European Radiocommunications Committee (ERC)
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COMPATIBILITY BETWEEN MSS (SPACE-TO-EARTH) IN THE BAND 1559 - 1567 MHz AND ARNS/RNSS INCLUDING GNSS IN THE BAND 1559 - 1610 MHz

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**COMPATIBILITY BETWEEN
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ARNS/RNSS INCLUDING GNSS IN THE BAND 1559 - 1610 MHz**

1 INTRODUCTION

ITU Resolution 220 (WRC-97) “requests the ITU to study the technical criteria and operational and safety requirements to determine if sharing between the aeronautical radionavigation and radionavigation-satellite services operating, or planned to operate in the band 1559 - 1610 MHz, and the mobile-satellite service in a portion of the 1559 - 1567 MHz frequency range, is feasible”.

GPS and GLONASS are established RNSS systems operating in the 1559 - 1610 MHz band. These systems are widely used with a range of different applications. In particular, it should be noted that these systems are already used for safety-of-life applications.

In addition to GPS and GLONASS plans have been published for second-generation RNSS systems, among others by ESA as E-NSS-1 and by France as LSATNAV (known as INES). Also, plans for terrestrial, GPS-like transmissions from so-called pseudolites are being discussed.

This report presents studies on the compatibility between proposed MSS (space-to-Earth) in the 1559 - 1567 MHz band and GPS, GLONASS, E-NSS-1, LSATNAV and pseudolites in the 1559 - 1610 MHz band.

2 MSS SYSTEMS

Various types of MSS services can be provided with a range of PFD levels. The required PFD depends mainly on modulation and access technique, MES receiver G/T and required link margin. For example, TDMA systems using QPSK modulation and providing service to handheld terminals require PFD levels of up to around -100 dB (W/m^2/MHz). Other types of MSS services could be operated at lower PFDs using MES terminals with some antenna directivity. In particular, it is estimated that a range of viable MSS services can be implemented at a PFD of around -112 dB(W/m^2/MHz). Broadband services, for example as part of the UMTS, would have to be provided through MES terminals with some antenna gain, due to the increased MES EIRP requirements. Some types of vehicular applications also use MES terminals with some directivity. In addition, various types of semi-fixed and fixed applications using directional antennas are provided today as extensions of the main-stream MSS services.

Thus, while a PFD-constrained MSS allocation would limit the range of applications and types of MSS systems that could be implemented, such an allocation would nevertheless benefit the MSS, especially if the band was used as a complement to other allocations.

Based on the discussion in **Annex 6**, the assumption should be that only one MSS system will be operating at a given frequency in a given coverage area.

3 RNSS SYSTEMS

The GPS system [1] uses the carrier frequency 1575.42 MHz which is modulated by two different codes, a Precision Code (P-Code) and a Coarse / Acquisition Code (C/A-Code). The chip rates of these codes are 10.23 Mchip/s and 1.023 Mchip/s respectively, corresponding to 3 dB bandwidths of approximately ±4.5 MHz and 0.45 MHz respectively. As the analysis in **Annex 1** shows, significant discrimination would therefore be available between GPS and a MSS allocation in the band 1559 - 1567 MHz. The calculations in **Annex 1**, of interference from the MSS into the GPS system, were based on the GPS interference protection requirements defined in Recommendation ITU-R M.1088 [2].

The GLONASS-M [3] frequency plan will have three stages of development. The lowest carrier frequency used will be 1598.0625 MHz (as of stage 2). GLONASS-M uses P- and C/A-Code chip rates of 5.11 and 0.511 Mchip/s respectively. Thus, it will be fair to assume that if GPS is protected, GLONASS would also be protected, since the frequency separation from the proposed MSS allocation to GLONASS is greater than to GPS. The increased discrimination from larger frequency separation would offset the differences due to more stringent protection requirements for GLONASS.

The European Space Agency, ESA, with the support of the European Commission and of user groups including Eurocontrol, is planning a second-generation RNSS network which has been advance published by ITU under the name E-NSS-1, which would use the bands 1559 - 1563 MHz and 1588 - 1592 MHz [4]. The parameters of this system were used as an example of a possible future RNSS system for the assessment of the co-frequency sharing feasibility.

CNES, the French Space Agency, and Alcatel are currently studying the implementation of a second-generation RNSS system. Alcatel, under contract from the European Commission, is planning this RNSS system, known as INES (Innovative Navigation European System), which has been advance published by ITU under the name of LSATNAV [5]. This system would also use the frequency bands 1559 - 1563 MHz and 1588 - 1592 MHz.

4 SCENARIOS

Five scenarios are analysed:

1) Interference from MSS into GPS (See Annex 1)
2) Interference from MSS into E-NSS-1 (See Annex 2)
3) Interference from MSS into LSATNAV (See Annex 3)
4) Interference from E-NSS-1 into MSS (See Annex 4)
5) Interference from MSS into pseudolites (See Annex 5)

In addition, considerations of the mutual interference between MSS and E-NSS-1 are included in **Annex 2** and a justification for the assumption that only one MSS network will be received in any place in any part of the frequency spectrum is given in **Annex 6**.

5 SUMMARY OF RESULTS

5.1 Interference from MSS into GPS

The single entry interference power flux density limit to protect existing GPS receivers against a MSS signal in a portion of the band 1559 - 1567 MHz is dependent on the proportion of the band used and the GPS receiver type against which this is being assessed.

Five scenarios are developed in **Annex 1**, all assuming that one fourth of the interference allowance is allocated to the MSS. The worst case found is for existing GPS receivers using the C/A-Code for civil aviation. The power flux density (PFD) limit needed to protect these systems from a MSS signal in the band 1559 - 1567 MHz is -114 dB (W/m^2) in any 1 MHz.

This figure is based on the ICAO assumption that the worst-case RNSS receiver antenna may have a peak gain of +7 dBi and a minimum gain, at 85° off axis, of –4.5 dBi. The feasibility of such an antenna has been questioned. Calculations based on an alternative antenna, characterised by a +3 dBi maximum gain, relax the PFD limit to –110 dB (W/m^2) in any 1 MHz.
In the future though, enhancements and additional frequencies are being offered to the civil community. One of these frequencies is likely to be 1565.19 MHz. In this instance, a MSS signal in the band 1559 - 1567 MHz will overlay this signal. In this case a PFD limit of -139.5 dB (W/m^2) in any 1 MHz is required to protect the new GPS frequency. If the MSS band is reduced to only 4 MHz, i.e. 1559 - 1563 MHz, the required PFD limit would be -121.8 dB (W/m^2) in any 1 MHz.

There was also concern that these PFD levels correspond to a tolerable increase of noise of only about 2%, which implies that GPS is much more sensitive to interference than either E-NSS-1 or LSATNAV.

Annex 1 derives the maximum PFD limits that need to be applied to MSS signals to protect the use of GPS and to allow the satisfactory development of its various applications. However, it has been assumed that the spectra of transmitted MSS signals may be considered as approximating to gaussian white noise. Further study would be required to determine the interference effect if the actual modulations used are such that this assumption is not tenable.

In addition the ITU defines PFD in three different ways, as an absolute limit, as an aggregate limit and as an effective limit. The latter two relate to the operation of non-GSO satellite systems. However, the interference from the proposed GSO MSS systems into the RNSS is static, so that the PFD limits derived in **Annex 1** have no statistical element and no reduction in PFD levels can be considered.

5.2 Interference from MSS into E-NSS-1

Annex 2 shows that the current design of E-NSS-1, based on a transmitter with 80 W output power and an optimised Earth-coverage antenna, there is a 3 dB margin between the carrier to (thermal plus intra-system) noise, C/No+Po, of 44.3 dBHz and the required overall C/No (= C/No+Po+Io) of 41.2 dBHz. On this basis, the maximum tolerable single-entry interference power spectral density at the output of the antenna of an E-NSS-1 receiver is -207.3 dB (W/Hz), which corresponds to a maximum power flux density limit for a geostationary MSS satellite of -125 dB (W/m²) in any 1 MHz and to a tolerable noise increase of 27%.

This limit is based on the assurance (supported by **Annex 6**) that only one satellite could be visible in any part of the frequency band from any RNSS receiver, and on the assumptions that one fourth of the interference allowance is allocated to the MSS and that the MSS signal can be approximated as additive gaussian white noise.

It has been suggested that E-NSS-1 could overcome the interference from the proposed MSS networks by increasing its satellite transmitter power. **Annex 2** shows that the imposition of MSS (at the stated operating power flux density of -112 dB (W/m²) in each 1 MHz) in the band 1559 - 1567 MHz would cause the maximum tolerable interference to E-NSS-1 to be exceeded by 5.4 dB and that increasing the E-NSS-1 transmitter power to the point where the negative margin caused by the MSS network is been balanced out would require an increase in transmitter power from 80 watts to 310 watts (which, it should be recalled, can not be achieved using current predictions of technological capability).

Moreover, as is discussed in Section 5.4 below, **Annex 2** also shows that this increased E-NSS-1 transmitter power would appear to decrease the operating margin of the MSS networks by 4 dB.

5.3 Interference from MSS into LSATNAV

Annex 3 presents analysis of the tolerable interference into LSATNAV based on degradation of noise by the MSS system in the LSATNAV receiver. The MSS PFD limits corresponding to noise degradations of 6% (0.25 dB) and 25% (1 dB) are respectively -135.4 dB (W/m²) and -129.0 dB (W/m²) in any 1 MHz.

However, as sharing between MSS systems on a co-frequency and co-coverage basis is not practical, regulatory provisions should be adopted in order to preclude this (for instance a footnote stating that sharing between MSS systems in 1559 - 1567 MHz should only be permitted on a band segmentation basis). The PFD limit obtained for 25% of noise degradation would then correspond to the contribution of a single MSS system.

With this limitation, the introduction of a new allocation to MSS in the Space-to-Earth direction in the 1559 - 1567 MHz band would be compatible with the planned LSATNAV system under the condition that a maximum PFD level of -129 dB (W/m²) in any 1 MHz be respected by each MSS network.

5.4 Interference from E-NSS-1 into MSS

The analysis of mutual interference between MSS and RNSS networks presented in **Annex 2** shows that the penalty to the MSS network of band sharing exceeds 3 dB if the planned characteristics of E-NSS-1 are used and exceeds 7 dB if the transmitter power of E-NSS-1 is augmented to overcome the interference from the MSS network.

However, **Annex 4** shows that it is nevertheless possible to design a mobile-satellite system which would operate satisfactorily in the presence of co-frequency interference generated by the E-NSS-1 system, even if the E-NSS-1 power is augmented in order to overcome the MSS interference, if the mobile earth station (MES) is equipped with a directional receiving antenna having a gain of some 12.5 dBi and uses robust modulation and coding techniques, such as QPSK modulation and 1/2-rate convolutional forward-error-correction (FEC) coding.

5.5 Interference from MSS into pseudolites

Annex 5 presents an analysis of the possible interference from MSS networks into pseudolites at 1561.19 MHz. Assuming that the signal level received by the RNSS receiver would be similar to that received from GPS satellites, it is calculated that a PFD limit between -121.6 and -125.4 dB (W/m²) in any 1 MHz would be needed.

However, it may be assumed that the pseudolites will need to transmit at higher powers than satellites at the equivalent range. Airborne receivers of pseudolites are expected to use the same antennas as for satellites, so will see the pseudolites with low gain at negative elevation angles. Land-based receivers will see the pseudolites with increased path losses due to terrain obstruction. Being ground-based, higher pseudolite transmitter powers will be practicable. As a consequence, the interference into MSS receivers (MES) from pseudolites may be significantly higher than from navigation satellites. However, this is a localised problem.

6 DISCUSSION OF RESULTS

6.1 General Considerations of Band Sharing

Successful sharing requires the loss of orthogonality in frequency and thus depends on that availability of orthogonality in space or time. For example, MSS (space-to-Earth) shares successfully with FS because satellites operate when they are above the horizon while terrestrial stations are fixed to the Earth's surface. Also, RNSS shares successfully with certain radar systems because RNSS uses continuous signals while radar uses pulsed signals. Also, RNSS can support limited out-of-band interference from MSS (Earth-to-space) because the MSS MES have only a local effect on RNSS receivers.

The possibility of sharing between RNSS (space-to-Earth) and MSS (space-to-Earth) is not obvious because there is a lack of any orthogonality in space or time so that the interference of each system into the other is continuous and inescapable.

6.2 Sharing between proposed MSS and GPS

This Report confirms in principle the basic assumptions presented prior to WRC-97, that a MSS PFD limit in the band 1559 - 1567 MHz of -112 dB (W/m^2) in any 1 MHz would meet the basic interference criteria of GPS, assuming the current signal structure and the basic use of GPS as described in Recommendation ITU-R M.1088 [2] and assuming a reasonable model of the GPS antenna (see Section 5.1), and that a mobile-satellite system could, in principle, be conceived with directive MES antennas which could operate under such a constraint.

However, planned future enhancements of GPS for new satellite signals, within the current notified frequency bands, and for ground-based augmentation systems using pseudolites would require significantly better protection from any proposed MSS networks, with the MSS PFD limited to -139 dB (W/m^2) in any 1 MHz and would also be likely to cause aggravated interference into such MSS networks.

6.3 Sharing between proposed MSS and new proposed RNSS Networks

Sections 5.2 and 5.3 present estimates of the impact of the proposed new MSS allocation on new RNSS systems being planned with participation and support of major European partners, including the EC, ESA, CNES and Eurocontrol.

These new systems, E-NSS-1 and LSATNAV, would be able to tolerate sharing the band with MSS networks only with a PFD limit on MSS of around -125 dB (W/m^2) in any 1 MHz. The suggested MSS PFD of -112 dB (W/m^2) in any 1 MHz would impose severe design penalties on the RNSS networks, requiring increased transmitted power far beyond that currently planned.

It was shown that a MSS system, if suitably designed, could accept the aggravated interference caused by this increase in power.

It should be noted that other intermediate solutions can also be envisaged. For example, a MSS PFD of –115 dB (W/m^2) in any 1 MHz or -118 dB (W/m^2) in any 1 MHz could be accommodated by an E-NSS-1 power increase of 2 dB or 4 dB respectively.

Finally, it should be noted that the analyses make a number of idealistic assumptions and must therefore be considered as best but not entirely reliable estimates.

7 CONCLUSIONS

The current published ITU-R Recommendations on the use of the RNSS band 1559 - 1610 MHz would permit use of part of this band for a restricted MSS operation, using mobile earth stations with directional antennas. However, the planned augmentations of existing RNSS networks and the published plans for new RNSS networks would not be able to tolerate the interference which would be caused by such MSS networks.

References

[1] Global Positioning System: Theory and Applications; American Institute of Aeronautics and Astronautics, Inc; 1996
[2] Recommendation ITU-R M.1088: Considerations for Sharing with Systems of Other Services Operating in the Bands Allocated to the Radionavigation-Satellite Service; 1994
[3] Recommendation ITU-R M.1317: Considerations for sharing between systems of other services operating in bands allocated to the radionavigation-satellite and aeronautical radionavigation services and the Global Navigation Satellite System (GLONASS-M)
[4] E-NSS-1 : A Possible Configuration of GNSS 2: CEPT Document SE28(97)27 Rev 1, ESA, April 1997.
[5] LSATNAV System Description: CEPT Document SE28(98)76, CNES, May 1998.

ANNEX 1

Annex 1 Interference from MSS into GPS current and planned networks

A 1.1 Introduction

The purpose of this annex is to determine the maximum interference of a potential allocation to MSS systems in the band 1559 - 1567 MHz which could be tolerated by existing GPS P- and C/A-codes on 1575.42 MHz. Future developments in the band 1559 - 1610 MHz were also to be considered. For this annex these changes relate to the enhancement of the existing transmitted GPS signals and the addition of new frequencies and applications.

ITU Resolution 220 from WRC-97 called for this investigation to be completed by the next World Radio Conference.

A 1.2 Background

The use of GPS [1] has grown enormously since its release for civilian use. Manufacturers have subsequently identified various ways in which to increase its accuracy. To cover all these existing and known future enhancements this annex will consider the following aspects.

a) Interference from MSS in a portion of the band 1559 - 1567 MHz into C/A-code GPS receiver, at 1575.42 MHz; Acquisition mode considering Recommendation ITU-R M.1088 [2].
b) Interference from MSS in a portion of the band 1559 - 1567 MHz into a C/A-code GPS receiver at 1575.42 MHz; acquisition mode and increased accuracy from Space Based Augmentations systems.
c) Interference form MSS in a portion of the band 1559 - 1567 MHz into GPS receiver P-code at 1575.42 MHz tracking mode considering Recommendation ITU-R M.1088 [2]
d) Interference from MSS in a portion of the band 1559 - 1567 MHz into a GPS Receiver using codeless comparison techniques on the L1 1575.42 MHz and L2 1227.6 MHz Frequencies.
e) New applications for C/A-Code GPS receiver at frequency 1565.19 MHz, and the interference effects from MSS in a portion of the band 1559 - 1567 MHz.

A 1.3 GPS characteristics

Civil users of GPS Navstar access the Standard Positioning Service (SPS), specifically the Course Acquisition C/A-code transmitted on the GPS L1 frequency of 1575.42 MHz. The resulting L1 SPS GPS frequency spectrum for the L1 signal has a sincx-squared function with a 2.046 MHz bandwidth to the first spectral null, Figure A 1-1. Several of the sidebands of the C/A-code are also transmitted as the bandwidth of the filter in the GPS satellites is designed for the P-code. The wide bandwidth transmission enables the sidelobes on the C/A-code to be used in the receiver to enhance the accuracy of the C/A-code measurements and provide a means of rejecting multipath.

The present GPS constellation has 24 satellites in operation. To enhance accuracy requirements a 30-satellite constellation is being considered for the future. In addition two new GPS C/A frequency(s) will be authorised, one on 1227.6 MHz, the other will probably lie within the nulls of the military P-code i.e. at 1565.19 MHz and/or 1587.69 MHz, confirmation of the choice is planned to occur in August 1998. Later analysis in this annex will consider the affect of a MSS signal on a GPS or similar signal at 1565.19 MHz (assuming the same 1.023 MHz C/A-code transmission)

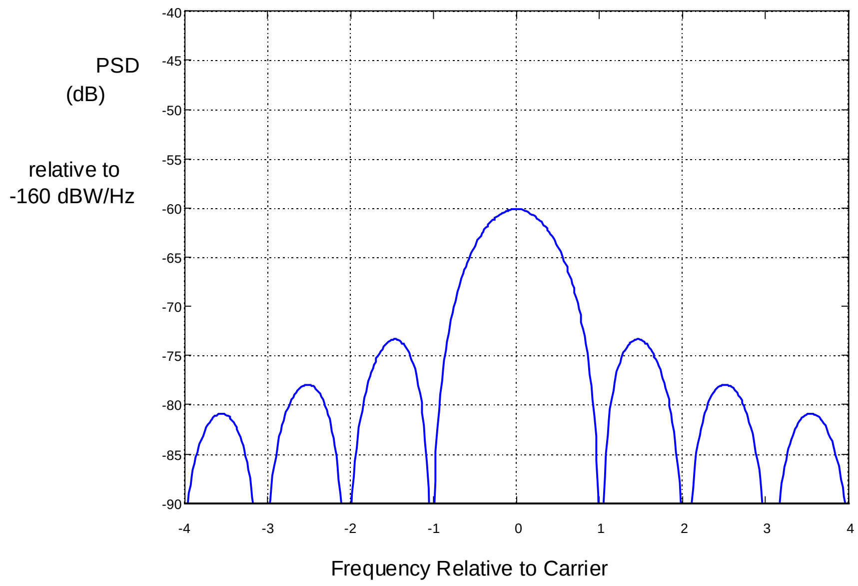


Figure A 1.1: Spectrum of GPS C/A-Code Signal

Recommendation ITU-R M.1088 [2] specifies characteristics of the GPS signals.

The minimum defined signal power of the Standard Positioning Signal SPS for C/A-code is -160 dBW from a 0 dBi gain antenna.

The minimum defined signal power of the Precision Positioning Signal PPS for P-code is -163 dBW from a 0 dBi gain antenna.

The maximum antenna gain towards the zenith (90°) is +7 dB and the minimum antenna gain towards 5° elevation is -4.5 dBi, in accordance with ICAO draft Standards and Recommends Practices (SARPs).

This annex also includes calculations based on GPS antenna gain of +3 dBi towards the zenith. Other applications of GPS, besides aviation, may require greater or lesser gains than +7 dBi.

The ITU-R provisional draft new recommendations (ITU-R Documents 8D/TEMP/24 and 8D/TEMP/25) define receivers, which provide augmentations to GPS signal. They are spaced based augmentation systems (SBAS) and ground based augmentation systems (GBAS). The standards are in line with those defined by ICAO. Recommendation ITU-R M.1088 [2] also specifies values for maximum interference to signal rejection ratios.

A 1.4 MSS signals

As discussed in Section A 2, a power flux density (PFD) of -112 dB(W/m^2/MHz) would allow a Mobile Earth Station (with directional gain) to operate with satellites at the GSO. This value is used as one parameter in this study. The signals considered are gaussian noise like. If MSS signals differ significantly from the assumed ideal white noise, then RNSS systems may require different PFD limits for MSS (s-E) signals.

A 1.5 Convolution of noise onto GPS receivers: Interference Mechanism

Within a GPS receiver, pseudo range measurements are calculated by correlating a received GPS signal against a receiver generated replica of the transmitted waveform. Interferences from other external sources are also correlated. Noise in the receiver code and carrier tracking loops is the result of the convolution of the interference with the replicated code spectrum.

The interference spectrum in the correlator, $I(f)$ is itself the convolution of the free space spectrum convoluted with the RF/IF filter shape and the sampling process in the receiver. At the output of the correlator, the noise power is the convolution of the input noise with the GNSS signal $Sgnss(f)$, equation 2.

The normalised power spectral densities of the GPS P- and C/A-codes can be described as follows

$$Sgnss(f) = T_c \frac{\sin^2(\pi f T_c)}{(\pi f T_c)^2} \qquad \text{(eq. 1)}$$

where $f_c = 1/T_c$ is the chip rate of the PRN code, i.e. $f_P = 1/T_P = 10.23 \cdot 10^6$ for the P-code or $f_{C/A} = 1/T_{C/A} = 1.023 \cdot 10^6$ for the C/A-code.
The output of the correlator is the convolution of the interference spectral density at the input to the correlator and the spectral density of the code, i.e.

$$Io = \int_{-\infty}^{\infty} Sgnss(f) I(f) \delta(fs) df \qquad \text{(eq. 2)}$$

where $\delta(fs)$ is the sampling process of the receiver and its internally generated code. Tight filtering is required in the RF and IF sections to ensure that any interference above the Nyquist rate of the sampling frequency is removed. Sampling rates vary but the rate must be at least the chipping rate of the PRN code. Substantially higher sampling rates are used in narrow correlator designs to reduce errors caused by multipath signals. Maximum rates can be as high as 40 MHz, if the receiver is also capable of P-code (or Y-code) operation.

$\delta(fs)$ can be approximated as a 1 dB loss, the power out of the correlator can be written for an interfering signal $I(f)$ of I W/Hz from frequency F1 to F2 as equation 3.

$$Io = I \int_{F1}^{F2} Sgnss(f) df \qquad \text{(eq. 3)}$$

Table A 1.1 shows the nominal calculation of GPS interference susceptibility.

Interference power MSS signal	-112	dB(W/m²/MHz)
Antenna Factor	25.3	dB(m²)
Received Power	-137.3	dB(W/MHz)
PSD	-197.3	dB(W/Hz)
$Io = 10^{-19.7} \int_{6.42MHz}^{8.42MHz} Sgnss(f) df$	-222.4	dB(W/H)z
Rx System noise of 500 K	-201.5	dB(W/Hz)
Resultant (*No+Io*)	-201.46	dB(W/Hz)
% degradation in noise power	0.81%	% N/N_o

Table A 1.1: GPS Interference Susceptibility

The effect of different interfering signal bandwidths *Bi* can be seen in Figure A 1.2

A) *Bi* > 100 kHz, C/A, PSD modelled as continuous sinc^2 function.
B) *Bi* >100 kHz, offset from GPS L1 frequency.
C) 1 kHz < *Bi* <100 kHz the code PSD is modelled as a series of multiple spectral lines with a single large spectral line 8 dB above the average sinc^2 envelope, reflecting the actual fluctuation of the GPS C/A-code spectrum from the ideal sinc^2 distribution.
D) *Bi* <1 kHz a single spectral line is assumed to dominate the model.

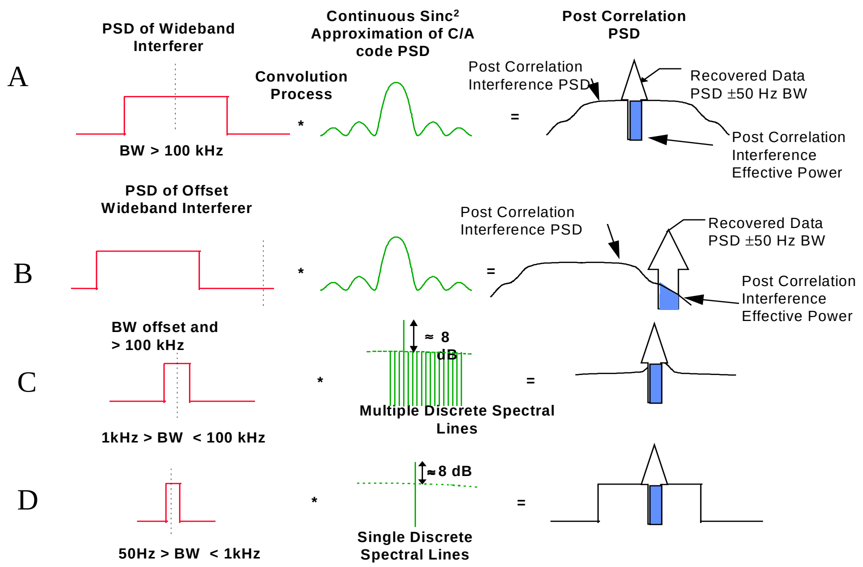


Figure A 1.2: Model of Correlation for varying Interfering Bandwidth

A 1.6 Interference from MSS in a portion of the band 1559-1567 MHz into C/A-Code GPS receiver, at 1575.42 MHz ; acquisition mode considering Recommendation ITU-R M1088

Recommendation ITU-R M.1088 [2] specifies the tolerable total interference to signal ratio of 24 dB. It is assumed that this figure comprises receive system noise, intra-system interference (due to other GPS satellites) and external interference. The system temperature for GPS receiver is taken as 500 K, an ambient noise power of -201.5 dB(W/Hz).

The total intra-system interference is taken to be

$$Po = 10 \log (k (m-1) P_{intra} / f_c)$$

where: k= 2/3 for one GPS code correlated against another;

m = number of satellites,

P_{intra} = -160 dBW for the C/A-Code or -163 dBW for the P-Code;

f_c = Chipping rate and

antenna gain averaged over hemisphere = 2.2 dBi.

It should be noted that this averaged antenna gain of 2.2 dBi is based on the ICAO antenna model with 7 dBi antenna gain and –4.5 dBi minimum gain. It is expected that the averaged antenna gain with a reduced +3 dBi peak gain would be more than 2 dB less than this, which would reduce the intra-system interference Po by more than 2 dB and allow the tolerable pfd to be increased by more than 2 dB.

For ten satellites, for the C/A-Code Po =-210.1 dBW-Hz.

Table A 1.2 shows the GPS Interference Budget for acquisition mode using the parameters of ITU-R Recommendation M.1088 [2]

	C/A-Code	**C/A/Code**	
Maximum receiver antenna gain	**+7.0**	**+3.0**	**dBi**
Signal power at output of reference antenna (0 dBi gain) (over 2.046 MHz)	-160	-160	dBW
Minimum antenna gain to GPS (5° elevation)	-4.5	-4.5	dBi
Minimum signal power at antenna output.	-164.5	-164.5	dBW
Tolerable (interference + noise) to signal ratio (acquisition)	24	24	dB
Tolerable total interference plus noise power referred to antenna output	-140.5	-140.5	dBW
Maximum correlator gain (code rate)	60.1	60.1	dBHz
Tolerable total (external + intra-system interference + thermal noise) power density referred to antenna output (Io+Po+No)	**-200.6**	**-200.6**	**dB(W/Hz)**
Thermal noise power spectral density of receiving system (No)	-201.5	-201.5	dB(W/Hz)
Received intra-system interference avg. (Po)	-210.1	-210.1	dB(W/Hz)
Tolerable total external interference power spectral density at antenna output (Io)	**211.8**	**211.8**	**dB(W/Hz)**
Ratio of single-entry / multiple entry interference	-6.0	-6.0	dB
Tolerable single-entry external interference power spectral density at antenna output (Io')	**-217.8**	**-217.8**	**dB(W/Hz)**
Convolution factor	25	25	dB
Antenna effective area	-18.3	-22.3	$dB(m^2)$
Bandwidth conversion (1 MHz / 1 Hz)	60	60	dB
Maximum tolerable PFD for 1559 - 1567 MHz.	**-114.5**	**-110.5**	**$dB(W/m^2)$ in 1 MHz**
Degradation in noise power (Io'+Po+No)/(Po+No)	**2.05**	**2.05**	**%**

Table A 1.2: GPS Interference Budget; acquisition mode; Rec. M.1088

A 1.7 Interference from MSS in a portion of the band 1559-1567 MHz into C/A-Code GPS receiver at 1575.42 MHz; acquisition mode; improved C/N_o for increased accuracy

Accuracy requirements for civil aircraft operating in the precision phase of flight are defined in Table A.2.5-1 of ICAO SARPS, reproduced in Table A 1.3 below.

ICAO SARPS Table A.2.5-1:-		
Typical operation	Accuracy Lateral 95%	Accuracy Vertical 95%
Category I	16 m	7.7 m to 4 m (3.8 m to 2.1m 1σ)
Category II	6.5 m	1.7 m (0.85 m 1σ)
Category III	3.9 m	0.8 m (0.4 m 1σ)

Table A 1.3: Civil Aircraft Navigation Accuracy Requirements

Note:- ICAO has specified that Category I, II and III operations can not rely on more than the minimum specified signal from the GPS satellites (i.e. 36.5 dBHz) down to near Category I. Precision approach operations need augmentations added to achieve the overall approach requirements.

For the conversion of these pseudorange navigation accuracy requirements to the required C/N_o at correlator input, the most significant performance threshold for a GNSS receiver, is that for the code tracking loop of the correlator.

The formula relating pseudo-range to C/N_o is:-

$$\sigma_{pr}^2 = 4 * (F_1 L_c^2 B_l d^2 (\alpha/2) / (C/N_o))* (2 (1\text{-}d) + 4 * F_2 * d / (C/N_o*T))$$

Where: L_c = wavelength =293 metres;
- d = correlator spacing in chip spacing = 0.5 to 0.1;
- B_L = code loop filter bandwidth = ~1 Hz;
- α= carrier smoothing constant = 0.02;
- F1 = 1 for time shared correlator or 2½ for dedicated correlator;
- F2 = 1 for a power discriminator or either 1 or ½ for a dot product discriminator;
- T = integration time = 20 ms;
- σ_{pr} = Pseudo Range error = 0.23 metres.

The accuracy requirements for Category I relate to C/N_o (dBHz) at the input to the correlator. It relates to the maximum Navigation System Error required at the lowest height for the precision approach operations and for a vertical dilution of precision (VDOP) of 4.95: (2.1 m / 4.95) = 0.45 m. 0.23 m is attributable to multi-path interference.

The resulting C/N_o = carrier to noise power density = 38 dBHz.

Correlation loss due to the less-than-ideal nature of the transmitted satellite waveform and the generated waveform in the GNSS receiver totals 1 dB.

Required GPS C/N_o for precision approach is 39 dBHz.

The minimum defined C/N_o available from a current GPS satellite at 5° elevation is ~36.5 dBHz, assuming a receiver system noise temperature of about 500 K.

To achieve Category I operational accuracy, GPS receivers must use SBAS augmentations, which provide a data broadcast of differential corrections and an additional GPS look-alike signal to enhance the accuracy of the calculated position.

Category II / III requirements are outlined in ITU-R Provisional Draft New Recommendations (PDNRs). These accuracy requirements need SBAS and GBAS augmentations. It is considered very difficult to reduce the overall noise of an aircraft receiver system. Some receivers may be designed to have better noise figures, however, not all aircraft require receivers to Category II / III standards, and therefore this annex uses the defined system noise temperatures of ~500k.

Table A 1.4 summarises the GPS C/N_o Requirements.

Accuracy requirement	Resulting C/N_o (VDOP of 4.95)
GPS/SBAS	39 dBHz
GPS/SBAS/GBAS	>42 dBHz
GPS/SBAS/GBAS	48 dBHz

Table A 1.4: GPS C/No Requirements

The ITU-R PDNRs partly reflect this additional need of GPS receivers to operate to increased accuracy limits. The PDNRs indicate change from -140.5 dB(W/MHz) (total intra system, external and receiver noise from Rec. ITU-R M.1088 [2]) to -146.5 dB(W/MHz) (total intra-system and external interference only) for the interference limits for these type of receivers.

A 1.8 Interference from MSS in a portion of the band 1559-1567 MHz into a C/A-Code SBAS receiver at 1575.42 MHz ; acquisition mode; increased accuracy

A receiver using a space-based augmentation system (SBAS) will receive a signal at the GPS “L1” frequency of 1575.42 MHz similar to the GPS C/A-Code but with a higher-rate data modulation and at a reduced minimum received power of –161 dBW in addition to the GPS signals.

If the wanted SBAS signal is received with the minimum antenna gain of –4.5 dBi in the presence of ten interfering GPS satellites, the total Intra-system interference will be:

$$Po = 10 \log (k\ (m)\ P_{intra} / f_c\ )$$

where: k= 2/3 for one GPS code correlated against another;
m = number of satellites;
P_{intra} = -160 dBW for C/A-Code;
f_c= Chipping rate;
Po for C/A-Code is –209.7 dB(W/Hz), assuming antenna gain averaged over hemisphere of 2.2 dBi and 10 GPS satellites.

The system temperature for GPS receiver is taken as 500K, an ambient noise power of -201.5 dB(W/Hz). Table A 1.5 shows the GPS Interference Budget for acquisition mode with this increased accuracy.

	C/A-Code SBAS	**C/A-Code**	
Maximum receive antenna gain	**+7.0**	**+3.0**	**dBi**
Specified maximum total interference power spectral density at antenna output (acquisition)	-146.5	-146.5	dB(W/MHz)
Tolerable total interference power spectral density referred to antenna output (Io+Po)	**-206.5**	**-206.5**	**dB(W/Hz)**
Total intra system power spectral density (Po)	-209.7	-209.7	dB(W/Hz)
Tolerable total external interference power spectral density (Io)	**-209.4**	**-209.4**	**dB(W/Hz)**
Single- / multiple-entry interference ratio	-6.0	-6.0	dB
Tolerable single-entry external interference power spectral density antenna output. (Io')	**-215.4**	**-215.4**	**dB(W/Hz)**
Convolution factor	25	25	dB
Antenna effective area	-18.3	-22.3	dB(m^2)
Bandwidth conversion (1 MHz / 1 Hz)	60	60	dB
Maximum tolerable PFD for 1559 - 1567 MHz.	**-112.1**	**-108.1**	**dB(W/m^2) in 1 MHz**
Degradation in noise power (Io'+Po+No)/(Po+No)	**3.56**	**3.56**	**%**

Table A 1.5: SBAS Interference Budget; acquisition mode

The tolerable total interference specified at the output of an antenna is -146.5 dB(W/MHz) (-206.5 dB(W/Hz)) in any direction of interference (PFD limit for interference relies on knowledge of antenna gain) The total external tolerable interference figure is taken from new ITU-R PDNRs (ITU-R Documents 8D/TEMP/24 and 8D/TEMP/25) and is defined as the total interference at the output of an antenna, it does not include the Rx system noise. Recommendation ITU-R M.1088 [2] is assumed to cover all external and receive system noise.

A 1.9 Interference from MSS in a portion of the band 1559-1567 MHz into a P-code GPS receiver at 1575.42 MHz in tracking mode, considering Recommendation ITU-R M.1088

The acquisition of the C/A-Code is a pre-requisite for acquiring the P-code for some receivers. Recommendation ITU-R M.1088 [2] specifies the tolerable total interference-to-signal ratio as 24 dB for C/A acquisition and 41 dB for P-code tracking. These ratios comprise receive system noise, intra-system interference (due to other GPS satellites) and external interference. The system temperature for GPS receiver is taken as ~500K, an ambient noise power of -201.5 dB(W/Hz). Intra-system interference totals taken to be:

$$Po = 10 \log (k\,(m-1)\,P_{intra} / f_c)$$

where: k = 2/3 for one GPS C/A-Code correlated against another and 0.82 for one P-Code correlated against another;

m = No. of satellites;

P_{intra} = -160 dBW for the C/A-Code or -163 dBW for the P-Code;

f_c = Chipping rate.

For 10 GPS satellites and an antenna gain averaged over hemisphere of 2.2 dB, Po for the C/A-Code is -210.3 dB(W/Hz) and for the P-Code is –222.2 dB(W/Hz).

Table A 1.6 shows the GPS Interference Budget for P-Code tracking.

	C/P-Code Tracking	**P-Code tracking**	
Maximum Receive Antenna Gain	**+7.0**	**+3.0**	**dBi**
Signal power at output of reference Antenna (0 dBi gain)	-163	-163	dBW
Minimum antenna gain to GPS (5° elevation)	-4.5	-4.5	dBi
Signal power at antenna output.	-167.5	-167.5	dBW
Reference bandwidth	10.23	10.23	MHz
Tolerable total interference plus noise to signal ratio	41	41	dB
Tolerable total interference plus noise power referred to antenna output	-126.5	-126.5	dBW
Maximum correlator gain (code rate)	70.1	70.1	dBHz
Tolerable total (external interference + intra-system interference + thermal noise) power density (Io+Po+No).	**-196.6**	**-196.6**	**dB(W/Hz)**
Thermal noise power density of receiving system. (No)	-201.5	-201.5	dB(W/Hz)
Received intra-system interference (Po)	-222.2	-222.2	dB(W/Hz)
Tolerable total external interference power spectral density at antenna output (Io)	**-198.3**	**-198.3**	**dB(W/Hz)**
Single- / multiple-entry interference ratio	-6.0	-6.0	dB
Tolerable single-entry external interference power density at antenna output (Io')	**-204.3**	**-204.3**	**dB(W/Hz)**
Convolution factor	16.8	16.8	dB
Antenna effective area	-18.3	-22.3	dB(m^2)
Bandwidth conversion (1 MHz / 1 Hz)	60	60	dB
Resultant PFD for 1559-1567 MHz.	**-109.2**	**-105.2**	**dB(W/m^2) in 1 MHz**
Degradation in noise power (Io'+Po+No)/(Po+No))	**52**	**52**	**%**

Table A 1.6: GPS Interference Budget: P-Code tracking

A 1.10 Interference from MSS in a portion of the band 1559-1567 MHz into GPS Receiver using the technique of codeless comparison on L1 and L2 (1575.42 MHz 1227.6 MHz) frequencies.

The civil user community of GPS generally uses the C/A component. However, to provide enhanced accuracy, some receivers derive corrections for ionospheric delay by comparing the GPS P-Code transmission on frequencies 1575.42 MHz and 1227.6 MHz, called L1 and L2 respectively. Access to the more accurate encoded GPS P-Code, has not been authorised by the United States Government. The L1 and L2 comparison does not rely on knowledge of the encrypted P-Code GPS signal, only the underlying P-Code. Therefore receivers of this type are termed ‘codeless’. There are important uses for these type of receivers in the derivation of Differential GPS (DGPS) signals. For example the survey industry are reliant on these for oil exploration and for aviation in the derivation of DGPS signals for precision approach operations.

For the codeless GPS type of receiver, the lack of knowledge of the encrypted code means that the recovered P-Code power is below that possible by convolution. Several techniques have been designed to reduce this degradation, however the minimum loss achievable today is -13 dB degradation. Encoded P-Code transmissions on L1 and L2 are multiplied by a copy of an unencoded P-Code (one copy is delayed in time), the resulting signals are multiplied and compared to each other to determine any additional time delay that is due to the ionosphere. The multiplication of these signals against each other and cross comparison reduces resultant signal power available by about 13 dB. It is based on a technique denoted Z-Technique[tm] (Ashjaee and Lorenz 1992). This is included in the link budget for the codeless technique.

It must be stressed that the codeless techniques are very susceptible to non-linear effects away from the designed operating parameters.

The link budget for GPS codeless tracking receiver is presented in Table A 1.7, using the following assumptions:

Intra-system interference totals taken to be

$$Po = 10 \log (k\ (m-1)\ P_{intra} / f_c\ )$$

where: k = 2/3 for one GPS C/A-Code correlated against another and 0.82 for one P-Code correlated against another;

m = No. of satellites

P_{intra} = -160 dBW for the C/A-Code or -163 dBW for the P-Code

f_c = Chipping rate and

antenna gain averaged over upper hemisphere is 2.2 dBi.

This average has been assumed for all variations of GPS antenna gain.

For ten satellites is Po C/A =-210.1 dB(W/Hz) or –222.2 dB(W/Hz) for P-Code

The system temperature for GPS receiver is taken as ~500K, an ambient noise power of -201.5 dB(W/Hz).

	P-Code	P-Code	
Maximum receive antenna gain	**+7.0**	**+3.0**	**dBi**
Signal power at output of reference antenna (0 dBi gain)	-163	-163	dBW
Antenna gain to GPS and MSS (90° elevation)	+7	+3	dBi
Signal power at antenna output.	-156	-160	dBW
Correlator loss - Codeless Comparison	-13	-13	dB
Minimum recovered power	-169	-173	dBW
Minimum C/N_o required for codeless comparison	30	30	dBHz
Tolerable total interference power spectral density at output of antenna (Io+Po+No)	**-199**	**-203**	**dB(W/Hz)**
Total intra-system interference power spectral density (Po)	-222.2	-222.2	dB(W/Hz)
Receiving system noise power density (No)	-201.5	-201.5	dB(W/Hz)
Tolerable total external interference power spectral density (Io)	**-202.6**	**No margin for external interference**	**dB(W/Hz)**
Single- / multiple-entry interference ratio	-6.0	-6.0	dB
Tolerable single entry external interference power spectral density (Io')	**-208.6**	**None**	**dB(W/Hz)**
Convolution factor P-Code	16.8	16.8	dB
Minimum antenna effective area in direction of MSS signal	-18.3	-22.3	dB(m^2)
Bandwidth conversion (1 MHz / 1 Hz)	60	60	dB
Resultant maximum tolerable power flux density for MSS 1559 – 1567 MHz.	**-113.5**	**thermal noise**	**dB(W/m^2) in 1 MHz**
Degradation in noise power (Io'+Po+No)/(Po+No)	**19%**	**none possible**	**%I/(No+Po)**

Table A 1.7: GPS Interference Budget: Codeless tracking

A 1.11 New applications for GPS C/A-Code at frequency 1565.19 MHz, and the interference effects from MSS in a portion of the band 1559-1567 MHz

ITU WRC 97 Resolution 220 called for the assessment of interference from MSS into current and future planned developments of the radionavigation satellite band 1559 - 1610 MHz. For GPS, an additional civil frequency for C/A-Code has been offered on L2. Another frequency offset from L1 is also being considered. Operational use of these will not become available for number of years (>2005).

A system element supporting GPS civil operations is likely to be placed at 1565.19 MHz or 1587.69 MHz. Only the frequency 1565.19 MHz is considered here, as this is within the band 1559 - 1567 MHz. Therefore there are a minimum of two scenarios,

> i) MSS signals from 1559 - 1567 MHz would partially overlap the new GPS signal, and therefore be co-frequency and co-coverage, or
> ii) MSS signals would be restricted to, say, 4 MHz band between 1559 MHz and 1563 MHz, and therefore be in the adjacent band.

For a co-frequency and co-coverage MSS signal between 1559 - 1567 MHz, there is no reduction due to convolution process in a GPS receiver (i.e. 0 dB).

For MSS at 1559 - 1563.19 MHz and GPS signal at 1565.19 MHz with a chip rate of 1.023 MHz, the convolution factor is 17.7 dB. (equation 3).

The link budget for a GPS C/A-code receiver at 1565.19 MHz is shown in Table A 1.8, using the following parameters:

Recommendation ITU-R M.1088 [2] specifies the tolerable total interference to signal ratio of 24 dB. This figure comprises receive system noise, intra-system interference (due to other GPS satellites) and external interference. The system temperature for GPS receiver is taken as ~500K, an ambient noise power of -201.5 dB(W/Hz)dB(W/Hz).

Intra-system interference totals taken to be:

$$Po = 10 \log (k (m-1) P_{intra} / f_c)$$

where: k= 2/3 for one GPS code correlated against another;

m = No. of satellites;

Po = -160 dBW for the C/A-Code or -163 dBW for the P-Code;

f_c= Chipping rate, and

antenna gain averaged over hemisphere is 2.2 dBi.

For ten satellites, Po C/A =-210.3 dB(W/Hz)dB(W/Hz)

	C/A-Code	**C/A-Code**	
MSS spectrum	**1559-1567**	**1559-1563**	**MHz**
Signal power at output of reference antenna (0 dBi gain) (over 2.046 MHz)	-160	-160	dBW
Minimum antenna gain to GPS (5° elevation)	-4.5	-4.5	dBi
Minimum signal power at antenna output.	-164.5	-164.5	dBW
Tolerable interference +noise to signal ratio (acquisition)	24	24	dB
Tolerable total interference plus noise power referred to antenna output	-140.5	-140.5	dB(W/MHz)dB(W/MHz)
Maximum correlator gain (code rate)	60.1	60.1	dBMHz
Tolerable total (external + intra-system interference + thermal noise) power spectral density referred to antenna output. (Io+Po+No)	**-200.6**	**-200.6**	**dB(W/Hz)dB(W/Hz)**
Thermal noise power spectral density of receiving system. (No)	-201.5	-201.5	dB(W/Hz)dB(W/Hz)
Received intra-system interference avg. (Po)	-210.1	-210.1	dB(W/Hz)
Tolerable total external interference power density at antenna output (Io)	**211.8**	**211.8**	**dB(W/Hz)**
Single- / multiple-entry interference ratio	-6.0	-6.0	dB
Tolerable single-entry external interference power spectral density at antenna output (Io')	**-217.8**	**-217.8**	**dB(W/Hz)**
Convolution factor	0	17.7	dB
Antenna effective area (+7dBi GPS antenna)	-18.3	-18.3	dB(m^2)
Bandwidth ratio (1 MHz / 1 Hz)	60	60	dB
Maximum tolerable MSS power flux density	**-139.5**	**-121.8**	**dB(W/m^2) in 1 MHz**
Degradation in noise power (Io'+Po+No)/(Po+No)	**2%**	**2%**	**%**

Table A 1.8: GPS Interference Budget: C/A Code; new applications; different MSS Allocations

ANNEX 2

Annex 2 Interference from MSS into ESA E-NSS-1 Network including Consideration of Mutual Interference between MSS and RNSS Networks

A 2.1. Introduction

The purpose of this Annex is to determine the maximum interference from MSS systems in the band 1559 – 1567 MHz which could be tolerated by the E-NSS-1 Network without causing harmful interference. E-NSS-1 plans to use a carrier at 1561 MHz, so the proposed MSS systems would be co-frequency with this RNSS network.

In addition, consideration is given to mutual interference between MSS and RNSS networks sharing the band 1559 - 1567 MHz, which shows the effect of each network on the other.

A 2.2 E-NSS-1 Characteristics

The E-NSS-1 Network [4] is aimed at the provision of enhanced navigation services by a second-generation, global, international navigation-satellite system. An improved signal and a comprehensive constellation of satellites are required to ensure proper visibility to all users, not only at sea, in the air and in open country but also in built-up areas where visibility is poor and to provide a signal which is more powerful and more robust in order to provide the improved accuracy of navigation required by the full range of users.

The E-NSS-1 Network will offer improved spectral efficiency but will achieve the required accuracy without unreasonably high-power transmissions only if interference can be maintained within controlled limits. Users in the air or on the high seas will be able to maintain relatively safe distances from local interferers such as mobile phones or other terrestrially-based sources of interference. Users on the ground may need to incorporate operational procedures to allow acceptance of occasional interference. However, the suggestion to permit space-to-Earth transmissions in the mobile-satellite service would impose continuous and unavoidable interference on all users of the RNSS networks.

The E-NSS-1 constellation will comprise up to 48 satellites in inclined geosynchronous orbits (IGSO), with inclinations of around 60°, with satellites placed in “loops” centred on 6 longitude points spaced 60° apart.

The maximum practicable E-NSS-1 EIRP is currently considered to be nearly 36 dBW, corresponding to a solid-state transmitter with 80 W RF output power and an Earth-coverage antenna with gain optimised to operate in both the 1215 - 1260 MHz and 1559 - 1610 MHz bands and to compensate for free-space path loss variations. This EIRP delivers -157.3 dBW into an isotropic receiving antenna on the Earth’s surface (compared with only -160 dBW for GPS and -161 dBW for WAAS/EGNOS).

The E-NSS-1 receiver antenna is assumed to have a maximum gain towards the azimuth of +3 dBi and a minimum gain of –4.5 dBi at 5° elevation angle (See Doc. SE28(97)48 Rev. 1).

The maximum intra-system interference received in the full 48-satellite E-NSS-1 constellation corresponds to visibility of twenty satellites at various elevation angles from 90° down to 5°, as discussed in Section A 2.4 below.

The target positioning error, derived from the study of a full range of civil users in the aeronautical, maritime and inland navigation, road and rail transport, exploration and surveying, agriculture, sport and leisure fields, is ± 3 to 4 metres. This converts, via calculations of UERE (user equivalent range error), PDOP (position dilution of precision), constellation geometry, signal processing performance and transmission link design, to a requirement for a minimum overall C/No in the range +40 dBHz to +43 dBHz. ("Overall C/No" is defined as C/No+Po+Io, where No is thermal noise power spectral density, Po is intra-system interference power spectral density and Io is external interference power spectral density.) For the analyses which follow, a minimum overall C/No of 41.2 dBHz has been taken, as a compromise intermediate value. However, the results will show that the deficit in the sharing analyses exceed the overall C/No range quoted.

A 2.3 E-NSS-1 Protection Criteria

Table A 2.1 shows the overall link budget, demonstrating that, with no external-system interference, a margin of 3 dB exists between the carrier to (thermal plus intra-system) noise, C/No+Po, of 44.3 dBHz and the required overall C/No (= C/No+Po+Io) of 41.2 dBHz. The calculation of intra-system interference (Po) is explained in detail in Section A 2.4.

Satellite network	E-NSS-1	E-NSS-1	
Satellite orbit	IGSO	IGSO	
Frequency	1561.00	1561.00	MHz
Modulation	CDMA/BPS	CDMA/BPS	
Signal	2M20X2D	2M20X2D	
Data rate	1.0	1.0	kbit/s
Symbol rate	3072.0	3072.0	kbit/s
<u>Transmitting Station</u>	edge of coverage	centre of coverage	
Symbol rate	64.9	64.9	dBHz
Transmitter output power	80.0	80.0	W
Output losses	1.2	1.2	dB
Antenna gain	18.0	16.8	dBi
EIRP	35.8	34.6	dBW
EIRP density	-29.0	-30.2	dB(W/Hz)
Elevation angle	5.0	90.0	deg.
Range	41124.6	35784.0	km
Free-space path loss	188.6	187.4	dB
Received power flux density	-132.3	-132.3	dB(W/m².MH
<u>Receiving Station</u>			
Antenna gain (to wanted satellite)	-4.5	3.0	dBi
Antenna effective area	-29.8	-22.3	dB(m²)
Received signal power (C)	-157.3	-149.8	dBW
Antenna noise temperature	125.0	125.0	K
Receiver noise figure	2.5	2.5	dB
Receive system noise temperature	350.0	350.0	K
Received noise power spectral density (No)	-203.2	-203.2	dB(W/Hz)
C/No	45.9	53.4	dBHz
Number of own-system interfering satellites	19.0	19.0	
Total relative intra-system interference power	15.4	7.5	dB
Received intra-system interference power	-141.9	-142.3	dBW
Intra-system interference power spectral density	-206.7	-207.1	dB(W/Hz)
No+Po	-201.6	-201.7	dB(W/Hz)
C/No+Po	44.3	51.9	dBHz
Tolerable external interference power spectral	-201.3	-201.4	dB(W/Hz)
No+Po+Io	-198.4	-198.5	dB(W/Hz)
Overall C/No = C/No+Po+Io	41.2	48.8	dBHz
Required overall C/No for precision navigation	41.2	41.2	dBHz
Margin for precision navigation	0.0	7.6	dB

Table A 2.1 : Link and Interference Budget for E-NSS-1

Table A 2.1 also shows that the total external interference power spectral density (Io) which can be tolerated at the output of the antenna of an E-NSS-1 receiver is -201.3 dB(W/Hz).

It is proposed that a ratio of 6 dB be taken between the total tolerable interference and the acceptable single-entry interference. The adoption of a such a ratio for total / single-entry acceptable interference is discussed in CCIR Report 455-5 and is applied in several ITU-R Recommendations: In Recommendation ITU-R S.466-6, the ratio for an analogue telephony satellite channel is 2000 pW0p / 600 pW0p, equivalent to 5.2 dB; In Recommendation ITU-R S.483-3, the ratio for a FM television satellite channel is 10/4, equivalent to 4 dB; In Recommendation ITU-R S.523-4, the ratio for a digital telephony satellite channel is 25% / 10%, equivalent to 4 dB and in Recommendation ITU-R S.735-1, the ratio for an ISDN satellite channel is 25% / 6%, equivalent to 6.2 dB. The maximum tolerable single-entry interference power spectral density at the output of the antenna of an E-NSS-1 receiver, using the current E-NSS-1 design parameters, is therefore -207.3 dB(W/Hz).

In the cases quoted above, the interferer is assumed to be present for a limited portion of time, e.g. 20% of any month. In other cases, where communications are critical, higher availability is required. For example, Recommendations ITU-R 609 and ITU-R SA.1155 require interference into telecommunication links for manned and unmanned near-Earth Research satellites to be limited to 0.1% of time. In the case of MSS (space-to-Earth) interfering into RNSS (space-to-Earth), the interference is for 100% of time, so extreme care needs to be taken to ensure that the interference limit can not be exceeded under any circumstances.

A 2.4 E-NSS-1 Intra-System Interference

Figure A 2.1 shows the satellites visible in the user receive antenna beam, indicating the worst case where the wanted satellite is at the minimum elevation angle of 5° as seen by the receiver and also the receiver is at the edge of the satellite coverage. Two interfering satellites are on the beam axis at maximum elevation (in the centre of the diagram) with seventeen more interfering satellites visible out of the 48 in the E-NSS-1 constellation.

Table A 2.2 shows the disposition of the interfering satellites and the relative power generated by each, compared to the received power of this wanted satellite at 5° elevation. With two interfering satellites on the axis of the receive antenna and seventeen more at different off-axis angles as shown, the total interference power is 17.2 dB above the wanted-satellite signal power. However, the cross-correlation of the code spectra reduces this by 2 / 3 = 1.8 dB to 15.4 dB.

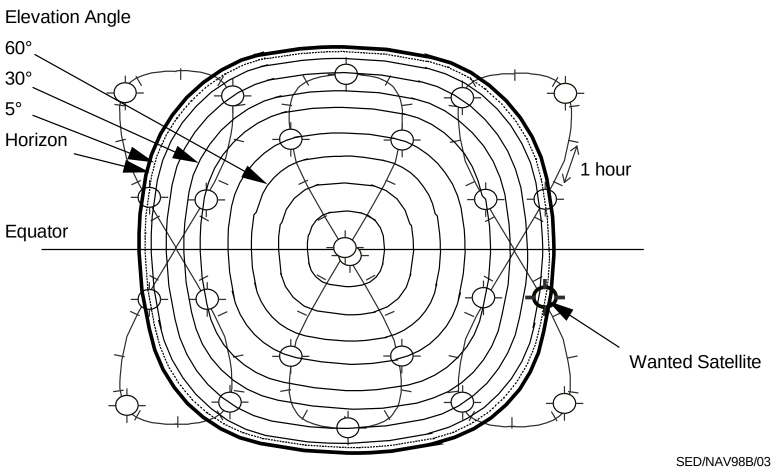


Figure A 2.1 : E-NSS-1 Interference Model

Elevation angle	5	20	40	50	90	degrees
Number of interfering satellites in set	3	6	4	4	2	
Receive antenna gain Antenna gain w. r. t. wanted satellite Relative received power per satellite Relative received power per set	-4.5 0.0 1.0 3.0	-2.1 2.4 1.7 10.5	0.4 4.9 3.1 12.4	1.3 5.8 3.8 15.3	3.0 7.5 5.6 11.2	dBi dB
Total received interference power relative to wanted signal	52.4 = +17.2 dB					
Code cross-correlation factor	2 / 3 = - 1.8 dB					
Effective total interference power relative to wanted signal	34.9 = +15.4 dB					

Table A 2.2 : E-NSS-1 Intra-System Interference Budget (worst-case)

Table A 2.3 shows the situation when the wanted E-NSS-1 is on the axis of the receiver antenna, corresponding to the centre of coverage for the normally zenith-pointing receiver antenna.

Elevation angle	5	20	40	50	90	degrees
Number of interfering satellites in set	4	6	4	4	1	
Receive antenna gain Antenna gain w. r. t. wanted satellite Relative received power per satellite Relative received power per set	-4.5 -7.5 0.18 0.72	-2.1 -5.1 0.31 1.86	0.4 -2.6 0.55 2.20	1.3 -1.7 0.68 2.72	3.0 0.0 1.00 1.00	dBi dB
Total received interference power relative to wanted signal	8.5 = + 9.3 dB					
Code cross-correlation factor	2 / 3 = - 1.8 dB					
Effective total interference power relative to wanted signal	5.7 = + 7.5 dB					

Table A 2.3 : E-NSS-1 Intra-System Interference Budget (best-case)

A 2.5 Tolerable MSS PFD

The interference from a geostationary satellite in the MSS could appear on the axis of the RNSS receiver antenna, which has been assumed to have a maximum gain of +3 dBi (cf. GPS +7 dBi). On the assurance that only one satellite could be visible in any part of the frequency band from any RNSS receiver, and on the assumption that the MSS signal can be approximated as additive gaussian white noise, the provision of precision navigation services by E-NSS-1 imposes a limit on the power flux density from the MSS of -125.0 dB(W/m²) in any 1 MHz, as shown in Table A 2.4.

Tolerable single-entry interference power spectral density	-207.3	dB(W/Hz)
Antenna effective area (zenith gain +3 dBi)	-22.3	dB(m²)
Tolerable single-entry interference power flux density	-185.0	dB(W/m².Hz)
Tolerable MSS power flux density (in any 1 MHz)	-125.0	dB(W/m²)

Table A.2.4 : Tolerable MSS PFD

A 2.6 Mutual Degradations of E-NSS-1 and MSS due to band sharing

A 2.6.1 E-NSS-1 Reference Link Budget

Table A 2.5 shows a reference link budget for E-NSS-1 with no MSS band sharing. It is the same as the E-NSS-1 link budget of Table A 2.1, but with the external interference (Io) divided into two parts, one due to the MSS (Io') and the other due to all other sources (Io"). The latter (Io") is set at 75%, 1.25 dB below the total external interference (Io) of Table A 2.1.

A 2.6.2 MSS Reference Link Budget

Table A 2.6 shows a reference MSS link budget, with no RNSS band sharing. It is assumed that the MSS system would require an operating power flux density of -112 dB(W/m²) in each 1 MHz and that it would use directive earth-station antennas with a nominal gain of 12.5 dBi. A receive system noise temperature of 350° has been assumed, as for the E-NSS-1 receiver. In the absence of any specific performance requirement, the resultant C/N_o is taken as the reference for evaluation of the effect if interference in the subsequent analyses.

A 2.6.3 E-NSS-1 / MSS Interference Budgets

Table A 2.7 shows the effect of MSS / RNSS band sharing, combining Tables A 2.5 and A 2.6. It shows that imposition of MSS (at the stated operating power flux density of -112 dB(W/m²) in each 1 MHz) in the band 1559 - 1567 MHz would cause the maximum tolerable interference to E-NSS-1 to be exceeded by 5.4 dB.

The interference from the MSS system into E-NSS-1 assumes that only a single MSS satellite may appear on the axis of the radionavigation receive antenna.

The interference from the E-NSS-1 constellation into the MSS receiver (the mobile earth station, or MES) assumes the best case, with the equivalent of 1.8 E-NSS-1 satellites on the axis of antenna of the mobile earth station. An analysis of the visibility of E-NSS-1 from the MES is presented in Section A 2.6.4.

Table A 2.7 shows that the MSS network performance is degraded by 3.3 dB relative to the reference in Table A 2.6.

Tables A 2.8 shows the effect of increasing the E-NSS-1 transmitter power to the point where the negative margin caused by the MSS network has been balanced out. This requires a transmitter power of 310 dB (which, it should be recalled can not be achieved using current predictions of technological capability).

These analyses assume that the MSS satellite can be placed in the optimum position, mid-way between two E-NSS-1 loops. If this can not be arranged, the MSS satellite will suffer additional interference from E-NSS-1, which will vary between the minimum and maximum described in Section A 2.6.4 below. Calculations of the effect of this maximum interference show that the MSS penalties are increased by between 1.1 dB and 1.4 dB.

Satellite network	E-NSS-1	
Satellite orbit	IGSO	
Frequency	1561.00	MHz
Modulation	CDMA/BPSK	
Signal	2M20X2D	
Data rate	1.0	kbit/s
Symbol rate	3072.0	kbit/s
Transmitting Station	edge of coverage	
Symbol rate	64.9	dBHz
EIRP	35.8	dBW
EIRP density	-29.0	dB(W/Hz)
Elevation angle	5.0	deg.
Range	41124.6	km
Free-space path loss	188.6	dB
Received power flux density	-132.3	dB(W/m².MHz)
Receiving Station		
Antenna gain (to wanted satellite)	-4.5	dBi
Antenna effective area	-29.8	dB(m²)
Received signal power (C)	-157.3	dBW
Antenna noise temperature	125.0	K
Receiver noise figure	2.5	dB
Receive system noise temperature	350.0	K
Received noise power spectral density (No)	-203.2	dB(W/Hz)
C/No	45.9	dBHz
Number of own-system interfering satellites	19.0	
Total relative intra-system interference power	15.4	dB
Received intra-system interference power	-141.9	dBW
Intra-system interference PSD (Po)	-206.7	dB(W/Hz)
No+Po	-201.6	dB(W/Hz)
C/No+Po	44.3	dBHz
MSS interference power flux density	none	dB(W/m²) in 1 MHz
Antenna peak gain (to interferer)		dBi
Antenna peak effective area		dB(m²)
Received MSS interference PSD (Io')	none	dB(W/Hz)
Other external interference PSD (Io'')	-202.5	dB(W/Hz)
No+Po+Io'+Io''	-199.0	dB(W/Hz)
C/No+Po+Io	41.7	dBHz
Required C/No for precision navigation	41.2	dBHz
Margin for precision navigation	0.5	dB

Table A 2.5 : Reference Link Budget for E-NSS-1 with no MSS band sharing

Satellite network	MSS	
Satellite orbit	GSO	
Frequency	1561.00	MHz
	-112.0	dB(W/m².MHz)
<u>Receiving Station</u>		
Antenna gain (to wanted satellite)	12.5	dBi
Antenna effective area	-12.8	dB(m²)
Received signal power spectral density (Co)	-184.8	dB(W/Hz)
Receive system noise temperature	350.0	K
Received noise power spectral density (No)	-203.2	dB(W/Hz)
C/N	18.3	dB
Number of own-system interfering satellites	none	
Intra-system interference PSD (Po)	none	
No+Po	-203.2	dB(W/Hz)
C/N+P	18.3	dB
RNSS interference power flux density	none	
Received RNSS interference PSD (Io)	none	
No+Po+Io	-203.2	dB(W/Hz)
C/N+P+I	18.3	dB

Table A 2.6 : Reference MSS Link Budget with no RNSS band sharing

Satellite network	E-NSS-1	MSS	
Satellite orbit	IGSO	GSO	
Frequency	1561.00	1561.00	MHz
Modulation	CDMA/ BPSK		
Signal	2M20X2D		
Data rate	0.25		kbit/s
Symbol rate	3072.0		kbit/s
<u>Transmitting Station</u>			
Symbol rate	64.9		dBHz
Transmitter output power	80.0		W
Output losses	1.2		dB
Antenna gain (edge-of-coverage)	18.0		dBi
EIRP	35.8		dBW
EIRP density	-29.0		dB(W/Hz)
Elevation angle	5.0		deg.
Range	41124.6		km
Free-space path loss	188.6		dB
Received power flux density	-132.3	-112.0	dB(W/m².MHz)
<u>Receiving Station</u>			
Antenna gain (to wanted satellite)	-4.5	12.5	dBi
Antenna effective area	-29.8	-12.8	dB(m²)
Received signal power (C)	-157.3		dBW
Received signal power spectral density (Co)	-222.1	-184.8	dB(W/Hz)
Receive system noise temperature	350.0	350.0	K
Received noise power spectral density (No)	-203.2	-203.2	dB(W/Hz)
C/No	45.9		dBHz
C/N		18.3	dB
Number of own-system interfering satellites	19.0	none	
Total relative intra-system interference power	15.4		dB
Received intra-system interference power	-141.9		dBW
Intra-system interference PSD (Po)	-206.7		dB(W/Hz)
No+Po	-201.6	-203.2	dB(W/Hz)
C/No+Po	44.3		dBHz
C/N+P		18.3	dB
External interference PFD from band-sharer	-112.0	-132.3	dB(W/m²) in 1 MHz
Number of other-system interfering satellites	1.0	1.8	
Antenna peak gain (to interferer)	3.0	12.5	dBi
Antenna peak effective area	-22.3	-12.8	dB(m²)
Received mutual interference PSD (Io')	-194.3	-202.6	dB(W/Hz)
Other external interference PSD (Io")	-202.5		dB(W/Hz)
No+Po+Io'+Io"	-193.1	-199.9	dB(W/Hz)
C/No+Po+Io	35.8		dBHz
C/N+P+I		15.0	dB
Required RNSS C/No for precision navigation	41.2		dBHz
RNSS Margin for precision navigation	-5.4		dB
Reference MSS C/N+P+I		18.3	dB
MSS Margin relative to Reference		-3.3	dB

Table A 2.7 : Combined RNSS / MSS Link Budget with band sharing

Satellite Network	E-NSS-1	MSS	
Satellite orbit	IGSO	GSO	
Frequency	1561.00	1561.00	MHz
Modulation	CDMA/ BPSK		
Signal	2M20X2D		
Data rate	0.25		kbit/s
Symbol rate	3072.0		kbit/s
<u>Transmitting Station</u>			
Symbol rate	64.9		dBHz
Transmitter output power	310.0		W
Output losses	1.2		dB
Antenna gain (edge-of-coverage)	18.0		dBi
EIRP	41.7		dBW
EIRP density	-23.2		dB(W/Hz)
Elevation angle	5.0		deg.
Range	41124.6		Km
Free-space path loss	188.6		dB
Received power flux density	-126.4	-112.0	dB(W/m²) in 1.MHz
<u>Receiving Station</u>			
Antenna gain (to wanted satellite)	-4.5	12.5	dBi
Antenna effective area	-29.8	-12.8	dB(m²)
Received signal power (C)	-151.4		dBW
Received signal power spectral density (Co)	-216.3	-184.8	dB(W/Hz)
Receive system noise temperature	350.0	350.0	K
Received noise power spectral density (No)	-203.2	-203.2	dB(W/Hz)
C/No	51.8		dBHz
C/N		18.3	dB
Number of own-system interfering satellites	19.0	none	
Total relative intra-system interference power	15.4		dB
Received intra-system interference power	-136.0		dBW
Intra-system interference PSD (Po)	-200.9		dB(W/Hz)
No+Po	-198.8	-203.2	dB(W/Hz)
C/No+Po	47.5		dBHz
C/N+P		18.3	dB
External interference PFD from band-sharer	-112.0	-126.4	dB(W/m²) in 1 MHz
Number of other-system interfering satellites	1.0	1.8	
Antenna peak gain (to interferer)	3.0	12.5	dBi
Antenna peak effective area	-22.3	-12.8	dB(m²)
Received mutual interference PSD (Io')	-194.3	-196.7	dB(W/Hz)
Other external interference PSD (Io")	-202.5		dB(W/Hz)
No+Po+Io'+Io"	-192.6	-195.8	dB(W/Hz)
C/No+Po+Io	41.2		dBHz
C/N+P+I		11.0	dB
Required RNSS C/No for precision navigation	41.2		dBHz
RNSS Margin for precision navigation	0.0		dB
Reference MSS C/N+P+I		18.3	dB
MSS Margin relative to Reference		-7.3	dB

Table A 2.8 : Combined RNSS / MSS Link Budget with band sharing and augmented RNSS Transmitter Power

A 2.6.4 Interference from E-NSS-1 into reference MES

The E-NSS-1 constellation of up to 48 satellites, as currently published, will comprise eight satellites in each of six inclined geostationary loops.

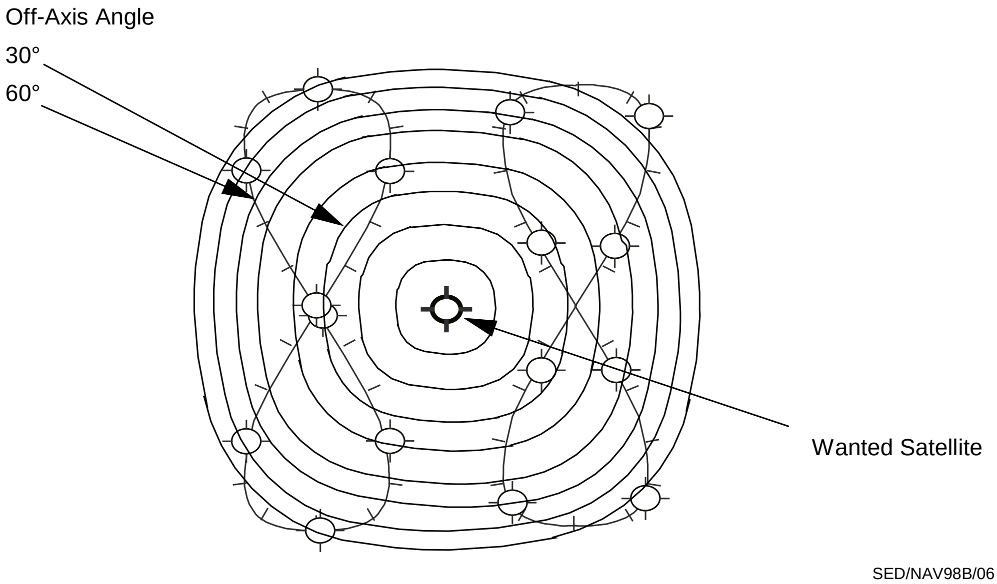


Figure A 2.2 : MES Interference from E-NSS-1 for optimum MSS location

The optimum orbit location for a geostationary mobile satellite would be mid-way between two loops, so that the E-NSS-1 satellites are kept as far as possible from the MES antenna beam axis, as shown in Figure A 2.2.

In this case, the mobile earth station (MES) would see up to sixteen satellites, between 22° and 85° off the antenna beam axis. The view from the MES will depend on its location. If the MES elevation angle is below about 30°, some of the E-NSS-1 satellites close to the antenna beam axis will not be visible, but other E-NSS-1 satellites, in other loops, will become visible. Table A 2.9 shows the optimum interference budget for an MES with high elevation angle, concluding that the whole E-NSS-1 constellation is equivalent to 1.83 E-NSS-1 satellites on the axis of the MSS antenna beam, which value is assumed in Tables A 2.7 and A 2.8.

Off-axis angle (degrees)	22	26	40	46	≥48
Number of interfering satellites in set	2	2	2	2	8
Receive antenna gain (dBi)	9.0	7.5	0.0	-4.0	-5.0
Receive antenna gain (linear)	7.9	5.6	1.0	0.40	0.32
Relative received power per satellite	0.44	0.31	0.06	0.02	0.02
Relative received power per set	0.88	0.63	0.12	0.04	0.16
Total received power relative to one interfering satellite on beam axis	1.83				

Table A 2.9 : Optimum Budget of Interference from E-NSS-1 into MES

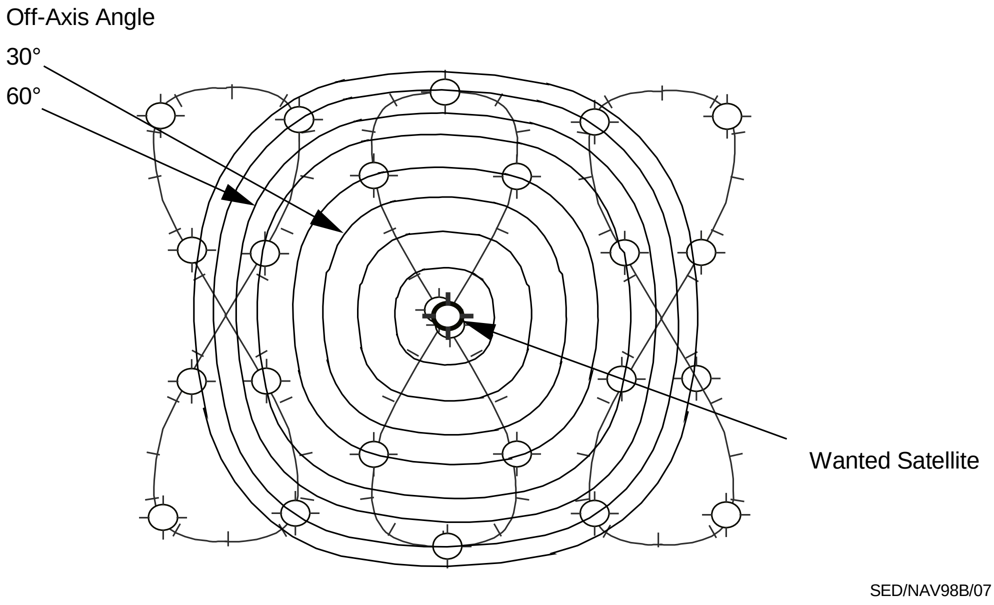


Figure A 2.3 : MES Interference from E-NSS-1 for worst-case MSS location

If the mobile-satellite is located at the centre of one of the loops of the E-NSS-1 constellation, two E-NSS-1 satellites will together cross the main-beam of the MES and the worst-case pattern of Figure A 2.3 will occur for periods of about an hour every three hours.

Table A 2.10 shows the resulting interference budget, concluding that the whole E-NSS-1 constellation is equivalent to 2.5 E-NSS-1 satellites on the axis of the MSS antenna beam.

Off-Axis Angle (degrees)	0	40	≥48
Number of interfering satellites in set	2	4	14
Receive antenna gain (dBi)	12.5	0.0	-5.0
Receive antenna gain (linear)	17.7	1.0	0.32
Relative received power per satellite	1.00	0.06	0.02
Relative received power per set	2.00	0.24	0.28
Total received power relative to one interfering satellite on beam axis	2.52		

Table A 2.10 : Worst-Case Budget of Interference from E-NSS-1 into MES

A 2.7 Possible Evolution of E-NSS-1

The above discussion has assumed that the E-NSS-1 system would use the minimum power necessary to achieve the current estimation of required performance.
Refinement of the design or future evolution of the E-NSS-1 system may require additional power, to give enhanced performance or to provide added protection for safety-of-life applications from existing and evolving terrestrial interference sources.
Calculations, bases on the link budget of Table A 2.8, show that additional E-NSS-1 transmitter power would allow improved navigation performance but would further degrade the MSS system performance, as shown in Table A 2.11. It may be necessary that the MSS system would permit such RNSS network enhancements in future years. Table A 2.11 also shows the equivalent thermal noise increase for E-NSS-1 and for the MSS system due to mutual interference from each other.

E-NSS-1 Transmitter Power	Navigation performance C/No	E-NSS-1 thermal noise degradation due to interference	MSS system penalty	MSS system thermal noise degradation due to interference
310 W	41.2 dBHz	763 %	7.3 dB	114 %
520 W	43 dBHz	763 %	9.2 dB	441 %
1000 W	45 dBHz	763 %	11.8 dB	1423 %

Table A 2.11 : Impact of enhanced E-NSS-1

ANNEX 3

Annex 3 Sharing study between MSS (Space-to-Earth) and the LSATNAV system

A 3.1 Introduction

This Annex assesses the maximum tolerable power level of MSS (space-to-Earth) emissions in the 1559 - 1567 MHz band in order to be compatible with the planned second generation radionavigation satellite system known as LSATNAV [5].

A 3.2 LSATNAV system description

A 3.2.1 General

The Low Satellite Navigation system (LSATNAV) consists of 64 satellites orbiting in Low Earth Orbit. They are equally spaced in eight orbital planes, each plane having an inclination of near 55°. Each satellite transmits navigation signals on the same frequency in both the L1 (1.6 GHz) and L2 (1.2 GHz) bands.

These navigation signals are modulated with a continuous bit stream which contains coded ephemeris data and time and a pseudo-random code used for pseudo-range measurements.

The LSATNAV navigation signals can be tracked simultaneously with navigation signals transmitted by the EGNOS system allowing a user equipment to provide accurate position determination in three dimensions at any location in Europe. Extension of the coverage could be obtained with the addition of other geostationary payloads in the system.

The LSATNAV navigation signal has a strong compatibility with the GPS signal so providing users band of this system with complementary information in case of difficult reception or for accuracy improvement.

The system operates on the principle of passive triangulation. The LSATNAV user equipment tracks the signal coming from at least four satellites. It measures then the pseudo-ranges and pseudo-range rates relative to these spacecraft and receives information about the satellite ephemeris and clock parameters. From these data, the three position and velocity coordinates of the user are calculated as well as the receiver clock and frequency offset.

A 3.2.2 Frequency requirements

The frequency requirements for the LSATNAV system are based upon an assessment of user accuracy requirements, space-to-earth propagation delay resolution, multipath reduction equipment cost, compatibility with existing equipments and radio-regulation rules provisions.

Each LSATNAV satellite will broadcast a dual frequency navigation signal, one in band L1, and one in band L2.
LSATNAV will use one of the following carrier frequencies in each band.

- in band L1 : 1561.098 MHz, 1589.742 MHz
- in band L2 : 1216.347 MHz, 1217.37 MHz, 1258.29 MHz

All of these frequencies are integer multiple of the frequency f_0=1.023 MHz.

The use of a second frequency provides the necessary frequency diversity for ionospheric delay removal, allowing user position to be resolved to within about 15 m.

The LSATNAV system provides world-wide navigation signals. The requirement for navigation safety demanded by such a service underscores the critical importance that other radio services do not cause harmful interference to the LSATNAV receivers.

A 3.2.3 System description

The LSATNAV system consists of three major segments: the space segment, the Mission and control segment and the user segment.

A 3.2.3.1 Space segment

As currently planned, the LSATNAV space segment has the following orbital characteristics:

- Number of satellites : 64 satellites
- Number of orbital planes : 8 orbital planes
- Number of satellites per orbital plane : 8 satellites
- Orbit inclination : 55 °
- Orbital plane separation : 45 °
- Satellite separation within the same orbital plane: 45 °
- Orbital period : 116 minutes
- Orbit altitude : 1450 km

The satellite is a passively stabilised satellite. The major elements of the navigation payload are:
- on-board clock for accurate timing,
- processor to compute and store navigation data,
- pseudo-random noise signal assembly for generating the ranging signal,
- transmitting antennas for both L1 and L2 bands.

Each satellite performs autonomous on-board orbit determination and clock shift estimation

A 3.2.3.2 Mission and control segment

The control segment performs the tracking, computation and monitoring functions needed to control all the satellites in the system on a day-to-day basis.

The control segment comprises the system control centre and a monitoring station network.

The monitoring stations measure, for each satellite, the clock shift relative to the main system clock as well as frequency shift. These data are then transmitted in quasi-real time by the monitoring stations to the satellites which update autonomously their clock parameters and orbit state.

These data are also transmitted to the system control centre for payload and system monitoring purposes.

A 3.2.3.3 User segment

The user segment is composed of a great number of different user receiver types with various performance characteristics.

The user set typically consists of
- an antenna
- a receiver/processor
- computer and input/output devices

It acquires and tracks the signal of 4 or more satellites in view, measure their RF transit times and doppler frequency shifts, convert them to pseudo-range and pseudo-range rates and solve for three-dimensional position, velocity and system time.

The antenna typically provides hemispheric coverage of both L1 and L2 frequencies. This omnidirectionnal antenna has no need for pointing to receive all visible satellite signals, but it will also not have much capability to discriminate spatially against interference.

A 3.2.3.4 Signal structure

The LSATNAV navigation signal consists of two modulated carriers, one in L1 and one in L2.

Signal on the two frequencies is biphase-modulated with a pseudo-random noise (PRN) having a chip rate of 1.023 10^6 chips per second. Each of these codes is added modulo 2 to a 50 bits/s binary navigation data stream prior to the phase modulation.

The function of PRN codes are:

- to provide multiple access among the different satellite since all the satellites transmit at the same frequency
- to allow measurement of time of arrival
- to allow rejection of multipath and interference signals

The 50 bits/s data stream is not yet defined.

A 3.2.3.5 Signal power and spectra

The LSATNAV satellites carry a shaped-beam antenna that compensates partially the distance variation from satellite to system users.

Transmitted signals are Right Handed Circularly Polarized.

A 3.3 Interference analysis

A 3.3.1 Assumptions

A 3.3.1.1 Frequency

LSATNAV emissions will use parts of the allocated frequency bands 1240-1260 MHz and 1559-1610 MHz not used by the existing GPS and GLONASS networks.

This interference analysis concentrates on the LSATNAV L1-b frequency signal which is contained within the MSS possible allocation. Table A 3.1 below shows the carrier frequency and code rate, and the minimum necessary bandwidth of 1.5 times the chip rate.

Ref.	Centre Frequency MHz	Code Rate Mchip/s	Frequency Band MHz
L1-b	1561.098	1.023	1559.5635 - 1562.6325

Table A 3.1: LSATNAV signal at L1-b frequency

A 3.3.1.2 LSATNAV link budget parameters

The transmitted power is 10 dBW on each carrier.

The transmitter antenna is designed to compensate for free-space loss variations. The gain at the edge of coverage is 3 dBi. The LSATNAV receiver antenna is assumed to have a maximum gain of 7dBi for a 90° elevation, and a value of -4.5 dBi for a 5° elevation (see RTCA DO-228, which corresponds to ITU-R PDNR 8D/TEMP/24, on technical characteristics of current and prospective RNSS receivers). Other analysis refer to a maximum gain of 3dBi for a 90° elevation: this 4dB difference would have a direct impact on the maximum MSS PFD level calculated in this analysis, which would be increased by 4 dB.

The intra-system interference is assumed to come from three LSATNAV LEO satellites, whose signals are present simultaneously with the studied signal, and are received with a mean relative power of 3 dB with respect of the wanted signal.

The intra-system interference power density is:

$$P_0 = 3 \cdot k \cdot P_I / f_c$$

where:

- 3 is the number of interference signals,
- k = 2/3 for a C/A code signal,
- P_I = mean received power per interference signal = -158.2 dBW,
- f_c = 1.023 MHz for the code chip rate.
-

With these assumptions, the value of P_0 is - 215.3 dB(W/Hz).

The receiver noise equivalent temperature is 500 K, so N_0= -201.6 dB(W/Hz). It has to be noted that N_0 is much higher than P_0, which means that assumptions made above for the evaluation of P_0 don't have much impact on the final result.

As a worst case, the MSS signal is received with the maximum receiver antenna gain: 7 dBi.

A 3.3.2 Maximum acceptable level for MSS emissions

The introduction of MSS emissions has the effect of adding a third component to the total noise: an « external system interference » (I_0) is added to the thermal noise (N_0) and intra-system interference (P_0) components.

The evaluation of the contribution of this new component I_0 to the total noise N_0+ P_0+ I_0 is made, depending on the maximum PFD level of the MSS emission. Classical interference allowances for external systems are:

- 6% for a single entry criterion: typical contribution to the total noise allowed for a single interferer. This corresponds to a 0.25 dB degradation of the noise plus intra-system interference floor (N_0+P_0).
- 25% for aggregate criteria: total contribution allowed for all MSS interfering systems. This corresponds to a 1 dB degradation of the noise plus intra-system interference floor (N_0+P_0).

Figure A 3.1 below shows the evolution of noise degradation due to external interference with respect to the power flux density of external interferer.

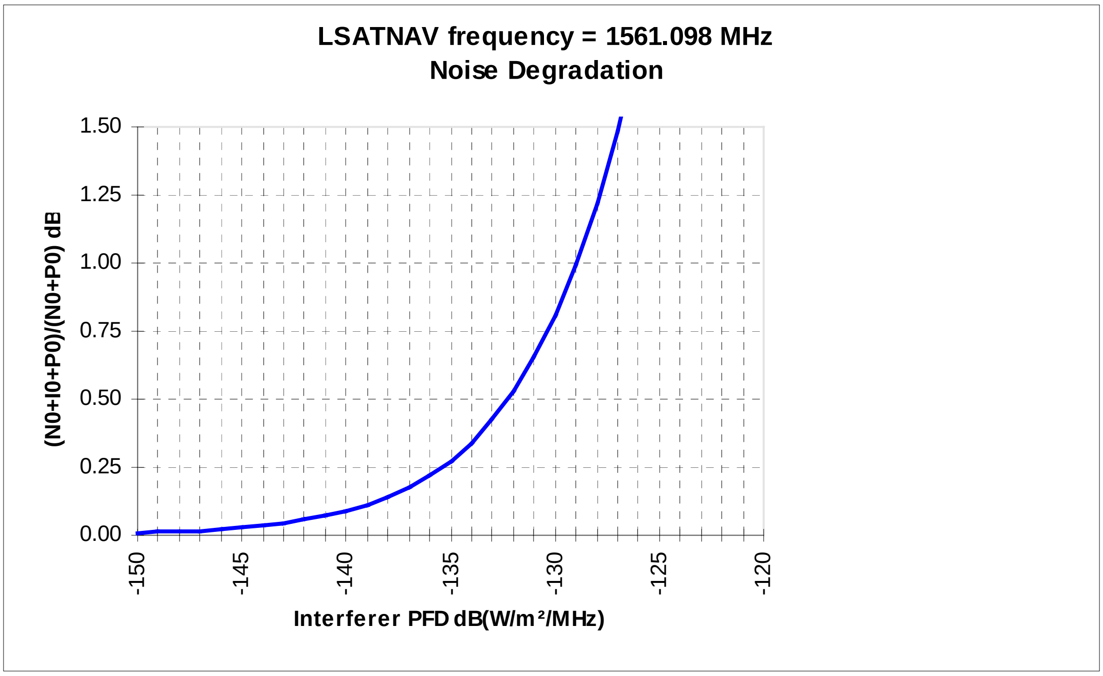


Figure A 3.1 : LSATNAV Noise Degradation

In addition, Tables A 3.2 and A 3.3 below detail the calculations which permit to assess the PFD level of MSS corresponding to a noise degradation (N_0+P_0+I_0)/(N_0+P_0) of 0.25 dB (6%) and 1 dB (25%) respectively.

LSATNAV		
Frequency	1561.098	MHz
Chip Rate	1.023	Mchip/s
SSPA RF Power	10.0	dBW
Losses	1.2	dB
Transmitter Antenna gain	3.0	dBi
EIRP	11.8	dBW
Path loss	168.5	dB
Receiver Antenna Gain (5°)	-4.5	dBi
Receive Signal Power	-161.2	dBW
System Noise temperature	500	K
Thermal noise density (N_0)	-201.6	dB(W/Hz)
Number of Intra-System Interfering Satellites	3	
Mean relative Powers of Interferers	+3.0	dB
Total intra-system Interference Power	-153.4	dBW
Intra-system Interference Power density (P_0)	-215.3	dB(W/Hz)
$N_0 + P_0$	-201.42	dB(W/Hz)
External Interference Power Flux Density	-135.4	dB(W/m²) in any 1 MHz
Receiver antenna gain (90°)	7.00	dBi
Antenna peak effective area	-18.3	dBm²
Received Interference power density (I_0)	-213.7	dB(W/Hz)
$N_0+P_0+I_0$	-201.17	dB(W/Hz)
Noise degradation due to External Interference	0.25	dB

Table A 3.2 : MSS PFD limit for LSATNAV 6% noise degradation

LSATNAV		
Frequency	1561.098	MHz
Chip Rate	1.023	Mchip/s
SSPA RF Power	10.0	DBW
Losses	1.2	DB
Transmitter Antenna gain	3.0	DBi
EIRP	11.8	DBW
Path loss	168.5	DB
Receiver Antenna Gain (5°)	-4.5	DBi
Receive Signal Power	-161.2	DBW
System Noise temperature	500	K
Thermal noise density (N_0)	-201.61	dB(W/Hz)
Number of Intra-System Interfering Satellites	3	
Mean relative Powers of Interferers	3	DB
Total intra-system Interference Power	-153.4	DBW
Intra-system Interference Power density (P_0)	-215.3	dB(W/Hz)
$N_0 + P_0$	-201.42	dB(W/Hz)
External Interference Power Flux Density	-129	dB(W/m²) in any 1 MHz
Receiver antenna gain (90°)	7.00	dBi
Antenna peak effective area	-18.3	dBm²
Received Interference power density (I_0)	-207.30	dB(W/Hz)
$N_0+P_0+I_0$	-200.42	dB(W/Hz)
Noise degradation due to External Interference	1.00	dB

Table A 3.3 : MSS PFD limit for LSATNAV 25 % noise degradation

A 3.4 Conclusion

The MSS PFD limits corresponding to a noise degradation of 6% (0.25 dB) and 25% (1 dB) have been assessed and are indicated in Table A 3.4 below.

Noise degradation	PFD limits
6 %	-135.4 dB(W/m²) in any 1 MHz
25 %	-129 dB(W/m²) in any 1 MHz

Table A 3.4 : MSS PFD Limits to protect LSATNAV

In typical sharing / coordination studies, the 6% figure usually corresponds to a single entry criteria while the 25% figure corresponds to an aggregate criteria.

However, one should take into account the specific nature of MSS systems: it is agreed within SE28 that sharing between MSS systems on a co-frequency and co-coverage basis is not practical. Regulatory provisions should be adopted in order to ensure this (for instance a footnote stating that sharing between MSS systems in 1559 - 1567 MHz should only be permitted on a band segmentation basis). The PFD limit obtained for 25% of noise degradation would then correspond to the contribution of a single MSS system.

In this context, the introduction of a new allocation to MSS in the Space-to-Earth direction in the 1559 - 1567 MHz band would be compatible with the planned LSATNAV system under the condition that a maximum PFD level of -129 dB(W/m²) in any 1 MHz be respected by each MSS network.

ANNEX 4

Annex 4 Interference from E-NSS-1 into MSS

A 4.1 Simulation methodology

A simulation was performed to assess whether a MSS system can operate in the interference environment caused by the E-NSS-1 system. The following methodology was used.

An MES is assumed to be at a given location. The available C/N for the MES to operate satisfactorily is then calculated at appropriate time intervals over a period of time as described below.

1. At each time step, the interference power spectral density from each visible E-NSS-1 satellite is calculated:

$$P_i = P_{ENSS} + G_{ENSS} - \Delta G_{ENSS} - L_b + G_r - 10\log(f_c)$$

where:

- P_{ENSS} is the augmented E-NSS-1 satellite transmit power = 23.7 dBW;
- G_{ENSS} is the peak E-NSS-1 satellite antenna gain = 18 dBi
- ΔG_{ENSS} is the satellite antenna discrimination in the direction of the earth station in dBi (Figure A 4.1 shows the E-NSS-1 satellite pattern);
- L_b is the free-space propagation loss in dB;
- G_r is the MES receiver antenna gain in dBi (Figure A 4.2 shows the MES antenna pattern).
- f_c is the E-NSS-1 chip code rate = $3.072 \cdot 10^6$ chips/s

2. The aggregate E-NSS-1 interference spectral density into the MES is then calculated:

$$I_0 = 10\log\left(\sum_i 10^{P_i/10}\right)$$

3. The available MSS signal power is calculated:

$$C_0 = \text{pfd\_limit} - 10\log\left(10^6\right) + 10\log\left(\frac{\left(\frac{300}{f}\right)^2}{4\pi}\right) + G_r - \alpha - \beta$$

where:

- PFD_limit is the proposed MSS PFD limit of -112 dB(W/m^2/MHz)
- f is the frequency in MHz, 1561 MHz
- α is a random variable representing the variation in MSS PFD between beam peak and beam edge, uniformly distributed between 0 and 2 dB
- β is a random variable representing the variation in propagation attenuation, uniformly distributed between 0 and 2 dB.

4. Finally the required MSS C/N is calculated:

$$\frac{C}{N} = C_0 - 10\log\left(10^{\frac{N_0}{10}} + 10^{\frac{I_0}{10}}\right)$$

where N_0 is the system noise temperature of the MES = 10log(kT) = -199.1 dBW/Hz (corresponding to a noise temperature of T = 900 K).

A 4.2 Simulation results

A large number of simulations were run with the MES location varied over the entire service area of a MSS satellite. The following cases were studied:
- GSO positions: 20°, 25°, 30°, 35°, 40°, 45° and 50° East longitude;
- MES locations: as per Table A 4.1.

Lat (°N)	Lon (°E)	Lon (°E)	Lon (°E)	Lon (°E)	Lon (°E)
60	GSO-45°	GSO-20°	GSO	GSO+20°	GSO+45°
45	GSO-60°	GSO-30°	GSO	GSO+30°	GSO+60°
30	GSO-70°	GSO-30°	GSO	GSO+30°	GSO+70°
15	GSO-70°	GSO-30°	GSO	GSO+30°	GSO+70°
0	GSO-70°	GSO-30°	GSO	GSO+30°	GSO+70°

Table A 4.1: MES locations used in simulation
(“GSO” is the longitude of the MSS satellite)

These cases span all the possible geometrical alignments between the E-NSS-1 system and the MES receiver.

The overall results can be seen in Figure A 4.3. The MSS system would thus have to be designed for a C/N requirement of around 5 dB. This can be done for example using QPSK modulation with 1/2 FEC.

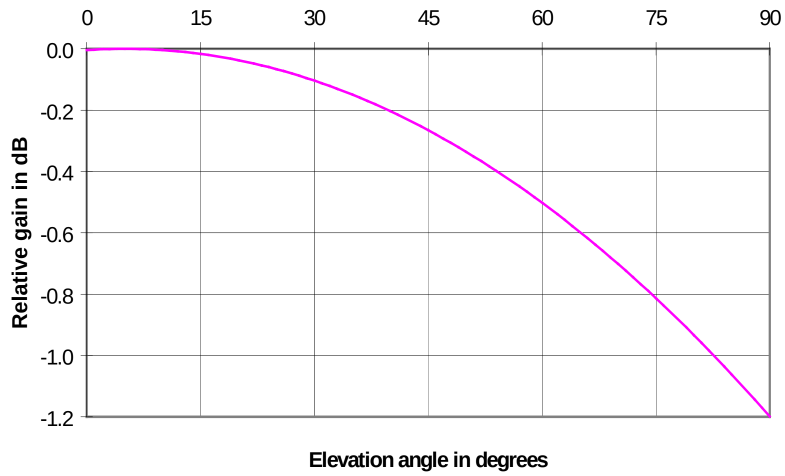


Figure A 4.1: E-NSS-1 satellite antenna pattern

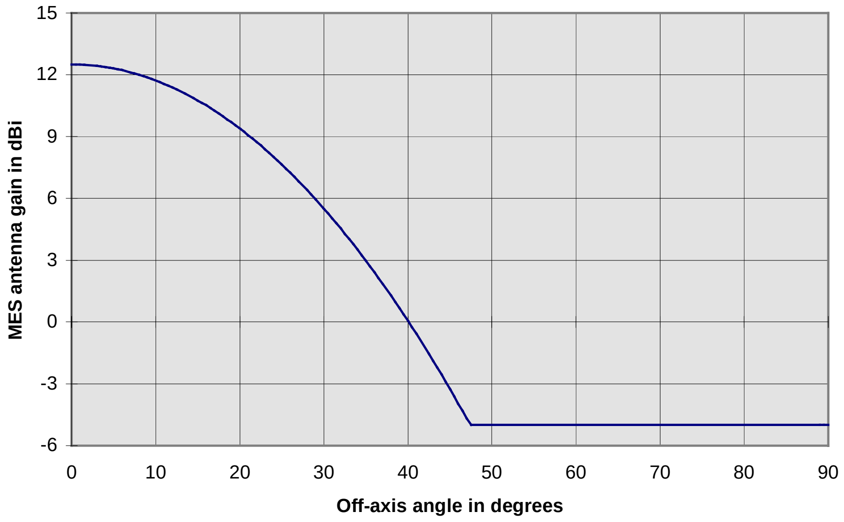
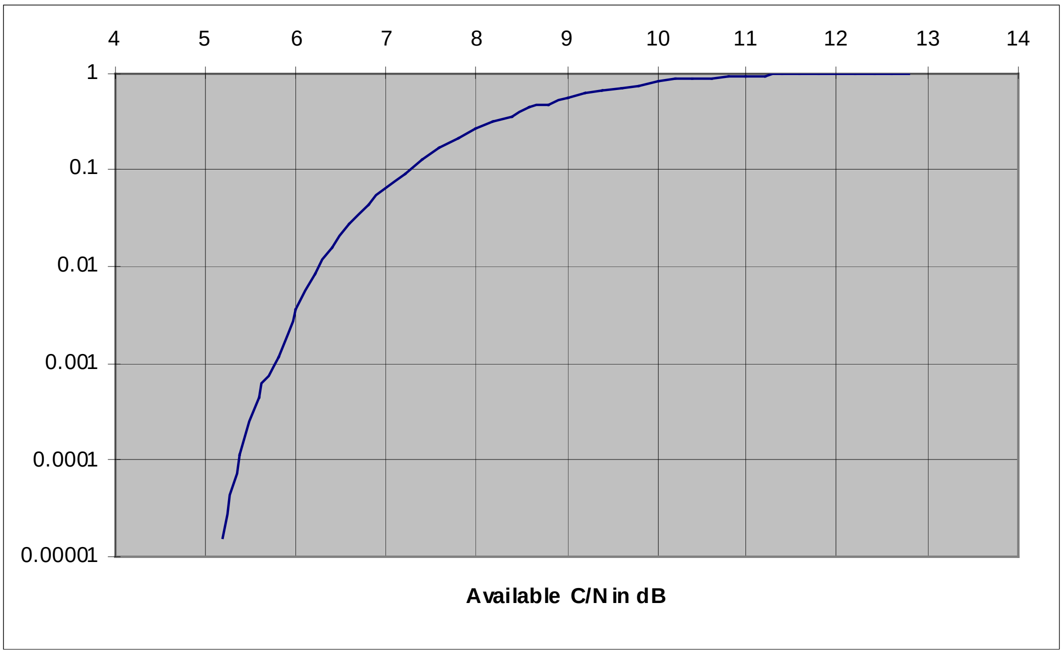


Figure A 4.2: MES antenna pattern

Figure A 4.3: Simulation results



ANNEX 5

Annex 5 Interference from MSS into Pseudolites

Pseudolites are ground-based transmitters which are assumed to use the same transmission characteristics as GPS and to be placed at 1561.19 MHz. For this study, the GPS C/A code protection requirement used in Annex 1 has been assumed. It was also assumed that the minimum received signal power from Pseudolites ranges between 0 dB and 3 dB greater than the minimum GPS C/A code signal power, i.e. between -160 dBW and -157 dBW. This appears to be a necessary assumption, for compatibility purposes. The pseudolite transmitter power will have to be set according to the gain of the airborne receiver antenna towards the pseudolite. As it is expected that this antenna will be the existing GPS antenna, its gain towards the pseudolite may be -6 to -10 dBi or even less. Ten intra-system interferers at the same level as the wanted signal have been assumed. This may be an optimistic assumption, given that the ranges of pseudolites and the receiver antenna gain towards different pseudolites may vary significantly. It has then been assumed that 25% of this interference could be assigned to a single interferer, as in Annex 1. The deterministic calculation of the PFD required to protect pseudolites under these assumptions, shown in Table A 5.1, leads to a PFD limit of between -121.6 and -125.4 dB(W/m^2) in any 1 MHz.

Nominal received signal power	-157.0	-160.0	dBW
Code rate	1.023	1.023	Mchip/s
Minimum received power spectral density	-217.1	-220.1	dB(W/Hz)
I / S margin	24.0	24.0	dB
Total tolerable noise plus intra-system and external interference PSD (No+Po+Io)	-193.1	-196.1	dB(W/Hz)
Thermal noise PSD (No)	-201.5	-201.5	dB(W/Hz)
Number of interferers	10	10	
Code cross-correlation factor	-1.8	-1.8	dB
Intra-system interference PSD (Po)	-208.9	-211.9	dB(W/Hz)
Total tolerable external interference PSD (Io)	-193.9	-197.7	dB(W/Hz)
Ratio single- / multiple-entry interference	-6.0	-6.0	dB
Tolerable single-entry external interference PSD	-199.9	-203.7	dB(W/Hz)
Maximum antenna gain towards interferer	+7.0	+7.0	dBi
Maximum tolerable interference power flux density	-181.6	-185.4	dB(W/m^2.Hz)
MSS power flux density limit in any 1 MHz	-121.6	-125.4	dB(W/m^2)

Table A 5.1: Pseudolite protection

ANNEX 6

Annex 6 Discussion of multiple MSS networks

Generally, MSS systems are designed to operate at the minimum C/N required, i.e.

$$\left(\frac{C}{N}\right) = \left(\frac{C}{N}\right)_{Threshold}$$

Further, since the MSS allocation under study would be shared with the RNSS, a MSS system implemented in this band is likely to operate in an interference-limited mode, i.e.

$$\left(\frac{C}{I_{RNSS}}\right) = \left(\frac{C}{N + I_{RNSS}}\right) = \left(\frac{C}{N}\right)_{Threshold}$$

In either case, interference from other networks has to be limited to 6% of the total noise, i.e.

$$\left(\frac{C}{I_{MSS}}\right) = \left(\frac{C}{N + I_{RNSS}}\right) + 12 \text{ dB} = \left(\frac{C}{N}\right)_{Threshold} + 12 \text{ dB}$$

For example if the threshold C/N were 6 dB, C/I_{MSS} would have to be 18 dB. In this scenario, co-frequency, co-coverage sharing is not feasible, since 18 dB antenna discrimination would not be available from MES antennas.

Thus, the assumption should be that only one MSS system will be operating at a given frequency in a given coverage area.