Electronic Communications Committee (ECC)
within the European Conference of Postal and Telecommunications Administrations (CEPT)

TECHNICAL AND OPERATIONAL PROVISIONS REQUIRED FOR THE USE OF GNSS REPEATERS

Dublin, January, 2009

0 EXECUTIVE SUMMARY

GNSS repeaters are devices designed to receive GNSS signals and re-radiate them inside buildings in order to provide a usable signal within the buildings. A number of potential uses for such devices have been identified, such as the provision of a signal for test and development purposes and avoiding the need for receivers in emergency vehicles to re-acquire lock upon leaving a garage.

However, the use of GNSS repeaters can cause harmful interference to several services. For example, if the re-radiated signal is received outside of the building it can interact with the direct satellite signal and cause a receiver to give false positioning information. In addition, the repeater will re-radiate signals from all other services operating in the GNSS band, and without adequate filtering it could re-radiate signals in adjacent bands.

Band-by-band studies

For the RNSS band 1215-1300 MHz, also occupied by radar EESS and Wind Profiler radar, the GNSS repeater signals may cause effects inside a radar clutter response zone or enhance the signals to EESS satellites. This would not be the case if the maximum output power of the system is restricted to -20 dBm.

For the RNSS band 1164-1215 MHz, also occupied by DME, the analysis indicates that there should be no cause for concern in the use of repeaters subject to the assumptions made on the filtering constraints as stated previously. To have an impact on DME the analysis section would have to make large errors in its assumptions. However, aviation authorities are still concerned that no actual tests against DME equipment have been performed.

For the band 1559-1610 MHz, there are no other apparent sharing services and the main protection should be provided by a geographic protection distance. GNSS operation in this band should be protected by providing suitable gain/power limitations for these devices.

Proposed limitations on repeater installations

- It is proposed that the overall gain of a RNSS repeater system (equation 5) is limited to a maximum of 45 dB where the indoor transmit antenna gain is limited to +3dB.
- The maximum output power of the final amplifier should be limited to -20dBm (-50dBW)
- The device should incorporate filtering, which can be associated with the receiver and transmit antennas or it can be by separate filters. The filter response should be centred on the frequency of the GNSS signal to be radiated and the -3 dB points should be ± 20 MHz.
    - For a repeater operating in the 1164 - 1215 MHz band the filtering should provide at least 37 dB of rejection at frequencies below 1151 MHz.
    - At 1300 MHz, the repeater combined filtering losses (antenna related and any installed filter) should exceed 45dB.
    - In the case of a repeater operating in the band 1559-1610 MHz, and designed to re-radiate signals centred on the L1 frequency :
        - 5dB of filtering should be provided at the 1559 MHz band edge. It could be provided by means of the receiving and transmitting antennas. This constraint would, however, not be practical for repeaters designed for lower frequency signals such as the B1 channel used by the COMPASS system
        - at least 10 dB of filtering should be provided at the 1610 MHz band-edge. However, this would not be practical for repeaters designed for the GLONASS system which would need to radiate signals up to 1605.375 MHz.
    - In specific instances, for example where repeaters are used in aircraft hangars, additional filtering may be required. Such situations should be considered on a case by case basis.

Proposed limitations on repeater operations

With the limitation of the overall total system gain to a value of +45 dB, and if the building loss in the direction of a GNSS receiver was 0dB, then the protection distance for a repeated GNSS signal power to be below -170dBW/24 MHz = -140 dBm/24 MHz would need to be around 10 metres. This means for the issue of enforcement, that the repeated GNSS signal, at a distance of 10 m from the building housing the indoor-antenna, must not exceed the protection level of -140 dBm/24 MHz.

It is considered, subject to further regulatory scrutiny, that use of GNSS repeaters should be limited to the bands 1164-1215 MHz, 1215-1300 MHz and 1559-1610 MHz.

Mobile use of these devices in an uncoordinated manner will increase potential risks to normal GNSS (GPS) receiver operation. Thus, mobile use is not considered as feasible with respect to the required protection of GNSS receivers and other services.

Table of contents

LIST OF ABBREVIATIONS

Abbreviation	Explanation
ARINC	Aeronautical Radio, Incorporated
CEPT	European Conference of Postal and Telecommunications Administrations
DME	Distance Measurement Equipment
EMC	Electromagnetic Compatibility
EESS	Earth-Exploration Satellite Service
EIRP	Equivalent Isotropic ally Radiated Power
ETSI	European Telecommunications Standards Institute
GLONASS	Global Navigation Satellite System
GNSS	Global Navigation Satellite Service
GPS	Global Positioning System
ICAO	International Civil Aviation Authority
IMO	International Maritime Organization
ITU	International Telecommunications Union
JTIDS	Joint Tactical Information Distribution System
MDS	Minimum Discernible Signal
MIDS	Multi-functional Information Distribution
NTIA	National Telecommunications and Information Administration
RNSS	Radionavigation Satellite System
R&TTE	Radio and Telecommunications Terminal Equipment
SAR	Synthetic Aperture Radar
UWB	Ultra-Wideband
WPR	Wind Profiler Radar

1 INTRODUCTION

GNSS repeaters are devices designed to receive GNSS signals and re-radiate them inside buildings in order to provide a usable signal within the buildings. A number of potential uses for such devices have been identified, such as the provision of a signal for test and development purposes and avoiding the need for receivers in emergency vehicles to re-acquire lock upon leaving a garage.

However, the use of GNSS repeaters can cause harmful interference to several services. For example, if the re-radiated signal is received outside of the building it can interact with the direct satellite signal and cause a receiver to give false positioning information. In addition, the repeater will re-radiate signals from all other services operating in the GNSS band, and without adequate filtering it could re-radiate signals in adjacent bands.

This report identifies the services that could suffer interference from GNSS repeaters. These include aeronautical radionavigation (distance measuring equipment and radar), earth exploration satellite services, wind profiler radar, mobile satellite and GNSS itself. In each case the extent of the interference is assessed and where appropriate protection distances are derived. There is also some discussion of filtering requirements to limit interference to adjacent bands. The report concludes with recommendations on power and other limitations appropriate for consideration if the devices are authorised for use.

2 DESCRIPTION OF A GNSS REPEATER

2.1 Potential use of GNSS repeaters

Many industries use GNSS (GPS) receivers for position location determination and timing references and their use have become widespread. Position location applications include leisure (hiking, sailing), vehicle navigation, professional tracking of vehicle, surveying and use in the defence industry (where it is a fundamental defence utility). Timing sources also use GNSS receivers in many synchronous telecommunications links.

Radionavigation satellite system developers and some user organisations and commercial users of GNSS receiver equipment have at times the need to prove correct receiver operation when receivers are out of sight of the constellation. This can be achieved either, by connecting the unit's external antenna port to suitable test signal generator or by the availability of a suitable radiated signal. A significant number of GNSS receiver products do not incorporate a suitable external antenna port and consequently a radiated signal is the only option. The simplest and cheapest way found by industry is to re-radiate the actual GNSS signals at the remote location.

GNSS (GPS) repeater devices re-radiate the GNSS signal to provide a suitable signal to GNSS receivers out of sight of the GNSS satellite constellation. Uses so far identified for GNSS receivers include, test-bench testing of GNSS receivers; final verification tests on GNSS receivers on car production lines; and the provision of GNSS signals to receivers in garaged vehicles for rapid acquisition of the GNSS signal on exit. In these latter applications users require the GNSS repeated signal to be received, over reasonable areas.

2.2 General details of a GNSS repeater

A GNSS repeater unit consists of: an external antenna for the reception of GNSS signals, often mounted on a building; a pre-amplifier and sometimes a band filter; and cabling to a second antenna (perhaps equipped with another amplifier) which re-radiates the GNSS signal.

Some available GNSS repeater equipment transmits in a bandwidth ±10 MHz centred on either 1227.6 MHz or 1575.42 MHz. It should be recognised that equipment described as GNSS repeaters will in fact re-transmit any RNSS or other signal in the transmit frequency band.

Some of these products are already available on US websites. See US NTIA manual section 8.3.28 [1] which outlines the US restrictive conditions of use. The US is using repeater devices within large transport aircraft.

2.3 Types of repeater

Scenarios of GNSS repeater use can generally be divided into several main usage types.

The first type of repeater is where the re-radiated signal is required for the testing of products incorporating GNSS receivers on test-benches. In such a situation, only a relatively small power would be needed.

The second type is where the re-radiated signal is required for acquisition of signals in a larger, manufacturing or garage environment, e.g. to enable the rapid re-acquisition of the GNSS signal following the parking or storage of vehicles in garages, or for verification testing of SatNav equipment in cars on the production line.

Another type that has been suggested is a repeater installed in a moving vehicle intended to provide reception to hand-held units. However, such an application represents a serious interference risk at potentially any location. Examples of different environments where GNSS repeaters have been found to be useful are given in Annex 1.

3 REGULATORY ENVIRONMENT

3.1 International considerations

Within the R&TTE legislation, GNSS repeaters are radio equipment and, therefore, cannot be on the market for general sale without first satisfying the requirements of the Directive. To do this the equipment would have to meet the “essential requirements” set out in the Directive. The essential requirements relate to protection from harmful radio interference to other users, protection from excessive electromagnetic emissions and health and safety. Equipment can be demonstrated to meet these requirements by following a conformity assessment procedure or by meeting a harmonised standard, where such a standard exists. To date, it appears that the issue with GNSS repeaters is that they could cause harmful interference to other users (by re-radiating the “false” GNSS signal to other GNSS devices or by re-radiating other services in the GNSS band or adjacent bands). This may also mean that the devices would fail the electromagnetic compatibility requirements and indeed health and safety requirements. However, in some circumstances the supply of this equipment to security type services can occur within an R&TTE exemption clause (providing that the equipment is exclusively used for these purposes).

Note that the R&TTE directive does not apply to the individual components which make up a repeater (cables connectors, amplifiers, antennas etc). However, it does apply to a unit combining all these parts to form a repeater. If there is separate purchase of sub-components, which are subsequently combined by a user to put such a system into use, then the ‘put into service’ clause in the R&TTE directive comes into effect.

3.2 Other Administration views

US NTIA manual section 8.3.28,[1] outlines the US restrictive conditions of use.

The United States has put in place regulations that only allow NTIA sponsored or FCC authorized under Part 5 usage of GNSS repeaters. Where GNSS repeater use is licensed, the US imposes power level constraints.

The main protection criteria applied by the US, is that the GNSS repeated signal is less than -170 dBW i.e greater than 10 dB below the wanted signal power levels (which at the L1 frequencies is -160 dBW), at a proscribed protection distance. Specifically, the maximum received power level at 100ft from the perimeter of the facility where the GNSS repeater is used is -140 dBm/24 MHz or -170 dBW. This has to be met under clear sky conditions (i.e. no additional attenuation due to walls).

The noise bandwidth is specified as the occupied bandwidth of the GNSS system (24 MHz) covering both the civil GPS C/A code and the US P and future M codes.

The US operates other regulatory measures in that an applicant has to be in full control of all affected areas within 100ft of the perimeter of the facility where the GNSS repeater is used and licences are valid for a 2 year period only, with a possibility of renewal.

4 BAND CONSIDERATIONS

4.1 Introduction

The bands shown in Annex 2 have multiple radio spectrum allocations within them. The spectrum is used by applications such as: terrestrial based navigation systems, used by aircraft; radar used for civilian air traffic control; and military defence purposes; it also extends to the use by the Earth Exploration Satellite, Space Research Satellite services and Radionavigation Satellite services, the latter service is used for some safety related navigation.

The above services have many operational terrestrial assignments and ITU satellite filings. The radionavigation, radionavigation satellite and radar uses relate to safety of life services. Millions of GNSS (GPS) receivers are in use for vehicular-based position reporting systems and navigation. For the international aeronautical and maritime communities (represented internationally by ICAO and IMO), these GNSS services provide accurate navigation, which are used to provide safe navigation, movement of goods and people. Many industries are now reliant on the use of GNSS (GPS) signals and the ability of GNSS receivers to provide very accurate position determination and accurate timing references in the provision of consumer services.

For GNSS Repeaters, there is no recognition of these within any international standards; there is also a question as to what service category applies to these devices in the ITU Radio Regulations.

4.2 Consideration of the potential affects of GNSS repeaters on GNSS

The design of GPS and other GNSS receivers does not anticipate repeater devices and therefore require protection from these re-radiator systems. The radiated signals have two distinct components, both of which have the potential to cause harmful effects. Firstly there is the re-radiated GPS/GNSS signal. This appears as a multi-path signal in addition to the directly received GPS signal. This additional signal has the capacity to decrease the accuracy, or provide an inaccurate report of the receiver's position. Secondly, the higher level noise component has the ability to degrade the noise floor of nearby GPS/GNSS receivers.

4.3 Consideration of the potential affects on other services

As indicated above, there are other services sharing these bands. Therefore, it is necessary in this report to consider whether or not these services might be adversely affected by themselves being repeated or due to the radiated noise raising the local noise floor. The re-radiated GNSS signal will be more than 20 dB below the noise and its effect on non-GNSS systems is likely to be insignificant.

5 EXAMPLE REPEATERS

5.1 Test-bench

For testing GNSS devices on the test-bench the re-radiating antenna could be in relatively close proximity to the device under test. Consequently, it is only necessary to provide a usable GNSS signal at a distance of, say 30 cm. At such distances free-space propagation cannot be assumed and a mutual coupling such as that shown ***Figure*** 1 is appropriate.

Testing embedded GNSS products on the bench requires that the system provide a reasonably accurate signal level to enable functional testing of products. GNSS receivers come in various qualities. Some have limited automatic gain control, while others have perhaps 10-20dB of control. A received power of ~ -160dBW is required.

The distance between two antennas could range from a closely coupled induction, i.e. antennas touching, to a maximum limit of placing the radiating element within say 0.3 metre of the receive antenna. The coupling loss between the re-radiating antenna and the GNSS receiver antenna for this scenario ranges from around -15dB to - 30dB for a GNSS patch antenna of around 25mm in size.

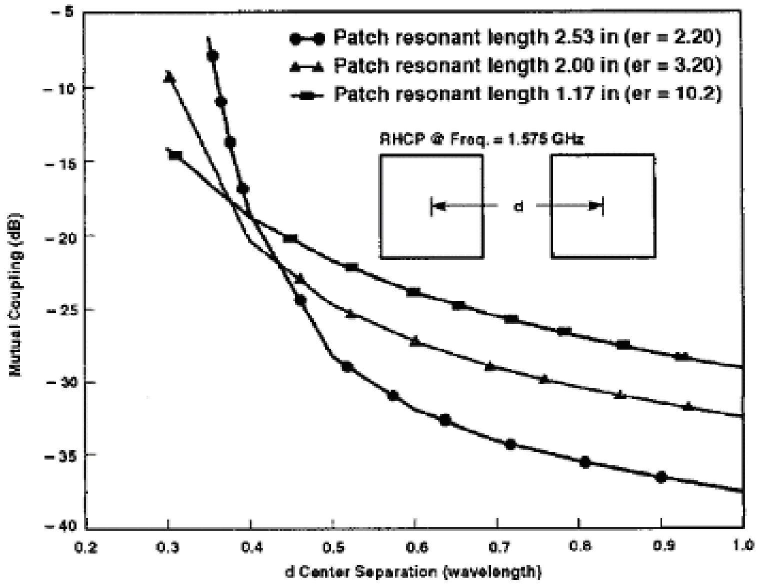

Figure* 1: *Mutual coupling between two identical RFCP square micro strip patches versus centre separation at 0° orientation angle

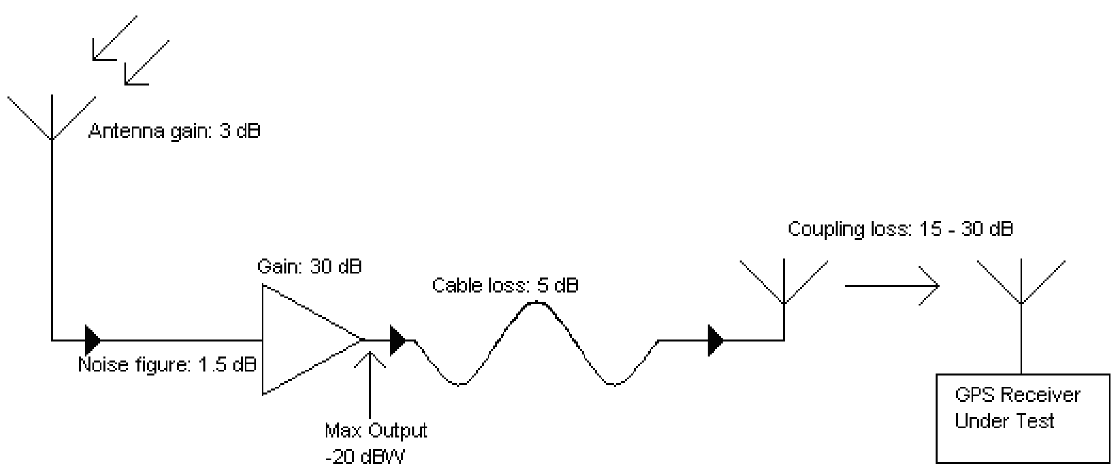

Figure 2: Simple repeater for test-bench applications

Figure 2 shows a suitable configuration for a test-bench repeater, which would generally use a single amplifier. The arrangement consists of a GNSS receiving antenna with a gain of 3 dB, a low-noise amplifier with gain 30 dB, connected to the GNSS transmitting antenna via around 20 metres of good quality cable with a loss of around 5 dB.

The overall gain through the system is given by:

Overall gain [dB] = Antenna Gain(s) + Amplifier Gain – Feeder Loss – Coupling Loss (1)

Assuming a coupling loss in the range 15 – 30 dB, the overall gain is between 13 and -2 dB.

One of the problems that might be encountered with these devices is the lack of any suitable input or output filtering. The pre-amplifiers used can have a wide (1-2 GHz) frequency range, and consequently there exists the possibility that signals in adjacent bands could be re-radiated along with the wanted GNSS signal. Filtering issues will need to be understood. In reality the receiver and transmit antennas will provide a degree of filtering, therefore some consideration is needed on the effect of repeated signals to adjacent bands.

Using Figure 2 as an example, the signals radiated by the repeater will consist of the repeated signal and a noise component. The GPS (GNSS) signals at the Earth's surface are below the noise floor. Assuming a noise figure of 1.5 dB, the noise temperature Ta of the amplifier is given by:

$$Ta = (10^{(1.5/10)} - 1) \cdot 290K = 120K\ (21\ dBK) \qquad (2)$$

The noise power at the output of the amplifier and the resultant noise e.i.r.p. can then be calculated as shown in Table 1.

Technical factor	**Value**
Amplifier Noise Temperature	21 dBK
Boltzmans Constant	-228.6 dB
Noise Bandwidth (24 MHz)	73.8 dB/Hz
Amplifier Gain	30 dB
Noise from amplifier	**-103.8 dBW/24MHz**
Gain of transmitting antenna	3 dB
Cable Loss	5 dB
Noise e.i.r.p.	**-105.8 dBW/24MHz**

Table 1: Test-bench GNSS repeater noise output power and e.i.r.p.

Assuming a GPS/GNSS signal strength of -160 dBW referenced to an isotropic antenna, the GPS/GNSS signal at the output of the amplifier, and the resultant signal e.i.r.p. can be calculated as shown in Table 2.

Technical factor	**Value**
GPS/GNSS signal at the Earths Surface	-160 dBW
Receiving antenna gain	3 dB
Amplifier gain	30 dB
GPS/GNSS signal from the amplifier	**-127 dBW/24MHz**
Gain of transmitting antenna	3 dB
Cable Loss	5 dB
GPS/GNSS e.i.r.p.	**-129 dBW/24MHz**

Table 2: Test-bench GNSS repeater GNSS signal output power and e.i.r.p.

5.2 Large enclosure

In order to cover a larger area more gain will be required. For the purpose of this study, a large area repeater will be considered the same basic architecture as the test-bench version. The antenna gains and cable loss are as before. However, the amplifier gain is increased to 45 dB (see Figure 3). Note that, in practice, the system could be implemented as using two lower gain amplifiers.

The compatibility studies in the remainder of this report will be carried out on the basis of the large area repeater. In view of the larger distances between the repeater and the GNSS receivers it serves, we will assume free-space loss between the repeater and the receiver instead of the coupling loss approach adopted in the test-bench case.

In this case:

Repeater overall gain [dB] = Antenna Gain(s) + Embedded Amplifier’s Gain – Feeder Loss (2)

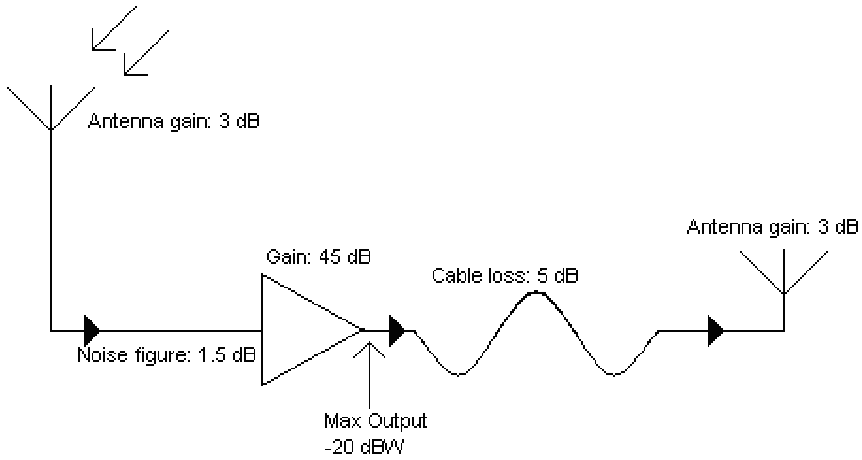

Figure 3: Basic repeater for Large Enclosure

The noise figure is 1.5 dB as before. The e.i.r.p. of both the noise and signal components can be calculated as shown in Table 3 and 4.

The maximum output of repeater is assumed to occur when the internal amplifier is operating at its 1dB compression point; this output power is assumed to be -20dBW. Therefore for a 30 or 45 dB gain repeater, the maximum input signal levels would be -50dBW and -65dBW respectively.

Technical factor	**Value**
Amplifier Noise Temperature	21 dBK
Boltzmans Constant	-228.6 dB
Noise Bandwidth (24 MHz)	73.8 dBHz
Amplifier Gain	45 dB
Gain of transmitting antenna	3 dB
Cable Loss	5 dB
Noise e.i.r.p.	**-90.8 dBW/24MHz or -104.6 dBW/MHz**

Table 3: Large enclosure GNSS repeater noise output power and e.i.r.p.

GPS/GNSS signal at the Earth's Surface	-160 dBW
Receiving antenna gain	3 dB
Amplifier gain	45 dB
Gain of transmitting antenna	3 dB
Cable Loss	5 dB
GPS/GNSS signal e.i.r.p.	**-114 dBW/24MHz**

Table 4: Large enclosure GNSS repeater GNSS signal output power and e.i.r.p.

5.3 Calculation of coverage and multipath protection areas

The radius of the achieved coverage area can be calculated, based on a minimum usable GNSS signal strength of -160 dBW (See Table 5).

Technical factor	**Value**	**Value**
Repeater type	Test-bench	Large area
Repeater e.i.r.p.	-129 dBW	-114 dBW
Edge of coverage	-160 dBW	-160 dBW
Free-Space loss	31 dB	46 dB
Distance	0.5 metres	3.0 metres

Table 5: Radius of the GNSS repeater coverage area

Any residual signal from a repeater could cause false readings to be given by GNSS repeaters outside the coverage area due to multipath effects. In order to guard against this it will be assumed that the signal level should be at least 10 dB below the normal GNSS signal level (i.e. -170 dBW).

The distance needed to achieve this can be calculated for the repeater indoors and outdoors (see Table 6).

Technical factor	**Value**	**Value**	**Value**	**Value**
Repeater e.i.r.p.	-129 dBW		-114dBW	
Location	Indoors	Outdoors	Indoors	Outdoors
Protection Criterion	-170 dBW	-170 dBW	-170 dBW	-170 dBW
Path loss	41 dB	41 dB	56 dB	56 dB
Building loss	8 dB	0 dB	8 dB	0 dB
Free-space loss	33 dB	41 dB	48 dB	56 dB
Distance	0.7 metres	1.7 metres	3.8 metres	9.6 metres

Table 6: Radius of the area where the GNSS repeater signal is 10 dB below the GNSS satellite signal

6 SPECIFIC ISSUES RELATING TO THE 1164-1215 MHz BAND AND AERONAUTICAL SYSTEMS SUCH AS DME

Aeronautical Distance Measuring Equipment (DME) ground based transponders operate in this band. Basically, these devices transmit a response to received signals from aircraft interrogations, which are transmitted on other frequencies.

6.1 Basic details of DME

The aeronautical radio navigation system DME comprises two parts: an interrogator on the aircraft and a transponder at a fixed location on the ground. To measure distance the aircraft interrogates the transponder by transmitting a series of pulse-pairs. After a precise time delay the ground-based transponder replies with an identical sequence of reply pulse-pairs. In order to calculate distance, the aircraft receiver searches for pulse pairs with the correct timing between them. The reply and interrogator frequencies separated by 63 MHz.

The DME system is channelled at a 1 MHz frequency separation raster. The airborne interrogator transmits on one of 126 channels in the range 1025 – 1150 MHz and the ground-based transponder transmits on one of 252 frequencies in the range 962 – 1213 MHz.

6.2 Interference to DME receivers

Aircraft DME receivers are protected via ITU Radio Regulations to an aggregate limit for RNSS signals in this band to -121.5dBW/m^2/MHz at the Earth's surface. According to the ITU the worst case pfd from all current and planned GNSS systems is calculated to produce an aggregate of around -122.3dBW/m^2/MHz in 2008[1]. The GNSS repeater, will re-broadcast all of the RNSS signals within its receive bandwidth. The aviation authorities in Europe seek clarification that the GNSS repeaters will not cause this limit to be exceeded.

In addition, the aviation authorities wish clarification on the effect that might occur, due to GNSS repeaters repeating the DME transponder signals.

To clarify the above situation assumptions on the likely technical characteristics of any GNSS repeater have to be made see Figure 2 and Figure 3. There are some published technical materials available that will allow assessment of the risks of the above cases.

The assumed characteristics of the GNSS repeater are as described for the large enclosure. These parameters plus details of the receiving antenna are given in Table 7.

Technical factor	**Value**
Overall gain (amplifier, cable loss, transmit antenna gain)	43 dB
Amplifier noise figure	1.5 dB
Frequency	1200 MHz
Maximum amplifier output (approx 1dB compression point)	-20dBW
Receiving antenna gain (10 – 90 degrees from horizontal)	3 dB
Receiving antenna gain (-10 – +10 degrees from horizontal)	0 dB

Table 7: Large enclosure GNSS repeater characteristics

A GNSS repeater could potentially cause interference to a DME receiver. There are two mechanisms by which this could occur.

- The intentionally radiated GNSS signal from the repeater could raise the aggregate signal level above the ITU limit of -121.5 dBW/m^2.
- The DME signal could itself be re-radiated and compromise the performance of the DME system.

6.2.1 GNSS signal exceeding DME GNSS protection

For this part of the analysis, we will assume a large enclosure GNSS repeater as detailed in Figure 3. The repeater has an overall gain of 43 dB (including cable loss and transmitting antenna gain), and is situated inside a building, for which a penetration loss of 8 dB is assumed.

The scenario is illustrated in Figure 4.

[1] http://www.itu.int/ITU-R/space/res609/docs/5th_res-609.pdf

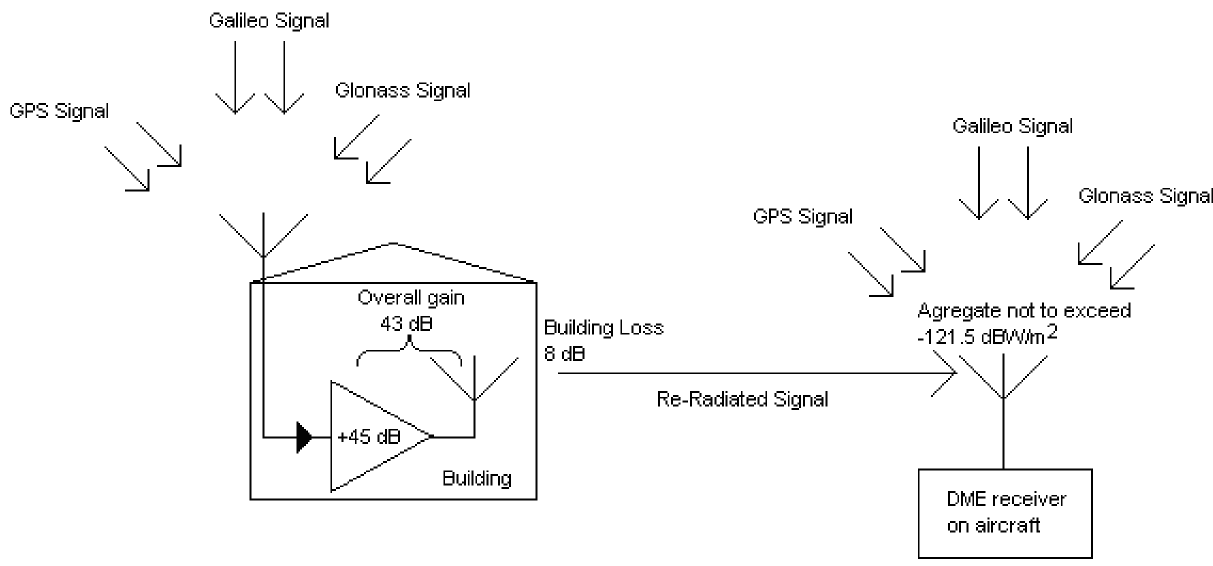

Figure 4: Scenario for repeater causing the DME GNSS protection limit to be exceeded

Since the GNSS signal are at least 20dB below the noise floor of the repeater system, we need only really consider the noise radiated by the repeater as adding to the aggregate value of the RNSS signals.

Assuming a Noise Figure of 1.5 dB, the radiated noise e.i.r.p. will be -104.6 dBW/MHz. 1MHz being the reference bandwidth of measurement.

To assess the severity of any potential interference we will calculate the physical separation needed (see Table 8) between the GNSS repeater and the DME equipment in order for the interference contribution of the repeater to be 10 dB below the ITU limit of -121.5 dBW/m^2/MHz.

Technical factor	**Value**
ITU aggregate level for GNSS interference	-121.5 dBW/m^2/MHz (effectively includes aviation safety margin)
Required Margin – 10% interference allotment for repeater noise	-10 dB
Allowable interference	-131.5 dBW/m^2/MHz
Allowable interference (in dBW/MHz)	-154.6 dBW/MHz
e.i.r.p. of noise transmitted by repeater	-104.6 dBW/MHz
Required path loss	50.0 dB
Building loss	8 dB
Required free-space loss	42.0 dB
Frequency	1200 MHz
Path length	2.5 metres

Table 8: Necessary separation distance between the GNSS repeater and the DME receiver

Therefore, it can be concluded that the repeater will not cause the aggregate limit to be exceeded, as aircraft will always be more than 2.5 metres away. This calculation assumes a building loss of 8dB. If the loss is less than this the protection distances must be adjusted accordingly. Such a situation might occur, for example, if the building materials used are more transparent to radio waves, or if the repeater is operated in an aircraft hanger with open doors. In a situation with no building loss, the distances will increase by a factor of approximately 2.5, which is ~6.3 metres. (see also En-route navigation scenario page 38).

6.2.2 A repeated DME transponder signal affecting aircraft DME reception

The scenario for a repeated DME transponder signal affecting aircraft DME reception is shown in Figure 5.

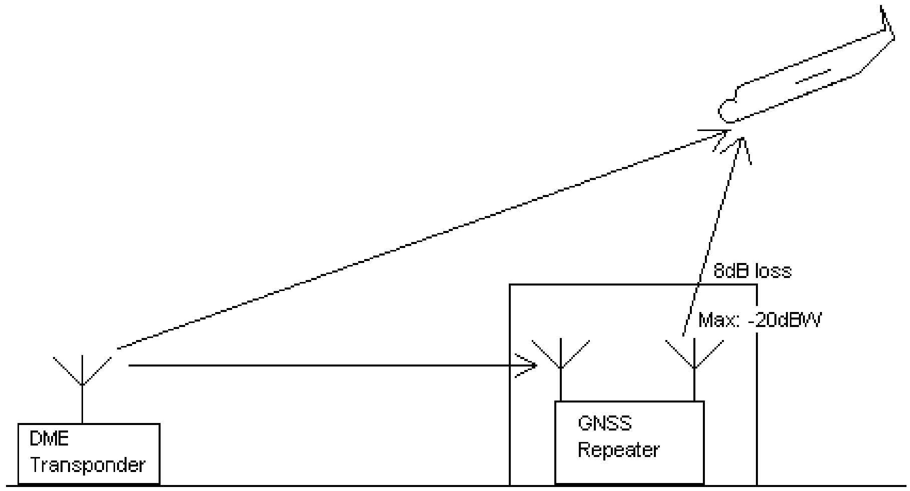

Figure 5: Scenario for repeated DME pulse affecting aircraft reception

In order to assess the compatibility of GNSS repeaters with DME we will consider a situation where a repeater is situated under the path of an aircraft coming to land, such that the plane passes directly over the location of the repeater. The parameters assumed in the analysis are shown in Table9.

Technical factor	**Value**
DME transponder e.i.r.p. A	29 dBW
DME transponder e.i.r.p. B	39 dBW
Aircraft receiving antenna	Omnidirectional
Propagation model	Free space
Building loss	8 dB
Maximum level of delayed signal with respect to direct reply signal for correct locking of aircraft interrogator[2]	-10 dB
Aircraft approach angle	3 degrees

Table 9: Parameters used in the study related to the DME reception

Figure 6 shows the level of the delayed signal received by the aircraft via the GNSS repeater relative to the direct wanted signal. Curves are given for four locations of the repeater, 1km, 2.5km, 10km and 20km from the transponder. The transponder e.i.r.p. is assumed to be the higher value of 39dBW. It can be seen that the delayed signal reaches a maximum when the aircraft is directly overhead. The delayed signal levels for 1km and 2.5km are equal. This is because of the output limitation of the repeater amplifier which restricts its e.i.r.p. to -20dBW for distances up to 2.5km.

Figure 7 shows the level of the delayed signal relative to the wanted signal for the worst case (i.e when the aircraft is directly overhead) plotted against the separation between the transponder and the GNSS repeater. Plots are shown for both available transponder power levels. The flat regions represent the situation where the repeater power limitation is in effect. It can be seen that, even for the lower power transponder, the delayed signal does not exceed -31dB relative to the wanted direct signal. This is more than 20dB below the maximum delayed signal quoted in the equipment specification [2].

The analysis, however, assumes than the transponder is exactly located at the runway threshold (touchdown point of the aircraft). In reality, the transponder is away from the runway threshold. It is, therefore, necessary to ensure that such

[2] Mark 5 Airborne Distance Measuring Equipment (ARINC Characteristic 709-8)

relocation of the transponder can not cause the delayed/direct ratio to increase to the extent that it approaches the -10dB limit.

If we assume that the delayed/direct ratio should not increase above -20dB, this implies that the repeater input is 11dB above the GNSS repeater's limiting value. This would occur for a repeater to runway threshold distance of about 250 metres.

From this, it can be concluded that provided the repeater to runway threshold distance is more than 250 metres from the runway threshold, no location of the transponder will result in a delayed/direct ratio above -20dB. Furthermore, this value would only occur as the aircraft is directly above the repeater. At this distance the aircraft would only be 13 metres above the ground, an unlikely situation for a repeater location as any repeater will be further away than this, and therefore the distance to the aircraft would be much greater than 13 metres so the delayed/direct ratio would be much less than -20dB.

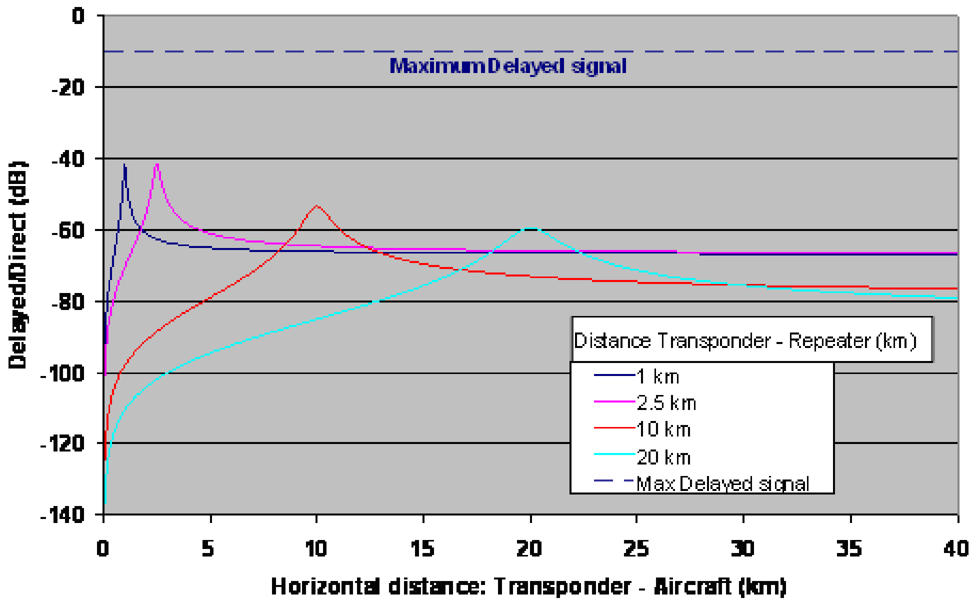

Figure 6: Delayed signal for GNSS repeater below path of landing aircraft relative to direct DME signal vs. aircraft position

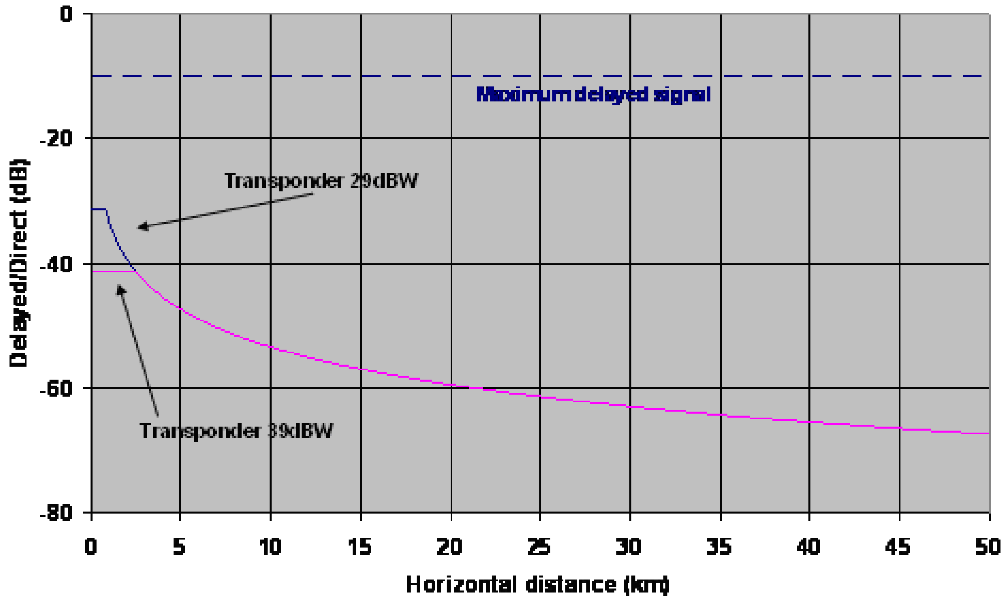

Figure 7: Worst case delayed signal vs. repeater position

6.2.3 DME locking

As seen above, even for situations where a GNSS repeater is directly below the path of a landing aircraft, the maximum level of the delayed signal from the repeater is more than 31dB below the wanted signal. This is more than 20dB below the maximum operating level given in the specification[2]. Additionally, it is estimated that large buildings such as aircraft hangers, terminal buildings etc could create echoes of a similar level.

Moreover, the specification states that the equipment should search in the direction of increasing distance starting at zero. This would ensure that it locks to the direct wanted signal even in the presence of delayed signals. The receiver would periodically repeat this search in order to ensure that it is has not changed lock to a delayed signal due to a loss of the direct signal. It is, therefore, considered most unlikely that false locking to a delayed signal from a GNSS repeater would represent a problem. Increase transmission rate of DME transponder signal

The aviation industry has expressed a concern that the continuous re-transmission of a transponder signal will add to contamination in the band and reduced reliability of the DME systems. In addition, a transponder continually generates its own self-test interrogations (at the interrogation frequency) which are crucial to its safety critical monitoring function. These would, of course, also be re-transmitted.

Furthermore, as will be seen later, there is the possibility of the interrogation pulses from the aircraft being re-transmitted causing additional replies from the transponder, further adding to the issue. Therefore, to prevent the DME transponder receiving and responding to re-transmitted aircraft interrogation pulses from the repeater there might be a need to ensure a separation distance and/or guarantee a receiver filter characteristic (that is to be determined) in the repeater. This is discussed later in this report, but actual filter characteristics will need detailed work.

6.2.4 Reflected rays of radiated DME transponder signal

To prevent reception of false transponder replies at an aircraft, it is important that an echo of the first transponder DME pulse (of the pulse pair) of sufficient amplitude does not coincide with the leading edge of the second pulse. This is because if large enough, this reflected ray could cause destructive interference and result in a loss of lock.

Aviation authorities manage the DME physical environment through safeguarding, one element of this is to minimise the probability of potential destructive echoes. The level of echo considered as acceptable by aviation authorities is not known; therefore the required separation distance is unknown.

However, the minimum pulse separation is 12 µs. If we look at all relative locations of the aircraft, the transponder and the repeater in order to produce this delay, the maximum level of reflected signal possible is 50.8 dB below the direct signal.

This ECC report is based on an analysis of GNSS repeater compatibility. No test work has been done on these environments.

6.2.5 A repeated aircraft interrogator signal affecting transponder DME reception

With no filtering on the input to a repeater, adjacent band aircraft generated interrogations below 1164 MHz, might be repeated. This scenario is illustrated in Figure 8.

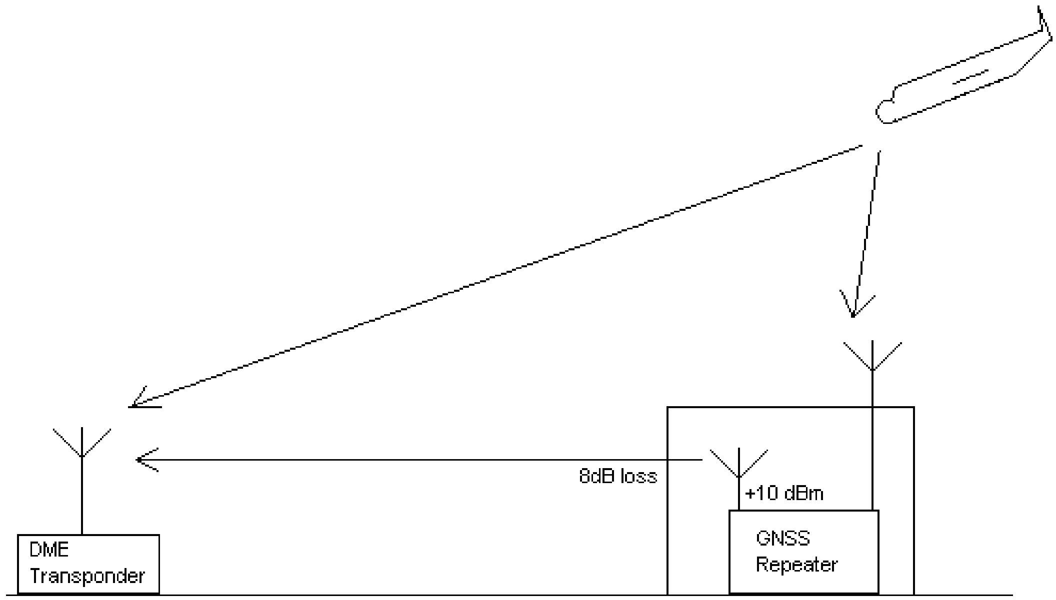

Figure 8: Scenario for repeated DME pulse affecting transponder operation

The potential effect of the repeated pulse is that it could cause the DME transponder to transmit a response. It will be assumed that in order to prevent this, the pulse received by the transponder needs to be below its minimum operating input level. Table 10 presents a calculation of the distance required between the transponder and repeater in order to ensure that the received power falls below the minimum input level by a margin of M dB plus the aviation safety margin. An output filter with a rejection of F dB is assumed.

Technical factor	**Value**
Minimum required DME signal at input to a DME transponder receiver [3]	-121 dBW
Required margin to ensure that transponder does not respond	-M dB
Aviation safety margin	-6 dB
Receiving antenna gain	10 dBi
Maximum interference power relative to isotropic antenna for repeated signal	**-137–M dB**
Maximum e.i.r.p. of a repeated DME signal from unfiltered GNSS repeater	-20 dBW
Repeater output filter rejection	-F dB
Required path loss	117+M-F dB
Building loss	8 dB
Required free-space loss	**109+M-F dB**

Table 10: Propagation loss required for the protection for the protection of the DME transponder reception

[3] www.icao.int/anb/panels/acp/WG/F/WGF14/ACP-WGF14-WP12-L-band%20eqpt%20interf%20suscept.doc

Figure 9 shows plots of the required separation distance vs filter rejection for various values of margin. The filter rejection would need to be achieved at the highest frequency DME interrogator frequency of 1151 MHz. The filter pass band could be tailored to the frequency of the GNSS signal to be covered and need not pass the entire 1164-1215 MHz band. Nevertheless, achieving any significant rejection at 1151 MHz is likely to result in considerable additional cost.

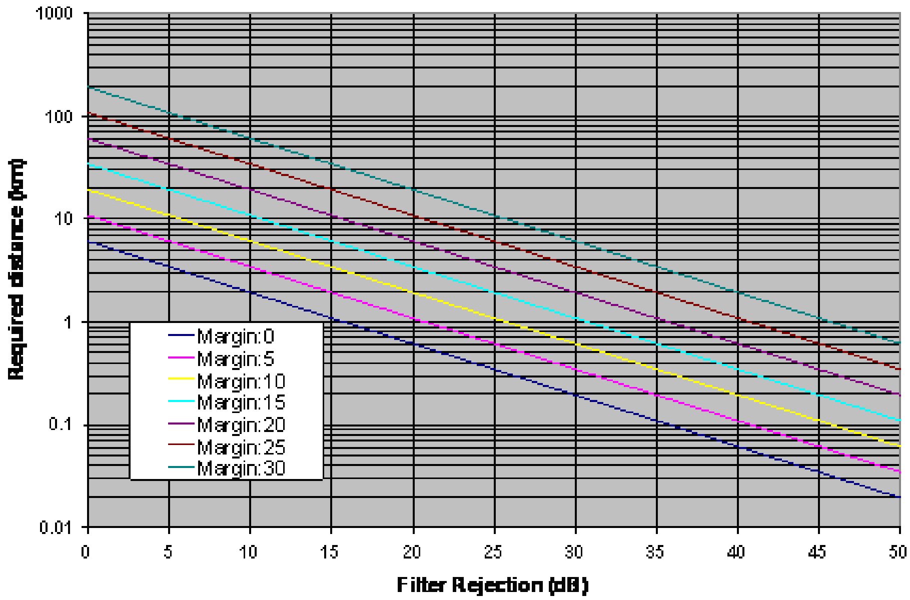

Figure 9: Required separation distance vs filter isolation for various values of margin

We need to therefore check that DME transponder reception is not affected by this, using the above scenario. For the above we assume that almost all DME transponders will be based on airfields, and separated from local buildings where GNSS repeaters may be operating by at least 300 metres. This assumption is taken as a representative minimum taking into account most DME are either situated on airfields or in rural areas away from buildings (these ground based equipment need visibility to aircraft). It is known that the sensitivity performance of some DME receivers are better than the specification so that minimum signal levels are in some cases more than 6dB lower than the -121dBW figure. We will, therefore, assume a margin of 10-15dB to stop false repetition of signals. From Figure 9 the minimum required filter characteristics to stop re-transmission will range from 37-42 dB at edge of the transponder reply frequency at 1151 MHz. If we assume that this minimum is achieved at the RNSS band edge starting at 1164 MHz, then filtering attenuation >42dB will always be available at 1151 MHz, and the above interference scenario will not occur.

If an aircraft DME interrogators is tested in a hangar with an installed GNSS repeater, the separation distance will be small (~10 metres), therefore for 10-15dB margin the filter loss must be much greater and exceed 60dB at 1151 MHz. This is a limited specific case which must be catered for in this particular instance only and must be dealt with in any installation on a case by case basis.

In reality, a certain degree of filtering will be performed by the repeater transmit and receive antenna. To assess this aspect, it is useful to look at the filtering characteristics of a typical GNSS antenna. The device chosen is a quadrifilar helix antenna, GeoHelix-SMP from Sarantel[4]. Figure 10 shows the response of this filter at the GPS L1 frequency of 1575.42 MHz. The 3 dB bandwidth is quoted as 20 MHz. Assuming a similar antenna was constructed for the L5 frequency of 1176.45 MHz with the same bandwidth, the lower 3 dB point would be at around 1166 MHz. Consequently, the rejection at the GNSS band edge of 1164 MHz would be only slightly greater than 3 dB. It would not, therefore, be possible to achieve the required 37 – 42 dB rejection at the at the band edge using this means.

However, the crucial frequency is actually the maximum DME interrogator frequency of 1151 MHz. In order to gauge the filtering that might be achieved with an L5 version of the antenna, Figure 11 shows the response of the filter scaled to the L5 frequency. It is assumed that the same Q-factor will be achieved. Consequently, the bandwidth has been scaled in order to retain the same relative bandwidth.

---

[4] http://www.sarantel.com/technology/specifications

It can be seen that filtering by the transmit antenna might be expected to provide up to about 10dB of rejection at 1151 MHz. Consequently, about 27 – 32 dB of additional rejection would be needed. However, this calculation assumes that the repeater is sufficiently close to the aircraft interrogator that the repeater limitation of -20 dBW applies. If this distance is greater than about 800 metres, this will not apply (assuming 0dB receive antenna gain). Consequently, if a similar antenna is used as the repeater receive antenna, there would be a further rejection of 10dB, resulting in a total of 20dB. At a distance of around 250 metres, the amplifier would still limit even with the 10dB of rejection. Consequently, the input filtering will have no effect. Between 250 and 800 metres, the filtering will have an effect, but it will not be the full 10dB.

From this analysis it seems that additional filtering will be required over and above that provided by the antennas. For an aircraft-repeater separation of 250 metres or less 27-32 dB additional rejection would be needed at 1151MHz. At 800 metres this figure would be 17-22 dB. Above 800 metres the filtering can be reduced according to the additional free-space loss. As before, it should be stressed that these calculations assume 8dB building loss. If the loss is different, the distances should be adjusted accordingly.

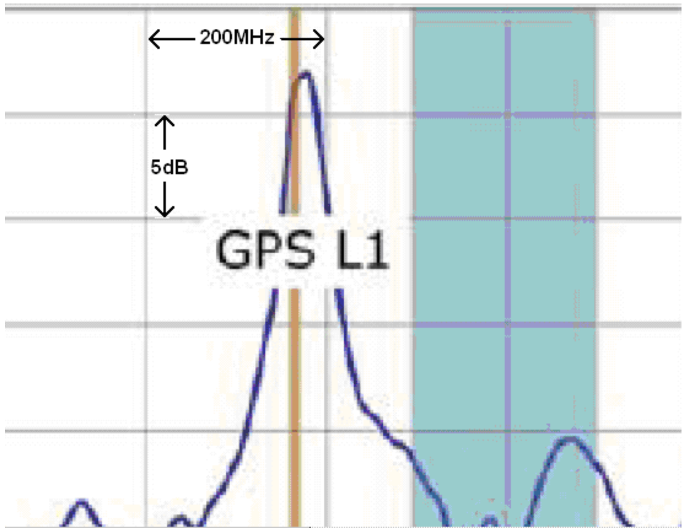

Figure 10: Response of Sarantel antenna at GPS L1 frequency

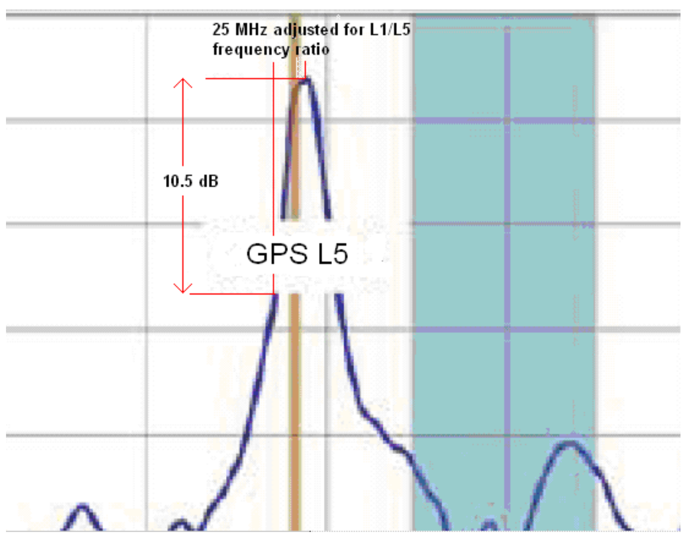

Figure 11: Assumed response of antenna at GPS L5 frequency

6.2.6 Harmonic generation when re-radiating large pulses

When the repeater is subjected to a large pulse from a DME system such that the amplifier limits, the repeater could produce harmonics. These would generally be odd harmonics, the lowest of which would be the third harmonic. Based on the DME interrogator frequency range of 962-1213 MHz, these harmonics would be in the range 2886-3639 MHz and so outside any 1-2 GHz amplifier's operating range the level of this harmonic from the amplifier is unlikely to exceed -10dB relative to the fundamental at -20dBW. Moreover, based on the example Sarantel antenna, there is likely to be more than 30dB of transmitting antenna rejection. The total e.i.r.p. would, therefore, be -60dBW at the most and not be an issue.

6.3 Interference to JTIDS/MIDS

JTIDS (Joint Tactical Information Distribution System) and its successor MIDS (Multi-functional Information Distribution) are highly-survivable military radio communications systems design to meet the most stringent requirements of modern warfare. Both systems belong to a category known as Link-16, using frequency hopping spread spectrum with 51 carrier frequencies between 969 and 1206 MHz.

Previous studies within CEPT have investigated interference from mobile services into JTIDS/MIDS [3]. However, interference from a GNSS repeater would be somewhat different. The effect of a repeater would be similar to multipath, resulting in a delayed version of the signal being received by the JTIDS/MIDS receiver.

To analyse the effect of a repeater we assume a wide area repeater with a receive antenna gain of 3dB (i.e. a total gain of 46dB) and a building loss of 8dB. The repeater is in the vicinity of one of the JTIDS/MIDS terminals, which we will assume is receiving. Consequently the path loss between the JTIDS/MIDS transmit terminal and the GNSS repeater is almost identical to that between the transmit terminal and the receive terminal. Assuming free-space loss between the repeater and the JTIDS/MIDS receiver, provided the GNSS repeater is more than 5.2 metres from the receiver, the delayed signal will be below -10dB relative to the direct signal. At 16.3 metres, the figure would be -20dB. In the absence of building loss the separations for -10 and -20dB would be 13 and 41 metres respectively. If the GNSS repeater were located close to the transmitting terminal and assuming that it did not have a power limitation, by reciprocity the effect would be exactly the same. However, in reality, the repeater power limitation would reduce the delayed signal by many tens of dB relative to the case where it is close to the receiver. Based on these calculations a GNSS repeater should have no more detrimental effect on JTIDS/MIDS that that of local multipath, and this would only occur if it were close to the receive terminal.

6.4 Conclusions regarding 1164-1215 MHz and services other than GNSS

The analysis has indicated that there are no practical/real impacts to non-GNSS services in this band under the assumptions made with which includes any necessary filtering. However, aviation authorities have still expressed concern that no real tests have been conducted against DME services.

7 SPECIFIC ISSUES RELATING TO THE BAND 1215-1300 MHz BAND AND RADIOLOCATION/ RADIONAVIGATION SYSTEMS SUCH AS RADAR

In this band military and civilian radars operate. GNSS repeaters operating in this band will repeat any transmitted radar signal. The likely effect of this has to be assessed.

To clarify the above situation assumptions on the likely technical characteristics of any GNSS repeater have to be made. Some published technical material is available that will allow CEPT to assess the risks of the above cases.

7.1 Interference to military and civilian radar

A GNSS repeater could potentially cause interference to radar receivers. As with DME, there are two mechanisms by which this could occur.

- The intentionally radiated GNSS signal from the repeater could raise the noise floor of the received radar signal.
- The radar signal itself could be re-radiated.

For the purpose of this analysis we will assume that the received interference should be at a level at least 10-15 dB below the noise for of the radar receiver.

7.1.1 Noise increase to radar system

This scenario for noise increase to radar is illustrated in Figure 12. As previously noted, the GNSS signal will be below the noise floor of the system and, we need only consider the noise radiated by the repeater. Assuming a Noise Figure of 1.5 dB, the radiated noise e.i.r.p. will be -106.8 dBW/MHz.

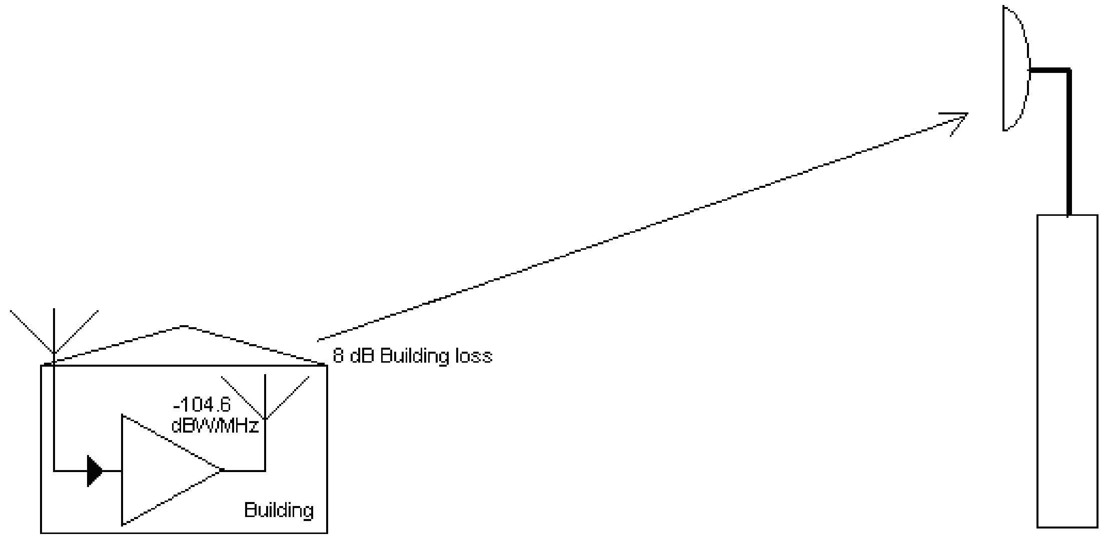

Figure 12: Scenario for GNSS repeater interfering with radar

Calculation of the maximum level of noise interference from a GNSS repeater into a radar antenna is given in Table 11.

Technical Parameter	**Value**
Frequency	1250 MHz
Radar Noise Figure	3.1 dB
Radar bandwidth (1.25 MHz)	61.0 dBHz
Boltzmans Constant	-228.6 dB
Reference temperature (290k)	24.6 dB
Noise floor of receiver	**-139.9 dBW**
Assumed I/N	-10 dB
Bandwidth correction 1.25 MHz to 1 MHz	-1 dB
Maximum permissible noise interference at receiver input	**-150.9 dB/MHz**

Table 11: Maximum noise interference level at the radar receiver input

An analysis has been carried out based on a radar antenna at a height of 20 metres above ground level and a GNSS repeater transmitting antenna at a height of 3 metres above ground level. Two different radar antenna vertical radiation patterns (see Annex 3) have been considered, these patterns have been taken from radar study material input originally to CEPT work item on RNSS versus Radar. The first of these is a high (cosecant) beam directed slightly above the horizon, and the second is a low beam or pencil beam for detecting objects on the horizon. The total transmitter power is 40 kW, 25% of which is fed to the low beam antenna and 75% of which is fed to the high beam antenna. Note that the radiation patterns given in Annex 3 are relative to the back of the antenna. If radar is situated at a significantly higher altitude than the height of land towards the horizon, the antenna itself will generally need to be tilted downwards. In this worth case a downwards tilt of 2 degrees is assumed.

The repeater antenna will be at a negative elevation angle with respect to the radar antenna and will, therefore, be subject to a reduced radar antenna gain relative to its bore sight gain. This elevation angle will, of course, depend on the horizontal distance between the radar antenna and the repeater.

Figure 13 shows the expected GNSS repeater noise interference at the radar receiver input plotted against horizontal distance between the repeater and the radar antenna. The analysis takes account of the vertical pattern of the radar antenna, free-space loss and an assumed building loss of 8 dB. It should be noted that the antenna patterns are not defined for angles of declination greater than 8°, corresponding to a distance of 120 metres. The results for distances below this should, therefore, be treated with caution. Also shown in red is the maximum level of -150.9 dB. It can be seen that the expected level is below the maximum for all distances. In reality, the interference levels at longer distance will be lower than shown in the plot because of attenuation by terrain clutter.

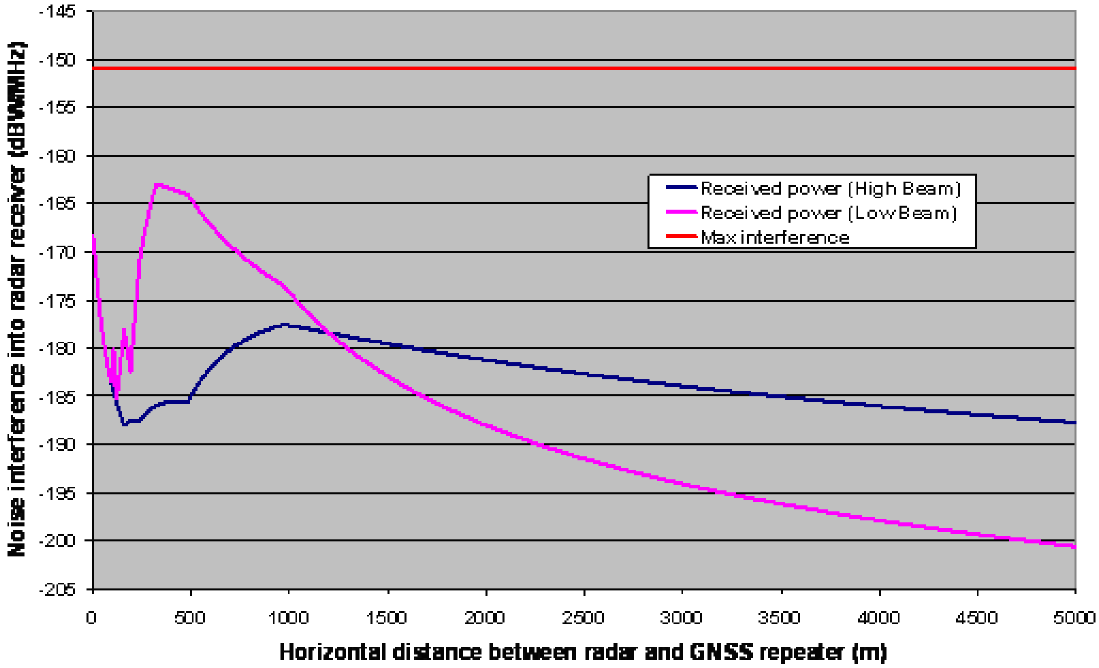

Figure 13: Radar interference vs horizontal distance for noise from GNSS repeater

7.1.2 Repeated radar signal interfering with radar

The scenario for interference from a repeated radar signal is illustrated in Figure 14. Note that for all but short distances the angle of arrival for the radar signals at the repeater will be less than 10 degrees from horizontal. Therefore, we will assume a repeater receiving antenna gain of zero.

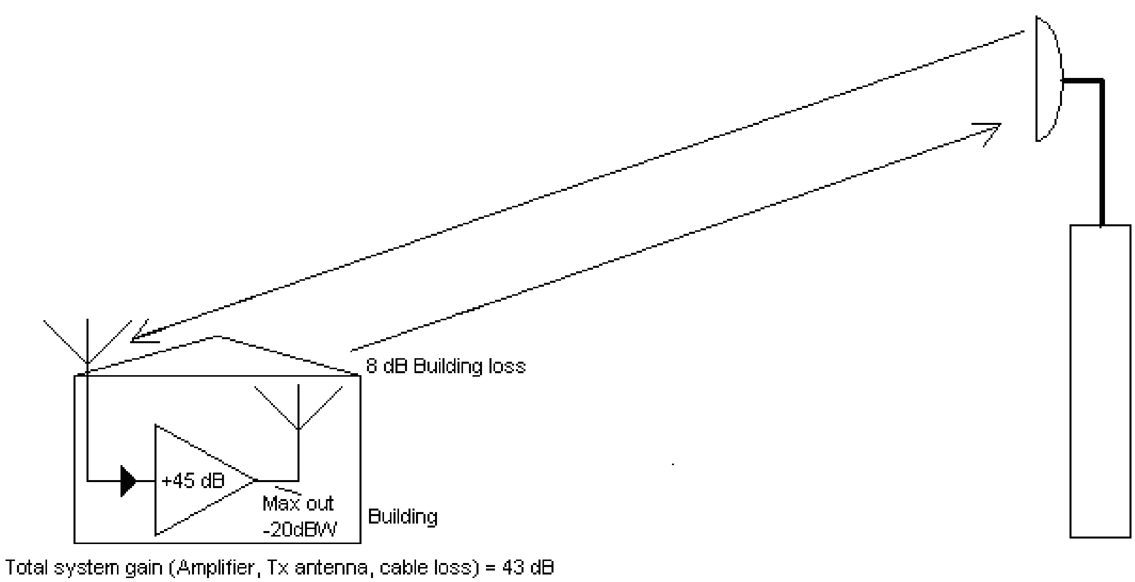

Figure 14: Scenario for re-radiated radar signal interfering with radar

As with the case of DME signals we will consider a maximum repeater output power of -20dBW. Figure 15 shows the expected level of the re-radiated pulse at the input of the radar receiver plotted against horizontal distance. The red line indicates the minimum discernible signal level (MDS) quoted in the chosen radar specification [5]. It can be seen that in this case the interfering pulse is significantly greater than the minimum discernible signal level at all distances up to and beyond 5000 metres.

For comparison, Figure 15 also shows the level of a reflection from a building with a radar cross section of $20m^2$ and a reflection coefficient of -8dB. It can be seen from these results that the effect of the repeater is significantly less than that of the building. At some distances the difference is as much as 40dB. Note that, in dB terms, the effect of the radar antenna pattern and free space loss is doubled for the building reflection compared to the repeater. This is because the former occurs for propagation in both directions. The re-radiated pulse from the repeater, however, is limited by the -20dBW output limitation and does not vary with distance, until the distance at which the input to the repeater falls below the level at which the output is -20dBW. At longer distances the repeater power restriction becomes less significant. Figure 16 shows the re-radiated pulse level for longer distances. It can be seen that the traces for the repeater and building cross over and at long distances the repeater provides a stronger signal than the building. Note that a dual slope propagation model was used whereby free-space loss is assumed at distances up to 5 km and a factor of 40log(d) is applied at distances over 5km.

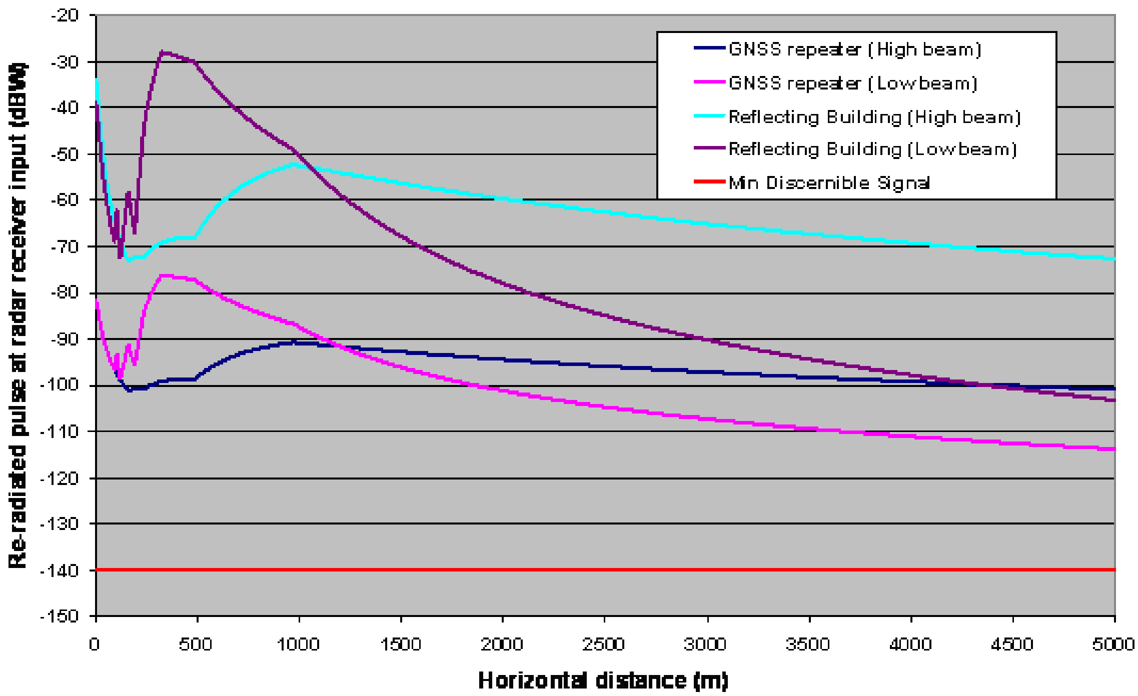

Figure 15: Re-radiated pulse interference at input of radar receiver Vs horizontal distance

[5] Taken from radar study material input originally to CEPT work item on RNSS versus Radar

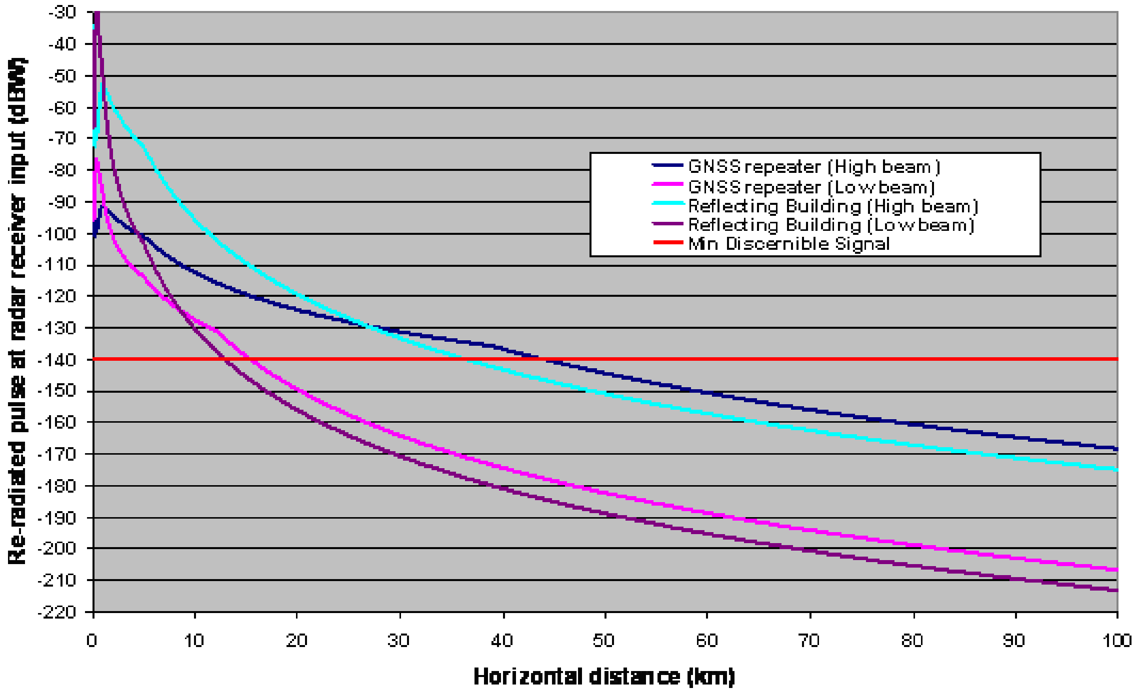

Figure 16: Re-radiated pulse interference at input to radar receiver for longer distances

The calculation below derives the distance at which the received pulse would fall below the MDS, assuming the radar antenna gain corresponding to the horizontal direction. A dual slope propagation model was used whereby free-space loss is assumed at distances up to 5 km and a factor of 40log(d) is applied at distances over 5km. This model has been widely used for terrestrial sharing studies. The 40log(d) term reflects increased loss due to ground clutter for longer paths which will generally be non line of sight.

This analysis suggests that interference from re-radiated pulses occurs for distances up to 44.4 km for the high beam and 14.5 km for the low beam**.** Analysis for the 20m^2 building gives distances of 36.7 km for the high beam and 12.0 km for the low beam (See Table 12).

	High Beam	**Low Beam**
Radar transmitter power	46 dBW	
Individual beam powers	44.8 dBW	40 dBW
Radar antenna gain	36.4	19.4 dB
Path length	**44.4 km**	**14.5 km**
Dual slope path loss	-146.3 dB	-126.9 dB
Repeater receiving antenna gain	0 dB	0 dB
Repeater gain	43 dB	43 dB
Theoretical repeater output	-22.1 dBW	-24.5 dBW
Limited output	**-22.1 dBW**	**-24.5 dBW**
Path loss	-146.3 dB	-126.9 dB
Building loss	-8 dB	-8 dB
Radar antenna gain	36.4dB	19.4 dB
Radar receiver input	**-140.0 dBW**	**-140.0 dBW**

Table 12: Required separation distance from the radar

This shows that unlike the case of short distances shown in Figure 15, for long distances the repeater has more effect than the building and will be detected by the radar over a longer distance. This is because the repeater output never reaches its amplifier maximum output power as it would be at close range.

It should be noted, however, that the overall impact is not likely to be great as the repeater will essentially appear as ground clutter. Some radar would reject it on the basis of zero Doppler shifts.

Subsequent analysis shows that when the amplifier is not limiting, the repeater produces the same reflected power as a building with a radar cross section of 180m^2 and a reflection coefficient of -8dB.

7.1.3 Radar Conclusions

From the analysis performed, GNSS repeaters do have the potential to appear as a reflected primary radar signal at a significant level such that this might cause an additional signal. However, on the basis that the repeater will not be moving, the zero doppler should allow this signal to be discounted, similar to all the other local clutter signals.

Although the repeater signal might not cause a problem for the radar, the significant predicted separation distances involved should prompt some caution. CEPT administration should carefully consider on a case by case basis any proposal to use GNSS repeaters with a maximum output power up to +10 dBm local to radar. Any practical GNSS repeater system need not have a maximum output power greater than -20 dBm, which will significantly reduce the separation distances.

7.2 Earth Exploration Satellite Service (Active) (EESS)

7.2.1 Interference assessment

EESS operates in the band 1215-1300 MHz in the form of space borne SAR (Synthetic Aperture Radar). This system transmits a signal to the Earth and receives a reflection back from the Earth's surface. They are used typically to produce radar image maps of the Earth's terrain as the spacecraft motion creates a synthetic aperture over a typical aperture time of 0.2 – 1.5 s. Processing of the collected data is used to simulate a radar antenna with dimensions many times the physical size of the actual antenna. Associated with this processing are two separate processing gains known as azimuth and range. These gains will be different for the radar signal, noise and different types of interfering signal.

The most significant interference scenario relating to GNSS repeaters is that the repeater re-radiates the satellite signal and the receiver on the satellite receives the re-radiated signal, which appears as a reflection that could hide the natural image (see Figure 17).

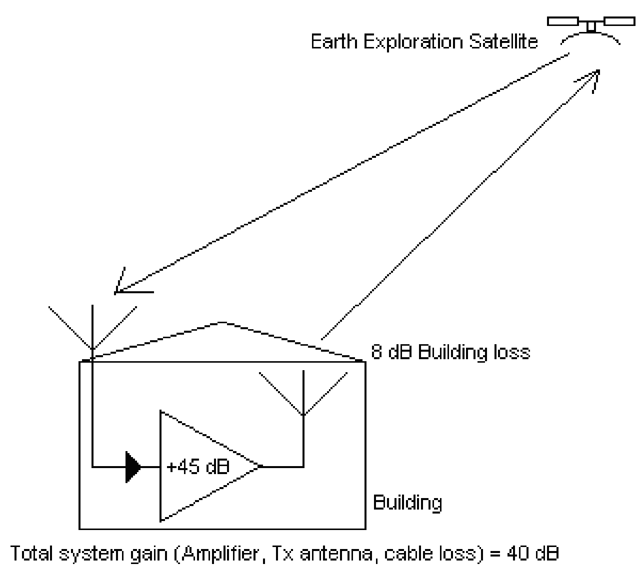

Figure 17: Interference to Earth Exploration Satellite Services

Two typical SAR characteristics are given in Recommendation ITU-R RS.1347. Relevant parameters are given in Table 13. Assuming the bandwidth of the SAR transmission falls inside the repeater bandwidth.

	SAR 1	**SAR 2**
Frequency MHz	1227.6[6]	1227.6
Peak radiated power (dBW)	35.1	30.8
Transmitter antenna gain (dB)	36.4	33
Orbital altitude (km)	400	568
Antenna orientation (degrees from nadir)	20	35
Path length (km)	427.5	709.3
Free-space loss (dB)	146.8	151.2
Received Signal at Earth's surface (dBW) for 0dBi antenna	**-75.3**	**-87.4**

Table 13: EESS (active) systems parameters

From the above the signal level at the SAR receiver input due to a GNSS repeater is calculated in Table 14.

	SAR 1	**SAR 2**
Frequency MHz	1227.6	1227.6
Received Signal at Earth's surface (dBW) assuming 0dBi antenna	-75.3	-87.4
Antenna polarisation mismatch loss (dB)[7]	3	3
Receive antenna gain	3	3
Repeater gain (assuming Tx antenna gain= 0[8])	40	40
Building loss (dB)	8	8
Free-Space loss (dB)	146.8	151.2
SAR receiving antenna gain (dB)	36.4	33
SAR antenna polarisation mismatch loss (dB)[9]	3	3
Interference at SAR receiver input (dBW)	**-156.7**	**-176.6**

Table 14: GNSS repeater interference level at the SAR receiver input

Maximum interfering power can be calculated as:

$$P_I = I/N . \cdot P_N \cdot (G_{NAZ}/ G_{IAZ}) \cdot (G_{NRNG}/ G_{IRNG}) \quad (3)$$

where:

P_I = Maximum interference power at receiver input

I/N = Required interference to noise ratio after SAR processing (-6 dB)

P_N = Receiver reference noise power (-127.7 dBW)

G_{NAZ} = Azimuth processing gain of noise (30.6 dB)

G_{IAZ} = Azimuth processing gain of interference (61.2 dB)

G_{NRNG} = Range processing gain of noise (0 dB)

G_{IRNG} = Range processing gain of interference (28.2 dB)

The following values are taken from Recommendation ITU-R RS.1166-3. Since the characteristics of the reflected/repeated interfering signal are the same as those of the wanted reflected signal, the processing gain values used for the interference

[6] The ITU recommendation does calculations for the GPS L2 frequency, since it refers to compatibility issues with GPS. In reality, the radar can operate anywhere in the band 1215-1300MHz.
[7] Linear to circular
[8] The repeater transmitting antenna will, most likely be installed such that it radiates downwards rather than towards the sky. Consequently, the relevant gain will be less than the boresight value of 3dB. A gain of 0dB is assumed here, although the gain may actually be less than this.
[9] Circular to linear

are the same as those quoted for the wanted signal. Based on these values, maximum interference power, P_I = -192.5dBW. It is clear that the repeated signal will be seen at a considerable increase on that expected by the EESS for both SAR1 and SAR2, resulting in erroneous imagery data at the location of any repeaters.

7.2.2 Conclusion

The effects occur when the SAR radar beam is oriented towards the GNSS repeater receiver. The phenomena occurs during a limited period of time (a few seconds) since the radar beam is very sharp (1 degree in azimuth, or 7.5 km at ground level) and the radar beam ground velocity is close to 6 km/s (Rec. ITU-R RS.1347). However, the response will always occur at that location and perhaps affect data collection.

7.3 Wind Profiler Radar

7.3.1 Interference assessment

Wind Profiler Radar (WPR) operates in the band 1270-1295 MHz. As with other radar systems, there is the possibility that the radar signals will be re-radiated by a GNSS repeater and the repeated signal is subsequently received by the radar receiver. The scenario is shown in Figure 18.

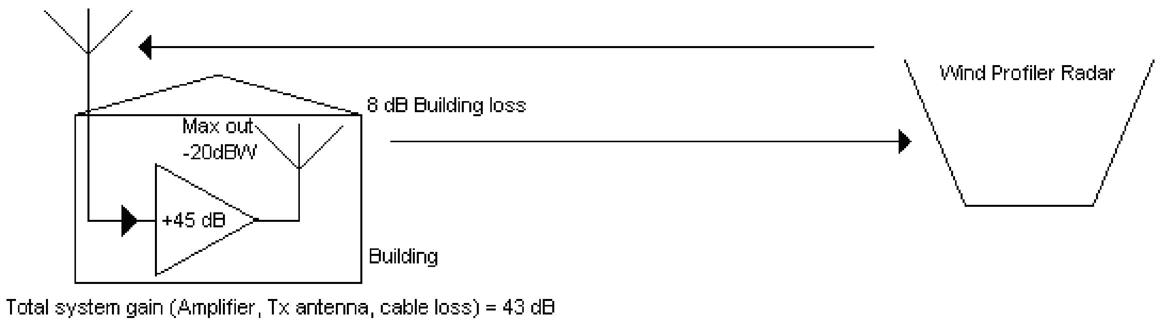

Figure 18: Scenario for re-radiated Wind Profiler Radar signal

Typical parameters for such WPR systems are given in Table 15.

Parameter	**Value**
WPR transmitter power	35 dBW
WPR antenna gain in horizontal direction	-18 dB
WPR receiver noise power[10]	-144.5 dB(W/MHz)
Assumed bandwidth	1 MHz
I/N	-10 dB
Maximum interference	**-154.5 dBW**

Table 15: Typical wind profiler radar characteristics

Figure 19 shows the level of the re-radiated signal at the input of the WPR receiver, based on the large area repeater, plotted against distance. The WPR receiving antenna is directed upwards and is assumed to have -18dB gain in a horizontal direction. The repeater transmitting antenna gain in the direction of the WPR will depend on the repeater configuration and is assumed to have a gain of 3dB. For comparison, the reflecting building is also plotted and the maximum interference level of -154.5dBW is shown.

[10] Noise power based on receiver noise figure: 1.5dB, antenna noise temperature: 30k, cable loss: 1dB, cable temperature: 290k.

It can be seen that the re-radiated signal exceeds the minimum interference level for distances up to about 1km. However, the building reflection also exceeds the minimum level for distances up to 0.7km. The radar should recognise that these signals have no Doppler shift and reject them.

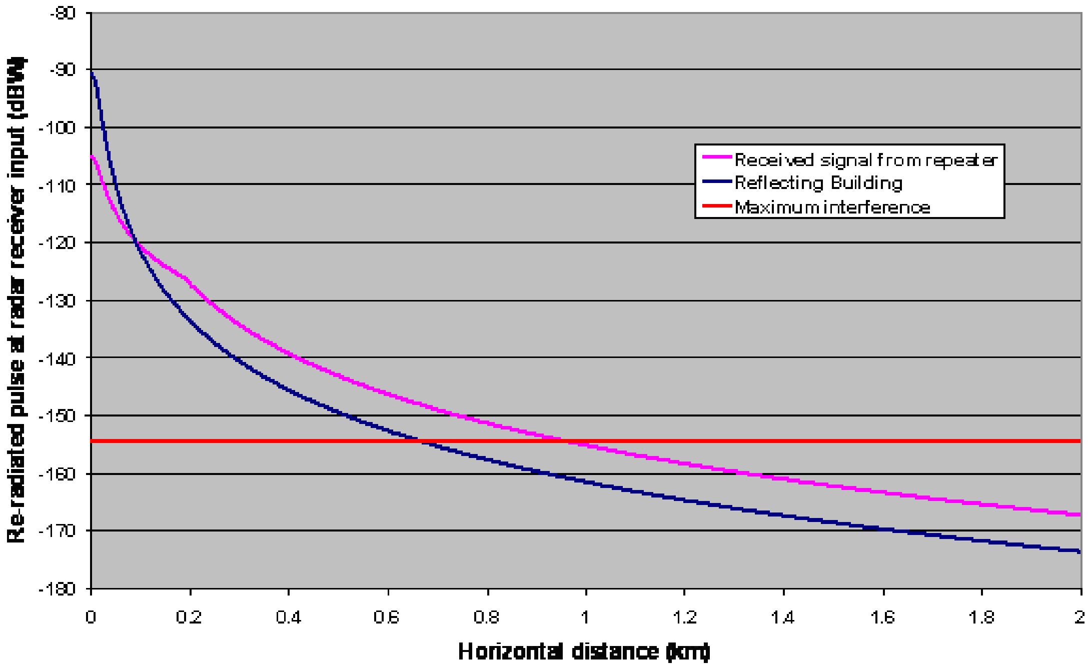

Figure 19: Re-radiated pulse interference at input of WPR receiver Vs horizontal distance

7.3.2 Conclusion for WPR

A GNSS repeater using an output power up to +10 dBm at distances up to 1km may cause an affect to WPR data collection. Therefore, the installation of any GNSS repeater within the band 1270-1295 MHz, local to a WPRC should be treated on a case by case basis to ensure compatibility. Such difficulty would be alleviated when considering more realistic output power such as -20 dBm.

8 SPECIFIC ISSUES RELATING TO GNSS RECEPTION

The bands in which GNSS systems operate are the so called L5/E5 bands of 1164-1215 MHz, the L2 bands at L2/E6 1215-1300 MHz and the L1 bands at 1559-1610 MHz. The other services sharing the bands 1164-1215 MHz and 1215-1300 MHz have been considered above. For the band 1559-1610 MHz there are no other services that need to be considered. This section therefore covers the effects of GNSS repeaters on other GNSS receivers operating close to these devices.

8.1 Noise interference to GNSS receivers

We will consider three GNSS receiver applications, aeronautical, maritime and railways. Relevant parameters and sharing scenarios were taken from similar applications described in reference [4] which includes reference to bands where RNSS services operate.

8.1.1 Aeronautical

Technical factor	**Value**
Frequency (GPS C/A code)	1575 MHz
Noise Interference threshold for C/A receiver (ITU-R)	-146.5 dBW/MHz
GNSS receiving antenna gain (towards ground)	-10 dB
Interference allotment to repeaters	10 dB (10%)
Aviation safety margin	6 dB
Variations in GPS receivers	3 dB
GNSS repeater e.i.r.p.	-104.6 dBW/MHz[11]
Required path loss	50.9 dB
Building loss	8 dB
Free-space loss	42.9 dB
Path length	2.1 metres

Table 16: Necessary separation distance between the GNSS repeater and the aeronautical GNSS receiver for noise interference

Since this path length includes the portion inside the building, the interference level may not exceed the threshold anywhere outside the building.

An in-flight aircraft will potentially be in sight of a number of repeaters. The exact number will depend on the horizon distance, which is determined by the aircraft height. The density of repeaters causing the aggregate interference level has been calculated for all repeaters in sight of an aircraft at variable height. The results are plotted in Figure 20 assuming no building loss.

At height the density of repeaters causing the aggregate effect levels out due to the increase in propagation loss. At 100 metres height the value is about 950 repeaters per km^2, corresponding to about one repeater every 30 metres. In practice, the density is likely to be far less than this.

A similar analysis at 100 metres height with a building loss of 8 dB gives a value of about 6000 repeaters per km^2, corresponding to one repeater every 13 metres.

[11] Based on amplifier with noise figure 1.5 dB gains 45dB.

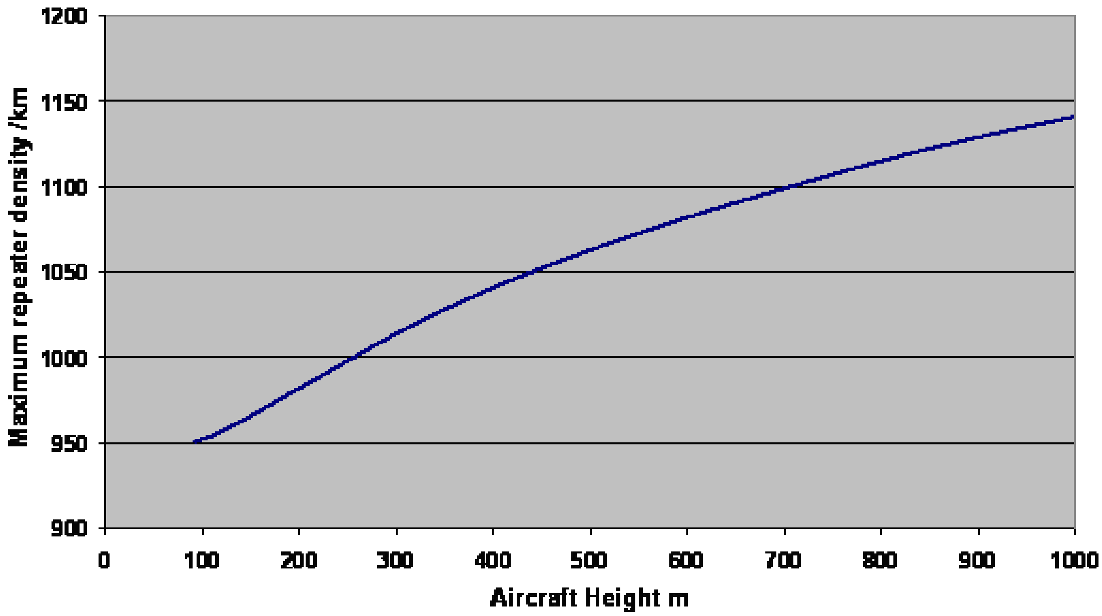

Figure 20: Maximum repeater density vs. aircraft height

8.1.2 Maritime

The table below gives a calculation of the minimum separation between a GNSS repeater and a ship mounted GNSS receiver. Note that this calculation is based on the GPS C/A code, the protection requirements for other GNSS services that use or will use this band (GPS SOL, Galileo open service and Galileo encrypted), will be similar.

Technical factor	**Value**
Frequency (GPS C/A code)	1575 MHz
Noise Interference threshold for C/A receiver (ITU-R)	-146.5 dBW/MHz[2]
GNSS ship receiving antenna gain in horizontal direction	0 dB
Interference allotment to repeaters	10 dB (10%)
Repeater noise Interference threshold for C/A receiver	-156.5 dBW/MHz
GNSS repeater e.i.r.p.	-104.6 dBW/MHz
Required loss	51.9 dB
Building Loss	8 dB
Free-Space Loss	43.9 dB
Distance	2.4 m

Table 17: Necessary separation distance between the GNSS repeater and the maritime GNSS receiver for noise interference

Since this path length includes the portion inside the building, the interference level is unlikely to exceed the threshold anywhere outside the building.

Reference document [4] quotes some typical scenarios for ship-based GNSS receivers. On this basis the minimum realistic physical separation occurring between a ship and a repeater is 37 metres. Therefore, the above separation distance indicates that for maritime services GNSS repeaters are not an issue.

8.1.3 Railways

Reference [4] quotes some typical scenarios for GNSS receivers mounted on trains. The separation distance assumed for these scenarios is greater than 7 metres. Therefore, the above separation distance indicates that for railway services GNSS repeaters are not an issue.

8.1.4 High Sensitivity Receivers

It is also necessary to consider high sensitivity receivers. These receivers are typically incorporated into mobile phone devices and use assistance information delivered via the phone network to enable operation in shadowed locations. Consideration has been given to these devices in a Preliminary Draft New Recommendation from the ITU-R [5]. The following extract is taken from this document.

> *A-RNSS refers to commercial-grade handheld and assisted RNSS receivers. This class of receivers operate within "stressed" environments such as under heavy foliage, indoors or in urban canyons. They are sometimes "cell-phone assisted," since aiding information (Doppler, timing, navigation data) is provided in real-time to enable RNSS signal acquisition and tracking through significant attenuation (such as building walls). Because of heavy foliage or wall attenuation, it is not appropriate to define standard RNSS received signal levels. Thus, interference power thresholds cannot be defined relative to received signal levels. Therefore, the accepted approach is to define the aggregate interference power density threshold at a level that will not raise the total noise floor by more than 1 dB above the environmental noise floor. Here, that environmental noise floor is that of an indoor environment (−144 dBW/MHz), which translates to a receiver noise power density of −141 dBW/MHz for a receiver with a 3 dB noise figure, resulting in an aggregate wideband interference power density threshold of –146.9 dBW/MHz, at the output of a 0 dBi circularly polarized passive antenna.*

The derived value for aggregate wideband interference power density threshold is within 0.5dB of the value used in the above analysis. It can, therefore, be assumed that this analysis is also applicable to high sensitivity assisted receivers.

8.2 Multipath interference to GNSS receivers

In addition to the noise considerations the re-radiated GNSS signal can act as an additional multipath component, causing a loss of positional accuracy returned by an affected receiver. To avoid such effects it is considered that the re-radiated signal should be at least 10 dB below the direct GNSS signal, i.e. below -170 dBW. The calculation is given below.

Technical factor	**Value**
Frequency (GPS C/A code)	1575 MHz
Received GNSS signal	-160 dBW
Total repeater gain (excluding receiving antenna)	43 dB
e.i.r.p. of GNSS signal	-114 dBW
Interference threshold for C/A receiver	-170 dBW
Required free space loss with no building loss	56 dB
Distance	9.5 metres
Building loss	8 dB
Required free space loss with building loss	48 dB
Distance	3.8 metres

Table 18: Necessary separation distance between the GNSS repeater and the GNSS receiver for GNSS signal interference

8.2.1 Multipath effects

As stated, a potential problem is the effect of the low level re-radiated GNSS signal on nearby receivers. This signal is delayed relative to the signal received directly from the constellation and produces similar effects to those caused by multipath, potentially leading to errors in the position reported by the receiver. In this section we will look at the magnitude of the errors that could occur.

8.2.2 Example situation of pseudo range error

Essentially, the effect of a delayed signal is to modify the correlator output such that the output is no longer symmetrical. A multipath simulation[12] is used to indicate this effect. Figure 21 shows a simulated correlator output for a multipath signal with amplitude of 0.3 x direct signal, and a delay of 0.6 x chip period. It should be noted that this is a rather extreme example intended to demonstrate the mechanism by which errors can occur. The purple trace represents the correlation function of the direct signal, the red trace represents that of the delayed signal, and the black trace shows that of the overall signal. The blue points represent the outputs from the early and late correlators, which in this case are separated by 0.5 chip period. These correlator outputs are significantly different which would result in an error in the pseudo range[13] calculated by the receiver. The time separation between the correlators is actually a receiver design choice with typical values of 0.1, 0.5 and 1.0 chip periods. The error due to the repeater would depend on this time separation - a small separation value of typically 0.1 chips would give a smaller error than a large separation of 1 chip. Note that a small separation of early/late correlators implies a large bandwidth receiver, 0.1 of a chip for GPS C/A code (1.023Mcps chip rate) implies a ±10.23 MHz bandwidth receiver.

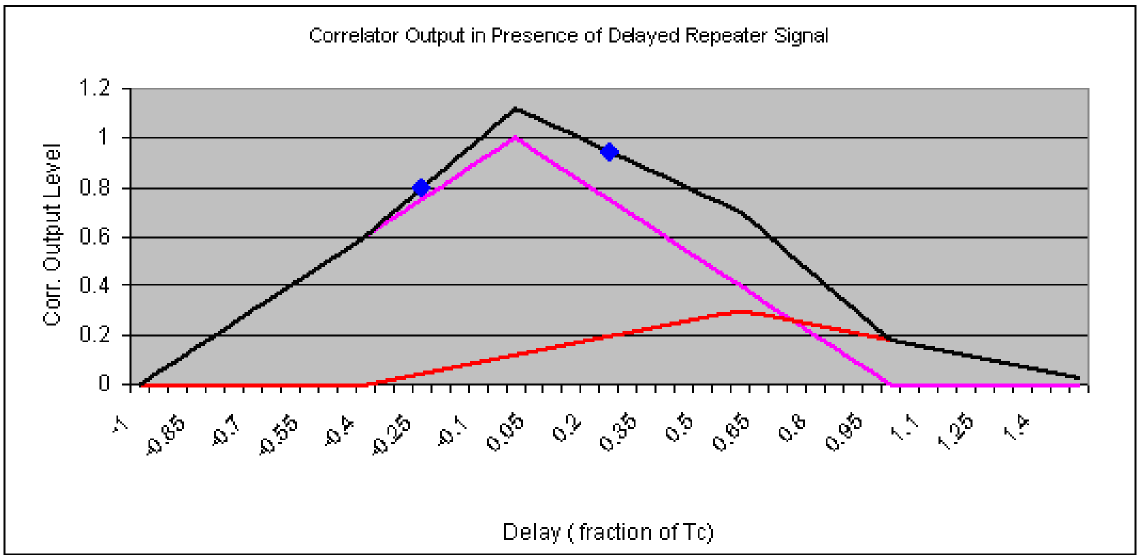

Figure 21: Correlator output in the presence of a repeater

8.2.3 Derivation of pseudo range error at the protection distance

The calculated maximum distance at which the selected protection value of -170dBW occurs is around 9.5 metres in the absence of building loss. Therefore, if a GNSS receiver is placed directly in the GNSS satellite signal to repeater path, the maximum delay of the multipath signal will be 2 x 9.5 metres, or 19 metres. A chip delay of 19/293 for GPS C/A code and 19/29.3 for GPS P code. The signal amplitude will be 0.1 of the direct signal and if a 0.5 chip correlator is assumed then we might expect the errors for this single satellite path as shown in Figure 22. The pseudo range error would be 1.7 metres.

---

[12] http://www.gpssource.com/

[13] A pseudo range is a measure of the distance between the receiver and a particular satellite, subject to an unknown receiver clock error. To derive a position, a pseudo range must be calculated for at least four satellites.

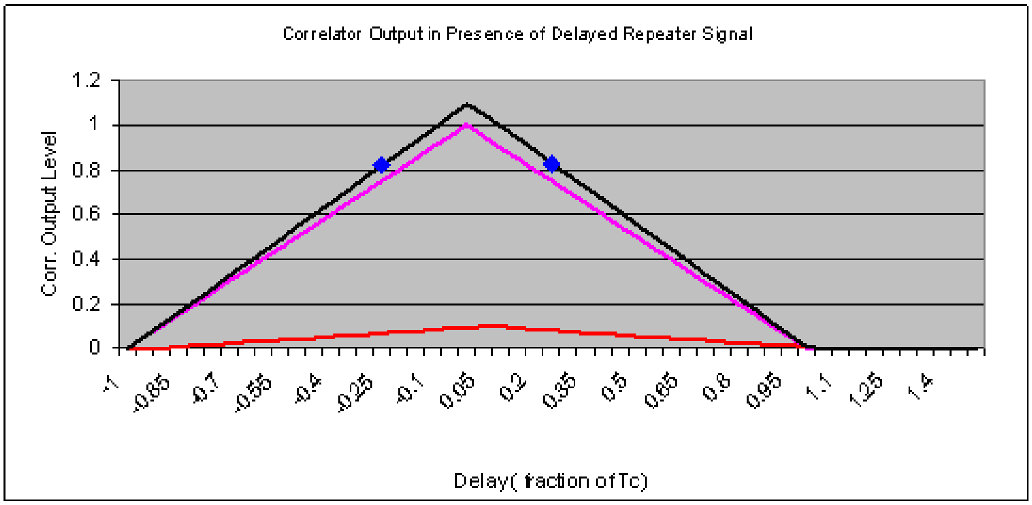

Figure 22: Correlator output at -170dBW protection distance for large area repeater

The simulator also generates pseudo error plots vs distance for a GNSS repeater situation in which there is a direct signal with a fixed level of -160 dBW and a re-radiated signal which decreases with distance from the transmitting antenna according to normal free-space propagation, as shown in Figure 23.

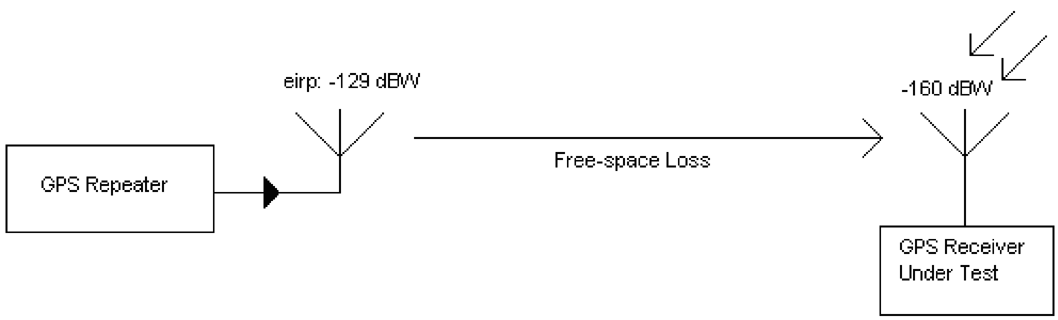

Figure 23: GNSS repeater multipath situation

Figure 24 and Figure 25 show the results of this simulation for a test-bench GPS re-radiated with an e.i.r.p. of -129 dBW as previously described, with and without a building attenuation of 8dB. A correlator separation of 0.1 chips is assumed, corresponding to a good quality receiver. The maximum error is 0.21 metres with building loss and 0.52 metres without. This occurs at a distance of 15 metres from the repeater and the error drops sharply at further distance.

Figure 26 and Figure 27, show the results of this simulation for the large enclosure re-radiator with an e.i.r.p. of -114 dBW as previously described. As before, the results are given with and without a building attenuation of 8dB. The maximum error is.1.1 metres with building loss and 2.5 metres without.

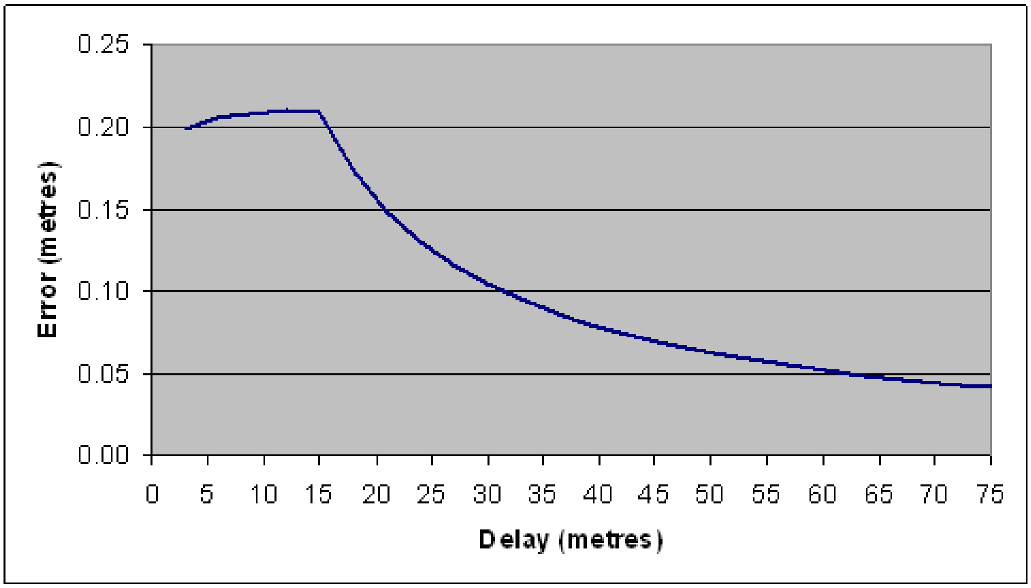

Figure 24: Test-bench repeater: Worst case Pseudo range error vs. distance (Building loss = 8dB)

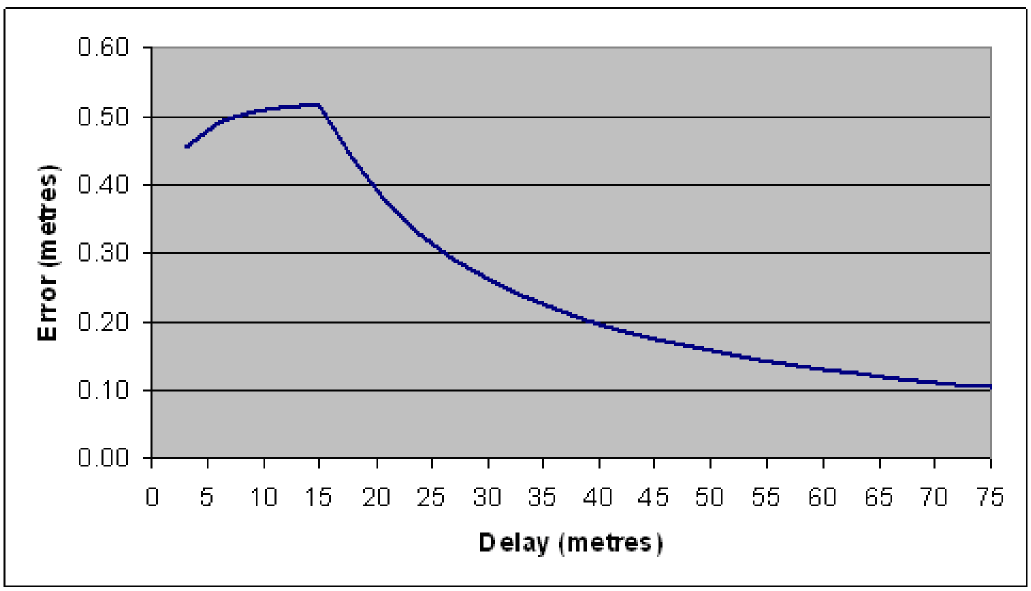

Figure 25: Test-bench repeater: Worst case Pseudo range error vs. distance (no building loss)

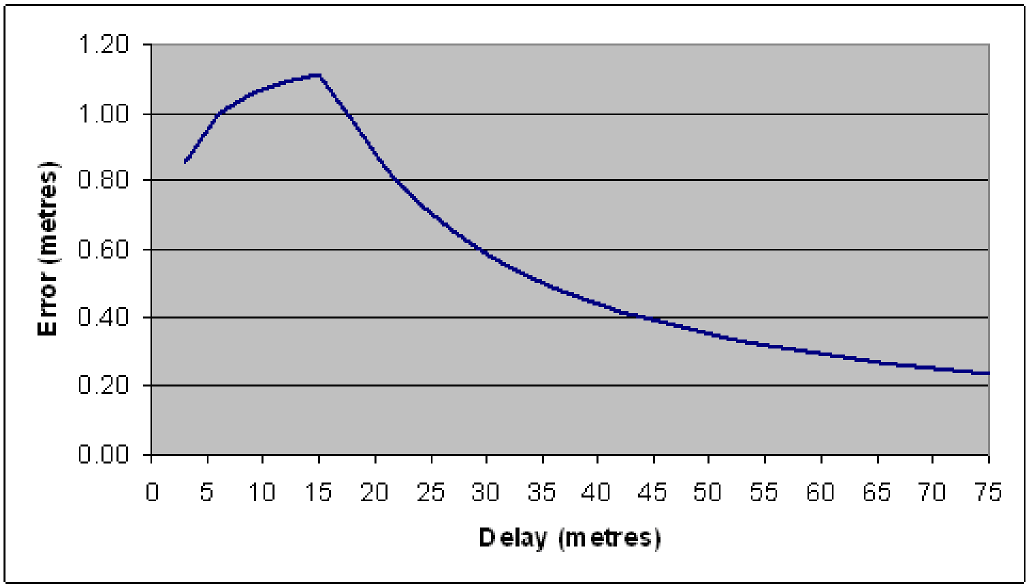

Figure 26: Wide area repeater: Worst case Pseudo range error vs. distance (Building loss = 8dB)

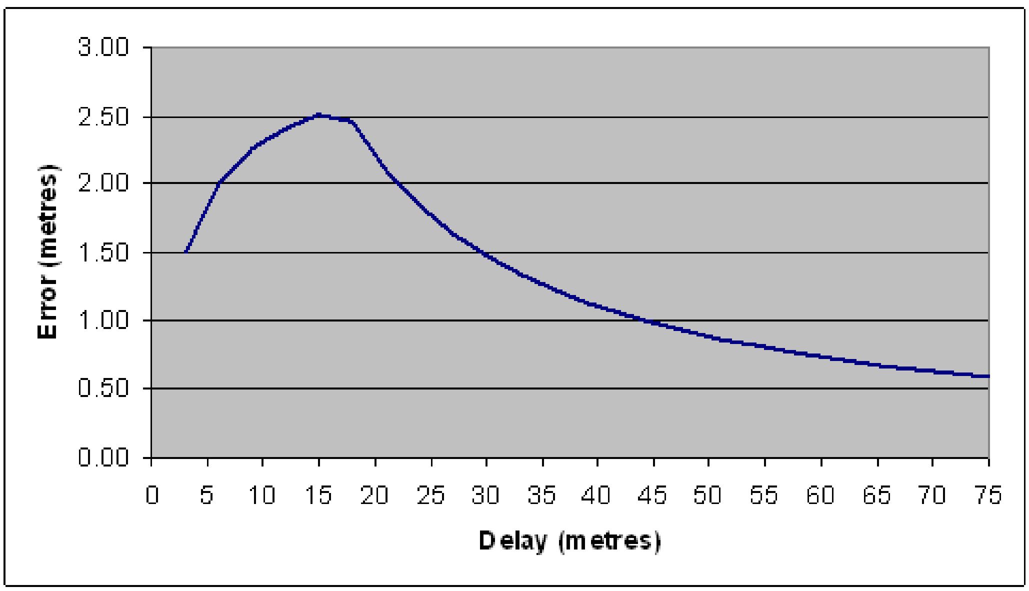

Figure 27: Wide area repeater: Worst case Pseudo range error vs. distance (No building loss)

8.2.4 Possible Position error

In reality, these are worst case errors for a single satellite signal, this will not be the case for all the satellite signals, No account is taken of attenuation due to building materials. If the repeater is located inside a building there will almost certainly be significant attenuation between the repeater and any external GPS receiver. Finally, the simulations represent the error that would be seen in a pseudo-range measurement for a single satellite. The actual location fix is the result of a calculation based on four or more pseudo-range measurements the relationship of the GNSS receiver/GNSS repeater/ and satellites will be different for each case.

The resulting position errors are a function of differing receiver implementations. The pseudo range error calculations should therefore be taken as a figure of merit and not necessary indicative of the actual resulting position accuracy.

8.2.5 Issues relating to road transport applications

In a typical situation a building equipped with a GNSS repeater might be located at the side of a road. As seen above, noise interference from the repeater would not cause a problem at distances above about 2.4 metres. Consequently, the maximum length of road that could be affected is 4.8 metres. In reality, the repeater transmitting antenna is unlikely to be less than 2.4

metres from the roadway and it is unlikely that any interference will be experienced. In the absence of building loss the maximum length of affected road would be about 12 metres.

Considering multipath, as seen above, the maximum pseudo-range error for an indoor repeater (i.e. taking account of building loss is 1.1 metres.

At distances greater than 18 metres, the additional pseudo-range error would be less than 1 metre. It is thought extremely unlikely that this would present a problem to the operation of road transport applications.

In the absence of building loss, the maximum additional pseudo-range error would be less than 2 metres at distances above 22 metres, indicating a maximum length of affected road of 44 metres. For an additional pseudo-range error of 1 metre this figure would be 90 metres of road. However, as noted above, the pseudo range error calculations should therefore be taken as a figure of merit and not necessary indicative of the actual resulting position accuracy.

8.2.6 En-route navigation scenario; aircraft GPS receivers at an altitude of 1000ft or more

The maximum radio line of site distance can be calculated according to

$$d_{LOS} = (2 \cdot R \cdot h_1 + h_1^2)^{0.5} + (2 \cdot R \cdot h_2 + h_2^2)^{0.5} \qquad (4)$$

where:

R = Median Effective Earth Radius (m) = 1.33 * Median Earth Radius
h_1 = aircraft height (m)
h_2 = GPS repeater transmitting antenna height (m)

Assuming R = 6360*1.33 km, h_1 = 303 m (1000 ft) and h_2 = 10 m:

d_{LOS} =85km

We may assume an absence of building loss and that the protection distance needed against multipath signals is 9.5metres. Then with an aircraft at altitude of 303m (1000ft), the repeated signals will be a further 30dB below (20log (9.5m/303m)) the defined protection level i.e. -40dB below GPS, a level of -200dBW. Therefore, many thousands of repeaters with a separation distance of 1000ft would need to be in view to cause a problem; we do not consider this a likely occurrence.

For frequencies above 1GHz, the current EMC specification for electronic devices gives a radiated emission limit in ETSI EN 301 489[5]. Specifically In Table 3: section 8.2.3 of this standard, the limits for radiated disturbance above 1 GHz at a measurement distance of 3 m for 1MHz bandwidth measurement are as presented in Table 19.-

Frequency range	**Average Limit (dBµV/m)**	**Peak limit (dBµV/m)**
1 000 MHz to 3 000 MHz	50 measured at 3 metres	70

Table 19: Radiated emission limit above 1 GHz

With thousands of consumer devices radiating at 50dBuV/M(equates to -96dBW/MHz at 3metres), the consumer sources should create 10dB or more interference than the repeaters and therefore we do not consider the aggregate effect of GNSS repeaters a likely occurrence compared to other sources of interference.

8.2.7 Use of GNSS systems as timing sources

Timing sources can be based on GNSS receivers. The protection criteria to protect these systems against unwanted multipath effects should be a value of -170dBw as for normal location based GNSS receivers. This protection limit will allow GNSS receivers to obtain correct GNSS signals and therefore to determine a correct timing measurement, these receivers are not considered different to other GNSS receivers in terms of their required signal protection requirements.

9 PROPOSED GNSS REPEATER TECHNICAL CONSTRAINTS

9.1 GNSS repeater re-radiating out of band signals

As stated, GNSS repeaters, if not designed with inherent filtering are likely to re-radiate signals in bands adjacent to the bands. There are four potential issues relating to such band-edge problems:

a) Re-radiation of signals below 1164 MHz

b) Re-radiation of signals above 1300 MHz

c) Re-radiation of signals below 1559 MHz

d) Re-radiation of signals above 1610 MHz.

Case a) would result in interference to ground-based DME transponders (see section on DME), and assumes a margin of I/N= -10dB. Then any repeater system at 1151 MHz requires a filter loss around 27dB or more below peak gain.

Case b) the frequencies above 1300 MHz have similar allocations to the 1215-1300 MHz band, and they are mainly used for radar, or fixed links. For a fixed service receiver in the allocation above 1300MHz and a repeater located nearby to the corresponding fixed service transmitter, the repeater will not be an issue. Alternatively, with the repeater near to the fixed link receiver, but separated by a few metres from it, then the relative gain of any fixed receiver signal will dominate the input. This will mask any effect of any repeater, noting that geographic separation of more than 3 metres will ensure protection anyway between the repeater and the fixed receiver antenna. To protect the radar from unwanted out of band effects, we would presume that at the band edge, the attenuation loss of the repeater system met or exceeded that of its maximum gain, i.e. a net gain of <0dB. For 45dB max gain a 45dB loss assumed at 1300 MHz.

Case c) would cause re-radiation of the mobile satellite (space to earth) signals. Note that both the GNSS and mobile satellite use Right Hand Circular polarisation. The GPS L1 and Galileo frequencies are of course, very close to the band edge. Therefore, there would be little antenna rejection to the MSS. On the basis of the example commercial quadrifilar antenna (Sarantel) , about 5dB total for both receive and transmit antennas would be realistic. Using the “wide area” repeater assumptions operating inside a building with 8dB building loss, a mobile satellite handset would receive a delayed signal from the repeater at -10dB relative to the direct signal at a distance of about 2 metres from the repeater’s transmitting antenna. Without the building loss, the distance would be about 5.5 metres. It does not; seem likely that interference to handsets would be a serious issue for repeaters designed for the L1 frequency.

A repeater designed for the COMPASS system would need to re-radiate signals at 1561.098 MHz, which would imply virtually no filtering at the 1559 MHz band-edge. However, even without filtering, the distances for a repeated signal at -10dB relative to the direct signal are 4 metres with building loss and 9.5 metres with no building loss. Although these distances are larger than for the case of L1, they should still not present a problem.

Case d) would cause re-radiation of mobile satellite (earth to space) signals. If the repeater to handset separation were close, the signal would be repeated so that the satellite could receive a multipath signal. However, we could expect about 10dB of transmit antenna rejection at 1610 MHz and that a repeater is well separated from a MSS handsets. Even assuming a maximum re-radiated signal of -20dBW, the maximum re-radiated e.i.r.p. would be -30dBW or 1mW, this is 27dB below their maximum authorised e.i.r.p of -3dBW/4kHz., and therefore very unlikely to cause an issue. If the repeater were designed for the GLONASS system it would need to pass a frequency of 1605.375 MHz. In this instance little or no filtering can be assumed. The re-radiated signal would then be -20dBW, still 17dB below the maximum authorised e.i.r.p.

9.2 Overall Gain

The gain through the repeater is given by:

Repeater gain [dB] = Rx/Tx Antenna Gain + embedded amplifier Gain – Feeder Loss (5)

It is proposed that the gain of a RNSS repeater system (equation 5) is limited to a maximum of 45 dB.

9.3 Maximum output power

The maximum possible output power of the final amplifier should be limited to -20dBm (-50dBW).

9.4 Filtering

The device should incorporate filtering, which can be associated with the receiver and transmit antennas or it can be by separate filters. The filter response should be centred on the frequency of the GNSS signal to be radiated and the -3 dB points should be ± 20 MHz.
For a repeater operating in the 1164-1215 band the filtering should provide at least 37 dB of rejection at frequencies below 1151 MHz.

At 1300 MHz, the repeater combined filtering losses (antenna related and any installed filter) should exceed 45dB.

In the case of a repeater operating in the band 1559-1610 MHz, and designed to re-radiate signals centred on the L1 frequency:

- 5dB of filtering should be provided at the 1559 MHz band edge. It could be provided by means of the receiving and transmitting antennas. This constraint would, however, not be practical for repeaters designed for lower frequency signals such as the B1 channel used by the COMPASS system
- at least 10 dB of filtering should be provided at the 1610 MHz band-edge.

The above constraint would not be practical for repeaters designed for the GLONASS system which would need to radiate signals up to 1605.375 MHz.

In specific instances, for example where repeaters are used in aircraft hangars, additional filtering may be required. Such situations should be considered on a case by case basis.

9.5 Output power measurement

Equipment should incorporate some means to measure and control the output signal (e.g. parasitic oscillations).

10 SEPARATION DISTANCE TAKING ACCOUNT OF TECHNICAL CONSTRAINTS ABOVE

All of the scenarios show that with an 8dB building loss assumption, the worst case protection distance is around 3.8 metres, except for radar in the band 1215-1300 MHz, which might have many concerns due to local reply signal levels. If the building loss in the direction of a GNSS receiver was 0dB, then the protection distance for a repeated GNSS signal power to be less than -170dBW would need to be around 10 metres. At this distance the maximum expected pseudorandom distance error to a single satellite would be about 1.2metres, this would not be true of all satellites used in a GNSS receiver’s position calculation.

11 CONCLUSIONS ON BAND BY BAND CONSIDERATIONS

For the RNSS band 1215-1300 MHz, also occupied by radar EESS and Wind Profiler radar, the GNSS repeater signals may cause effects inside a radar clutter response zone or enhance the signals to EESS satellites. This would not be the case if the maximum output power of the system is restricted to -20 dBm.

For the RNSS band 1164-1215 MHz, also occupied by DME, the analysis indicates that there should be no cause for concern in the use of repeaters subject to the assumptions made on the filtering constraints as stated previously. To have an impact on DME the analysis section would have to make large errors in its assumptions. However, aviation authorities are still concerned that no actual tests against DME equipment have been performed.

For the band 1559-1610 MHz, there are no other apparent sharing services and the main protection should be provided by a geographic protection distance. GNSS operation in this band should be protected by providing suitable gain/power limitations for these devices.

It is suggested subject to further regulatory scrutiny that detailed consideration of GNSS repeaters should be limited to use in the bands 1164-1215 MHz, 1215-1300 MHz and 1559-1610 MHz.

The GNSS repeater maximum gain should also be limited to a value of 45dB.

The risk of mobile use of these devices in an uncoordinated manner will increase potential risks to normal GNSS (GPS) receiver operation and should not be considered.

ANNEX 1: GNSS REPEATER SCENARIOS

This section outlines the potential scenarios, identified where GNSS repeater have been used and the expected distance for repeater operation. This distance is distinct from, but related to the protection distance. Given an expected -10dB difference between the wanted signal and the maximum interference level, the operational distance will be 1/(10^(0.5)) times the defined protection distance. Its based on free-space loss 20log(d). Alternatively 0.32 times protection level. Industry supplied these scenarios as examples of potential uses.

Scenario 1 - Semiconductor test lab which utilise GNSS as a timing reference

Lab sizes: about 8 metres square by about 2.5m high. There is a conventional suspended ceiling and the roof above is tiled with aluminium. The floor is solid concrete. There are four small windows facing south, with internal glass partitions to other rooms on the north side. The building has slightly larger windows on the north side. The sidewalls are brick.

Without the GNSS repeater, the signal strength inside the building is never great enough to allow operation of a GNSS device. The building envelope is a good signal attenuator. This attenuation will apply towards the outside of the building as well, even when the repeater is operating

Expected Operational Distance ~8 metres

Scenario 2 - Tetra radio test lab in a controlled environment

A lab located in a heavy concrete building of cold war origins with foot thick walls, floors and roof. There is no usable GNSS signal in the lab area. To overcome this GNSS signal is distributed on coax around a number of systems within the lab from an outside aerial. This application is the type approval of Tetra hand held radio terminals for use by emergency services and other approved users. Most modern terminals have inbuilt GNSS receivers, with no external antenna connection. It is required to prove this functionality under controlled conditions. It is presently proving to be very difficult, without use of a local GNSS repeater within the lab. Size of the lab is approx 30m x 10m.

Expected Operational Distance ~10 metres

Scenario 3 - Telematics equipment production lines

Test on ground floor or certainly sky-obscured situations of up to 20 units, at any one time, on soak or intermittent test when new products are introduced.

In this situation it is obviously advantageous to be able to use a repeater and standard antennas. Given the attenuation of the GNSS signals into the test areas, it is reasonable to expect a similar attenuation of any re-radiated signal to the outside

Expected Operational Distance Unknown – Assumed same as Tetra 10 metres.

Scenario 4 - Test and type approval of products with GNSS capability at EMC labs

All tests conducted in a properly designed EMC chamber.

Required Operational Distance Compliance with R&TTE is needed, however no requirement for a WT Act license is assumed as system is not free radiating.

Scenario 5 - Test facility for GNSS receivers used in off-shore oil exploration

Dimensions of room where re-radiator required (high up in one corner) is 10x10x3 meters. Receivers used are latest hand-held devices so may have newer higher sensitivity type.

Expected Operational Distance ~10 metres

Scenario 6 - Radio training facilities

Sizes of the classrooms used for training are:

- 10m x 8m
- 12m x 8m
- 15m x 9m
- 20m x 10m

Required Operational Distance ~10-20 metres

Scenario 7 - Testing passenger jet GNSS receivers whilst in maintenance hangars

Large passenger aircraft and jets with sometimes multiple GNSS receiving antennas located at different positions on the airframe. A hangar of dimensions 67m x 40m x 15m, with steel roof trusses at a height of around 10m. Minimum coverage of around 3mx 3m in 3 different locations in each hangar.

The aircraft GNSS receivers pick up no GNSS signal when the hangar doors are closed.

Expected Operational Distance ~30 to 40m

Scenario 8 - In-car GNSS in a moving production line environment

Many new cars are now fitted with GNSS as standard, which need to be tested in the final stages of production line. Typically, the production line is 200/300m in length and the required GNSS testing area is 30/50m in length. Testing typically is needed to be carried out at the minimum signal strength in order to test the performance of the wiring loom from antenna to receiver.

Factories are typically metal structures with a pitched roof at about 15m max above the production area. Cars move under a metal screen to stop random items falling and damaging the car roofs. Two types of repeater systems have been identified – individual antennas or leaky feeders.

An industry view is that a leaky feeder system was the preferred solution along the track. The feasibility of this is unknown. A protection distance limit in this instance would probably be set at 15 metre from any point on the cable, for a leaky feeder system. However, the aggregate power across the total length could exceed expectations and therefore, leaky feeder systems might need to be forbidden, and spot radiating points preferred, and limited to a maximum number at any specific location.

One view from industry was that the required operational distance of ~15 metres, another view was that the

Expected operational distance ~30 metres

Scenario 9 - Operational vehicles - Continuous tracking of GPS GNSS signals

This requirement comes from a need for a vehicle to have its GPS GNSS receiver readily available with a current position fix, so that when it exits the storage or parking area it can get an immediate position fix. This it often automatically reports back to a central resource management unit. We provide below, an example-building outline.

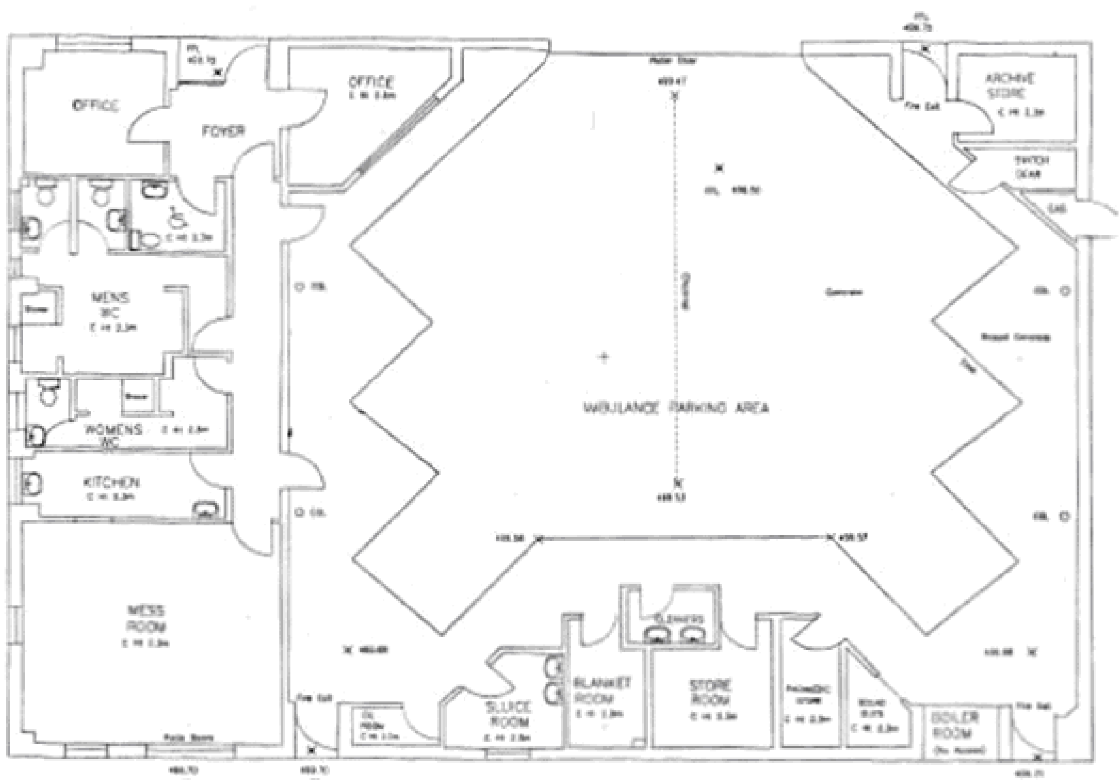

Figure 28: Example Operational vehicle storage location

Required Operational Distance ~15 metres

Scenario 10 - Use of Repeater in a mobile vehicle

This is an application of GNSS repeaters in mobile vehicles to assist in protection of “lone worker” working practises. Staff has a body worn GNSS receiver which is updated by a GNSS repeater mounted in the cab of a vehicle, such as an ambulance, to allow a location fix on the staff member when they would otherwise have been out of sight of the satellite constellation.

The risk of mobile use of these devices in an uncoordinated manner will increase potential risks to normal GNSS (GPS) receiver operation.

ANNEX 2: RNSS BANDS

The following bands have Radionavigation Satellite Service (RNSS) allocations within them.

Band (MHz)		Services
1164	1215	AERONAUTICAL RADIONAVIGATION SERVICE
		RADIONAVIGATION SATELLITE SERVICE (Space to Earth and Space to Space)
1215	1240	EESS
		RADIOLOCATION
		RADIONAVIGATION
		RADIONAVIGATION SATELLITE (Space to Earth and Space to Space)
1240	1260	EESS
		RADIOLOCATION
		RADIONAVIGATION
		RADIONAVIGATION SATELLITE (Space to Earth and Space to Space)
		SPACE RESEARCH
		amateur
1260	1300	EESS
		RADIOLOCATION
		RADIONAVIGATION
		RADIONAVIGATION SATELLITE (Space to Earth and Space to Space)
		SPACE RESEARCH
		Amateur
		Amateur satellite
1559	1610	AERONAUTICAL RADIONAVIGATION
		RADIONAVIGATION SATELLITE (Space to Earth and Space to Space)

ANNEX 3: RADAR ANTENNA PATTERN

The vertical radiation patterns used in the analysis are shown below. Note that the patterns are not defined for angles below -8 degrees. The analysis assumes that the -8 degree value applies for all angles below this value.

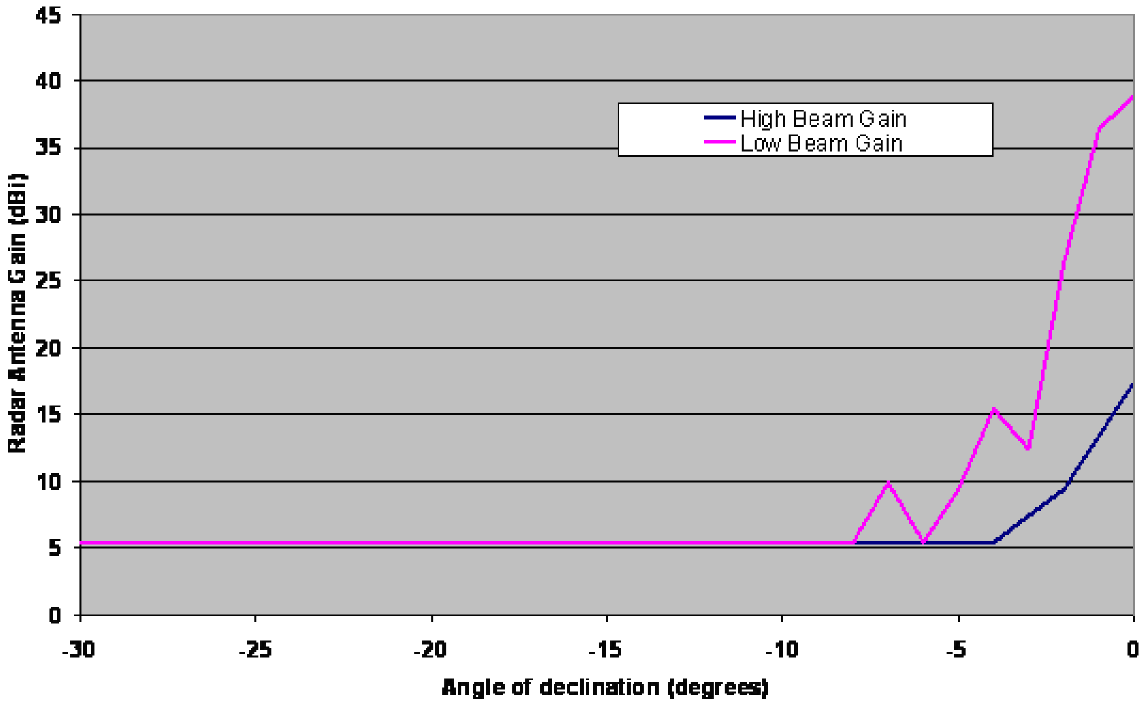

Figure 29: Radar elevation antenna pattern

ANNEX 4: REFERENCES

[1] NTIA, Manual of Regulations and Procedures for Federal Radio Frequency Management (Redbook), May 2003 Edition, January 2007 Revisions www.ntia.doc.gov/osmhome/redbook/redbook.html

[2] ARINC Characteristic 709-8. Mark 5 Airborne Distance Measuring Equipment. October 31, 1988.

[3] Compatibility between UMTS 900/1800 and systems operating in adjacent bands. ECC Report 096.

[4] NTIA Special Publication 01-45 Assessment of compatibility between UWB and GPS receivers, D Anderson Edward Dorcella, Steven Jones Mark Settle dated February 2001

[5] ITU-R PRELIMINARY DRAFT NEW RECOMMENDATION ITU-R M.[1477_NEW] Annex 7 to Document 4C/66

[6] ETSI EN 301 489 “Electromagnetic compatibility and Radio spectrum Matters (ERM); Electromagnetic Compatibility (EMC) standard for radio equipment and services; Part 1: Common technical requirements.