by large beamwidth antennas (e.g. 3 degrees). Reducing the CMN provides two benefits: 1) angle guidance signal-in-space power density requirements can be reduced; and 2) dynamic side-lobe level requirements can be relaxed.

2.3.3.1 In general, this function will reduce the CMN caused by wide bandwidth, uncorrelated sources such as diffuse multipath or receiver thermal noise by a factor of $\sqrt{1/3}$ relative to the basic 13 Hz function rate. However, the full reduction of power density by $\sqrt{1/3}$ cannot be realized for all ground antenna beamwidths because of the requirement to provide sufficient power density for signal acquisition on a single scan basis. The power required for DPSK transmissions may be such that no economies are realized in the ground equipment transmitters by using the higher data rate (see Table G-1).*

2.3.3.2 However, with respect to the CMN performance, the full benefit of the increased data rate can be realized. For example, at the minimum signal levels shown in Table G-2, the azimuth CMN can be reduced from 0.10 degree to 0.06 degree for the 1-degree and the 2-degree beamwidth antennas.

2.3.4 *Clearance*

2.3.4.1 Where used, clearance pulses are transmitted adjacent to the scanning beam signals at the edges of proportional guidance sector as shown in the timing diagram in Figure G-7. The proportional guidance sector boundary is established at one beamwidth inside the scan start/stop angles, such that the transition between scanning beam and clearance signals occurs outside the proportional guidance sector. Examples of composite waveforms which may occur during transition are shown in Figure G-8.

2.3.4.2 When clearance guidance is provided in conjunction with a narrow beamwidth (e.g. one degree) scanning antenna, the scanning beam antenna is to radiate for 15 microseconds while stationary at the scan start/stop angles.

2.3.4.3 At some locations it may be difficult to satisfy the amplitude criteria of Chapter 3, 3.11.6.2.5.2, because of clearance signal reflections. At these locations the scan sector may be extended.

2.3.4.4 Care is to be taken with respect to the fly-right/fly-left clearance convention change when approaching azimuth stations in an opposite direction (e.g. approach towards the back azimuth antenna).

2.3.5 *Approach azimuth monitoring.* The intention of monitoring is to guarantee the guidance integrity appropriate for the promulgated approach procedure. It is not intended that all azimuth angles be monitored independently, but that at least one approach azimuth, normally aligned with the extended runway centre line, be monitored and that adequate means be provided to ensure that the performance and integrity of the other azimuth angles are maintained.

2.3.6 *Lower coverage limit determination.* When the threshold is not in line of sight of the approach azimuth antenna, the height of the lower limit of the approach azimuth coverage in the runway region is determined by simulation and/or field measurements. The lower limit of the azimuth coverage to be published is the height above the runway surface that satisfies the accuracy requirements in Chapter 3, 3.11.4.9.4 as determined by field measurements.

2.3.6.1 If operations require coverage below the coverage limits obtainable from 2.3.6, the azimuth antenna can be offset from the runway centre line and moved toward the runway threshold to cover the touchdown region. The airborne installation must use the azimuth guidance, precision distance and siting coordinates of the ground equipment to compute the centre line approach.

2.3.6.2 The landing minima obtainable from a computed centre line approach are, among other things, a function of the combined reliability and integrity of the MLS approach azimuth, DME/P transponder and airborne equipment.

2.4 Elevation guidance functions

2.4.1 *Scanning conventions.* Figure G-9 shows the approach elevation scanning conventions.

* All tables are located at the end of the Attachment.

2.4.2 *Coverage requirements.* Figures G-10A and G-10B illustrate the elevation requirements specified in Chapter 3, 3.11.5.3.2.

2.4.3 *Elevation monitoring.* The intention of monitoring is to guarantee the guidance integrity appropriate for the promulgated approach procedure. It is not intended that all elevation angles be monitored independently, but that at least one, normally the minimum glide path, be monitored, and that adequate means be provided to ensure that the performance and integrity of the other elevation angles are maintained.

2.5 Accuracy

2.5.1 *General*

2.5.1.1 System accuracy is specified in Chapter 3, in terms of the path following error (PFE), path following noise (PFN), and control motion noise (CMN). These parameters are intended to describe the interaction of the angle guidance signal with the aircraft in terms which can be directly related to aircraft guidance errors and the flight control system design.

2.5.1.2 The system PFE is the difference between the airborne receiver angle measurement and the true position angle of the aircraft. The guidance signal is distorted by ground and airborne equipment errors and errors due to propagation effects. To assess the suitability of the signal-in-space for aircraft guidance, these errors are viewed in the pertinent frequency region. The PFE includes the mean course error and the PFN.

2.5.2 *MLS measurement methodology*

2.5.2.1 The PFE, PFN and CMN are evaluated by using the filters defined in Figure G-11. The filter characteristics are based on a wide range of existing aircraft response properties and are considered adequate for foreseeable aircraft designs as well.

2.5.2.2 While the term "PFE" suggests the difference between a desired flight path and the actual flight path taken by an aircraft following the guidance signal, in practice, this error is evaluated by instructing the flight inspection pilot to fly a desired MLS azimuth and recording the difference between the airborne equipment output guidance indication from the PFE filter and the corresponding aircraft position measurement as determined by a suitable position reference. A similar technique using the appropriate filter determines the CMN.

2.5.2.3 *Error evaluation.* The PFE estimates are obtained at the output of the PFE filter (test point A in Figure G-11). The CMN estimates are obtained at the output of the CMN filter (test point B in Figure G-11). Filter corner frequencies are shown in Figure G-11.

2.5.2.3.1 The PFE and CMN for approach azimuth or for back azimuth are evaluated over any 40-second interval of the flight error record taken within the coverage limits (i.e. $T = 40$ in Figure G-12). The PFE and CMN for approach elevation are evaluated over any 10-second interval of the flight error record taken within the coverage limits (i.e. $T = 10$ in Figure G-12).

2.5.2.3.2 The 95 per cent probability requirement is interpreted to be met if the PFE or CMN does not exceed the specified error limits for more than 5 per cent of the evaluation interval (see Figure G-12).

2.5.2.3.3 An alternative flight inspection procedure can be used which does not rely on an absolute reference. In this procedure, only the fluctuating components of the flight record produced at the output of the PFE filter are measured and compared with the PFN standard. The average value of the PFE is assumed to not exceed the mean course alignment specified during the flight inspection period. Therefore, the mean course alignment is added to the PFN measurement for comparison with the specified system PFE. The CMN may be similarly evaluated without accounting for the mean course alignment.

2.5.2.4 *Ground and airborne instrumentation errors.* The instrumentation error induced by the ground and airborne equipment may be determined by measurements taken in an environment which is free from reflected signals or other propagation anomalies which can cause beam envelope perturbations.

2.5.2.4.1 First, the instrumentation errors associated with the standard airborne receiver are determined using a bench test instrument, and the centring error is adjusted to zero. Airborne equipment errors can be measured by recording 40 seconds of data using a standard bench test set. The data can then be divided into four 10-second intervals. The average of each interval is considered to be the PFE while twice the square root of its associated variance is the CMN.

Note.— The receiver output may be evaluated using the PFE and CMN filters, if desired.

2.5.2.4.2 Second, this standard receiver is used to measure the total system instrumentation error by operating the ground equipment on an antenna range or in some other reflection-free environment. Since the receiver centring error has been made negligible, the measured PFE can be attributed to the ground equipment. The ground equipment CMN is obtained by subtracting the known standard receiver CMN variance from the CMN variance of the measurement. The average error over a 10-second measurement interval is considered to be the PFE, while twice the square root of the differential variances is considered to be the instrumental CMN.

2.6 Power density

2.6.1 *General*

2.6.1.1 Three criteria establish the angle power budgets:

a) angle single-scan acquisition requires a 14-dB signal-to-noise ratio (SNR) as measured at the beam envelope filter (i.e. the video SNR);

b) the angle CMN must be maintained within specified limits;

c) the DPSK transmissions must have a detection probability at the extremes of coverage of at least 72 per cent.

2.6.1.2 The source of CMN at 37 km (20 NM) is primarily internal receiver thermal noise. The noise induced error (dθ) can be estimated by:

$$d\theta = \frac{\theta_{BW}}{2\left(\sqrt{SNR}\sqrt{g}\right)}$$

$$g = \frac{\text{Function sample rate}}{2\ (\text{Filter noise bandwidth right})}$$

where θ_{BW} is the antenna beamwidth in degrees and *g* is the ratio of the function sample rate to the noise bandwidth of the receiver output filter. For a single pole filter, the noise bandwidth is $\pi/2$ times the 3 dB bandwidth. This expression reflects the CMN dependence upon ground antenna beamwidth and sample rate.

2.6.2 *System power budget*

2.6.2.1 The system power budget is presented in Table G-1. The power density specified in Chapter 3, 3.11.4.10.1, is related to the signal power specified in Table G-1 at the aircraft antenna by the relation:

$$\text{Power into isotropic antenna (dBm)} = \text{Power density (dBW/m}^2\text{)} - 5.5$$

2.6.2.2 The angle function measurement assumes a 26-kHz beam envelope filter bandwidth. The video (SNR) given in 2.6.1 is related to the intermediate frequency (IF) SNR by:

$$\text{SNR (Video)} = \text{SNR (IF)} + \\ +10\log\left[\frac{\text{IF noise bandwidth}}{\text{Video noise bandwidth}}\right]$$

2.6.2.3 The DPSK preamble function analysis assumes: 1) a carrier reconstruction phase lock loop airborne receiver implementation; and 2) that the receiver preamble decoder rejects all preambles which do not satisfy the Barker code or fail the preamble parity check.

2.6.2.4 Items a) through e) in Table G-1 are functions of the aircraft position or weather, and thus have been assumed to be random events. That is, they will simultaneously reach their worst-case values only on rare occasions. Therefore, these losses are viewed as random variables and are root-sum-squared to obtain the loss component.

2.6.2.5 To support autoland operations, power densities higher than those specified for the approach azimuth angle signals in Chapter 3, 3.11.4.10.1 are required at the lower coverage limit above the runway surface to limit the CMN to 0.04 degree. Normally, this additional power density will exist as a natural consequence of using the same transmitter to provide the scanning beam and DPSK signals and considering other power margins such as the available aircraft antenna gain, propagation losses, coverage losses at wide angles and rain losses which can be, at least partially, discounted in the runway region (see Table G-1).

2.6.3 *Airborne power budget*

2.6.3.1 Table G-2 provides an example of an airborne power budget used in developing the power density standards.

2.7 Data applications

2.7.1 *Basic data.* The basic data defined in Chapter 3, 3.11.4.8.2.1 are provided to enable airborne receivers to process scanning beam information for various ground equipment configurations and to adjust outputs so they are meaningful to the pilot or airborne system. Data functions are also used to provide additional information (e.g. station identification and equipment status) to the pilot or airborne system.

2.7.2 *Auxiliary data*

2.7.2.1 The auxiliary data defined in Chapter 3, 3.11.4.8.3.1 and 3.11.4.8.3.2 are provided to digitally uplink the following types of information:

a) *Data describing ground equipment siting geometry.* These are transmitted in words A1-A4 and in some of the words B40-B54.

b) *Data to support MLS/RNAV operations.* These are transmitted in words B1-B39.

c) *Operational information data.* These are transmitted in words B55-B64.

2.7.2.2 The rates of transmission of auxiliary data words are based on the following criteria:

a) Data that are required to be decoded within six seconds upon entering the MLS coverage volume should be transmitted with a maximum time between transmissions of 1 second (see 7.3.3.1.1).

b) Data that are required for an intended operation but are not required to be decoded within six seconds should be transmitted with a maximum time between transmissions of 2 seconds. This rate will allow the generation of a warning upon loss of data within 6 seconds.

c) Operational information data should be transmitted with a maximum time between transmissions of 10 seconds. This will allow the generation of a warning upon loss of data within 30 seconds.

2.7.3 *Application of MLS/RNAV data words B1 through B39*

2.7.3.1 The data contained in auxiliary data words B1-B39 are designed to allow MLS/RNAV operations to be supported utilizing only the data contained within the MLS data words. In order to support computed centre line approaches to both the primary and secondary runways, curved approaches and departures, and missed approaches, these data include information on procedure type (approach or departure), procedure name, runway and way-points.

2.7.3.2 The data transmitted by approach azimuth and back azimuth are segregated. This means, for example, that each will have a separate cyclic redundancy check (CRC) and be decoded independently by the airborne equipment. Data for a given MLS/RNAV procedure are transmitted in the coverage where the procedure begins. Normally this means that approach and missed approach data would be transmitted by approach azimuth and departure data would be transmitted by back azimuth equipment. However, way-points belonging to approaches, missed approaches or departures could be transmitted in either the azimuth or the back azimuth coverage. For example, a departure may be initiated in approach azimuth coverage, therefore that data would be transmitted by approach azimuth. If the procedure begins in a common coverage region the associated data can be transmitted in only one region, except where otherwise dictated by operational requirements.

2.7.3.3 The procedures are defined by a series of way-points. The way-points are specified in a cartesian coordinate system with X, Y and Z coordinates whose origin is at the MLS datum point. The coordinate system is illustrated in Figure G-13.

2.7.3.4 The segments between way-points are either straight or curved. Curved segments are defined as the arc joining two way-points, as illustrated in Figure G-14. The arc of the circle is always tangent to the preceding and following segments, straight or circular. Final approach segments and segments pointing to the initial way-point of an approach procedure or extending from the last flown way-point of a departure or missed approach procedure are always straight. They are extensions to straight segments or tangents to circular segments. These straight segments would not necessarily require a way-point at the edge of the coverage, thus way-points could be saved.

2.7.3.5 For any procedure type the coding starts with the way-point farthest from the threshold and ends with the way-point nearest to the runway. All way-points for approach procedures must be coded before any missed approach way-points or departure way-points. This rule simplifies the decoding by segregating the way-points belonging to the approaches from the others. Several procedures can share one or more way-points. When this is the case it is feasible to transmit this information only once. The shared way-points must be the final ones for approach procedures and the initial ones for missed approach and departure procedures. Approaches, missed approaches and departures can share data provided the data are transmitted in the same coverage sector. When way-points are shared with a procedure previously defined in the database this is indicated by a way-point index following a way-point. The way-point index gives the location in the database of the first shared way-point.

2.7.3.6 The way-point index is the value representing the sequential order in which the way-points are listed in the database. It is used in the coding to indicate where the way-points for a procedure are located. A way-point index of zero in the procedure descriptor indicates that this is a computed centre line application where no way-points are provided.

2.7.3.7 Although way-points are defined by X, Y and Z coordinates, in a variety of cases not all coordinates have to be transmitted. Way-points located on the primary runway centre line have a Y coordinate equal to zero. The corresponding field defining this value can be omitted by setting the "Y coordinate follows" bit to ZERO.

2.7.3.8 Whenever the Z coordinate is not necessary for path construction, data can be saved by not transmitting this value. This is indicated by setting the "Z coordinate follows" bit to ZERO. This may apply to initial way-points preceding the final approach fix where guidance is based on altimetry and not on a computed MLS vertical position. It may also apply to way-points located on a constant gradient between way-points for which the Z value is defined. In this case, the airborne equipment would compute the Z coordinate assuming a constant gradient. Missed approach and departure way-points located in back azimuth coverage are also candidates for deleting the Z coordinate, since vertical guidance is not available. For the back azimuth application, the Z coordinate may be transmitted for use by the airborne equipment to resolve the horizontal position of the aircraft. This allows for a reduction of the lateral errors introduced in the conversion from the slant range and conical back azimuth angle to X-Y coordinates.

2.7.3.9 The 3-bit field following the way-point coordinates contains the next segment/field identifier. This data item indicates whether the next segment of the procedure is straight or curved, whether the current way-point is the last one defined for the procedure, and whether to link the procedure to a missed approach or a shared portion of another procedure identified by a missed approach index or next way-point index. It also indicates whether a data field for threshold crossing height or virtual azimuth to way-point distance is appended to the way-point definition.

2.7.3.9.1 Some typical applications of the identifiers in Appendix A, Table A-17 are listed below. This list is not all inclusive:

a) identifiers 0 and 1 are used when the next way-point in the procedure is not a shared way-point, or is a shared way-point coded for the first time;

b) identifiers 2 and 3 are used to refer to the next way-points in the procedure that are already coded and shared with another procedure. The coding of these way-points is not repeated but the index allows the connection of the procedure to the shared way-points of the other procedure;

c) identifiers 4 and 5 are used in the next-to-last way-point for procedures ending or beginning on the primary runway. The last way-point is the threshold. For this way-point only, the threshold crossing height is specified since the exact location of the threshold with respect to the MLS datum is given in the auxiliary A words. Identifier 4 is used when the MLS/RNAV missed approach guidance is not required, and identifier 5 is used when a "missed approach index" follows;

d) identifiers 6 and 7 are used for the final way-point of any procedure except as noted in c) above. For the primary runway these identifiers are used if there is a need to fully specify the X, Y and Z coordinates of the last way-point. These identifiers are also used for secondary runways and helipads. Identifier 6 is used when no missed approach is following and identifier 7 when a missed approach follows; and

e) identifiers 5 and 7 do not apply to missed approaches and departures.

2.7.3.10 Following the convention for other MLS basic and auxiliary data, all digital data encoded in the database are transmitted with the least significant bit first and the sign bit is transmitted as the most significant bit, with a ONE indicating a negative value. It is noted that the auxiliary data word addresses used to indicate the last approach azimuth database word and the first back azimuth database word are transmitted with the most significant bit first.

2.7.4 *Example application of MLS/RNAV data words*

2.7.4.1 The following paragraphs provide an example of the data assignment process for MLS/RNAV data words contained in auxiliary data words B1-B39. A sample set of approach and departure procedures is provided and the process by which the various way-points and associated procedure characteristics are interpreted and formatted for transmission is described.

2.7.4.2 Table G-3 depicts a set of sample approach, missed approach, and departure procedures for two hypothetical runways. Table G-4 contains way-point data for the sample procedures indicated in Table G-3 and illustrated in Figure G-15.

2.7.4.3 Prior to inserting the procedures data into the structure of B1-B39, the characteristics of the MLS/RNAV data must be understood in order to optimally use the available number of data words. In the data set of Tables G-3 and G-4, the following specific characteristics can be noted: procedures KASEL and NELSO share the same way-points No. 1 (WP 1) and No. 2 (WP 2); procedures KASEL and NELSO link to a missed approach procedure; procedure SEMOR is a secondary runway approach; procedure LAWSO is a departure procedure and will be transmitted in back azimuth coverage; all way-points outside of the precision final approach fix (PFAF) will not require the Z coordinate to be transmitted; the Y coordinate will not have to be transmitted for several way-points that are located on the extended primary runway centre line.

2.7.4.4 Data word B1 specified in Appendix A, Table A-15, defines the structure of the MLS/RNAV data to be transmitted in the approach azimuth coverage sector. This word also contains the approach azimuth CRC code. The number of procedures to be transmitted in the approach azimuth sector is 3. This can be determined from Table G-3. The data word address with the last approach azimuth MLS/RNAV data word is determined after the complete set is inserted into the format. In this case, the address of the last word is B11. The CRC code is calculated as described in Note 3 to Table A-15. Words B42 and B43 are not transmitted so that the relevant bits are set to ZERO. Word A4 is transmitted so that the relevant bit is set to ONE. The coding for data word B1 is shown in Table G-5.

2.7.4.5 Data word B39 specified in Appendix A, Table A-15 defines the structure of the MLS/RNAV data to be transmitted in the back azimuth coverage sector. This word also contains the back azimuth CRC code. The number of procedures to be transmitted in the back azimuth sector is 1. The data word address with the first back azimuth MLS/RNAV data word is determined after the complete set is inserted into the format. In this case the address of the first word is B36. The CRC code is calculated as described in Note 3 to Table A-15. Word B43 is not transmitted so that bit is set to ZERO. The back azimuth map/CRC indicator bit is set to ONE to indicate that this is a map/CRC word. The coding for data word B39 is shown in Table G-5.

2.7.4.6 Procedure descriptor words specified in Appendix A, Table A-15 are defined for all approach and departure procedures. Missed approach procedures are linked to approach procedures in the data format and hence do not require a procedure descriptor. Procedure descriptor words for the sample data set are shown in Table G-6. It is noted that the procedure descriptor data words cannot be fully defined until the completion of the actual assignment of the way-point data due to the need for a "first way-point index" associated with each procedure. This item is the first way-point for the procedure sequence. The index is generated as indicated in 2.7.3.6. It is noted that the "validity indicator" of a procedure name (see Table G-4) is the version number of the procedure and is a value from 1 to 9.

2.7.4.7 The way-point data assignment process is in accordance with Appendix A, Tables A-15, 16 and 17. Table G-7 represents the assignment of the sample data set. The preambles, addresses and parity bits have been left out of the table. Starting with the data word immediately after the approach procedure descriptor words, the first way-point of the first procedure is assigned. For the sample data set, it means that data word B5 is the first word with way-point data. The next step is to insert the data into the appropriate format. The procedures data always commence with the X coordinate of the initial way-point. The structure of the database allows for individual data items to overlap between auxiliary data words. For example, the first 14 bits of the X coordinate of WP 3 of procedure KASEL are transmitted in word B5. The final bit is transmitted in word B6.

2.7.4.7.1 Because of the bit weight of the way-point coordinate least significant bit, the coded way-point coordinate must be rounded. It is desirable to achieve a result as close as possible to the actual way-point coordinate value. Such rounding is normally performed by adding to the actual value half the weight of the LSB then performing integer division on the result. For example, the X coordinate of WP 2 of procedure KASEL is 6 556 m (actual). The coded binary value should be 2 561 since,

$$Integer\left[\frac{\left(|\,6\,556\,|+\frac{2.56}{2}\right)}{2.56}\right] = 2\,561$$

For negative numbers the sign bit should be carried through the calculation.

2.7.4.8 After the X coordinate is the "Y coordinate follows" bit. This bit would be set to zero, and the Y coordinate would not be transmitted as shown in Table G-7 for KASEL WP 2 and WP 1. As shown in KASEL WP 3, the Y coordinate is needed and is transmitted after the "Y coordinate follows" bit.

2.7.4.9 Depending on the coding of the "Y coordinate follows" bit, the "Z coordinate follows" bit is coded after the Y coordinate information. For procedure KASEL, WP 4 does not require the Z coordinate since it is prior to the PFAF. The Z coordinate is also not required for WP 2 because there is a constant glide path between WP 3 and WP 1. As shown in KASEL WP 3, the Z coordinate is needed and is transmitted after the "Z coordinate follows" bit.

2.7.4.10 The next segment/field identifier is assigned in accordance with Appendix A, Table A-17. For the identifier following WP 2 in procedure KASEL, the value 5 indicates that the threshold way-point height is transmitted next, followed by the way-point index of the missed approach procedure. For procedure NELSO, since the last two way-points are shared with procedure KASEL the identifier following WP 3 has the value 3, indicating that the index for the next way-point is transmitted next. In this case the index is 3, pointing to WP 2 of procedure KASEL. For the missed approach procedure the identifier is set to 6, indicating that this is the last way-point in the procedure. For secondary runway procedure SEMOR the identifier is also set to 6. In this case, however, it indicates that the virtual azimuth to way-point distance follows.

2.7.4.11 Table G-8 shows the assignment of the departure procedure way-points. The departure data start with word B36, the procedure descriptor. The way-points data begin with word B37. Departure data are assigned using the same method as for the approach data.

2.7.4.12 After the database is completely assigned, the CRC values may be calculated using B1-B39 and the other required data items. Table G-9 shows the results of this calculation for the sample data set including the auxiliary A words, basic word B6, and auxiliary words B40-B41.

2.8 Adjacent channel interference considerations

2.8.1 The standard has been structured such that there is at least a 5-dB margin to account for variations in the effective radiated power above the minimum power density specification. The interference specification is based upon worst-case antenna beamwidth combinations, data rate, and undesired interference synchronization.

3. Ground equipment

3.1 Scanning beam shape

3.1.1 The azimuth scanning beam envelope on the antenna boresight and the elevation scanning beam envelope at the preferred elevation angle, as detected by a standard receiver, has to conform to the limits specified in Figure G-16 under conditions of high SNR and negligible multipath (e.g. during a trial on an antenna range). The –10 dB symmetry relative to accuracy performance is not necessarily expected in the equipment design.

3.2 Scanning beam side lobes

3.2.1 *Performance specification.* The antenna side-lobe design has to satisfy two conditions: 1) the dynamic side-lobe level does not prevent the airborne receiver from acquiring and tracking the main beam. Satisfactory performance cannot be assured if dynamic side lobes persist at levels above –10 dB; 2) the effective side-lobe level is compatible with the system error budget.

3.2.2 The effective side-lobe level (P_{ESL}) is related to the dynamic side-lobe level (P_{DYN}) by:

$$P_{ESL} = K \times P_{DYN}$$

where K is a reduction factor which depends upon the antenna implementation. The reduction factor may be dependent upon:

a) a directive antenna element pattern which reduces the multipath signal level relative to the coverage volume;

b) the degree of randomness in the dynamic side lobes.

Note.— The dynamic side lobes are of least concern, if the measured dynamic side-lobe levels are less than the specified effective side-lobe levels.

3.2.3 Lateral multipath reflections from the azimuth antenna side lobes and ground multipath reflections from elevation antenna side lobes can perturb the main beam and induce angular errors. To ensure that the error dv generated by the antenna side lobes is within the propagation error budgets, the required effective side-lobe level ESL can be estimated using:

$$P_{ESL} = \frac{d\theta}{\theta_{BW} P_R P_{MA}}$$

where P_R is the multipath obstacle reflection coefficient, θ_{BW} is the ground antenna beamwidth and P_{MA} is the motion averaging factor.

3.2.4 The motion averaging factor depends on the specific multipath geometry, the aircraft velocity, the function data rate and the output filter bandwidth. For combinations of multipath geometry and aircraft velocity such that the multipath scalloping frequency is greater than 1.6 Hz, the motion factor is:

$$P_{MA} = \sqrt{\frac{2\ (\text{output filter noise bandwidth})}{\text{Function data rate}}}$$

3.2.5 This factor can be further reduced at higher multipath scalloping frequencies where the multipath-induced beam distortions are uncorrelated within the time interval between the TO and FRO scans.

3.3 Approach elevation antenna pattern

3.3.1 If required to limit multipath effects, the horizontal radiation pattern of the approach elevation antenna gradually de-emphasizes the signal away from the antenna boresight. Typically the horizontal pattern of the approach elevation antenna is to be reduced by 3 dB at 20 degrees off the boresight and by 6 dB at 40 degrees. Depending on the actual multipath conditions, the horizontal radiation pattern may require more or less de-emphasis.

3.4 Approach/back azimuth channels

3.4.1 When a runway has MLS installed for both approach directions, the equipment not in use for the approach may be operated as a back azimuth. If it is desired to assign different channels to each runway direction, necessarily the azimuth units will be operated on different frequencies depending on the mode of operation — approach or back azimuth. Care must be taken in the channel assignments so that the two frequencies are close enough to avoid any mechanical adjustment of the azimuth antenna vertical pattern when the approach direction is reversed.

3.4.2 The frequency separation should be limited such that the loss in pattern gain for back azimuth (from the optimum approach value) can be accommodated by the transmitter power margins shown in Table G-1 for the back azimuth function.

4. Siting considerations

4.1 MLS/ILS collocation

4.1.1 *MLS elevation antenna*

4.1.1.1 *Introduction*

4.1.1.1.1 When collocating an MLS elevation antenna with an ILS glide path, a series of decisions will have to be made to determine an elevation antenna location. Siting criteria have been developed based on minimizing the effects of MLS elevation equipment on the ILS glide path signal. This criteria along with signal-in-space, operational, critical areas, and obstacle clearance considerations will influence the final location of the elevation antenna.

4.1.1.1.2 The purpose is to start with a general region for siting the elevation antenna and then to reduce this region to an optimum location for a particular facility. This goal is achieved by stepping through a series of factors and considerations. This decision-making process is shown as a logic flow diagram in Figure G-17. These guidelines are not intended to be an all-inclusive MLS siting manual, but only to provide additional guidance when MLS collocation with ILS is required.

4.1.1.1.3 Referring to Figure G-17, the section number corresponds to one of the three siting geometries, that is 4.1.1.2 for "siting the elevation antenna between the glide path and runway", etc. The numbers in each block reference the specific paragraph in the supporting text for Figure G-17. This paragraph provides a more detailed description of the factor(s) to be considered for that step.

4.1.1.1.4 The two general regions for siting the elevation antenna are shown in Figure G-18. Depending on the location of the glide path, either one region or the other may not exist. In addition, these regions must already satisfy signal-in-space criteria prior to their consideration.

4.1.1.2 *Siting the elevation antenna between the glide path and the runway*

4.1.1.2.1 The setback for the elevation antenna is dependent upon the MLS approach reference datum (ARD) height. The MLS ARD must satisfy the criteria stated in Chapter 3, 3.11.4.9.1. The elevation antenna setback can be determined by the equation (see Figure G-19):

$$SB = \frac{ARDH - RPCH}{\tan\theta} \geq \frac{15 - RPCH}{\tan\theta}$$

Where:

all distances are in metres;

SB is the setback distance of the elevation antenna phase centre from the runway threshold, parallel to the runway centre line;

RPCH is the relative phase centre height of the elevation antenna compared to the runway surface at threshold. (This includes the elevation antenna phase centre height and the difference in terrain elevation between the threshold and the elevation antenna site.);

ARDH is the desired MLS approach reference datum height; and

θ is the minimum glide path.

4.1.1.2.2 The conical coordinate system of the elevation antenna and its offset from centre line will cause the minimum glide path elevation guidance to be above the approach reference datum. Considering the recommendation of Chapter 3, 3.11.5.3.5.2.2 this offset should be limited by the following equation:

$$(OS)^2 + (SB)^2 \leq \left[\frac{(18 - RPCH)}{\tan\theta}\right]^2$$

Where:

all distances are in metres; and

OS is the offset distance between the elevation antenna phase centre and the vertical plane containing the runway centre line (see Figure G-19).

4.1.1.2.3 Furthermore, the MLS ARD should be coincident with the ILS reference datum within one metre as stated in Chapter 3, 3.11.5.3.5.3. This is given in the following equation:

$$\frac{RDH - 1 - RPCH}{\tan\theta} \leq SB \leq \frac{RDH + 1 - RPCH}{\tan\theta}$$

Where:

all distances are in metres; and

RDH is the height of the ILS reference datum.

4.1.1.2.4 To determine the diagonal boundary for Region 1 of Figure G-18 two factors need to be considered. The first factor is that the elevation antenna must not penetrate the region through which the Fresnel zone for the ILS glide path migrates during an approach. In general, this requirement can be achieved by siting the elevation antenna to the runway side of the diagonal line between the glide path antenna mast and the runway centre line at threshold. The value for φ in Figure G-18 is dependent on the location of the glide path antenna mast relative to centre line at threshold. The second factor is to minimize lateral penetration of the glide path antenna pattern (see 4.1.1.3.2). However, for this elevation antenna region satisfying the second factor is preferable but not essential.

4.1.1.2.5 After determining the acceptable range of elevation antenna locations based on the above criteria, the minimum elevation antenna offset is determined by the obstacle limitation requirements in Annex 14, Chapter 4.

4.1.1.2.6 When possible the elevation antenna location is to be adjusted to minimize the effects of the elevation antenna critical area on flight operations. Furthermore, it may be desirable to choose the elevation antenna location in a way which maximizes the union of the MLS elevation critical area and the ILS glide path critical area. This union will minimize any enlargement of the combined critical areas. Due to the necessity to site the elevation antenna in front of the glide path, the elevation antenna will normally have to be sited in the glide path critical area. For elevation antenna critical areas see Section 4.3. For a description of the glide path critical area see Attachment C, Section 2.1.10.

4.1.1.2.7 Once the site for the elevation antenna has been identified, a location for the elevation antenna monitor must be found. The elevation signal is to be monitored as stated in 2.4.3. The height of the elevation field monitor is dependent on the use of integral monitoring of the minimum glide path and obstacle clearance criteria. The following considerations may be helpful in determining a monitor location:

a) It is desirable to have the field monitor as close to the far field as practical to minimize near field effects on the monitor. However, this distance is to be limited to avoid false alarms due to vehicle and aircraft traffic between the field monitor and the antenna.

b) It is desirable to minimize blockage and distortion of the elevation signal by the monitor in the final approach region. This may be achieved if the monitor location is offset up to 30 degrees from the elevation antenna boresight and at distances from 40 m (130 ft) to 80 m (260 ft) depending on particular equipment designs.

c) The field monitor offset from the antenna boresight is to be limited to maintain the appropriate monitor sensitivity to mechanical stability. It is not intended that the field monitor offset will exceed 30 degrees from the elevation antenna boresight.

d) The elevation field monitor is to be sited to avoid affecting, or being affected by, the ILS glide path field monitor.

4.1.1.3 *Siting the elevation antenna at a greater offset than the glide path*

4.1.1.3.1 When siting the elevation antenna at offsets of 130 m (430 ft) to 180 m (590 ft) from runway centre line, the conical effect on the achieved approach reference datum height becomes more prominent. Depending on the facility, the elevation antenna setback may have to be adjusted to satisfy the criteria discussed in 4.1.1.2.1, 4.1.1.2.2 and 4.1.1.2.3.

4.1.1.3.2 When siting the elevation antenna at an offset from runway centre line greater than that of the resident glide path, the elevation antenna should not penetrate the lateral pattern of the glide path. The value of Φ in Figure G-18 is dependent on the type of glide path antenna present and the physical characteristics of the elevation equipment. In general, "Φ" denotes the –10 dB point in the glide path antenna lateral pattern. The –10 dB value may be relaxed to –4 dB, particularly for capture-effect glide path antennas, subject to verification of glide path signal quality.

4.1.1.3.3 After determining the acceptable range of elevation antenna locations based on the above criteria, this location may have to be bounded further to satisfy obstacle limitation requirements in Annex 14, particularly taxiway-to-obstacle separation criteria.

4.1.1.4 *Alternatives*

4.1.1.4.1 If collocation of the elevation antenna with the glide path cannot readily be achieved, an alternative is to site the elevation antenna on the opposite side of the runway.

4.1.2 *MLS azimuth antenna*

4.1.2.1 *Introduction*

4.1.2.1.1 When collocating the MLS azimuth antenna with the ILS localizer, one will have to make a series of decisions which will determine the azimuth antenna location. Siting criteria have been developed based on minimizing the effects of the MLS azimuth antenna equipment on the ILS localizer signal and vice versa. The criteria developed along with signal-in-space, operation, critical areas, and obstacle clearance considerations will influence the final location of the azimuth antenna. Since the presence of a humped runway or approach lighting system may require an increase in the azimuth antenna phase centre height (PCH), these factors must be considered when applying any of the following criteria.

4.1.2.1.2 The purpose is to start with a general region for siting the azimuth antenna and then reduce this region to an optimum location for a particular facility. This goal is achieved by stepping through a list of considerations shown as a logic flow diagram in Figure G-20.

4.1.2.1.3 Referring to Figure G-20, the section numbers refer to one of the four siting geometries (i.e. 4.1.2.2 corresponds to "azimuth antenna sited ahead of the localizer antenna", etc.). The numbers in each box reference a specific paragraph in the supporting text for Figure G-20. This paragraph provides a more detailed description of the factors to be considered for that step.

4.1.2.1.4 The general regions for siting the azimuth antenna are shown in Figure G-21.

4.1.2.2 *Azimuth antenna sited ahead of localizer antenna*

4.1.2.2.1 The azimuth antenna is to be symmetrically sited on the localizer course line at least 30 m (100 ft) ahead of the localizer antenna array. The limit for the maximum distance (variable "X" in Figure G-21) is determined by the requirement to satisfy the obstacle limitation requirements set forth in Annex 14 for both the azimuth antenna structure and azimuth monitor. This is the preferred location for the azimuth antenna. However, factors such as the presence of a localizer near field monitor may require the location of the azimuth antenna to be modified. The azimuth antenna cannot be sited such that it blocks line-of-sight between the localizer antenna and the localizer field monitor. Due to line-of-sight blockage of the ILS ground check point by the azimuth station, the ILS ground check points may have to be reassessed.

4.1.2.2.2 It is desirable to collocate the DME/P antenna with azimuth antenna whenever possible. However, if the DME/P antenna cannot be collocated with the azimuth antenna due to violation of obstacle limitation requirements, one may consider an offset DME/P site or selecting an alternate collocation configuration (see Attachment C, Section 7.1.6 and Section 5 below).

4.1.2.2.3 When possible, the azimuth antenna location can be adjusted to minimize the effect of the azimuth antenna critical area on flight operations. In addition, it may be desirable to maximize the union of azimuth and localizer critical areas. Due to the necessity to collocate the azimuth antenna in close proximity to the localizer antenna, normally one of the antennas will have to be sited in the critical area of the other antenna. For the azimuth antenna critical area, see 4.3. For the localizer critical areas see Attachment C, Section 2.1.10.

4.1.2.2.4 After a suitable site for the azimuth antenna has been determined, a location for the azimuth antenna field monitor must be found. The azimuth antenna should be monitored as stated in 2.3.5. The preferred location for the field monitor is on the extended runway centre line. However, the monitor pole can be a source of azimuth signal degradation. Therefore, if this monitor location causes unacceptable signal degradation or unsatisfactory monitoring capabilities due to the presence of light lane structures, ILS localizer, etc., an alternate field monitor location may be desirable. This second procedure is only recommended if integral monitoring of the approach radial is available. The following considerations may be helpful in determining a monitor location:

a) It is desirable to have the field monitor as close to the far field as practical to minimize near field effects on the monitor. However, this distance should be limited to avoid false alarms due to vehicle and aircraft traffic between the monitor and azimuth antenna.

b) It is desirable to minimize blockage and distortion of the azimuth signal by the field monitor in the final approach region. The field monitor should be sited as far below the azimuth antenna phase centre as practical.

c) The field monitor offset from the antenna boresight should be limited to maintain the appropriate monitor sensitivity to mechanical stability.

d) The azimuth antenna field monitor should be sited to avoid affecting, or being affected by, the localizer monitor.

4.1.2.3 *Azimuth antenna sited behind ILS localizer*

4.1.2.3.1 The distance between the localizer and the MLS azimuth antenna will depend on obstacle limitation requirements, availability of real estate, presence of a localizer back course, and the desirability of collocating the DME/P antenna with the azimuth antenna. If a localizer back course is being utilized, a distance of at least 30 m (100 ft) between the azimuth and localizer antennas is preferred, and the azimuth antenna must be symmetrically sited on the localizer course centre line. For localizer antennas with a high front-to-back power ratio, it may be possible to reduce the 30 m (100 ft) separation. Once the distance between the azimuth and localizer antennas is known, Figure G-22 can be used to determine the height of the azimuth antenna phase centre relative to the localizer antenna array. To ensure that the azimuth guidance errors due to signal scattering by the ILS localizer remain insignificant (≤0.03 degree) throughout the azimuth coverage volume, point "W" (Figure G-22) is typically selected to determine the value for variable "X" of Figure G-22. If selection of that point results in an azimuth antenna siting which violates obstacle clearance requirements or a tower-mounted installation that is not feasible, the following actions may be considered:

a) knowing the specific localizer and azimuth equipment involved, an analysis may be performed to determine the height of the azimuth antenna phase centre. Generally, it is recommended that the azimuth antenna phase centre height be selected so that the errors due to signal scattering from the localizer are limited to 0.03 degree. However, that allocation may be increased after considering the contribution from other error sources such as ground and airborne equipment errors, side lobe reflections from buildings, ground reflections, and errors due to interfering aircraft (see Table G-10); and

b) a point on the line W – W_N (Figure G-22) may be selected to determine the value for variable "X". It is preferred that the point selected be as close to point "W" as practical and it must be operationally acceptable for the procedure concerned. Since the error allocation used in the development of this criteria represents a small portion of the total propagation error budget, the azimuth signal might meet the accuracy requirement even below the plane which contains the point selected and the azimuth antenna phase centre. The point to which acceptable azimuth signal exists along the minimum glide path angle may be determined by flight measurements.

4.1.2.3.2 If a localizer near field monitor is present on the extended runway centre line, adjustment of the azimuth antenna phase centre height (PCH) or the localizer monitor height may be required to minimize the effects of the localizer monitor pole on the azimuth signal. However, it is expected that as long as the monitor pole is at or lower than the localizer antenna element height no further adjustment due to the presence of the monitor pole will be required.

4.1.2.4 *Integrated azimuth and localizer configuration*

4.1.2.4.1 *Azimuth antenna integrated under the localizer array*

4.1.2.4.1.1 The first consideration for this configuration is to determine the height of the obstacle clearance surface at the localizer array. The vertical distance between the ground and the obstacle clearance surface at this point should be at least equal to the azimuth antenna height, including the pedestal, plus the required vertical spacing between the top of the azimuth antenna and the localizer antenna element. If this condition is not observed an alternate collocation configuration has to be considered.

4.1.2.4.1.2 Experimental results, from a 24-element log-period localizer, indicate that the vertical spacing between the top of the azimuth antenna and the bottom of the localizer antenna elements has to be at least 0.5 m (1.6 ft) with a spacing of greater than 0.7 m (2.3 ft) being preferred. For localizers with elements having relatively higher coupling, increased vertical spacing is preferred.

4.1.2.4.2 *Azimuth antenna integrated within the localizer array*

4.1.2.4.2.1 For this configuration it may not be necessary to consider the height of the obstacle clearance surface since the azimuth antenna is usually lower than the existing localizer antenna. When integrating the azimuth antenna, some modifications at the localizer antenna are required which may influence the localizer signal-in-space. However, effects depend very much on the type of localizer.

4.1.2.4.2.2 Experimental results, from a two-frequency localizer using dipole antennas, indicate that it is possible to compensate these effects by minor on-site modifications at the localizer antenna. The feasibility of this integrated configuration has to be confirmed for each type of localizer.

4.1.2.4.3 If an ILS near field monitor is present, it is necessary to determine the increase in azimuth antenna phase centre height or decrease in the localizer monitor height required to minimize the effects of the monitor pole on the azimuth signal. In general, satisfactory results may be obtained by siting the azimuth antenna phase centre approximately 0.3 m (1 ft) above the monitor pole. This value is dependent on the localizer monitor design and location.

4.1.2.5 *Offset azimuth*

4.1.2.5.1 At some sites where ILS and MLS are to be collocated, it may be found impossible because of physical restrictions to locate the MLS azimuth antenna in front of or back of the ILS localizer antenna or to integrate it with the ILS localizer antenna. At those sites an advantageous solution could be to offset the MLS and DME/P antennas. The siting information contained in auxiliary data would enable computation in the aircraft of an MLS centre line approach.

4.1.2.5.2 For this collocation configuration, the preferred siting is with the azimuth antenna radome in the localizer array plane (Area 1 of Figure G-21). A minimum distance of 3 m (10 ft) between the azimuth equipment and the localizer array (end element) is preferable.

4.1.2.5.3 If siting the azimuth antenna abeam the localizer is not practical, the azimuth antenna may be sited behind the localizer array plane (Area 2 of Figure G-21). The azimuth antenna offset has to provide at least a 3 m (10 ft) distance and prohibit penetration of the azimuth proportional guidance region by the localizer array.

4.1.2.5.4 If siting the azimuth antenna ahead of the localizer array plane is required, degradation of the localizer signal may result. The region where the least effect of the azimuth equipment on the localizer signal is expected is shown in Area 3 of Figure G-21. The azimuth antenna location can be verified using an azimuth equipment mock-up.

4.2 MLS siting within an approach lighting system

4.2.1 The presence of an approach lighting system serving the opposite end approach will affect the siting of an MLS azimuth antenna. Factors to be considered in proper siting are coverage requirements (see 2.3.2), the need to avoid visual blockage of lights, obstacle limitation requirements, and azimuth signal multipath from the light structures.

4.2.2 These criteria are applicable for typical installations where the approach lights are mounted at essentially a constant height or rise with increasing distance from the runway.

4.2.3 The following guidance is based on MLS siting within existing lighting system structures. It may be more practical to use light structures which do not affect the signal-in-space if these are available.

4.2.4 If the location of an MLS azimuth antenna on extended runway centre line 60 m (200 ft) beyond the far end of the approach lighting system is not possible or practical, it may be sited within the light plane boundaries given the following criteria:

a) in the horizontal plane, the antenna is to be sited on extended runway centre line not closer than 300 m to the runway stop end and as far as possible from the nearest light position toward runway stop end. (This places the back of the azimuth equipment against a light position.)

b) the siting of the azimuth station is to be such that the shadowing of the lights of the approach lighting system is minimized, particularly within decision height boundaries. The azimuth station should not shadow any light(s) other than that located in a centre part of a cross bar or a centre line barrette (see Annex 14, Volume I, Attachment A, Section 11.3 for further guidance).

4.2.4.1 If the spacing between adjacent light stations is 30 m (100 ft) or more, the phase centre should be at least 0.3 m (1 ft) above light centre line of the closest light station toward runway stop end. This could be relaxed to 0.15 m (0.5 ft), if necessary, if the site is otherwise free of significant multipath problems. This may require the use of an elevated azimuth station.

4.2.4.2 If the spacing between adjacent light stations is less than 30 m (100 ft), the phase centre should be at least 0.6 m (2 ft) above light centre line of the closest light station toward runway stop end.

4.3 Critical and sensitive areas

4.3.1 The occurrence of interference to MLS signals is dependent on the reflection and shadowing environment around the MLS antennas and the antenna beamwidths. Vehicles and fixed objects within 1.7 beamwidths of the receiver location are considered “in-beam” and will cause main lobe multipath interference to the MLS guidance signals. Typically, the ground equipment beamwidths are chosen such that no azimuth in-beam reflections exist along the final approach course and no elevation in-beam multipath exists along the commissioned glide paths. However, movable objects may enter the in-beam multipath regions and cause interfering reflections to or shadowing of the guidance signals to the extent that the quality becomes unacceptable. The areas within which vehicles can cause degraded performance need to be defined and recognized. For the purpose of developing protective zoning criteria, these areas can be divided into two types, i.e. critical areas and sensitive areas:

a) The MLS critical area is an area of defined dimensions about the azimuth and elevation antennas where vehicles, including aircraft, are excluded during all MLS operations. The critical area is protected because the presence of vehicles and/or aircraft inside its boundaries will cause unacceptable disturbance to the guidance signals.

b) The MLS sensitive area is an area extending beyond the critical area where the parking and/or movement of vehicles, including aircraft, is controlled to prevent the possibility of unacceptable interference to the MLS signals during MLS operations. The sensitive area provides protection against interference caused by large objects outside the critical area but still normally within the airfield boundary.

Note 1.— Where disturbance to the guidance signal can occur only at some height above the ground the terms “critical volume” or “sensitive volume” are used.

Note 2.— The objective of defining critical and sensitive areas is to afford adequate protection of the MLS guidance signals. The manner in which the terminology is applied may vary between States. In some States, the term “critical area” is also used to describe the area that is referred to herein as the sensitive area.

4.3.2 Typical examples of critical and sensitive areas that need to be protected are shown in Figure G-23 and Figure G-24. The tabled values associated with Figure G-23 and Figure G-24 apply to approach procedures with elevation angles of three degrees or higher. To assure the signal quality, it is necessary normally to prohibit all entry of vehicles and the taxiing or parking of aircraft within this area during all MLS operations. The critical area determined for each azimuth and elevation antenna should be clearly designated. Suitable signal devices may need to be provided at taxiways and roadways which penetrate the critical area in order to restrict the entry of vehicles and aircraft.

4.3.3 Computer modelling techniques can be employed to calculate the magnitude and duration of signal disturbances caused by structures or by aircraft of various sizes and orientation at differing locations. Typically, the parameters required to operate such a model are the antenna beamwidths and the size, location and orientation of reflecting and shadowing objects. Taking into account the maximum allowable multipath degradation of the signal due to aircraft on the ground, the corresponding critical and sensitive areas can be determined. Such a method has been used in developing Figures G-23 and G-24, after validation of computer models which included comparisons at selected points of computed results with actual field and flight data on parked aircraft interference to the MLS guidance signals.

4.3.4 Control of critical areas and the designation of sensitive areas on the airport proper generally will be sufficient to protect MLS signals from multipath effects caused by large, fixed ground structures. This is particularly significant when considering the size of new buildings. Structures outside the boundaries of the airport generally will not cause difficulty to the MLS signal quality as long as the structures meet obstacle limitation criteria.

4.3.5 The boundary of the protected zone (i.e. the combined critical and sensitive areas) is defined such that interference caused by aircraft and vehicles outside that boundary will not cause errors in excess of typical allowances for propagation effects. The derivation of error allowances to protect centre line approach profiles, as shown in Tables G-10 and G-11 for a "clean" and "complex" propagation environment, proceed as follows. Allowances for equipment errors are subtracted (on a root sum square basis (RSS)) from the system error limits at the approach reference datum (ARD) and the resulting balance of the error budget is available for propagation anomalies. The ground reflection is accommodated at both clean and complex sites, while in complex environments, a margin is reserved to accommodate additional error sources such as support structure vibration, diffracted signals from, for example, approach lighting system (ALS) lights and supports or more intense lateral reflections. Finally, 70 per cent of the remaining error balance is allocated to define the protected zone boundary. Thus, error balances are available to define protected zone boundaries for the extreme cases of a very clean propagation environment with only ground reflections and for a very complex environment with several significant sources of propagation errors.

4.3.6 The MLS critical areas are smaller than the ILS critical areas. Where MLS antennas are located in close proximity to the ILS antennas, the ILS critical areas in most cases will protect the MLS for similar approach paths.

Note.— A reduction of the MLS critical and sensitive areas may be obtained by measurements or analysis which consider the specific environment. It is recommended that samples be taken at least every 15 m (50 ft).

4.3.7 *Azimuth.* For an azimuth antenna supporting an aligned approach along the zero degree azimuth, the region between the azimuth antenna and runway stop end is to be designated as a critical area. The sensitive area of Figure G-23 provides additional signal protection when low visibility landing operations are in progress. In general, the azimuth sensitive area will fall within the runway boundaries such that adequate control can be exercised over all moving traffic to prevent unacceptable interference to the MLS signals. In developing the sensitive area lengths of Table G-12A it was assumed that the landed B-727 (or B-747) type aircraft has cleared the runway before the landing aircraft reaches a height of 90 m (300 ft) (or 180 m (600 ft) for B-747)). That assumption resulted from consideration of the following factors:

a) 5.6 km (3 NM) separation behind B-747 size aircraft;

b) 3.7 km (2 NM) separation behind B-727 size aircraft;

c) runway occupancy time for the landing aircraft is 30 seconds; and

d) approaching aircraft speed is approximately 220 km/hr (2 NM/min).

4.3.7.1 For an azimuth antenna supporting an offset approach the critical and sensitive areas will depend on the azimuth antenna location and the approach track orientation relative to the zero degree azimuth. The critical area extends for at least 300 m (1 000 ft) in front of the azimuth antenna. To avoid shadowing while landing operations are in progress, additional protection is to be provided in the form of a sensitive area. Table G-12B gives sensitive area length for use with an offset azimuth installation. When a procedure is along an azimuth other than the zero degree azimuth, the plan view definition has to take into account beam spreading. Figure G-25 shows typical examples.

Note.— This guidance material also applies to an azimuth antenna providing the back azimuth function.

4.3.7.2 *Critical and sensitive areas for the computed centre line approach.* Figure G-26 provides a general illustration of the areas to be protected from uncontrolled movement of ground traffic. The exact shape of that area will depend on the azimuth antenna location, azimuth to threshold distance, decision height, type of aircraft operating at the facility, and the multipath environment.

4.3.7.2.1 In determining the area to be protected, the following steps are appropriate:

a) determine the direction of line AG (Figure G-26) from the azimuth antenna (point A) to the nearest point to the runway centre line where guidance is required (point G);

b) locate point C on line AG at a distance from the azimuth antenna found by entering Table G-12C or G-12D with azimuth to threshold distance, size of the largest aircraft on ground and height of point G on the minimum glide path;

c) line AB has the same length as line AC and lines AC and AB are angularly separated by an amount for in-beam multipath (1.7 beamwidth) and a value for flight path deviation allowance to account for deviations of the approaching aircraft about the nominal approach track;

d) determine the direction of line AF from the azimuth antenna to point F at a height of 300 m (1 000 ft) on the minimum glide path;

e) determine the direction of line AD which is angularly separated by 1.7 BW from line AF;

f) the length of line AD is taken from Table G-12C or G-12D with information on the height of point F; and

g) the area to be protected is bounded by the polygon ABCD.

4.3.7.2.2 Typically the areas of polygon ABCD in Figure G-26 within at least the first 300 m (1 000 ft) or 600 m (2 000 ft) of the azimuth antenna are to be designated, respectively, as a critical area where B-727 or B-747 size aircraft are operating. The balance of the region is designated as a sensitive area. Where possible, the azimuth antenna is to be offset to the runway side away from that of active taxiways. At facilities where the azimuth antenna is set back less than 300 m (1 000 ft) or located ahead of the runway stop end, a detailed analysis and consideration of the airport layout may support reductions of the area to be protected.

4.3.7.3 *Critical and sensitive areas for MLS/RNAV procedures.* For MLS/RNAV approach procedures, the critical and sensitive areas will require expansion to protect against in-beam multipath in the sectors used. These expanded areas protect approach procedures which are not possible with ILS. The length of the area to be protected depends on the operational minimum height surface selected from Table G-13. Information for determining the area to be protected is given in Figure G-27. For a wide range of profiles, simulation indicated that, where B-727 size aircraft are operating, adequate protection would be afforded if the first 300 m (1 000 ft) of the protected area is designated as a critical area and the remainder as a sensitive area. For B-747 size aircraft, the corresponding length is 600 m (2 000 ft). For higher approach profiles, the length derived from Table G-13 or an equation therein may be less than these values; in this case the entire expanded area is to be designated as a critical area. Increased flexibility may be obtained by performing an analysis considering the specific approach profile and airport environment.

4.3.8 *Elevation.* The elevation critical area to be protected results from the critical volume shown in Figure G-24. Normally no sensitive area is defined for the elevation antenna. As the lower surface of the critical volume normally is well above ground level, aircraft may hold near the elevation antenna as long as the lower boundary of the critical volume is not penetrated.

4.3.8.1 For normal siting of a 1.0 degree beamwidth elevation antenna and flat ground, the fuselage of most aircraft types will fit under the profile lower surface of the critical volume of Figure G-24.

4.3.8.2 For a 1.5 degree beamwidth elevation antenna, limited penetration of the profile lower surface of the critical volume of Figure G-24 by an aircraft fuselage may be tolerated by defining the lower part of the critical volume between 1.5 degrees and 1.7 beamwidth below the minimum glide path as sensitive volume. At sites performing well within tolerance, aircraft may hold in front of the antenna provided:

a) the separation angle between the glide path and the top of the aircraft fuselage is at least 1.5 degrees;

b) the aircraft tail fin does not penetrate the lower surface of the critical volume; and

c) the fuselage is at right angle to the centre line.

4.3.8.3 For MLS/RNAV approach procedures, the plan view of the elevation critical area will require expansion to ensure the elevation signal quality along the nominal approach track (Figure G-28). These expanded areas protect approach procedures which are not possible with ILS. The characteristics of the profile view (Figure G-24) remain unchanged, noting that the lower boundary is referenced to the nominal approach track. This guidance material covers a wide range of profiles. Increased flexibility may be obtained by performing an analysis considering the specific approach profile and airport environment.

5. Operational considerations on siting of DME ground equipment

5.1 The DME equipment should, whenever possible, provide indicated zero range to the pilot at the touchdown point in order to satisfy current operational requirements.

5.1.1 When DME/P is installed with the MLS, indicated zero range referenced to the MLS datum point may be obtained by airborne equipment utilizing coordinate information from the MLS data. DME zero range should be referenced to the DME/P site.

6. Interrelationship of ground equipment monitor and control actions

6.1 The interrelationship of monitor and control actions is considered necessary to ensure that aircraft do not receive incomplete guidance which could jeopardize safety, but at the same time continue to receive valid guidance which may safely be utilized in the event of certain functions ceasing to radiate.

Note.— The interrelationship of ground equipment monitor and control actions is presented in Table G-14.

7. Airborne equipment

7.1 General

7.1.1 The airborne equipment parameters and tolerances included in this section are intended to enable an interpretation of the Standards contained in Chapter 3, 3.11 and include allowances, where appropriate, for:

a) variation of the ground equipment parameters within the limits defined in Chapter 3, 3.11;

b) aircraft manoeuvres, speeds and attitudes normally encountered within the coverage volume.

Note 1.— The airborne equipment includes the aircraft antenna(s), the airborne receiver, the pilot interface equipment and the necessary interconnections.

Note 2.— Detailed "Minimum Performance Specifications" for MLS avionics have been compiled and coordinated by the European Organization for Civil Aviation Electronics (EUROCAE) and RTCA Inc. ICAO periodically provides to Contracting States current lists of the publications of these organizations in accordance with Recommendations 3/18(a) and 6/7(a) of the Seventh Air Navigation Conference.

7.1.2 *Function decoding*

7.1.2.1 The airborne equipment is to be capable of decoding and processing the approach azimuth, high rate approach azimuth, back azimuth, and approach elevation functions, and data required for the intended operation.

7.1.2.2 In addition, the receiver utilizes techniques to prevent function processing resulting from the presence of function preambles embedded within the data fields of basic and auxiliary data words and scanning beam side lobe radiation. One technique to accomplish this is to decode all function preambles. Following the decode of a preamble, the detection and decoding of all function preambles is then disabled for a period of time corresponding to the length of the function.

7.1.2.3 Range information is decoded independently.

7.1.3 The receiver decodes the full range of angles permitted by the signal format for each function. The guidance angle is determined by measuring the time interval between the received envelopes of the TO and FRO scans. The decoded angle is related to this time interval by the equation given in Chapter 3, 3.11.4.5.

7.1.4 The receiver is capable of normal processing of each radiated function without regard to the position of the function in the transmitted sequences.

7.1.5 If the MLS approach azimuth and back azimuth information is presented on the selector and/or flight instruments, it is to be displayed in magnetic degrees. Receivers in the automatic mode display the relevant information transmitted by the ground station as part of the basic data word 4.

7.1.6 The receiver has the capability for both manual and automatic selection of approach track, elevation angle and back azimuth radial when provided. When in automatic mode, the selection is made as follows.

7.1.6.1 *Approach azimuth* — select the angular reciprocal of the approach azimuth magnetic orientation in basic data word 4.

7.1.6.2 *Elevation angle* — select the minimum glide path in basic data word 2.

7.1.6.3 *Back azimuth* — select the angle of the back azimuth magnetic orientation in basic data word 4.

Note.— The receiver indicates when deviation is referenced to the back azimuth signal.

7.1.7 The MLS airborne receiver system must have an integrity compatible with the overall integrity of MLS which is at least $1 - 1 \times 10^{-7}$ in any one landing.

7.1.8 For airborne equipment used in MLS/RNAV operations the capability is to be provided to unambiguously display the procedure selected.

7.2 Radio frequency response

7.2.1 *Acceptance bandwidth*

7.2.1.1 The receiver should meet acquisition and performance requirements when the received signal frequency is offset by up to plus or minus 12 kHz from the normal channel centre frequency. This figure considers possible ground transmitter offsets of plus or minus 10 kHz and Doppler shifts of plus or minus 2 kHz. The receiver should decode all functions independently of the different frequency offsets of one function relative to another.

7.2.2 *Selectivity*

7.2.2.1 When the receiver is tuned to an inoperative channel and an unwanted MLS signal of a level 33 dB above that specified in Chapter 3, 3.11.4.10.1 for the approach azimuth DPSK is transmitted on any one of the remaining channels, the receiver should not acquire the signal.

7.2.3 *In-channel spurious response*

7.2.3.1 The receiver performance specified in Chapter 3, 3.11.6, should be met when, in addition, interference on the same channel is received at a level not exceeding that specified in Chapter 3, 3.11.4.1.4.

7.2.4 *Interference from out-of-band transmissions*

7.2.4.1 The receiver performance in Chapter 3, 3.11.6 is to be met when, in addition, interference from undesired signals is received at a level not exceeding –124.5 dBW/m^2 at the MLS receiver antenna.

7.3 Signal processing

7.3.1 *Acquisition*

7.3.1.1 The receiver should, in the presence of an input guidance signal which conforms to the requirements of Chapter 3, 3.11.4, acquire and validate the guidance signal before transitioning to the track mode within two seconds along the critical portion of the approach and within six seconds at the limits of coverage.

7.3.2 *Tracking*

7.3.2.1 While tracking, the receiver should provide protection against short duration large amplitude spurious signals. When track is established, the receiver should output valid guidance information before removing the warning. During track mode, the validation process should continue to operate.

7.3.2.2 After loss of the tracked signal for more than one second, the receiver should provide a warning signal. Within the one-second interval, the guidance information should remain at the last output value.

Note 1.— A validated guidance signal is one that satisfies the following criteria:

a) the correct function identification is decoded;

b) the preamble timing signal is decoded;

c) *the "TO" and "FRO" scanning beams or left/right clearance signals are present and symmetrically located with respect to the midpoint time; and*

d) *the detected beamwidth is from 25 to 250 microseconds.*

Note 2.— Guidance signal validation also requires that the receiver repeatedly confirm that the signal being acquired or tracked is the largest and most persistent signal within the coverage.

7.3.3 *Data functions*

7.3.3.1 *Data acquisition.* Performance in the airborne acquisition of data provided on either the basic or auxiliary data function is broken into two items: the time allowed to acquire the data and the probability of an undetected error in the acquired data.

7.3.3.1.1 At the minimum signal power density, the time to acquire basic data word 2 which is transmitted at a rate of 6.25 Hz does not exceed two seconds on a 95 per cent probability basis. The time to acquire data that are transmitted at a rate of 1 Hz does not exceed 6 seconds on a 95 per cent probability basis.

7.3.3.1.2 In the acquisition process, the receiver decodes the appropriate data words and applies certain tests to ensure that the probability of undetected errors does not exceed 1×10^{-6} at the minimum signal power density for those data requiring this level of integrity. The recommended performance specifications for undetected errors may require additional airborne processing of the data beyond simple decoding. For example, these may be achieved by processing multiple samples of the same data words.

7.3.3.1.3 If the receiver does not acquire data required for the intended operation, a suitable warning is to be provided.

7.3.3.1.4 At the minimum signal power density the time to acquire all data words required to support MLS/ RNAV operations (auxiliary data words B1-B41, A1/B42, A2, A3, A4/B43 and basic data word 6) must not exceed 20 seconds on a 95 per cent probability basis. The MLS/RNAV equipment has to ensure that the probability of undetected errors for this block of data does not exceed 0.5×10^{-9}. This performance assumes a 2 dB improvement in signal to noise. This may be achieved through reduced cable loss, margin or improved receiver sensitivity (see the airborne power budget given in Table G-2). Additionally, with signal levels above this, the acquisition time is intended to be less than 20 seconds.

7.3.3.2 *Data validation.* After acquisition of data, the receiver repeatedly confirms that the data being received are the same as the acquired data. The receiver decodes several consecutive and identical data different from that previously acquired before taking action to accept the new decoded data.

7.3.3.2.1 For data required to support MLS/RNAV operations, the airborne equipment applies the cyclic redundancy check (CRC) to the data to ensure sufficient integrity has been achieved. Data that continue to be received continue to be validated. The MLS/RNAV equipment does not accept a new block of data to be used until it is validated with the CRC.

7.3.3.3 *Data loss.* Within 6 seconds after the loss of basic data or auxiliary data that is transmitted with a maximum interval of 2 seconds or less, the receiver provides a suitable warning and removes the existing data. Within 30 seconds after the loss of auxiliary data other than that referred to above, the receiver provides a suitable warning.

7.3.3.3.1 For data required to support MLS/RNAV operations, the airborne equipment does not remove existing data following validation except under the conditions described in 7.3.3.2.1. An MLS/RNAV data block that has been validated by the CRC is not removed until a new data block has been received with a different ground equipment identification in basic data word 6, a new MLS channel is selected, or power is removed. Additionally the data block is not removed when transitioning to back azimuth coverage.

7.3.4 *Multipath performance*

7.3.4.1 Where the radiated signal power density is high enough to cause the airborne equipment thermal noise contribution to be insignificant, the following specifications should apply for scalloping frequencies between 0.05 Hz and 999 Hz.

7.3.4.1.1 *In-beam multipath.* Multipath signals coded less than two beamwidths from the direct signal and with amplitudes of 3 dB or more below the direct signal should not degrade the angle guidance accuracy output by more than plus or minus 0.5 beamwidth (peak error).

7.3.4.1.2 *Out-of-beam multipath.* Multipath signals coded 2 beamwidths or more from the direct signal and with amplitudes of 3 dB or more below the direct signal should not degrade the angle guidance accuracy by more than plus or minus 0.02 beamwidth.

7.3.5 *Clearance*

7.3.5.1 The airborne equipment should provide clearance guidance information whenever the antenna is in the presence of a valid clearance guidance signal.

7.3.5.2 When the decoded angle indication is outside the proportional guidance sector defined in Chapter 3, Table A-7, the MLS guidance signal should be interpreted as clearance guidance.

7.3.5.3 When clearance pulses are transmitted, the receiver shall be able to process the range of pulse envelope shapes that may appear in the transition between clearance and scanning beam signals. A particular pulse envelope is dependent on the receiver position, scanning antenna beamwidth, and the relative phase and amplitude ratios of the clearance and scanning beam signals as shown in Figure G-8. The receiver is also required to process rapid changes of indicated angle of the order of 1.5 degrees (peak amplitude) when outside the proportional guidance limits.

7.3.5.4 In receivers with the capability to select or display azimuth angle guidance information greater than plus or minus 10 degrees, the proportional coverage limits in basic data must be decoded and used to preclude use of erroneous guidance.

7.4 Control and output

7.4.1 *Approach azimuth and approach elevation deviation scale factor*

7.4.1.1 *Approach azimuth.* When the approach azimuth deviation information is intended to have the same sensitivity characteristics as ILS, it is a function of the "approach azimuth antenna to threshold distance", as supplied by the basic data, in accordance with the following table:

Approach azimuth antenna to threshold distance (ATT)	Nominal course width
0 – 400 m	± 3.6 degrees
500 – 1 900 m	± 3.0 degrees
2 000 – 4 100 m	$\pm \arctan\left(\frac{105}{\text{ATT}}\right)$ degrees
4 200 – 6 300 m	± 1.5 degrees

7.4.1.2 *Approach elevation.* The deviation information is a continuous function of the manually or automatically selected elevation angle (Θ) in accordance with the formula Θ/4 = half a nominal glide path width, so that glide path widths are nominally in accordance with the following examples:

Selected elevation angle (degrees)	Nominal glide path width (degrees)
3	± 0.75
7.5	± 1.875

Note.— These sensitivity characteristics are applicable to elevation angles up to 7.5 degrees.

7.4.2 *Angle data output filter characteristics*

7.4.2.1 *Phase lags.* To assure proper autopilot interface, the receiver output filter, for sinusoidal input frequencies, does not include phase lags which exceed:

a) 4 degrees from 0.0 to 0.5 rad/s for the azimuth function; and

b) 6.5 degrees from 0.0 to 1.0 rad/s and 10 degrees at 1.5 rad/s for the elevation function.

7.4.3 *Minimum glide path.* When there is capability of selecting the approach elevation angle, a suitable warning is to be issued if the selected angle is lower than the minimum glide path as provided in basic data word 2.

7.4.4 *Status bits.* A suitable warning is to be provided when the function status bits in acquired basic data indicate that the respective function is not being radiated or is being radiated in test mode.

7.5 Use of back azimuth guidance for missed approaches and departures

7.5.1 *Usable back azimuth angles*

7.5.1.1 Flight test results indicated that back azimuth angles of up to ±30 degrees from the runway centre line can be used for navigation guidance for missed approaches and departures. With appropriate interception techniques, larger angle offsets might be acceptable up to the flyable limits of back azimuth coverage. Departure guidance can utilize the back azimuth signal for centre line guidance throughout the take-off roll and initial departure. It is intended that a turn to intercept the back azimuth is initiated at an operationally acceptable altitude, and the prescribed procedure is protected according to appropriate obstacle clearance criteria.

7.5.2 *Back azimuth deviation scale*

7.5.2.1 The scaling of back azimuth deviations must be sufficient to support back azimuth departures and missed approaches not aligned with the approach azimuth, as well as missed approach and departure tracks aligned with the approach azimuth. Deviation scaling effects are most pronounced when manoeuvring to intercept a back azimuth. Very sensitive scaling will cause lateral overshoots and limit flyability of the signal, whereas very insensitive scaling will result in the large consumption of airspace. A nominal course width sensitivity of ±6 degrees provides for an acceptable interception of back azimuth during missed approach and departure.

7.5.3 *Approach azimuth to back azimuth switching*

7.5.3.1 Following initiation of a missed approach using back azimuth guidance, the guidance must switch from approach azimuth to back azimuth. The switching, either automatically or manually, from approach azimuth to back azimuth guidance is intended to provide continuous flyable guidance throughout the missed approach sequence. Switching is not expected to occur until the aircraft receives a validated back azimuth signal, but it is intended to occur before the approach azimuth guidance becomes too sensitive to fly. Switching based on loss of approach azimuth may not occur until the aircraft is very close to the approach azimuth antenna resulting in unflyable guidance. Switching based only on loss of elevation guidance may occur prior to the aircraft receiving a valid back azimuth signal. However, switching might be based on loss of elevation guidance once the back azimuth signal has been validated. Automatic switching at or near the mid-point between azimuth antennas will provide a method which results in continuous guidance during the transition. The mid-point switching methodology may require the use of DME information by the MLS receiver. Precautions are to be taken so that approach to back azimuth switching does not automatically occur unless a missed approach has been initiated.

8. Operations at the limits of and outside the promulgated MLS coverage sectors

8.1 The limits of the azimuth proportional guidance sectors are transmitted in basic data words 1 and 5. These limits do not indicate the maximum flyable MLS approach and back azimuth angles which will normally be at some angle inside these limits. For example, for an approach azimuth providing a proportional guidance sector of ±40 degrees, flyable MLS approach azimuth angles with a full course width of ±3 degrees will exist to approximately ±37 degrees. For a back azimuth, flyable back azimuth angles with full course width will exist to within 6 degrees of the proportional guidance sector limits.

8.2 The basic MLS antenna designs should preclude the generation of unwanted signals outside coverage. Under some unusual siting conditions, MLS signals might be reflected into regions outside the promulgated coverage with sufficient strength to cause erroneous guidance information to be presented by the receiver. As in current procedure the implementing authority would specify operational procedures based on the use of other navaids to bring the aircraft into landing system coverage without transiting the area of concern or may publish advisories which alert pilots to the condition. In addition, the MLS signal format permits the use of two techniques to further reduce the probability of encountering erratic flag activity.

8.2.1 If the undesired MLS signals are reflections and if operational conditions permit, the coverage sector can be adjusted (increased or decreased) such that, at the receiver, either the direct signal is greater than any reflection or the reflector is not illuminated. This technique is referred to as coverage control.

8.2.2 Out-of-coverage indication signals can be transmitted into the out-of-coverage sectors for use in the receiver to ensure a flag whenever an undesired angle guidance signal is present. This is accomplished by transmitting an out-of-coverage indication signal into the region which is greater in magnitude than the undesired guidance signal.

8.3 If it is operationally required to confirm the selected MLS channel outside the promulgated coverage sectors of the MLS, it is intended that this confirmation be derived from the identification of the associated DME. MLS status information is not available outside the promulgated MLS coverage sectors.

9. Separation criteria in terms of signal ratios and propagation losses

9.1 Geographical separation

9.1.1 The separation criteria are provided in 9.2 and 9.3 as desired signal-to-noise ratios and when combined with appropriate propagation losses allow evaluation of MLS C-Band frequency assignments as regards on-channel and adjacent channel interference. When selecting frequencies for MLS facilities, a similar criteria for the DME/P element or an associated DME/N as provided in Attachment C to this Part need to be considered.

9.2 Co-frequency requirements

9.2.1 Co-frequency MLS channel assignments should be made to preclude the acquisition of DPSK preambles of an undesired co-channel facility. The required level of the undesired signal is less than minus 120 dBm, which is 2 dB below a sensitive MLS airborne system, as shown below:

— receiver sensitivity	=	−112 dBm
— margin for aircraft antenna gain above minimum	=	−6 dBm
		−118 dBm

Considering the system power budget in Table G-1, which shows the minimum signal level at the aircraft is required to be at least minus 95 dBm, the minus 120 dBm requirement is achieved by placing the undesired co-channel at a geographic separation which exceeds the radio horizon distance at any point in the promulgated coverage sector of the desired facility.

Note.— The DPSK signal requires more protection than the scanning beam so that by limiting the undesired co-channel signal to minus 120 dBm, interference from the scanning beam is negligible.

9.3 Adjacent frequency requirements

9.3.1 Considering the absence of requirements on transmitter spectrum characteristics for the first and second adjacent channels, the ground stations operating at these frequencies should be placed at a geographical separation that exceeds the radio horizon distance at any point in the promulgated coverage sector of the desired facility.

Note.— Where for specific reasons (for example, ILS/MLS/DME pairing channels) the first or second adjacent channels need to be assigned, a less conservative method to assure receiver protection is to guarantee that the minimum SNR values as quoted in 3.11.6.1.4 are available at any point in the promulgated coverage sector of the desired facility while the undesired facility is transmitting.

9.3.2 For the third and subsequent adjacent channels, the ground stations operating at these frequencies should be placed at a geographical separation which guarantees that the minimum SNR values as quoted in Chapter 3, 3.11.6.1.4 are available at any point in the promulgated coverage sector of the desired facility while undesired facilities are transmitting.

9.3.2.1 If there is no undesired MLS transmission situated at less than 4 800 m from any point of the promulgated coverage, the −94.5 dBW/m^2 maximum power of Chapter 3, 3.11.4.1.4.2 compared to the minimum power density of Chapter 3, 3.11.4.10.1 assures that the SNR minimum values will be met. No constraints are anticipated.

9.3.2.2 If there is an undesired MLS transmission situated at less than 4 800 m from a point of the promulgated coverage, the maximum power produced by this transmission and measured, during transmission time for angle and data signals, in a 150 kHz band centred on the desired nominal frequency has to be assessed taking into account the frequency separation, spectrum performances and antenna pattern of the transmitter and the appropriate propagation losses. This maximum power has then to be compared to the desired angle and data level to check that the minimum SNR values defined in 3.11.6.1.4 are met. If not, another channel offering a larger frequency separation has to be assigned in order to reduce this maximum undesired power taking benefit of the spectrum characteristic of the transmitter.

9.4 Development of frequency planning criteria

9.4.1 The controlling factor when developing adjacent channel frequency planning criteria is the radiated spectrum from the MLS ground station. When developing frequency planning criteria for the third adjacent channel and above, ideally, the radiated spectrum output of individual MLS ground stations should be considered. However it may be possible in a geographic region to use a generic MLS transmitter mark which meets the requirements of that region.

10. Material concerning MLS installations at special locations

10.1 MLS facility performance throughout the coverage volume

10.1.1 It is recognized that at some locations the requirements for MLS specified in Chapter 3, 3.11 cannot be met throughout the whole volume of coverage due to environmental effects on the signal. It is expected that at such locations the requirements of Chapter 3, 3.11 are to be met at least in the guidance sector for all published instrument procedures to a defined point beyond which the MLS guidance is not used for intended operations. To assist appropriate authorities with the initial appraisal of the suitability of such individual MLS installations for the intended operations, relevant coverage restrictions need to be promulgated.

11. Integrity and continuity of service — MLS ground equipment

11.1 Introduction

11.1.1 This material is intended to provide description of the integrity and continuity of service objectives of MLS ground equipment and to provide guidance on engineering design and system characteristics of this equipment. The integrity and continuity of service must of necessity be known from an operational viewpoint in order to decide the operational application which an MLS could support.

11.1.2 It is generally accepted, irrespective of the operational objective, that the average rate of a fatal accident during landing, due to failures or shortcomings in the whole system, comprising the ground equipment, the aircraft and the pilot, should not exceed 1×10^{-7}. This criterion is frequently referred to as the global risk factor.

11.1.3 In the case of Category I operations, while minimum standards of accuracy and integrity are required during the early stages of landing, most of the responsibility for assuring that the above objective is not exceeded is vested in the pilot. In Category III operations, the same objective is required but must now be inherent in the whole system. In this context it is of the utmost importance to endeavour to achieve the highest level of integrity and continuity of service of the ground equipment. Integrity is needed to ensure that an aircraft on approach will have a low probability of receiving false guidance; continuity of service is needed to ensure that an aircraft in the final stages of approach will have a low probability of being deprived of a guidance signal.

11.1.4 It is seen that various operational requirements correspond to varied objectives of integrity and continuity of service. Table G-15 identifies and describes four levels of integrity and continuity of service that are applicable for basic procedures where DME is not a critical element.

11.2 Achievement and retention of integrity and continuity of service levels

11.2.1 An integrity failure can occur if radiation of a signal which is outside specified tolerances or which is incorrect (in the case of digital data) is either unrecognized by the monitoring equipment or the control circuits fail to remove the faulty signal. Such a failure might constitute a hazard if it results in a gross error.

11.2.2 Clearly not all integrity failures are hazardous in all phases of the approach. For example, during the critical stages of the approach, undetected failures producing significant path following error (PFE) are of special significance whereas an undetected loss of clearance or identification signals would not necessarily produce a hazardous situation. The criterion in assessing which failure modes are relevant must however include all those deleterious fault conditions which are not unquestionably obvious to the automatic flight system or pilot.

11.2.3 It is especially important that monitors be designed to provide fail-safe operation through compliance with the Standards of Chapter 3, 3.11.5.2.3 and 3.11.5.3.3. This often requires a rigorous design analysis. Monitor failures otherwise may permit the radiation of erroneous signals. Some of the possible conditions which might constitute a hazard in operational performance Categories II and III are:

a) an undetected fault causing a significant increase in PFE as seen by an approaching aircraft;

b) an undetected error in the minimum glide path, transmitted in basic data word 2;

c) an undetected error in the TDM synchronization resulting in overlap; and

d) loss of power that increases CMN to unacceptable limits.

11.2.4 The highest order of protection is required against the risk of undetected failures in the monitoring and associated control system. This would be achieved by careful design to reduce the probability of such occurrences to a low level and by carrying out periodic checks on the monitor system performance at intervals which are determined by the design analysis. Such an analysis can be used to calculate the level of integrity of the system in any one landing. The following formula can be applied to certain types of MLS and provides an example of the determination of system integrity, *I*, from a calculation of the probability of transmission of undetected erroneous radiation, *P*.

$$I = 1 - P$$

$$P = \frac{T^2}{\alpha_1 \alpha_2 M_1 M_2}$$

Where:

I = integrity;

P = the probability of a concurrent failure in transmitter and monitor systems resulting in undetected erroneous radiation;

M_1 = transmitter mean time between failure (MTBF)

M_2 = MTBF of the monitoring and associated control system;

$\frac{1}{\alpha_1}$ = ratio of the rate of failure in the transmitter resulting in the radiation of an erroneous signal to the rate of all transmitter failures;

$\frac{1}{\alpha_2}$ = ratio of the rate of failure in the monitoring and associated control system resulting in inability to detect an erroneous signal to the rate of all monitoring and associated control system failures; and

T = period of time (in hours) between checks on the monitoring and associated control system.

This example formula would be applicable to a non-redundant monitor design in which a single value of *T* applies to all elements of the monitoring and associated control system.

11.2.5 With regard to integrity, since the probability of occurrence of an unsafe failure within the monitoring or control equipment is extremely remote, to establish the required integrity level with a high degree of confidence would necessitate an evaluation period many times that needed to establish the equipment MTBF. Such a protracted period is unacceptable and therefore the required integrity level can only be predicted by rigorous design analysis of the equipment. However, a degree of confidence in the analysis can be achieved by demonstration of independence between the transmitter and monitor functions. The predicted performances of the transmitter and monitor can then be evaluated independently, resulting in more feasible evaluation periods.

11.2.6 The MTBF and continuity of service of equipment is governed by basic construction characteristics and by the operating environment. The basic construction characteristics include the failure rate of the components of the equipment and the physical relationship of the components. Failure rate (1/MTBF) and continuity of service are not always directly related because not all equipment failures will necessarily result in an outage, e.g. an event such as a failure of a transmitter resulting in the immediate transfer to a standby transmitter. The manufacturer is expected to provide the details of the design to allow the MTBF and the continuity of service to be calculated. Equipment design has to employ the most suitable engineering techniques, materials, and components, and rigorous inspection should be applied during manufacture. It is essential to ensure that equipment is operated within the environmental conditions specified by the manufacturer.

11.2.7 The design continuity of service is expected to exceed that given in 12.4 by as large a margin as is feasible. The reasons for that are as follows:

a) the MTBF experienced in an operational environment is often worse than that determined by the design calculations due to the impact of operational factors;

b) the continuity of service objectives given in 12.4 are minimum values to be achieved in an operational environment. Any improvement in performance above these values enhances the overall safety of the landing operation;

c) a margin between the continuity of service objective and that achieved is required in order to reduce the chance of falsely rejecting the suitability of an equipment for a particular level of service due to statistical uncertainty.

Note.— The Level 3 and 4 continuity of service values include a factor that accounts for the pilot's capability to avoid a fatal accident in the event of a loss of guidance. It is particularly desirable to reduce this factor to the maximum extent practical by achieving the best possible continuity of service for Level 3 and 4 equipment.

11.2.8 Experience has shown that there is often a difference between the calculated continuity of service and that experienced in an operational environment both because the performance of the equipment may be different from the calculated value and because of the impact of operational factors, i.e. airport environment, inclement weather conditions, power availability, quality and frequency of maintenance, etc. For these reasons, it is recommended that the equipment MTBF and continuity of service be confirmed by evaluation in an operational environment. Continuity of service may be evaluated by means of mean time between outages, where an outage is defined as any unanticipated cessation of signal-in-space. It is calculated by dividing total facility up-time by the number of operational failures. For integrity and continuity of service Levels 2, 3 or 4, the evaluation period is to be sufficient to determine achievement of the required level with a high degree of confidence. To determine whether the performance record of an individual equipment justifies its assignment to Levels 2, 3 or 4 requires judicious consideration of such factors as:

a) the performance record and experience of system use established over a suitable period of time;

b) the average achieved MTBO established for this type of equipment; and

c) the trend of the failure rates.

11.2.9 The minimum acceptable confidence level for acceptance/rejection is 60 per cent. Depending on the service level of the MLS, this may result in different evaluation periods. To assess the influence of the airport environment, a minimal evaluation period of one year is typically required for a new type of installation at that particular airport. It may be possible to reduce this period in cases where the operating environment is well controlled and similar to other proven installations. Subsequent installation of the same type of equipment under similar operational and environmental conditions may follow different evaluation periods. Typically, these minimal periods for subsequent installations are for Level 2, 1 600 hours, for Level 3, 3 200 hours and for Level 4, at least 6 400 hours. Where several identical systems are being operated under similar conditions, it may be possible to base the assessment on the cumulative operating hours of all the systems. This will result in a reduced evaluation period.

11.2.10 During the evaluation period it should be decided for each outage if it is caused by a design failure or if it is caused by a failure of a component due to its normal failure rate. Design failures are, for instance, operating components beyond their specification (overheating, overcurrent, overvoltage, etc., conditions). These design failures should be dealt with such that the operating condition is brought back to the normal operating condition of the component or that the component is replaced with a part suitable for the operating conditions. If the design failure is treated in this way, the evaluation may continue and this outage is not counted, assuming that there is a high probability that this design failure will not occur again. The same applies to outages due to any causes which can be mitigated by permanent changes to the operating conditions.

11.2.11 A suitable method to assess the behaviour of a particular installation is to keep the records and calculate the average MTBO over the last five to eight failures of the equipment. A typical record of this method is given in Figures G-35A and G-35B.

11.2.12 During the equipment evaluation, and subsequent to its introduction into operational service, records have to be maintained of all equipment failures or outages to confirm retention of the desired continuity of service.

Note.— If an equipment requires redundant or standby units to achieve the required continuity of service, an arrangement such as that described in 11.3.4 is required to assure that the standby equipment is available when needed.

11.3 Additional considerations concerning continuity of service and integrity

11.3.1 The stringent requirement for integrity and continuity of service essential for Category III operations requires equipment having adequate assurance against failures. Reliability of the ground equipment must be very high, so as to ensure that safety during the critical phase of approach and landing is not impaired by a ground equipment failure when the aircraft is at such a height or attitude that it is unable to take safe corrective action. A high probability of performance within the specified limits has to be ensured. Facility reliability in terms of MTBF clearly has to be related on a system basis to the probability of failure which may affect any characteristic of the total signal-in-space.

11.3.2 The following configuration is an example of a redundant equipment arrangement that is likely to meet the objectives for integrity and continuity of service Levels 3 and 4. The azimuth facility consists of two transmitters and an associated monitor system performing the following functions:

a) monitoring of operation within the specified limits of the main transmitter and antenna system by means of majority voting among redundant monitors; and

b) monitoring the standby equipment.

11.3.2.1 Whenever the monitor system rejects one of the equipments the facility continuity of service level will be reduced because the probability of cessation of signal consequent on failure of other equipment will be increased. The change of performance must be automatically indicated at remote locations.

11.3.2.2 An identical monitoring arrangement to the azimuth is used for the elevation facility.

11.3.3 In the above example, the equipment would include provision to facilitate monitoring system checks at intervals specified by the manufacturer, consequent to his design analysis, to ensure attainment of the required integrity level. Such checks, which can be manual or automatic, provide the means to verify correct operation of the monitoring system including the control circuitry and changeover switching system. It is desirable to perform these checks in such a way that there is no interruption to operational service. The advantage of implementing an automatic monitor integrity test is that it can be accomplished more frequently, thereby achieving a higher level of integrity.

11.3.4 Interruption of facility operation due to primary power failures is avoided by the provision of suitable standby supplies, such as batteries or "no-break" generators. Under these conditions, the facility should be capable of continuing in operation over the period when an aircraft may be in the critical stages of the approach. Therefore the standby supply should have adequate capacity to sustain service for at least two minutes.

11.3.5 Warnings of failures of critical parts of the system, such as the failure of the primary power supply, must be given at the designated control points if the failure affects operational use.

11.3.6 In order to reduce failure of equipment that may be operating near its monitor tolerance limits, it is useful for the monitor system to include provision to generate a pre-alarm warning signal to the designated control point when the monitored parameters reach a limit equal to a value on the order of 75 per cent of the monitor alarm limit.

11.3.7 Protection of the integrity of the signal-in-space against degradation, which can arise from extraneous electromagnetic interference falling within the MLS frequency band or from reradiation of MLS signals, must be considered.

11.3.8 A field monitor can provide additional protection by providing a warning against exceeding path following error limits due to physical movement of the MLS antenna or by protecting against faults in the integral monitor.

11.3.9 In general, monitoring equipment design is based on the principle of continuously monitoring the radiated signals-in-space at specific points within the coverage volume to ensure their compliance with the Standards specified at Chapter 3, 3.11.5.2.3 and 3.11.5.3.3. Although such monitoring provides to some extent an indication that the signal-in-space at all other points in the coverage volume is similarly within tolerance, this is largely inferred. It is essential therefore to carry out rigorous inspections at periodic intervals to ensure the integrity of the signal-in-space throughout the coverage volume.

11.3.10 An equipment arrangement similar to that at 11.3.2, but with no transmitter redundancy, and the application of the guidance outlined in 11.3.5, 11.3.6, 11.3.7, 11.3.8, and 11.3.9, would normally be expected to achieve the objectives for integrity and continuity of service for level 2.

12. Classification of MLS approach azimuth, elevation and DME ground facilities

12.1 The classification system as described in the following paragraphs, is intended to identify in a concise way essential information to be used by instrument procedure designers, operators and air traffic services regarding the performance of a particular MLS installation. The information is to be published in the aeronautical information publication (AIP).

12.2 The information concerning MLS facility performance should comprise:

a) the limits of the azimuth proportional guidance sector;

b) the vertical guidance limit;

c) the availability of the guidance signal along the runway; and

d) the reliability of the guidance signal (azimuth, elevation and DME).

12.3 The classification system, containing information of a particular MLS facility, is defined using the following formats:

a) *Azimuth proportional guidance sector limits.* This field identifies for a particular MLS the azimuth proportional guidance sector limits as defined in basic data word 1. Two values separated by a colon (XX:YY) indicate the sector limits as seen from the approach direction; the first value being the sector limit left of the zero degree azimuth and the second value being the sector limit right of the zero degree azimuth.

b) *Vertical guidance limit.* This field, located directly after the azimuth limit (format: XX:YY/ZZ m (or XX:YY/ ZZ ft)), represents the minimum height (in metres or feet) above threshold on the final approach segment along the minimum glide path (MGP) to which the system conforms to the signal characteristics specified in Chapter 3, 3.11.

c) *Runway guidance.* The character D or E (as defined in Section 1 of Attachment G) represents the point to which the azimuth guidance along the runway conforms to the signal characteristics specified in Chapter 3, 3.11 (format: XX:YY/ZZ/E). If the guidance signal along the runway does not conform to the above-mentioned characteristics, then a dash (—) is used in the format.

d) *Reliability of the guidance signal.* The character 1, 2, 3 or 4 indicates the level of integrity and continuity of service of the guidance signal (Table G-15). The character A, which is placed after the Level 3 or 4 designation, indicates that the elevation and DME/P objectives are equivalent to the azimuth objectives in accordance with Note 6 of Table G-15 (format: XX:YY/ZZ/E/4).

Note 1.— Where DME is not required for the intended MLS operations, there is no need to include DME/P reliability in MLS classification.

Note 2.— Where an improved elevation and/or DME/P reliability is required according to Note 6 of Table G-15 for the intended MLS/RNAV operations, the improved elevation and/or DME/P reliability is to be included in the MLS classification.

12.3.1 Any degradation of the signal below Annex 10 Standards, or below previously published performance, should be promulgated by the appropriate authority (Chapter 2, 2.1.2 and Section 10 above).

12.4 Table G-15 gives continuity of service and integrity objectives for MLS basic and MLS/RNAV operations.

Note.— In relation to specific MLS operations it is intended that the level of integrity and continuity of service would typically be associated as follows:

1) *Level 2 is the performance objective for MLS equipment used to support low visibility operations when guidance for position information in the landing phase is supplemented by visual cues. This level is a recommended objective for equipment supporting Category I operations;*

2) *Level 3 is the performance objective for MLS equipment used to support operations which place a high degree of reliance on MLS guidance for positioning through touchdown. This level is a required objective for equipment supporting Category II and IIIA operations; and*

3) *Level 4 is the performance objective for MLS equipment used to support operations which place a high degree of reliance on MLS guidance throughout touchdown and rollout. This level basically relates to the needs of the full range of Category III operations.*

12.5 The following example of MLS facility classification:

40:30/50 ft/E/4A

denotes a system with:

a) a proportional guidance sector of 40 degrees left and 30 degrees right of the zero-degree azimuth;

b) vertical guidance down to 50 ft above threshold;

c) roll-out guidance to MLS point E; and

d) integrity and continuity of service Level 4 with elevation and DME/P objectives equivalent to azimuth.

13. Computed centre line approaches

13.1 General

13.1.1 Computed centre line approaches considered below are based on a computed path along a runway centre line where the azimuth antenna is not sited on the extended runway centre line. The simplest form of a computed centre line approach is one in which the nominal track is parallel to the zero-degree azimuth. In order to conduct MLS/RNAV operation, a greater capability than that available in the basic MLS receiver is required.

13.1.2 Computed centre line approaches to the MLS primary runway are conducted to the runway whose relationship to the MLS ground equipment is identified in the auxiliary data words.

13.1.3 When the final segment is contained in the MLS coverage volume, computed centre line approaches can be conducted along a straight final segment on a descent gradient down to the decision height (DH). Computed centre line approaches may result in decision heights that are above decision heights achievable with aligned MLS approaches.

13.2 Computed centre line approach error budget

13.2.1 RTCA (RTCA/DO-198) has described a total system error budget for MLS area navigation (RNAV) equipment. This error budget includes contributions due to:

a) ground system performance;

b) airborne sensor performance;

c) ground system geometry effects;

d) MLS/RNAV computer computational error; and

e) flight technical error (FTE).

13.2.2 The composite of the above errors with the exclusion of FTE is referred to as total position error. Within 3.7 km (2 NM) of the MLS approach reference datum the permissible total lateral position error for MLS/RNAV equipment at a position 60 m (200 ft) above the MLS datum point on a 3-degree elevation angle and a runway length of 3 000 m (10 000 ft), is 15 m (50 ft) (see the note below). Similarly, the permissible total vertical position error is 3.7 m (12 ft) at the same position. A portion of the total position error budget has been reserved for the MLS/RNAV computer performance (computational error). Within 3.7 km (2 NM) of the MLS approach reference datum, the portion of the error budget reserved for computational error is ±0.6 m (2 ft) both laterally and vertically. The results presented in 13.5 are dependent on meeting this computational accuracy requirement.

13.2.3 Using root sum square methodology the permissible total lateral position error, exclusive of MLS/RNAV computer performance, is slightly less than ±15 m (50 ft). Similarly, the permissible total vertical position error, exclusive of computational error is slightly less than ±3.7 m (12 ft). Hence, the combined error due to ground system performance, airborne sensor performance and ground system geometry effects is not expected to exceed ±15 m (50 ft) laterally and 3.7 m (12 ft) vertically at the described location. Using this information and assumptions about ground and airborne sensor performance, the maximum permissible azimuth and elevation antenna offsets (geometry effects) from the runway centre line can be obtained.

13.2.4 The CMN does not exceed ±7.3 m (24 ft) laterally and ±1.9 m (6.3 ft) vertically, or the linear equivalent of ± 0.1 degree, whichever is less. The linear values are based on nominal antenna sitings (azimuth antenna to threshold distance of 3 300 m (11 000 ft) and datum point to threshold distance of 230 m (760 ft)), with a 3-degree elevation angle. Within 3.7 km (2 NM) of the MLS approach reference datum, the portion of the CMN budget reserved for computational error is 1.1 m (3.5 ft) laterally and 0.6 m (2.0 ft) vertically.

Note.— All errors represent 95 percentile errors.

13.3 Siting and accuracy considerations

13.3.1 Theoretical and operational analysis has shown that several factors will impact the amount of azimuth antenna lateral offset that can be permitted and still obtain lateral and vertical position accuracy identified in 13.2.

13.3.2 *Distance between azimuth and elevation antennas*

13.3.2.1 For a given azimuth antenna offset, a short azimuth to elevation distance results in relatively large azimuth angles at positions near the approach reference datum. As a result, the error contribution from the DME is large, and the lateral accuracy may degrade unacceptably. At a runway where a large azimuth antenna offset and a short azimuth to elevation distance exist, use of DME/P rather than DME/N may be required to achieve the required lateral accuracy.

13.3.3 *Azimuth accuracy*

13.3.3.1 The azimuth antenna offset limits presented in 13.5 are based on the ±6 m (20 ft) azimuth path following error accuracy specification (see Chapter 3, 3.11.4.9.4). The recommended ±4 m (13.5 ft) azimuth accuracy specification would permit larger azimuth antenna offsets and still obtain required computed position accuracy at DH. Azimuth angle accuracy is assumed to degrade in accordance with Chapter 3, 3.11.4.9.

13.3.4 *DME accuracy*

13.3.4.1 Smaller errors in position determination result when DME/P equipment is used and the final approach segment is contained within 9.3 km (5 NM) of the MLS approach reference datum. There are two DME/P final approach mode accuracy standards in this region. Resulting azimuth antenna offset values when using DME/P as presented in 13.5, are based on final approach mode Standard 1 accuracy. Larger azimuth antenna offset values may be permissible if DME/P equipment meeting final approach mode Standard 2 accuracy is used. DME/P final approach mode Standard 1 ranging accuracy is assumed to degrade in accordance with Chapter 3, 3.5.3.1.3.4 and Table B. DME/N is assumed to degrade in accordance with Chapter 3, 3.5.3.1.3.2.

13.3.5 *Use of elevation information in the lateral position computation*

13.3.5.1 Generally, lateral position computation that excludes elevation information will be sufficient for computed centre line approaches to the primary runway. If elevation information is not used in lateral computation, the lateral error increases. This error increases with azimuth angle, height and decreasing range. Permissible azimuth antenna offsets presented in 13.5 are reduced if elevation information is not used in the lateral computation. Elevation angle accuracy is assumed to degrade in accordance with Chapter 3, 3.11.4.9.

13.4 Equipment considerations

13.4.1 Performance of airborne sensors, MLS ground equipment and MLS/RNAV avionics implementation influence the range of application of computed centre line approaches. Information presented in 13.5 is based on the following equipment considerations.

13.4.2 *Airborne sensors*

13.4.2.1 It is assumed the receiver will decode all auxiliary data words required for MLS computed centre line approaches unless the information contained in the data words is available from other avionics sources with the same accuracy and integrity as required for auxiliary data. Digital MLS angle data and range data are needed for computing lateral and vertical position. Angle data quantization is 0.01 degrees. Range quantization is 2.0 m (0.001 NM).

13.4.3 *RNAV computations*

13.4.3.1 No assumption is made about where the RNAV position computations are made. A portion of the computed centre line approach error budget has been reserved for computation error. This permits flexible algorithm implementation.

13.4.4 *Permissible azimuth antenna offset calculation techniques*

13.4.4.1 RTCA (RTCA/DO-198, Appendix D) has identified several different position determination algorithms. Different algorithms can handle different ground equipment configurations. The algorithm designed to handle any ground equipment geometry is the RTCA case 12 algorithm. Permissible antenna offset values were obtained using Monte Carlo simulation techniques. The results were also obtained using a direct analytical method. The analytical method uses geometric transformations of the maximum MLS angle and range errors to determine system performance. The Monte Carlo technique through the emulation of an MLS/RNAV system is a statistical method used to determine system performance.

13.4.4.2 *Possible restriction in position determination.* Depending on ground equipment geometry a region of possible multiple solutions to the position determination algorithm may exist. This region of multiple solutions is dependent on the locations of the elevation antenna and DME transponder relative to the runway and computed approach path. The most pronounced effect occurs when the DME transponder lies in the region between the approach path DH point and the elevation antenna. The position ambiguities can be resolved when the DME transponder is located behind the elevation antenna when viewed from the approach direction. When the DME transponder is located in front of the elevation antenna it may not be possible to resolve the position ambiguity.

13.4.5 *Ground equipment geometry*

13.4.5.1 The nominal ground equipment geometry in terms of the relative position of the ground components is depicted in Figure G-29. The DME/P transponder is assumed to be collocated with the approach azimuth antenna. When DME/P ground equipment is not available, the DME/N transponder is assumed to be located between the MLS approach azimuth and elevation antennas.

13.4.5.2 Because of the relatively large error induced by the DME/N, the location of the DME/N transponder has no significant influence on the calculated permissible azimuth antenna offset. This permits DME/N siting over a large area between the azimuth and elevation antennas. Similarly, the offset of the elevation antenna will have little effect.

13.5 Permissible approach azimuth antenna offset positions for computed centre line approaches to the primary runway

13.5.1 *DME results*

13.5.1.1 The maximum azimuth offset represents, for a given set of conditions, the largest offset that does not exceed the computed centre line approach error budget identified in 13.2. DME/P results are presented as a function of the azimuth to elevation distance. The permissible azimuth antenna offsets with DME/P are presented in Figure G-30.

13.5.1.2 For a given azimuth to elevation distance, the azimuth antenna can be sited any place in the shaded area and the resulting computed centre line approach meet requirements of 13.2.

13.5.1.3 Results were obtained when DME/N ranging accuracies are used. These results are presented in Figure G-31.

13.6 Low visibility approaches

13.6.1 *Possible applications*

13.6.1.1 The possibility of low visibility computed centre line applications may be limited to operations on the primary instrument runway because of the geometry considerations involved in achieving adequate accuracy. Primary instrument runway applications where computed centre line capability would be useful are those where the azimuth is offset from the runway centre line due to a severe siting restriction. There may be such azimuth offset applications where low visibility operations would be considered beneficial.

13.6.1.2 The expected airborne implementation for such low visibility computed centre line approaches would use non-computed elevation guidance (assuming the elevation ground antenna is sited normally) and lateral guidance derived from a combination of azimuth (including MLS siting data contained in the basic and auxiliary data functions) and range from the DME/P transponder.

13.6.2 *Airborne system performance*

13.6.2.1 Safety-critical software associated with the guidance function for non-computed low visibility approaches mainly involves the MLS receiver. For computed centre line approaches, the DME interrogator and the navigation computations must also be considered. The safety-critical software for these functions will have to be designed, developed, documented and evaluated.

13.6.2.2 The necessary algorithms are relatively simple and do not pose any certification difficulty. However, experience with flight management system (FMS) computers indicates that it would be difficult to certify a safety-critical function implemented within an existing FMS. Current FMS architectures are not partitioned to allow separate certification of different functions to different levels of criticality and the size and complexity of an FMS precludes safety-critical certification of the entire FMS computer. Consequently, alternatives to FMS implementation can be considered for computed centre line capability intended for low visibility applications (e.g. incorporation within the autopilot or within the MLS receiver). These alternatives would provide output guidance with the same output characteristics as a normal straight-in approach.

13.6.3 *Ground system performance*

13.6.3.1 Based on the implementation assumed in 13.3.5, elevation guidance would be used in exactly the same manner as for basic MLS approaches. Consequently, the elevation ground equipment integrity and continuity of service objectives would remain unchanged from those already given in Table G-15. For lateral guidance, the integrity and continuity of service objectives given in Table G-15 for azimuth would apply to the azimuth and DME combined, resulting in objectives for both that are more stringent than those needed for basic MLS operations. However, a low visibility computed centre line operation to a 30 m (100 ft) DH may be achieved by the use of ground equipment meeting the level 4 objectives contained in Table G-15.

13.6.4 *Accuracy*

13.6.4.1 MLS/RNAV will support computed paths to Category I decision heights for the primary runway given siting limitations as identified in Figure G-30. In addition, under certain conditions MLS/RNAV may provide sufficient accuracy to support Category II and III approaches. In order to accomplish this, the airborne implementation is as stated in 13.6.1.2.

13.6.4.2 The error budgets for Category II and III procedures are the following. For Category III, the lateral accuracy requirements are the same as the MLS approach azimuth accuracies specified at the approach reference datum. These requirements are ± 6 m (20 ft) for PFE and ± 3.2 m (10.5 ft) for CMN (Chapter 3, 3.11.4.9.4). For Category II the lateral requirements are obtained by splaying the allowed Category III values from the approach reference datum out to the Category II decision height of 30 m (100 ft). The equations used to compute these values (in metres) are:

$$PFE = 6 \times \frac{(D_{\text{AZ-ARD}} + R)}{D_{\text{AZ-ARD}}}$$

$$CMN = 3.2 \times \frac{(D_{\text{AZ-ARD}} + R)}{D_{\text{AZ-ARD}}}$$

$$R = \frac{DH_{\text{CatII}} - DH_{\text{CatIII}}}{\tan\theta}$$

Where:

$D_{\text{AZ-ARD}}$	=	distance between approach azimuth antenna and approach reference datum (threshold)
R	=	distance between $DH_{\text{Cat II}}$ and $DH_{\text{Cat III}}$
θ	=	elevation angle

As an example, for a 3 000 m runway and a 3-degree elevation with an approach azimuth setback of 300 m, a Category III decision height of 15 m (50 ft) and a Category II decision height of 30 m (100 ft), the following values are obtained:

$D_{\text{AZ-ARD}}$	=	3 300 m
R	=	286 m
$PFE_{\text{DH Cat II}}$	=	6.5 m (21.3 ft)
$CMN_{\text{DH Cat II}}$	=	3.5 m (11.5 ft)

13.6.4.3 The computed centre line capability down to Category II decision height will not necessarily support autoland operations as the guidance may not be provided down to the runway and in the runway region. Also, the more stringent error tolerances for Category II/III will result in more constraints in antenna siting than for Category I. Primarily this will constrain the lateral offset of the approach azimuth from runway centre line.

13.7 Computed centre line approaches to parallel secondary runways

13.7.1 A secondary runway as defined here is a runway that has a different geometric relationship than the one contained in the auxiliary data A words. Computed centre line approaches to a parallel secondary runway are approaches along a computed path on the extended runway centre line which is not aligned with an MLS azimuth radial and/or elevation angle but is parallel to the primary runway centre line.

13.7.2 The material in this section provides guidance on permissible runway geometries for computed centre line approaches to a parallel secondary runway to decision heights of 60 m (200 ft). The material in this section is based on the theoretical application of MLS and DME/P (Standard 1) SARPs. The error budget used is the conservative error budget identified in 13.2, and relaxations of this error budget are described in 13.7.6.1.

13.7.3 *Runway geometry considerations*

13.7.3.1 Figure G-32 presents the runway and equipment geometry. The secondary runway location is established laterally with the use of runway spacing in metres. Negative values represent secondary runway locations left of the primary runway. The longitudinal position of the secondary runway threshold is referred to as threshold stagger relative to the primary runway. Negative values represent threshold stagger forward of the primary runway threshold.

13.7.4 *Large runway spacing considerations*

13.7.4.1 Additional considerations are necessary for computed centre line approaches to widely spaced parallel runways. These considerations include:

a) adequate signal coverage to DH for some parallel runway geometries may require the use of an elevation antenna with more than ±40 degrees of horizontal coverage;

b) the critical areas around the MLS antennas may have to be increased for these operations; and

c) these operations require the use of elevation guidance below the primary runway minimum glide path.

13.7.5 *Runway geometry*

13.7.5.1 Figure G-33 shows permitted runway spacings and threshold staggers for the secondary runway. It represents results for a 3 000 m (10 000 ft) primary runway. The geometrics change marginally with primary runway length. The shaded area represents results obtained using existing MLS and DME/P (Standard 1) SARPs and the error budget identified in 13.2. To use Figure G-33, enter the values for secondary runway spacing and threshold stagger. If the resulting point lies within the shaded area a computed centre line approach to a 60 m (200 ft) DH on a 3-degree elevation is possible.

Note.— The circular region near the 1 200 m runway threshold stagger is due to the upper limit of elevation guidance used. This region is not expected to present any practical operational limitations.

13.7.6 *Extensions to the runway geometries*

13.7.6.1 Flight and ground tests have shown that the shaded area can be expanded with the following additional considerations:

a) an angular expansion is possible by utilizing existing elevation guidance outside the minimum specified azimuth proportional guidance sector. Elevation guidance for this angular expansion must be verified; and

b) a radial expansion is possible with a slight relaxation of the vertical error budget to 4.9 m (16 ft). This relaxation is still very conservative and equates to 66 per cent of the equivalent ILS error budget [7 m (24.1 ft)].

13.7.6.2 An example of the use of Figure G-33 is presented by point A. Using the foregoing expansions, a computed centre line approach to a secondary runway is possible for a –1 400 m runway spacing and +200 m threshold stagger.

14. Application of Table G-15 service level objectives for MLS/RNAV operations

14.1 MLS/RNAV procedures discussed below can be conducted with ground equipment meeting integrity and continuity of service objectives identified in Table G-15. Many of these operations may be accomplished with MLS ground equipment meeting Level 2 objectives only. Further a majority of the procedures may not require positive guidance during the discontinued approach/missed approach procedure. Where procedural means cannot provide the required obstacle clearance along an unguided discontinued approach/missed approach, some form of secondary guidance will be required. The accuracy requirements of the secondary guidance system will be determined by the nature of the obstacle-rich environment.

14.1.1 In those rare cases where an MLS/RNAV procedure is in an obstacle-rich environment, the calculated obstacle exposure time (OET) may require a higher level of equipment type than that required for landing.

14.1.2 *Determination of critical segments*

14.1.2.1 The following terms are used to determine the length of the critical segments of an MLS/RNAV procedure.

Obstacle-rich environment. An environment where it is not possible to construct an unguided discontinued approach/missed approach using procedural means. Secondary guidance will be required to achieve a climb to minimum sector altitude.

Critical segment. A segment where an unguided discontinued approach/missed approach would expose the aircraft to an obstacle.

Obstacle exposure time (OET). The time interval required to fly the critical segment of an MLS/RNAV procedure. This time is used to establish the required level of service of the non-aircraft guidance equipment.

14.1.2.2 In order to determine OET the following procedure can be followed (see Figure G-34):

a) determine if there is an obstacle-rich environment by aligning the unguided discontinued approach/missed approach surface with any potential heading that may be used during an unguided discontinued approach/missed approach from the MLS/RNAV procedure;

b) determine whether there is a procedural means for avoiding the obstacle without the need for secondary guidance; and

c) determine the OET as the period of time during which the obstacle is within the unguided discontinued approach/missed approach surface, while there is no procedural means for avoiding the obstacle.

14.2 Computed centre line operations

14.2.1 When conducted to the primary runway, these operations require the airborne system to compute lateral guidance only. Vertical guidance is provided by the elevation function directly. The airborne equipment providing the lateral guidance must have the same integrity as the MLS receiver is required to have for basic MLS operations being conducted to an equivalent decision height. Computed centre line operations conducted to a decision height below a Category I decision height require that the DME have an accuracy, integrity and continuity of service level applicable to the type of operation.

14.2.2 When conducted to a parallel secondary runway these operations require the airborne system to compute both lateral and vertical guidance. Decision heights may be limited by the MLS signal coverage and computed guidance accuracy achievable.

14.2.3 MLS ground equipment meeting Level 2 service objectives may be sufficient for computed centre line operations when:

a) the operation is conducted to Category I decision heights or higher; and

b) reference path construction and computed lateral and vertical guidance by the airborne equipment meets the same level of integrity as the MLS receiver for a basic MLS operation.

14.2.4 When computed centre line operations are conducted below Category I decision heights, the service level of the MLS ground equipment must be commensurate with the decision height used. Identically the airborne equipment providing computed guidance must have the same integrity as the basic receiver would have to conduct MLS basic operations to an equivalent decision height.

14.3 MLS curved path procedures

14.3.1 These procedures must be examined carefully to determine the level of service needed for the ground equipment. With MLS curved path operations the most stringent requirement for integrity and continuity of service may be based on a portion of the flight path prior to decision height. In these situations, the integrity and continuity of service objectives of the MLS ground equipment cannot be predicated solely on the category of the landing. For operations where the obstacle clearance requirements place a high degree of reliance on guidance accuracy, the ground equipment integrity and continuity of service objectives can be determined using the risk tree method described in Attachment A. The following requirements must also be considered:

a) airborne equipment must have the capability of reference path construction and computed vertical and lateral guidance with positive control in the turns; and

b) airborne integrity and continuity of service must be consistent with the degree of reliance on the guidance accuracy necessary to safely execute the procedure.

15. Application of simplified MLS configurations

15.1 While SARPs for basic and expanded MLS configurations state a single signal-in-space standard, a simplified MLS configuration is defined in Chapter 3, 3.11.3.4 to permit the use of MLS in support of RNP-based approach and departure operations (Chapter 2, 2.1.6).

15.2 Relaxed coverage, accuracy, and monitor limits do not exceed those specified in Chapter 3, 3.1 for a Facility Performance Category I ILS. Such a simplified MLS configuration is capable of supporting Category I operations with significant reductions in size of azimuth and elevation antennas. Further reductions in equipment complexity can be achieved as the CMN requirement is waived for applications in support of approach and landing operations which do not require autopilot coupling.

15.3 The simplified MLS is compatible with the basic and expanded MLS configurations.

Table G-1. System power budget
(±40° azimuth coverage; 0–20° vertical coverage; 37 km (20 NM) range)

Power budget items (Note 1)	Approach azimuth function					Elevation function			Back azimuth function			
			Angle BW				Angle BW			Angle BW		
	DPSK	Clearance	1°	2°	3° (Note 2)	DPSK	1°	2°	DPSK	1°	2°	3°
Signal required at aircraft (dBm)	–95.0	–93.5	–91.2	–85.2	–81.7	–95.0	–93.5	–90.0	–95.0	–93.5	–88.2	–84.7
Propagation loss (dB) (Notes 3, 4)	139.0	139.0	139.0	139.0	139.0	138.1	138.1	138.1	133.9	133.9	133.9	133.9
Probabilistic losses (dB):												
a) Polarization	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
b) Rain	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	1.3	1.3	1.3	1.3
c) Atmospheric	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
d) Horizontal multipath	3.0	3.0	0.5	0.5	0.5	3.0	–	–	3.0	0.5	0.5	0.5
e) Vertical multipath	2.0	2.0	2.0	2.0	2.0	2.0	1.0	1.0	2.0	2.0	2.0	2.0
Root – sum – square (RSS) total a) through e) (dB)	4.3	4.3	3.1	3.1	3.1	4.3	2.5	2.5	3.9	2.5	2.5	2.5
Horizontal and vertical pattern loss (dB)	–	1.0	2.0	2.0	2.0	–	6.0	6.0	–	2.0	2.0	2.0
Monitor margin (dB)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Antenna gain (dB) (Note 5)	–	–13.3	–23.0	–20.0	–18.0	–	–20.8	–17.8	–	–23.0	–20.0	–18.0
Net power gain at coverage extremes (dB)	–7.3	–	–	–	–	–7.3	–	–	–7.3	–	–	–
Required transmitter power (dBm)	42.5	39.0	31.4	40.4	41.1	41.6	33.8	40.3	37.1	23.4	31.7	37.2
Example 20 watt transmitter (dBm)	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0
Transmitter power margin (dB)	0.5	4.0	11.6	2.6	1.9	1.4	9.2	2.7	5.9	19.6	11.3	5.8

NOTES.—

1. Losses and antenna gains are representative values.
2. High data rate for 3° azimuth beamwidth will reduce required transmitter power by 4.8 dB.
3. Distance to azimuth antenna taken as 41.7 km (22.5 NM).
4. Distance to back azimuth antenna taken as 23.1 km (12.5 nautical miles).
5. The required transmitter power can be reduced by using higher efficiency antennas.

Table G-2. Airborne power budget

Power budget items	DPSK	Clearance	Approach azimuth function Angle BW 1°	2°	3°	3° (Note 1)	Elevation function Angle BW 1°	2°	Back azimuth function Angle BW 1°	2°	3°
IF SNR (dB) required for:											
a) 72% decode rate	5.0	—	—	—	—	—	—	—	—	—	—
b) 0.1° CMN (Note 2)	—	—	8.8	14.8	18.3	13.5	—	10.0	—	11.8	15.3
c) Acquisition	—	6.5	—	—	—	—	6.5	—	6.5	—	—
Noise power in 150 kHz IF bandwidth (dBm)	–122.0	–122.0	–122.0	–122.0	–122.0	–122.0	–122.0	–122.0	–122.0	–122.0	–122.0
Signal power required at IF (dBm)	–117.0	–115.5	–113.2	–107.2	–103.7	–108.5	–115.5	–112.0	–115.5	–110.2	–106.7
Noise figure (dB)	11	11	11	11	11	11	11	11	11	11	11
Cable loss (Note 3) (dB)	5	5	5	5	5	5	5	5	5	5	5
Airborne antenna gain (dBi)	0	0	0	0	0	0	0	0	0	0	0
Margin (dB)	6	6	6	6	6	6	6	6	6	6	6
Signal required at aircraft (dBm)	–95.0	–93.5	–91.2	–85.2	–81.7	–86.5	–93.5	–90.0	–93.5	–88.2	–84.7

NOTES.—

1. High rate approach azimuth function.
2. 0.2° CMN for the back azimuth function.
3. Provides for either front or rear antenna cable losses in typical installations. Additional losses (up to 11 dB) may be accommodated by air carrier class avionics.

Table G-3. Sample RNAV procedures for MLS installation on Runway 23R
(see Figure G-15)

Procedure name	Procedure type	Runway	Missed approach	Number of way-points	AAZ or BAZ
KASEL-1-A	Approach	23R	Yes	4	AAZ
NELSO-1-B	Approach	23R	Yes	3	AAZ
N/A	Missed approach	23R	N/A	2	AAZ
SEMOR-1-C	Approach	26 (Note)	No	2	AAZ
LAWSO-6-D	Departure	23R	N/A	3	BAZ

Note.— Runway 26 is a secondary runway. The virtual azimuth to way-point distance is 3 000 m.

Table G-4. Sample way-point information for MLS/RNAV procedures

Basic indicator	Validity indicator	Route indicator	Way-point number	X (metres)	Y (metres)	Z (metres)	Notes
KASEL	1	A	4	8 200	–9 094	N/A	No Z
			3	9 954	–5 336	789	PFAF
			2	6 556	0	344	No Z, No Y
			1	259	0	16.8 (Note)	Threshold
NELSO	1	B	3	9 742	6 499	819	PFAF
			2	6 556	0	344	Shared with KASEL
			1	259	0	16.8 (Note)	Shared with KASEL
N/A (missed approach)	N/A	N/A	2	–7 408	0	N/A	No Z, No Y
			1	0	0	N/A	No Z, No Y
SEMOR	1	C	2	5 567	–5 276	346	PFAF
			1	159	–2 401	16	Threshold
LAWSO	6	D	3	–8 018	3 057	N/A	No Z
			2	–4 964	0	N/A	No Z, No Y
			1	0	0	N/A	No Z, No Y

Note.— This value is the threshold crossing height, referenced to ground level at threshold. The height of the threshold with respect to the MLS datum point is given in auxiliary word A2.

Table G-5. Example of B1 and B39 data word assignments

Data word title	Data word	Bit numbers	Data item	Value	Coding
Approach azimuth map/CRC	B1	I_{21-24}	Number of procedure descriptors	3	1100
		I_{25-30}	Last approach azimuth database word	11	001011 (Note 2)
		I_{31-62}	CRC code	See Table G-9	
		I_{63}	Word B42 transmitted	No	0
		I_{64}	Word A4 transmitted	Yes	1
		I_{65}	Word B43 transmitted	No	0
		I_{66-69}	Spare	zeros	0000
Back azimuth map/CRC (Note 3)	B39	I_{21-24}	Number of procedure descriptors	1	1000
		I_{25-30}	First back azimuth database word	36	100100 (Note 2)
		I_{31-62}	CRC code	See Table G-9	
		I_{63}	Word B43 transmitted	No	0
		I_{64-68}	Spare	zeros	00000
		I_{69}	Back azimuth map/CRC indicator	map/CRC	1

NOTES.—

1. Bit coding is indicated with the lower bit number on the left.
2. Data word addresses are as defined in Table A-9, Appendix A with the most significant bit first.
3. Facility without back azimuth database may employ all words up to B39 for the approach azimuth database.

Table G-6. Example of procedure descriptor word assignments

Data item	Bit numbers	Procedure descriptor data words							
		KASEL		NELSO		SEMOR		LAWSO	
		B2		B3		B4		B36	
		Value	Coded	Value	Coded	Value	Coded	Value	Coded
Basic indicator (first character)	I_{21}-I_{25}	K	11010	N	01110	S	11001	L	00110
Second character	I_{26}-I_{30}	A	10000	E	10100	E	10100	A	10000
Third character	I_{31}-I_{35}	S	11001	L	00110	M	10110	W	11101
Fourth character	I_{36}-I_{40}	E	10100	S	11001	O	11110	S	11001
Fifth character	I_{41}-I_{45}	L	00110	O	11110	R	01001	O	11110
Validity indicator	I_{46}-I_{49}	1	1000	1	1000	1	1000	6	0110
Route indicator	I_{50}-I_{54}	A	10000	B	01000	C	11000	D	00100
Runway number	I_{55}-I_{60}	23	111010	23	111010	26	010110	23	111010
Runway letter	I_{61}-I_{62}	R	10	R	10	–	00	R	10
Procedure type	I_{63}	APP	0	APP	0	APP	0	DEP	1
First way-point index	I_{64}-I_{69}	1	100000	4	001000	5	101000	1	100000

Note.— Bit coding is indicated with the lower bit number on the left.

Table G-7. Example of way-point assignments for MLS/RNAV approach procedures

Procedure name	Data word	Bit numbers	Data item	Value	Value	WP Index
KASEL	B5	I_{21-35}	WP 4 – X coordinate	8 200 m	110000010011000	1
		I_{36}	Y coordinate follows	Yes	1	
		I_{37-51}	WP 4 – Y coordinate	–9 094 m	000001111011001	
		I_{52}	Z coordinate follows	No	0	
		I_{53-55}	Next segment/field identifier	straight = 0	000	
		I_{56-69}	WP 3 – X coordinate (first 14 bits)	9 954 m	00001100111100	2
	B6	I_{21}	WP 3 – X coordinate (last bit)		0	
		I_{22}	Y coordinate follows	Yes	1	
		I_{23-37}	WP 3 – Y coordinate	–5 336 m	001001000001001	
		I_{38}	Z coordinate follows	Yes	1	
		I_{39-51}	WP 3 – Z coordinate	789 m	1001111011000	
		I_{52-54}	Next segment field/identifier	curved = 1	100	
		I_{55-69}	WP 2 – X coordinate	6 556 m	100000000101000	3
	B7	I_{21}	Y coordinate follows	No	0	
		I_{22}	Z coordinate follows	Yes	1	
		I_{23-35}	WP 2 – Z coordinate	344 m	0011110110000	
		I_{36-38}	Next segment/field identifier	5	101	
		I_{39-44}	Threshold way-point height	16.8 m	010001	
		I_{45-50}	Missed approach index	7	111000	
NELSO		I_{51-65}	WP 3 – X coordinate	9 742 m	101110110111000	4
		I_{66}	Y coordinate follows	Yes	1	
		I_{67-69}	WP 3 – Y coordinate (first 3 bits)	6 499 m	110	
	B8	I_{21-32}	WP 3 – Y coordinate (last 12 bits)		101111001000	
		I_{33}	Z coordinate follows	Yes	1	
		I_{34-46}	WP 3 – Z coordinate	819 m	1110100111000	
		I_{47-49}	Next segment/field identifier	shared = 3	110	
		I_{50-55}	Next way-point index	3	110000	
SEMOR		I_{56-69}	WP 2 – X coordinate (first 14 bits)	5 567 m	11111110000100	5
	B9	I_{21}	WP 2 – X coordinate (last bit)		0	
		I_{22}	Y coordinate follows	Yes	1	
		I_{23-37}	WP 2 – Y coordinate	–5 276 m	101100000001001	
		I_{38}	Z coordinate follows	Yes	1	
		I_{39-51}	WP 2 – Z coordinate	346 m	0111110110000	
		I_{52-54}	Next segment/field identifier	straight = 0	000	
		I_{55-69}	WP 1 – X coordinate	159 m	011111000000000	6
	B10	I_{21}	Y coordinate follows	Yes	1	
		I_{22-36}	WP 1 – Y coordinate	–2 401 m	010101011100001	
		I_{37}	Z coordinate follows	Yes	1	

Procedure name	Data word	Bit numbers	Data item	Value	Value	WP Index
		$I_{38\text{-}50}$	WP 1 – Z coordinate	16 m	0010111000000	
		$I_{51\text{-}53}$	Next segment/field identifier	6	011	
		$I_{54\text{-}59}$	Virtual azimuth distance	3 000 m	011110	
Missed Approach		$I_{60\text{-}69}$	WP 2 – X coordinate (first 10 bits)	–7 408 m	0111001011	7
	B11	$I_{21\text{-}25}$	WP 2 – X coordinate (last 5 bits)		01001	
		I_{26}	Y coordinate follows	No	0	
		I_{27}	Z coordinate follows	No	0	
		$I_{28\text{-}30}$	Next segment/field identifier	straight = 0	000	
		$I_{31\text{-}45}$	WP 1 – X coordinate	0	000000000000000	8
		I_{46}	Y coordinate follows	No	0	
		I_{47}	Z coordinate follows	No	0	
		$I_{48\text{-}50}$	Next segment/field identifier	6	011	
		$I_{51\text{-}69}$	Spare	zeros	000...000	

Note.— Bit coding is indicated with the lower bit number on the left.

Table G-8. Example MLS/RNAV departure way-point assignments

Procedure name	Data word	Bit numbers	Data item	Value	Coding	WP Index
LAWSO	B37	I_{21-35}	WP 3 – X coordinate	–8 018 m	001111000011001	1
		I_{36}	Y coordinate follows	Yes	1	
		I_{37-51}	WP 3 – Y coordinate	3 057 m	010101010010000	
		I_{52}	Z coordinate follows	No	0	
		I_{53-55}	Next segment/field identifier	curved = 1	100	
		I_{56-69}	WP 2 – X coordinate (first 14 bits)	–4 964 m	11001001111000	2
	B38	I_{21}	WP 2 – X coordinate (last bit)		1	
		I_{22}	Y coordinate follows	No	0	
		I_{23}	Z coordinate follows	No	0	
		I_{24-26}	Next segment/field identifier	straight = 0	000	
		I_{27-41}	WP 1 – X coordinate	0	000000000000000	3
		I_{42}	Y coordinate follows	No	0	
		I_{43}	Z coordinate follows	No	0	
		I_{44-46}	Next segment/field identifier	Last WP = 6	011	
		I_{47-69}	Spare	zeros	000...000	

Note.— Bit coding is indicated with the lower bit number on the left.

Table G-9. Example of complete MLS/RNAV database

	Bit position															
	1	2			3		4			5		6			7	
Word	3456	7890	1234	5678	9012	3456	7890	1234	5678	9012	3456	7890	1234	5678	9012	3456
A1	0000	0111	0011	0010	0101	1101	1001	1000	0010	0110	0010	0100	0000	0000	0000	0100
A2	0000	1010	0011	0010	0111	0000	0010	0111	1001	1000	0000	0000	0110	0000	0001	1010
A3	0000	1101	0011	0010	0001	0111	0110	0110	0011	0000	0100	0110	0111	0000	0111	1101
A4	0001	0011	0011	0010	0111	0000	0010	0000	0000	0000	0001	0000	0000	0000	0110	1000
B1	0000	0111	1100	0010	1100	0111	0100	0011	1111	0000	0001	1001	0001	0000	0010	0111
B2	0000	1010	1101	0100	0011	0011	0100	0011	0100	0100	0011	1010	1001	0000	0111	1001
B3	0000	1101	0111	0101	0000	1101	1001	1111	0100	0010	0011	1010	1000	0100	0000	1101
B4	0001	0011	1100	1101	0010	1101	1110	0100	1100	0110	0001	0110	0001	0100	0011	1110
B5	0001	0100	1100	0001	0011	0001	0000	0111	1011	0010	0000	0001	1001	1110	0000	0001
B6	0001	1001	0100	1001	0000	0100	1110	0111	1011	0001	0010	0000	0001	0100	0011	0000
B7	0001	1110	0100	1111	0110	0001	0101	0001	1110	0010	1110	1101	1100	0111	0110	1001
B8	0010	0010	1011	1100	1000	1111	0100	1110	0011	0110	0001	1111	1100	0010	0000	0011
B9	0010	0101	0110	1100	0000	0100	1101	1111	0110	0000	0001	1111	0000	0000	0101	0110
B10	0010	1000	1010	1010	1110	0001	1001	0111	0000	0001	1011	1100	1110	0101	1110	0100
B11	0010	1111	0100	1000	0000	0000	0000	0000	0000	1100	0000	0000	0000	0000	0110	0100
B36	1001	0001	0011	0100	0011	1011	1001	1111	0011	0001	0011	1010	1011	0000	0010	0101
B37	1001	0110	0011	1100	0011	0011	0101	0101	0010	0000	1001	1001	0011	1100	0100	0000
B38	1001	1011	1000	0000	0000	0000	0000	0000	1100	0000	0000	0000	0000	0000	0001	1101
B39	1001	1100	1000	1001	0010	1011	0010	0001	1000	1011	1111	0010	0000	0000	1010	1001
B40	1010	0000	0111	0011	0110	0110	0110	1000	0101	0110	0101	0010	0010	1010	0110	1001
B41	1010	0111	1100	0000	0000	0110	1101	1001	0111	0000	0000	0000	0000	0000	0001	1111
B44	1011	0011	1110	1010	0101	1000	0100	1010	0000	1110	1110	1000	1000	0000	0001	1011
B45	1011	0100	1111	1001	0000	0000	0000	1101	0010	0100	0000	0000	0010	1111	0000	0011
BDW6	0011	0011	1000	1000	0011											

Note.— Preamble bits I_1 to I_{12} are not shown.

Table G-10. Error allocations for MLS azimuth critical and sensitive area development
(distances are in metres (feet); error values are in degrees)

	Azimuth to threshold distance metres (feet)							
	1 830 (6 000)	2 140 (7 000)	2 440 (8 000)	2 750 (9 000)	3 050 (10 000)	3 360 (11 000)	3 660 (12 000)	3 960 (13 000)
Antenna beamwidth	2°	2°	2°	2°	2°	1°	1°	1°
a) System budget for PFN = 3.5 m (11.5 ft)	0.1098	0.0941	0.0824	0.0732	0.0659	0.0599	0.0549	0.0507
b) Ground equipment error allowance	0.0120	0.0120	0.0120	0.0120	0.0120	0.0120	0.0120	0.0120
c) Ground reflection allowance	0.0400	0.0400	0.0400	0.0400	0.0400	0.0200	0.0200	0.0200
d) Clean site error allocation $\left[d=\sqrt{a^2-b^2-c^2}\right]$	0.1016	0.0844	0.0710	0.0601	0.0510	0.0552	0.0497	0.0450
e) ALS/monitor pole allowance	0.0300	0.0300	0.0300	0.0300	0.0300	0.0150	0.0150	0.0150
f) Complex site error allocation $\left[f=\sqrt{d^2-e^2}\right]$	0.0970	0.0788	0.0643	0.0521	0.0412	0.0531	0.0474	0.0424
g) 70 per cent complex site error allocation	0.0679	0.0552	0.0450	0.0365	0.0288	0.0372	0.0332	0.0297
a) System budget for CMN = 3.2 m (10.5 ft)	0.1003	0.0859	0.0752	0.0668	0.0602	0.0547	0.0501	0.0463
b) Ground equipment error allowance	0.0315	0.0270	0.0236	0.0210	0.0189	0.0172	0.0158	0.0145
c) Airborne equipment error allowance	0.0150	0.0150	0.0150	0.0150	0.0150	0.0150	0.0150	0.0150
d) Allowance for structure vibration	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320
e) Clean/complex site error allocation $\left[e=\sqrt{a^2-b^2-c^2-d^2}\right]$	0.0884	0.0735	0.0620	0.0527	0.0449	0.0380	0.0319	0.0261
f) 70 per cent complex site error allocation	0.0619	0.0515	0.0434	0.0369	0.0314	0.0266	0.0223	0.0183

Table G-11. Error allocations for MLS elevation critical area development
(all allocation values are in degrees)

Antenna beamwidth		1.5°	1.0°
a)	System budget for PFN = 0.4 m (1.3 ft)	0.083	0.083
b)	Ground equipment error allowance	0.010	0.010
c)	Sidelobe reflections allowance	0.055	0.037
d)	Clean site error allocation $\left[d = \sqrt{a^2 - b^2 - c^2}\right]$	0.061	0.073
e)	Vertical diffractions (field monitors)	0.030	0.030
f)	Lateral reflections allowance	0.031	0.043
g)	Complex site error allocation $\left[g = \sqrt{d^2 - e^2 - f^2}\right]$	0.043	0.051
h)	70% complex site error allocation	0.030	0.036
a)	System budget for CMN = 0.3 m (1.0 ft)	0.064	0.064
b)	Ground equipment error allowance	0.032	0.032
c)	Airborne equipment error allowance	0.010	0.010
d)	Sidelobe reflections allowance	0.015	0.010
e)	Allowance for structure vibration	0.010	0.010
f)	Clean/complex site error allocation $\left[f = \sqrt{a^2 - b^2 - c^2 - d^2 - e^2}\right]$	0.052	0.053
g)	70% complex site error allocation	0.036	0.037

Table G-12A. Typical azimuth sensitive area lengths
(aligned approach along zero degree azimuth, see 4.3.7)
(distances are in metres (feet); values in both units have been rounded)

Azimuth to threshold distance	2.0° beamwidth					1.0° beamwidth		
	1 830 (6 000)	2 140 (7 000)	2 440 (8 000)	2 750 (9 000)	3 050 (10 000)	3 350 (11 000)	3 660 (12 000)	3 960 (13 000)
B-747, clean site	490 (1 600)	520 (1 700)	580 (1 900)	610 (2 000)	640 (2 100)	670 (2 200)	700 (2 300)	700 (2 300)
B-727, clean site	300 (1 000)	300 (1 000)	300 (1 000)	300 (1 000)	300 (1 000)	300 (1 000)	460 (1 500)	490 (1 600)
B-747, complex site	490 (1 600)	550 (1 800)	580 (1 900)	640 (2 100)	700 (2 300)	730 (2 400)	760 (2 500)	820 (2 700)
B-727, complex site	300 (1 000)	300 (1 000)	300 (1 000)	460 (1 500)	550 (1 800)	460 (1 500)	490 (1 600)	550 (1 800)

Table G-12B. Typical azimuth sensitive area lengths
(offset approach, see 4.3.7.1)
(distances are in metres (feet); values in both units have been rounded)

Azimuth to threshold distance	2.0° beamwidth					1.0° beamwidth		
	1 830 (6 000)	2 140 (7 000)	2 440 (8 000)	2 750 (9 000)	3 050 (10 000)	3 350 (11 000)	3 660 (12 000)	3 960 (13 000)
B-747, clean site	640 (2 100)	730 (2 400)	790 (2 600)	880 (2 900)	880 (2 900)	920 (3 000)	940 (3 100)	1 010 (3 300)
B-727, clean site	300 (1 000)	300 (1 000)	300 (1 000)	300 (1 000)	300 (1 000)	300 (1 000)	490 (1 600)	550 (1 800)
B-747, complex site	670 (2 200)	760 (2 500)	820 (2 700)	880 (2 900)	1 010 (3 300)	980 (3 200)	1 070 (3 500)	1 130 (3 700)
B-727, complex site	300 (1 000)	300 (1 000)	330 (1 100)	460 (1 500)	550 (1 800)	490 (1 600)	520 (1 700)	550 (1 800)

Table G-12C. Typical azimuth sensitive area lengths
(computed centre line approach, see 4.3.7.2, clean sites)
(distances are in metres (feet); values in both units have been rounded)

Azimuth to threshold distance	2.0° beamwidth					1.0° beamwidth		
	1 830 (6 000)	2 140 (7 000)	2 440 (8 000)	2 750 (9 000)	3 050 (10 000)	3 350 (11 000)	3 660 (12 000)	3 960 (13 000)
B-727, clean site								
Height: 300 (1 000)	300 (1 000)	300 (1 000)	300 (1 000)	300 (1 000)	300 (1 000)	300 (1 000)	300 (1 000)	300 (1 000)
75 (250)	300 (1 000)	300 (1 000)	300 (1 000)	300 (1 000)	300 (1 000)	300 (1 000)	490 (1 600)	550 (1 800)
60 (200)	300 (1 000)	300 (1 000)	300 (1 000)	460 (1 500)	490 (1 600)	610 (2 000)	610 (2 000)	670 (2 200)
45 (150)	300 (1 000)	300 (1 000)	490 (1 600)	550 (1 800)	610 (2 000)	670 (2 200)	760 (2 500)	820 (2 700)
30 (100)	300 (1 000)	520 (1 700)	610 (2 000)	700 (2 300)	820 (2 700)	920 (3 000)	980 (3 200)	1 100 (3 600)
15 (50)	610 (2 000)	730 (2 400)	880 (2 900)	1 010 (3 300)	1 070 (3 500)	1 100 (3 600)	1 040 (3 400)	1 190 (3 900)
B-747, clean site								
300 (1 000)	430 (1 400)	460 (1 500)	490 (1 600)	520 (1 700)	520 (1 700)	550 (1 800)	580 (1 900)	610 (2 000)
75 (250)	640 (2 100)	730 (2 400)	790 (2 600)	850 (2 800)	880 (2 900)	920 (3 000)	940 (3 100)	1 010 (3 300)
60 (200)	700 (2 300)	790 (2 600)	820 (2 700)	920 (3 000)	940 (3 100)	940 (3 100)	1 010 (3 300)	1 010 (3 300)
45 (150)	760 (2 500)	820 (2 700)	920 (3 000)	1 010 (3 300)	1 070 (3 500)	1 070 (3 500)	1 190 (3 900)	1 400 (4 600)
30 (100)	850 (2 800)	960 (3 100)	1 100 (3 600)	1 250 (4 100)	1 400 (4 600)	1 550 (5 100)	1 710 (5 600)	1 890 (6 200)
15 (50)	1 070 (3 500)	1 340 (4 400)	1 580 (5 200)	1 830 (6 000)	1 980 (6 500)	2 040 (6 700)	2 070 (6 800)	2 070 (6 800)

Table G-12D. Typical azimuth sensitive area lengths
(computed centre line approach, see 4.3.7.2, complex sites)
(distances are in metres (feet); values in both units have been rounded)

Azimuth to threshold distance	2.0° beamwidth					1.0° beamwidth		
	1 830 (6 000)	2 140 (7 000)	2 440 (8 000)	2 750 (9 000)	3 050 (10 000)	3 350 (11 000)	3 660 (12 000)	3 960 (13 000)
B-727, complex site								
Height: 300 (1 000)	300 (1 000)	300 (1 000)	300 (1 000)	300 (1 000)	300 (1 000)	300 (1 000)	300 (1 000)	300 (1 000)
300 (1 000)	300 (1 000)	300 (1 000)	330 (1 100)	460 (1 500)	550 (1 800)	490 (1 600)	520 (1 700)	550 (1 800)
300 (1 000)	300 (1 000)	330 (1 100)	330 (1 100)	490 (1 600)	550 (1 800)	580 (1 900)	610 (2 000)	730 (2 400)
330 (1 100)	330 (1 100)	330 (1 100)	490 (1 600)	550 (1 800)	670 (2 200)	700 (2 300)	790 (2 600)	880 (2 900)
330 (1 100)	330 (1 100)	550 (1 800)	640 (2 100)	730 (2 400)	1 010 (3 300)	940 (3 100)	1 040 (3 400)	1 160 (3 800)
640 (2 100)	640 (2 100)	790 (2 600)	940 (3 100)	1 070 (3 500)	1 250 (4 100)	1 250 (4 100)	1 280 (4 200)	1 430 (4 700)
B-747, clean site								
300 (1 000)	430 (1 400)	460 (1 500)	490 (1 600)	520 (1 700)	670 (2 200)	550 (1 800)	580 (1 900)	610 (2 000)
75 (250)	670 (2 200)	760 (2 500)	820 (2 700)	880 (2 900)	1 010 (3 300)	980 (3 200)	1 070 (3 500)	1 130 (3 700)
60 (200)	730 (2 400)	820 (2 700)	920 (3 000)	1 010 (3 300)	1 130 (3 700)	1 040 (3 400)	1 070 (3 500)	1 220 (4 000)
45 (150)	820 (2 700)	880 (2 900)	980 (3 200)	1 100 (3 600)	1 220 (4 000)	1 100 (3 600)	1 190 (3 900)	1 430 (4 700)
30 (100)	920 (3 000)	1 010 (3 300)	1 130 (3 700)	1 280 (4 200)	1 430 (4 700)	1 580 (5 200)	1 770 (5 800)	1 950 (6 400)
15 (50)	1 100 (3 600)	1 370 (4 500)	1 620 (5 300)	1 830 (6 000)	2 130 (7 000)	2 230 (7 300)	2 350 (7 700)	2 380 (7 800)

Table G-13. Minimum height surface angle and related protected coverage volume lengths for MLS/RNAV approach procedures

Protected coverage volume length L[m(ft)] PCH = 2.0 m	Minimum height surface angle (degrees), θ B-727	B-747
300 (1 000)	1.81	3.49
450 (1 500)	1.23	2.36
600 (2 000)	0.95	1.79
750 (2 500)	0.77	1.44
900 (3 000)	N/A	1.21

The following equation can be used to determine the minimum height surface angle (Θ) in respect to an azimuth antenna phase centre for arbitrary protected coverage volume length "L".

$$\theta = \tan^{-1}\left[\frac{TFH + \frac{\sqrt{\lambda(L)}}{4} - PCH}{L}\right]$$

where:

TFH = tail fin height;
PCH = phase centre height of MLS antenna;
λ = MLS wave length.

Note.— TFH equals 10.4 m for B-727 and 19.3 m for B-747, and λ is 0.06 m. PCH and L must be in metres if TFH and λ are in metres.

Table G-14. Interrelationship of ground equipment monitor and control action

Sub-system failure	Resultant action: Approach azimuth	Approach elevation	Back azimuth	Basic data radiated into approach azimuth coverage	Basic data radiated into back azimuth coverage	Auxiliary data	DME/N or DME/P
Approach azimuth	*	*		+		+	
Approach elevation		*					
Back azimuth			*		+		
Basic data radiated into approach azimuth coverage	*	*		*		+	
Basic data radiated into back azimuth coverage			*		*		
Auxiliary data	+	+		+		*	
DME/N or DME/P							*

* Indicates radiation should cease.
\+ Indicates radiation may continue when operationally required.

Table G-15. Continuity of service and integrity objectives for MLS basic and MLS/RNAV operations

Level	Azimuth or elevation: Integrity in any one landing	Azimuth or elevation: Continuity of service	Azimuth or elevation: MTBO (hours)	DME/P (Note 6): Integrity in any one landing (Note 4)	DME/P (Note 6): Continuity of service	DME/P (Note 6): MTBO (hours)
1	Not demonstrated, but designed to meet the Level 2 requirements (Note 3)					
2	$1 - 1 \times 10^{-7}$	$1 - 4 \times 10^{-6}$ (15 s)	1 000	$1 - 1 \times 10^{-7}$	$1 - 4 \times 10^{-6}$ (15 s)	1 000
3	$1 - 0.5 \times 10^{-9}$	$1 - 2 \times 10^{-6}$ (15 s)	2 000	$1 - 1 \times 10^{-7}$	$1 - 4 \times 10^{-6}$ (15 s)	1 000
4 (Note 5)	$1 - 0.5 \times 10^{-9}$	$1 - 2 \times 10^{-6}$ (30 s Az) (15 s El) (Note 6)	4 000 Az 2 000 El (Note 6)	$1 - 1 \times 10^{-7}$	$1 - 4 \times 10^{-6}$ (15 s)	1 000

NOTES.—

1. Data word continuity of service and integrity are included in the specified values of the angle function for each level of service.
2. Back azimuth is not required for basic operations.
3. It is intended that all equipments meet at least Level 2 requirements.
4. If DME/N is used with MLS the figures may be reduced to $1 - 1 \times 10^{-5}$.
5. The Level 4 exposure times are based on experience with ILS and are consistent with existing operational capabilities. As experience is gained with MLS, and enhanced operational capabilities are proposed, it may be necessary to adjust these values.
6. MLS/RNAV procedures may require the Level 3 and 4 integrity, continuity of service and MTBO objectives of the elevation, DME/P and, if used, back azimuth to be equivalent to the approach azimuth equipment.

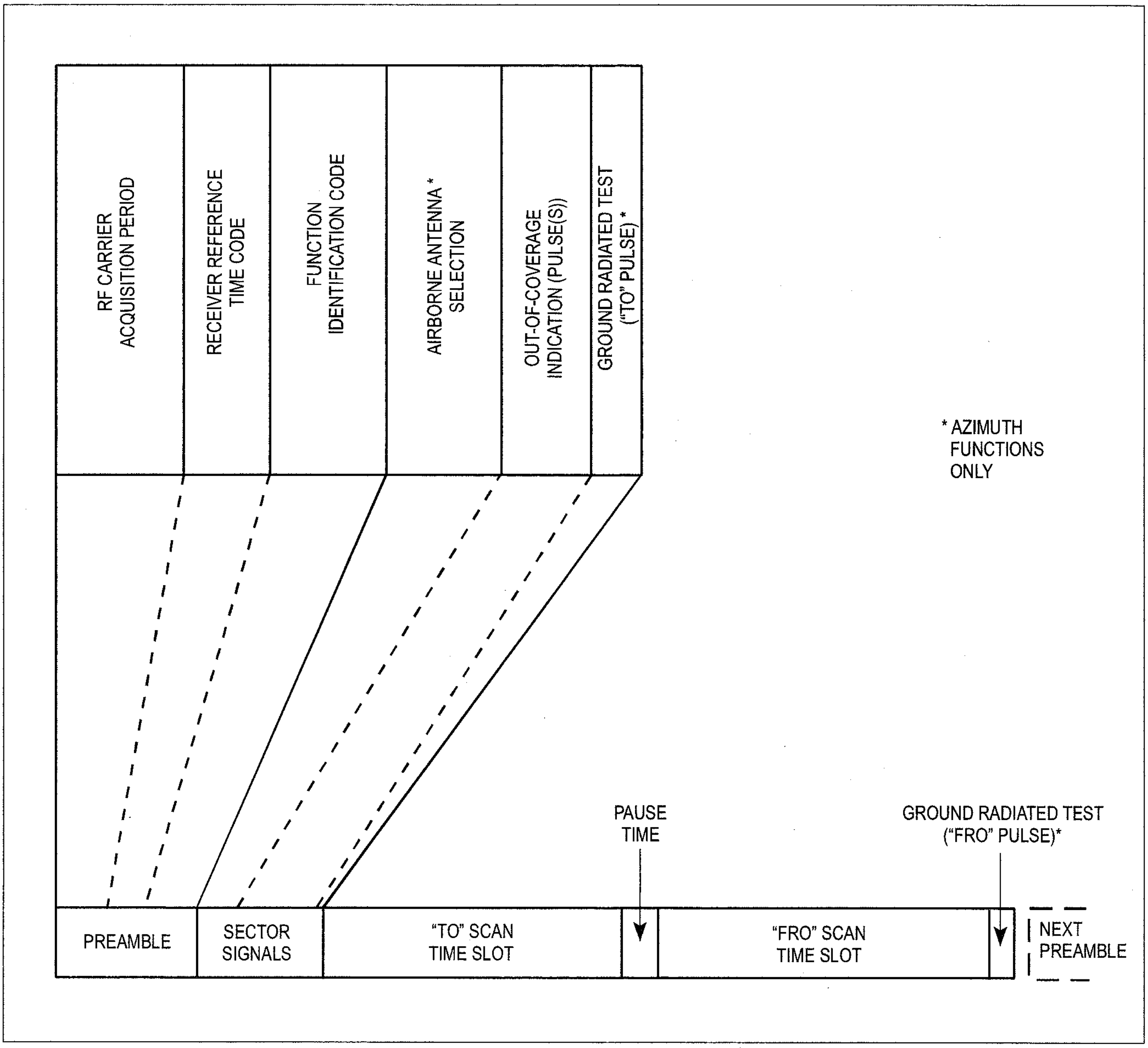


Figure G-1. Angle function organization

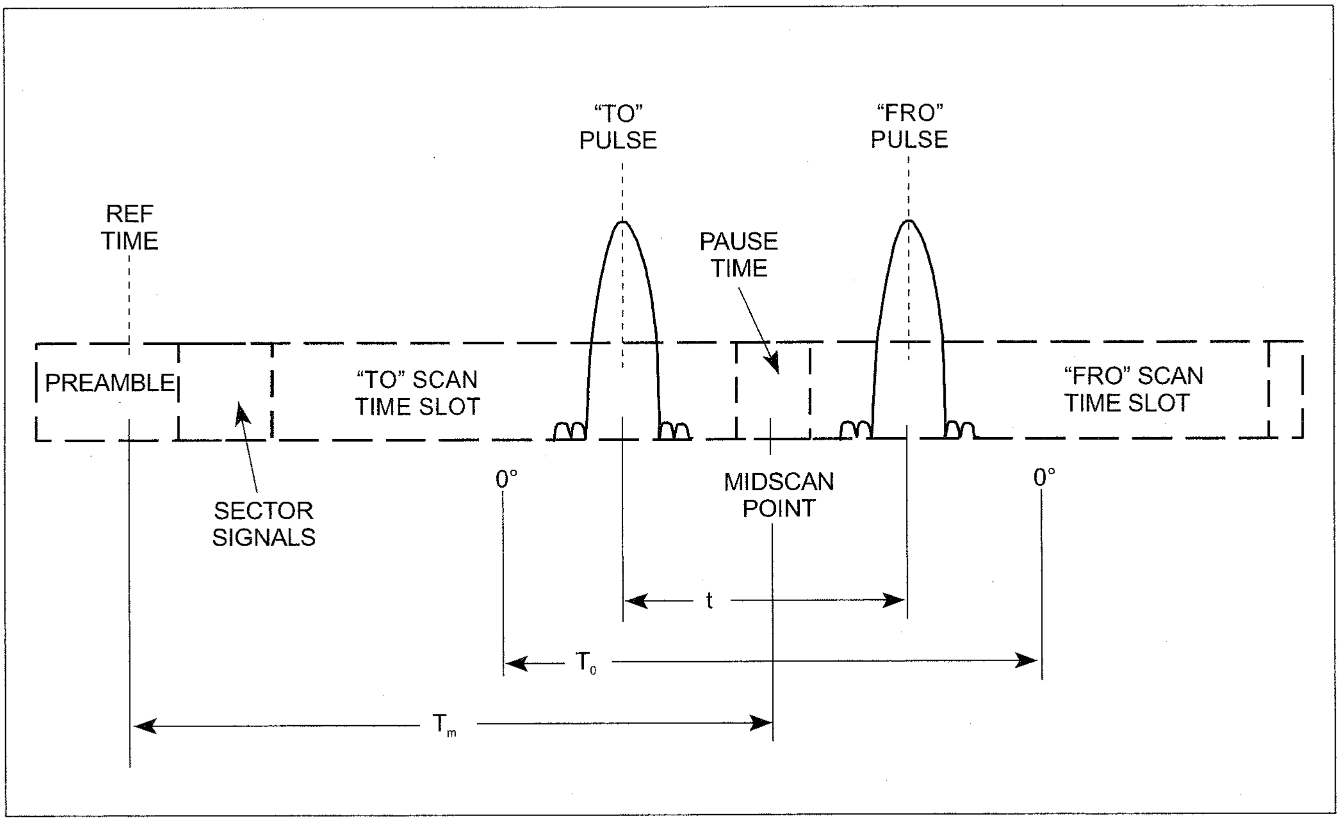
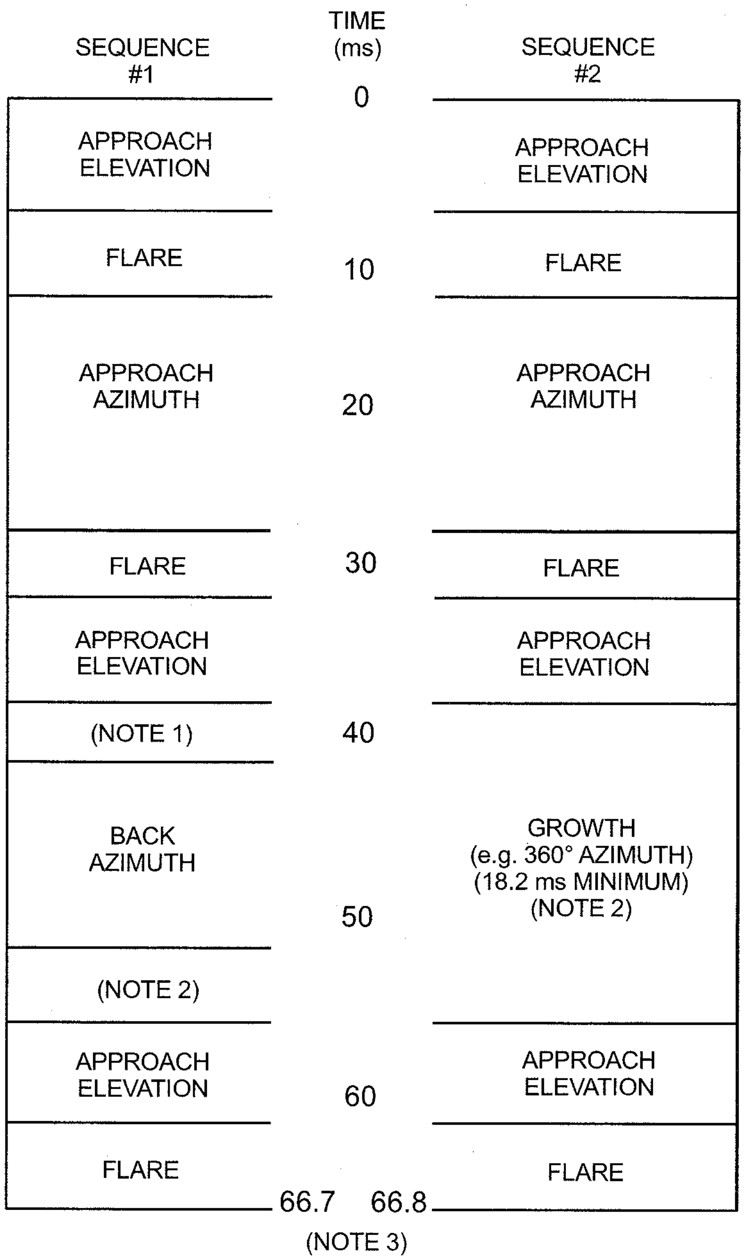


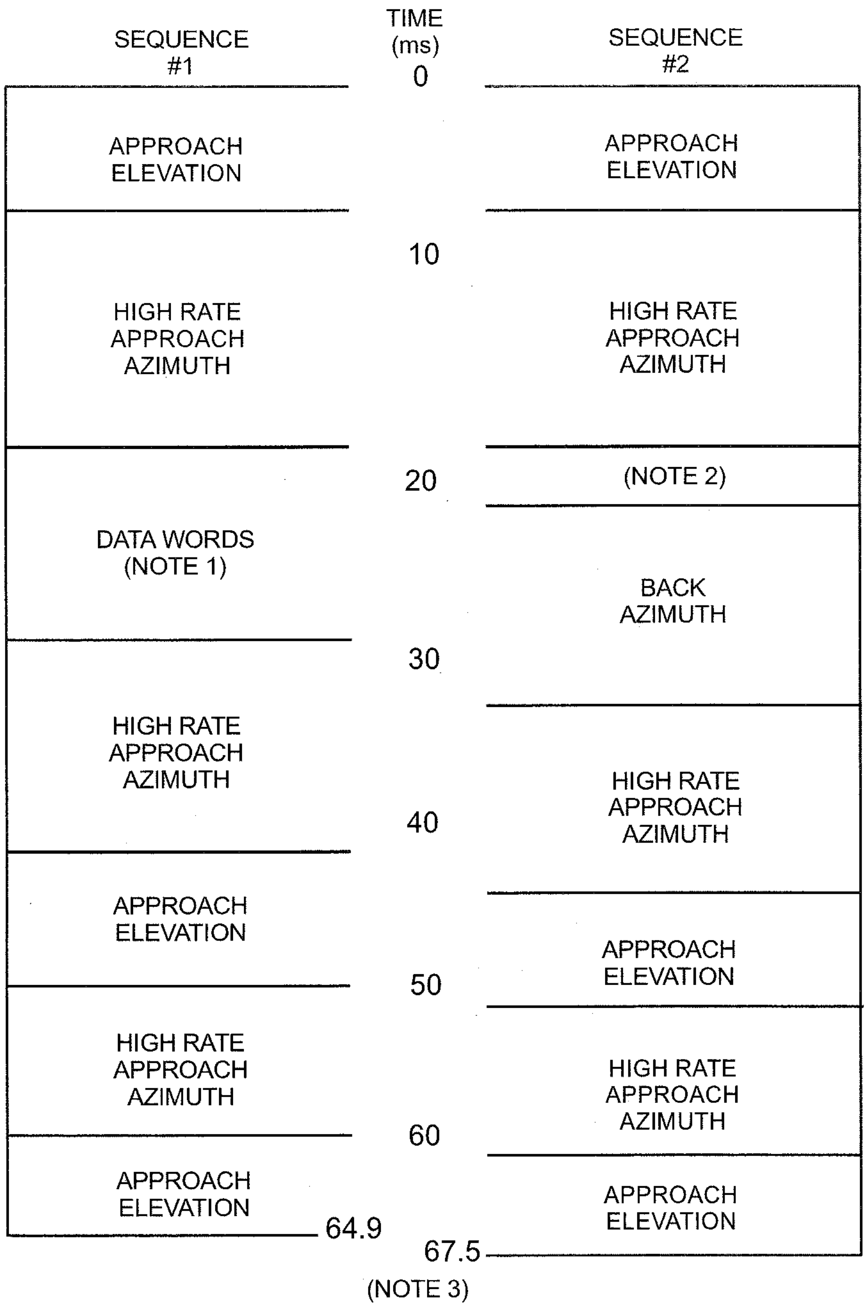
Figure G-2. Angle scan timing parameters



Notes:

1. When back azimuth is provided, basic data word 2 must be transmitted only in this position.
2. Data words may be transmitted in any open time periods.
3. The total time duration of sequence #1 plus sequence #2 must not exceed 134 ms.

Figure G-3A. Transmission sequence pair which provides for all MLS angle guidance functions



Notes:

1. Data words may be transmitted in any open time periods.
2. When back azimuth is provided, basic data word 2 must be transmitted only in this position.
3. The total time duration of sequence #1 plus sequence #2 must not exceed 134 ms.

Figure G-3B. Transmission sequence pair which provides for the MLS high rate approach azimuth angle guidance function

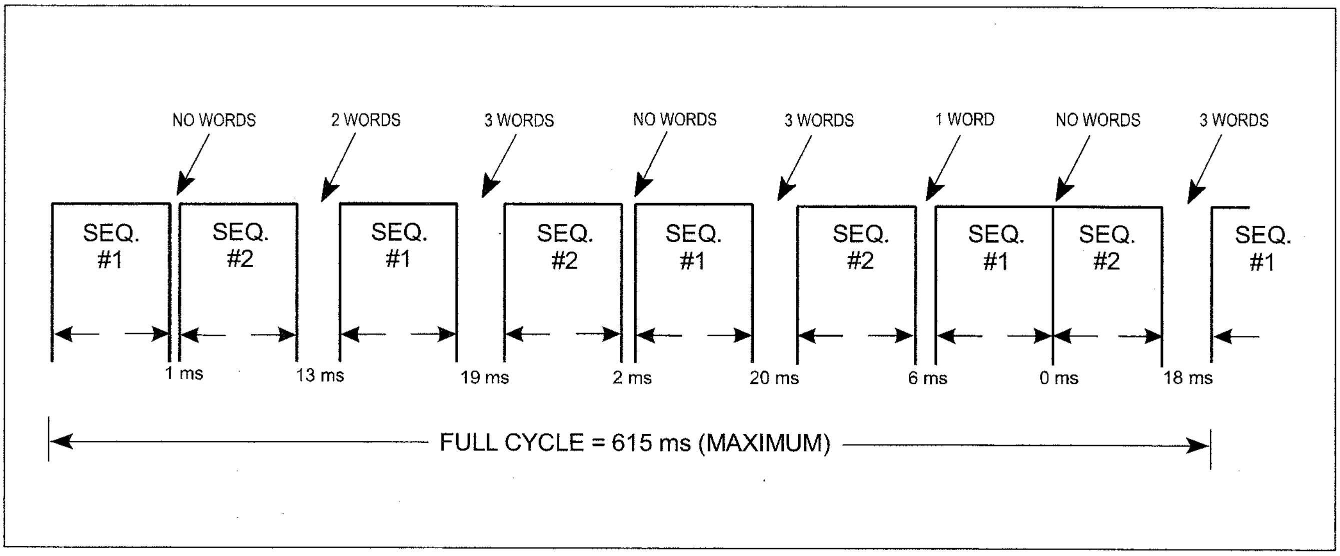


Figure G-3C. Complete multiplex transmission cycle showing open time periods available for data words

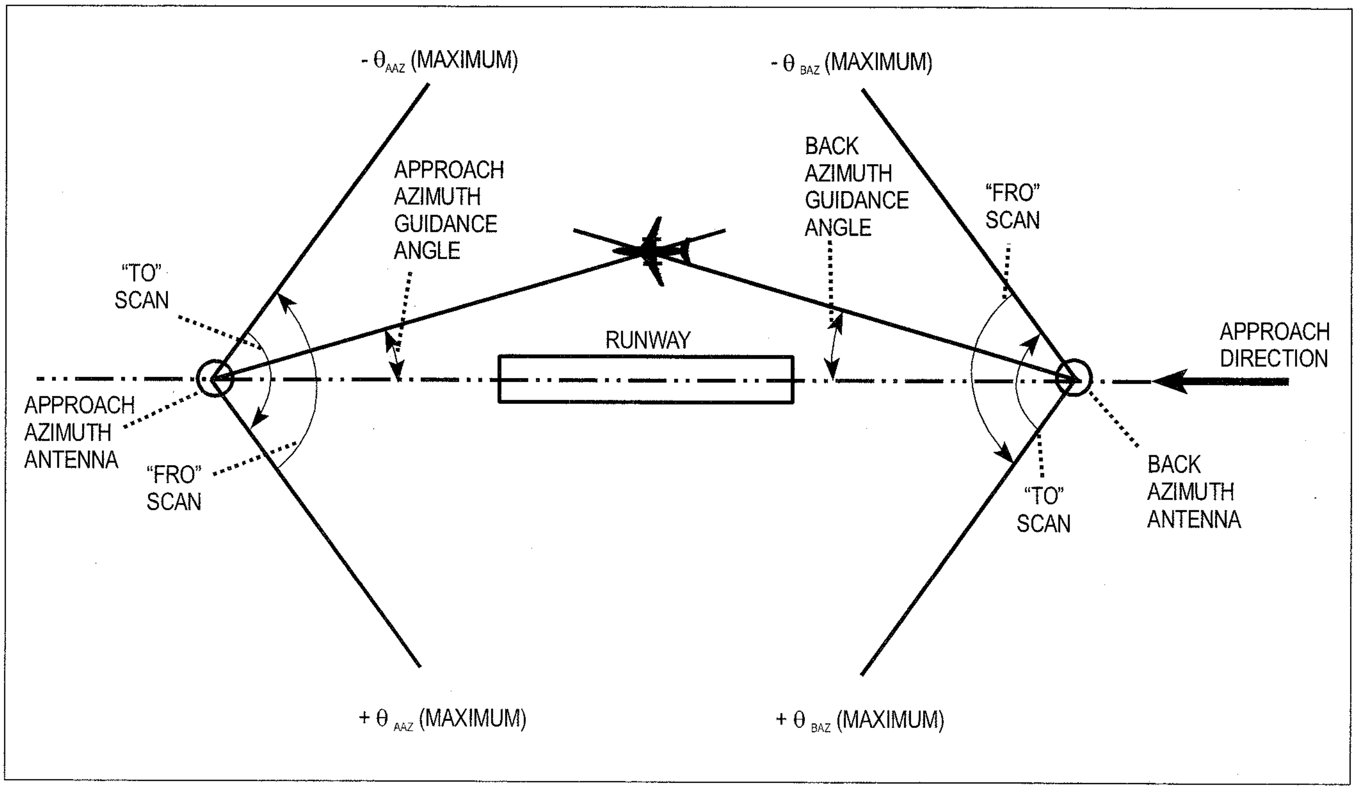
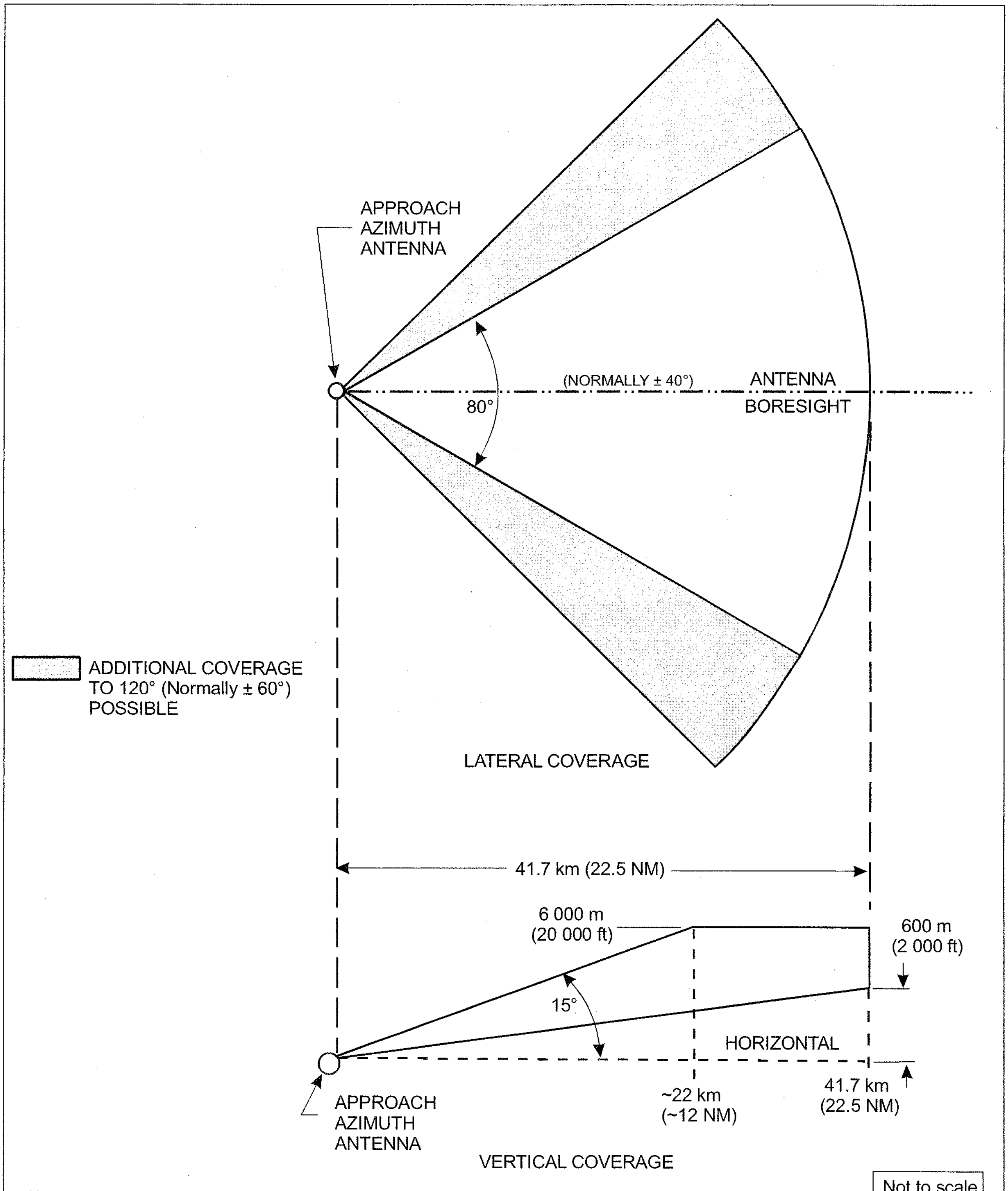
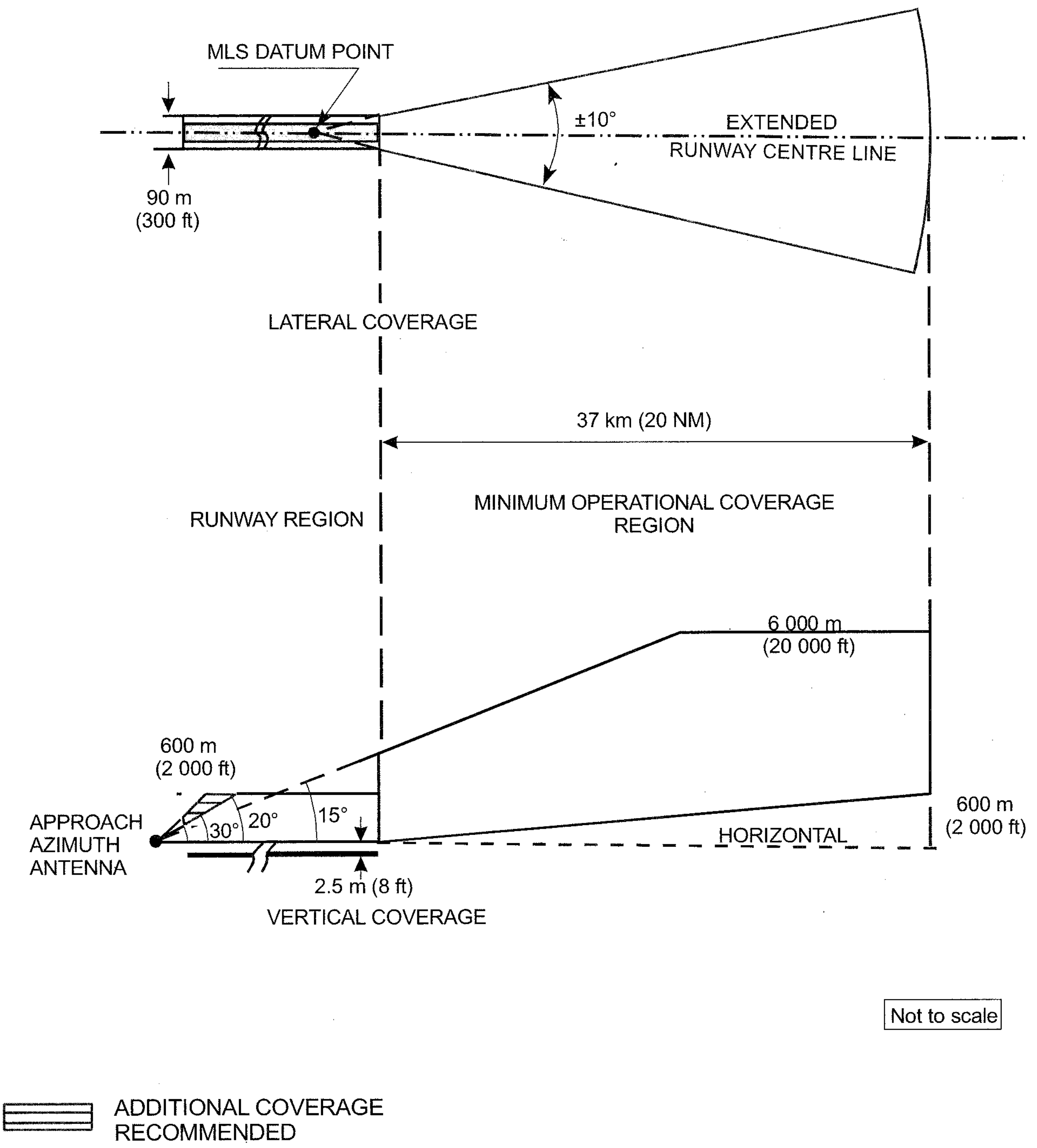


Figure G-4. Scanning conventions for azimuth guidance functions



Note.— The above represents the coverage sector originating at the phase centre of the installed antenna.

Figure G-5A. Approach azimuth region coverage



Note.— The above represents the minimum proportional guidance sector required, irrespective of equipment location or orientation.

Figure G-5B. Azimuth runway region coverage and minimum operational coverage region

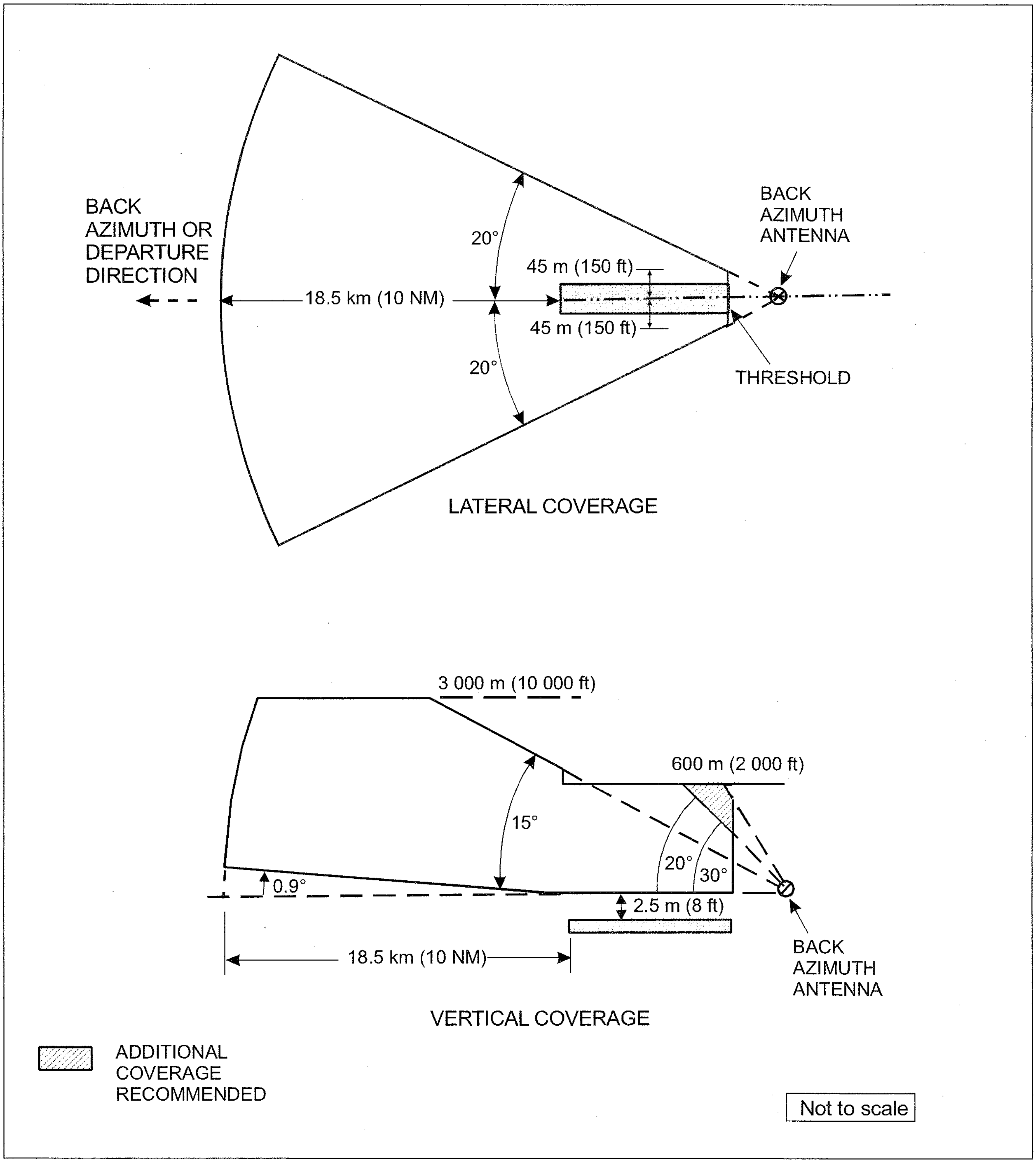


Figure G-6. Back azimuth region coverage

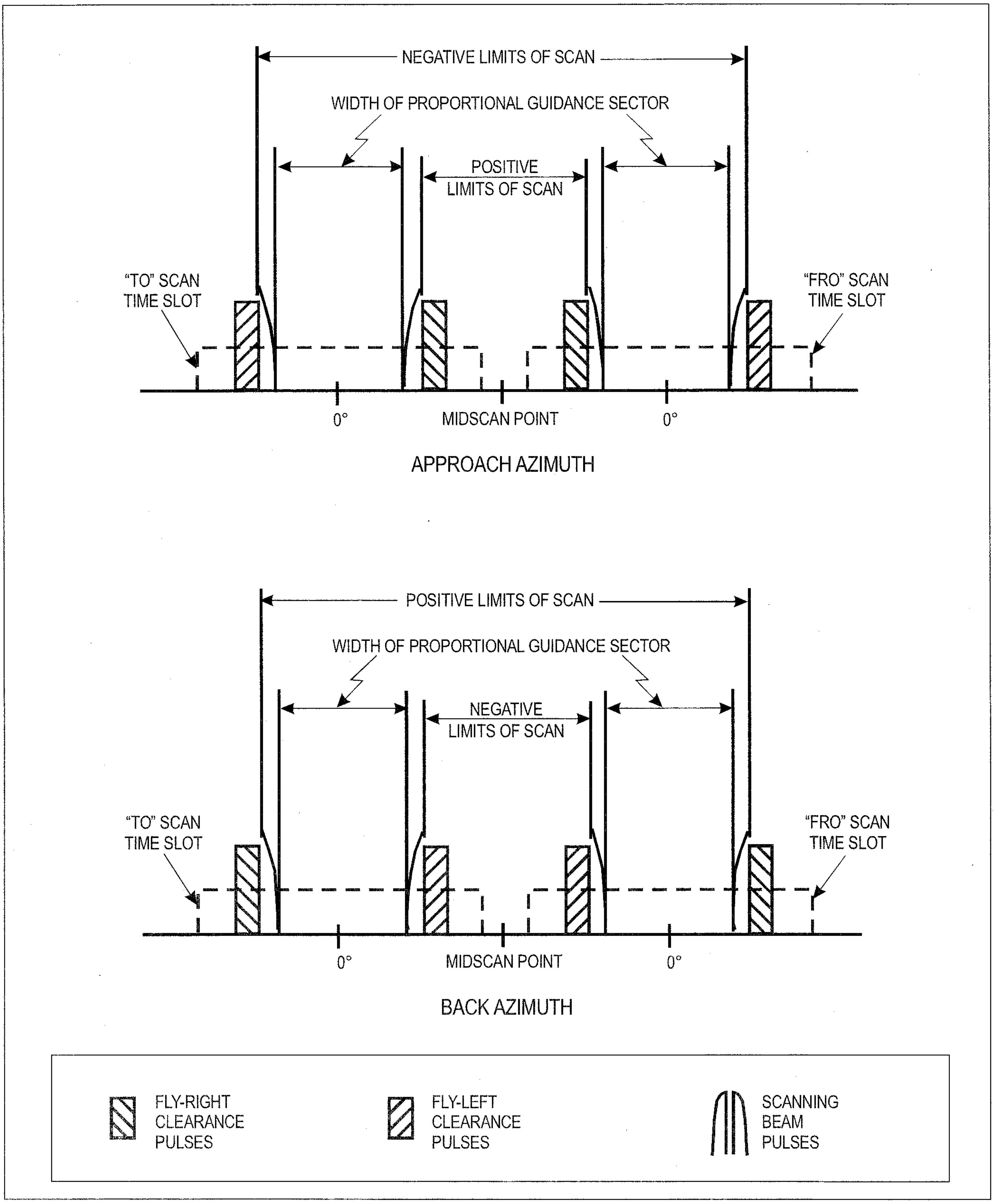


Figure G-7. Clearance pulse conventions for azimuth functions

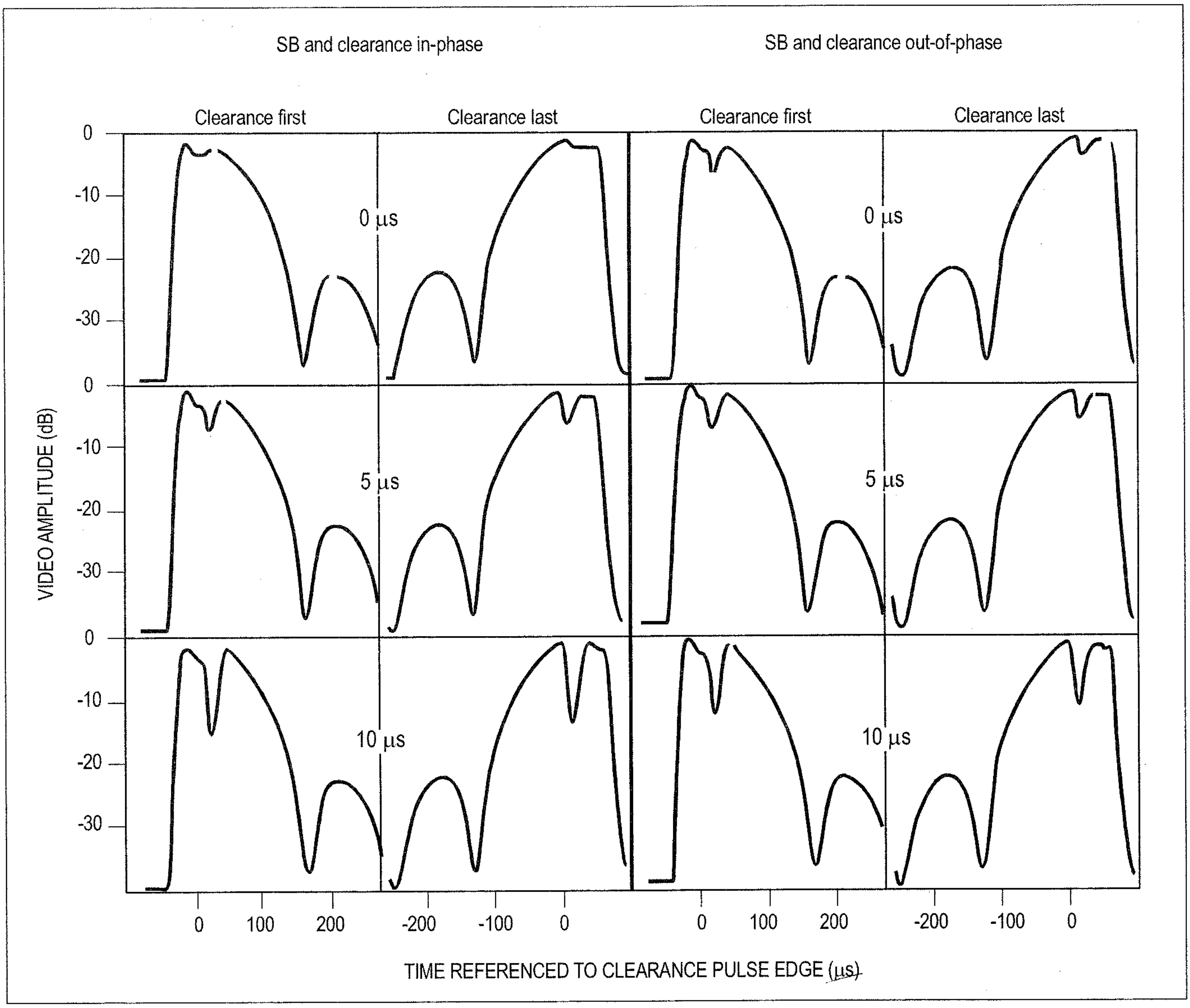


Figure G-8. Examples of received video waveforms in SB/clearance transition region for switching times of 0, 5 and 10 microseconds

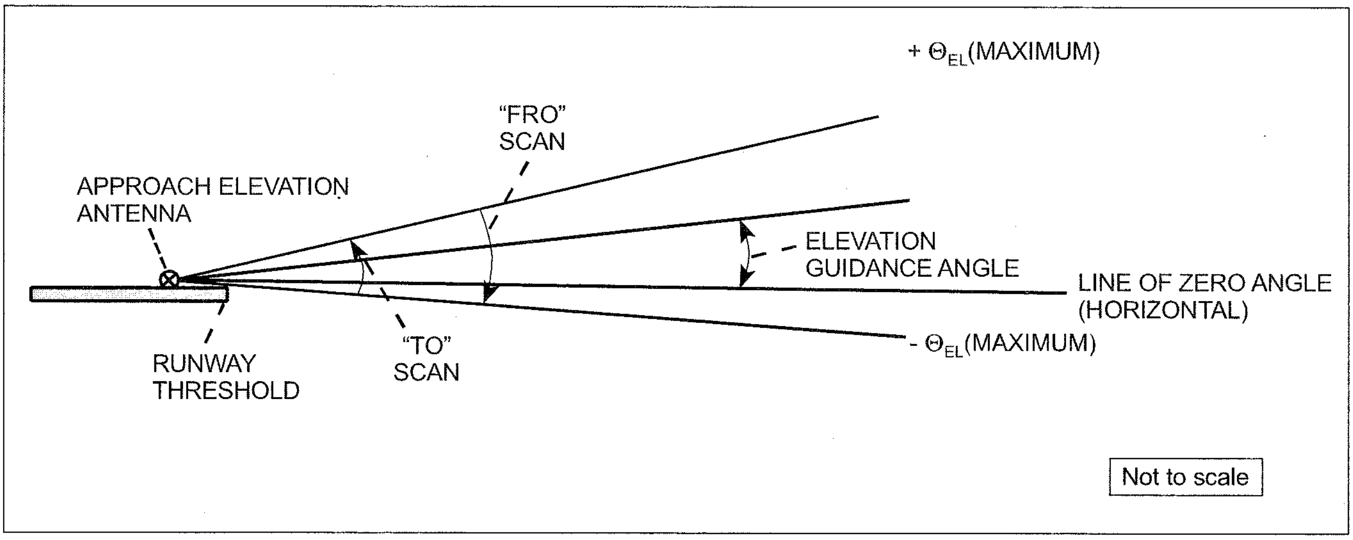
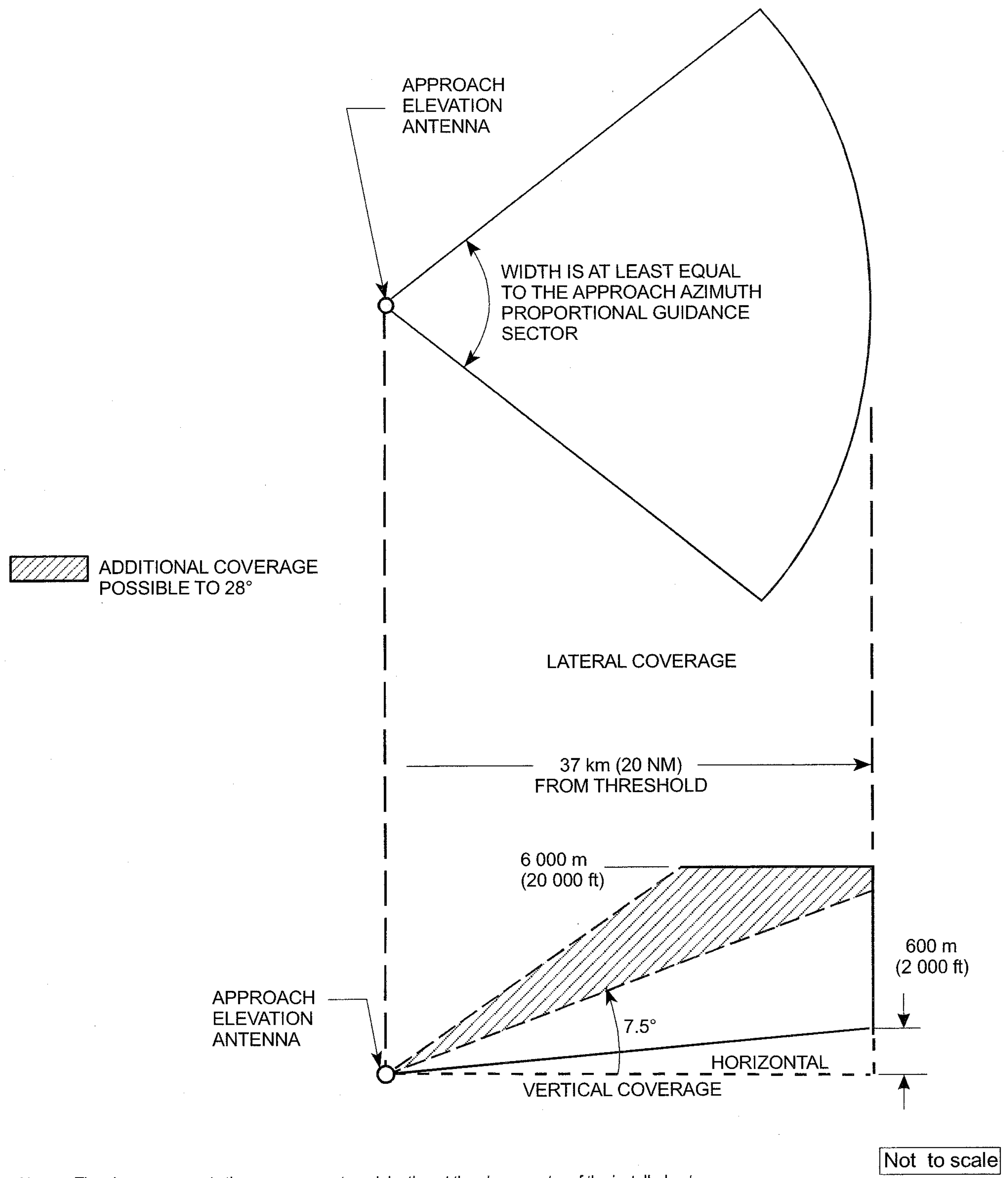
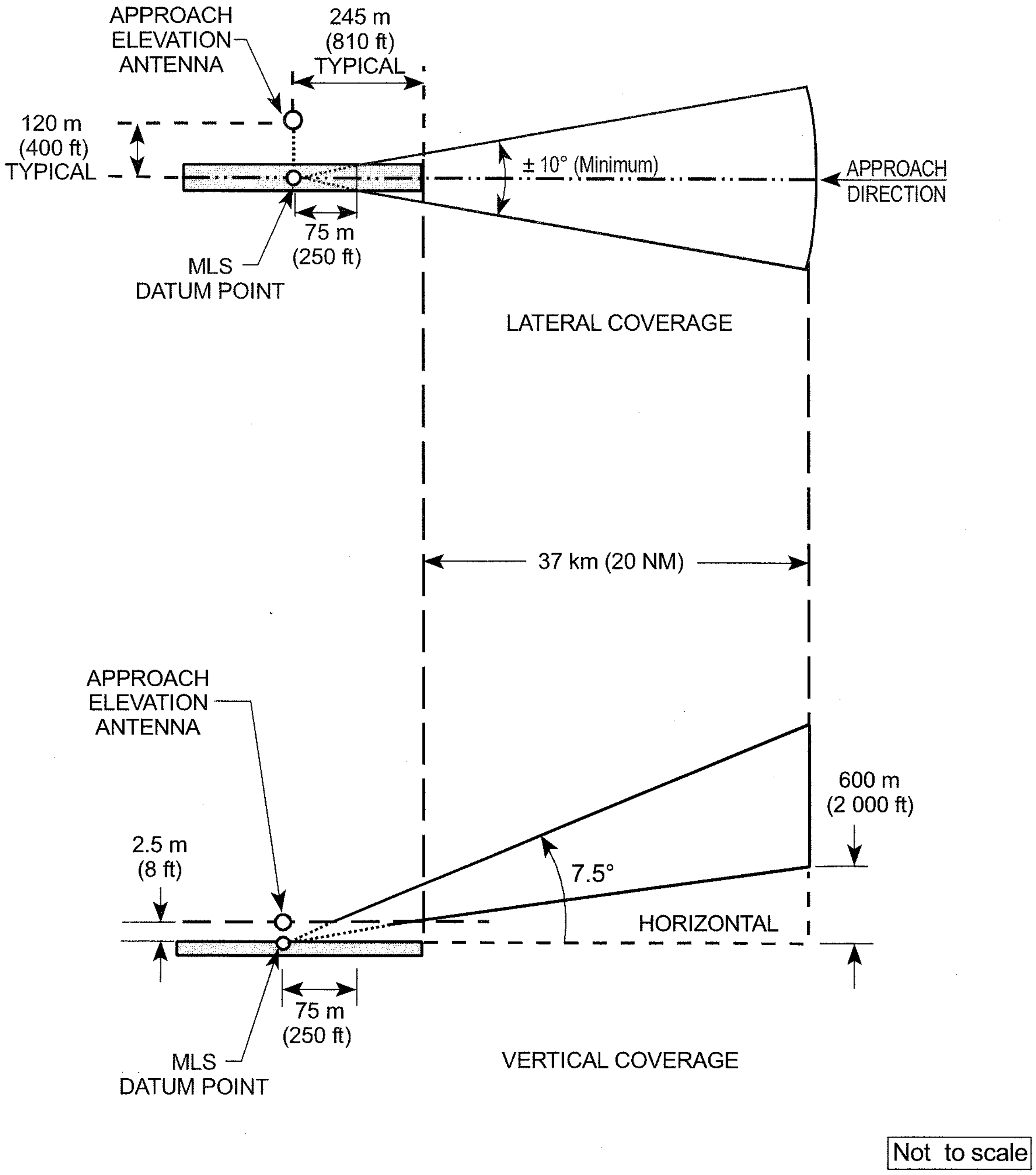


Figure G-9. Scanning conventions for approach elevation function



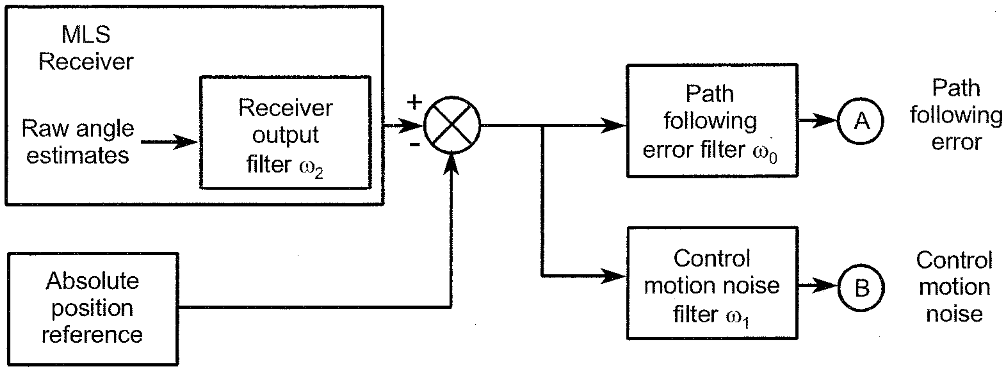
Note.— The above represents the coverage sector originating at the phase centre of the installed antenna.

Figure G-10A. Elevation approach region coverage



Note.— The above represents the minimum proportional guidance sector required, irrespective of equipment location or orientation.

Figure G-10B. Elevation minimum operational coverage



Guidance function	Corner frequencies (Radians/sec)		
	ω_0	ω_1	ω_2
Approach azimuth	0.5	0.3	10
Approach elevation	1.5	0.5	10
DME//P	1.5	0.5	10

Receiver output filter: $\dfrac{\omega_2}{S + \omega_2}$

Path following filter: $\dfrac{\omega_n^2}{S^2 + 2\zeta\omega_n S + \omega_n^2}$ $\qquad \zeta = 1$, $\omega_0 = 0.64\,\omega_n$

Control motion noise filter: $\dfrac{S}{S + \omega_1}$ $\qquad S = j\omega$

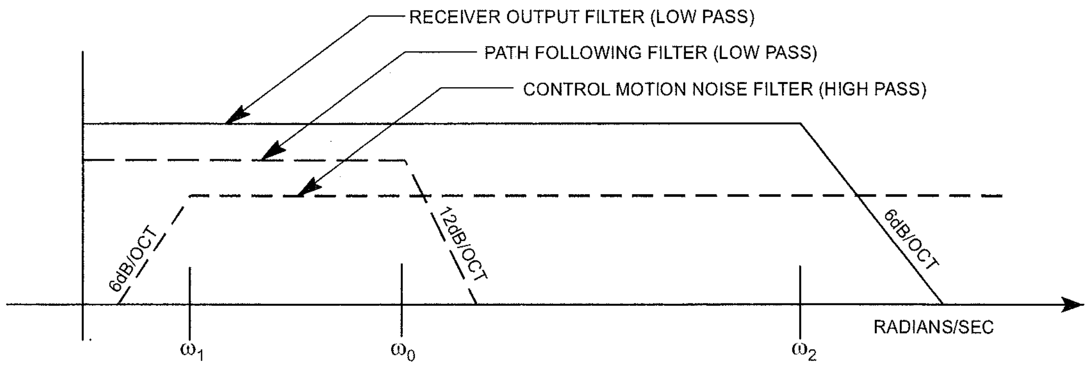
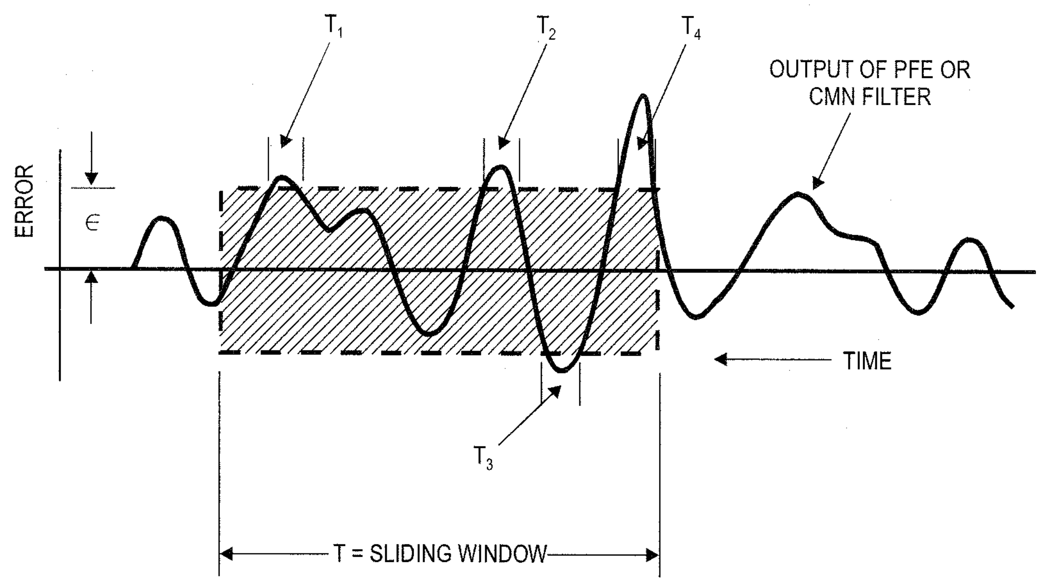


Figure G-11. Filter configurations and corner frequencies



Notes:

$\in$ = Error specification
T = Region to be evaluated
$T_1\ T_2\ T_3 \cdots$ = Time intervals that error exceeds specifications.
For the ground equipment to be acceptable in this region, the following inequality should be true:

$$\frac{(T_1 + T_2 + T_3 + \ldots)}{T} \leq 0.05$$

Figure G-12. MLS measurement methodology

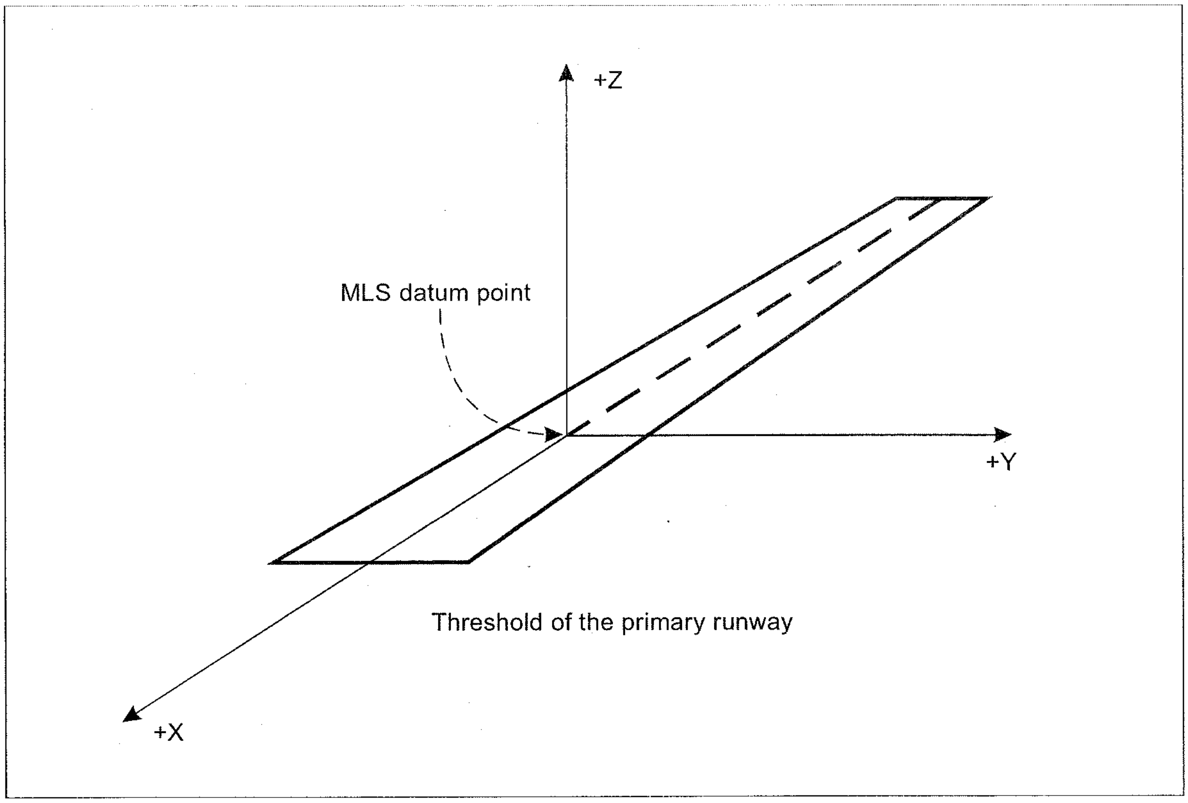


Figure G-13. MLS/RNAV way-point coordinate system

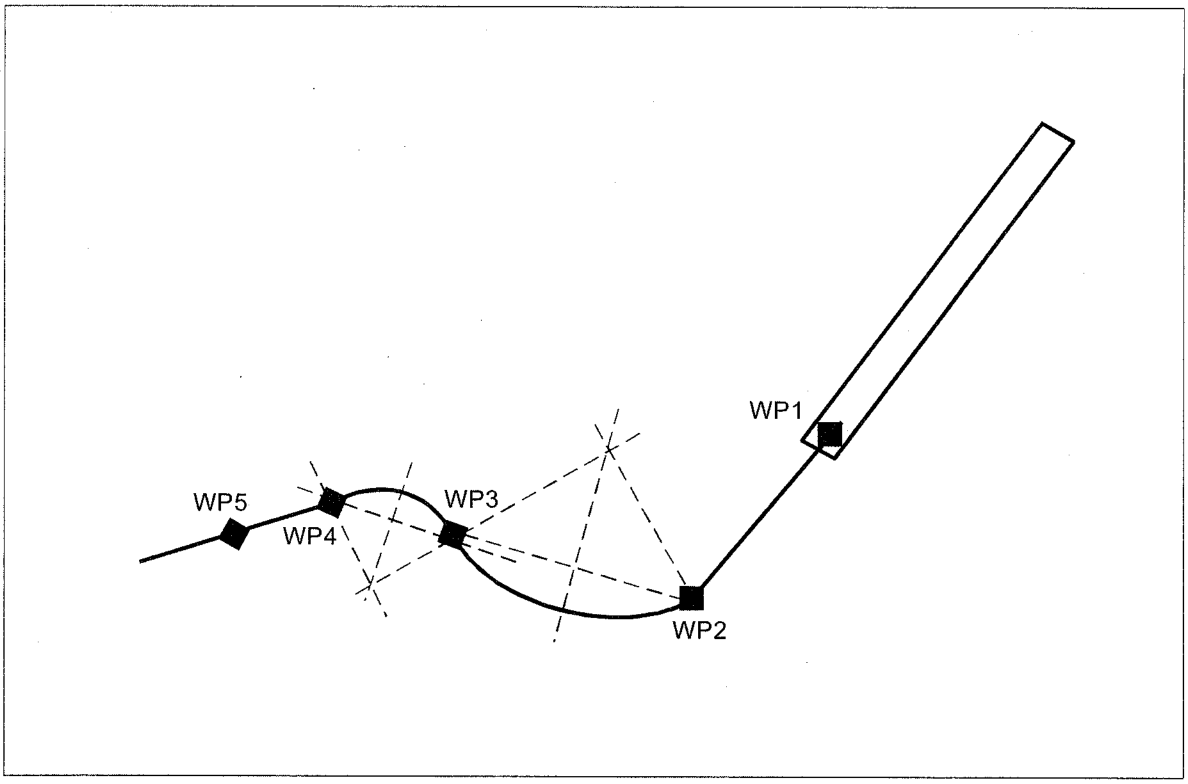


Figure G-14. Definition of curved segments

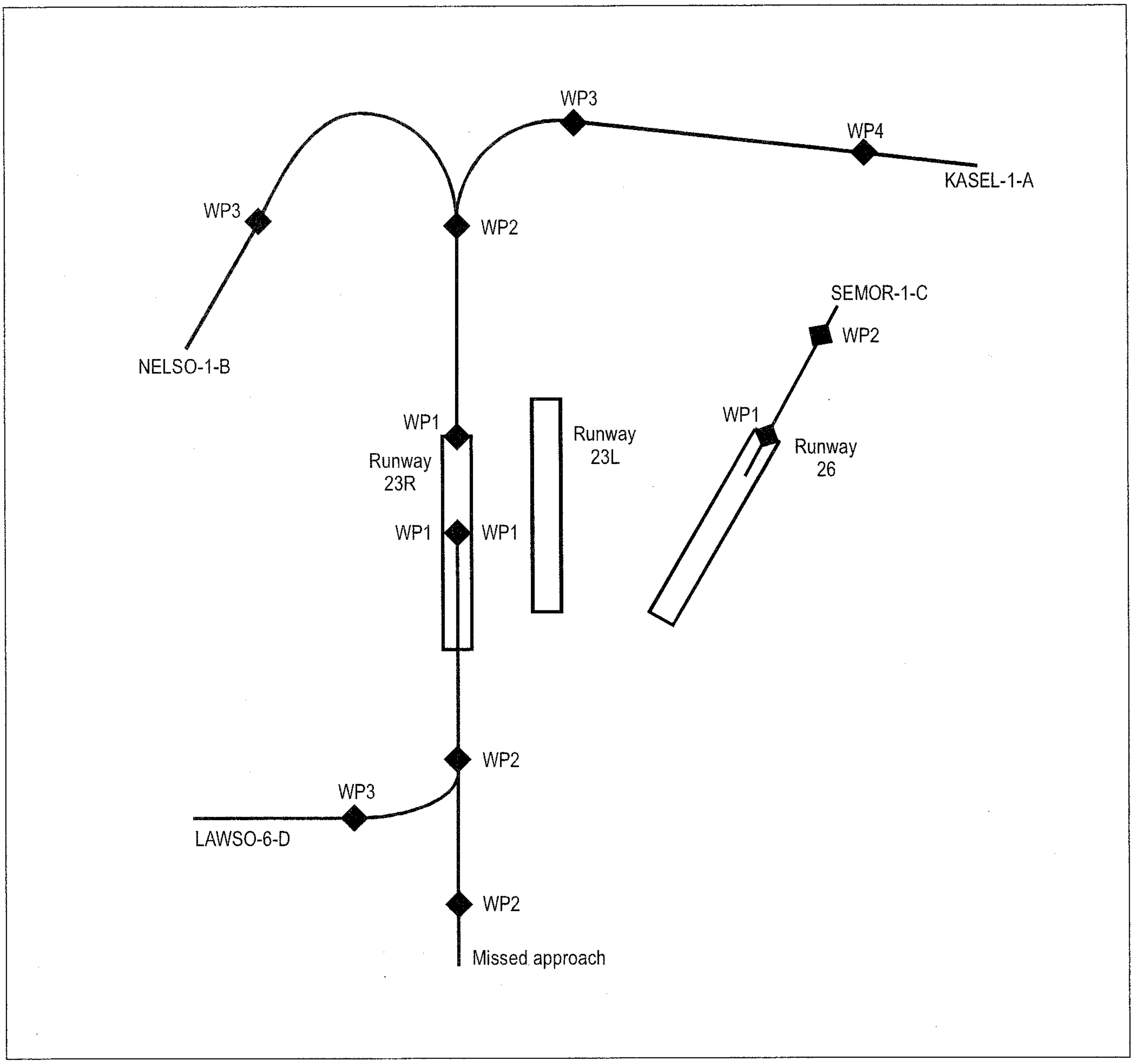
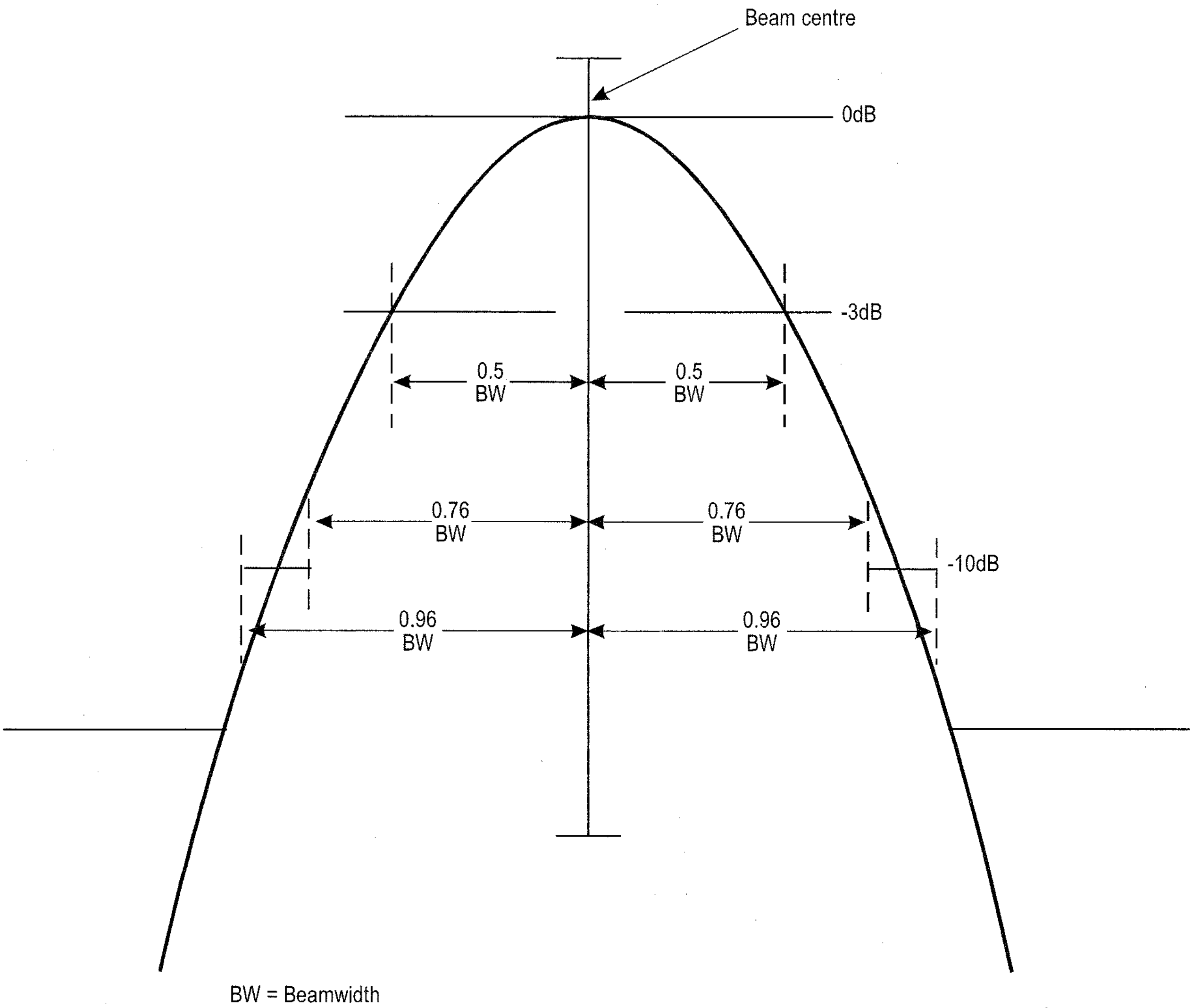


Figure G-15. Diagram of sample MLS/RNAV procedures



Note.— The beam envelope is smoothed by a 26 kHz video filter before measurement.

Figure G-16. Far field dynamic signal-in-space

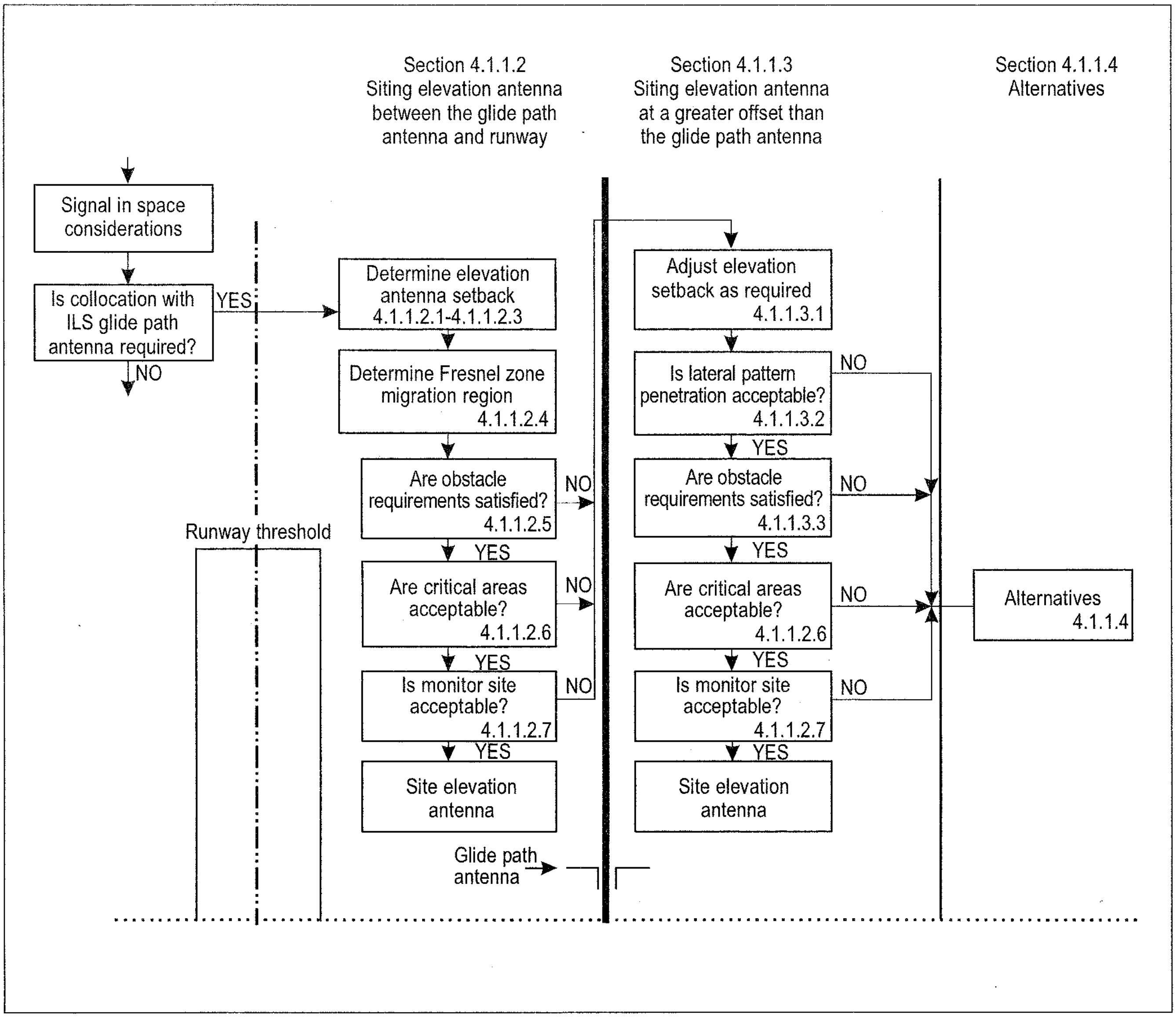
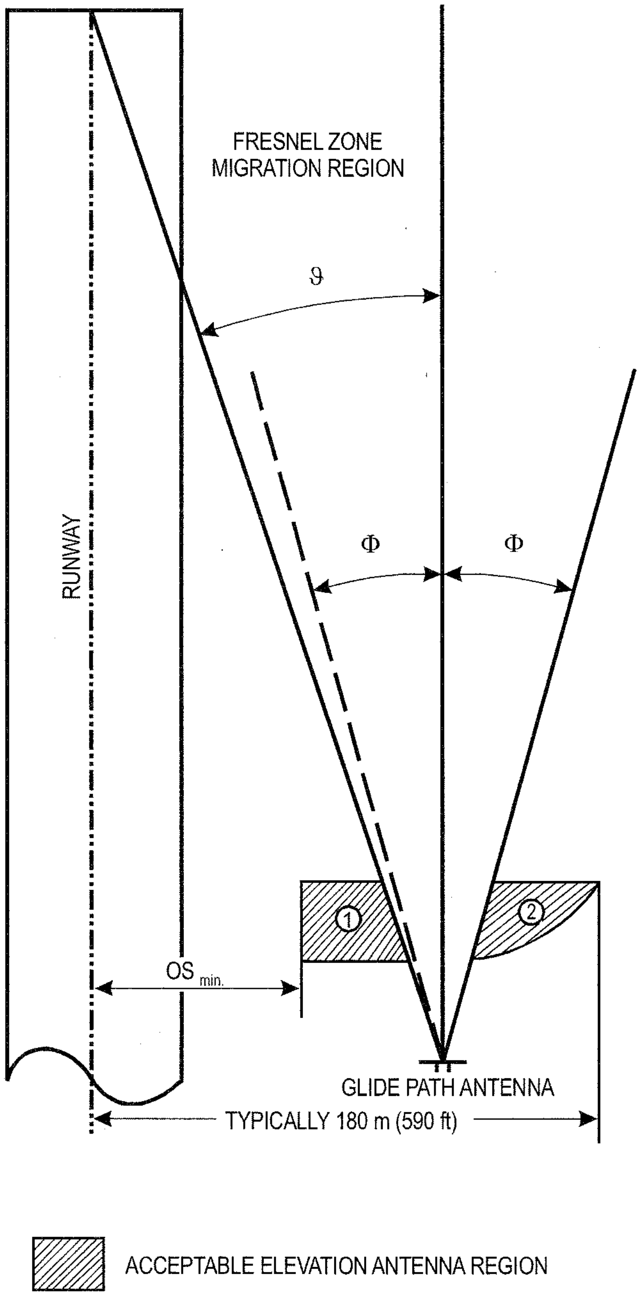


Figure G-17. Elevation/glide path logic flow diagram



Note.— If | ϑ | < | Φ | lateral pattern penetration factor will prevail over Fresnel zone factor in region 1.

Figure G-18. Elevation antenna regions for collocation with ILS (3° minimum glide path)

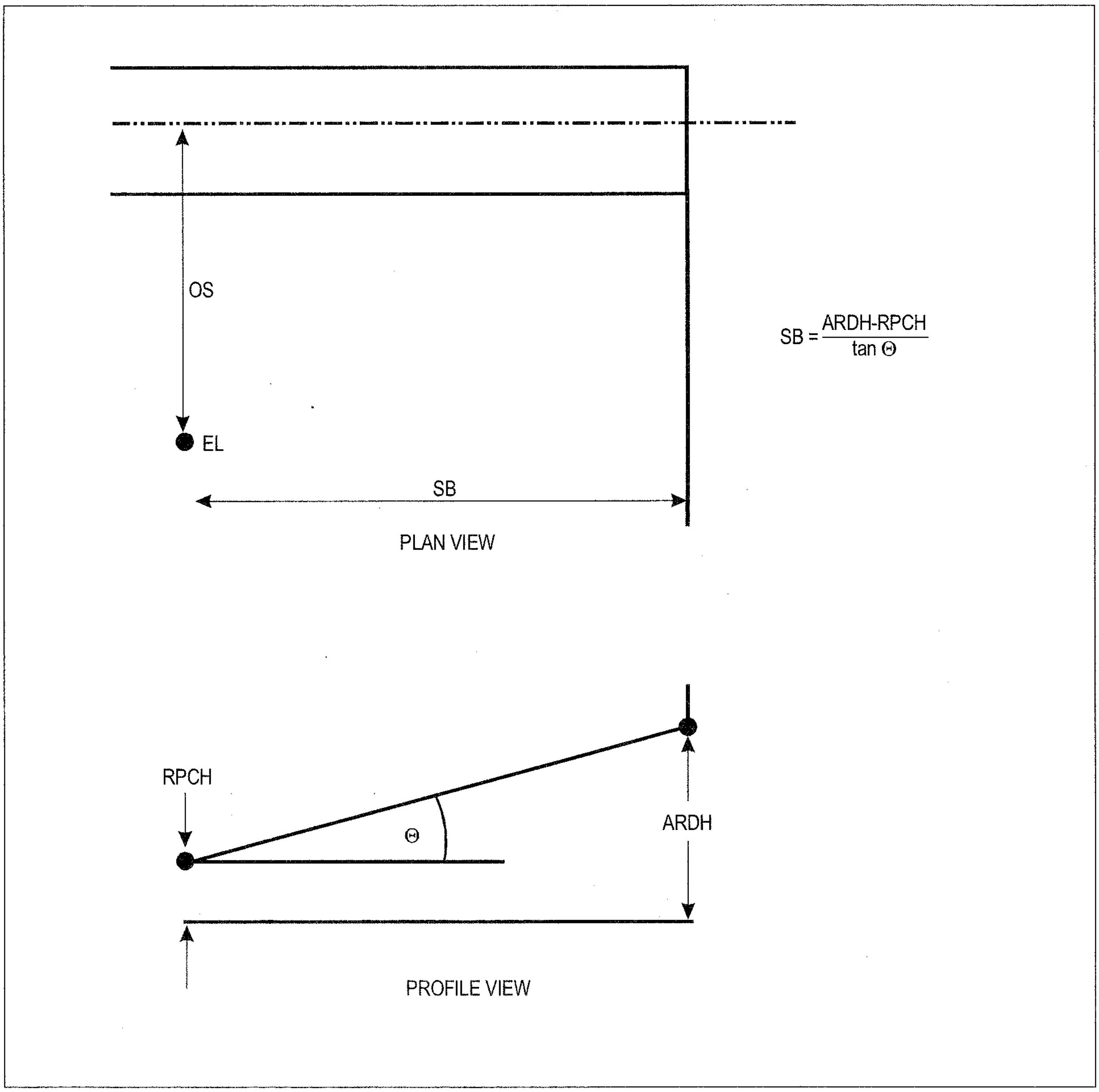


Figure G-19. Elevation siting parameters

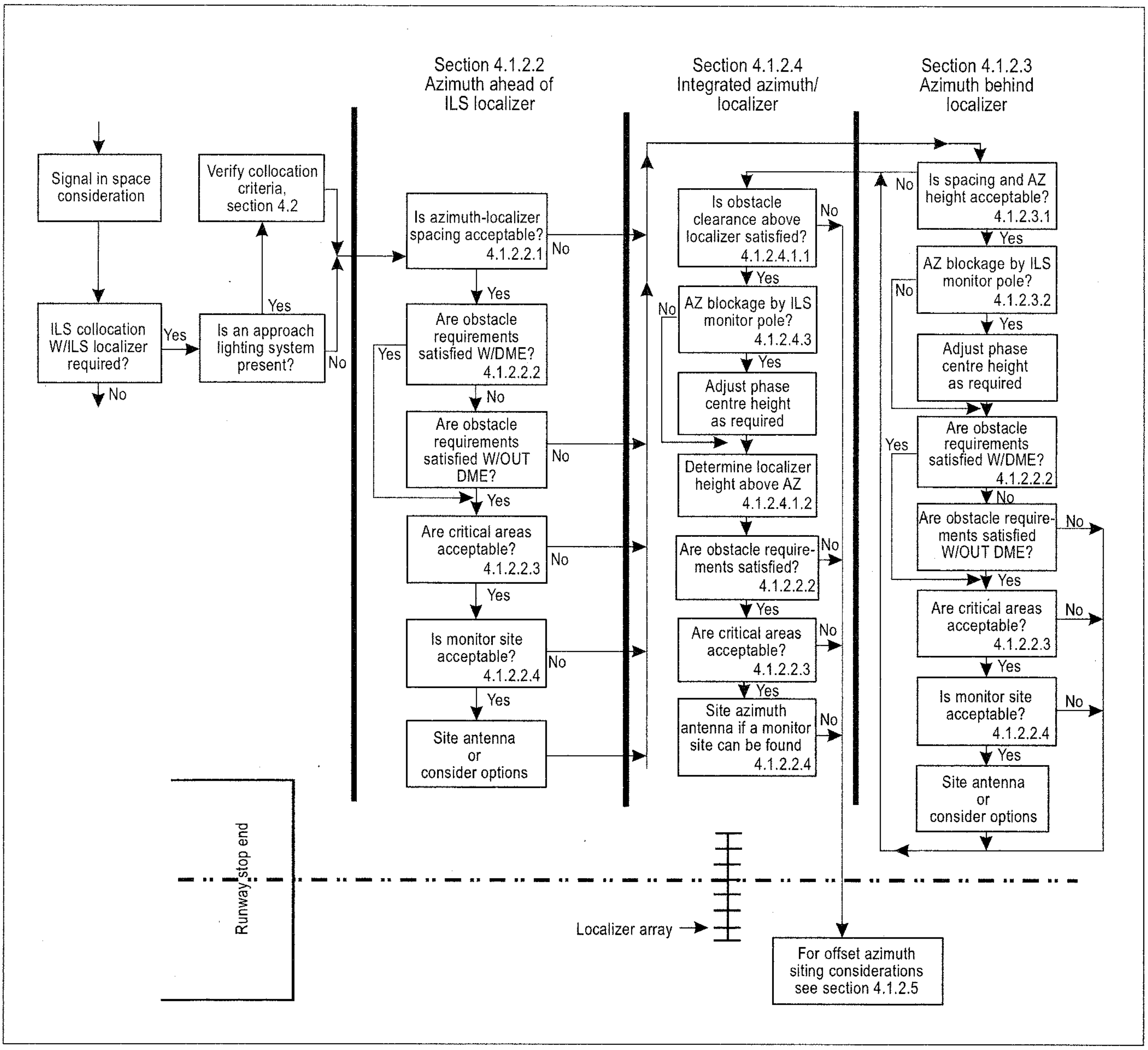


Figure G-20. Azimuth/localizer logic flow diagram

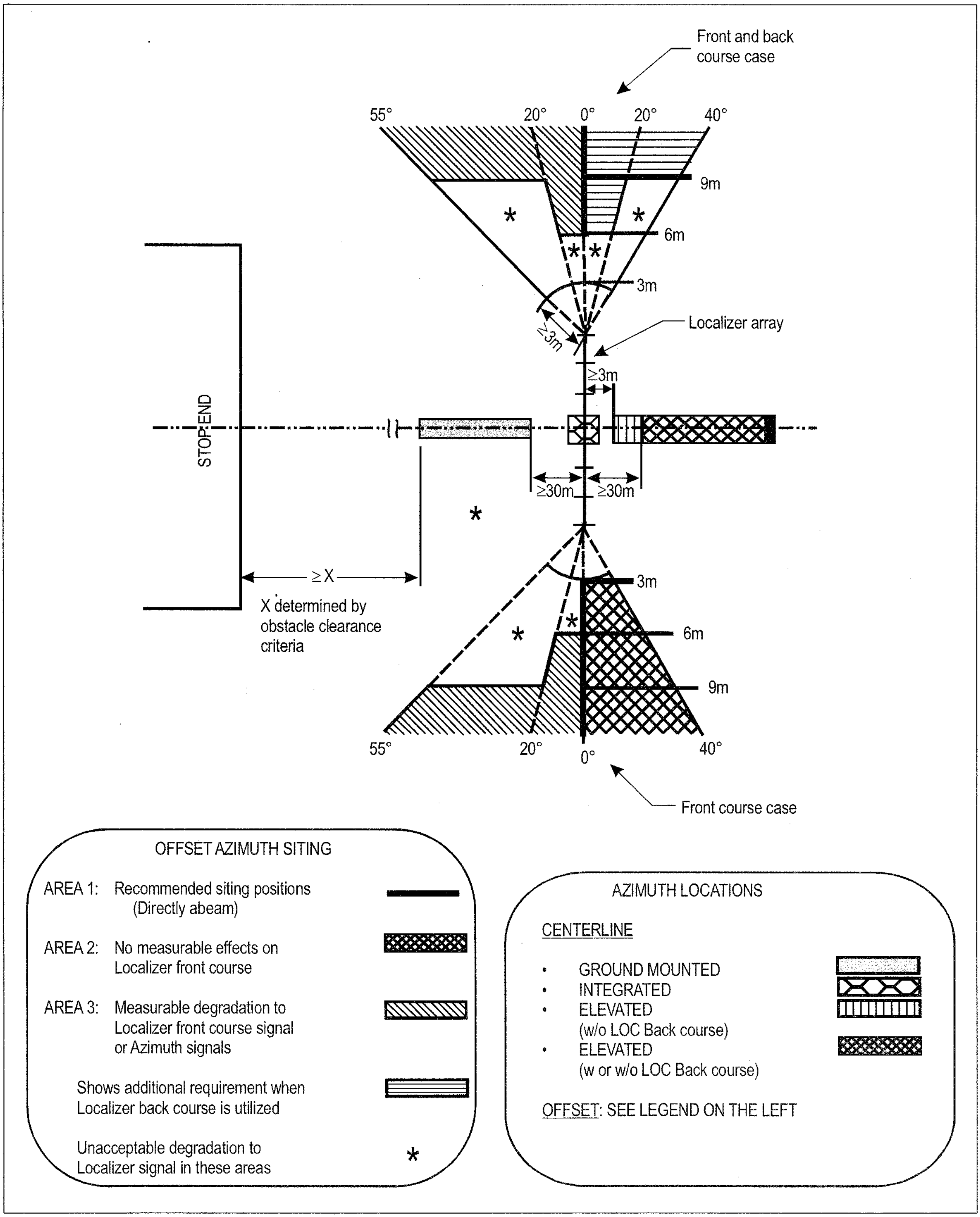


Figure G-21. Azimuth antenna regions for collocation with ILS

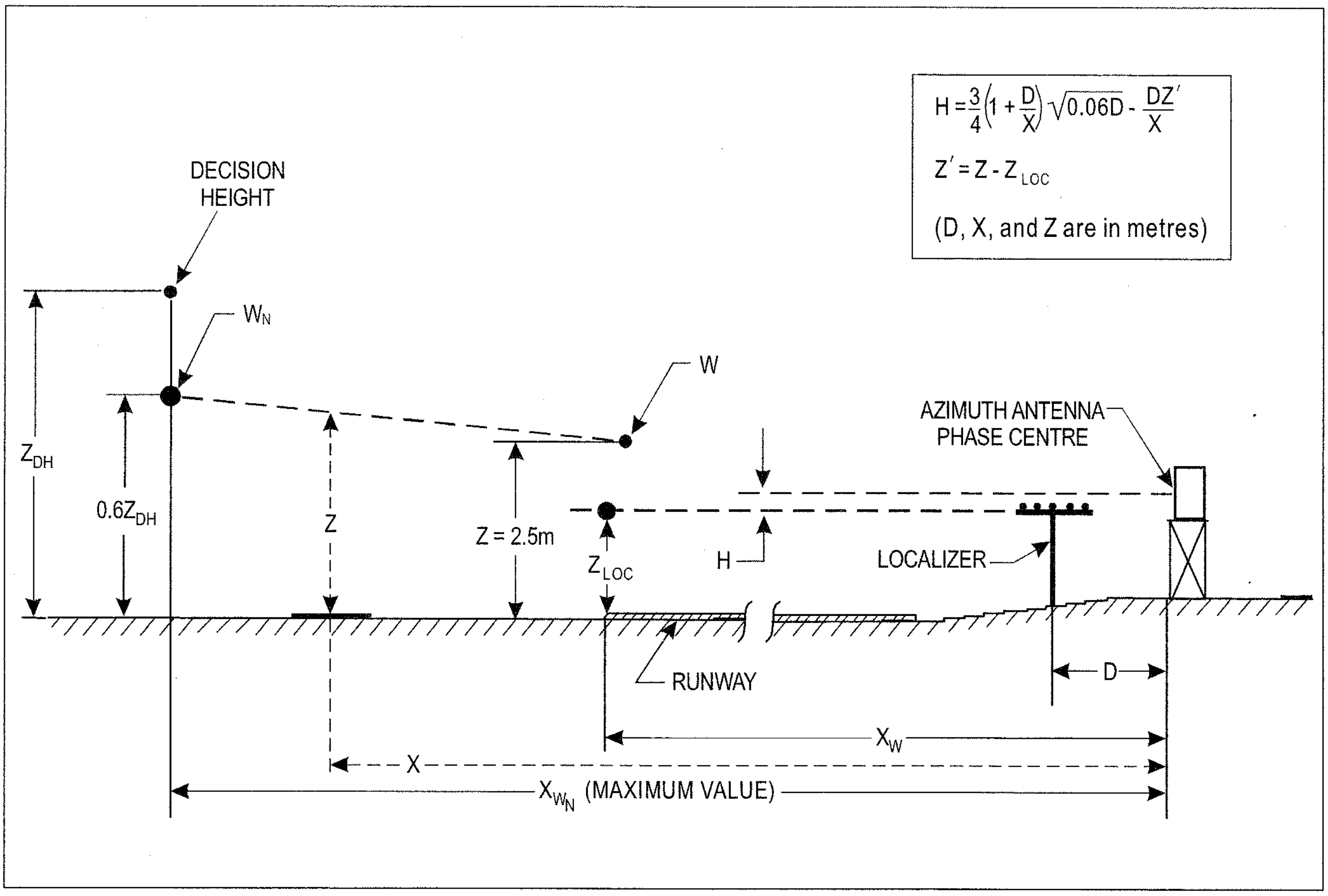
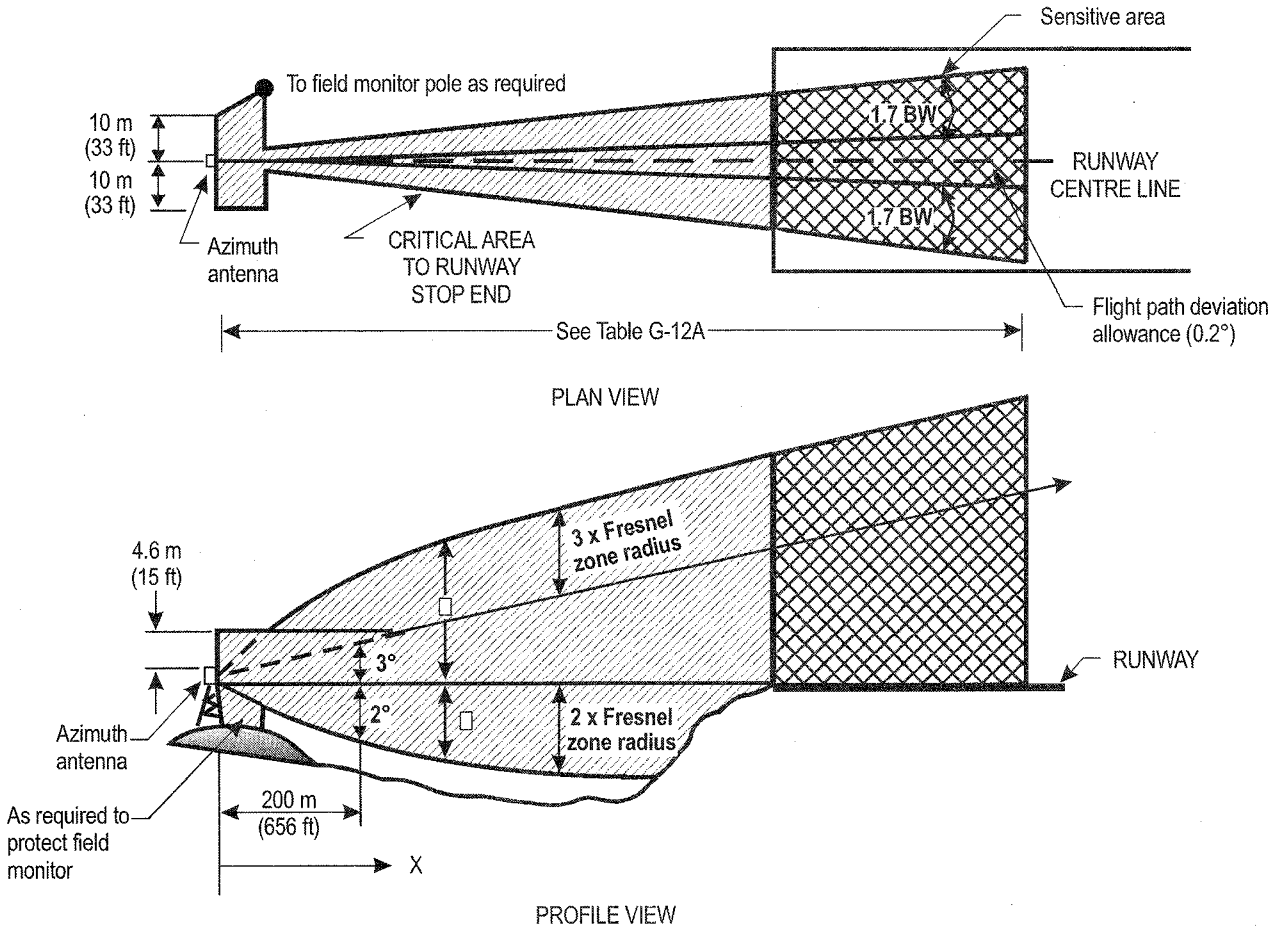


Figure G-22. Azimuth phase centre height requirement when siting an azimuth antenna behind an ILS localizer



VALUE FOR α and b

* X m (ft)	** α m (ft)	** β m (ft)
30 (100)	1.1 (3.5)	5.7 (18.6)
75 (250)	2.7 (8.7)	10.5 (34.3)
150 (500)	5.3 (17.5)	17.1 (56.2)
225 (750)	7.5 (24.5)	23.2 (76.0)
300 (1 000)	8.6 (28.3)	28.9 (94.8)

Where:

$\alpha = 0.035\,X$ $X < 200\text{m}$

$\alpha = 2\sqrt{0.06\,X}$ $X > 200\text{m}$

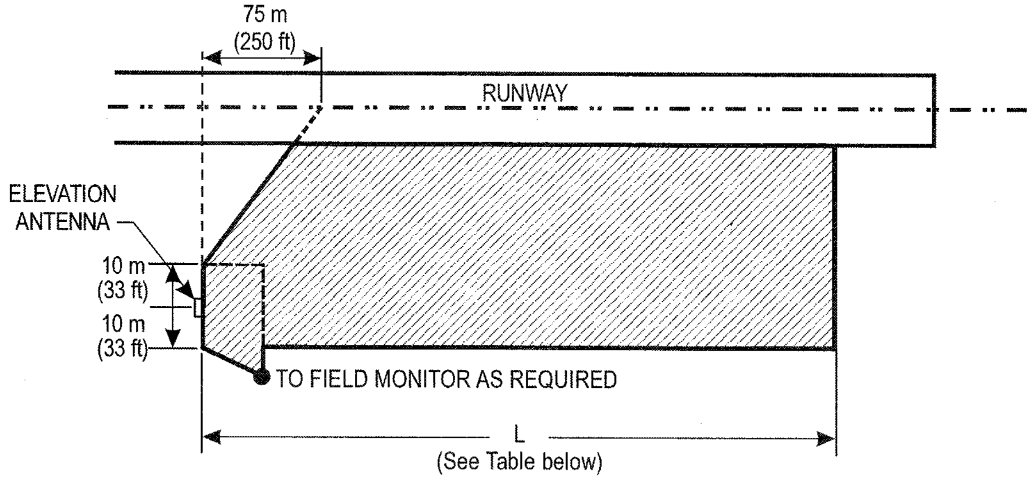
$\beta = X \tan 3° + 3\sqrt{0.06\,X}$

* MEASURED HORIZONTALLY FROM AZIMUTH ANTENNA

** MEASURED VERTICALLY FROM BOTTOM OF AZIMUTH ANTENNA APERTURE

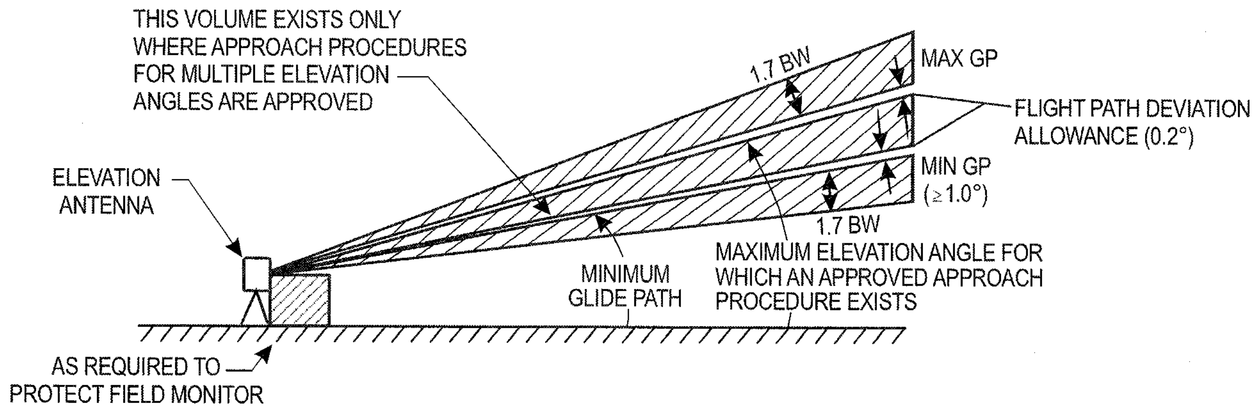
BW = BEAMWIDTH

Figure G-23. Typical azimuth critical and sensitive areas



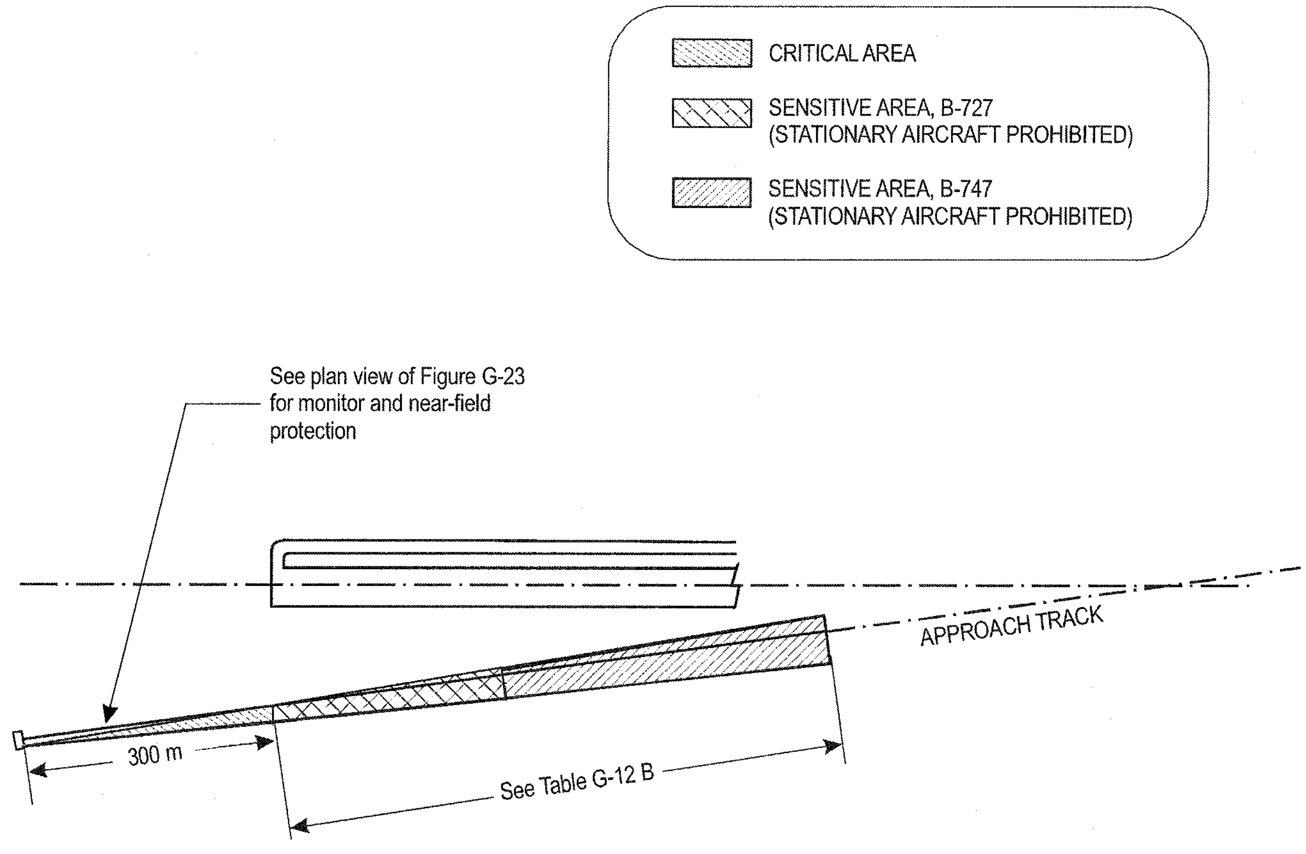
BEAMWIDTH	CLEAN SITE		COMPLEX SITE	
	B-747	B-727	B-747	B-727
1.0°	320 m (1 050 ft)	170 m (560 ft)	385 m (1 260 ft)	180 m (600 ft)
1.5°	400 m (1 310 ft)	250 m (820 ft)	565 m (1 860 ft)	300 m (990 ft)

PLAN VIEW



PROFILE VIEW

Figure G-24. Typical elevation critical and sensitive areas/volume



Note.— Profile view is shown in Figure G-23.

Figure G-25. Typical azimuth critical and sensitive areas for offset azimuth installation

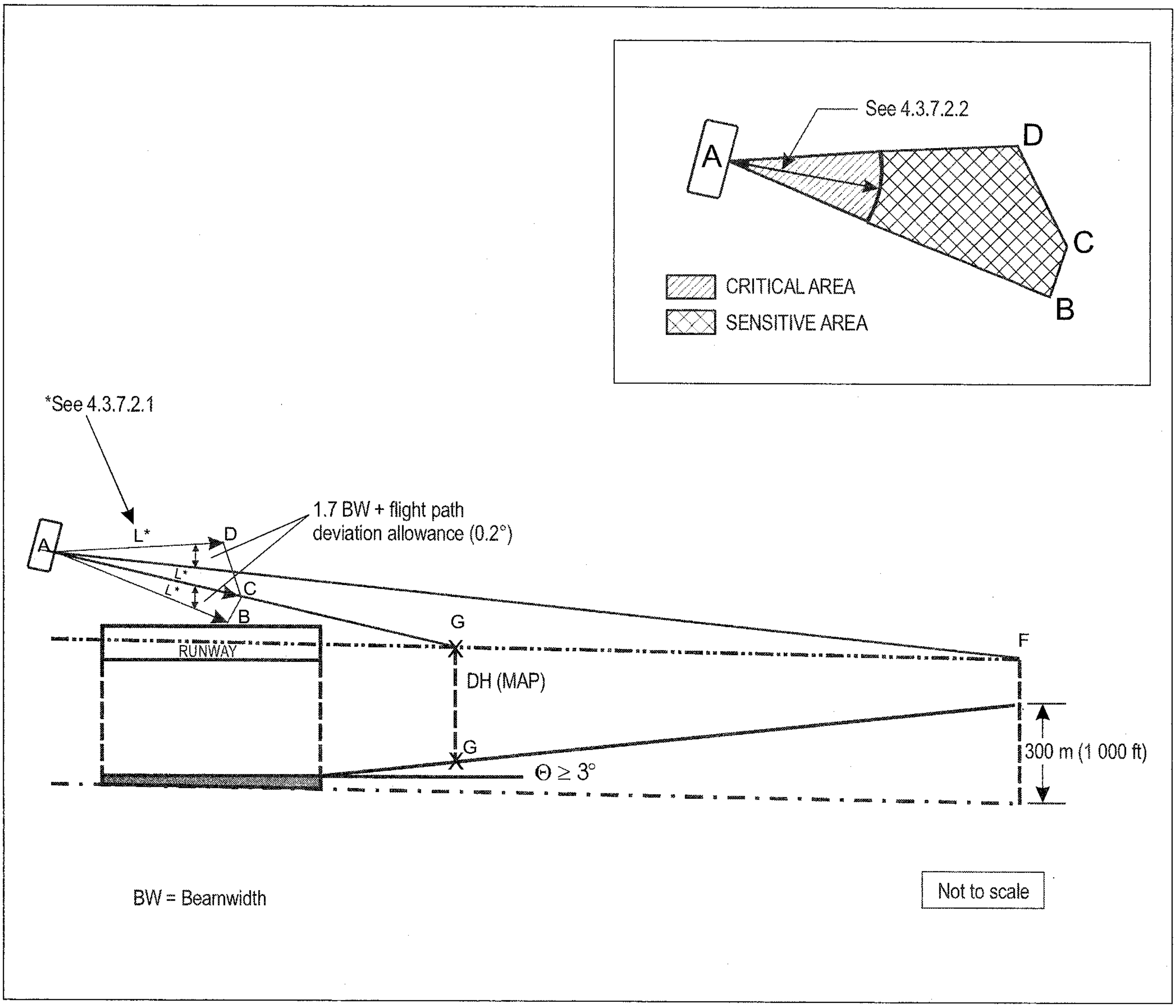


Figure G-26. Typical azimuth critical and sensitive areas/volume for the computed centre line procedure

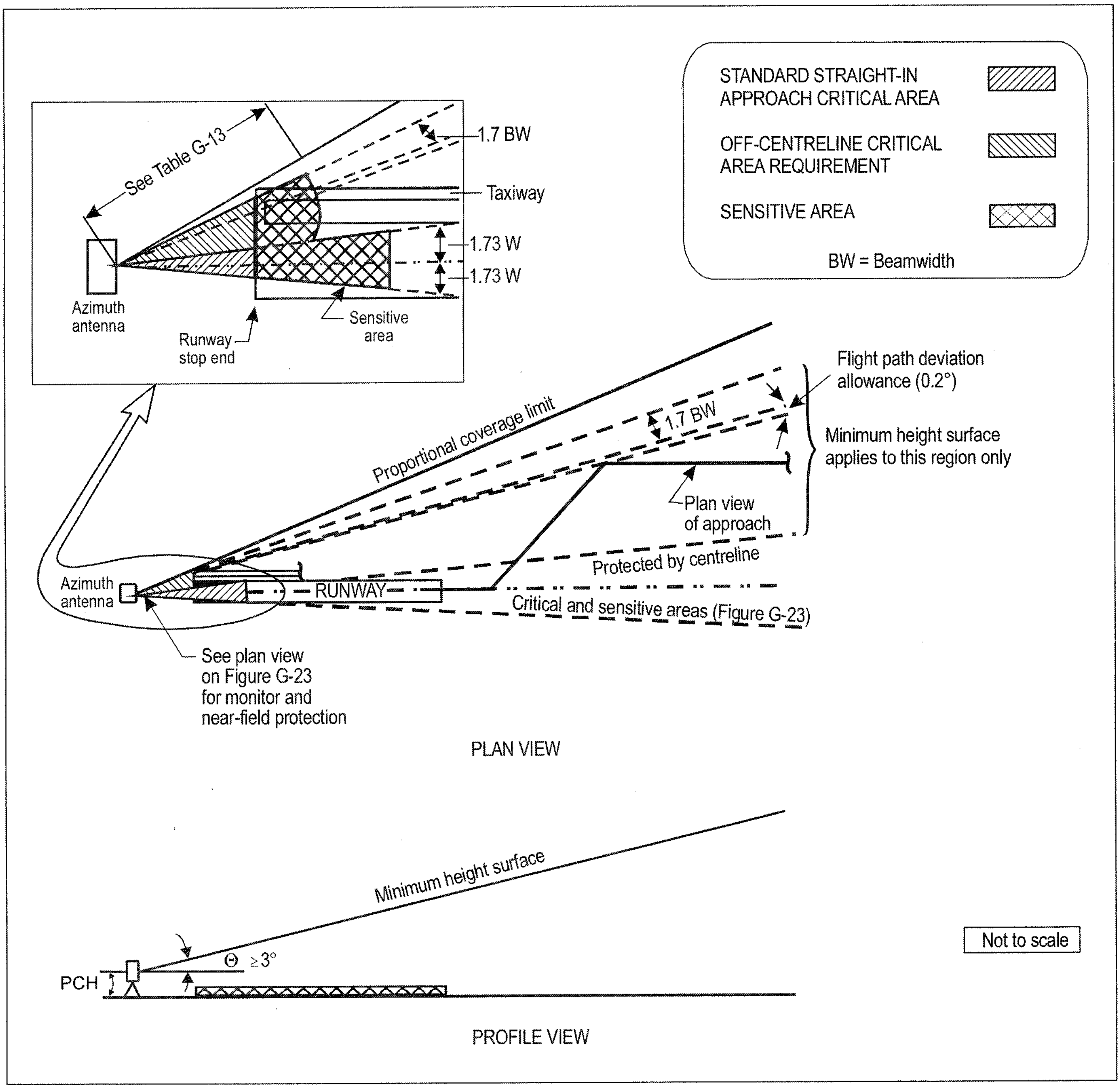


Figure G-27. Typical extension of azimuth critical and sensitive areas for segmented and curved approaches

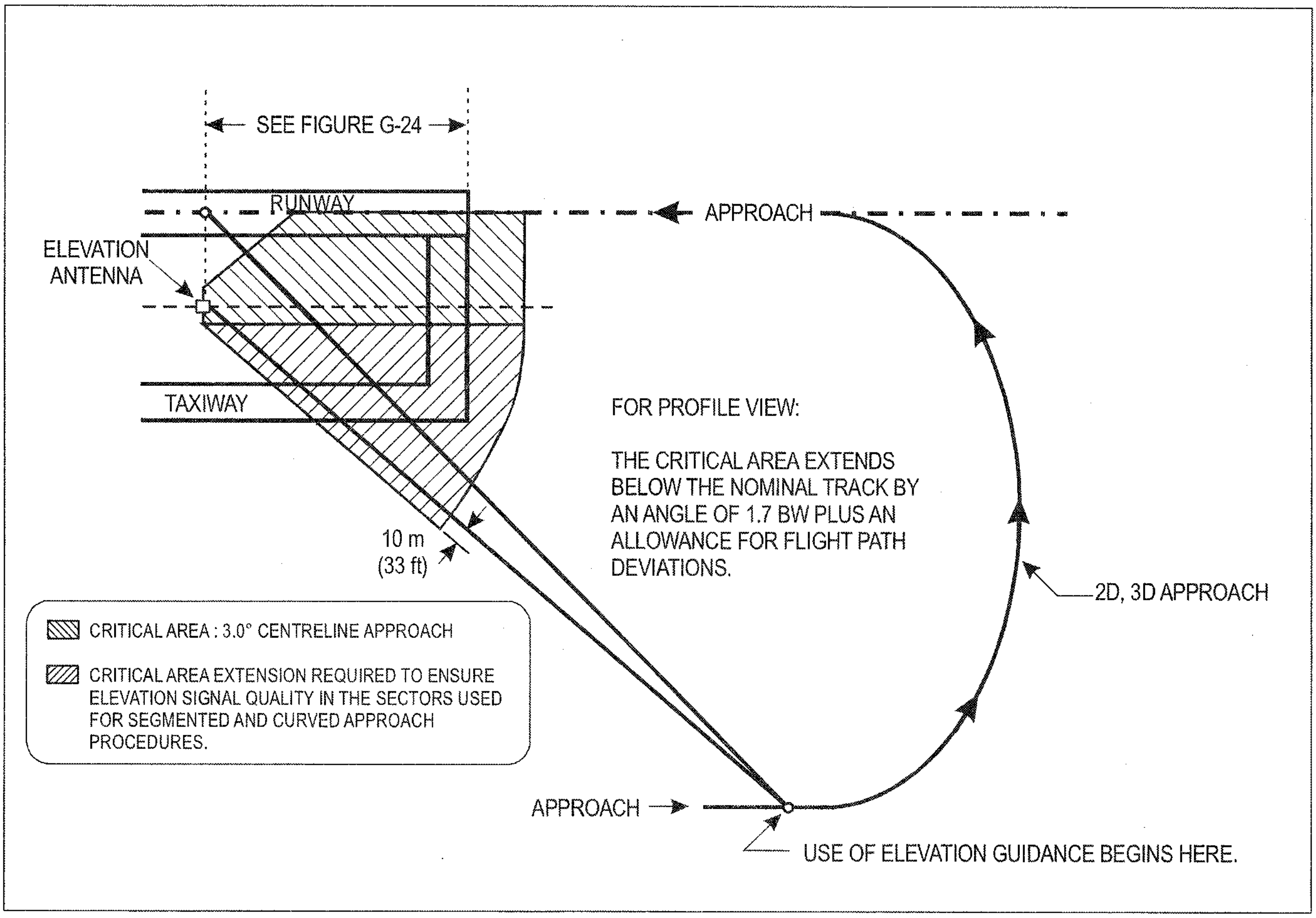


Figure G-28. Typical extension of the elevation critical area for segmented and curved approach procedures

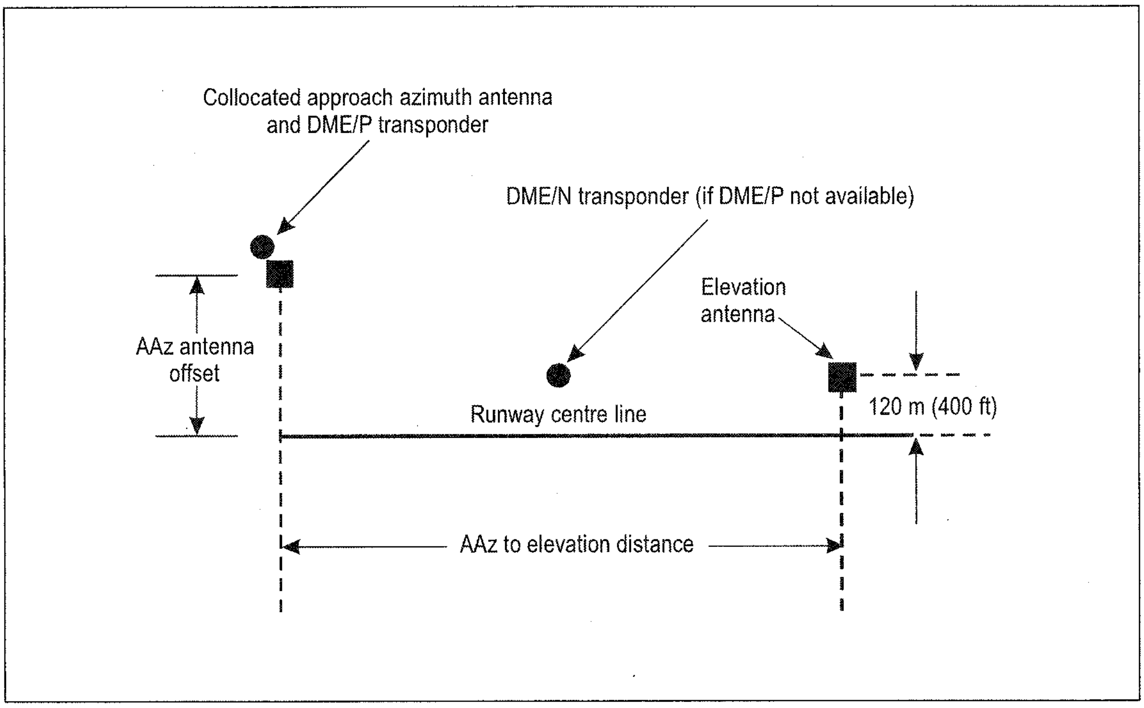


Figure G-29. Ground equipment geometry for computed centre line approaches

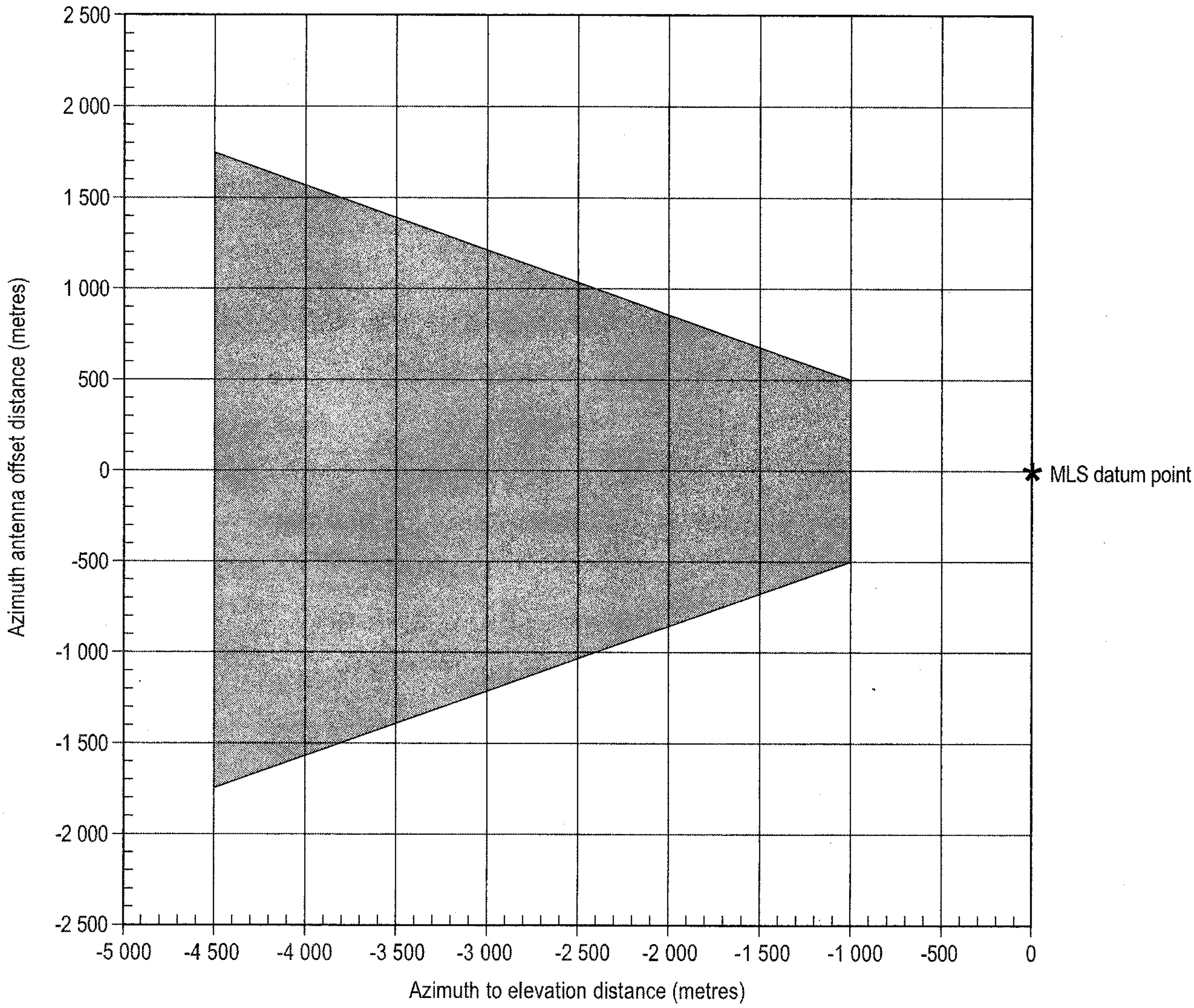


Figure G-30. Permissible azimuth antenna offsets for computed centre line approaches with DME/P (Standard 1) ranging

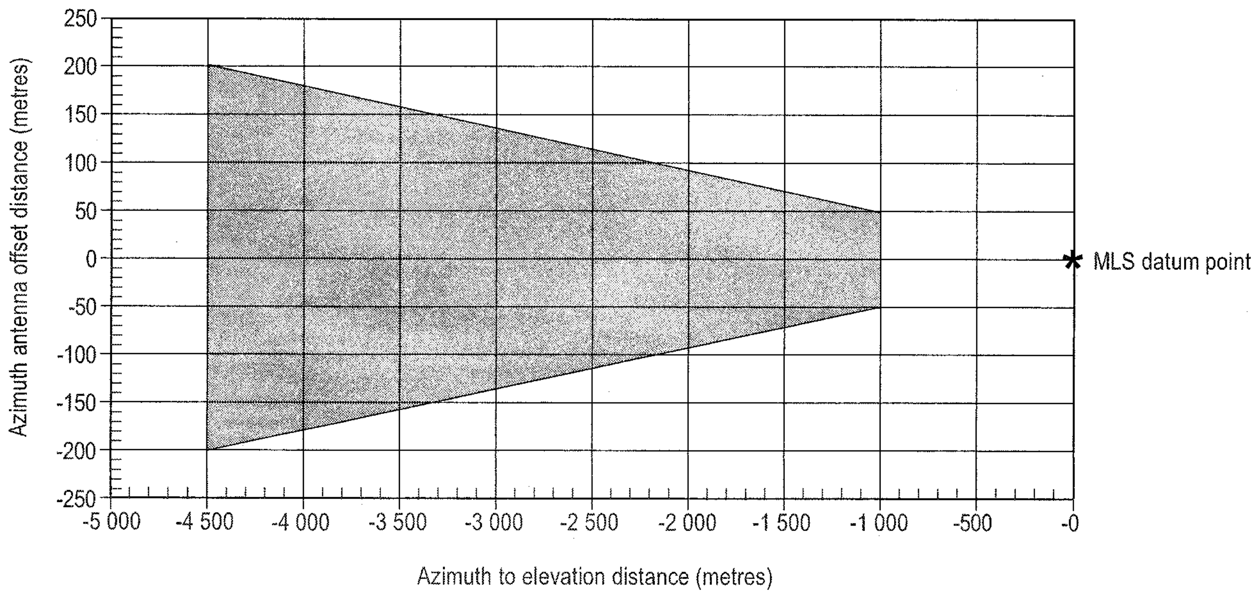
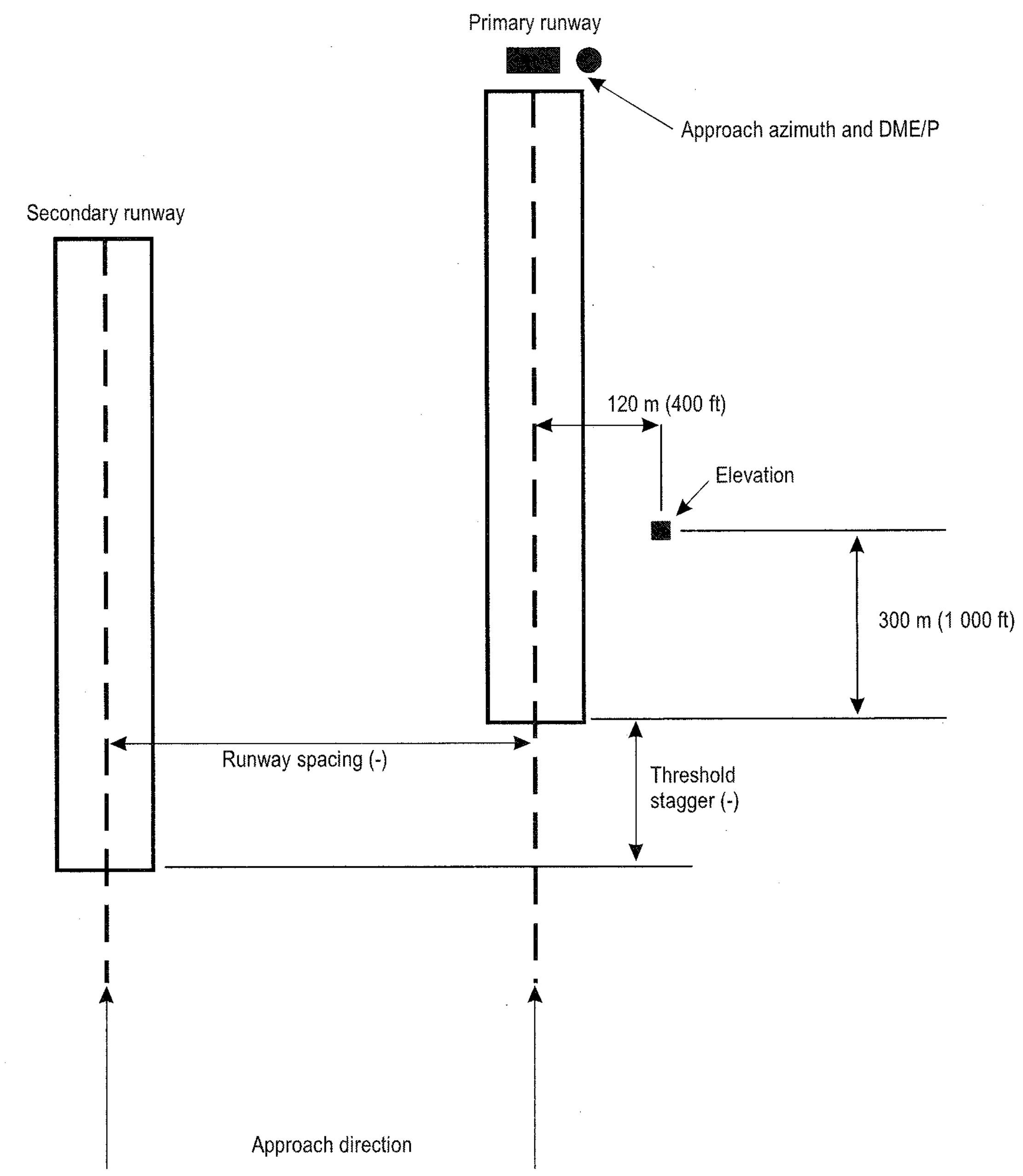
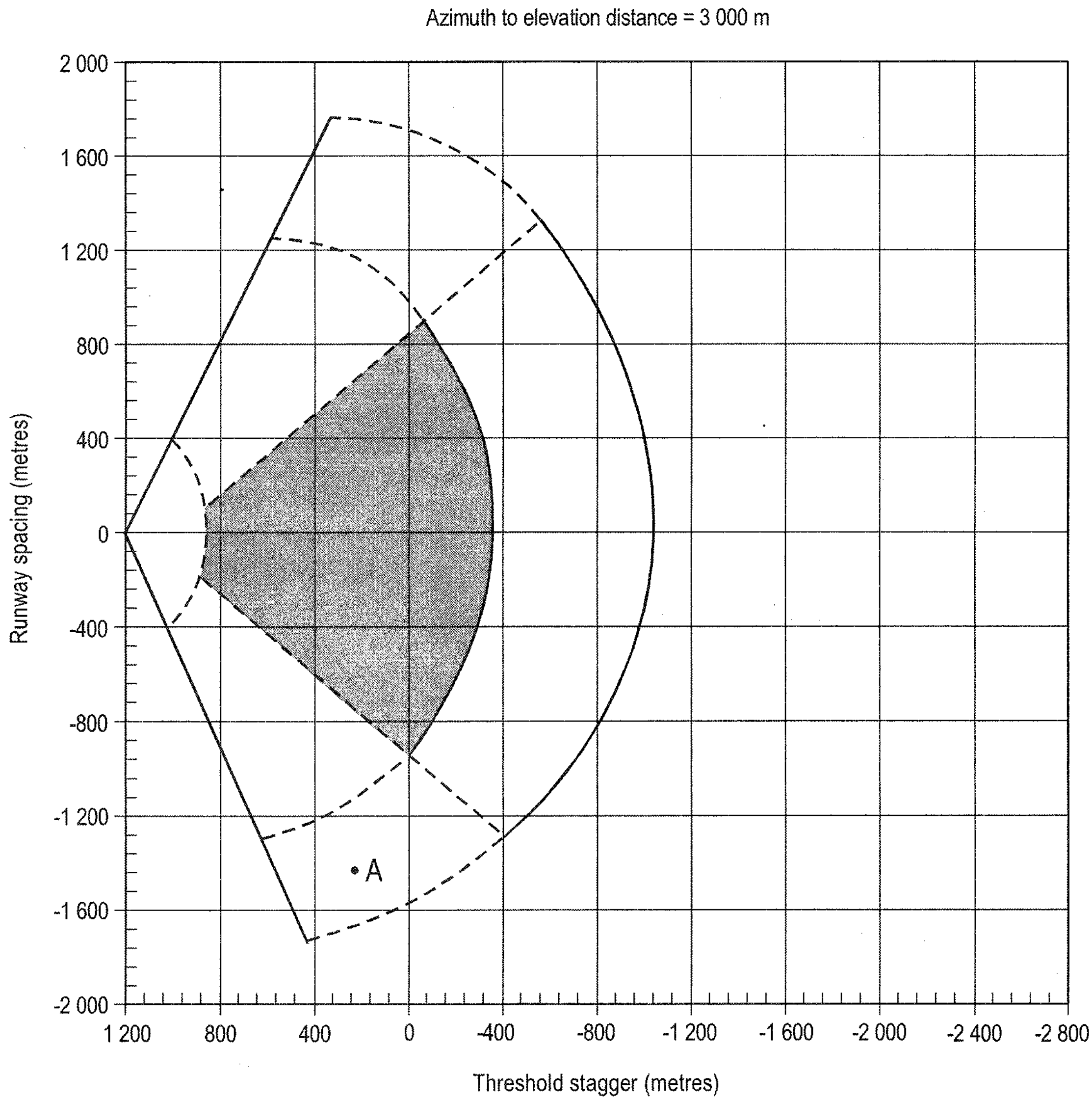


Figure G-31. Permissible azimuth antenna offsets for computed centre line approaches with DME/N ranging



Note.— The position shown for the elevation antenna is defined by typical values that are used to compute the data shown in Figure G-33.

Figure G-32. Runway and equipment geometry for computed centre line approaches to parallel secondary runways



Notes:

1. The radial boundary is dependent on elevation antenna performance.
2. Point A represents the example described in 13.7.6.

Figure G-33. Permissible runway geometries for computed centre line approaches to parallel secondary runways

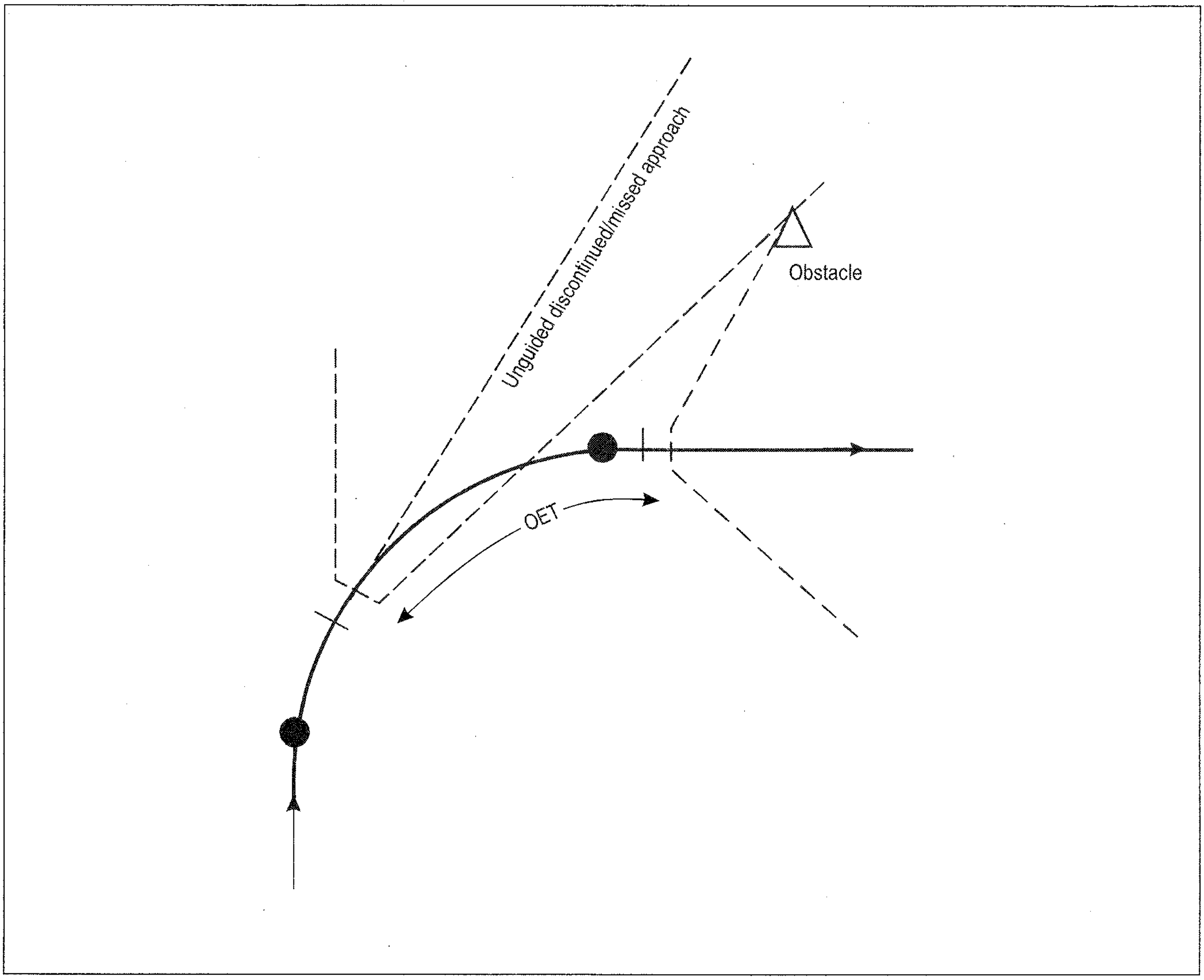


Figure G-34. Determination of obstacle exposure time (OET)

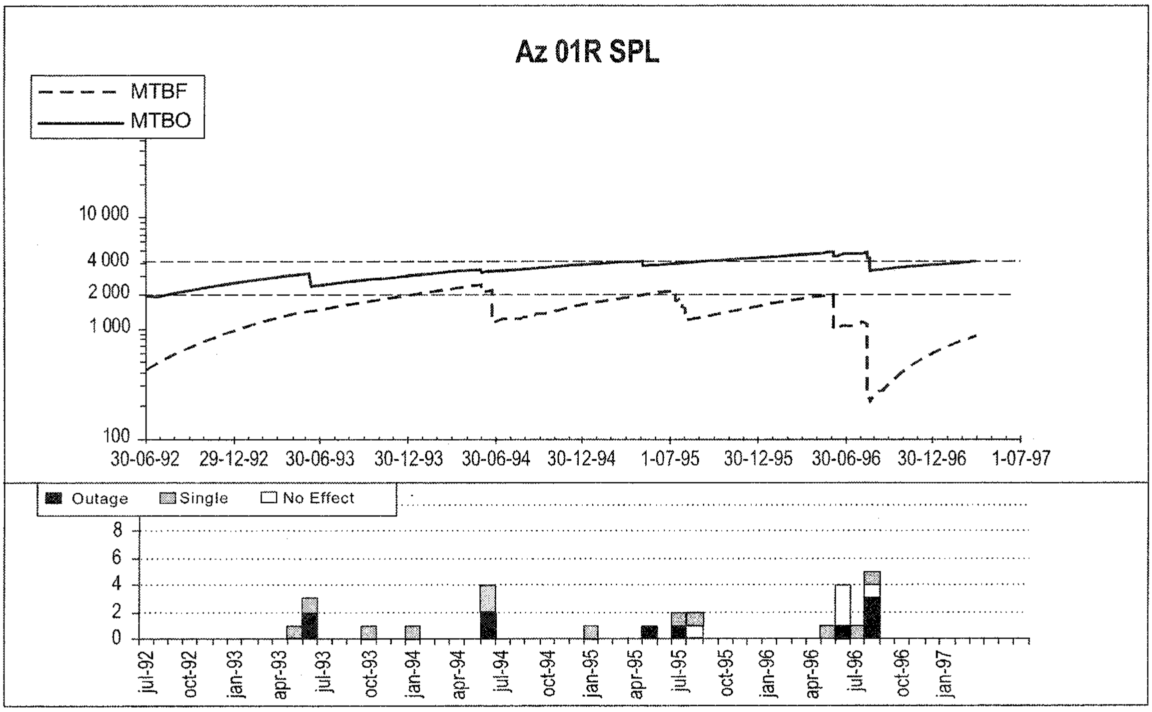


Figure G-35A. Example outage record for MLS azimuth facility

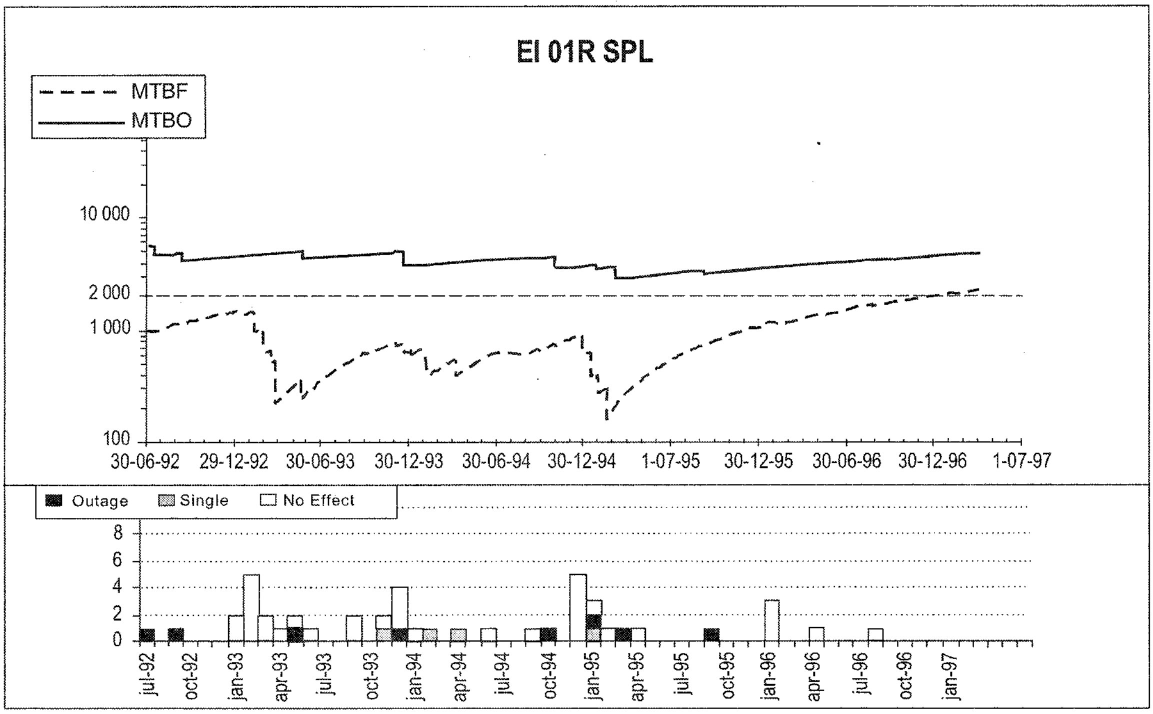


Figure G-35B. Example outage record for MLS elevation facility

— END —