INTERIM GNSS ANTENNA MOPS

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1 INTRODUCTION

1.1 PURPOSE

The purpose of this document is to summarize the requirements specification of user terminal antenna equipment to support future Multistandard GNSS for Airborne Applications. It was produced as part of the EU STANDARDS Project.

This particular document is part of the Avionics Applications Section and aims to provide the Minimum Operational Performance Requirements (MOPS) for the Multistandard Receiving Antenna for airborne GNSS equipment.

Specifically this covers the capabilities of a GNSS airborne antenna designed to support GPS (L1, L5) and Galileo (L1, • 5• , • 5•) bands augmented as required by other systems and techniques as appropriate, ensuring that the combined precision provided satisfies the requirement for a primary means of navigation suitable for a all phases of flight and ground movements.

The antenna can be active (i.e. integrated with or attached to a preamplifier) or passive. Nevertheless the present document will attempt to minimise discrimination between the two cases defining the antenna block primarily with prime references assuming a 'Black Box' style approach as much as possible.

Furthermore, the current specification delivery has been driven by the desire to:

- Harmonise with ideas expressed by modern standardisation activities
- Avoid proliferation of unnecessary variation of specific performance specification pointers and parameters
- Rely on gained practical performance of working hardware and available technologies while at the same time correlate specification to system performance

1.2 BACKGROUND

The GNSS is a system intended for worldwide operation providing its users position and velocity information of accepted accuracy. In the context of the present MOPS the GNSS is assumed to compose of a civilian GPS elements as well as the planned civilian Galileo component. The present MOPS is applicable to the GPS L1 and L5 frequencies as well as the E5A, E5B and E1 Galileo system. It is also assumed that the GNSS system may be augmented in its delivered performance by other means both space based (SBAS), Ground based (LBAS) or with additional on board systems (ABAS).

The Antenna draft MOPS will also aim to support those augmentation systems that are spectrally collocated with the prime GNSS systems declared.

1.3 STRUCTURE OF THE DOCUMENT

The document initially sets out the prime aims of the standardisation presented.

It outlines the general requirements for its introduction to an aircraft.

Detailed specification parameters are exhaustively presented setting the limits of acceptable performance.

The issue of installed GNSS antenna performance is addressed.

Future Versions will be amended with the details of the environmental envelope of operation. It is expected that the environmental compliance matrix be entirely similar to legacy standards.

Testing procedures will be added towards the final form of document at a top brief level description only in line within the scope of current WP 2400 activities. As this subject is on its own of substantial complexity, full details and expositions can only be finalised as a result of dedicated practical realistic exercises towards demonstrating the current MOPS.

It must be stressed that the document in its current form is of evolutionary nature and changes amendments and modifications are expected as a result of feedback from project participants, industry stakeholders and other interested 3rd parties.

1.4 ENVIRONMENTAL TEST CONDITIONS

1.4.1 Applicable Documents

Ref.	Document title	Document reference	Issue	Date
[AD1]	STANDARDS Service Contract	GSA/OP/07/07	-	15.12.2008

Table 1: Applicable Documents

1.4.2 Reference Documents

Ref.	Document title	Document reference	Issue	Date
[RD1]	Galileo Open Service, Signal In Space Interface Control Document	ESA_European GNSS Authority	1	Feb-2008
[RD2]	Navstar GPS Space Segment/Navigation User Interfaces	IRN-200D-001	Revision D	Mar-2006
[RD3]	Navstar GPS Space Segment - User Segment L5 Interfaces	IS-GPS-705	IRN-705-003	Sept-2005
[RD4]	Minimum Operational Performance Standards for Global Navigation Satellite System (GNSS) Airborne Antenna Equipment	RTCA DO-228 Change No 1		Oct-1995
[RD5]	Minimum Operational Performance Standards for Global Navigation Satellite System (GNSS) Airborne Active Antenna Equipment for the L1 Frequency Band	RTCA DO-301		Dec-2006
[RD6]	Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment	RTCA DO-229D		Dec-2006
[RD7]	Minimum Operational Performance Specification for Airborne Galileo Satellite Receiving Equipment	Eurocae MOPS	Version 01	Sep-2009
[RD8]	Environmental Conditions and Test Procedures for Airborne Equipment	RTCA DO-160F		Dec-2007

Table 2: Reference Documents

2 GENERAL EQUIPMENT REQUIREMENTS

2.1 AIRWORTHINESS

Under no circumstance shall the installed and connected GNSS antenna impair the aircraft or the air vehicle's airworthiness.

2.2 INTENDED FUNCTION

The antenna shall perform its intended functions, and its proper use shall not create a hazard or any other impediment whatsoever to others users of the Air or Land recourses and Systems

2.3 INTERFERENCE TO RADIO SERVICES

The GNSS shall not degrade any Radio Serves and should operate according to applicable European and other Applicable Standards.

2.4 FIRE PROTECTION

The GNSS antenna should comply to Aviation Regulations dealing with fire hazards and should not significantly contribute to the propagation of fire.

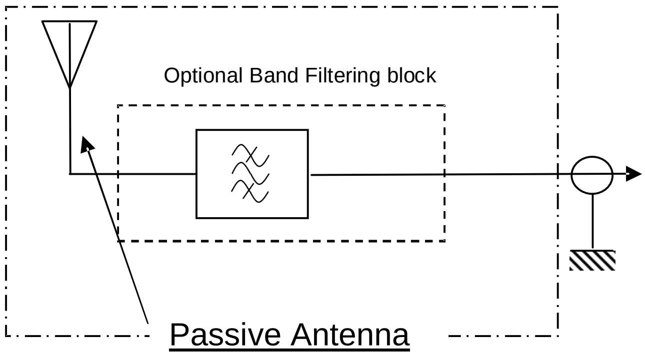
2.5 EFFECTS OF TEST

The antenna shall be designed in a way that demonstration of its performance during test will not affect in any way its integrity and its evaluated performance.

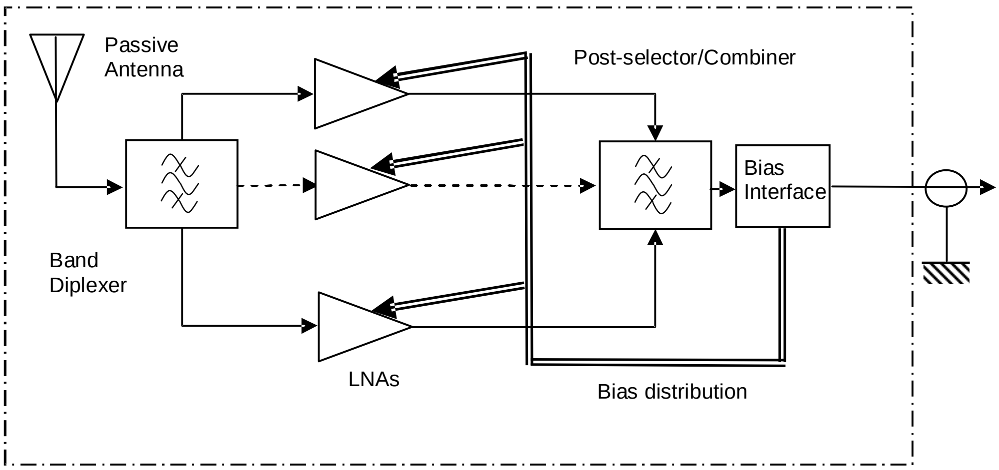
3 GNSS ANTENNA: PERFORMANCE – STANDARD CONDITIONS

By Standard conditions we mean the Laboratory environment and related testing facility conditions. By GNSS antenna we refer to the complete unit comprised of all subsystems including the passive radiator, diplexers, LNAs, combiners and DC bias interface circuitry.

The MOPS define some key performance parameters equally applicable to candidate GNSS antennas either passive or active (either integrated or based on discrete unit assembly) as shown in Figure 1 a-c.

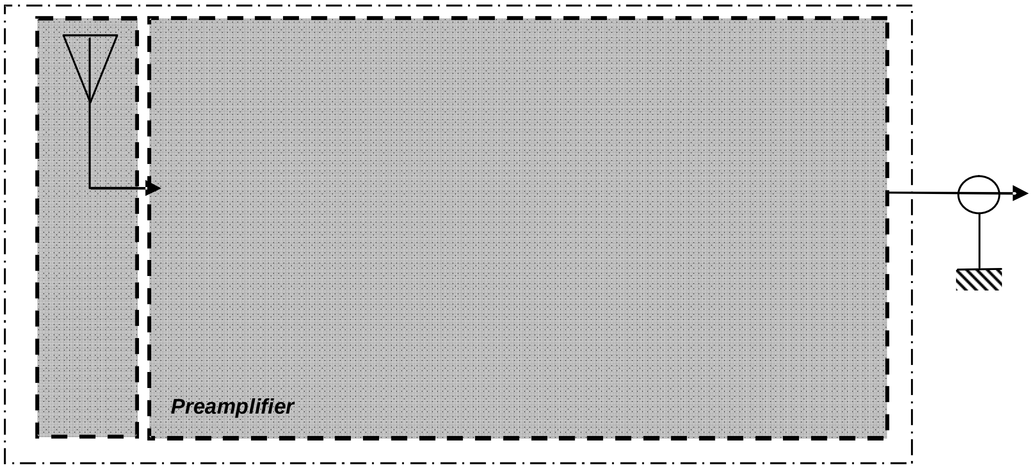


(a)



Integrated Active Antenna

(b)



Discrete Unit Active Antenna

(c)

Figure 1: GNSS antenna

It is understood that the bulk of applications will require active antennas, especially those dealing with a significant separation distance between GNSS antenna and receiver. For those cases a maximum distance of 30m low loss (**12dB** attenuation maximum) cable may be used to connect the units. Passive antennas may not be applicable for such cases and this option may only be suitable for short connections (cable loss **less** than **0.75 dB**) between antenna and receiver. For a passive case, the relevant specifications will include the antenna AND the cable attached for those specifications naturally applicable for those units. For active antennas the output port will be the applicable point of reference. The document will make the distinction between active passive antenna when appropriate, whereas certain specifications (those dealing with linear performance) can be satisfied by default by passive antennas. Certain specifications are only applicable for active antennas and others. This document is not intended to give any further guidance of what is a suitable (active or passive) configuration for the GNSS antenna and this will be task of the designer or installer.

3.1 FREQUENCY OF OPERATION

The antenna unit shall operate over the bands outlined in Table 3.

The frequency of operation is defined in terms of the 3dB points of the total antenna response.

	Central frequency (MHz)	Lower frequency limit (MHz)	Upper frequency limit (MHz)	Bandwidth (MHz)
E5a-Gallileo	1176.45	1166.45	1186.45	20
E5b-Galilleo	1207.14	1197.14	1211.14	14
E1 Galileo	1575.42	1563.144	1587.696	24.552
L5 GPS	1176.45	1164.22	1188.68	24
L1 GPS	1575.42	1565.19	1585.65	20.46

Table 3: GNSS Bands

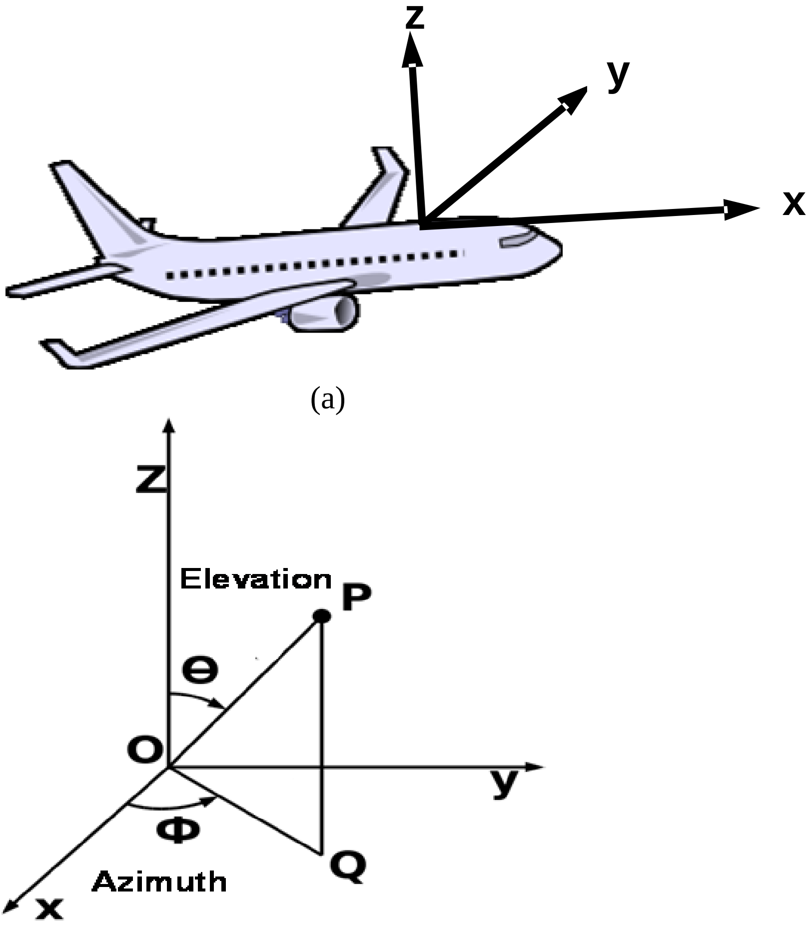
3.2 ANTENNA UNIT OUTPUT RETURN LOSS AND IMPEDANCE

The GNSS antenna should provide at the output port with a Return Loss of no more -14 dB (1.5:1 VSWR) referred to 50 Ohm impedance throughout the bandwidths of the GNSS bands outlined in Table 3. This cannot degrade more to -10 dB (2:1 VSWR) when 12 mm of ice is accumulated over the antenna.

3.3 ANTENNA UNIT RADIATION PATTERNS

The antenna radiation patterns shall refer to a coordinate system depicted in Figure 2 a-b. The definition of azimuth and elevation angles is also denoted. These are the angles traditionally defined in conjunction with radiation patterns in antenna engineering. The antenna is assumed to be placed at the origin of the coordinate system O (Figure 2 b).

The GNSS antenna quantity defined is the <u>relative radiation pattern</u> that is the radiation pattern normalised to its <u>peak value</u> expressed in dB. The peak normalisation reference value is the maximum value based on all available of azimuthal cuts restricted within an elevation angle cone of 15° from zenith.



(a)

(b)

Figure 2: Coordinate systems for radiation patterns

It is assumed that the radiation patterns are measured with an increment of a maximum of 1° in elevation and a maximum of 3° in azimuth.

It is also assumed that the antenna to be measured is mounted over a circular shaped ground plane of diameter at least 1200mm with a diffraction reduction treatment beyond its rim. Such treatment may be implemented with a rolled section with a diameter of at least 100mm.

The relative radiation pattern measured at the GNSS band centres (Table 3) shall comply with the maximum and minimum Gain templates described in Table 4. These templates are assumed to form in a linear piecewise fashion with break points defined by the values of Table 4 as shown graphically in Figure 3.

Elevation Angle (degrees)	Minimum (dB)	Maximum (dB)
-90	-10	-7
-85	-8.5	-5
-80	-7	-3
-75	-5.5	-1
-60	-3.5	-0.75
-15	-2.5	0
15	-2.5	0
60	-3.5	-0.75
75	-5.5	-1
80	-7	-3
85	-8.5	-5
90	-10	-7

Table 4: Relative Radiation Pattern template

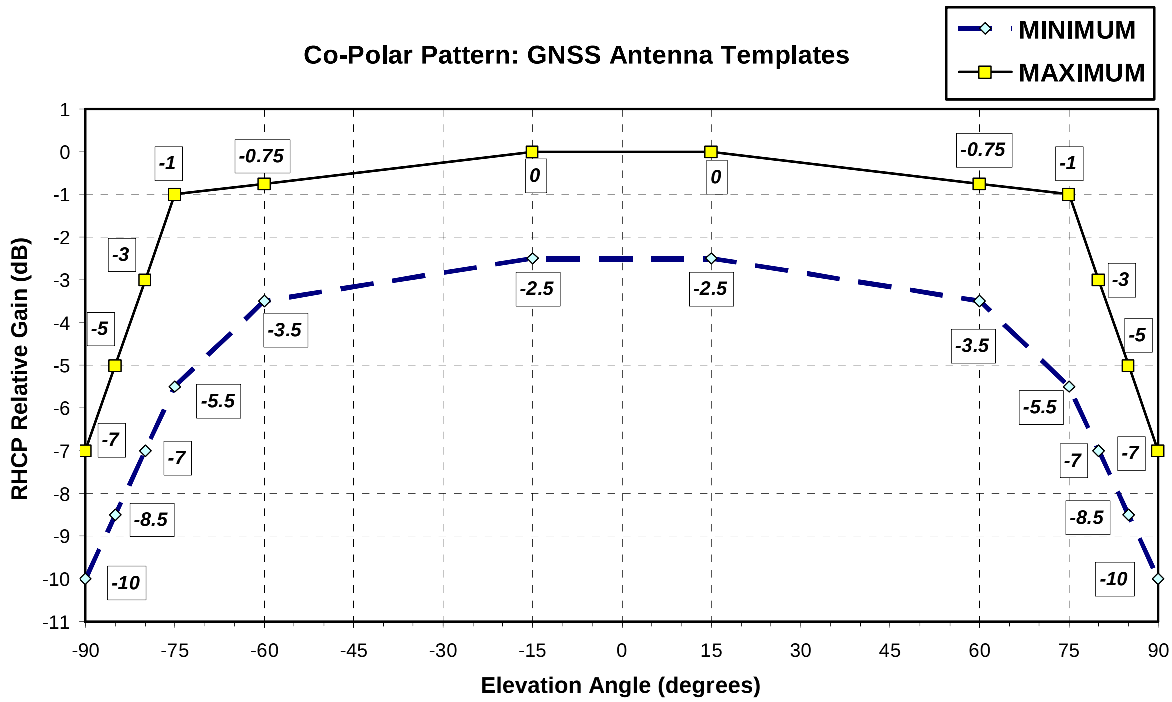


Figure 3: Relative Radiation Pattern template

<u>Note 1</u>: Small deviations may still be considered acceptable provided that their magnitude does not exceed the 1 dB and the percentage of the angular regions of deviation do not exceed the 5% of total angular directions measured taking into account the above guidance for the elevation-azimuth grid of points.

<u>Note 2</u>: The relative antenna Gains shall not vary by more than 1 dB taking into account the full operational temperature range.

<u>Note 3</u>: The defined relative template is compatible with a Gain value of -5.5 dBi for the embedded passive antenna at 85° from boresight.

3.4 POLARISATION

The antenna shall receive a nominally Right Hand Circularly Polarised wave and its polarisation purity will be defined by an Axial ratio at bore sight that should be 3dB or better.

3.5 ANTENNA SENSITIVITY: THE G/T RATIO

The antenna, irrespective of its implementation, shall ensure delivery of a minimum acceptable C/No GNSS signal to the receiver.

The quantity for ensuring this (as used traditionally with other satellite communication systems) is the G/T.

The GNSS antenna has to demonstrate that its G/T value is at least -33 dBK^{-1} for all elevation angles θ when: $0° \leq \theta \leq 85°$ and for all frequencies within f_C±8MHz; with f_C the band centres as defined in Table 3.

Note 1 Compliance to the minimum G/T figure quoted has to be unequivocal including all operational temperatures.

Note 2: Demonstration of the G/T performance can be achieved either by measuring the G/T directly or its constituent parts G and T.

Note 3: The G/T requirement is equally applicable both to passive and active antennas with the former as already indicated including any attached cables.

3.6 TRANSDUCER GAIN

The transducer gain is a term containing both and inseparably the passive antenna gain and the gain of the preamplifier.

The specification here deals only with the active GNSS antennas. Its purpose is to ensure the quality of the delivered GNSS signal to the receiver when both are connected with a long length of cable.

The quantity specified here refers to the peak value of the transducer gain over the bandwidth of the respective GNSS bands defined in Table 3 and assuming the peak angular response. This value should be no less than 29 dBiC.

3.7 LINEARITY: BORESIGHT TRANSDUCER GAIN COMPRESSION POINT

This refers to active antenna configurations.

For the case of passive antennas the issue of nonlinear performance does not arise when most common materials are used.

This is a measure of the linearity of the active antenna performance and the definition is based on the input port 1 dB compression point traditionally defined in amplifier and receiver circuitry.

The 1 dB input compression power is referred to the **input** port of the associated preamplifier. The limits of acceptable performance can be seen in Table 5 or equivalently in Figure 4.

Frequency (MHz)	1dB Input Compression Point (dBm)
1000	23
1100	23
1160	-25
1215	-25
1278	23
1315	23
1525	-10

Frequency (MHz)	1dB Input Compression Point (dBm)
1557	-25
1593	-25
1610	-15
1625	8
1660	8
2000	20

Table 5: 1dB input compression point (list)

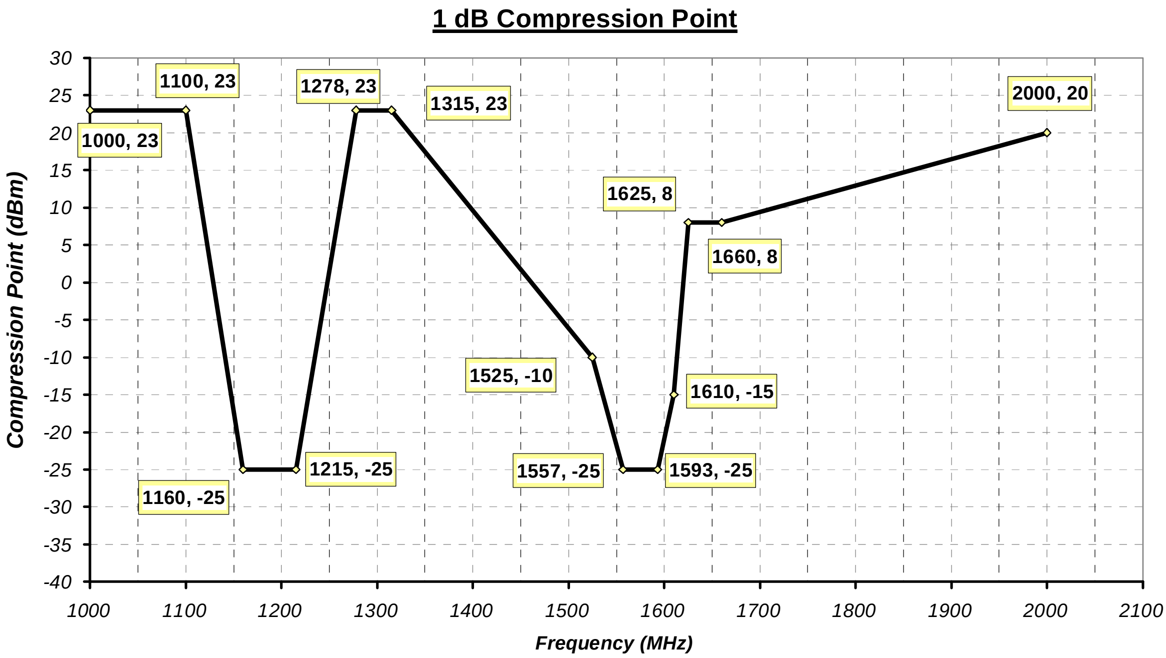


Figure 4: 1 dB compression point

*Note 1: In case of an integrated antenna the input preamplifier port may not be easily accessible or when a test point cannot be easily inserted the 1dB compression power points can be translated as an externally applied Electrical field (**E**) illuminating the full antenna assembly along a preselected direction.*

The formula for deriving the filed strength of the applied electrical filed producing the set power at the internal input of the preamplifier is:

$$E\left[dBV/m\right]=P_{IN}\left[dBm\right]-G_{p}\left[dBi\right]+20\log\left(f\ \left[GHz\right]\right)+17.21$$

Equation 1

With G_P the reference total Gain of the embedded passive antenna used. For active antennas compliant to the relative pattern template of ***Error! Reference source not found.*** *the value of -5.5 dBi at 85° degrees can be used to calculate the required impressed field corresponding to the 1 dB compression point limit.*

Scaling at any other direction is possible and permissible using the above formula and the measured relative pattern.

3.8 LOAD STABILITY

The active antenna shall be unconditionally stable for any passive load impedance.

3.9 RELATIVE FREQUENCY RESPONSE

The *Relative Frequency Response* (RFR) is defined as the Transducer Gain variation in dB at the boresight direction (Elevation angle $\theta=0°$) normalised to the peak response at the same direction taking into account the Transducer Gain values across the GNSS frequencies at the combined bands :

a) L5+E5A+E5B (**Error! Reference source not found.**)

b) L1+E1 (**Error! Reference source not found.**)

The normalisation is done separately for (a) and (b)

The purpose of the RFR is to ensure the operation of the GNSS receiving system mitigating adverse effects in the presence of the expected interference in avionics environment.

The RFR specification is dealing with:

- The case of an active GNSS antenna
- The case of a passive GNSS antenna having built in dedicated filtering functions in excess of the natural filtering occurring in the basic passive radiator

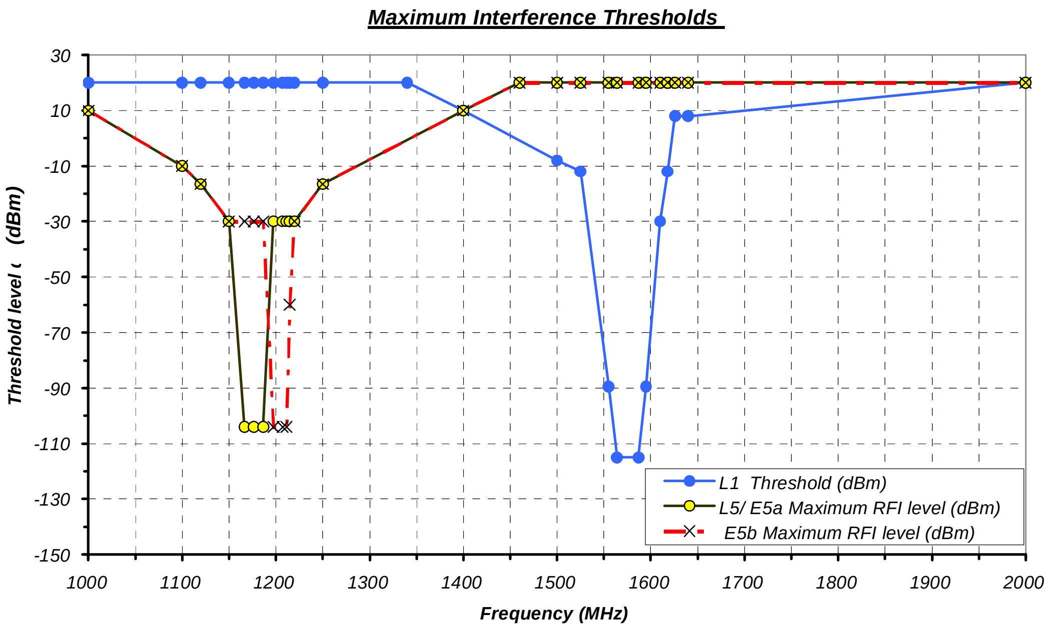


Figure 5: Interference Threshold for out of band interference

In the case of a simple passive antenna that does not employ any additional embedded filtering the full specification to be outlined here is not fully applicable. In this case however it is mandatory that the GNSS antenna-receiver installation or equipment combination to demonstrate performance compatibility and compliance with the maximum interference thresholds as they are presented in Figure 1 [RD7]. It is obvious that in this case the receiver should provide the main mitigation required.

3.9.1 Maximum Boresight frequency response limits

The maximum RFR limits for the GNSS antenna are defined in Table 6 and illustrated equivalently in Figure 6.

Frequency (MHz)	Selectivity (dB)
1000	-50
1100	-50
1160	0
1215	0
1278	-50

Frequency (MHz)	Selectivity (dB)
1400	-50
1504.42	-50
1554.42	-5
1558.42	0
1591.92	0
1605.42	-23.35
1625.42	-50
2000	-50

Table 6: Maximum Boresight RFR

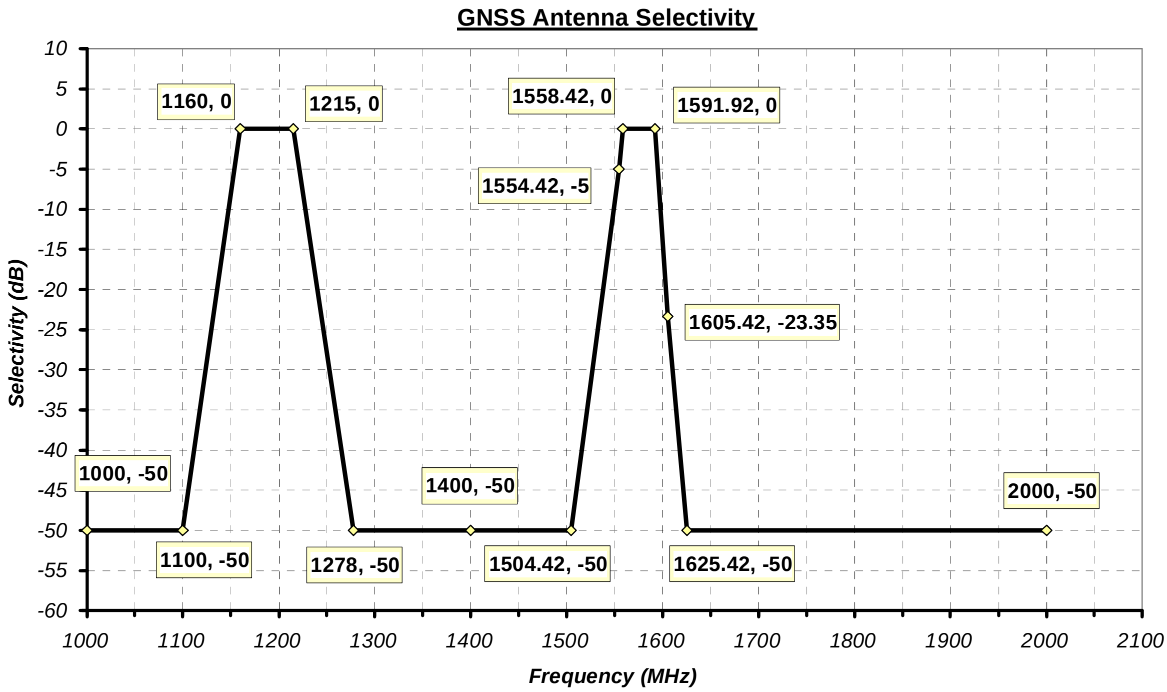


Figure 6: Boresight RFR –Antenna Selectivity

3.10 GROUP DELAY

3.10.1 Boresight Differential Group Delay (BDGD)

The Group delay in the present context deals with the behaviour of the phase pattern of the Copolar (RHCP) Transducer pattern.

If the transducer pattern (voltage or electric field terms) is denoted in complex form is expressed as:

$$\mathbf{E}(\theta, \phi, f) = \left\| E(\theta, \phi, f) \right\| \ \angle E(\theta, \phi, f)$$

θ: the Elevation angle

ϕ: the azimuth angle

f: t he Frequency (Hz)

The phase pattern is the angular part of it:

$$\Phi(\theta, \phi, f) = \angle E(\theta, \phi, f) \text{ In degrees}$$

The Group Delay is defined as:

$$\boxed{\delta\tau(\theta, \phi, f) = \frac{-1}{360} \frac{\partial \Phi(\theta, \phi, f)}{\partial f}} \text{ In seconds}$$

The *Boresight Differential Group Delay (BDGD)* is defined <u>individually</u> and <u>separately</u> for each of the Bands in Table 3 as:

$$\boxed{\Delta T_B = \max \left\| \delta\tau(\theta_B, \phi_B, f_i) - \delta\tau(\theta_B, \phi_B, f_j) \right\|}$$

Where:

θ_B, ϕ_B denote the boresight direction

And f_i, f_j any frequency within the individual bandwidth of the GNSS bands as defined in Table 3.

- The BDGD in any of the GNSS bands in consideration should be less than 25ns
- In the case of a simple passive antenna without any embedded additional filtering this quantity should not exceed the 2 ns.

Note 1: The requirement for a BDGD is equally applicable to active as well as passive GNSS antennas.

Note 2: The BFGD represents the combined effects of both the passive radiator as well as the built-in preamplifier or and included the embedded filtering functions.

3.10.2 Differential Group Delay versus Angle (DGA)

This is defined as:

$$\boxed{\Delta T_A = \max \left\| \mathrm{dt}\left(\mathrm{q}, \mathrm{f}_C, f_G\right) - \mathrm{dt}\left(85°, \mathrm{f}_C, f_G\right) \right\|}$$

With f_G the centre of each of the GNSS Bands (Table 3) individually addressed.

The above expression for the DGA is further calculated for every elevation angle θ within an azimuthal pattern cut f = f_C and for all the azimuthal angle subsets individually. It is assumed that the phase pattern is retrieved within an angular grid complying with the requirements outlined in the Relative pattern paragraph 3.3.

The requirements are that the DGA calculated for each GNSS band separately should not exceed the limit:

$$\boxed{\Delta T_A \le 3ns}$$

This limit is applicable to all values calculated individually from the azimuth cuts per GNSS band.

Note 1: The DGA quantity is affected solely by the intrinsic properties of the passive radiator.

Note 2: Compliance has to be demonstrated by both active as well as active configurations.

3.11 BURNOUT LIMIT

This specification is applicable only to active GNSS antennas.

In particular, this deals with the maximum CW carrier that the preamplifier can withstand.

The antenna preamplifier shall withstand a CW input carrier of + 20 dBm without damage. Under these conditions the output of the preamplifier shall be limited to +20dBm. The input carrier is referred to the notional or real output of the passive antenna radiator constituent of the antenna assembly.

For those cases where the passive radiator and the preamplifier are closely integrated, an alternative requirement can be formulated by translating the input power and thus specifying the externally impressed electric field producing the above stated output. The details are entirely analogous to the methodology outlined in Note 1 of paragraph 3.7.

Note 1: This requirement is applicable to in- band signals and transition band signals. Out-of band performance is warranted to comply by virtue of the compression point specifications (see Section.3.7)

3.12 RECOVERY TIME

This specification is applicable only to active GNSS antennas.

It deals with the delay of resuming normal operation after a strong spurious pulse signal is applied to the active antenna. The specification takes into account the realistic scenarios for these strong signals sources and at points makes explicit reference to them.

This refers to excitation powers at the real or notional output of the passive radiator component of the active antenna

For those cases where the passive radiator and the preamplifier are closely integrated, an alternative requirement can be formulated by translating the input power and thus specifying the externally impressed electric field producing the above stated power. The details are entirely analogous to the methodology outlined in Note 1 of paragraph 3.7.

3.12.1 In band maximum pulse input at L1+E1 Band

The GNSS active antenna shall resume normal operation within 10 µs of the trailing edge of a pulse with a width of up to 1ms and a peak power of 20 dBm and a duty cycle of 10 %.

3.12.2 In band maximum pulse input at L5+E5+E5B Band

The GNSS active antenna shall provide normal and unobstructed performance when a DME type pulse with peak power of no more than -60 dBm is received at the notional or real output of the embedded passive radiator.

For higher peak power DME-like pulse signals of up to 20 dBm, the GNSS antenna shall resume normal operation within 10 µs.

Main characteristics of ground and airborne DME are provided in Annex 1.

3.12.3 Out of band maximum pulse input

For higher peak power pulses than the one defined in Figure 1 and up to 20 dBm, the GNSS antenna shall resume normal operation within 1 µs.

3.13 DC INTERFACES

Any DC power that may be required shall be supplied directly through the coaxial RF output connector.

If required, the GNSS antenna shall operate with a DC input voltage anywhere within the range 4.5 -14.5 V and it shall draw no more than 200mA of current.

Note 1: The load capacitance of the central conductor of the RF coaxial output to any internal interfaces shall not exceed the 0.75 mF.

Note 2: The current allocation exceeds the legacy 60 mA specification on existing GPS only antenna installation as this reflects the increased complexity due to multiple bands and the demands for increased linearity.

4 ANTENNA PERFORMANCE - ENVIRONMENTAL CONDITIONS

The antenna is intended to operate satisfactorily and to withstand the environmental conditions encountered in Civilian Aviation. The Environmental conditions described here refers to testing at laboratory only level under conditions that are representative of the actual; operation.

Some of the tests described here are mandatory but others can only be performed if the manufacturer wishes to qualify the antenna under special conditions when he can seek an extended approval beyond the scope of current. In almost all cases here we refer to ‘before’ and ‘after’ environmental stress test and we rely on judgment and experience if a more detail ‘in operation’ test is to be performed

The prime guideline for the environmental test is the latest version of RTCA’s DO-160 [RD8]. Methods and conditions can also refer to this document.

Section No	Section Title	Category
4	Temperature & Altitude	F2
5	Temperature Variation	A
6	Humidity	B
7	Shock & Crash Safety	B
8	Vibration	C,L,Y
9	Explosion	X
10	Water-proof	S
11	Fluids	F
12	Sand & Dust	D
14	Salt Spray	S
15	Magnetic Fields	A
19	RF Conducted Susceptibility	ZC
20	Spurious RF	RR
21	Lightning	H

Section No	Section Title	Category
22	Lightning: Induced Effects	A3J33
23	Lightning: Direct Effects	1A
24	Icing	C
25	Electrostatic Discharge	A

Table 7: Environmental Test Conditions Summary - DO160 Reference

4.1 ENVIRONMENTAL TEST CONDITIONS

The GNSS antenna shall be subject to verification tests for the environmental conditions outlined in Table 7 assuming external environment

4.1.1 Temperature and Altitude

As specified in RTCA's DO-160. The following specified the various specific performance parameters that shall be tested. A before /after testing is assumed.

Alternative 'live' tests can also be acceptable subject to specific test implementation; here the minimum required is specified.

4.1.1.1 Operating Low – High Operating Temperature

The equipment shall be subject to the Low/High Temperature test as specified in DO-160 (sect 4.5) and compliance (before and after) shall be ensured on the following antenna performance parameters:

1. Return Loss of Active Antenna
2. Load Stability
3. 3dB Relative Response – Frequency of Operation
4. Transducer Gain
5. Bore sight Frequency Response
6. Relative patterns
7. G/T
8. Transducer Gain Compression Points

9. Differential Group Delay
10. Burn-out protection
11. Recovery time
12. DC power consumption limits

4.1.1.2 Altitude Test

The equipment shall be subject to the test conditions as specified in DO160 (Sec 4.6.10) and compliance (before and after) shall be ensured on the following antenna performance parameters:

1. Return Loss of Active Antenna
2. Load Stability
3. 3dB Relative Response – Frequency of Operation
4. Transducer Gain
5. Bore sight Frequency Response
6. Relative patterns
7. G/T
8. Transducer Gain Compression Points
9. Differential Group Delay
10. Burn-out protection
11. Recovery time
12. DC power consumption limits

4.1.2 Temperature variation

The equipment shall be subject to the test conditions as specified in DO160 (Sec 5) and compliance (before and after) shall be ensured on the following antenna performance parameters:

1. Return Loss of Active Antenna
2. Load Stability

3. 3dB Relative Response – Frequency of Operation
4. Transducer Gain
5. Bore sight Frequency Response
6. Relative patterns
7. G/T
8. Transducer Gain Compression Points
9. Differential Group Delay
10. Burn-out protection
11. Recovery time
12. DC power consumption limits

4.1.3 Humidity test

The equipment shall be subject to the test conditions as specified in DO160 (Sec 6) and compliance (before and after) shall be ensured on the following antenna performance parameters:

1. Return Loss of Active Antenna
2. Load Stability
3. 3dB Relative Response – Frequency of Operation
4. Transducer Gain
5. Bore sight Frequency Response
6. G/T
7. Transducer Gain Compression Points
8. Burn-out protection
9. Recovery time
10. DC power consumption limits

4.1.4 Shock test

The equipment shall be subject to the test conditions describe in DO160 for shock.(sections 7 and 8)

These to include Operational Shock, Vibration test as well as Crash safety check. Explosion test (DO160 Sec 9) is not required due to the civilian nature of the intended applications.

It is understood that crash safety test may irretrievably damage the antenna so not only this has to be performed the very last but the notion of specification compliance after test has no other meaning than that the antenna is still attached to its mounting

For all other conditions in shock test compliance (before and after) shall be ensured on the following antenna performance parameters:

1. Return Loss of Active Antenna
2. 3dB Relative Response – Frequency of Operation
3. Transducer Gain
4. Bore sight Frequency Response
5. Relative patterns
6. G/T
7. Transducer Gain Compression Points
8. Differential Group Delay
9. Burn-out protection
10. Recovery time
11. DC power consumption limits

4.1.5 Waterproofness test

The equipment shall be subject to the test conditions as specified in DO160 (Sec 10.3) and compliance (before and after) shall be ensured (spray directed during test perpendicular to the main antenna body – or other designated vulnerable parts –seals, attachments etc) on the following antenna performance parameters:

1. Return Loss of Active Antenna
2. Load Stability

3. 3dB Relative Response – Frequency of Operation
4. Transducer Gain
5. Bore sight Frequency Response
6. Relative patterns
7. G/T
8. Transducer Gain Compression Points
9. Differential Group Delay
10. Burn-out protection
11. Recovery time
12. DC power consumption limits

4.1.6 Fluid Susceptibility test

The equipment shall be subject to both spray as well as immersion test conditions as specified in DO160 (Sec 11.4.1 and 11.4.2) and compliance (before and after testing assuming thereafter 2 hours of ambient temperature and conditions following the 160 h exposure at elevated temperature) shall be ensured (spray directed during test perpendicular to the main antenna body – or other designated vulnerable parts –seals, attachments etc) on the following antenna performance parameters:

1. Return Loss of Active Antenna
2. Load Stability
3. 3dB Relative Response – Frequency of Operation
4. Transducer Gain
5. Bore sight Frequency Response
6. Relative patterns
7. G/T
8. Transducer Gain Compression Points
9. Differential Group Delay
10. Burn-out protection
11. Recovery time

12. DC power consumption limits

During the 24h exposure period of the main test the equipment still has to operate at a level indicating no failure of its components or parts

4.1.7 Sand and Dust test

The equipment shall be subject to the test conditions as specified in DO160 (Sec 12) and compliance (before and after) shall be ensured on the following antenna performance parameters:

1. Return Loss of Active Antenna
2. 3dB Relative Response – Frequency of Operation
3. Transducer Gain
4. Bore sight Frequency Response
5. Relative patterns
6. G/T
7. Differential Group Delay

4.1.8 Salt spray test

The equipment shall be subject to the test conditions as specified in DO160 (Sec 14) and compliance (before and after) shall be ensured on the following antenna performance parameters:

1. Return Loss of Active Antenna
2. 3dB Relative Response – Frequency of Operation
3. Transducer Gain
4. Bore sight Frequency Response
5. Relative patterns
6. G/T
7. Differential Group Delay

4.1.9 Magnetic effects

The equipment shall be subject to the test conditions as specified in DO160 (Sec 15) and its magnetic effects should be compliant with the magnetic class designated:

4.1.10 Induced susceptibility

The equipment shall be subject to the test conditions as specified in DO160 (Sec 19)

Whenever an external magnetic field needs to be applied this has to be from under the active antenna.

The induced signals specified in testing need only applied to the coaxial cable connected to the TNC coaxial terminal of the unit

Compliance (during test) shall be ensured on the following antenna performance parameters:

1. Return Loss of Active Antenna
2. Transducer Gain

4.1.11 Radio Frequency susceptibility test

The equipment shall be subject to the test conditions as specified in DO160 (Sec 20)

This includes both *Radiated* as well as *Conducted* susceptibility performance of the unit over the frequency range 1-2 GHz following power level as in Figure 1.

Wherever applicable power values can be converted to impressed field strengths using Equation 1 if needed

Compliance) shall be ensured on the following antenna performance parameters in case of *conducted susceptibility*:

1. Return Loss of Active Antenna
2. Transducer Gain

In case of *radiated susceptibility* the performance observed should be compliant with:

1. Transducer Gain Compression Points
2. Burn-out protection
3. Recovery time

4.1.12 Emissions of radio Frequency Energy

The equipment shall be subject to the test conditions as specified in DO160 (Sec 21) and its magnetic effects should be compliant with the requirements specified there!

4.1.13 Susceptibility test for lightning induced transients

The equipment shall be subject to the test conditions as specified in DO160 (Sec 22) and compliance (before and after) shall be ensured on the following antenna performance parameters:

1. Return Loss of Active Antenna
2. Load Stability
3. 3dB Relative Response – Frequency of Operation
4. Transducer Gain
5. Bore sight Frequency Response
6. Relative patterns
7. G/T
8. Transducer Gain Compression Points
9. Differential Group Delay
10. Burn-out protection
11. Recovery time
12. DC power consumption limits

4.1.14 Direct lighting effects tests

The equipment shall be subject to the test conditions as specified in DO160 (Sec 23) and compliance (before and after) shall be ensured on the following antenna performance parameters:

1. Return Loss of Active Antenna
2. Load Stability
3. 3dB Relative Response – Frequency of Operation
4. Transducer Gain

5. Bore sight Frequency Response
6. Relative patterns
7. G/T
8. Transducer Gain Compression Points
9. Differential Group Delay
10. Burn-out protection
11. Recovery time
12. DC power consumption limits

4.1.15 Icing effects tests

The equipment shall be subject to the test conditions as specified in DO160 (Sec 24) and compliance shall be ensured on the following antenna performance parameters:

1. Return Loss of Active Antenna
2. Relative patterns
3. G/T
4. Transducer Gain Compression Points

4.1.16 Electrostatic discharge effects tests

The equipment shall be subject to the test conditions as specified in DO160 (Sec 25) and compliance (before and after) shall be ensured on the following antenna performance parameters:

1. Return Loss of Active Antenna
2. Load Stability
3. 3dB Relative Response – Frequency of Operation
4. Transducer Gain
5. Bore sight Frequency Response
6. G/T
7. Transducer Gain Compression Points

8. Differential Group Delay
9. Burn-out protection
10. Recovery time
11. DC power consumption limits

5 INSTALLED ANTENNA PERFORMANCE

While the present MOPS deals with specifications verifiable by standard RF Laboratory test procedures, the scope and detail of specifications aims directly of ensuring the set out performance on full operational deployment.

Demonstration compliance in this context may be achieved by both direct measurements of the installed GNSS assembly (when feasible) and detailed modelling (including both theoretical simulations and hardware models) but highly representative exercises (particularly on quantities related to the antenna pattern) including a realistic model of the airframe used.

It is understood that deployment may cause slight and unavoidable degradations that are airframe specific. It is however the duty of the installer or Airframe- GNSS system integrator to quantify probable deviations (if any) and justify the offered performance in the wider GNSS system operational concept taking into account all relevant equipment/System MOPS.

ANNEX 1

A1.1 DME/TACAN ground beacons

Frequency (MHz)	Angle of arrival (°)	Power at antenna input (dBW)	Typical Maximum Pulse repetition frequency (ppps)	Frequency (MHz)	Angle of arrival (°)	Power at antenna input (dBW)	Typical Maximum Pulse repetition frequency (ppps)	Frequency (MHz)	Angle of arrival (°)	Power at antenna input (dBW)	Typical Maximum Pulse repetition frequency (ppps)
1156	-3.6	-116.3	3600	1177	-1.5	-109.7	2700	1192	-3.7	-100.2	2700
1156	-4.8	-113.8	3600	1177	-2.3	-104.1	2700	1192	-2.0	-109.7	3600
1156	-3.5	-116.6	3600	1178	-1.8	-116.5	2700	1193	-3.0	-111.9	2700
1156	-2.7	-118.7	3600	1178	-2.6	-105.1	2700	1193	-14.4	-108.6	2700
1157	-1.8	-106.3	2700	1178	-3.2	-101.5	2700	1193	-2.6	-101.3	3600
1157	-2.4	-103.6	2700	1179	-2.6	-113.1	2700	1194	-2.1	-104.1	3600
1157	-1.8	-108.0	3600	1179	-7.5	-108.2	3600	1194	-2.5	-113.5	2700
1158	-1.8	-108.4	2700	1179	-4.1	-109.2	2700	1195	-1.6	-109.5	2700
1159	-3.0	-111.8	2700	1180	-2.0	-111.3	2700	1195	-3.8	-99.1	3600
1159	-3.8	-98.8	3600	1180	-2.6	-113.1	2700	1196	-3.6	-99.5	3600
1160	-1.9	-107.9	2700	1180	-4.1	-109.3	2700	1197	-1.7	-109.1	2700
1160	-2.4	-113.9	2700	1181	-2.6	-113.1	2700	1197	-5.3	-109.2	2700
1160	-1.6	-106.1	3600	1181	-2.6	-100.3	3600	1198	-2.0	-109.6	3600
1161	-3.5	-100.5	2700	1181	-4.1	-109.3	2700	1200	-1.6	-111.6	2700
1162	-2.7	-104.8	2700	1181	-1.6	-111.3	3600	1201	-10.4	-98.5	3600
1162	-2.9	-104.2	2700	1182	-23	-103.2	3600	1201	-1.5	-109.8	2700
1163	-1.9	-105.7	2700	1182	-3.9	-99.8	2700	1202	-2.2	-109.9	3600
1164	-5.3	-106.0	3600	1182	-4.3	-100.9	2700	1203	-2.0	-105.4	2700
1165	-2.6	-109.0	2700	1183	-1.9	-111.8	2700	1203	-2.7	-113.1	2700
1165	-1.8	-105.4	3600	1183	-1.7	-112.6	2700	1203	-2.7	-102.0	3600
1165	-4.1	-109.2	2700	1183	-4.2	-99.2	2700	1203	-2.0	-107.6	2700
1166	-1.7	-105.6	3600	1184	-1.8	-108.3	2700	1204	-2.2	-106.9	2700
1166	-2.1	-106.9	2700	1184	-2.5	-102.6	3600	1204	-4.0	-96.6	3600
1167	-1.6	-109.3	2700	1184	-1.9	-110.0	3600	1205	-4.9	-96.9	3600
1167	-1.7	-105.7	2700	1185	-1.8	-106.4	2700	1206	-2.4	-103.0	3600
1168	-4.8	-97.0	3600	1186	-2.1	-105.1	2700	1206	-2.3	-108.5	3600
1169	-1.6	-111.2	2700	1186	-2.8	-102.5	2700	1207	-2.6	-103.5	2700
1169	-1.9	-107.7	2700	1187	-2.8	-112.5	2700	1207	-1.7	-110.0	2700
1169	-2.6	-113.0	2700	1187	-2.6	-113.1	2700	1208	-1.9	-112.2	2700
1169	-1.8	-105.4	3600	1187	-3.6	-99.5	3600	1209	-1.7	-117.0	2700
1169	-1.6	-106.5	3600	1187	-4.1	-109.3	2700	1210	-1.9	-108.3	2700
1170	-3.7	-99.2	3600	1188	-2.0	-115.3	2700	1210	-3.7	-102.4	2700
1170	-2.5	-102.5	3600	1188	-2.1	-115.0	2700	1210	-1.6	-109.6	2700
1171	-4.8	-98.0	2700	1188	-4.3	-100.9	2700	1211	-1.8	-106.4	2700
1172	-2.0	-109.5	2700	1188	-4.1	-109.4	2700	1211	-17.0	-101.4	2700
1172	-2.1	-108.8	3600	1190	-3.0	-100.9	2700	1212	-5.3	-106.4	3600
1174	-1.8	-105.2	3600	1191	-2.0	-117.4	2700	1212	-1.9	-108.2	2700
1175	-1.8	-105.4	3600	1191	-3.0	-105.2	2700	1213	-2.3	-103.6	3600
1175	-12.0	-108.1	3600	1191	-3.8	-110.1	2700	1213	-2.9	-101.6	3600
1176	-15.3	-99.0	3600	1192	-1.8	-116.5	2700				

A1.2 On board DME interrogator

The closest on-board DME channel to the E5/L5 band is 126X/Y, which has a centre frequency of 1150 MHz. This channel has a distance of 16 MHz to the band edge of the E5/L5 band at 1166 MHz, and a distance of 26.45 MHz to the carrier frequency of E5A/L5 of 1176.45 MHz. Except during acquisition, the maximum rate at which an airborne DME interrogator can generate pulse pairs is assumed to be 48 pulse pairs per second. During acquisition, DME interrogators employ higher transmission rates, as high as 150 pulse pairs per second, for brief intervals.

The performance specifications for interrogators EUROCAE ED-54 and RTCA DO-189 limit their peak power to 2 KW (63 dBm). The peak power in any 0.5 MHz bandwidth channel more than 2 MHz from the channel on which the airborne interrogator is transmitting is required to be at least 38 dB below that (63 dBm – 38 dB = 25 dBm). This results in a peak level of -15 dBm for an assumed isolation between antenna ports of E5/L5 and DME antennas of 40 dB.

A1.3 System performance evaluation

This document introduces composite performance figures to describe the sensitivity and radiation performance namely

- Relative radiation pattern
- The G/T

We can demonstrate that these quantities alone can be used to evaluate the crucial system performance measure that is the composite C/NI quantity, namely the ratio o *signal to noise plus interference* (if present).

This can readily be found using the following expression described at large only using those terms included in MOPS:

:

$$\boxed{\frac{C}{NI} = \left(\frac{N^{th}}{C} + \frac{N^{\text{int}}}{C}\right)^{-1} = \left(\left(\frac{k}{SIS} \times \left(\frac{G^{sig}}{T}\right)^{-1}\right) + \sum_n \left(\left(\frac{G_n^{\text{int}}}{G^{sig}}\right) \times \frac{P_n^{\text{int}}}{SIS}\right)\right)^{-1}}$$

Where:

SIS The Signal power in space

N^{th}, N^{int} The thermal and composite interference signal power

k The Boltzman's constant

G^{sig} /T The **G/T** ratio towards the GNSS signal SV

$\left(\frac{G_n^{\text{int}}}{G^{sig}}\right)$ The **relative pattern** towards the n-th interfering source and GNSS signal respectively

P_n^{int} The power of the n-th interfering signal

Hence as said the true Minimum attainable GNSS system performance specification can be based upon the quantities selected and provide all information required for the deduction of its state.