INTERNATIONAL CIVIL AVIATION ORGANIZATION

EUROPEAN AND NORTH ATLANTIC OFFICE

SUPPLEMENT

TO

EUR FREQUENCY MANAGEMENT MANUAL (EUR DOC 011)

for

Aeronautical Mobile

and

Aeronautical Radio Navigation

Edition 2020

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A. GUIDANCE ON BI-LATERAL FREQUENCY COORDINATION

1 Introduction

1.1 This section provides guidance material on the conditions under which the bi-lateral coordination of a frequency assignment may take place. Provision is also made for the inclusion of text detailing novel or refined planning criteria which has not received full endorsement from FMG for inclusion in Part II or Part III of this Manual.

2 General

2.1 States may agree on a bi-lateral basis to a frequency allocation that does not comply with the general Doc 011 planning criteria providing there is no impact on other States. The compatibility between this frequency allocation and those of non-participating States shall conform to the applicable planning criteria contained within Part II and Part III of this Manual.

2.2 By use of the following codes, a State co-ordinating a proposal for a frequency assignment which displays apparent incompatibilities with frequency assignments of other States should record in the ‘remarks’ field of the SAFIRE message:

- the rationale which would justify the acceptance of this proposal, or
- the frequency assignments of affected States about which bilateral agreements are already concluded or proposed to be concluded.

Code	Reason why the incompatibility is considered to be acceptable
TERRAIN	The existence of terrain reduces sufficiently the probability of interferences.
DIST	The incompatibility involves a very small distance.
AREA	The incompatibility involves a very small area.
NIO	The incompatibility has no impact on the Operational Service (e.g. the incompatible assignments are never operational at the same time)
DIR	The use of directive antennas ensures that the incompatibility has no impact on the operational service.
NIB<SAFIRE REFERENCE(s)>	The new assignment may operate subject to not causing harmful interference to nor claiming protection from the listed assignments.
*BILAT <SAFIRE REFERENCE(s)>	Bilateral agreements concluded or proposed to be concluded regarding the incompatibilities with the listed assignments. Justifications on request.

**this code is to be used when none of the others above is applicable*

3 Inclusion of Detailed Refined Planning Criteria

3.1 Full details of novel or refined planning criteria which has not received full endorsement from FMG for inclusion in Part II or Part III of this Manual may be published in the subsequent paragraphs within this section subject to the following approval requirements:

3.1.1 Approval for its inclusion has been given by a majority of FMG members at an FMG plenary, or

3.1.2 Approval for its inclusion has been given by a majority of FMG members through the issuance of a State Letter by the ICAO secretariat.

B. GUIDANCE ON THE COORDINATION OF COMMON ASSIGNMENTS

1 Introduction

1.1 This section provides guidance material on the coordination of Common Assignments in the EUR Region. It also contains an approach for the compatibility assessment between common assignments.

2 General

2.1 Common assignments are a specific type of national frequency assignments[1] where a channel is to be reserved for a common use over several States. Common assignments are treated as national frequency assignments with the following special features:

- Common assignments receive the same protection as national frequency assignments;
- Common assignments on the same channel are considered to be compatible with each other, allowing neighbouring States to create common assignments on the same channel for the same purpose;
- Independent discrete assignments for other operational purposes on a 'common channel' can also be created. Such assignments, however, are not considered a priori compatible with any of the existing assignments and, therefore, are subject to coordination.

3 Coordination of Common Assignments

3.1 A state proposing a Common assignment shall include in the Remarks field of the coordination request the word '' Common'' and the purpose of the assignment. Whereever possible, the expected channel occupancy should be provided as well.

3.2 A table with the agreed Common channels is available on the EUROCONTROL RFF OneSky Teams site and accessible to all SAFIRE Frequency Managers

C. TECHNICAL JUSTIFICATION FOR THE CONSIDERATION OF TERRAIN IN COMPATIBILITY ASSESSMENT

1 Introduction

1.1 The ICAO EUR Doc 011 VHF communications co-channel (~~COM 2~~COM) planning rules are currently applied using free space attenuation and a spherical earth model. This approach assumes that there is direct line of sight between an interfering transmitter and a victim receiver at any distance up to the radio horizon. In the real environment, in the event that the path profile between a transmitter and a receiver is intersected by terrain, the resulting field strength at the receiver will be lower than that which would have occurred if there was direct line of sight. It is possible to make use of this factor when calculating the compatibility of co-channel frequency assignments.

1.2 Highly sophisticated computer modelling tools are available for the calculation of radio propagation. These are based on various propagation models, most usually those provided in ITU-R Recommendations. These modelling tools tend to be complex and expensive, particularly where high levels of accuracy are required. As an alternative, the following simplified approach is recommended for the inclusion of terrain masking when calculating the compatibility of co-channel frequency assignments.

2 Path Loss

2.1 In the event that the path profile of the undesired co-channel transmission is intersected by terrain, it is possible to calculate the effect of atmospheric refraction and surface diffraction on the received field strength as compared to the free space attenuation over the same distance.

2.2 In practical terms, line of sight propagation occurs only when the first Fresnel ellipsoid between the transmitter and receiver does not intersect the earth's surface or obstacles upon it. Conversely, propagation by diffraction will occur when the first Fresnel ellipsoid does intersect surface obstacles.
The minimum additional path loss compared to free space attenuation can be calculated using the following assumptions:

a) The path profile is based on $k = 1.33$[1] to take atmospheric refraction into account;
b) Only the largest surface obstacle is taken into consideration;
c) Any additional protrusion of the largest surface obstacle above the path profile will be ignored for the calculation of path loss;
d) The largest surface obstacle is assumed to be an isolated knife-edge obstacle.

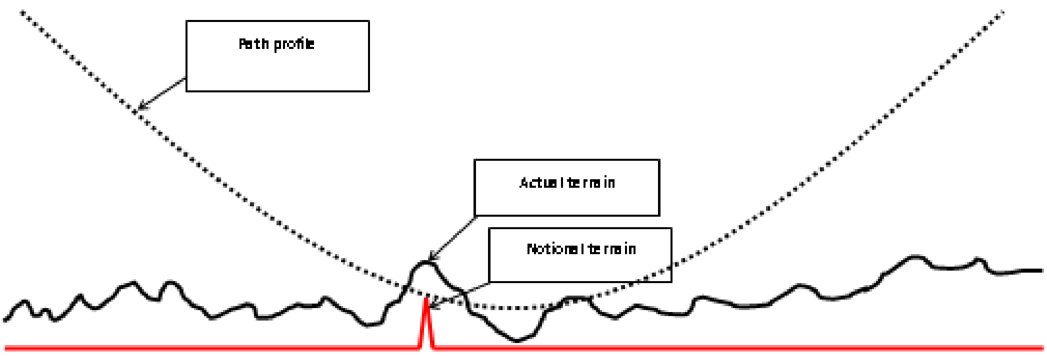

Figure 1 – Simplified Diffraction Loss Model

[1] This assumption is already applied in Doc 011 for the calculation of the radio horizon distance.

2.3 ITU-R Recommendation P.526-13 provides guidance on the calculation of propagation by diffraction. Single knife-edge diffraction should be used because this is the case where forward diffraction is at a maximum (i.e. where the undesired path loss will be least). If terrain intersects with the path profile, by the application of this recommendation[2] it can be shown that the field strength is reduced to no more than 50% of its unobstructed value, which entails that the minimum increase in path loss compared to free-space attenuation is approximately 6dB.

3 Equating D/U to Distance

3.1 When considering the undesired signal, in cases where free space attenuation applies (i.e. where, for all practical purposes, there is no diffraction) a 6 dB reduction in interfering field strength equates to a 50% reduction in separation distance between interferer and victim. This is because, in accordance with ITU-R Recommendation P.525-2, the basic transmission loss in dB is proportional to 20*log distance (NM).

4 Applying Revised Compatibility Calculations to 5:1 Cases

4.1 This calculation applies in cases where ICAO EUR Doc 011 requires that the separation distance between the interferer and victim must be at least 5 times the length of the desired path. This criterion applies to circular-versus-circular and circular-versus-broadcast cases. It is also used for the part of the area-to-broadcast case where the aircraft taking the broadcast service is the victim and the aircraft on the edge of the area service is the interferer.

4.2 The 5:1 distance ratio equates to a D/U of at least 14dB as described in ICAO Annex 10 Volume V Attachment A. In cases where the undesired ray path is intersected by terrain, the D/U ratio will be preserved. Thus compatibility will be achieved, providing the undesired-to-desired distance ratio is not less than 2.5:1.

5 Applying Revised Compatibility Calculations to RLOS Cases

5.1 This calculation applies in cases where ICAO EUR Doc 011 requires that the minimum separation distance between DOC-edges is the sum of the RLOS distances of the two services. This criterion applies to area-versus-circular and area-versus-area cases. It is also used for the part of the area-to-broadcast case where the aircraft taking the area service is the victim and the broadcast transmitter is the interferer.

5.2 The use of the RLOS distance as the compatibility criterion is based on the requirements of ICAO Annex 10 Volume V, which states: "The geographical separation between facilities operating on the same frequency shall, except where there is an operational requirement for the use of common frequencies for groups of facilities, be such that the protected service volume of each facility is separated from the protected service volume of the other facility by a distance not less than that required to provide a desired to undesired signal ratio of 20 dB or by a separation distance not less than the sum of the distances to associated radio horizon of each service volume, whichever is smaller."

5.3 Applying the 20 dB D/U calculation in cases where the undesired ray path is intersected by terrain, the minimum D/U criterion will be met providing the undesired-to-desired distance ratio is not less than 5:1.

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[2] In P.526-13, Section 4.1, Equation 26 and Figure 9 can be used to calculate the additional path loss attributable to a single knife-edge obstacle. The equations are used to derive a single dimensionless parameter, v, that can be used to read-off the additional path loss, J(v) dB, in Figure 9. As the obstacle is assumed to coincide with the path profile, the value of v will be 0 in accordance with Equation 26. Consequently, from Figure 9, the value of J(v) will be 6 dB regardless of its position along the signal path.

In cases where the desired path length is not known (i.e. where the location of the desired ground station has not been coordinated) it is recommended that the desired path length is taken to be 70% of the length of the maximum diagonal of the desired polygon. A value of 70% is recommended on the basis that the desired ground station can normally be expected to be close to the centre of the polygon.

5.4 The 70% value is considered to be safe because, in the worst case, if the 70% criterion is applied and the ground station is at the farthest possible distance from the victim aircraft, the D/U ratio would fall to 17 dB in the event that the EIRP of the ground station was identical to that of the aircraft. However, it can be expected that the typical ground station EIRP will be at least 50W and the maximum aircraft EIRP will be 25W, and in this case the 20 dB D/U value would be achieved.

6 Mechanism for Identifying Cases of Terrain Masking

6.1 MANIF AFM contains a feature to identify cases where the undesired signal path is intersected by terrain. Details are provided in section 4 of the user manual. When AFM makes terrain computations between a circular or area DOC versus another circular or area DOC, the terrain computation is carried out on various lines joining the two volumes (see Figure A-2). For AFM to declare the two DOCs potentially compatible, all the ray path lines must be blocked by an obstacle.

Note: The terrain calculation features of MANIF AFM and the supporting database are intended purely for use in the assessment of frequency assignment compatibility. These are not intended for use in the calculation of aeronautical information services such as obstacle clearance data etc.

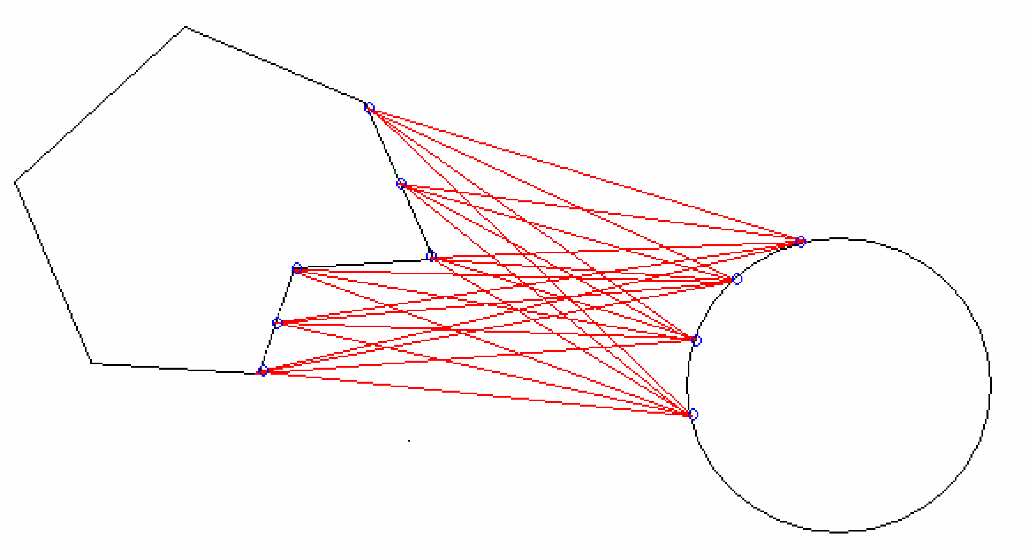

Figure 2 – MANIF AFM Terrain Computation – Polygon vs Circle

7 Terrain Database

7.1 It is recommended that the SRTM_GTOPO_u30_DEMETER database is used for compatibility assessment. This provides a digital terrain model based on a grid of 30 arc-seconds, which equates to approximately 0.3-0.5 NM in Europe. The database is available in the MANIF AFM folder on the RFF One Sky Team.

D. PRIORITISATION METHOD FOR DME CHANNELS

1. Introduction

1.1. The GNSS L5/E5 bands are centred around 1176.45 and 1207.14 MHz and fall within the band used by the upper DME X-channels (77X – 126 X) for the beacon reply frequency. There are concerns that excessive use of these frequencies for DME may have a detrimental effect on GNSS aeronautical receiver performance. Recommendation 6/8 of the ICAO Air Navigation Conference ANC-12 (Nov 2012) requires that States:

"a) assess the likelihood and effects of global navigation satellite system vulnerabilities in their airspace and apply, as necessary, recognized and available mitigation methods; and

b) provide effective spectrum management and protection of global navigation satellite system (GNSS) frequencies to reduce the likelihood of unintentional interference or degradation of GNSS performance."

1.2. It is therefore recommended that the assignment of new DME facilities on channels 77X-126X are, where feasible, restricted to areas beyond the radio horizon of the European GNSS L5/E5 hotspot. The hotspot is defined as the airspace in which the GNSS L5 C/N0 margin is less than 2dB.

2. Prioritization method

2.1 Other than for ILS/DME facilities, when selecting the preferred channel for a new DME facility, the following prioritization method is recommended:

a) For cases where the DME beacon is less than 250NM to the hotspot:
  - 1st priority should be given to compatible channels in the range 18X-59X and all unrestricted Y channels.
  - 2nd priority should be given to channels 70X-76X and 103X-126X.

b) For cases where the DME beacon is between 250NM and 600 NM from the hotspot:
  - 1st Priority should be given to compatible channels in the range 77X-102X (where the DME reply frequency falls within the band 1164 – 1189 MHz used by GNSS L5/E5a).
  - 2nd priority should be given to channels 70X-76X and 103X-126X (where the DME reply frequency is outside the GNSS L5/E5a band but within the Galileo E5b/GLONASS L3 band).
  - 3rd priority should be given to channels 18X-59X and all unrestricted Y channels (i.e. where the DME reply frequency is outside the GNSS bands).

c) EUR States planning DME beacons beyond 600 NM from the hotspot will have no impact on channel availability within the hotspot. Given also the relatively low density of DMEs in those areas and the number of channels currently available, the channel selection beyond 600 NM from the hotspot:

- Has no direct impact on the hotspot channels availability, and
- Has no significant impact on the channels availability in closest areas to the hotspot.

These States are encouraged to select channels outside of the L5/E5 band for new DME beacons in order to be consistent with the policy of protecting GNSS.

2.2 MANIF AFM (version 2.5.5 onwards) supports the above recommendation by:

a) Providing a GNSS European hotspot map that is updated on an annual basis, and

b) Identifying the preferred channels when using the facility frequency search.

E. PRIMARY SURVEILLANCE RADAR

1. Introduction

1.1 The diversity of radar characteristics, in terms of frequency, power, antenna properties and waveforms define an extremely complex electromagnetic environment. Most radar systems operate in the scanning mode and cover a 3-dimensional service volume. Coupled with the fact that radar systems are operated from fixed and mobile land sites, aboard ship and aircraft and from space vehicles, the potential for interference between radar systems and other services requires careful consideration.

1.2 In ICAO EUR Region, the frequency bands 1215 – 1400 MHz, 2700 – 3300 MHz and 9000 – 9500 MHz[3] are extensively used for primary surveillance radar, mainly providing long, medium and short range independent non-cooperative airspace surveillance. Often, these bands are shared with other radar users including military, maritime and meteorological services.

1.3 This Chapter considers some general regulatory and technical aspects of the frequency assignment and licensing process for aeronautical primary radar systems, which must provide for the normal operation of existing radar systems as well as new systems with a specified performance.

1.4 Since there are no ICAO Standards detailing performance requirements for radar systems, no uniform frequency planning criteria, agreed within the ICAO framework, are available. Protection requirements of radars are heavily dependent on their characteristics and specifications. Various ITU-R Recommendations (see reference section) provide typical radar characteristics intended to support frequency compatibility studies but do not cover the complete set of radar systems being in operation. Thus radar assignment planning needs to be performed on a case-by-case basis, taking into account the relevant protection requirements.

2. Frequency Assignment Planning and Coordination Fundamentals

2.1 Radar frequency assignment planning is performed on a national basis. For this a national process of assigning frequencies should be implemented to ensure that new frequency use does not cause unacceptable interference to existing users on a national and international basis.

2.2 Coordination among national radio regulatory authorities is the usual mechanism for bilateral and multilateral discussions. Such a process may include the compatibility analysis for proposed radar services, and the assignment of frequencies in accordance with the national frequency allocation plan.

2.3 This process may also include actions necessary to protect the national radar systems from potential interference from international assignments published in the ITU Radiocommunication Bureau International Frequency Information Circular (BR IFIC).

2.4 BR IFIC is a consolidated regulatory publication issued on a regular basis by the ITU Radiocommunication Bureau. It contains information on the frequency assignments/allotments submitted by

[3] See ICAO Doc 9718 Volume I for details on the frequency allocation tables.

administrations to the Radiocommunication Bureau for recording in the Master International Frequency Register.

3. International Registration

3.1 International registration of a national radar frequency assignments in the BR IFIC provides international recognition and protection for the station's operations. It is in the best interest of an administration and its operators to register with the ITU all its radar frequency assignments which it feels needs protection from interference from other international users. It is usual to notify international frequency use after coordination with any other country has been successfully completed. Aviation frequency managers are encouraged to pre-coordinate through information exchange with adjacent States, as appropriate.

3.2 It is also the responsibility of national radio regulatory authorities to examine any new radar frequency proposals, or modifications to existing frequency assignments, circulated through the BR IFIC. The examination should ensure that any of these published international frequency requirements that may cause harmful interference to existing or planned national radar assignments are commented upon by the due date. Note that International Frequency Information Circulars requiring comment by a particular date as included in the circulars.

3.3 It should also be noted that not all radars, e.g. military stations, are registered by administrations through the ITU process.

4. Methods of interference analysis for frequency-site planning

4.1 The need for an interference analysis arises when performing frequency-site planning for radar stations and in carrying out frequency coordination between national radio regulatory authorities of different countries.

4.2 The acceptability of frequency assignment requests, including specific technical parameters of the systems, are to be agreed by the national radio regulatory authorities in close cooperation with the operators. In particular, the received interference power needs to be compared with the maximum tolerable interference power. Moreover, the effects of various signal types such as constant or pulse like interference need to be considered appropriately.

4.3 Interference analysis starts with determination of the power of interfering signals at a receiving point, and the comparison with requirements for a maximum tolerable interference power level and associated protection ratios for the particular type of interfering signals.

5. Interference Analyis

Step 1: determination of the interference power level at the receiver

5.1 Basically the interference power level at the receiver is a function of P_t - the interferer transmitter power, G_t - the gain of the interferer antenna in the direction of the receiver (dBi), G_r - the gain of the receiver antenna in the direction of the interferer (dBi), $L_b(d)$ - the basic loss based on free-space propagation for a separation distance *d* between the receiver and the interferer, and FDR (Δf) - the frequency dependent rejection depending on Δf, as prescribed in Recommendation ITU-R SM.337, and is expressed by:

$$I = P_t + G_t + G_r - L_b(d) - FDR(\Delta f)$$

5.2 The frequency dependent rejection is a function of Δf which is the difference between the interferer tuned frequency and the receiver tuned frequency. It is also dependent on the characteristics of the receiver.

$$FDR(\Delta f) = 10 \log \frac{\int_0^\infty P(f)\mathrm{d}f}{\int_0^\infty P(f)\left|H(f+\Delta f)\right|^2 \mathrm{d}f}$$

where:

$P(f)$: power spectral density of the interfering signal equivalent intermediate frequency (IF);
$H(f)$: frequency response of the receiver

$$\Delta f = f_t - f_r$$

where:

f_t: interferer tuned frequency;
f_r: receiver tuned frequency.

5.3 Another general characteristic regarding radio interference in a multiple source interference environment is that the total interference power is the sum of individual interference powers:

$$I = I_1 + I_2 + \cdots + I_k$$

5.4 Alternatively, if individual interference power levels are difficult to determine, an allowance should be made for such aggregate interference (e.g. 6 dB to cater for circumstances with four similar interference signals being "visible" for a victim receiver at the same time).

5.5 When two or more radars with rotating antennas operating within line of sight of each other, these radars may not need to be considered as multiple interference sources because of the low probability of coincidence when interference signals from these radars are received simultaneously.

Step 2: Evaluation of the maximum tolerable interference power level

5.6 The maximum aggregate value of interference signal power that still allows the radar to meet its performance requirements need to be determined in close cooperation with the operator.

5.7 There are two primary interference mechanisms that affect radar receivers. The first is higher power level interference resulting in front-end saturation and the generation of inter-modulation products. The second is lower power level emissions that fall within the receiver IF pass-band, leading to desensitisation and performance degradation.

5.8 The effects of interference on aeronautical surveillance radars can be determined through testing, calculation or a combination of both. Testing can be accomplished by injecting simulated known targets into the radar, and visually determining the interference effects including range reduction, dropped tracks, track seduction and false targets, the last of which is less common in modern radars due to the use of constant false alarm rate (CFAR) circuits and pulse compression. The effect of low-level interference is insidious so it is not generally sufficient to assess performance solely through visual observation of the radar screen. Consequently, this technique needs to be supplemented by theoretical calculation and/or measurement.

5.9 Even though the protection criteria for radars are dependent on their technical characteristics and operational environment, it is generally accepted that, for constant interference, an I/N = −10 dB delivers an acceptable degradation in radar performance compared to the "no interference" case. This I/N level represents an increase of about 0.4 dB in the effective noise power of the receiving channel, which equates to a degradation of around 1.5% for a nominal probability of detection (P_D) of 0.9. This criterion is consistent with existing ITU R Recommendations, i.e. M.1464 which states "the results of two administrations' tests on aeronautical radionavigation radars … concludes that a -10 dB I/N protection criteria will fully protect those types of radars [aeronautical] in the frequency band 2700-2900 MHz band".

5.10 For pulsed interference, analysis and tests have shown that, depending on characteristics of the interfering and victim systems (primarily pulse repetition frequency (PRF) and pulse width), a higher I/N relating to the peak power of the pulsed interference is possible. This is due to the widespread use of interference suppression techniques such as interference rejection (IR), pulse compression, moving target detection (MTD), CFAR and binary integration (see ITU-R M.1372). As further described in ITU-R M.1372, low-duty cycle asynchronous pulse interference in the order of 1%, will allow a radar to meet its system performance requirements until I/N ratios are in the order of 30 dB. For higher duty cycles pulse signals, these techniques are moderately effective. The figure below shows the impact of interference suppression techniques for various interference duty cycles.

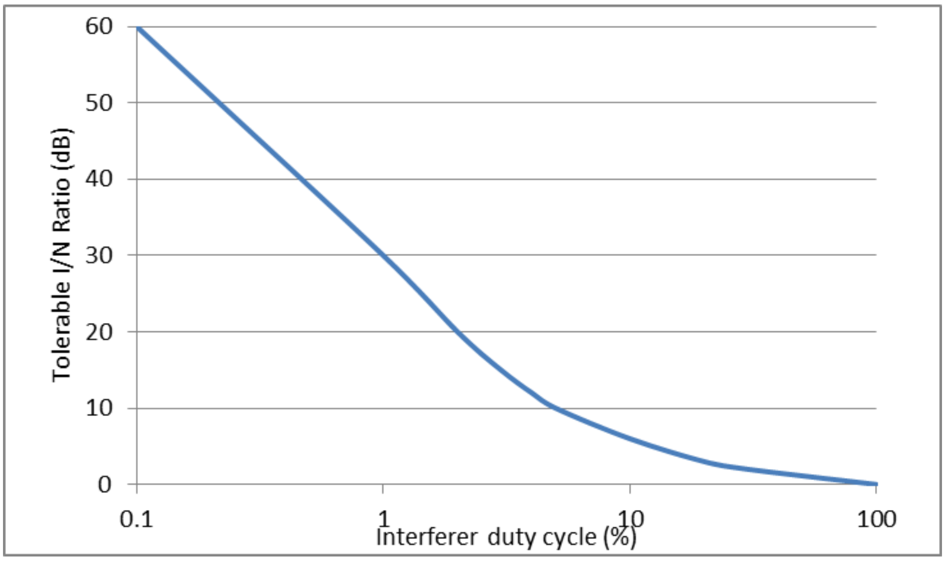

Figure 1: Effect of interference suppression at various interference duty cycles

Note: Asynchronous co-frequency interfering signals that are similar or identical to the victim radar's own transmissions are likely to pass through its pulse compression circuits with less degradation than other types of interference. Typically these are detected at levels 10 dB or more lower than for other types of interference.

5.11 In addition, the applicability of an aeronautical safety margin (e.g. 6 dB) should be considered in order to take into account various uncertainties in the compatibility analysis (see also ITU-R Recommendations M.1477 and M.1535).

Step 3: comparison of the maximum tolerable with the received interference power levels

5.12 If the model indicates that the received interference power level exceeds the maximum tolerable level that would impair the proper function of the radar, a more detailed and dynamic analysis may be required.

6. Simplified Generic Model for the Evaluation of interference to radar systems

6.1 A simplified static model, based on the interference analysis as outlined above, can be used for the initial evaluation of the potential for interference to aeronautical primary radar systems from emissions of other interference sources.

Step 1: determination of the interference power level at the receiver

Parameter	Comments
a) P_t – interferer transmit power density (dBW/MHz)	
b) G_t – interferer antenna gain (dBi)	Gain of the interferer antenna in the direction of the radar receiver antenna
c) G_r - Radar receiver antenna gain (dBi)	Radar receiver antenna gain towards the interference signal including polarization loss. See also section on antenna coupling.
d) $L_b(d)$ – Basic path loss between radar receiver antenna and interference source (dB)	Free space propagation loss between the radar receiver antenna and the interference source (see Recommendation ITU-R P.341): $L_b(d) = 20 \log f(MHz) + 20 \log d(m) - 27.55$
e) I - interference power density level at the receiver (dBW/MHz)	$I = P_t + G_t + G_r - L_b(d) - FDR(\Delta f)$

Step 2: Evaluation of the aggregate interference power level tolerable at radar receiving antenna's output (depends on radar system design)

Parameter	Comments
f) Maximum aggregate interference power density measured for the radar (dB(W/MHz))	Maximum value of interference signal power referenced to its passive antenna terminals that still allows the radar to meet its performance requirements. To be derived by measurements, and the result may be specific to the interference signal waveform tested. For such measurements, a reduction in 1% probability of detection has been accepted in the past on various occasions as an interference criterion.
g) Aeronautical safety factor (dB)	The applicability of an additional margin for the protection of the safety service (e.g. 6 dB) may be considered in order to take into account various uncertainties in the compatibility analysis (see also ITU-R Rec. M.1477 and M.1535).
h) Aggregate interference power density level tolerable at receiver (dB(W/MHz))	Maximum tolerable interference power density level, h = f – g
i) Multiple interference source factor (dB)	If there is a potential for more than one source of interference at the same time, an allowance should be made for the aggregate interference.

Step 3: comparison of the maximum tolerable with the received interference power levels

Parameter	Comments
j) I (dB(W/MHz))	Interference power density level at the receiver, j = e
k) $I_{aggregate}$ (dB(W/MHz))	Aggregate interference power density level tolerable at receiver (dB(W/MHz)), k = h - i
	If $I < I_{aggreagte}$, compatibility can be assumed. In case $I_{aggregate}$ exceeds at the specified distance from the radar receiver antenna, and the simplified model indicates a potential for interference that would impair the proper function of the radar, a more detailed and dynamic analysis may be required.

7. Additional Guidance on a more detailed and dynamic analysis

7.1 For a more detailed and dynamic analysis, the general formula, as introduced in section 5, can be expanded to include additional factors thus:

$$I = P_t + G_t + G_r - L_t - L_r - L_b(d) + P_f + F_t + F_r + F_p + C_{a-a} - FDR(\Delta f)$$

Where

L_t: *insertion loss in the interfering radar transmission line (dB)*
L_r: *insertion loss in the victim radar receiving line (dB)*
P_f: *propagation factor (dB)*
F_t: *interfering antenna pattern correction (dB)*
F_r: *victim antenna pattern correction (dB)*
F_p: *polarisation factor (dB)*
C_{a-a}: *antenna-to-antenna coupling (dB)*

Notes:

(a) P_f, the propagation factor, takes into account the difference in free space propagation loss compared to a path loss which takes significant interference propagation mechanism into account, such as multipath propagation, diffraction and refraction. This will often be calculated using sophisticated modelling software. Previous radar compatibility studies have tended to use a propagation loss of 6 dB less than free space loss (for multipath) for short separation distances of a few kilometres and within radio line-of-sight, and a value derived in accordance with ITU-R P.452 for longer distances.

(b) F_t and F_r are correction factors to take account of the reduction in antenna gain compared to the direction of maximum radiation. In flat terrain, radar antennas are typically installed with an up-tilt of 2-3° and the reduction in gain at 0° elevation is typically in the order of 3-4 dB.

(c) F_p, the polarisation factor, takes into consideration the losses due to polarization mismatch between transmitting and receiving antennas. Values are provided in the following table:

Antenna 1	Antenna 2	F_p *(dB)*
Circular (RH or LH)	Vertical	-3
Circular (RH or LH)	Horizontal	-3
Circular (RH or LH)	Slant (45 or 135°)	-3
Circular RH	Circular RH	0
Circular LH	Circular LH	0
Circular RH	Circular LH	-20*
Vertical	Vertical	0
Vertical	Horizontal	-20*
Vertical	Slant (45 or 135°)	-3
Horizontal	Horizontal	0
Horizontal	Slant (45 or 135°)	-3

* Typical cross-polarisation isolation

(d) $C_{a\text{-}a}$ addresses interactions between the scanning of two radar antenna beams. In the case of primary radars with rotating antennas, the interference power level varies greatly with time due to the highly directive nature of their antennas, and that the impact of the interfering signal is a function of both its amplitude and the probability of occurrence. For example, a typical S-band aeronautical radar will have a 3 dB horizontal beam-width of 1.5°. The maximum antenna main-beam-to-main-beam coupling between two radars occurs with a probability of less than 0.000017. It should be noted that reflector type antennas typically have a main-beam gain of around 30 dBi and an average antenna back-lobe levels of -10 dBi. Consequently, back-lobe-to-back-lobe coupling is typically 70 to 80 dB weaker than main-beam-to-main-beam coupling.

8. Reference Material

Recommendation ITU-R SM.337 – Frequency and distance separations

Recommendation ITU-R P.341 – The concept of transmission loss for radio links

Recommendation ITU-R P.452 – Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz

Recommendation ITU-R M.1372 – Efficient use of the radio spectrum by radar stations in the radiodetermination service

Recommendation ITU-R M.1461 – Procedures for determining the potential for interference between radars operating in the radiodetermination service and systems in other services

Recommendation ITU-R M.1463 – Characteristics of and protection criteria for radars operating in the radiodetermination service in the frequency band 1 215 - 1 400 MHz

Recommendation ITU-R M.1464 – Characteristics of and protection criteria for radionavigation and meteorological radars operating in the frequency band 2 700 – 2 900 MHz

Recommendation ITU-R M.1796 – Characteristics of and protection criteria for terrestrial radars operating in the radiodetermination service in the frequency band 8 500-10 680 MHz

Recommendation ITU-R M.1851 – Mathematical models for radiodetermination radar systems antenna patterns for use in interference analyses

Recommendation ITU-R M.2069 – Antenna rotation variability and effects on antenna coupling for radar interference analysis

REPORT ITU-R M.2112 – Compatibility/sharing of airport surveillance radars and meteorological radar with IMT systems within the 2 700-2 900 MHz band

REPORT ITU-R M.2136 – Theoretical analysis and testing results pertaining to the determination of relevant interference protection criteria of ground-based meteorological radars

EUROCONTROL-SPEC-0147 – Specification for ATM Surveillance System Performance (Volume 1 and Volume 2 Appendices)

F. GNSS RFI INTERFERENCE REPORTING FORMS

1 Guidance on GNSS Interference Reporting to ICAO

(Source: ICAO NSP SeptOct 2014WG1&2 Flimsy 9)

Before approaching ICAO in case of GNSS interference, it is recommended to take into account all suitable measures for dealing with interference laid down in Article 15 of the ITU Radio regulations.

Moreover, please note the "Memorandum of Cooperation (MoC) between ICAO and the International Telecommunication Union (ITU) for Providing a Framework for Enhanced Cooperation Regarding the Protection of the Global Navigation Satellite System from Harmful Interference with a Potential Impact on Aviation Safety" has established a framework for enhanced cooperation between the Parties in matters related to harmful interference to GNSS with a potential impact on international civil aviation safety.

In this MOC the following Cooperation Procedure was agreed:
ICAO will institute a process whereby ICAO Member States and relevant aviation stakeholders will report to ICAO cases of harmful interference to international civil aviation uses of
GNSS.

- ICAO will perform a prompt analysis of the interference reports with regard to their impact on safety, regularity and efficiency of air navigation.
- In cases where the analysis determines that there is a significant impact on air navigation with an international scope, ICAO will transmit the results of the analysis to ITU without delay.
- ITU will duly consider and, as appropriate, take into account the information received from ICAO when providing assistance to administrations to ensure a prompt resolution of the problem of interference pursuant to Article 15 of the Radio Regulations.
- ICAO will make aeronautical expertise available to ITU on request, if needed to assist ITU in settlement of the problem.
- ITU will keep ICAO informed of the progress in application of the procedure defined in Article 15 of the Radio Regulations, Section VI, for the cases of harmful interference to GNSS identified by ICAO.
- ITU will notify ICAO as soon as the interference incident can be considered as settled.

Interference reporting to ICAO shall focus on the reporting of cases with cross-border impact, which cannot be solved nationally or internationally through routine procedures and which therefore may need to be also reported to ICAO for coordination with ITU on the basis of the Memorandum of Cooperation between ICAO and the ITU for Providing a Framework for Enhanced Cooperation Regarding the Protection of the Global Navigation Satellite System from Harmful Interference with a Potential Impact on Aviation Safety". This procedure does in no way replace the reporting requirements identified within an individual State.

The following details are be deemed useful for reporting GNSS interference cases to ICAO:

- **Originator of this report** [Originating State , Organisation, Address]
- **Description of interference**
  - Affected GNSS Service [GNSS constellation, SBAS, GBAS]:
  - Observablility of the interference [Interference was noticeable only on board of aircraft, only on ground, both]

- Degradation of GNSS performance [Large position errors, Loss of integrity, loss of single/multiple satellites in view]
- Problem duration [duration time, continuous/intermittent impact]
- Affected area [local/wide spread]
- Operational Impact [loss of navigation, need to change the navigation procedure]
- Information on presumed source of interference
  - Actions taken to rule out that the interference source is domestic
  - Presumed location of interference source/country
  - Interfering frequency
  - Interference signal strength and reference bandwidth
  - Presumed possible causes

- **Actions taken to mitigate the interference**
- **Was a "Report of an irregularity or infringement" submitted to ITU?** (as foreseen in Article 15 with a reporting from provided in Article 9 of the ITU radio regulations)
- **Attachments** [Spectrum plot, Map, Log entries, recorded GNSS data]

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2 Guidance for GNSS interference reporting to States

(Source: ICAO NSP SeptOct 2014WG1&2 Flimsy 8)

<u>GNSS interference reporting form to be used by ATS personnel:</u>

Originator of this report:	
Organisation:	
Department:	
Street / No.:	
Zip-Code / Town:	
Name / Surname:	
Phone No.:	
E-Mail:	
Date and time of report:	
Description of interference	
Affected GNSS Element:	[ ] GPS [ ] GLONASS [ ] other constellation [ ] EGNOS [ ] WAAS [ ] other SBAS [ ] GBAS (VHF data-link for GBAS)
Observablility of the interference:	Interference was noticeable: [ ] only on board of aircraft

	[ ] only on ground [ ] both
Source of initial interference report:	Pilot [ ], Engineer/Technician [ ], Other [ ]
Degradation of GNSS performance:	[ ] Large position errors (details): [ ] Loss of integrity (RAIM warning/alert): [ ] Complete outage [ ] Loss of satellites in view/details: [ ] Lateral indicated performance level changed from:___to ___ [ ]Vertical indicated performance level changed from: __ to __ [ ] Indicated Dilution Of Precision changed from __ to__ [ ] Information on PRN of affected satellites (if applicable) [ ] Low Signal-to-Noise (Density) ratio [ ] other
In case of report by Pilot:	
Airline Name:	
Aircraft Type and Registration:	
Flight Number:	
Airway/route flown:	
Coordinates of the first point of occurrence / Time (UTC):	UTC: Lat: Long:
Coordinates of the last point of occurrence / Time (UTC):	UTC: Lat: Long:
Flight level or Altitude at which it was detected:	
Affected ground station [e.g. GBAS]	Name/Indicator; Lat: Long:
In case of report by ATS personnel	
Coordinates of the first point of occurrence / Time (UTC):	UTC: Lat: Long:
Coordinates of the last point of occurrence / Time (UTC):	UTC: Lat: Long:
Affected area:	
Affected flight route:	
Problem duration:	Days, Hours, Minutes, Seconds_____________ ________________________ [ ] continuous [ ] intermittent
Information on presumed source of interference	
Presumed location of interference source:	Lat/Long: or Nearest City or Landmark
Interfering frequency (if known:)	
Signal strength and reference bandwidth: (if known)	
Further descriptions of the interference case:	[ ] Spectrum plot [ ] Map Other material:

GNSS interference reporting form to be used by pilots:

Note: Only applicable fields need to be filled!

Originator of this report:	
Organisation:	
Department:	
Street / No.:	
Zip-Code / Town:	
Name / Surname:	
Phone No.:	
E-Mail:	
Date and time of report	
Description of interference	
Affected GNSS Element	[ ] GPS [ ] GLONASS [ ] other constellation [ ] EGNOS [ ] WAAS [ ] other SBAS [ ] GBAS (VHF data-link for GBAS)
Aircraft Type and Registration:	
Flight Number:	
Airway/route flown:	
Coordinates of the first point of occurrence / Time (UTC):	UTC: Lat: Long:
Coordinates of the last point of occurrence / Time (UTC):	UTC: Lat: Long:
Flight level or Altitude at which it was detected:	
Affected ground station (if applicable)	Name/Indicator; [e.g. GBAS]
Degradation of GNSS performance:	[ ] Large position errors (details): [ ] Loss of integrity (RAIM warning/alert): [ ] Complete outage [ ] Loss of satellites in view/details: [ ] Lateral indicated performance level changed from:___to ___ [ ]Vertical indicated performance level changed from: __ to __ [ ] Indicated Dilution Of Precision changed from __ to__ [ ] information on PRN of affected satellites (if applicable) [ ] Low Signal-to-Noise (Density) ratio [ ] other
Problem duration:	[ ] continuous [ ] intermittent

G. VDL GROUND STATION INSTALLATION GUIDANCE

1. General considerations

1.1. Consideration to the guidelines, as contained in this document, should be given during the design phase for a new VDL ground station or modification of existing stations to maintain interference free and reliable VHF air/ground data link systems.

1.2. VDL Mode 2 communications use a D8PSK modulation operating at a data rate of 31.5 Kbps. It is considerably less tolerant of interference as compared to classic ACARS operation, which uses Amplitude Modulation (AM) and a sub modulation of minimum shift key (MSK) at a data rate of 2400 bps.

1.3. Non co-site operations

1.3.1. VDL Mode 2 operations can co-exist with other ACARS (AM with MSK modulation), VDL Mode 2 data, and voice services if the proper frequency and channel separations are observed. Based on a transmitter power of 25 watts and omni-directional antennas:

1.3.1.1. A VDL Mode 2 station can be expected to operate satisfactorily within 50 kHz of another VDL Mode 2, AM Voice, or ACARS station if the antennas are separated by a distance in the order of 2 kilometres.

1.3.1.2. Unacceptable interference and degradation can be expected if the ground stations are operated closer than 0.8 kilometre unless proper filtering is applied.

1.3.1.3. A generic method for the determination of the required distance separation between antennas is described below.

1.4. Co-site operation of active VDL channels

1.4.1. For co-site installations a combination of frequency and distance separation should be applied based on the principles set out below.

1.4.2. It is expected that the VDL service will require three active VDL channels in an airport, co-site environment (e.g., the Common Signaling Channel (CSC), Alternate #1, and Alternate #2). Therefore, it is expected that each VDL transceiver will require two or three cavity filters with the notch tuned to the other two frequencies that are being rejected.

1.4.3. By illustration, a VDL transceiver (or VDR) operating on the CSC may require two serially connected filters between the transceivers and antenna, one notch tuned to Alt #1 and one notch tuned to Alt #2 if sufficient isolation cannot be obtained through geographical separation (see Figure 1).

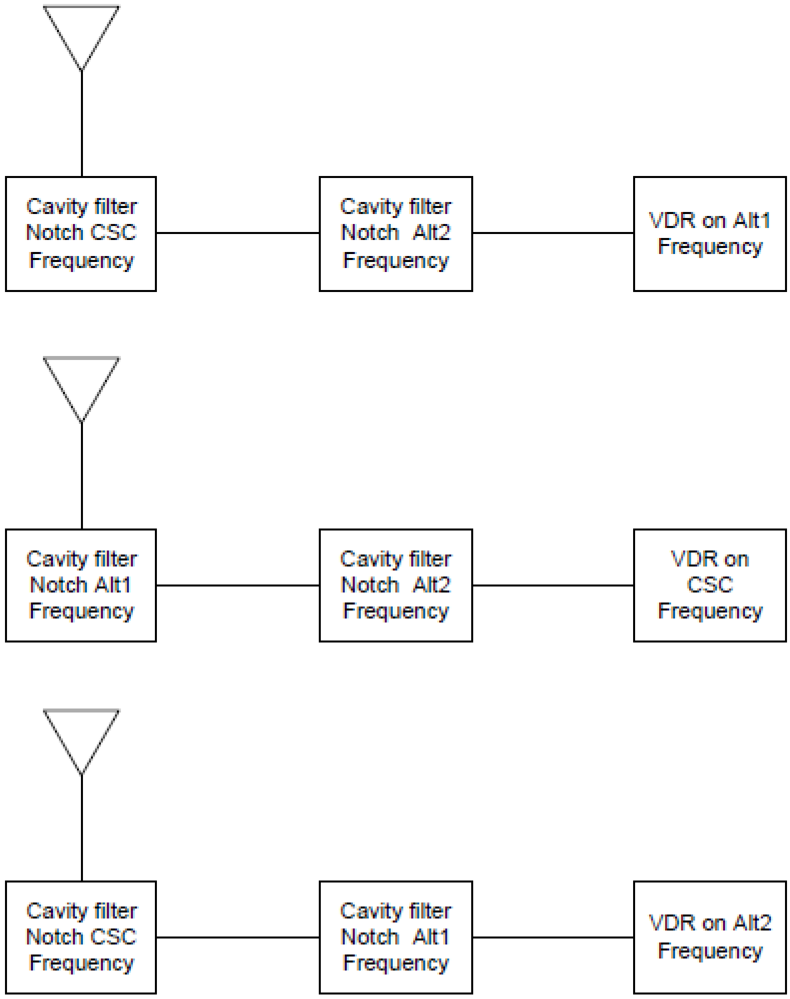


Figure 1 - Three VDRs with the corresponding cavity filter configuration

1.5. Transmitter intermodulation considerations

1.5.1. When two collocated transmitters are activated, third order intermodulation products are produced at frequencies 2F1 – F2 and 2F2 – F1. If there is no channel assigned at these offset frequencies, then the intermodulation products are transmitted without detriment to any other user of the band. As an example, if 136.975 MHz and 136.875 MHz (100 kHz offset) are used, the third frequency cannot be 136.775 MHz (another 100 kHz offset) because the 2F1-F2 product is on the CSC 136.975 MHz. To avoid intermodulation problems between co-site installations at airports where there is the CSC plus two alternate channels in use for communications with aircraft on the ground, the first alternate channel is assigned to 136.875 MHz (i.e. 100 kHz from the CSC) and the second is assigned to 136.725 MHz (i.e. 150 kHz away from the first alternate channel).

1.6. Consideration should be also given to the effect of multiple interference, due to the arrival at the desired receiver of more than one undesired signals of comparable strength. This effect should be assessed on a case by case basis.

1.7. Lastly, the installation design must ensure that the minimum desired signal level is available at the receiver taking into consideration factors such as aircraft transmitter power, transmitter/receiver antenna patterns, local shielding, filter insertion loss etc.

2. Generic method for calculating VDL Mode 2 ground station separation

2.1. Introduction

2.1.1. This method is intended to assist the planning of data link services. However, because local conditions can have a significant impact on system performance, these guidelines should be complemented by a site survey prior to deployment in order to ensure that system components perform according to expectations.

2.2. Assumptions

2.2.1. Radio Propagation: To calculate the level of the interfering signal, free-space attenuation is assumed, this being:

$$Path\ loss\ (dB) = 20\log(d) + 20\log(f) - 27.6 \quad \text{[equation 1]}$$

Where:
d = distance (metres)
f = frequency (MHz)

2.2.2. Undesired Frequency: For calculation purposes, the undesired frequency can generally be taken as 136.975 MHz; i.e. the frequency of the VDL Mode 2 Common Signalling Channel (CSC).

2.2.3. Antenna Characteristics: The antenna systems are assumed to be omni-directional with a net gain of 0 dBi (antenna gain minus feeder/coupling losses).

2.2.4. Desired Signal: The minimum desired signal to be protected is taken to be -90dBm, measured at the input to the filter/receiver.

Note 1: ICAO Annex 10 Volume III SARPs require a minimum desired field strength of 20µV/m at the ground station which corresponds to a desired level of -94 dBm for an assumed antenna system gain of 0 dB at the input to the filter/receiver. However, in order to avoid greater complexity in the system design (e.g. additional filtering) and/or excessive separation distances, it is recommended that the ground station system is designed to support the higher value given above.

Note 2: Weaker desired signals (down to -94 dBm) may need to be protected in particular for the provision of en route coverage. While in this case the present method can be applied, the final formula (equation 3) should be adjusted to account for the level of the desired signal.

2.2.5. S/I Ratio: The minimum signal-to-interference value shall be 20 dB, measured at the input to the receiver. Thus the maximum tolerable level of the interfering signal is -110 dBm.

2.2.6. Adjacent Channel Emissions: In accordance with ICAO Annex 10 Volume III SARPs, adjacent channel emissions at various offset frequencies shall not exceed those in Table 1.

Frequency Separation (kHz)	Adjacent channel emissions (dBm)
25	2
50	-28
75	-33
100	-38
125	-39
150	-41
200	-43
400	-48
800	-53

Table 1 – VDL Mode 2 Adjacent Channel Emissions

Note: ICAO Annex 10 Volume III SARPS specifies that the adjacent channel emission for the fourth adjacent channel is at a maximum of -38dBm and that it shall monotonically decrease at a rate of 5 dB per octave thereafter. This is reflected in the above table.

2.3. Filter Rejection

2.3.1. To prevent interference, multiple tuned-cavity notch filters are generally required for each VDL Mode 2 frequency that is operated in a co-site environment. These limit the level of adjacent channel emissions from each undesired ground station. It is expected that the VDL service will require up to three active channels at an airport (i.e. the CSC plus two additional channels). It may therefore be expected that each VDL transceiver will require two or three cavity filters with the notch tuned to the other two frequencies to be rejected.

2.3.2. Filter rejection is defined as the total amount of attenuation provided by the undesired transmitter's filter(s) at of the victim receiver's frequency. For multiple filter configurations (e.g. Fig.1) the main contributor will be the filter whose notch is tuned to the victim receiver's frequency but each of the other filters in the chain will typically provide further attenuation in the order of 2-6 dB.

2.3.3. Typically, cavity filters used for this purpose are designed to pass the desired frequency with minimum insertion loss (passband) while simultaneously rejecting the undesired frequency. It is recommended that suitable cavity filters should yield a minimum rejection of 20 dB at a 125 kHz offset and a pass frequency insertion loss of 0.7 dB or less. 6-inch and 10-inch cavity filters are available for this purpose and, even though more costly, it is generally recommended that the latter is used as it provides increased notch rejection and reduced insertion loss. Typical rejection values are provided in Table 2.

Frequency separation	6-inch filter Rejection (dB)	10-inch filter Rejection (dB)
75 kHz	14.5	20
100 kHz	20	21
125 kHz	20	24
150 kHz	23	27
175 kHz	24	27

Table 2 – Typical Notch-Filter Rejection Characteristics

2.3.4. The filters are tunable in order that the passband frequency and rejection notch frequency can be finely tuned. They are manufactured such that the rejection notch is either above or below the passband. The tuning of the filters may need to be adjusted on-site because of mechanical vibration and shock during shipment.

2.4. Generic Separation Distance Formula

2.4.1. Applying the above assumptions, the interfering VDL Mode 2 signal strength at input of the victim receiver can be calculated using the following formula:

$$P_r = P_t - (20\log(d) + 20\log(f) - 27.6) - L_f \quad \text{[equation 2]}$$

Where:
Pr = Level of the adjacent channel emissions at the input to the victim filter/receiver (dBm)
Pt = Adjacent channel emissions of the interfering transmitter (dBm)
Lf = Filter rejection (dB)

2.4.2. By transposing equation 2 and assuming a frequency of 136.975 MHz and a maximum tolerable interfering signal of – 110 dBm, the minimum required separation distance between ground stations can be calculated using the following formula:

$$d = 10^{\frac{P_t - P_r - L_f - 15.1}{20}} = 10^{\frac{P_t - L_f + 94.9}{20}} \quad \text{[equation 3]}$$

Note 1: In the case of multiple interferers, the maximum tolerable level of each undesired signal is necessarily less than -110 dBm and, consequently, the required separation distance would need to be greater than that produced by the above formula.

Note 2: Placing radios closer than 6 metres together without cavity filters may have destructive effects on the front end of the receiving radio.

Note 3: Assuming an output power for VDL ground station transmitters of 25 W and a frequency separation of at least 100 kHz, ARINC recommends that the separation distance between VDL ground station antennas should be no less than 20m.

Note 4: Vertical separation of antennas may provide additional rejection of adjacent-channel emissions.

Numerical examples

2.4.3. On applying the above generic method to the configuration of Figure 1, the following results are obtained:

Frequency separation kHz	Emissions at this separation dBm	Notch filter rejection 10-inch cavity filter dB	Minimum antenna separation metres
25	2	0	69984.2
50	-28	0	2213.1
75	-33	20	124.5
100	-38	21	62.4
125	-39	24	39.4
150	-41	27	22.1
200	-43	27	17.6
400	-48	27	9.9
800	-53	27	5.6

Table 3 – VDL Mode 2 frequency separation vs. antenna separation with a single 10 inch cavity filter limiting the emissions of the undesired transmitter

Note 1: Additional isolation may be achieved by placing multiple filters in series. This will result in higher insertion loss.

Note 2: For the configuration shown in Figure 1, the filter rejection is likely to be higher than the values given in Table 2 because the transmitter is connected to two filters instead of a single one. In Figure 1, the main contributor to the attenuation of the emissions of the undesired transmitter is the filter whose notch is tuned to the victim receiver's frequency. However, for frequencies at least 100 kHz from the passband frequency of the undesired transmitter but not on its tuned notch, the second filter can provide an additional attenuation in the order of 2-6 dB. This additional attenuation may be taken into consideration when deriving the minimum separation distance between ground station antennas.

2.4.4. Without filter rejection, the following results are obtained for the required ground station antenna separation:

Frequency separation kHz	Emissions at this separation dBm	Minimum antenna Separation metres
25	2	69984.2
50	-28	2213.1
75	-33	1244.5
100	-38	699.8
125	-39	623.7
150	-41	495.5
200	-43	393.6
400	-48	221.3
800	-53	124.5

Table 4 – Frequency separation vs. geographical separation with no cavity filters

H. GUIDANCE MATERIAL FOR THE CALCULATION OF D/U ON DME AJACENT CHANNEL SERVICES

1. Introduction

For frequency planning purposes, there may be cases where the frequency manager wishes to calculate the minimum adjacent-channel D/U value for a given set of operational ~~criteria~~ parameters, as an aircraft overflies the undesired beacon. This guidance material provides a methodology for how this may be approached.

As background for the methodology, the minimum D/U requirements and the assumed undesired DME antenna pattern are first presented in sections 3 and 4 respectively.

Emphasis is placed on the aircraft operational height above ground level (AGL). This is because this height specifies the minimum distance between the aircraft and the undesired DME. Even though the required geographical separation between beacons is not met, the reception of the signal of the desired DME without harmful interference may be still possible, if an aircraft flies sufficiently high above the undesired DME. Knowing the height AGL of the aircraft permits with relative ease the determination of the least favorable distance from the undesired DME as well as the calculation of the resulting D/U ratio, as described in section 6.

Because of the importance of the operational height AGL, section 5 provides two different approaches for its assessment, assuming smooth spherical Earth:

> The first approach is based on a requirement to avoid the destructive interference occurring when the phase difference between the paths of the direct and the reflected wave is less than 60° and leads to a minimum operational height AGL for an aircraft.
>
> The second approach permits the approximate calculation of the operational height AGL as a function of the distance and the elevation angle from the desired DME.

2. Doc 011 separation requirements

ICAO EUR Doc 011 DME first adjacent channel frequency planning rules require that the minimum separation distance between DMEs operating on first-adjacent channels shall be 65 NM between beacons or 5NM from the DOC-edge of the desired beacon, whichever gives the lesser distance between beacons.

This rule ensures that the minimum D/U requirements set out in ICAO Annex 10 are met when an aircraft overflies the undesired beacon at the minimum practical height at which a DME service can be expected to be provided.

The practical implication of the planning rule is shown in Figure 1.

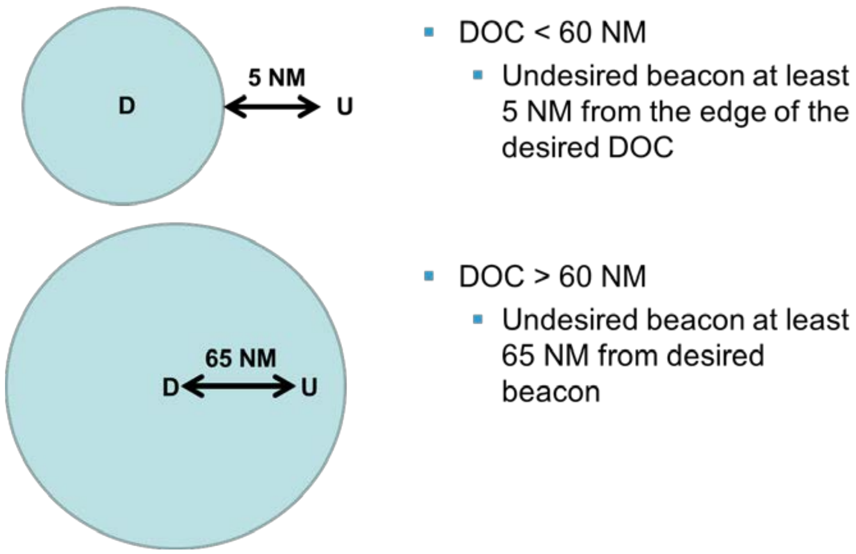


Figure 1 – DME first-adjacent channel planning rule

3. Minimum D/U criteria for pre-1989 and current DME interrogators

ICAO interrogator D/U requirements are covered in Annex 10, Volume I, Appendix C, Paragraph 7.8.1 and Table C-4. The table contains two values for the first-adjacent channel D/U, the first being for pre-1989 interrogators that have a decoder rejection of 6µs and the second for DME/N or DME/P interrogators having discriminators and decoder rejection conforming to the current Annex 10 requirements. All interrogators installed after 1 January 1989 are required to conform to the second value. The ICAO first-adjacent channel D/U requirements are reproduced below:

	Pre-1989 interrogator D/U (dB)	Current interrogator D/U (dB)
Same pulse code	$-(P_u - 1)$	–42
Different pulse code	$-(P_u + 7)$	–75
	Where P_u is the peak EIRP of the undesired signal in dBW.	

Table 1 – ICAO Annex 10 DME first-adjacent channel minimum D/U requirements (extract from Volume I Appx. C Table C-4)

Table 1 shows that Annex 10 places less demanding D/U requirements on "different pulse-code" than on "same pulse-code" combinations. It should be noted that different pulse-code refers only to X-versus-W and Y-versus-Z cases. There are no other adjacent channel different pulse-code combinations to consider because their reply frequencies are separated by many MHz. W and Z channels are only assignable to MLS/DME and there is no operational use of these channels in Europe. Thus, the adjacent channel D/U limits discussed below refer specifically to same pulse-code cases.

It is important to understand that the D/U limits for the pre-1989 and current interrogators are calculated by subtly different methods. This is explained below.

Normally, an adjacent-channel desired-to-undesired ratio, D/U_{adj}, is the difference of the power level of the desired signal minus the power level of the undesired signal at the receiver's input. The values of the above table correspond to this interpretation as the two power levels are measured on different (adjacent) channels, i.e.:

$$D/U_{adj} = pd_{o-c} - pu_{o-c}$$

where pd_{o-c} and pu_{o-c} are the on-channel power levels (dBm) or power flux densities of the desired and undesired signals at the victim receiver (i.e. measured over their own respective channels).

For pre-1989 interrogators, it is more common to apply a different method for the description of the adjacent channel performance of the receiver. More concretely, the adjacent-channel emissions of the undesired DME, $EIRP_{u.adj}$, which are assumed to be limited to -7dBW (see note below), are treated as co-channel interference. Thus, the co-channel D/U limit of 8 dB for the same or different pulse code can be applied to yield the following limit condition:

$$8 = D/U_{co} = pd_{o-c} - pu_{adj}$$

where pu_{adj} is the power level (dBm) or power flux density of an undesired signal at the victim receiver, co=-channel with the desired signal and produced by the undesired facility with an $EIRP_{u.adj}$ equal to -7dBW (as opposed to the peak EIRP of the undesired DME).

For pre-1989 interrogators with the same pulse-code, the two descriptions are equivalent given that:

$$pd_{o-co} - pu_{o-c} = (pd_{o-c} - pu_{adj}) + pu_{adj} - pu_{o-c} = 8 + EIRP_{u.adj} - EIRP_{u.o-c}$$
$$= 8 - 7 - EIRP_{u.o-c} = 1 - EIRP_{u.o-c}.$$

Either of the above formulations will deliver a correct result, provided consistent terminology is employed.

Note: In accordance with ICAO Annex 10 volume I paragraph 3.5.4.1.3e, the spectrum of the pulse modulated signal shall be such that during the pulse the EIRP contained in a 0.5 MHz band centred on frequencies 0.8 MHz above and 0.8 MHz below the nominal channel frequency in each case shall not exceed 200 mW (-7 dBW).

4. Impact of undesired DME vertical antenna pattern

The direction of maximum radiation in the vertical plane for en-route and terminal DMEs and TACANs is 3 ± 1° above the horizontal. The antennas have a "cone of silence" which significantly impacts the field strength at elevations above 10° or so.

Based on a range of manufacturer's data, a composite vertical antenna pattern is proposed as shown in Table 2 and Figure 2. The pattern is designed to provide reasonable but conservative D/U values.

Elevation (°)	Normalised gain (dBr)
0-10	0
11-20	- 3
21-30	- 9
31-40	- 11
41-90	- 14

Table 2 – Recommended values for composite antenna vertical gain (dBr)

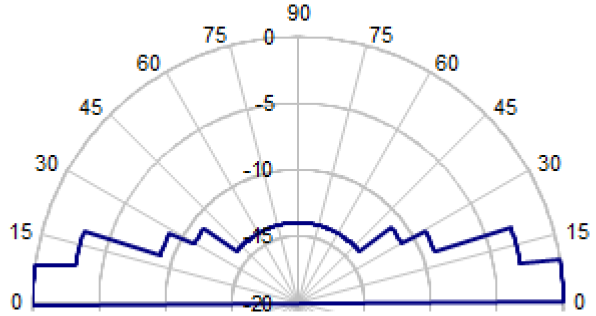


Figure 2 – Composite antenna vertical radiation pattern (dBi)

The minimum (worst-case) D/U value will occur when:

$$10^{-\frac{G(\theta)}{20}} \cdot \frac{Ru}{Rd} \quad \text{is at its minimum value}$$

where:
G is the normalized gain of the undesired beacon (G<0) in dB
Ru and Rd are distances of the aircraft from the undesired and desired beacons

By plotting this function, the worst-case elevation angle above the undesired beacon can be identified, i.e. the angle θ which renders the above quantity minimum.

For the composite antenna vertical radiation pattern given in Table 2, the above function is minimised at θ =20°, where G=-3 dB (see Figure 3).

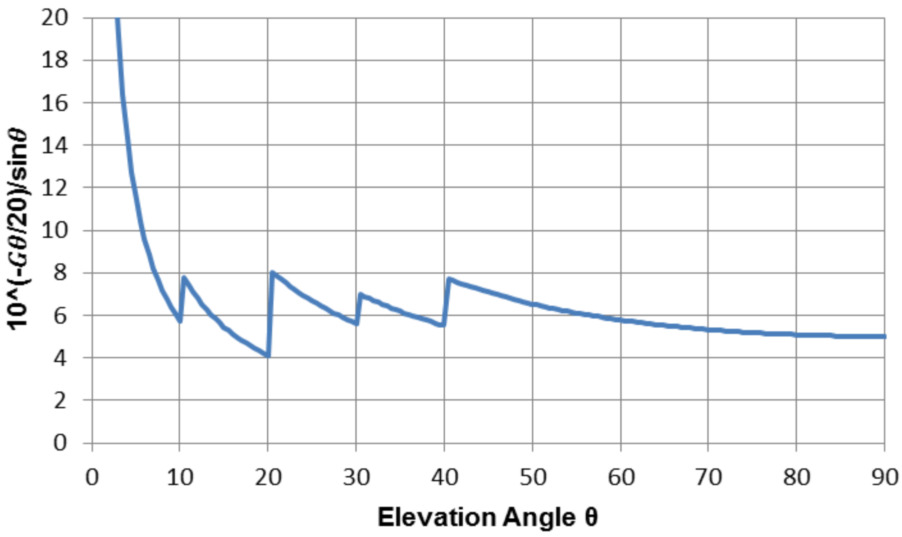


Figure 3 – Critical Elevation Angle (θ)

Note: If h denotes the height of the aircraft above the undesired facility, Ru=h/sinθ. Considering that the D/U is at minimum close to the undesired facility, it follows that the distance Rd is approximately equal to the separation of the two facilities. Hence the dependence of the D/U ratio with the elevation angle θ is essentially proportional to the quantity $10^{-\frac{G(\theta)}{20}}/sin\theta$*, which is plotted in the above graph.*

5. Consideration of minimum operational aircraft height

To calculate the minimum D/U value as an aircraft overflies the undesired beacon, it is necessary to establish the minimum height above the undesired beacon at which the DME navigation service will be provided.

5.1 Minimum reception altitude

Calculation of minimum reception altitude

If an aircraft is flying at, or close to, the radio horizon of the desired beacon, the desired signal is likely to be subjected to destructive interference from the reflected wave off the earth's surface. This will reduce the strength of the desired signal and the probability of delivery of a reliable DME service. When the phase difference between the paths of the direct and the reflected wave is close to 0, 2π, 4π, etc. the impact of destructive interference cannot be ignored. The deepest notch due to destructive interference occurs when the phase difference between the two paths is close to zero. To avoid this notch, a planning constraint may be introduced that the phase difference between the two paths be greater than π/3. This requirement leads to a minimum operational height for an aircraft receiving a DME service to avoid a reduction of the available signal strength due to destructive interference.

This minimum reception altitude at any given distance can be calculated as follows:

Because the elevation of the beacon is small compared to the aircraft elevation, the reflection point will be much closer to the desired beacon than to the aircraft. Therefore, flat Earth approximations can be used. Furthermore, the radio horizon is essentially parallel to the horizontal direction of the beacon antenna.

The phase difference between the two paths is given by the following formula:

$$\Delta\varphi = \frac{4\pi h_b h_a}{\lambda d} \qquad (1)$$

where:
h_b is the height of the desired beacon antenna (m);
h_a is the height of the aircraft above the radio horizon (m);
d is the distance between the desired beacon and the aircraft (m).

Thus:

$$\frac{\pi}{3} = \frac{4\pi h_b h_a}{\lambda d} \text{ and } \therefore\ h_a = \frac{\lambda d}{12 h_b} \qquad (2)$$

Minimum usable height above ground at which a DME service can be received

The minimum aircraft height AGL at which destructive interference can be ignored can be approximated by adding h_a to the radio horizon height h_{rh} at any given distance from the desired beacon, thus:

Using equation 2 and applying generic values of λ = 0.25 m and h_b = 30 feet, the approximate aircraft height in feet above the radio horizon, h_a, is given by the following formula:

$$h_a \approx 14d \qquad (3)$$

where d is the distance between the desired beacon and the aircraft in NM.

The radio horizon height can be calculated using the following formula:

$$d = 1.23\left(\sqrt{h_b} + \sqrt{h_{rh}}\right) \text{ and } \therefore\ h_{rh} \approx 0.66d^2 - 8.9d + 30 \qquad (4)$$

The minimum aircraft height AGL, $h_{agl} = h_a + h_{rh}$. Thus:

$$\boxed{h_{agl} = 0.66d^2 + 5.1d + 30} \qquad (5)$$

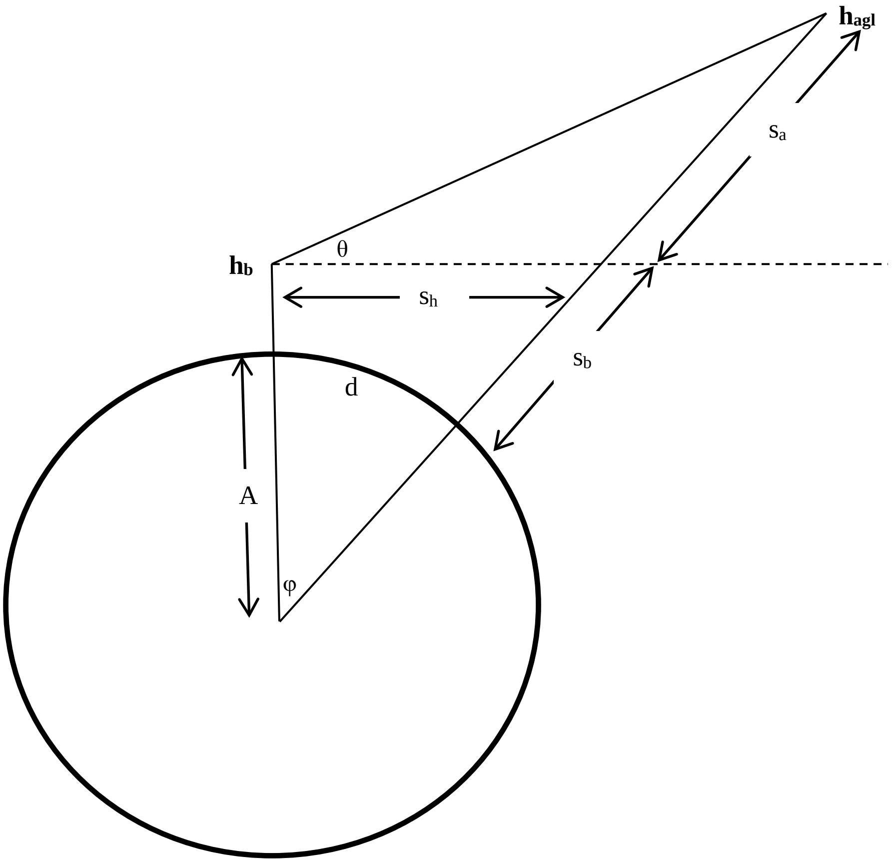
Some typical values for the minimum usable height at which a DME service can be delivered at various distances from the desired beacon are given in Table 3.

Distance from desired beacon (NM)	Minimum usable height at which a DME service can be delivered (ft)
25	570
50	1935
65	3150
75	4125
100	7140
125	10980
150	15645

Table 3 –Minimum usable height AGL at which a DME service can be delivered

5.2 Aircraft operational height based on angle of elevation

Rather than assuming an aircraft will be provided with a DME service at the minimum reception altitude described above, it may be preferred to calculate the aircraft operational height AGL based on angle of elevation, θ, from the desired beacon. For a given distance, this may be done as follows:



Let A be the true Earth radius (A=3444 NM) and d the arc length along the surface of the Earth. Then the angle, φ, of the radial with respect to Earth's axis is:

$$\varphi = d/A \tag{6}$$

Let θ denote the elevation angle of the desired DME above the horizontal.

$$h_{agl} = s_a + s_b \tag{7}$$

where h_{agl} is the aircraft height, s_a is the length of the part of the radial (from Earth's centre) above the horizontal and s_b that below the horizontal.

For $s_b >> h_b$, it can be shown that:

$$s_b = (A + h_b)/cos\varphi - A \approx (A + h_b)(1 + \varphi^2/2) - A \approx h_b + A\varphi^2/2 \approx A\varphi^2/2 = d^2/2A \tag{8}$$

Or:

$$s_b = 0.88d^2 \tag{9}$$

where s_b is in feet and d is in NM

Furthermore, the length s_h on the horizontal until its intersection with the radial from Earth's centre satisfies:

$$s_h = (A + h_b)tan\varphi \approx (A + h_b)\varphi \approx d(1 + h_b/A) \approx d \tag{10}$$

Noting that:

$$tan\theta = (s_a cos\varphi)/(s_h + s_a sin\varphi) \rightarrow s_a = (s_h tan\theta)/(cos\varphi - sin\varphi tan\theta) \tag{11}$$

Whilst:

$$s_h \approx d \text{ and } cos\varphi \approx 1 \tag{12}$$

Therefore:

$$s_a \approx dtan\theta \ (NM) \quad \text{equivalent to} \quad 6076dtan\theta \ (ft) \tag{13}$$

Hence:

$$\boxed{\boldsymbol{h_{agl} = s_a + s_b \approx \tan\theta * 6076d + 0.88d^2}} \tag{14}$$

Some typical values for the aircraft operational height AGL for various distances and elevation angles are given in Table 4.

Distance from desired beacon (NM)	Aircraft operational height at various elevation angles (ft)			
	0.3°	**0.4°**	**0.5°**	**0.6°**
25	1345	1610	1875	2140
50	3790	4320	4851	5381
65	5785	6475	7164	7853
75	7336	8131	8926	9722
100	11981	13041	14102	15163
125	17726	19052	20378	21703
150	24572	26162	27753	29344

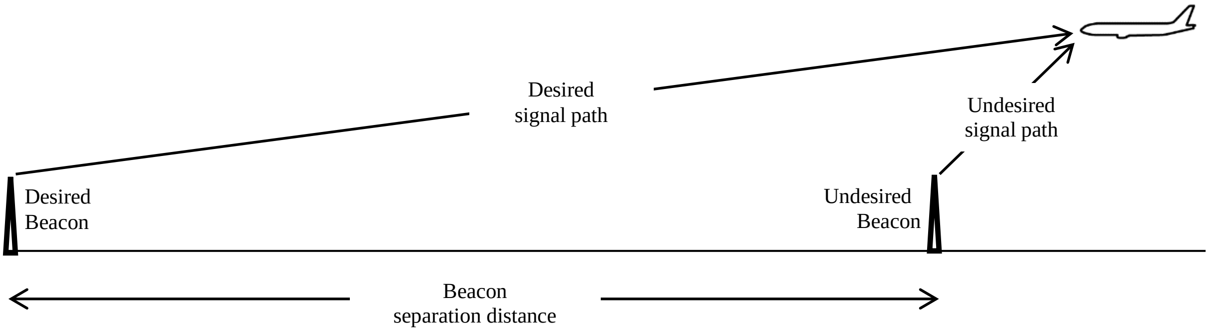
Table 4 - Aircraft minimum operational height based on angle of elevation

Note:

ICAO Doc 8071, the Manual on Flight Testing of Radio Navigation Aids, contains the following procedure for testing DME horizontal coverage:

"3.3.6 The aircraft is flown in a circular track with a radius depending on the service volume of the associated facility around the ground station antenna at an altitude corresponding to an angle of elevation of approximately 0.5° above the antenna site, or 300 m (1000 ft) above intervening terrain, whichever is higher."

6. Generic formula for the calculation of D/U



Considering that for the vertical radiation pattern of Fig.2:

- The minimum D/U occurs when the aircraft is at an elevation angle of 20° from the undesired beacon, and;
- The relative gain of the undesired beacon antenna at an elevation angle of 20° is -3 dB.

And assuming that:

- The aircraft is flying at or above the minimum aircraft height AGL at which destructive interference occurs such that free-space attenuation can be assumed.

The minimum D/U at a given height AGL at a specified separation distance between beacons can be calculated as follows:

$$D_u = \frac{h_{agl}}{\sin 20 \times 6076} \approx \frac{h_{agl}}{2078} \tag{15}$$

where:

D_u is the undesired signal path length (NM)
h_{agl} is the aircraft height above ground level (ft)

$$D_d = Ds + \frac{h_{agl}}{\tan 20 \times 6076} \approx Ds + \frac{h_{agl}}{2211} \tag{16}$$

where:

D_d is the desired signal path length (NM)
D_s is the separation distance between the desired and undesired beacons (NM)

Note: In formulas (15) and (16) the height above ground level of the undesired facility is assumed much lower than the height h_{agl} of the aircraft (compare with values of Table 4).

$$D/U = P_d - P_u + 3 + 20\log\left(\frac{D_u}{D_d}\right) \tag{17}$$

where:

P_d is the desired transmitted EIRP
P_u is the undesired transmitted EIRP
3 is the relative antenna loss at an elevation of 20°

6.1 D/U calculation for Pre-1989 Interrogators

For pre-1989 interrogators, the undesired transmitted power is – 7 dBW. Thus the D/U is calculated from the following formula:

$$\boldsymbol{D/U = EIRP_d + 10 + 20\log\left(\frac{D_u}{D_d}\right)} \tag{18}$$

where:

$EIRP_d$ is the desired transmitter effective isotropically radiated power

The calculated D/U value should be greater than 8 dB.

6.2 D/U calculation for Current Interrogators

For current interrogators, the D/U is calculated using on-channel EIRPs for both the desired and undesired beacons. Thus the D/U is calculated from the following formula:

$$D/U = EIRP_d - EIRP_u + 3 + 20\log\left(\frac{D_u}{D_d}\right) \quad (19)$$

where:

$EIRP_u$ is the undesired transmitter effective isotropically radiated power

The calculated D/U value should be greater than -42 dB.

6.3 Aircraft heights below the minimum usable height

In cases where there is a requirement to calculate the approximate D/U where the aircraft is above the radio horizon but below that at which destructive interference can be ignored, free-space propagation of the desired signal should not be assumed. There is no simple method to predict the field strength dependence on, or very close to the radio horizon, but a reasonable engineering approach would be to reduce the desired field strength by 6 dB.

I. CONVENTION FOR INDICATING THE ANGULAR LIMITS OF SECTORIZATION IN RANGE (old method used prior FMG/25)

Note: The method applied before FMG#25 (2019) which had divided a circle into 24 equal radials, each designated with a letter taken from A to X, is kept for reference purposes in the Supplement to Doc 011. It should not be used anymore in coordination and registration of frequency assignments.

Convention for indicating the angular limits of sectorization in range

1. The range values given for ICAO category facilities are the ICAO recommended designated operational ranges and, for national facilities, the declared operational range requirement. In both cases the ranges are normally circular, i.e. of the same value throughout 360°.

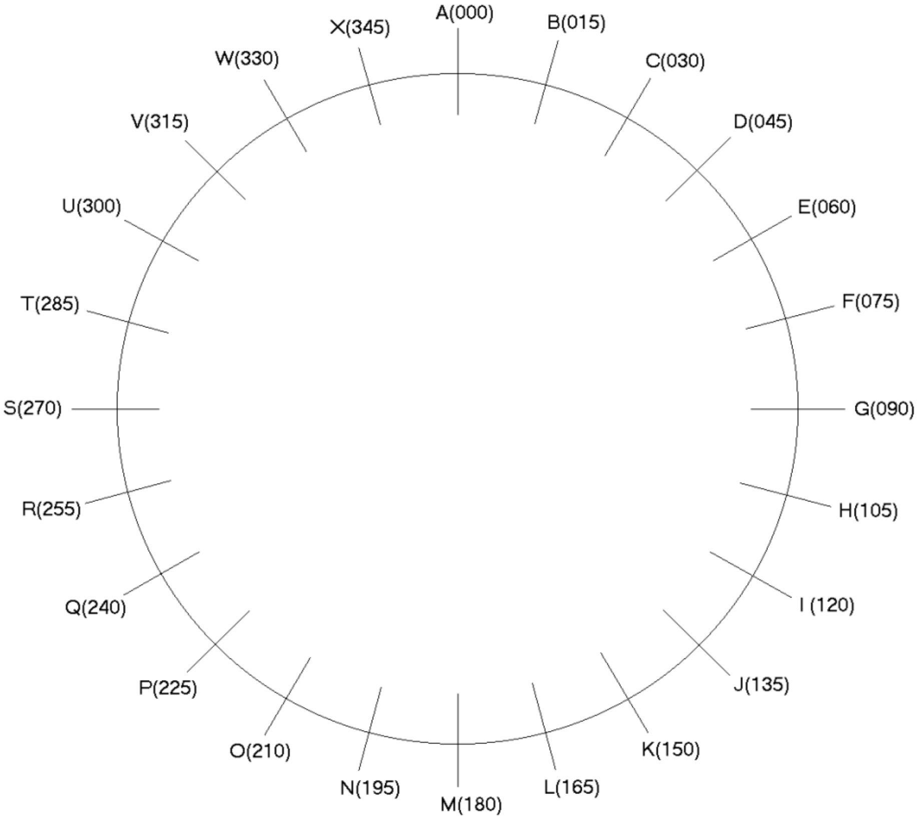
2. Where, however, the designated or declared values of operational range are not the same in all sectors, the following method is used to indicate the angular limits of sectors.

Method

3. The circle is divided into 24 radials, each designated with a letter taken from A to X in accordance with the Table and Figure below. The angular separation between adjacent radials is 15°.

Table - Sector designations

Code	Radials	Code	Radials	Code	Radials	Code	Radials
A	000	G	090	M	180	S	270
B	015	H	105	N	195	T	285
C	030	I	120	O	210	U	300
D	045	J	135	P	225	V	315
E	060	K	150	Q	240	W	330
F	075	L	165	R	255	X	345



Circle depicting the 24 radials

Illustrative examples of sectorization
(Figures below)

4. The sectorization as denoted is best described by the following examples. It should be borne in mind that a sector is always described by two letters taken from the Table below and that the sector is always drawn from the first letter, clockwise, to the second letter (e.g. GS is the 180° sector centred on South, while SG is the 180° sector centred on North).

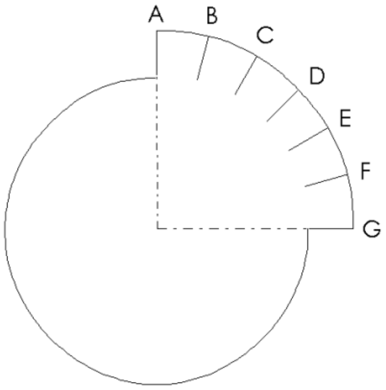
Example 1. 80AG/60 means 80 NM in sector 000° - 090° and 60 NM in other directions.

Example 2. 100VD/60 means 100 NM in sector 315° - 045°, clockwise, and 60 NM in other directions.

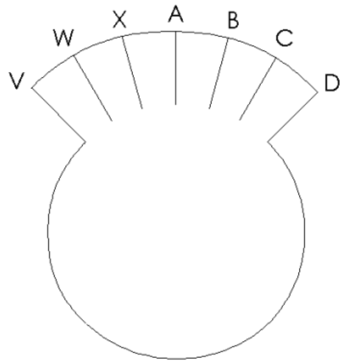
Example 3. 100DV/60 means 100 NM in sector 045° - 315°. Note that this is a sectorization that is the reverse of Example 2.

Example 4. 80DJ+PV/60 means 80 NM in sector 045° - 135 degrees, clockwise, and 225° - 315° also clockwise while 60 NM in what remains, that is the intermediate sectors 135° - 225° and 315° - 045°.

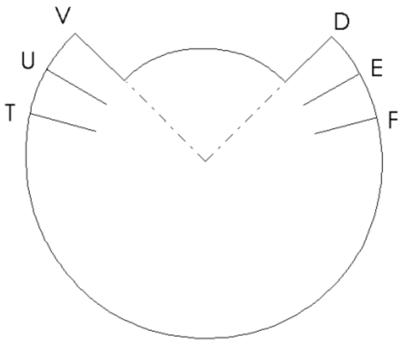
80AG60



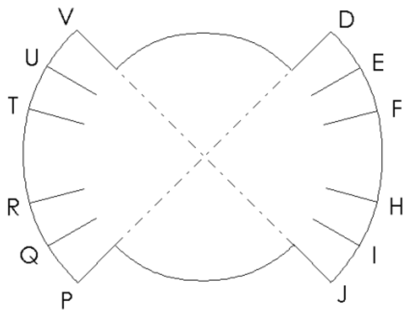
100VD/60



100DV/60



80DJ+PV/60



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