Compatibility between GNSS receivers and Stacom Transmitters on-board an aircraft - Technical Assessment

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Abstract

DERA, with support from Racal Avionics plc and Atlas Avionics Ltd and have carried out a study for EUROCONTROL into the essential technical requirements of mobile earth station terminals, operating to Non-Geostationary Satellite systems, to provide protection of Radio Navigation Satellite Service (RNSS) receivers, operating in the frequency band, 1559 - 1610 MHz. The signals used by services operating in this band, include the US Global Positioning Service, GPS NAVSTAR, and the Russian GLONASS as well as the proposed European Navigation Satellite Service, E-NSS-1. This study, in a separate companion report, provides material which indicates the organisations and processes involved in the approval and definition of these new Satcom standards and suggests avenues that can be used to protect aviation’s best interests.
Executive summary

This report is structured to first indicate the current spurious emission limits specified for NGSO services which through a discussion on antenna isolation on an aircraft airframe, then looks at the emission limits and their effects on the performance limits as specified for the Global Navigation Satellite System requirements of ICAO.

In the design of NGSO systems, installation designers and system designers have to consider the trade offs necessary between and antenna isolation and additional constraints on the NGSO systems.

There are two basic NGSO systems operating between 1610 and 1626.5MHz. In the lower band 1610-1616MHz there are spread spectrum systems (CDMA), while in the higher band time, domain multiple access systems operate (TDMA). The channel band width for the CDMA systems are about 1.25MHz while those of TDMA type are less.

Out of band and spurious emission from CDMA systems, are more difficult to control near to operating band edges than TDMA systems with lower channel bandwidths, and due to the highly sensitive nature of GNSS systems close to 1610MHz (-110dBm), large isolations are required between these and high power NGSO systems (+33dBm) i.e 143dB.

This large isolation, particularly for GLONASS can only be achieved by filtering of NGSO emissions, suitable separation (metres) of the respective antennas on an aircraft platform, or consideration of operating restrictions (regulatory means). In summary the report indicates:

- NGSO systems above 1616 MHz showed compatibility for GNSS receivers if the following was considered.

That some smoothing of the aeronautical NGSO emission limits mask occurs at 1605MHz, or the provision of small additional attenuation be given for GLONASS. Additional filtering requirements, could be provided if additional physical separation of GNSS and NGSO antenna was provided. Additional filtering at the receiver’s rf input, would introduce potential affects on navigation performance.

- For NGSO systems operating above 1610MHz (and below 1616MHz) compatibility with GNSS is difficult.

Unwanted emissions from the NGSO system in the band 1610 to 1616 MHz require large isolations from the GNSS antenna in order to reduce the levels at the receiver to below the current ICAO SARPS specification. Major modification of NGSO system elements are required. Limitations in terms of frequency of operation and more stringent emission limits -80dbW/MHz @1610MHz may also have to be applied.
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1. Introduction

ICAO has stated an intention to move to Global Navigation Satellite System GNSS as the basis for radionavigation in the 21st century. In Europe EUROCONTROL has endorsed the use of GNSS (GPS) for B-RNAV routes, that can not be flown with traditional ground radionavigation aides. GPS is also being used as a component in the evaluation of Reduced Vertical Separation Minima being conducted over the North Atlantic. Meanwhile there is also an explosion in the use of satellite communications for business and personal use. Detailed specifications and standards are available for Land Mobile Terminals, and some aeronautical GSO satellite terminals. The current aeronautical usage is with geostationary satellites, the new systems are designed for Non-GSO use. These Non-GSO systems having the potential, when installed on an aircraft to interfere with RNSS receivers. This is due to the reduced frequency separation between the two systems.

Initial GNSS operation (GNSS-1) is based on the US Global Positioning System (GPS), and the Russian GLONASS, combined with one or more wide area augmentation schemes, eg the US WAAS and European EGNOSS that employ additional range and integrity transmissions from geostationary satellites. However the continued availability of GNSS is a significant issue due to its susceptibility to interference.

Degradation of the performance of a GNSS receiver is due to increased noise in the code and carrier tracking loops. The noise can be traced to the result of the convolution of the interference with the GNSS code spectrum. Tight filtering is required in the GNSS receiver's RF and IF sections to ensure that interference present at the antenna outside of the GNSS signal bandwidth is rejected. These interference signals can be generated from on-board transmitters, or other external aircraft sources, e.g TV transmitters, harmonics of land mobile systems, or radars. This report concentrates on the issue of the effects of on-board transmitters, specifically Mobile Earth Stations operating in the band 1610-1626.5MHz and the requirements for spurious, harmonic and noise levels to protect GNSS receivers.

SATCOM transmission powers require filters with sharp cut offs to prevent interference into the RNSS receivers. Although interference from out-of-band signals into RNSS may be reduced by incorporating high order RF and IF filters, a limit is imposed by the devices phase linearity, size and weight in respect of the rejection that can be achieved against nearby strong signals. Unfortunately, however sharp the filter response, it can not protect against wide band noise generated by frequency synthesis in adjacent transmission systems that falls within the receiver's pass-band. The only jamming resistance against such noise is provided by the GPS processing gain, the ratio between the despread signal and the carrier tracking bandwidth, typically 5 Hz.
Any noise not filtered out will increase the noise floor of the GNSS receiver and degrade the receiver’s performance. It is also essential that the filters are linear so that they do not cause any harmonics which could fall inband to the wanted signal from the product of two or more out of band signals. Front end linearity must be maintained to a high power, typically -50 dBW and a high burn out power typically 1 w constant are specified. Higher sampling rates used in narrow correlator designs to reduce errors caused by multipath signals substantially increase the bandwidth of the rejection filters. Interference criteria for non-geostationary SATCOM MSS are indicated in ref 1 An interference rejection requirement for SPS GPS receivers was first stated in RTCA MOPS, ref 2 as reproduced at Figure 1

1.1 GNSS receiver protection

The power out of an RNSS receiver correlator can be written for an interfering signal $I(f)$ of 1 W/Hz from frequency $F1$ to $F2$ as Eq 1-1.

$$\text{No}(f) = \int_{F1}^{F2} S_{\text{gnss}}(f) \text{df}$$  \hspace{1cm} (1-1)
The rejection of interference caused by the despreading of the GNSS signal in the receiver is shown Figure 2, for GPS. Graphs are plotted for various interference bandwidths against centre frequency. From the graphs the receiver's processing gain against the interference can be established and used to calculate the degradation in carrier to noise ratio $C/N_0$. The resultant $C/N_0$ in the receiver can then be calculated by removing the rejection from the input interference power and compared to the post correlation satellite signal power. A plot of the Processing gain for GLONASS is given in Figure 3.

Accuracy and reductions in the capability to read the navigation data can then be calculated from well known formula. Figure 4 shows the laboratory results of tests of interference into a GPS GLONASS receiver. As can be observed inband interference has approximately the same effect on both GPS and GLONASS and completely jams the receiver at jammer to signal ratios of ~25 dB which is equivalent to an interference with a power of -140 dBW. The effect of out of band interference is due to filter rejection and the effect of the code processing gain, which are observed to be better for GPS than for GLONASS.
Fig 2-3
Figure 3 Variation of GLONASS Processing Gain as a function of Bandwidth and Frequency Offset from the Carrier.

Figure 4 Narrow Band Interference Rejection
Although the primary down links for GPS and GLONASS are in a frequency band allocated to the RadioNavigation Satellite Services (RNSS) interference into GNSS can arise from aircraft transmitters used for other aeronautical services. Low power near-band RFI can interfere with GNSS reception by increasing the noise power into the detection and signal tracking processes.

In order to protect GNSS receivers against interference specifications for isolation and spurious transmissions from transmission systems on board the aircraft and on the ground must be defined. Supplement 1 to ARINC characteristic 761, provides guidance on the separation of some high gain antennas to GPS. Two examples for the B777 and B767 are given which indicate a range from 46 to 52dB. A legacy value of 40dB is currently used that was derived in ARINC characteristic 741.

To protect essential services the ITU requires in RR S.4.10 (953), RR S.1.169 (163) and RR S.4.5 (343) that member states ensure that harmful interference is not generated by licensed systems, however the regulations are subjective. As states are using the electromagnetic spectrum as a source of revenue there are national economic pressures to achieve as high a utilisation as possible which has resulted in a drive for band sharing. However full compatibility of systems are often compromised. Such issues were fundamental to Recommendation ITU-R M1343 Ref 3, that allowed for the Satellite Personal Communications Network (S-PCN) Mobile Earth Stations (MES) to radiate up to -70 dB/MHz, which would causes significant interference into GNSS receivers at up to 100 m.

In a previous study for the UK National Air Traffic Services (NATS), into the environment for GNSS operation, satellite communications (Satcoms) in the 1626.5 to 1660.5 MHz band were identified as a problem. Prior to the 1997 World Radio Conference, (WRC-97) the band was split into several divisions for Maritime Mobile, Land Mobile and Aeronautical Mobile. The frequencies allocated to Aeronautical, earth to space transmissions were between 1 645.5 to 1656.5 MHz at the high end of the band. The frequency separation from GNSS was sufficient to allow the development of filters and diplexers that provided sufficient isolation for GNSS operations. Also the frequency selection on the aircraft was restricted to ensure any intermodulation products did not fall within the GPS band.

However at WRC-97 the band was assigned a generic allocation. Operation of GNSS and Satcom equipment on-board ships has demonstrated that significant interference into GPS receivers was present due to spurious transmissions from the Maritime Inmarsat terminals. When the specifications for aeronautical mobile satellite equipment were developed in ARINC Characteristic 741, particular care was taken to reduce the out of band emissions that fell in the GNSS band.
An allocation was made for MSS (Iridium and GLOBALSTAR) frequencies at WRC - 92 in the 1 610 - 1 626 MHz band initially (One direction of Iridium on a secondary basis); The MSS allocation has caused the Russian Federation to move GLONASS to 1 597 - 1 605 MHz, by the year 2005 as it overlapped the frequency band currently used above 1 610 MHz Out of band spurious transmissions from MSS terminals remain a problem and were one of the reasons why RTCA under SC159 commenced an investigation into radio frequency interference into GNSS. The results of the study were published in RTCA DO-235.

There is a further complication regarding the frequencies that must be protected. In June 1997 ESA and Alcatel registered with the ITU an interest in the frequencies around 1559.05 to 1 563.14 MHz and at 1 587.69 to 1 591.78 MHz, Fig 2-5 for a future European System. If a future European system will use these frequencies then consideration must be given to protecting them during the derivation of any future ARINC Characteristics. The system characteristics of these systems are still under development, however the general characteristics are likely to be very similar to GPS and GLONASS, i.e a Code Division Multiple Access type modulation. Preliminary information indicates that E-NSS-1 will have a 3 mega chip per second code rate, and a received power of about 7dB more than GPS or GLONASS.

Figure 5 Frequency Allocations and Applications Surrounding the ARSS Band
1.2 Aeronautical Satcom

The Airlines Electronic Engineering Committee (AEEC) drafted under ARINC Characteristic 741 specifications for aeronautical Satcoms equipment. Considerations were given in the specification to the design of the aircraft installation including antenna position, diplexer design, spurious emissions from the power amplifiers and frequency synthesisers and restrictions in the selection of the active channels to prevent any intermodulation products falling in the GNSS band. Such consideration became significantly more difficult if GLONASS and GPS have to be considered as GLONASS has a smaller frequency separation from Satcom band and a wider bandwidth. Antenna isolation specification of 40 dB, equivalent to a separation of 3m are standard for aircraft GPS and AMS(R)S antennas. SATCOM terminals spurious emission products should be at or below -145dBW (-115dBm) at the GNSS antenna. (The 40 dB isolation provided protection from two twenty watt carriers producing 7th order products in the GNSS band with the antenna steered towards the GNSS antenna).

ARINC Characteristic 741 defines the isolation that must be generated in the diplexer (Type A) for operation between AM(R)S and GPS. However Type A may not (does not) provide sufficient protection into a GLONASS receiver. Additional rejection requirements were specified to enable simultaneous operation of Satcoms with GPS GLONASS and TFTS (Type B). In addition frequency management techniques are required to prevent 3rd and 5th order intermodulation products falling inband to GPS, GLONASS and TFTS. A study into the feasibility of the Type B diplexer, was completed by Phase Devices (now part of COMDEV). The technical specification could only be achieved by expensive ceramic loaded cavities and to date these type of diplexers have not been developed. There are no production equipments or aircraft installations yet, high initial development charges will occur.

An example of a Satcom system is the Racal/Honeywell MCS-3000/6000 terminal equipment designed to transmit digital communication data at L band using INMARSAT. The equipment can select multiple frequency transmissions in 2.5 kHz steps between 1626.5075 to 1660.4925 at 0.6 kbps or 1626.5175 to 1660.4825 MHz at 21.0 kbps. The 0.6 kbps signals are modulated onto a carrier using Bi-Phase Shift Keying (BPSK) and the 21.0 kbps signals are modulated using Quad-Phase Shift Keying (QPSK). The total power emitted from the airborne transmitter is specified as 25.5 dBW which is 6 dB above the requirement for INMARSAT 3. The output power can be controlled by the high power amplifier (HPA) over an 18 dB range in 1 dB steps. The MCS-3000/6000 equipment has the capacity to output a maximum of 27 dBW (HPA can produce 60W) in ‘unfavourable geographic or flight conditions’.

The maximum power of harmonics, discrete spurious and noise of other unwanted products transmitted in the GNSS band from the output of the transmitter must be below -155 dBc/MHz. The effect of any non-linearities (and hence intermodulation products) as a result of these transmissions arriving at a GPS/GLONASS receiver’s antenna and RF stages will degrade GNSS performance.
Allocations for the Non-Gso mobile satcom systems in the 1610 - 1625 MHz band present a new and more difficult problem. The system designs (including diplexers) must provide sufficient rejection between the MSS transmissions at +7 dBW into GLONASS, E-NSS-1 and GPS. The highest frequency operational carrier of GLONASS is 1604.61MHz, which if the bandwidth of the modulation is considered (0.511MHz and potential use of narrow correlators, the radio spectrum requiring protection extends potentially to 1606.5MHz), means the rejection must be achieved by 1607 MHz, that is in less than 3 MHz. Such a design is extremely difficult and costly given the size and weight constraints. Beyond this however, the Russian Federation has stated a requirement to operate to beyond 1607MHz.

It should be noted that the ITU-R Recommendation M.1343 concerning spurious emissions from MSS terminals (1610 - 166.5 MHz), has resulted in the noise floor being raised by 1 dB in the vicinity with a transmitter at 100 metres separation and additional antenna rejection, effectively reducing the maximum C/No that can be achieved from the satellites. In this analysis the land mobile MSS (1610-1626.5MHz) effect is not included.

Currently ARINC are developing Characteristic 761, Second Generation Aviation Satellite Communication Systems, that includes revised specifications for Inmarsat operation and introduces the new ICO, Iridium and GLOBALSTAR systems. This analysis focuses on requirements of these systems. Figure 6 indicates the initial RTCA document for MSS services in the band 1616-1626.5MHz.

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**Figure 6 Initial Satellite Communications Specifications from ARINC 761**
2. Protection of RNSS from MSS emissions.

2.1 Introduction - Mss Emissions

This section of the report will determine the level of spurious emissions from MSS systems. Data has been correlated from various industry documents which are currently available.

It should be noted that the majority of documents used to determine emissions from Non-Geostationary MSS emissions are not yet formally adopted. The exception are those documents relating to the in-service AMSS system operating through the Geo-synchronous Inmarsat satellite constellation.

A typical aeronautical system includes the main terminal, a high power amplifier and a diplexer to split the transmit path from the reception elements. In the case of Iridium, the transmit and receive paths are in the same band. Therefore the tx and rx elements for this system contribute to the spurious emission characteristic.

2.1.1 Emission Limits

In this section the detailed emission characteristics limits placed upon the Aeronautical Earth Station (AES) evaluated. The first section details the published values for the existing AMSS. Secondly the limits for the new generation LEO/MEO Satellite systems (NGSO) are discussed. Finally, the limits for the two systems are compared and differences explained or identified as being inconsistent.

2.1.2 AMSS Limits

The following emission masks encompassing the satellite navigation bands have been collated from the current system specifications for the AMSS system.

Table 1 presents the specification limits in there published form.

In order to make a visual comparison easy the emission limits presented in figures 1 through 4 have been adjusted to a common baseline scale of dBm/Hz rather than dBW in a given bandwidth or dBc relative to the wanted signal. Obviously this scaling does not show the measurement bandwidth associated with the band of interest. However this data is contained in table 1 as a cross reference.

Figure 7 shows the values determined from the three DLNA characteristics contained in the AMSS ARINC 741 characteristic. Figure 8 shows the emission limits specified in RTCA DO-210C. Finally, Figure 9 &
Figure 11 show the characteristics for navigation band emissions as detailed in the Inmarsat System Definition Manual for Type A & B DLNA configurations.
### Table 1 Comparison of Published AMSS Emission Limits (see reference list)

#### AMSS Emission Limits

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Note: Figures presented under ARINC 741 have been determined based upon the specification of HPA output and DLNA Transmit to Antenna Port Isolation. Due to transition bands defined in the filter specification the figures in these tables represent the worst case level for the particular frequency band. Exact performance levels are shown in the associated graph detailing the navigation band.
Figure 7 Plot of Navigation Band Emission Limits Detailed in AMSS ARINC 741 Characteristic
Figure 8 Plot of Navigation Band Emission Limits Detailed in RTCA DO-210C
Figure 9 Plot of Navigation Band Emission Limits Detailed in Inmarsat Aeronautical SDM for Type B DLNA
Figure 11 Plot of Navigation Band Emission Limits Detailed in Inmarsat Aeronautical SDM for Type A DLNA
2.1.3 AMSS Emissions Conclusions

From the table and graphs presented above it can be seen that the GPS band from 1565 to 1585 MHz is required by all of the standards to have a limit of at least \(-190\text{dBw/Hz} \approx -160\text{dBm/Hz}\). All of the specifications agree that the measurement bandwidth shall be 1MHz for this band resulting in a consistent level of at least \(-130\text{dBW/MHz}\).

The GLONASS frequency band is more confused with different specification being applied by the different bodies as well as options being available within one of the specifications. To further complicate the issue the frequency band occupied by the GLONASS system is subject to changes during the next 5 to 10 years as the Russian Federation attempt to limit the occupied bandwidth thus ensuring a greater spectral separation for MSS transmissions.

AMSS emissions in the GLONASS frequency band can be anything up to 50dB higher than those for the GPS band according to the specifications. However, it should be noted that the specifications do recommend that when AMSS system are installed on aircraft having GLONASS systems then the tighter specifications would be necessary. This limits the emissions in the GLONASS band to being no more than \(~20\text{dB}\) above the GPS band.

It should also be noted that in general measurements of actual equipment performance shows that emissions are in the order of 10 dB better than the specification.

2.1.4 MSS Limits

Specifications for NGSO systems are currently only at a drafting stage within the organisations developing these standards. Therefore the following figures represent a snapshot of the current state of these standards at the time of writing this report.

As with the AMSS limits reported in the previous section the NGSO limits are shown in the published form in Table 2 and in \(\text{dBc/Hz}\) in the associated figures.

Four documents have been reviewed in the determination of the NGSO emission limits, these are:-

- Draft RTCA MOPS (generated by W/G-1 of SC-165)
- ARINC Characteristic 761
- ETSI TBR 041
The RTCA MOPS and ARINC 761 documents only contain detailed information only on the IRIDIUM system emissions performance thus far. Although ARINC 761 contains appendices for the Globalstar and ICO NGSO systems it does not yet have any emission limits in place.

The RTCA MOPS considers only the transmit frequency band from 1616 – 1626.5 MHz and can therefore be considered to only cover the IRIDIUM system at the present time.

The ICO system will not be considered further within this document as the system will be operating in the transmit band of 1985 to 2015MHz. It is considered that this degree of spectral spacing will enable the ICO system to achieve adequate emission limits in the Navigation band without the necessity for undue complexity in the transmit filtering. This is not to say that protection of other parts of the spectrum closer to the ICO transmit band may not require special attention.

ETSI TBR 041 can only be considered to cover land based systems, including handheld terminals.

*It is very important to recognise that the emission limits of this standard were developed from a sharing scenario, whereby the aircraft terminals were separated by a minimum of 100ft from the NGSO MES and that there existed a differential gain of -5.5 dBi between a GNSS signal at 5 degree elevation and an NGSO interferer on the ground.*

This can be seen clearly from the limits placed upon the satellite navigation band, as shown in Figure 14 where the limits are in the order of 40dB higher than either the IRIDIUM specification in Draft RTCA MOPS or any of the AMSS specifications.

A technical committee of ETSI is in the process of development of a draft standard for Satellite Earth Stations and systems (DEN/SES 00023).

2.1.5 MSS Emissions Conclusions

At this moment in time we are unable to identify any adopted/approved aeronautical specifications for the NGSO band of 1610 to 1626.5MHz. The above draft specifications are currently in various stages of development. However, even within these it is mainly the IRIDIUM system which appears to be being concentrated upon.
Although the ETSI TBR 041 specification is more generic in its specification of the complete frequency band, it only covers ground based systems and no regard to the particular constraints of an avionic installation are included at present.

The Draft specification, DEN/SES 00023, being developed by an ETSI Technical Committee specifically deals with Aeronautical mobile earth stations. Table 5 shows, in the left hand columns, the current specification for emissions from a transmitting terminal operating in the band 1610 to 1626.5 MHz. Development of this specification is still ongoing, for example Table 5 also shows, in the right hand columns, a proposal from the Russian Federation for a modification to the specification to enhance Glonass frequency band protection. The proposal is believed to have been tabled at an Ad Hoc meeting of the TC in September 1998, the outcome of this change unknown.

In addition to the organisations and specifications identified above it is known that the ICAO AMCP working group A is addressing the issue of Non-Geostationary Satellite Services (NGSS). This group has identified that the use of such systems as feasible, although more work was require to determine “its acceptability on the basis of a demonstrated verification of performance and benefits”. The working group is requesting a change in their terms-of-reference which would allow them to develop documentation and accomplish activities in support of implementation of AMS(R)S through NGSO systems.
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<td>1628.5</td>
<td>-60</td>
<td>0</td>
</tr>
<tr>
<td>1629</td>
<td>1631.5</td>
<td>-60</td>
<td>0</td>
</tr>
<tr>
<td>1632</td>
<td>1636.5</td>
<td>-60</td>
<td>-10LOG10(N)</td>
</tr>
<tr>
<td>1636.5</td>
<td>1646.5 dec to -78</td>
<td>-10LOG10(N)</td>
<td>down to -88</td>
</tr>
<tr>
<td>1647</td>
<td>1660</td>
<td>-78</td>
<td>-10LOG10(N)</td>
</tr>
<tr>
<td>1660</td>
<td>1670</td>
<td>-78</td>
<td>-10LOG10(N)</td>
</tr>
<tr>
<td>1670</td>
<td>1735</td>
<td>-78</td>
<td>-10LOG10(N)</td>
</tr>
<tr>
<td>1735</td>
<td>12000</td>
<td>-78</td>
<td>-10LOG10(N)</td>
</tr>
<tr>
<td>12000</td>
<td></td>
<td>-78</td>
<td>-10LOG10(N)</td>
</tr>
</tbody>
</table>

*Table 2 RTCA Draft MOPS Emission Limits for MSS services operating in the band 1616 - 1626.5MHz (Updated recent Draft Version 5 see section 4.1.1)*
ETS1 TBR 041: (February 1998)

S-PCN Specification for 1.6/2.4GHz Bands

<table>
<thead>
<tr>
<th>Frequency from (kHz) to (kHz)</th>
<th>EIRP (dBW)</th>
<th>Measurement bandwidth (kHz)</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01 30</td>
<td>-66</td>
<td>10</td>
<td>Peak Hold</td>
</tr>
<tr>
<td>30 1000</td>
<td>-66</td>
<td>100</td>
<td>Peak Hold</td>
</tr>
<tr>
<td>1000 1559</td>
<td>-60</td>
<td>1000</td>
<td>Average</td>
</tr>
<tr>
<td>1559 1580.42</td>
<td>-70</td>
<td>1000</td>
<td>Average (note 1)</td>
</tr>
<tr>
<td>1580.42 1605</td>
<td>-70</td>
<td>1000</td>
<td>Average</td>
</tr>
<tr>
<td>1605 1610</td>
<td>-70 to -10</td>
<td>1000</td>
<td>Average</td>
</tr>
<tr>
<td>1610 1626.5</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>1626.5 1628.5</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>1628.5 1631.5</td>
<td>-60</td>
<td>30</td>
<td>Average</td>
</tr>
<tr>
<td>1631.5 1636.5</td>
<td>-60</td>
<td>100</td>
<td>Average</td>
</tr>
<tr>
<td>1636.5 1646.5</td>
<td>-60</td>
<td>300</td>
<td>Average</td>
</tr>
<tr>
<td>1646.5 1666.5</td>
<td>-60</td>
<td>1000</td>
<td>Average</td>
</tr>
<tr>
<td>1666.5 2200</td>
<td>-60</td>
<td>3000</td>
<td>Average</td>
</tr>
<tr>
<td>2200 12750</td>
<td>-60</td>
<td>3000</td>
<td>Peak Hold</td>
</tr>
</tbody>
</table>

Note 1: In the sub-band 1573.42 to 1580.42MHz, the average measurement time is 20ms.

*Table 3 ETSI TBR 041 Emission Limits for MSS services operating in the band 1616 - 1626.5MHz*
<table>
<thead>
<tr>
<th>Frequency from (kHz)</th>
<th>EIRP (dBW)</th>
<th>B/W (kHz)</th>
<th>dBm/Hz</th>
<th>Frequency from (kHz)</th>
<th>EIRP (dBW)</th>
<th>B/W (kHz)</th>
<th>dBm/Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>-66</td>
<td>10</td>
<td>-76.00</td>
<td>0.0</td>
<td>-66</td>
<td>10</td>
<td>-76.00</td>
</tr>
<tr>
<td>30.0</td>
<td>-66</td>
<td>100</td>
<td>-86.00</td>
<td>30.0</td>
<td>-66</td>
<td>100</td>
<td>-86.00</td>
</tr>
<tr>
<td>1000.0</td>
<td>-60</td>
<td>1000</td>
<td>-90.00</td>
<td>1000.0</td>
<td>-60</td>
<td>1000</td>
<td>-90.00</td>
</tr>
<tr>
<td>1559.0</td>
<td>-120.2</td>
<td>1000</td>
<td>-150.20</td>
<td>1559.0</td>
<td>-120.2</td>
<td>1000</td>
<td>-150.20</td>
</tr>
<tr>
<td>1585.0</td>
<td>-108.2</td>
<td>1000</td>
<td>-138.20</td>
<td>1585.0</td>
<td>-108.2</td>
<td>1000</td>
<td>-138.20</td>
</tr>
<tr>
<td>1605.0</td>
<td>-70 to -10</td>
<td>1000</td>
<td>-100.00</td>
<td>1592.0</td>
<td>-115</td>
<td>1000</td>
<td>-145.00</td>
</tr>
<tr>
<td>1610.0</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>1610.0</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>1628.5</td>
<td>-60</td>
<td>30</td>
<td>-74.77</td>
<td>1628.5</td>
<td>-60</td>
<td>30</td>
<td>-74.77</td>
</tr>
<tr>
<td>1631.5</td>
<td>-60</td>
<td>100</td>
<td>-80.00</td>
<td>1631.5</td>
<td>-60</td>
<td>100</td>
<td>-80.00</td>
</tr>
<tr>
<td>1636.5</td>
<td>-60</td>
<td>300</td>
<td>-84.77</td>
<td>1636.5</td>
<td>-60</td>
<td>300</td>
<td>-84.77</td>
</tr>
<tr>
<td>1646.5</td>
<td>-60</td>
<td>1000</td>
<td>-90.00</td>
<td>1646.5</td>
<td>-60</td>
<td>1000</td>
<td>-90.00</td>
</tr>
<tr>
<td>1666.5</td>
<td>-60</td>
<td>3000</td>
<td>-94.77</td>
<td>1666.5</td>
<td>-60</td>
<td>3000</td>
<td>-94.77</td>
</tr>
<tr>
<td>2200.0</td>
<td>-60</td>
<td>3000</td>
<td>-94.77</td>
<td>2200.0</td>
<td>-60</td>
<td>3000</td>
<td>-94.77</td>
</tr>
</tbody>
</table>

Note 1: This table represents a change proposal presented by the Russian Federation at an Ad Hoc meeting of TC-SES on the 22/September/1998.

Table 5 Draft Emission Limits from Draft ETSI DEN/SES 00023
2.2 System Characteristics currently specified in ARINC 761 ref 4

Filter characteristics from the Iridium Tx port to Antenna port are currently specified as follows. While these values are interesting, for calculating emissions output from the high power amplifier, it is the overall output from the system that is critical.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Rejection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1585.0</td>
<td>0.0 to &gt;100dB</td>
</tr>
<tr>
<td>1610</td>
<td>1585.0 to &gt;85dB</td>
</tr>
<tr>
<td>1616.0</td>
<td>1610 to decreases</td>
</tr>
<tr>
<td>1626.5MHz</td>
<td>1616.0MHz &lt;0.5dB</td>
</tr>
<tr>
<td>1646.5MHz</td>
<td>1626.5MHz to increases</td>
</tr>
<tr>
<td>1660.5MHz</td>
<td>1646.5MHz &gt;70dB</td>
</tr>
<tr>
<td></td>
<td>1660.5MHz</td>
</tr>
</tbody>
</table>
Figure 14 Emission Limits for NGSO System (band 1610 to 1626.5MHz) from ETSI TBR 041
NGSO ETSI DEN/SES 00023 Navigation Band Emissions

Figure 13 ETSI Current NGSO DEN/SES 00023 Standard
2.3 GNSS System characteristics

2.3.1 SARPS

Within the international aeronautical community, there are continuing developments in the radio frequency protection for elements of GNSS, which includes GPS, GLONASS and other augmentation requirements. All these elements of GNSS are necessary to meet the accuracy, availability, reliability and integrity limits specified for phases of flight.

This section of the study indicates the current state of the protection limits given in the international Standards. Figure 14 and Figure 15 show the levels of tolerable interference relative to received GPS and GLONASS signal levels of -164.5 and -165.5 dBW respectively.

![Figure 14](image)

*Figure 14  Interference threshold versus bandwidth for GPS/ SBAS*
The above figures are not useful in themselves because they do not relate to interference sources at different offsets to the GPS or GLONASS centre frequencies. Little published or standardised information is available on the affect of moving an interfering source gradually away from these frequencies. However, a recent study by DERA, produced for Eurocontrol, did provide an overview on this effect.

Using the available SARPS material and taking into account the results of the previous DERA report, it is possible to generate a reasonable assumption on the complete, GNSS protection mask (including the CW requirement). This assuming that there is no RF filter at the front end of the receiver. This is shown in the following Figure 16. This diagram however, relates to received levels of -160 and -161 dBW for GPS and GLONASS. Figure 14 & Figure 15 include as factor, the -4.5dBW gain for 5 degree mask angle. The following figure uses a reference signal level of -160 and -161 respectively.
2.3.2 RF Filter protection

A previous DERA study developed the basis for GNSS receiver protection it did not include any element for RF filter protection, the GPS frequency protection diagram shown in Figure 16 above does appear to show some element of an RF filter in the last portion of the curve, however this is not documented in any of the standards. It also shows for certain portions of the GLONASS requirement above ~1606MHz MHz that the CW protection shown is very conservative, the CW protection limit extends to 1609. This may be due to a Russian Federation requirement.

GPS is registered within the ITU as having operating within a range of 1575.432MHz ± 12MHz, receivers. GLONASS, meanwhile over the period to 2005 will be adjusting its frequency plan to move operations below 1610MHz.

2.3.3 Consolidated protection needs

To have some idea of the overall spurious emission requirements for NGSO emissions, it is necessary to have information on the likely spurious emissions from NGSO equipment and to combine this with the expected GNSS receiver mask. This must take into account any assumptions made on the isolation between the two systems.
It is known that aeronautical systems are under development by Allied signals in the United States, and that hand held NGOS terminals are now available for commercial use. An example of the spurious emissions produced by a Beta version of a commercial hand held terminal is shown below. Detailed measurements of NGSO terminals is planned for in a further Eurocontrol study. A spurious emission level of -34 dBc in a bandwidth of 30kHz, and -40dBc for a 300kHz bandwidth have been observed.
2.4 Antenna Isolation

This section considers the isolation achievable between MSS and Navigation antennas situated upon the same airframe. ARINC are developing installing provisions for second generation SATCOM terminals details are in ref 4.

Reference is made to measurements made on actual aircraft installation of GPS and AMSS High Gain Antennas.

2.4.1 Previous Evaluation

During the generation of the specification of the AMSS system for the RTCA MOPS it became clear that direct measurement of the achieved isolation between High Gain Satcom and GPS antennas was required to verify assumptions that were being made.

Boeing, together with other parties, undertook a series of measurements of the isolation between these antennas on a range of airframes. Worst case figures obtained during these measurements have been used in determining the effects of Satcom systems upon GPS and now GNSS systems.

ARINC Characteristic 761 quotes isolation values of 52 and 46dB for antenna separations of 24.6metres and 10.1 metres (970 and 400 inches) respectively. It is important to note that these figures were measured from antenna port to antenna port and therefore include effects of antenna frequency discrimination and gain. Measurements were undertaken at both GPS and Satcom frequency bands and can therefore be used in the assessment of not only the GPS in-band interference but also in the assessment of the out-of-band interference.
Theoretical calculation of the free space loss factor as a function of antenna separation can be performed based upon the following equation:

\[
FSL = 10 \cdot \log_{10} \left( \frac{4 \pi \cdot f \cdot d}{c} \right)^2
\]

where:
- \( f \) = frequency (Hz)
- \( d \) = separation distance (m)
- \( c \) = speed of light (m/s)

\( FSL \) = Free Space Loss (dB)

The following plot shows the results for this equation across a range of separation distances. In addition, the two points obtained from are also plotted.

Finally, a secondary curve is shown which simply takes the theoretical Free Space Loss figures and deducts a fixed number of dB, in this case 10.6 dB. It can be seen that there is a reasonable correlation between the measured figures at 10.1 and 24.6 meters (400 and 970 inches) separation and this adjusted Free Space Loss value.

![Figure 18 Free space loss and adjusted for Antenna gain](image)

The adjustment value of 10.6 dB seems to be reasonable in terms of the gains of the antennas involved, i.e. 12 dBic for the Satcom antenna and 0 dBic for the GPS antenna. Since the relative elevation between the GPS and Satcom antenna will be approximately 0 degrees, the gain of both the GPS and Satcom antenna in the direction of the receiving system is likely to be below the average gain of that antenna.

Typically avionic GPS antennas will not be able to support 0 dBic gains at 0 degrees elevation, typically the antenna gain will be in the order –2 dBic at 0 degrees elevation.
Generally there are two types of Satcom antenna are employed, either mechanically steered or phase array.
Mechanically steered antennas would probably represent the worst case gain at 0 degrees elevation, i.e. towards a GPS antenna. However, mechanically steered antennas are generally only employed on corporate aircraft and then predominantly mounted on the tip of the vertical stabiliser. In such a configuration it is unlikely that (a) the GPS antenna will be situated in close proximity to the Satcom Antenna and (b) the relative elevation angle from the Satcom antenna towards the GPS antenna would be significantly below 0 degrees elevation.

Phase array antennas are the likely candidates for commercial aircraft since they offer the lowest cross sectional area and thus minimise drag. The penalty for this is that they tend to exhibit lower gain at low elevations with respect to mechanically steered antennas. However, this effect works in favour of the isolation between Satcom and GPS antennas.

2.4.2 NGSO Antenna Isolation

The previous section identified that the ARINC 761 draft document contained references to measurements made in the determination of the isolation between AMSS antenna and GPS antennas.

However, it is necessary to note that all of the figures used in the determination of the antenna isolation for the AMSS system have been between high gain satcom and GPS antennas. However, the fact that the NGSO systems are currently employing omni-directional antenna and not ‘steered’ high gain antennas makes a considerable difference to the isolation.

In the case of the IRIDIUM system the antenna is specified as nominally 0dBic, with gain variation over the coverage volume in the range −2 to +5dBic. Due to the path loss effects of satellite systems, antenna designs for optimal performance are likely to have toroidal beam patterns, i.e. slight degradation in gain at zenith and peak gain at a few 10’s of degrees above the horizontal. The performance of these antennas are therefore expected to be similar to those obtained by GPS antennas due to the similarity of the satellite constellations and the requirement to retain visibility of several satellites at once. Therefore, rather than the 10.6dB higher isolation than the free space loss assumed for the High Gain AMSS case, it is more realistic to anticipate a slight lower increase in isolation over that determined simply by the free space loss calculation for NGSO antenna systems.

The achieved gain of both GNSS and NGSO antennas at zero elevation is likely to be less than 0dBic. From a preliminary review of GPS avionic antennas gains as low as −7dBic have been quoted. If this is also applicable to the NGSO antennas then an isolation of some 14dB higher than the free space loss value might be achieved in an installed configuration. However, in the absence of measured figures it is suggested that a figure equal to that given by the free space loss is assumed for the isolation of NGSO to GPS/GNSS antennas, i.e. 400 inches separation gives 56dB attenuation and 970 inches gives 64dB’s.
3. Discussion of trade off issues

3.1 Filter Trade-off

3.1.1 Introduction

The filter requirement for mutual protection of NGSO Satcom system and GNSS receivers are derived on emission limits and GNSS receiver sensitivity to interference.

Once the requirements for filtering are determined, methods to achieve this are discussed.

Due to the lack of published information on aeronautical NGSO services operating below 1616 MHz (i.e. Globalstar) it is impossible to determine the potential for interference to the GNSS services from the frequency band 1610 to 1616 MHz. However, the draft ETSI DEN/SES 00023 specification has been used as a guideline. As it is in the process of development, the quoted NGSO limit values may be revised.

3.1.2 Filter Requirements

To determine the filtering requirements of the NGSO services the assess the antenna separation requirement must be considered.

Firstly the isolation between the NGSO and the GNSS antenna is addressed in terms of the attenuation required to satisfy the GNSS out-of-band interference level from the wanted NGSO signal. This will determine the minimum separation required between the antennas.

Having established this figure the GNSS in-band interference due to the NGSO systems will be examined with respect to the requirements of the GNSS receiver. In turn this will be used to assess the additional requirements of any transmit filtering needed within the NGSO system.

3.1.3 Rejection of Wanted MSS Transmission

Table 5 gives the maximum signal powers at the input to a GNSS receivers for frequencies of 1610, 1616 and 1626.5 MHz. These frequencies are chosen to represent the lower limits of frequency which can be transmitted from NGSO MSS systems. Although 1610 is the lower specified frequency limit, 1616 MHz is included as this represents the lower frequency band of the Iridium MSS system. Also included is the power at 1626.5 MHz which represents the lowest frequency transmitted by AMS(R)S systems.
Table 5 Allowable CW Interference at GNSS Receiver

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>CW Interference Level (dBm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GPS</td>
</tr>
<tr>
<td>1610</td>
<td>-30</td>
</tr>
<tr>
<td>1616</td>
<td>-16</td>
</tr>
<tr>
<td>1626.5</td>
<td>+8</td>
</tr>
</tbody>
</table>

For wideband interference (≥ 10kHz Bandwidth) –82 dBm

From Table 5 it is possible to determine the minimum isolation required between the MSS and GNSS antennas based upon the transmit EIRP requirements of the MSS system.

For comparison the analysis is performed for a typical AMS(R)S system. The maximum transmit power level is +16dBW (+46dBm). Installed antenna isolation from an Aeronautical High Gain Antenna to GPS antenna is specified as being 40 dB. Therefore the received level of interference at frequencies above 1626.5MHz is 46 – 40 = 6 dBm, i.e. 2 dB lower than the limits specified in the Table 5 above.

For the IRIDIUM MSS system operating in the band 1616 to 1626.5 MHz the maximum EIRP is 8.5dBW (38.5dBm). Therefore, in order for the GPS system to operate an isolation of 38.5 + 16 = 54.5 dB is required. For GLONASS reception this requirement increases to 38.5 + 40 = 78.5 dB. Using these isolation figures and the equation for free space loss the antenna separation can be assessed. For 54.5 dB the physical separation needs to be in the order of about 8 metres (26.3 feet) and for 78.5 dB the separation about 127 metres (417 feet).

The latter figure is obviously unrealistic for any MSS/GNSS system (using GLONASS) located on the same airframe.

Therefore, additional isolation will be required. This can only be achieved by considering all aspects of the installation.

- Antenna isolation - As derived in the assessment of antenna isolation, antenna gains for both NGSO and GNSS omni-directional at close to zero elevation are likely to be significantly lower than 0 dBi. A review of existing GPS aircraft antennas indicates that gains of −5.0 to −7.5 dBiC rather than 0 dBiC are realistic. Therefore, adding to the antenna isolation available just from free space loss

- Or, additional filtering could be applied at the GNSS receiver input,

- Or, major review of the operation of NGSO terminals is required. Taking into account frequency of operation and emission standards.
If we assume that the isolation between the antennas now includes an additional 10 dB due to the antenna gain characteristics, see Figure 18 (i.e. 54.5 db and 78.5 db isolation includes a relative antenna gain factor and free space loss) then the antenna separation will be in the order of 2.5 metres (8.3 feet) for the GPS system and 40 metres (132 feet) for GLONASS in order to achieve the 54.5 and 78.5 dB overall isolation.

The separation required for GLONASS protection is still considered unreasonable for most installations. Therefore, additional protection is required, the manner in which this is achieved is the subject of the next section of the report.

3.1.4 Determination of NGSO Interference in the GNSS band

The International Civil Aviation Organisation (ICAO) has produced Standards and Recommended Practises, which incorporate, stated requirements for operation of GNSS services, as defined by the two system providers, the US and Russian Federation. The current value for the CW element of the GNSS system can be seen in Figure 19. This figure also shows GNSS limits relative to the proposed Iridium standard. The dotted line represents a smoothed version of the Iridium standard.

With an assumed maximum isolation between the NGSO and GNSS antennas of 58.5 dB, achieved by 4 metres (13.2 feet) separation. A determination of the GNSS in-band interference level due to NGSO systems can be assessed.

3.1.5 GNSS Interference based upon RTCA MOPS (Iridium)

Figure 19 compares the GNSS CW receiver mask requirement and the Iridium Emission limits set out in the draft MOPS. Two curves for the IRI DIUM system are shown, the first is scaled in dBm/Hz and the second in dBm. The reason for this is that emission limits are defined in terms of a level plus a measurement bandwidth. For example; if the specification is -100 dBm in a 1 MHz bandwidth, then a transmitter could emit either a wideband noise like signal at -160 dBm/Hz across a 1 MHz band or alternatively it could transmit a single CW tone at a level of -100 dBm. A realistic scenario would in fact be somewhere between the two, i.e. a combination of lower level spurs plus a background noise contribution.

The effect upon the GNSS receiver of a -100 dBm CW signal at the correlator input would be to spread the signal in the form of a sinc function and thus can be considered as a noise like signal at the correlator output. However, a wideband noise signal at the correlator input would pass more or less unaffected through the correlator. Therefore, the worst case assumption of a CW carrier at the GNSS receiver input would seem justified, at least in the first order.
Considering the most pessimistic scenario of a single CW tone from the IRIDIUM system contributing entirely to the Emission limit and subtracting the 58.5dB antenna isolation value determined previously, results in an interference level as shown.

From inspection it can be seen that the only part of the IRIDIUM emission which exceeds the GNSS interference mask is the frequency band around 1610 MHz. Two factors will serve to mitigate this failure of the IRIDIUM emissions meeting the GNSS interference mask.

Firstly, the assumption that the specification of the IRIDIUM emission in terms of dBW/MHz could be concentrated into a single spurious output is unduly pessimistic. A combination of discrete spurious lines, modulated signals and wideband noise is more probable.

Secondly, the emission limits are presented as a series of specific break points, with one occurring exactly at 1610 MHz. In reality the emission characteristic will be a series of smooth transitions between the emission limit points. Some minor discontinuities might be present depending upon the exact nature of the output transmit filter, for example if a specific notch filter is used in conjunction with a bandpass filter. The dotted line represents a more typical emission limit mask rather than the hard limit steps as expressed in the IRIDIUM MOPS data.

With the assumption that the IRIDIUM emission mask is a series of smooth transitions between the specification points the current emission mask specified for IRIDIUM in the draft RTCA MOPS meets the CW interference limits for both GPS and GLONASS GNSS receivers.
Figure 19 Comparison of GNSS CW Interference Mask with IRIDIUM Emission Limits
3.1.6 GNSS Interference based upon ETSI DEN/SES 00023.

With ETSI DEN/SES 00023 providing the only information on aeronautical NGSO services operating close to the 1610 MHz at the lower frequency band of the MSS allocation, it will be used as the reference document for assessing requirements for additional protection to GNSS systems. If we now make the same assumptions, as for Iridium i.e. 58.5dB antenna isolation the emission limits contained in ETSI DEN/SES 00023 can be assessed in the same way.

Figure 20 shows the comparison between the GNSS CW interference mask and the ETSI emission limits contained in ETSI DEN/SES 00023. Two lines are shown, one for total power in dBm from the terminal and secondly that figure in terms of power spectral density dBm/Hz.

With no antenna isolation available, spurious emissions from the NGSO system, at frequencies above 1605 MHz, exceed levels allowed for in the GNSS CW interference mask.

If we consider that the emission is again a pure CW signal at the limit and that we have 58.5dB isolation, then the GPS CW interference mask is met up to the edge of the NGSO frequency band of 1610 MHz. However, the GLONASS interference mask is exceeded by as much as 70dB at 1610 MHz. If power signal limits in terms of dBm/Hz only are considered, at 1610MHz a 58.5dB antenna isolation would indicate that NGSO will exceed protection values by about 20dB. The true requirement is somewhere between the 70 and 20dB value depending on the NGSO CDMA characteristics.

3.1.7 GNSS Interference from NGSO Systems Operating Below 1616 MHz

It is clear that, since the GNSS interference mask extends up to 1610 MHz and the MSS band extends down to the same frequency, it will be impossible for the NGSO system to design any form of filter with attenuation for 0 Hertz transition band.

Even though the GLONASS system may transition to a reduced bandwidth extending to about 1605 MHz, the existing co-ordinated frequencies may be used well beyond 2005. Therefore, receivers which incorporate GLONASS as part of GNSS may well rely on channels upto the band edge at 1610MHz.

Assuming also that an aeronautical NGSO system can transmit with an EIRP of a few dBW on its selected channels, it would therefore imply there would be a limitation on the lower frequency i.e. near 1610 MHz, that could be used by NGSO to provide a service on an aircraft. This issue can be addressed from the emissions masks given in ETSI DEN/SES 00023, to meet the GNSS interference mask.
ETSI DEN/SES 00023 contains emission masks for the unwanted emissions within the MSS frequency band, i.e. 1610 to 1628.5 MHz. This includes one table for CDMA (Globalstar) transmissions. This emission mask is characterised in terms of EIRP as a function of frequency offset from “Nominated Bandwidth” and is shown graphically in The “Nominated Bandwidth”, defined by the system designers such that the emission characteristic of the particular system will comply with both in-band and out-of-band MSS requirements of DEN/SES 00023. It can be inferred that a CDMA signal could be operated close to a lower MSS operating frequency and still achieve the –10 dBW requirement.

It can be seen from Table 5 that the allowable GLONASS CW interference at a frequency of 1610 MHz is –110 dBm. The EIRP for the Globalstar system is expected to be in the range 26 to 33 dBm transmitting in the band 1610.73 to 1625.49 MHz (figures obtained from Qualcomm Internet Site). Assuming the same antenna isolation of 58.5 dB between the Globalstar and GNSS receiver this results in a level of approximately 33 – 58.5 = -25.5 dBm at the GNSS antenna port.

Simply comparing the –25.5 dBm Globalstar emission at the GNSS antenna port with the GLONASS CW interference level requirement of approximately -110 dBm indicates that there is a significant interference issue to be overcome. Since we are considering the wanted Globalstar emission with the rejection value of the GLONASS receiver there is little that the Globalstar transmitter can do to reduce its output without jeopardising its link integrity, however greater frequency separation is a possibility. This would effectively mean the NGSO service providing a guard area between the top frequency band of the GLONASS at 1610 MHz and the lower edge of the first chosen operational channel in the MSS band i.e not adjacent to 1610MHz.

If we look at Figure 20, then at 1610 MHz we can see that a minimum of about 20dB additional attenuation is required for GLONASS aeronautical NGSO protection, and may be upto 70dB, if there is a high level CW spurious which makes up the limit in the measurement bandwidth. We can bound the minimum and maximum restriction that would need to be placed on the NGSO. Figure 22 gives us a chance to assess this, though not precisely, due to lack of measured detail on the NGSO emission.

For 70dB it appears that at least 6MHz additional frequency separation is required. This will deny the lower part of the band for aeronautical services. While for 20dB, it would appear that the two lower CDMA channels should not be used in any aeronautical service. These factors indicate that DEN/SES/00023 specifications would probably require, a spurious level of at least -80dBW/MHz @1609MHz rising to a level of -10dBW/MHz very rapidly soon after that i.e say to the bottom edge of the third channel.
Figure 20 Comparison of Emission limits for DEN/SES 00023 and GNSS CW Interference Mask
Figure 22CDMA Emission mask from DEN/SES 00023
4. Summary and conclusions

4.1.1 Above 1616MHz

This report has shown that with a small amendment to the currently published specifications contained in the draft RTCA MOPS, the Iridium system can operate with the GNSS system.

The analysis performed above for a GNSS receiver mask shows that it would be possible to operate NGSO systems above 1616 MHz. However, in order to accomplish this an antenna separation of about 58.5dB or 4 metres (13.25feet) is assumed.

Some attention on the GLONASS protection mask at 1616MHz may still be required, depending on this isolation figure. Alternatively increasing the separation would help. With careful planning no additional filtering would be required for Iridium protection. The NGSO limits should be changed to remove the step change at 1605MHz

(-108.2dBW/MHz to -10dBW/MHz at 1610MHz, with no intermediate -70dBW/MHz value). Applicable to TDMA type systems above 1616MHz.

Since the start of this study RTCA have further developed the MOPS of Iridium NGSO services. These changes have made the spurious emissions limits more stringent. Additional protection between 11 and 20dB has been provided to GNSS. Therefore, allowing a reduction in the antenna separation distances (see Table 2)

4.1.2 Above 1610MHz

Although compatible with the GPS system, interoperability of the currently specified GNSS system (i.e. GLONASS) with, NGSO systems operating in the lower portion of the MSS band (i.e. Globalstar) will cause significant interference to the GLONASS system.

Operation of NGSO systems in the lower portion of the MSS frequency allocation, is difficult. Simply adding additional filtering requirements to the NGSO system will not solve these problems. The EIRP’s required by the NGSO systems operating in the lower portion of the MSS band far exceed the specified rejection capabilities in the region of 1605-1610MHz of the GLONASS receiver when realistic antenna isolations are considered. Wanted emissions from the NGSO system in the band 1610 to 1616 MHz require around 88 dB of antenna or isolation in order to reduce the levels at the GNSS receiver to below the current SARPS specification. This degree of isolation is believed to require a physical separation of approximately a great deal more than 400 feet which is obviously unacceptable on most aircraft structures.
The only method which would enable this separation to be reduced is increased filtering in the GNSS receiver, (not accepted by ICAO), or additional spatial separation to be given, together with restrictions on channels availability for aeronautical NGSO systems.

It is again noted that DEN/SES 00023 the emission mask for NGSO below 1616Mhz has a step in its characteristic at 1606 MHz resulting in a instantaneous transition of approximately 40 dB. This is unrealisable, and needs review, a smooth transition should in fact occur in reality.

In order to allow use of both GNSS in the band 1559-1610MHz and NGSO to operate in the band above 1610MHz, it is suggested that:

- Emission limits and a restriction on the bottom two channels used, needs to be addressed for NGSO systems specified in DEN/SES 00023 (those below <1616MHz), especially in the band between around 1610 MHz. With a restriction to channel used a value of about -80dBW/MHz at 1610MHz may be appropriate.

- Minimum antenna isolation requirements (>58dB) need to be established based upon achievable installed physical separation and measured values, this should include any assumed relative antenna gain between the NGSO and GNSS antenna.

- NGSO terminal specifications around 1610MHz could be improved to remove step changes, which appear unrealistic.

That the standards for NGSO terminals and their operation should be amended such that spurious emissions meet ICAO requirements

In regard to GLONASS protection, it is considered that DEN/SES 00023 as well as the GNSS SARPS should be reviewed carefully.

5. Other issues

An antenna isolation of at least 58.5dB has been assumed for the final part of the above study. RTCA have quoted a minimum of 40dB isolation for GSO AMS(R)S services. The RTCA value is a worst case situation for a high gain AMS(R)S (1626.5-1660.5MHz) antenna operating to the GSO and pointing at directly at the GNSS antenna. In the NGSO
case it is assumed that the coverage is more omnidirectional, thereby removing the change in link budget because of the movement of the NGSO satellites, unlike the GSO case.

It is very important for the ETSI process to recognise that the emission limits of the TBR 41 standard were developed from different sharing scenarios than this airborne platform case.

*The aircraft terminal in the TBR41 evaluation was separated by a minimum of 100ft from the NGSO MES and there existed a differential gain of -5.5 dBi between a GNSS signal at 5 degree elevation and an NGSO interferer on the ground. Free space rejection was 66 db, the total antenna isolation was therefore 71.5dB.*

It is also important to remember that extensive testing of GSO systems established that frequency management of the 3rd, 5th, and 7th intermodulation products is necessary to avoid spurious emissions in the GNSS band.

*Aircraft platforms, which incorporate GSO as well as NGSO systems, may well have to incorporate within their flight management systems, protocols which interact with the GSO and NGSO terminals, which avoid the generation of intermodulation signals, or that suitable isolation of GSO and NGSO antennas occurs in the aircraft design phase.*
6. References

The following documents have been used in the above study:

ref 1 RTCA MOPS for Avionics Equipment Providing Aeronautical Mobile satellite Services in the Band 1616 – 1626.5MHz. (DRAFT VERSION 3.2, 13/August/98)

ref 2 RTCA MOPS for Aeronautical Mobile Satellite Services (AMSS) Doc. No. RTCA/DO-210C, 16/January/96)

ref 4 ARINC Characteristic 761, “Second Generation Aviation Satellite Communications System, Aircraft Installation Provisions” (Draft 2 to Supplement 1, 22/September/98)

ref 6 INMARSAT Aeronautical System Definition Manual Module 2: Technical Requirements for INMARSAT Aircraft Earth Stations (Version 1.20.01, September 1997)

ref 7 ETSI Technical Basis for Regulation; “Satellite Personal Communications Networks (S-PCN);MES, including handheld earth stations, for S-PCN in the 1.6/2.4 GHz bands under the MSS: terminal essential requirements” TBR 041 (February 1998)

ref 8 ETSI Draft Standard; “Satellite Earth Stations and Systems (SES); Aircraft Earth Stations (AES) operating under Aeronautical Mobile Service (AMSS)/ Mobile Satellite Service (MSS)” DEN/SES 00023 (31/March/1998)
# 7. Glossary

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<tr>
<td>AES</td>
<td>Aeronautical Earth Station</td>
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<tr>
<td>AMSS</td>
<td>Aeronautical Mobile Satellite Service</td>
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<tr>
<td>ARINC</td>
<td>Aeronautical Radio Inc.</td>
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<tr>
<td>CDMA</td>
<td>Code Division Multiple Access</td>
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<tr>
<td>ETSI</td>
<td>European Telecommunications Standards Institute</td>
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<tr>
<td>GEO</td>
<td>Geostationary Orbit</td>
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<tr>
<td>GPS</td>
<td>Global Positioning System</td>
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<tr>
<td>GNSS</td>
<td>Global Navigation Satellite Service</td>
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<tr>
<td>LEO</td>
<td>Low Earth Orbit</td>
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<tr>
<td>MEO</td>
<td>Medium Earth Orbit</td>
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<td>MOPS</td>
<td>Minimum Operational Performance Standard</td>
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<tr>
<td>MSS</td>
<td>Mobile Satellite Service</td>
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Compatibility between GNSS receivers and Satcom transmitters on-board aircraft Technical Assessment.
DERA, with support from Racal Avionics plc and Atlas Avionics Ltd and have carried out a study for EUROCONTROL into the essential technical requirements of mobile earth station terminals, operating to Non-Geostationary Satellite systems, to provide protection of Radio Navigation Satellite Service (RNSS) receivers, operating in the frequency band, 1559 - 1610 MHz. The signals used by services operating in this band, include the US Global Positioning Service, GPS NAVSTAR, and the Russian GLONASS as well as the proposed European Navigation Satellite Service, E-NSS-1. This study, in a separate companion report, provides material which indicates the organisations and processes involved in the approval and definition of these new Satcom standards and suggests avenues that can be used to protect aviation’s best interests.