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FS - FSS Sharing in the 37.5-42.5 GHz band

Final Report

for UK Radiocommunications Agency

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1 Introduction

This report has been prepared by Ægis Systems Ltd for the UK Radiocommunications Agency (RA) and describes detailed investigations into the sharing of spectrum between the fixed satellite service (FSS) and the terrestrial fixed service (FS) in the 37.5 to 42.5 GHz frequency range. The work reported here has been carried out between the February and April 1999 (Contract No: AY3435(510002149)).

A variety of FSS and FS systems may be required to co-exist in parts of this frequency range. In the FSS, both geostationary orbit (GSO) and non-GSO (NGSO) systems may be deployed, whilst in the FS systems range from highly directional point to point links in the 37.5 - 39.5 GHz band to wide area point to multipoint or even multipoint to multipoint networks in the 40.5 - 42.5 GHz band.

To facilitate sharing between the FSS and FS, Article S21 of the ITU Radio Regulations defines power flux density (PFD) limits for emissions from FSS systems in various frequency bands up to 40 GHz. The current limits for both GSO and NGSO satellites in the 37.5 – 40.0 GHz band are:

-115 dBW/MHz/m^2 for $\theta \leq 5^o$

$-115 + 0.5(\theta - 5)$ dBW/MHz/m^2 for $5^o < \theta \leq 25^o$

-105 dBW/MHz/m^2 for $25^o < \theta \leq 90^o$,

where θ is the angle of the satellite above the horizon.

The principal objectives of these investigations were to establish

a) whether the existing PFD limits for FSS systems in the 37.5 – 40.0 GHz band are sufficient to protect all FS systems which may be operated in the band, and

b) whether the currently defined limits may be extrapolated to protect future FS systems in the 40.5 – 42.5 GHz band.

A number of static and dynamic simulations have been carried out, representing the various sharing scenarios likely to arise in these bands. These include:

i) interference from a fully populated GSO interferer (180 satellites at 2^o orbital spacing)

ii) interference from each of the currently notified NGSO FSS systems in each band

iii) interference from a hypothetical 288 satellite NGSO FSS system based on the Teledesic system orbital characteristics, in each band

iv) interference into highly directional point to point links in the 37.5 – 39.5 GHz band, with receive antenna elevations up to 10^o.

v) interference into directional and sectoral multimedia wireless system (MWS) receivers in the 40.5 – 42.5 GHz band, with receive antenna elevations up to 60^o (directional) and 20° (sectoral)

The simulations indicate that the current PFD limits defined in Article S21 do not adequately protect FS receivers when elevated antennas are deployed at certain azimuths. This is predominantly due to the relative lack of atmospheric attenuation and the higher PFD limits at higher interference arrival angles. This is particularly so in the 40.5 – 42.5 GHz band where less directional antennas and higher antenna elevations are likely to be deployed.

On the basis of the simulation results, revised PFD limits have been proposed for the 37.5 – 39.5 GHz band and separate, more stringent limits proposed for the 40.5 – 42.5 GHz band. In each case, different limits have been proposed for GSO and NGSO systems as the former present much more significant long term interference potential. The revised limits are:

i) 37.5 – 39.5 GHz GSO:

-140	dBW/MHz/m^2	for	$\theta \le 15^\circ$
$-140 + 3.5(\theta - 5)$	dBW/MHz/m^2	for	$15^\circ < \theta \le 25^\circ$
-105	dBW/MHz/m^2	for	$25^\circ < \theta \le 90^\circ$

ii) 37.5 – 39.5 GHz NGSO:

-123	dBW/MHz/m^2	for	$\theta \le 5^\circ$
$-123 + 0.9(\theta - 5)$	dBW/MHz/m^2	for	$5^\circ < \theta \le 25^\circ$
-105	dBW/MHz/m^2	for	$25^\circ < \theta \le 90^\circ$

iii) 40.5 – 42.5 GHz GSO:

-135	dBW/MHz/m^2	for	$\theta \le 5^\circ$
$-135 + 0.5(\theta - 5)$	dBW/MHz/m^2	for	$5^\circ < \theta \le 25^\circ$
-125	dBW/MHz/m^2	for	$25^\circ < \theta \le 90^\circ$

iv) 40.5 – 42.5 GHz NGSO:

-130	dBW/MHz/m^2	for	$\theta \le 5^\circ$
$-130 + 0.9(\theta - 5)$	dBW/MHz/m^2	for	$5^\circ < \theta \le 25^\circ$
-112	dBW/MHz/m^2	for	$25^\circ < \theta \le 90^\circ$,

where θ is the angle of the satellite above the horizon.

These limits are shown graphically and compared with the current Article S21 limits in figure 7.1 at the end of this report.

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2 Propagation Issues

The propagation characteristics are perhaps the most important factors influencing the feasibility of sharing between FS and FSS systems in the 37.5 to 42.5 GHz frequency range. Therefore, the principal factors affecting propagation of wanted and interfering signals into terrestrial FS receivers are considered in this section. At frequencies above 30 GHz, propagation tends to be dominated by the effects of attenuation due to atmospheric gases and hydrometeors (rain and other forms of precipitation). Rain attenuation can exceed 10 dB / km even in the UK at these frequencies (fig 2.1 shows attenuation per km for UK national grid square NN, based on ITU Recommendation PM.838), limiting the operational range of terrestrial radiocommunication systems to 10 km or less if reasonable link availability is to be achieved. Typically links are required to operate reliably for at least 99.99% of time averaged over a 12 month period and the link must therefore be designed to withstand the level of rain attenuation which is likely to occur for this percentage of time. This is achieved by adding a rain fade margin of typically 10 - 30 dB to the link power budget. Further information on the determination of link power budgets and specific rainfall statistics for the UK are available from the RA[1].

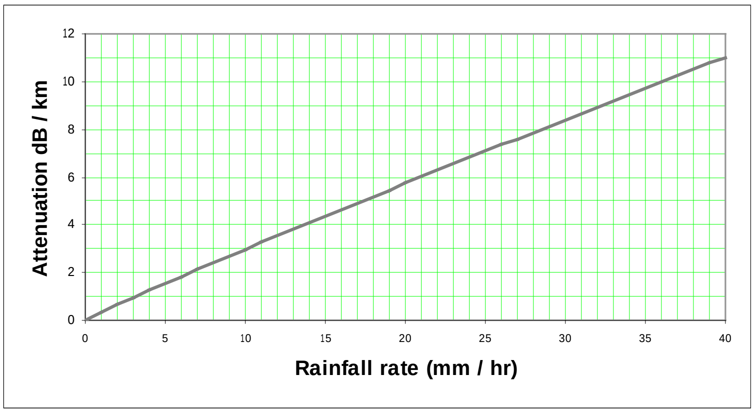

Fig 2.1 Rain attenuation vs Rainfall rate at 39.5 GHz for UK NG square NN.

Atmospheric attenuation, due principally to uncondensed water vapour and oxygen, is much lower (c. 0.1 dB/km) and consequently does not have a significant bearing on the design of terrestrial systems. It can however have a significant impact on the slant path attenuation between satellites and terrestrial stations where the satellite is situated low on the horizon. A recent draft new ITU-R Recommendation[2] has suggested that attenuation due to atmospheric

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[1] "Frequency Assignment Criteria for fixed point to point radio services with digital modulation operating in the frequency range 37.0 to 39.5 GHz", Doc Ref RA 350, January 1998

[2] Draft New Recommendation 4-9S/AD, "Minimum propagation attenuation due to atmospheric gases for use in frequency sharing studies between the fixed-satellite service and the fixed service", 6th October 1998

gases can be represented by the following mathematical formulae, for receivers located at latitudes of 45° or greater:

i) 37.5 GHz:

$$A = 14.44 / [1 + 0.73656\theta + 0.015420\theta^2 + h(0.2202 + 0.2754\theta) + 0.07416h^2]$$

ii) 40.5 GHz:

$$A = 18.92 / [1 + 0.65770\theta + 0.046780\theta^2 - 0.001484\theta^3 + 0.1139.10^{-4}\theta^4 + h(0.22 + 0.2811\theta) + 0.06507h^2]$$

where h = antenna altitude above sea level (km)

θ = elevation angle above the horizon (degrees)

These formulae are shown graphically in fig 2.2 below, for links at sea level.

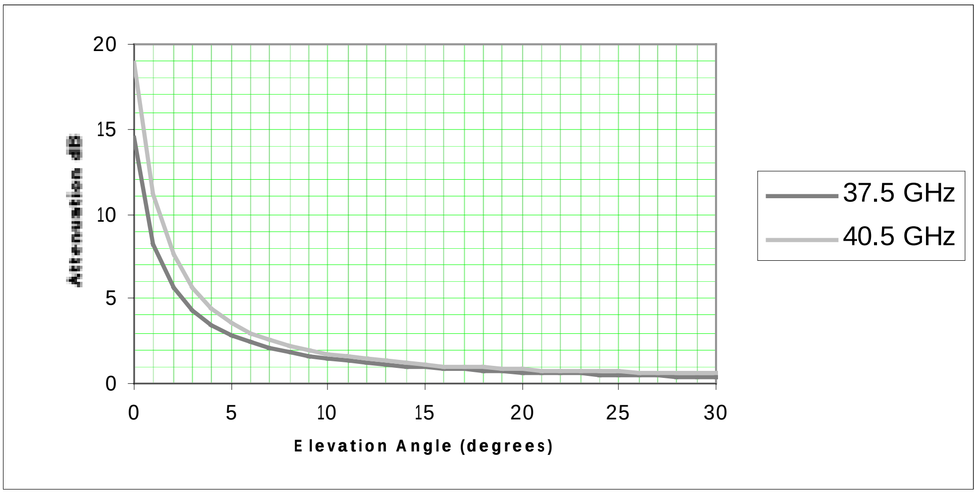

Fig 2.2 Atmospheric attenuation vs elevation angle at 37.5 and 40.5 GHz

It can be seen that attenuation is highly dependent upon the elevation angle of the satellite above the horizon, due to the much longer slant path through the atmosphere at low elevation angles. For the same reason, the effect of rain attenuation upon satellite signals is also accentuated at low elevation angles and the combination of this and the higher atmospheric loss means that reliable communication between satellites and earth stations is unlikely to be feasible at elevations of less than c. 25° above the horizon.

From an interference perspective, protection of FS receivers from interference arising from FSS satellites is achieved by limiting the PFD produced by FSS satellites at the surface of the earth. PFD limits are defined in the ITU Radio Regulations Article S21, for various frequency bands up to 40.5 GHz. Limits for the 37.5 - 40.0 GHz band are currently the same as those in the 17.7 - 19.7 GHz band, but are noted as applying only “until such time as modified by a competent world radiocommunication conference (WRC)”. It is noted in Article S21 that, for their own protection, FS receiving stations should avoid directing their antennas directly towards the GSO if their sensitivity is sufficiently high that interference from space station transmissions may be significant. This is generally practicable in lower FS frequency bands, where multi-hop trunk systems provide some flexibility in the choice of receiver location and orientation. However, this is not the case in the 37.5 - 42.5 GHz frequency range where the predominant applications are mobile network infrastructure links and direct customer access, both involving much higher link densities than in lower frequency bands and involving largely pre-determined receiver locations and orientations.

The need to review the current S21 PFD limits for this band was acknowledged in Resolution 133 of WRC 1997, which called for studies to be carried out. One of the principal objectives of this study is therefore to assess whether the current Article S21 limits are sufficient to protect FS receivers in all likely operational scenarios, which in light of the above will include the possibility of direct alignment with a GSO satellite.

3 Sharing Scenarios in the 37.5-40.0 GHz Band

3.1 Introduction

This section presents a detailed analysis of the likely sharing scenarios in this band, which is allocated on a co-primary basis to the FS and FSS in all ITU regions. Although WRC 97 Resolution 133 refers to the frequency band 37.5 – 40 GHz, it should be noted that in the UK only the lower 2 GHz is currently used for the deployment of civil FS systems, in accordance with RA specification MPT 1714[3]. There are no current plans to introduce FS systems into the 39.5 – 40 GHz band in the UK. This results of this investigation may be applied to the full 37.5 – 40 GHz band, on the assumption that only MPT 1714 compliant point to point systems will be deployed in the band.

3.2 FS Characteristics

The 37.5-39.5 GHz band is used extensively in the UK and Europe for point to point data links. These are primarily deployed within the infrastructures of GSM cellular telephony networks, for example to link base transceiver stations to base station controllers (BSCs). Because each link carries the entire communication traffic from at least one BTS, high reliability is essential and the links are therefore planned typically to have an availability of at least 99.99%, averaged throughout the year. This availability requirement determines the fade margin which must be added to the effective isotropically radiated power (EIRP) of the transmitter, to counter the effect of rain attenuation (see section 2 above).

Current over the air data rates are in the range 2 Mbit/s to 34 Mbit/s, typically using four level (QPSK) modulation. Since rain attenuation limits the transmission range to 10 km or less in the 37.5 - 39.5 GHz band, higher capacity long haul links such as those used to connect BSCs to mobile switching centres (MSCs) have historically tended to use lower frequency bands. This is likely to change in the future as increasing numbers of "micro" and "pico" cells are added to mobile networks, necessitating additional BSCs and MSCs, particularly in busy urban areas. Consequently an increasing demand for higher capacity links in the 37.5 - 39.5 GHz band, up to or beyond 155 Mbit/s, is anticipated. These links are likely to use high level (64 or 128 state) quadrature amplitude modulation (QAM) and may be subject to a higher availability criterion (99.999%) because of the greater proportion of network traffic which is being carried.

Point to point links are also deployed in this band by fixed telecommunications operators, to deliver medium to high capacity data services (2 to 34 Mbit/s) direct to corporate customers. Depending upon the nature of the traffic carried, these links may in some instances have a

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[3] Performance Specifications for digital radio relay systems in the frequency band 37 - 39.5 GHz, RA specification 1714, December 1998.

lower availability specification than those used in network infrastructures (99.9% may be adequate). However, all 37.5 - 39.5 GHz links in the UK are required to have a minimum fade margin of 10 dB, regardless of link length or availability requirement.

Antennas deployed are required to be highly directional, with tightly controlled side lobe emissions to maximise spatial re-use of frequencies. In Europe, an ETSI standard[4] has been developed to set minimum standards for antenna radiation patterns. Three classes of antenna are defined, applicable to a low, high or very high probability of interference. In the UK, only class 3 (corresponding to a very high probability of interference) is permitted. This pattern is similar to that defined in ITU-R Recommendation F.699, which defines generic antenna radiation patterns for high performance point to point links (see fig 3.1 below). Since it was an objective of this study to generate an input to ITU addressing PFD limits, the F.699 antenna pattern has been assumed for simulation purposes. As the ETSI pattern is the standard against which commercial antennas are type approved, typical antennas deployed in the field are likely to meet or exceed the F.699 envelope.

Receiver parameters vary depending upon the link capacity and modulation scheme, but for the purposes of the simulation were assumed to be:

Frequency Band:	37.5 – 39.5 GHz
Data Rate:	2 – 34 Mbit/s
Bandwidth:	3.5 – 28 MHz (7 MHz used in the simulations)
Receiver Noise Figure (F):	10dB typical
Receiver Thermal Noise (kTBF):	–125.5 dBW/7 MHz (T= 293K)
Link Availability:	99.99% typical
Link Fade Margin:	10 dB minimum.
Antenna:	45 dBi gain, consistent with ITU Rec. F.699 (see fig 3.1 below)

Antenna elevation: due to the relatively short distances over which links at these frequencies may be deployed, elevation angles significantly above the horizontal may be encountered. Analysis of United Kingdom point to point link statistics suggests that the maximum elevation angle likely to be encountered on a regular basis is 10^o.

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[4] Antennas used in point to point digital radio relay systems operating in the frequency band 3 to 60 GHz, ETSI standard prETS 300 833, February 1997

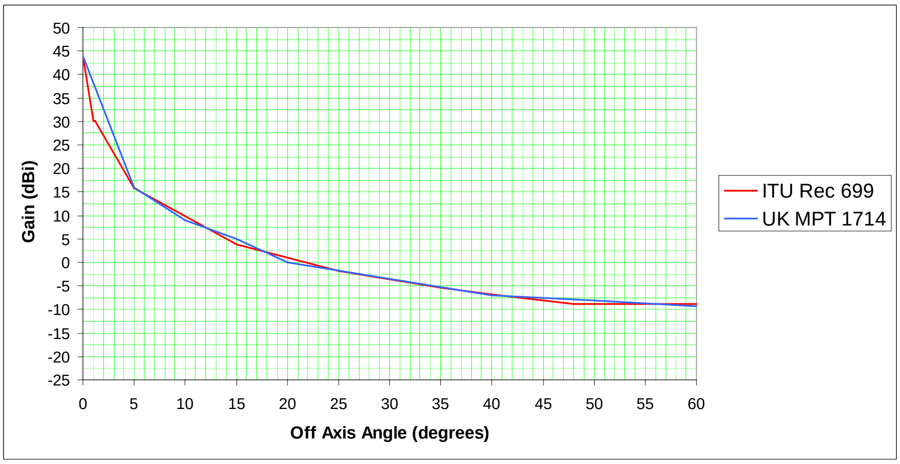

Fig 3.1: FS Antenna Radiation Pattern Envelopes for point to point links in the 37.5 – 39.5 GHz band

3.3 FSS Characteristics

The FSS systems that have been filed to date in this band include both GSO and NGSO systems, in one case based on a NGSO equatorial. One of their main characteristics is the high level of frequency reuse they achieve through the use of very small spot beams. These systems, in principle, aim to provide global, digital broadband communication services to fixed and mobile users. Real-time voice and data transmission and interactive multimedia type services will be offered to residential subscribers, service providers and business customers. The following table summarises the characteristics of the currently proposed FSS systems:

System name	System type	Downlink band (GHz)	No of satellites	Inclination	Altitude (km)	Orbital Planes
STARLYNX	GSO + NGSO	37.5 – 38.6	4 + 20	55°	10,352	4
EXPRESSWAY	GSO	35.5 – 42.5	14	n/a	36,800	n/a
SPACECAST	GSO	39.5 – 42.5	6	n/a	36,800	n/a
ORBLINK	NGSO	37.5 – 38.5	7	0°	9000	1
V-STREAM	GSO	39.5 - 42.5	12	n/a	36,800	n/a
GE STARPLUS	GSO	39.5 - 42.5	11	n/a	36,800	n/a
LOCKHEED	GSO	39.5 - 42.5	9	n/a	36,800	n/a
GESN	GSO + NGSO	37.5 - 40.5	4 + 15	50°	10355	3
M-STAR	NGSO	37.5 - 40.5	72	47°	1350	12

Table 3.1: Proposed Fixed Satellite Service Systems in the 37.5 - 40.0 GHz band

The system filings suggest that the use of high power small spot beams will enable these systems to meet the high data rate demand of densely populated areas. Examination of the filings has also shown that both FDMA/TDMA and CDMA techniques are employed in the system design in order to make the efficient use of the available spectrum.

Note that all but one of the NGSO systems are inclined at about 50^0. This feature provides multiple levels of coverage, i.e. the highly populated areas have a greater probability of having multiple satellites in view simultaneously. In the case of GSO systems, the global coverage is provided by means of inter-satellite links. The hybrid systems, network of GSO and NGSO satellites, also include inter-satellite links so that the GSO satellites can act as a relay for NGSO satellites to ensure worldwide communication.

The other important aspect of the proposed FSS systems is the use of high minimum elevation angles, typically within the range of 20 to 30 degrees, in order to overcome the adverse effects of rain and atmospheric attenuation (see section 2).

Currently notified NGSO systems comprise constellations of up to 72 satellites, however it is feasible that future systems could comprise constellations as large as, or even larger than, the currently proposed Teledesic Ka-band system, i.e. 288 satellites. Hence, a 288-satellite system based on the Teledesic orbital characteristics has been modelled as part of the simulation of interference from NGSO FSS systems into the FS.

3.4 Sharing Scenarios

The following interference scenarios were analysed for the 37.5 – 40.0 GHz frequency band:

Interferers:

i) Fully populated GSO (180 satellites equally spaced at 2^o intervals)

ii) Starlynx NGSO system

iii) Orblink NGSO system

iv) GESN NGSO system

v) MSTAR NGSO system

vi) 288 satellite NGSO system, based on Teledesic orbital characteristics

Victim:

Point to point link with receiver characteristics defined in 3.2 above, antenna characteristics based on Recommendation F.699. The location of the link receiver was generally assumed to be at 52^o latitude, 0^o longitude and at a height of 10 metres above the ground. However, for the Orblink NGSO system a simulation was also carried out for a FS receiver located on the equator, to consider the implications of a receiver aligned directly with the orbital plane.

3.5 Interference Criteria

Maximum allowable performance and availability degradations for digital radio relay systems due to emissions from other sources, including other radio services which share frequency allocations on a primary basis, are defined in ITU-R Recommendation F.1094. This specifies that the proportion of the total performance and availability degradation arising from other co-primary services should not exceed 10%.

Basic criteria for frequency sharing between the FS and FSS are defined in Annex 1 of ITU-R Recommendation F.758. As a general principle, to maintain a performance degradation of 10% or less, the aggregate long term interference into the victim receiver should not exceed a level 10 dB below the victim receiver noise floor (kTBF). Long term interference is defined in ITU-R Recommendation SF.1006 as that which is present for 20% of time. Since FS receivers may experience long term interference from both GSO and NGSO systems simultaneously, long term interference limits applicable to each interferer type should be reduced by a further factor of 3 dB.

The long term interference limit for a radio relay system with the characteristics defined in section 4.1 above is thus:

$$\mathbf{I_{20\%max} = kTBF - 10 - 3\ dBW,} \qquad \mathbf{(3.1)}$$

Where: k = Boltzmann's constant = 10log (1.37.10^{-23} JK^{-1})

T = ambient temperature = 10log (293K)

B = receiver bandwidth = 10log (7 MHz)

F = receiver noise figure = 10 dB

= **-138.5 dBW / 7 MHz**.

A short term limit is also necessary to reflect the time varying nature of interfering signals. The derivation of permitted short-term interference levels, and associated time percentages, is a complex process that includes careful examination of performance/availability objectives, assumptions about the fading characteristics and correlation of periods of wanted signal fading and interference enhancement. For short term interference into point to point systems using highly directional antennas, correlated fading of the wanted and interfering signals can be assumed, since the enhanced interfering signal will require the interferer to be aligned with the FS receiver antenna main beam. This means that the short term interference limit should take account of the link fade margin which, for links operating in the United Kingdom in the 37.5 – 39.5 GHz band, has a minimum value of 10 dB.

Performance degradations for FS systems due to interference from other co-primary sharers, have been defined in a recent Preliminary Draft New ITU-R Recommendation (DNR)[5]. This enables long term and short term interference levels from co-primary sharing services to be

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[5] Preliminary DNR F.[9.40], "Performance degradation due to Interference from other services sharing the same frequency bands on a primary basis with digital radio-relay systems operating at or above the primary rate and which may form part of the national portion of a 27,500 km hypothetical reference path", ITU Study Group 9, October 1998

defined in terms of the errored second ratio (ESR) for a typical multi-hop network. Table 2 of the DNR defines EPOs for short haul inter-exchange networks thus:

Rate (Mbit/s)	1.5 to 5	>5 to 15	>15 to 55	>55 to 160
ESR	0.004 x B	0.005 x B	0.0075 x B	0.016 x B

The value of the constant B has provisionally been agreed to be in the range of 0.075 to 0.085 (a value of 0.08 has been used in this study). For a 5-hop system operating at 15 - 55 MBit/s, the ESR per hop is (.0075 x .08)/5 = **0.00012, or 0.012%**

It has been suggested within ITU-R[6] that, for typical FS equipment, the receiver threshold level corresponding to this ESR level is 4 dB higher than that corresponding to the receiver threshold for 10^{-3} BER. The fade margin, when referenced to the ESR threshold is therefore reduced by 4 dB relative to the fade margin referenced to 10^{-3} BER. Thus a minimum effective fade margin of 6 dB should be assumed in determining the short term interference limit for point to point FS systems (fig 3.2).

If a fade margin of 6 dB is assumed, then during unfaded conditions the sum of short term interference from the FSS and the system noise (I+N) may also be permitted to rise by 6 dB relative to the system noise (kTBF) alone, to maintain a constant value of C/(I+N). The interference from co-primary shared services is therefore permitted to rise by 4.8 dB. For a radio relay system with the characteristics defined in section 4.1 above, the short term limit for interference from other co-primary sharing services (in this case the FSS) is therefore:

$$I_{0.012\%max} = kTBF + 4.8 \text{ dBW} \quad (3.2)$$

$$= \mathbf{-120.7 \text{ dBW / 7 MHz}}$$

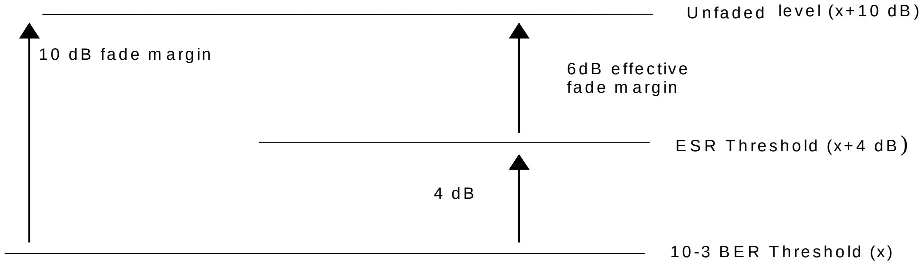

Fig 3.2. Receiver Threshold Levels and Fade Margins

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[6] ITU-R Working Party 9A, working document (99)58

4 Sharing Scenarios in 40.5-42.5 GHz Band

4.1 Introduction

This section presents a detailed analysis of the likely sharing scenarios in this band, which is allocated on a primary basis to the FS in all ITU regions and to the FSS in Regions 2 and 3 plus certain countries in Region 1. Resolution 129 of WRC 97 invited urgent studies of appropriate criteria and methodologies for sharing, including power flux density (PFD) limits, between the FSS and the other services with allocations in this band

4.2 FS Characteristics

4.2.1 Introduction

A wide variety of FS systems are being considered for possible future deployment in this band. For some time, the band has been available in the UK for analogue or digital Multipoint Video Distribution Services (MVDS), based on RA specifications MPT 1550 (analogue) and MPT 1560 (digital). MVDS is a unidirectional broadcast service, which is received via moderately directional dish antennas typically mounted on the subscriber’s rooftop. More recently, reflecting the advent of digital television and associated interactive services there has been increasing interest in the provision of two way broadband subscriber services using similar radio technology and spectrum. This concept has been defined within CEPT as “Multimedia Wireless Systems” (MWS) and efforts are being made to define common frequency allocations in the 40 GHz region. Elsewhere in the world, notably the USA and Canada, broadband radio data services are already being launched under the guise of “local multipoint distribution services” (LMDS) or “local multipoint communication services” (LMCS).

The current generation of LMDS / LMCS services are all based on point to multipoint (PMP) topology, where a single base station provides services to a number of subscribers within radio coverage range. Because of the propagation constraints at these frequencies, subscribers must generally have an unobstructed line of sight path to the base station. This effectively determines the maximum coverage range in a particular direction, although in practice the coverage range may deliberately be further restricted (by reducing the height or transmit power of the base station or downtilting the antenna) to facilitate frequency re-use by other nearby base stations. Networks are thus designed on a cellular basis, in a similar fashion to mobile telephone networks, but without the need for non-line of sight coverage.

In the UK, some potential providers of MWS services have been investigating alternative network topologies which it is claimed may provide significant increases in capacity and network performance. These topologies are variously described as “mesh” or “multipoint to multipoint” and effectively use the subscriber terminals as repeater stations, removing the need for hub stations and providing route diversity in the event of the failure of specific network links. Figure 4.1 below illustrates the difference between the two approaches.

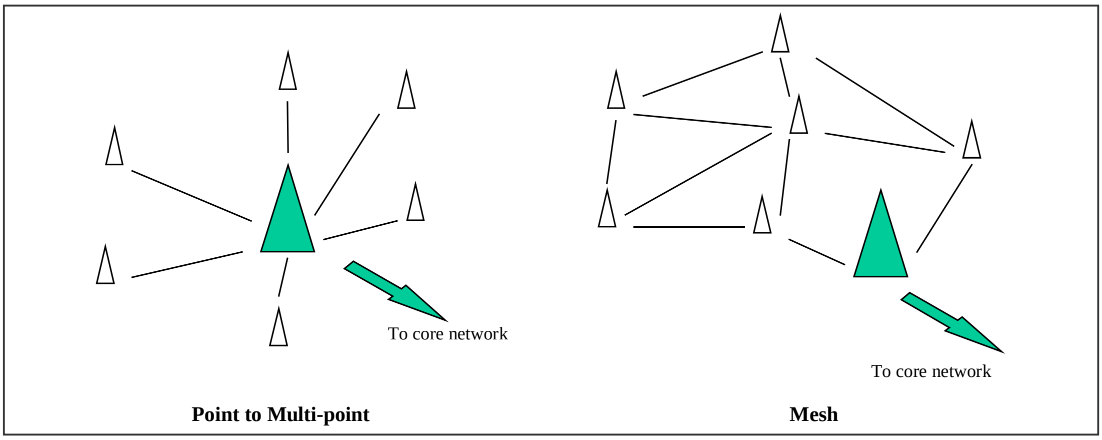

Fig 4.1 Comparison between PMP and mesh based MWS networks.

4.2.2 MVDS

Both analogue and digital MVDS systems may be deployed in this band, however it is assumed that all future systems will be digital, based on the UK specification MPT 1560. Typical antenna / receiver characteristics are as follows:

Noise figure: 8 dB max.

IF Bandwidth: 33 MHz

Antenna Gain: subscriber 33 dBi typical

base station 15 dBi typical

Service is planned on the basis of 99.9% availability, necessitating a rain fade margin of c. 19 dB for a typical 5 km service radius. The maximum interference into an individual MVDS receiver is 10 dB below the system noise level, specified in MPT 1560 as -132.8 dBW in a 33 MHz bandwidth).

4.2.3 Point to Multipoint MWS

Point to multipoint networks are architecturally similar to MVDS, but include a return path to provide two way connectivity. Many of the LMDS systems that are already operational are indeed predominantly television based services with an element of interactivity provided via the return path. These are akin to the services currently being rolled out by satellite and cable operators in the UK, which typically use conventional wire line telephony to provide the return path.

Antennas and receivers are typically similar to those used for MVDS, i.e. wide beam sector antennas at the base stations and directional antennas at the subscriber stations. Although there is a draft ETSI standard covering PMP antennas[7], this does not currently address frequencies above 30 GHz. There is also currently no ITU Recommendation applicable to

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[7] “Antennas for use in point to multipoint digital radio relay systems”, draft EN 301 215-2, v1.1.1, July 1998

PMP antennas at these frequencies. Most of the MWS simulations conducted under this study have therefore assumed antennas based on MPT 1560. However, comparisons have been made with antennas conforming to the ETSI standard for 24 - 30 GHz and with a proprietary high performance sector antenna.

Typically an MWS base station antenna has a 3 dB azimuth beamwidth of 45 ° or 90 °. To maximise gain and hence coverage area, the elevation beamwidth is narrower - 18 ° in the case of MPT 1560 but as narrow as 2 ° for some of the high performance proprietary designs[8]

A further important feature, which differentiates MWS systems from conventional point to point fixed services, is the range of antenna elevation angles that might be encountered, particularly for the subscriber stations. This is because base stations often need to be sited at a relatively high elevation (50 - 100 metres) to ensure line of sight access to customers within a reasonable (1 - 2 km) radius. The elevation of the subscriber antenna is of course constrained by the rooftop height of the subscriber's premises, which may be as little as 5 metres (see fig 4.2). A similar situation can arise in mesh networks where adjacent nodes are at significantly different elevations.

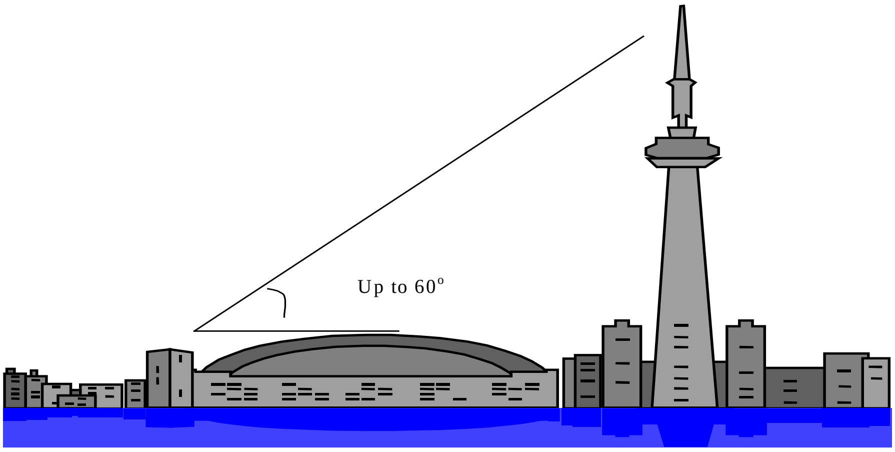

Fig 4.2 Possible operational MWS scenario, illustrating potential for high subscriber antenna elevation angles.

4.2.4 Mesh MWS Systems

Mesh based networks differ from conventional PMP systems in that there are no central "hub" or base stations linking the subscribers to the network. Instead, a distributed architecture is adopted, whereby each subscriber transceiver can act as a repeater to forward traffic to other adjacent subscribers.

At least two organisations in the UK are working on the development of mesh based systems.

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[8] "High Gain Sector Antennas for Broadband Wireless Hubs", Bill Corondon & Mike Wolfe, Wireless Design Online, 5th January 1998

Typically, subscriber stations or “nodes” comprise circular sectorised antenna arrays made up of anything from 4 to 30 or more individual horn antennas. Individual antennas may be switched or steered by mechanical or electronic means to align with other adjacent nodes. Hop lengths between nodes may be typically in the range 300m to 2 km. A variety of antenna types may be used, ranging from wide beam antennas similar to those used for PMP base stations, to directional antennas similar to PMP subscriber stations. The choice is largely a function of the number of antennas in the array.

A number of benefits are claimed for mesh networks. Firstly, the need to identify prominent elevated sites for base stations to ensure line of sight coverage to many potential subscribers is avoided. In principle, all that is required is to have one other subscriber node within line of sight, although in practice it is desirable to have more than one to provide route diversity and thus provide a more resilient service for a given level of individual link availability. The lack of high sited base stations and the ability to direct traffic between subscriber nodes is also claimed to provide greater network capacity than conventional PMP systems, a significant factor in the provision of high bandwidth multimedia services.

From a sharing perspective, mesh networks may provide greater flexibility in avoiding specific azimuths, by virtue of their inherent route diversity. On the other hand, there may be a greater likelihood of high antenna elevation angles where adjacent nodes are at significantly different heights. Route diversity also means that loss of a single node station is likely to affect only the subscriber directly connected to that node – other subscribers should still be able to access the network via alternative nodes. Loss of a PMP base station sector means that all subscribers connected to that sector lose service, however the probability of such a failure due to interference is significantly lower since PMP base stations rarely operate above 0^{o} elevation. On balance, it is likely that both system types will have similar susceptibility to FSS interference and the results of this study are therefore considered to be applicable to both.

4.2.5 MWS Receiver Characteristics

Receiver parameters for MWS systems have yet to be fully defined, however the latest draft of ITU-R Recommendation F.758 includes a summary of typical characteristics of anticipated system types. Receiver characteristics are quoted as within the following range:

Bandwidth: 10 - 75 MHz

Noise figure (F): 5 - 8 dB

Antenna Gain : subscriber stations 32 –38 dBi

base stations 15 dBi

System / feeder losses: 2 – 6 dB

For simulation purposes, receiver characteristics have been assumed to be the same as those for point to point systems in the 37.5 – 39.5 GHz band, namely:

Bandwidth: 3.5 – 28 MHz (7 MHz used in the simulations)

Receiver Noise Figure (F): 10 dB

Receiver Thermal Noise (kTBF): –125.5 dBW/7 MHz (T= 293K)

Link Availability: 99.99% typical

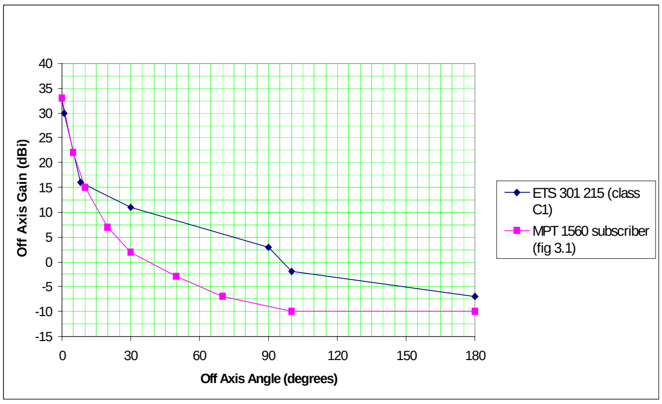
Link Fade Margin: 10 dB minimum.

The higher noise figure allows for additional system and feeder losses based on typical current systems. Should a lower noise figure be assumed this would have the effect of reducing the interference limits defined in section 4.5 by a corresponding amount.

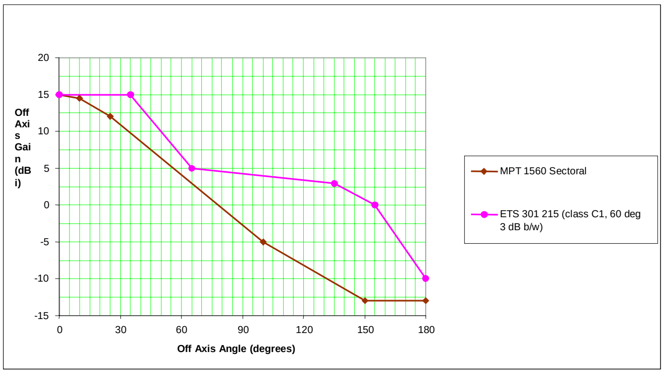
4.2.6 MWS Antennas

A variety of antenna types are being considered for deployment in MWS/LMDS systems around the world. Broadly speaking these can be split into two generic categories, namely directional and sectoral. Directional antennas are typically of lens horn construction, with 3 dB beamwidths of 2° to 6° and gains of 25 – 35 dBi. Note that this is a considerably larger beam width than antennas traditionally used for point to point FS applications, which may have beam widths as low as 0.25°. This is significant from a sharing perspective because it means worst case interference can no longer be assumed to be dominated by a single satellite interferer aligned with the antenna main beam. As noted in section 4.2.3, sectoral antennas have much wider azimuth beamwidths than directional antennas, typically in the range 45° to 90°.

Standards for antennas at these frequencies are somewhat sparse. The only current publicly available standard in the UK is the RA specification MPT 1560, which defines base station and subscriber antennas for digital MVDS systems. A draft ETSI standard, EN 301 215, currently defines PMP antennas only up to 30 GHz and is intended in the longer term to extend to 60 GHz. A number of radiation pattern envelopes for the 24 – 30 GHz band are defined in EN 301 215 but these have significantly less off-axis discrimination than the patterns in MPT 1560. Fig 4.3 below compares the ETSI and MPT 1560 patterns for a 33 dBi directional antenna and a 15 dBi sector antenna. The MPT 1560 patterns are considered to be more representative of the type of antennas which are likely to be deployed in practice therefore most of the simulations have been carried out on this basis. For comparison purposes some simulations were repeated with ETSI RPE pattern.



Directional, 33 dBi



Sectoral, 15 dBi

Fig 4.3 Comparison of MPT 1560 and ETS 301 315 PMP antenna pattern

4.3 FSS Characteristics

The FSS systems that have been filed to date in these bands include both GSO and non-GSO systems (see table 4.1 below). The one currently notified non-GSO system comprises a constellation of 99 satellites, however it is feasible that future systems could comprise constellations as large as, or even larger than, the currently proposed Teledesic Ka-band system, i.e. 288 satellites. Hence, a 288 satellite NGSO system based on the Teledesic orbital characteristics has been modelled as part of the simulation of interference from NGSO FSS systems into the FS.

System name	System type	Downlink frequency band	No of satellites	Inclination	Altitude	Orbital Planes
EXPRESSWAY	GSO	35.5 - 42.5 GHz	14	-	-	-
SPACECAST	GSO	39.5 - 42.5 GHz	6	-	-	-
V-STREAM	GSO	39.5 - 42.5 GHz	12	-	-	-
GE STARPLUS	GSO	39.5 - 42.5 GHz	11	-	-	-
LOCKHEED	GSO	39.5 - 42.5 GHz	9	-	-	-
CYBERPATH	GSO	40.5 - 41.5 GHz	10	-	-	-

LEO 3192*	NGSO	40.5 – 42.5 GHz	99	55°	1600 km	11

***Currently filed as a BSS system**

Table 4.1: Proposed FSS Systems in the 40.5 - 42.5 GHz frequency band

FSS system operational characteristics are similar to those in the 37.5 – 39.5 GHz band (section 3.3). It should be noted that the proposed GSO filings detailed in section table 3.1 aim to use the 40.5 – 42.5 GHz band as well.

4.4 Sharing Scenarios

The following interference scenarios were analysed for the 40.5 – 42.5 GHz frequency band:

Interferers:

i) Fully populated GSO (180 satellites equally spaced at 2° intervals)

ii) LEO 3192, 99 satellite NGSO system

iii) Teledesic constellation 288 satellite NGSO system

Victims:

i) LMDS / MWS system with characteristics defined in section 4.2.5, with directional antenna based on UK specification MPT 1560, fig A2.1

ii) LMDS / MWS system with characteristics defined in 4.2.5 above, with sector antenna based on UK specification MPT 1560, fig 3.1

Both victim types are assumed to be located at 52° latitude, 0° longitude and with a nominal antenna height of 10 metres above the ground.

4.5 Interference Criteria

For consistency and to facilitate comparison between systems in the two bands, a similar approach to interference criteria to that in the 37.5 – 40.0 GHz band was taken and the interference limits defined in section 3.5 have been assumed. However, since MWS systems are in most cases likely to be providing access links between network and subscriber, rather than multi-hop links within network infrastructures, a different short term criterion was applied.

Table 3 of DNR [9/40] defines EPOs for access links within networks thus:

Rate (Mbit/s)	1.5 to 5	>5 to 15	>15 to 55	>55 to 160	>160 to 3500
ESR	0.004 x C	0.005 x C	0.0075 x C	0.016 x C	Not defined

The value of the constant C has provisionally been agreed to be in the range of 0.075 to 0.085 (0.08 has been used in this study). For a single hop access system operating at 15 - 55 Mbit/s, the ESR is (.0075 x .08) = **.0006, or 0.06%**. It was assumed that the same fade margin would apply in this band as in the 37.5 – 40 GHz band, i.e. 10 dB, hence the same short term interference power limit will apply.

Equipment characteristics are not yet fully defined for this frequency band and will depend to some extent upon the application and network architecture. As noted in section 4.2.5, it has been assumed for simulation purposes that the receiver parameters are the same as those for point to point systems in the 37.5 – 40.0 GHz band. Any significant improvement in receiver performance relative to current point to point systems, such as improvement in overall noise figure, may require the interference limits assumed in this simulation to be modified accordingly. Cumulative interference levels from the FSS determined by the simulations will not be affected by any such changes.

Interference power limits assumed in the simulations are therefore:

Long term: $I_{20\%max}$ = - 138.5 dBW / 7 MHz

Short term: $I_{0.06\%max}$ = - 120.7 dBW / 7 MHz

5 Simulation Methodology

The simulations were carried out using the Frequency Sharing Computer Program (FSCP), developed by Ægis Systems on behalf of the RA to analyse interference between satellite and terrestrial radiocommunication services.

For a fully populated GSO interferer, static analyses were carried out to determine the cumulative level of interference from all visible satellites into a FS system with antenna and receiver characteristics as defined in sections 3.1 and 4.1 above. The analysis is repeated as the FS antenna is rotated in azimuth from 0^{o} to 360^{o}, in steps of 10^{o}. A plot of cumulative interference vs. FS antenna azimuth angle is then produced, which enables the interference level to be compared with the FS long term interference criterion (sections 3.5 and 4.5). This determines the range of azimuth angles over which the FS interference criterion is likely to be exceeded, but in the case of directional antennas with very narrow beam widths is unlikely to show the worst case interference level arising when the FS antenna is directly aligned with one of the GSO satellites. As explained in section 2, it is not practicable to avoid this scenario at these frequencies.

The worst case interference scenario for a single satellite interferer must therefore be determined separately using the formula:

$$\mathbf{I_{max} = PFD(\theta) - A_{atmos} + G_{FSAnt} - EIA + 8.5\ dBW/\ 7\ MHz} \qquad \mathbf{(5.1)}$$

Where: θ is the elevation angle of the satellite relative to the horizon

A_{atmos} is the atmospheric attenuation in between the satellite and the FS receiver

G_{FSAnt} is the gain of the FS antenna

EIA is the effective isotropic aperture, $10 \log(4\pi/\lambda^{2})$

8.5 dB is a bandwidth correction factor (PFD is specified in $dBW/MHz/m^{2}$)

For NGSO interferers, the sharing scenarios are dynamic. FSCP determines the position of each satellite in a given FSS system at regular time intervals over an extended time period and from this data calculates a series of "interference events". Over 1 million such events can be determined for each simulation, at time intervals of typically one second. The events are then analysed statistically and the results presented in the form of graphs showing interference level against the percentage of time over the simulated period for which that level was exceeded. Each simulation initially assumes every satellite in the GSO or NGSO constellation is transmitting continuously at the limits defined in the current S21 PFD mask for the frequency band 37.5 – 39.5 GHz. Plots of interference level against percentage of time for which the level is exceeded are then generated. For receivers employing directional antennas, long term interference arises from multiple satellite interferers located outside the main beam of the FS receive antenna. The value is dependent upon the azimuth pointing angle of the FS antenna and the worst case azimuth must therefore be determined for each sharing scenario.

Examination of UK point to point link statistics provided by the RA indicated that in the 37.5 –

39.5 GHz band there were currently at least 24 links with an antenna elevation angle of 10^o or greater. Simulations in this band were therefore carried out for FS elevation angles of 0^o and 10^o. For MWS systems in the 40.5 – 42.5 GHz band, significantly greater elevation angles may be necessary (see sec.4.1.3 above). Simulations in this band have therefore been carried out at 0^o, 20^o and 60^o elevation.

For simulation purposes, it was assumed that co-channel GSO and NGSO systems would be present in the band. A further 3 dB reduction in the long term interference criterion has been applied to reflect this assumption (section 3.5). Since the objective of this study is to identify worst case interference scenarios, no allowance has been made for polarisation discrimination between interferer and victim. In practice, where the interference source lies directly on the main beam and is circularly polarised, interference levels may be up to 3 dB lower than the worst case values indicated in this report.

6 Simulation Results

6.1 37.5 – 40.0 GHz Band

6.1.1 GSO Interferer

6.1.1.1 Fully Populated GSO interference into Point to Point antenna with ITU Rec.699 Antenna, at 0^{o} elevation angle

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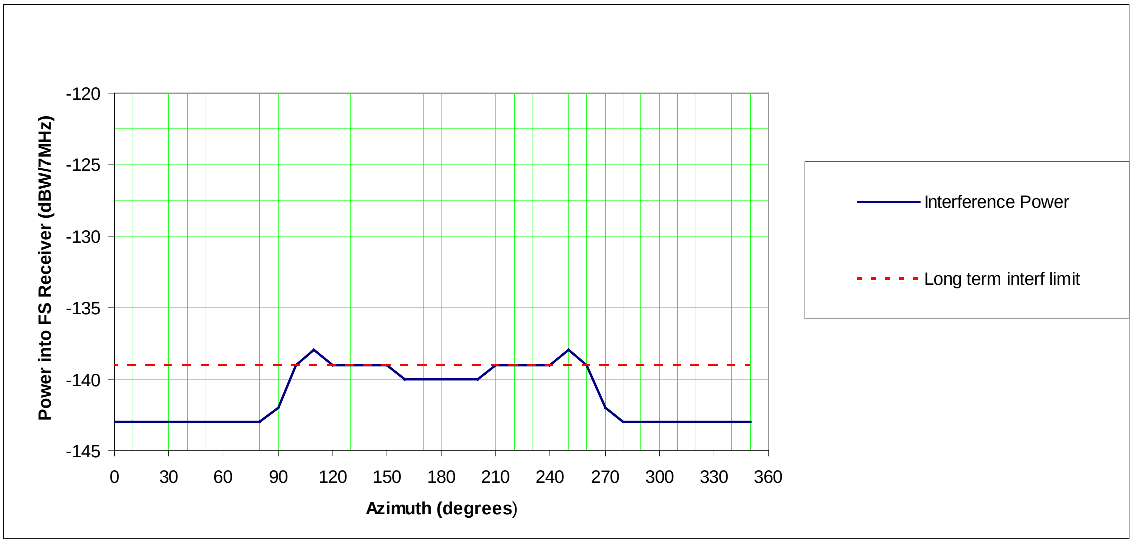
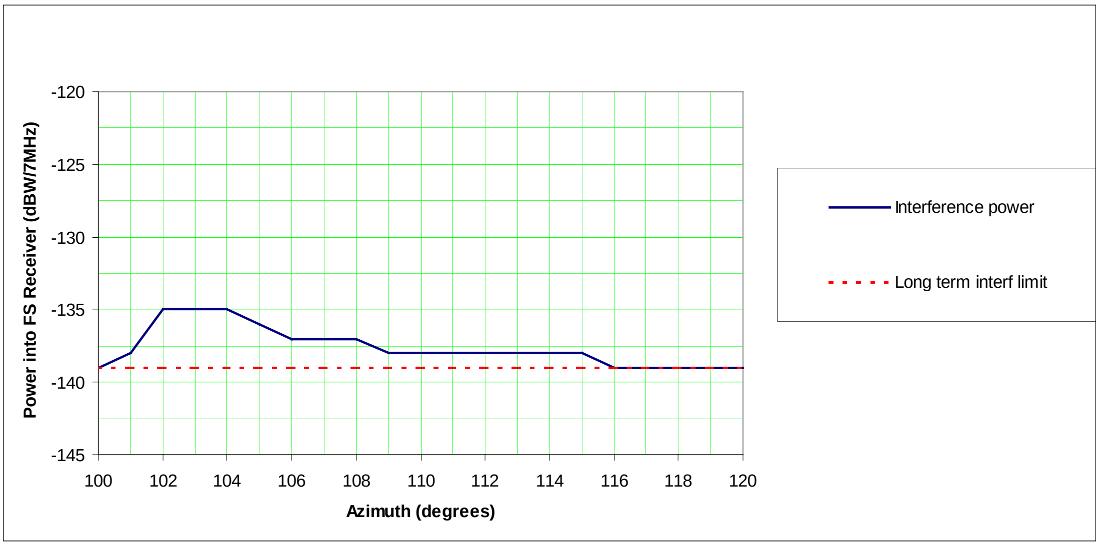


As the interference modelling is static, the result is compared with the long term interference criterion. It can be seen that over most of the 360^{o} azimuth range, the criterion is met.

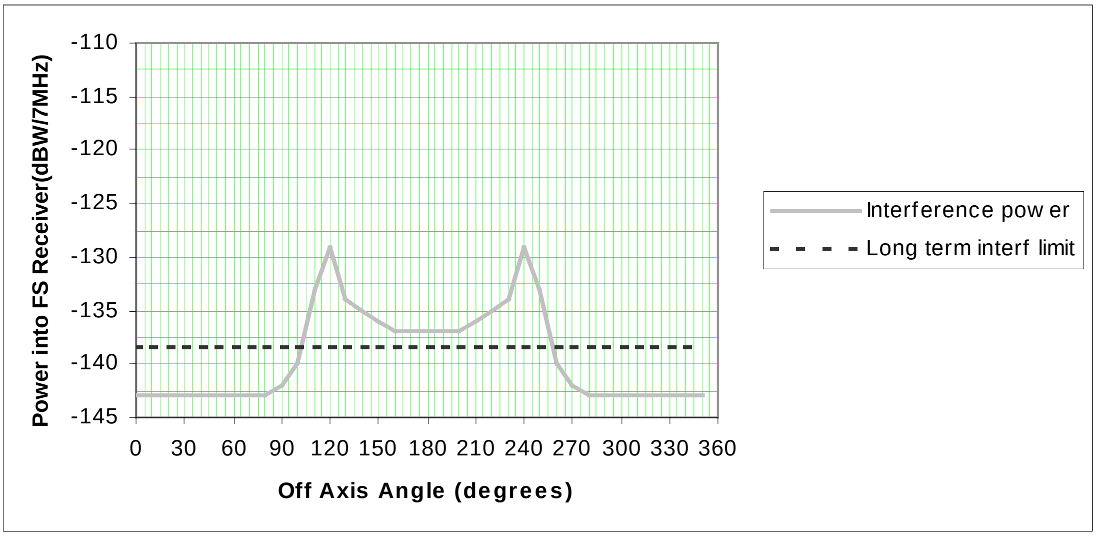
The simulation was repeated at 1^{o} intervals in the vicinity of the worst case azimuth:



It can be seen from this expanded plot that the worst case azimuth is between 102 and 104 degrees (there will be a corresponding worst case between 256 and 258 degrees on the opposite horizon).

The implication of this result is that whilst the majority of links would be adequately protected by the current PFD limits, those facing in the worst case azimuth direction could suffer severe long term interference from a GSO satellite. Assuming a random distribution of FS receiver azimuths, at least 1% would suffer interference at 3 dB or more above the accepted long term criterion. In the UK this could mean 50 or more links.

6.1.1.2 Fully Populated GSO interferer into Point to Point antenna with ITU Rec 699 Antenna, at 10° elevation angle



Here the reduced atmospheric attenuation has the effect of increasing the received interference level, particularly at azimuths close to the worst case. At 10° elevation, up to 20% of FS receivers may suffer interference 3 dB or more above the accepted long term criterion.

6.1.1.3 Fully Populated GSO interferer into Point to Point antenna with ITU Rec 699 Antenna, at worst case FS receiver azimuth

As noted in section 5, the above plots do not show the absolute worst case interference level, which arises at specific combinations of azimuth and elevation where the FS antenna is aligned directly with an FSS satellite (note that the Rec. 699 antenna 3 dB beam width is significantly less than the 2° spacing between GSO satellites). Depending upon link location, direct alignment could arise at any FS antenna elevation, up to and including the assumed maximum elevation angle of 10°.

Applying formula 5.1, at 0° elevation the worst case interference is –130 dBW / 7 MHz. At 10° elevation however, this figure increases to **–115 dBW / 7 MHz**, due to the lower atmospheric attenuation and the higher PFD limit at this elevation.

This figure is almost 24 dB above the accepted long term interference criterion and would effectively rule out the deployment of links in azimuths where direct alignment with a satellite might arise.

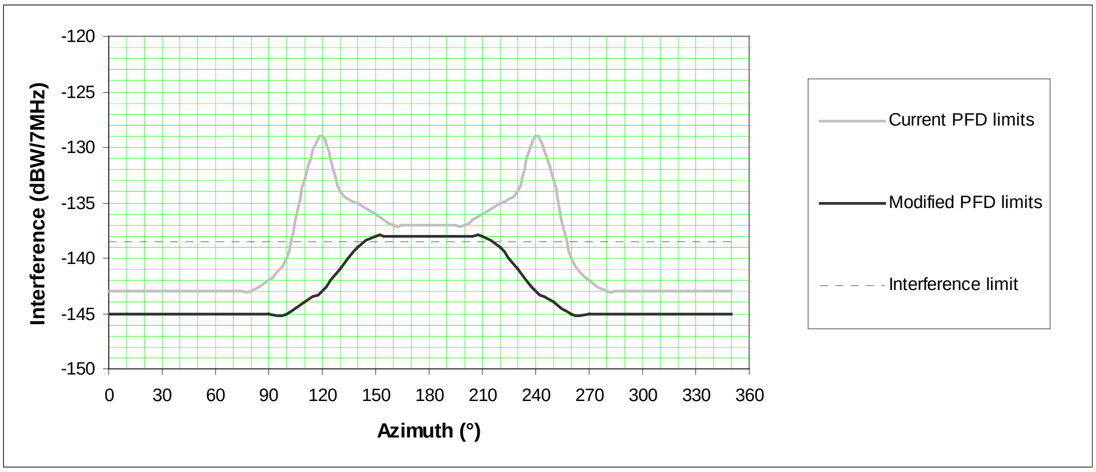
One solution to this problem would be to simply reduce the PFD limits by a uniform 24 dB, which would largely rule out deployment of GSO satellites in the band. However, because the maximum fixed link antenna elevation angle is 10^o and the worst case interference is determined essentially by the effect of a single satellite aligned with the FS antenna main beam, it is possible to retain the current PFD limit for interference arriving from high elevation angles ($>25^o$), providing there is an adequate reduction in the PFD limit at and around the maximum FS elevation angle of 10^o.

6.1.1.4 Effect of applying a modified PFD limit

This simulation was carried out with the following PFD limits applied to the FSS:

-140	dBW/MHz/m^2 for	$\theta \leq 15^o$
$-140 + 3.5(\theta - 5)$	dBW/MHz/m^2 for	$15^o < \theta \leq 25^o$
-105	dBW/MHz/m^2 for	$25^o < \theta \leq 90^o$,

Where θ is the angle of the satellite above the horizon.



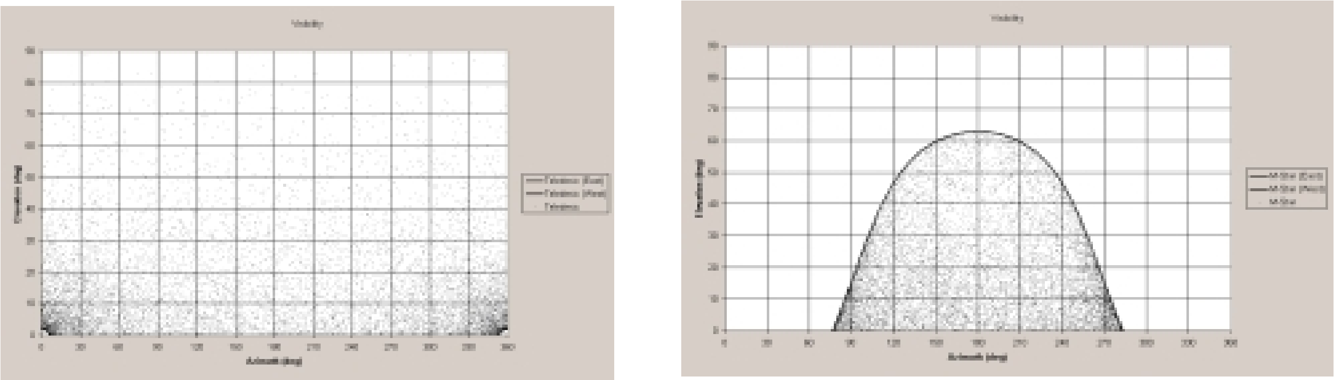
It is clear that raising the lower angular break point on the PFD mask from 5^o to 15^o is sufficient to reduce interference to the FS to an acceptable level without any change to the PFD limit above 25^o. The worst case interference from a single satellite interferer, derived using formula 5.1, is reduced to –140 dBW/MHz/m^2. Note this is slightly less than the maximum interference shown in the above plot, because the revised limits mean interference is no longer dominated by a single, directly aligned interferer. Such a solution may allow FS and GSO FSS systems to co-exist without having a significant adverse effect on FSS deployment in the band, as the effect of rain attenuation makes it unattractive for satellites to operate at such low elevation angles at these frequencies. These modified PFD limits have been submitted by the UK administration to ITU-R in response to Resolution 133 of WRC 1997.

6.1.2 NGSO Interferers

Simulations were carried out for each of the NGSO systems listed in Table 1. The plots below show the cumulative level of interference from each of the systems into a FS antenna operating at a 0° elevation angle, plotted against the percentage time over which the level is exceeded. The right hand edge of the plot corresponds to the maximum level of interference during the course of the simulation, which will approximate to the worst case single entry interference value determined earlier (-130 dBW at 0° elevation).

Effect of Azimuth Angle

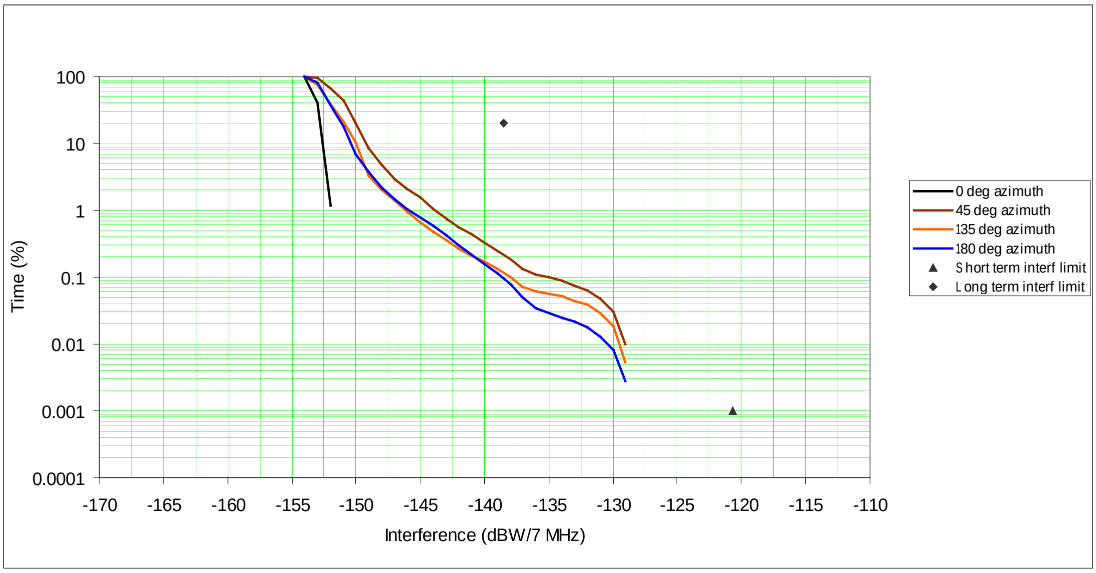
Each NGSO constellation will produce higher levels of cumulative interference over time at some azimuths than at others, for a given latitude and longitude. This is essentially due to the visibility statistics of the satellites, which in turn depend upon the orbital characteristics. Figure 6.1 below shows satellite visibility in the Teledesic and MSTAR constellations at 52° latitude, 0° longitude, over the course of a one million second simulation run. It can be seen that at low elevation angles the Teledesic satellites are visible in virtually all azimuth directions, whereas the MSTAR satellites are heavily concentrated over the southern horizon, with none visible north of 60° and 300° azimuth. These visibility statistics reflect the fact that Teledesic has an approximately polar orbit (87° inclination), whereas MSTAR has a 47° inclination and hence will not be visible at very high FS elevation angles.



Teledesic MSTAR

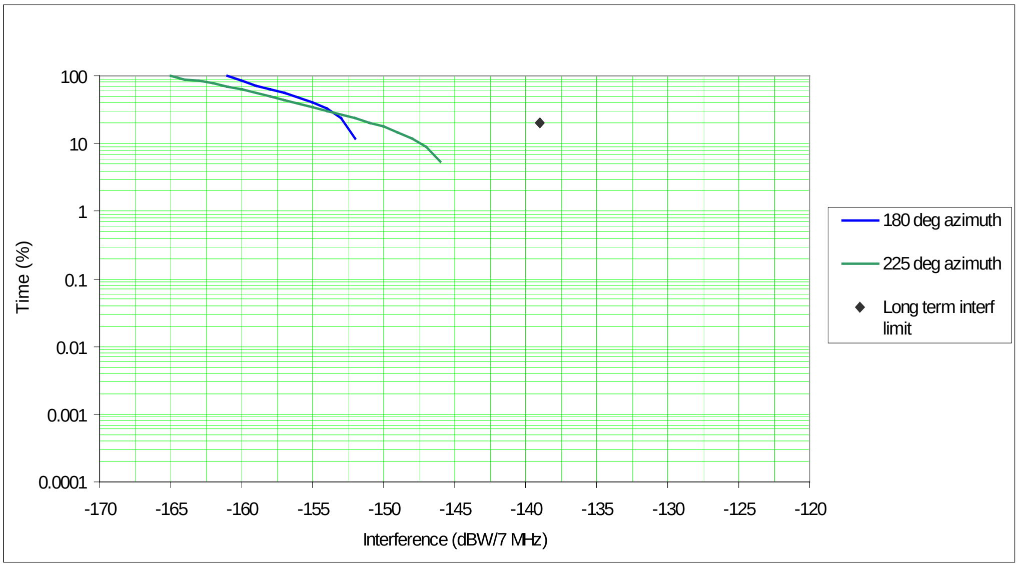
Fig 6.1 Satellite visibility for Teledesic and MSTAR constellations.

6.1.2.1 *Starlynx Interferer (20 Satellites, 4 Planes Inclined at 55 deg., 10352 km Altitude)*



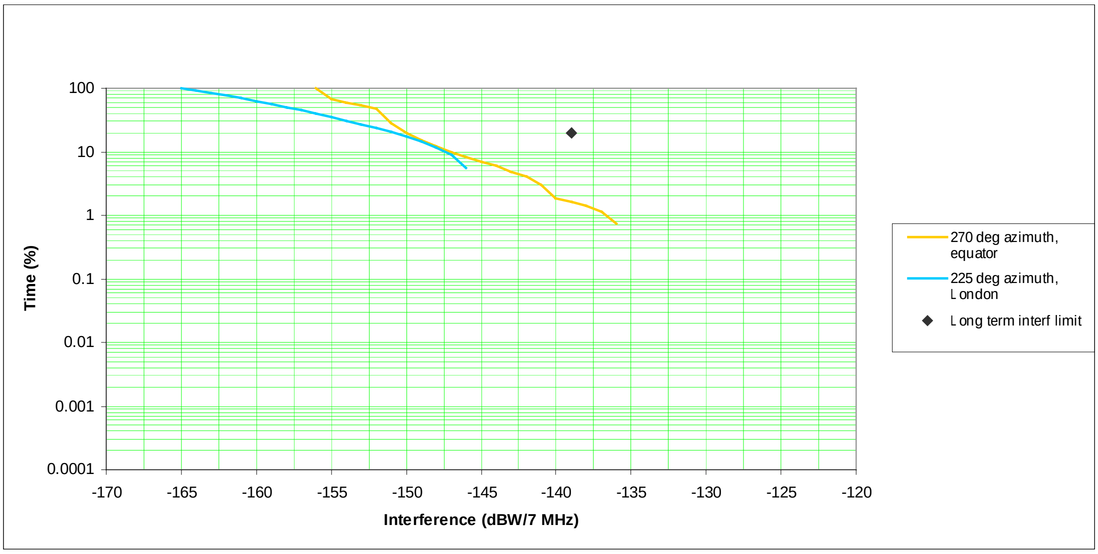
Note the dependence of interference on azimuth: at 0 degrees there is no probability of direct alignment between FS receiver and satellite. Long term interference is well below the limit at all azimuths, reflecting the relatively low number of side lobe interference entries.

6.1.2.2 Orblink interferer (7Satellites, Equatorial Plane, 9000 km Altitude)



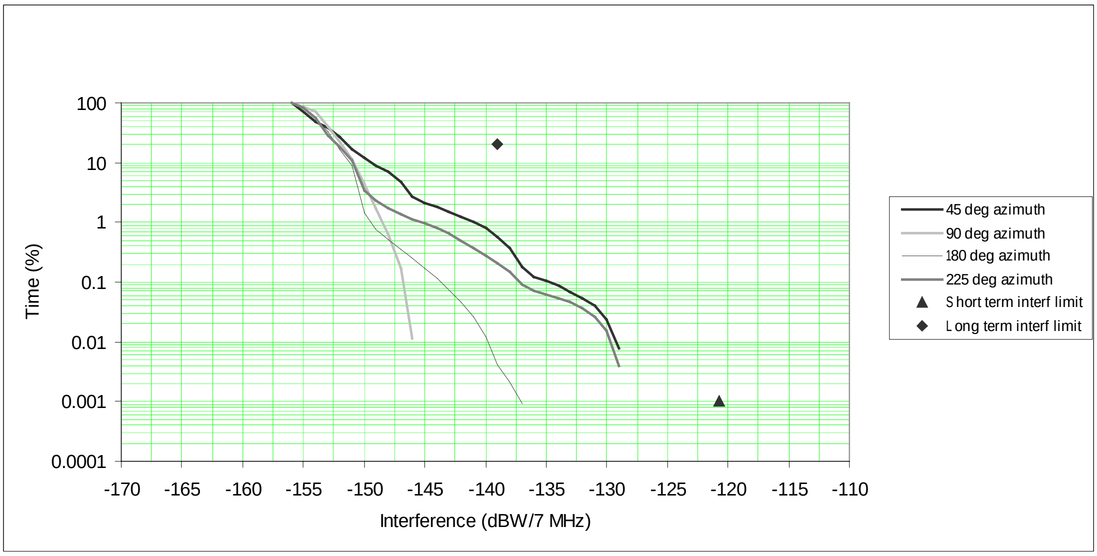
Here, the limited number of satellites and the single equatorial orbital plane means interference occurs only over a very narrow range of FS azimuths. Note however that there will be specific combinations of elevation and azimuth where direct alignment between satellite and FS receiver may periodically arise, so the worst case short term interference level should be assumed to be the same as for other, larger, NGSO constellations.

It is interesting to compare the interference levels that would be encountered by a FS receiver located on the equator, directly below the Orblink orbital plane:



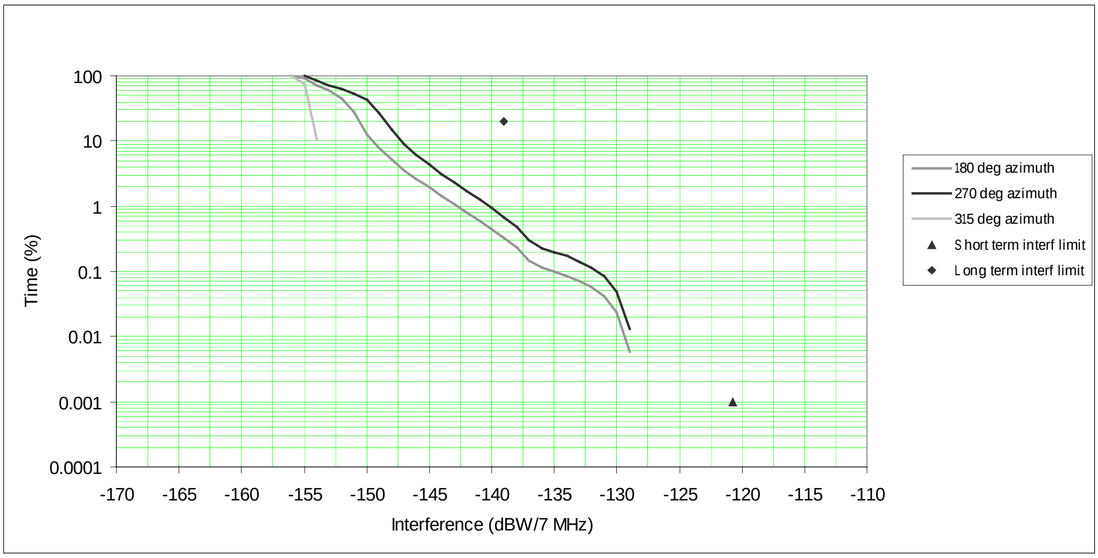
It can be seen that there is a significant increase in the maximum level of interference detected during the simulation, reflecting the greater probability of satellites appearing close to the antenna main beam. Note that in this case, because the FS antenna is aligned directly with the satellites' orbital plane, the maximum interference level on the plot is also the worst case level. This is however lower than the worst case interference in the UK, due to the higher level of atmospheric attenuation at low latitudes.

6.1.2.3 GESN Interferer (15 Satellites, 3 Planes Inclined at 50 deg., 10355 km Altitude)



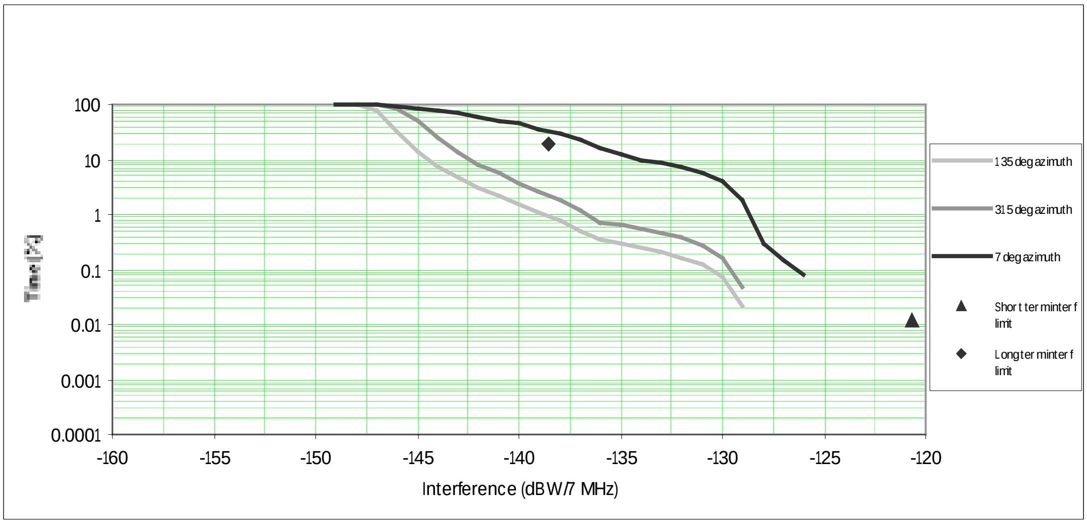
As would be expected, interference levels are similar to those from the Starlynx system, this has similar orbital characteristics but five additional satellites.

6.1.2.4 MSTAR interferer



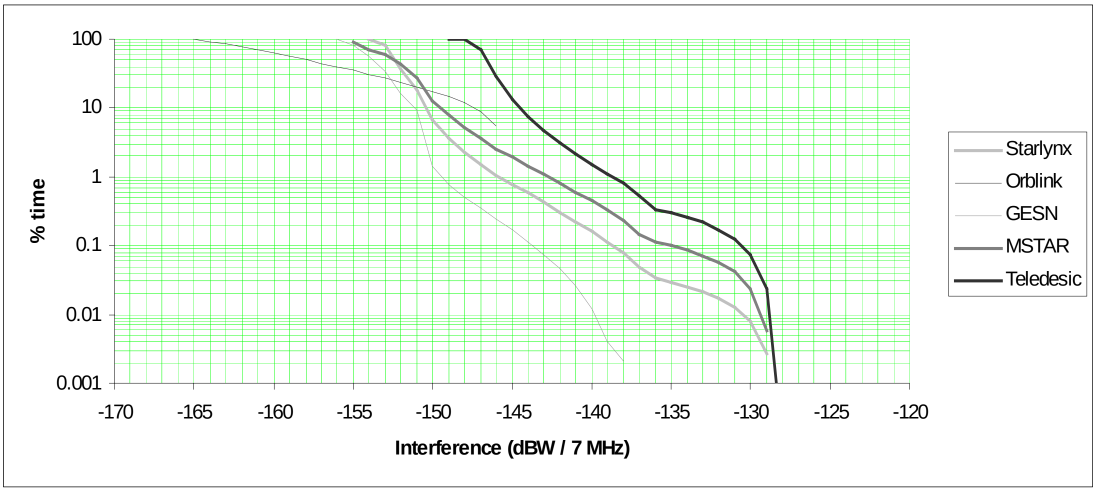
It is interesting to note the dependence of the interference level on FS azimuth angle, taking account of the satellite visibility statistics as illustrated in fig 6.1. Interference is highest at 270^{o} reflecting the high concentration of satellites around the edge of the visibility envelope. At 315^{o}, no satellites appear close to the FS antenna main beam and interference is negligible. No interference at all is detected at azimuths further north.

6.1.2.5 288 satellite interferer (modelled on the Teledesic Ka band system, 12 Planes Inclined at 84 deg., 1380 km Altitude)



In this case the interference level is highly dependent upon azimuth and exceeds the long term criterion in the worst case direction (7^{o}). Because of the high concentration of satellites at certain times in the worst case direction the short term interference can also exceed the level corresponding to a single directly aligned satellite. This may be due to the presence of more than one satellite in the antenna main beam, although this is unlikely because of the very narrow beam (c.0.25° 3 dB beam width). It is more likely to be the effect of several satellites present just outside the antenna main beam. Since there is a rapid fall off in atmospheric attenuation at elevation angles of just a few degrees, such off-axis interferers could make a significant contribution to short term interference from very large satellite constellations into horizontally aligned FS receivers. Note however that the high atmospheric attenuation in the direction of the main beam ensures that the short term interference criterion is not exceeded.

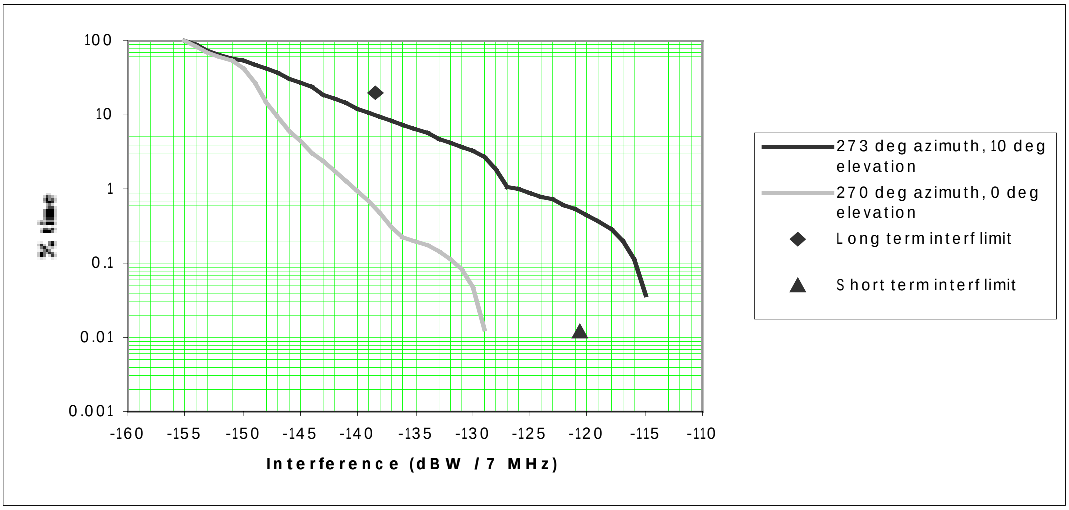
6.1.2.6 Comparison of NGSO interferers (FS receiver pointing due South)



This plot compares the cumulative interference levels from each of the simulated NGSO networks into a FS receiver pointing towards 180 degrees in azimuth. In general there is a clear relation between long term interference levels and the size of the constellation (the Orblink system is an exception due to its single equatorial plane and low satellite count). For the smaller systems (GESN and Orblink), a direct alignment between the FS receiver main beam and a satellite has not occurred during the simulation. Although the above plots do not necessarily represent the worst case FS azimuths for the various interferers they do provide a useful comparison of the relative impact the systems are likely to have on typical FS networks.

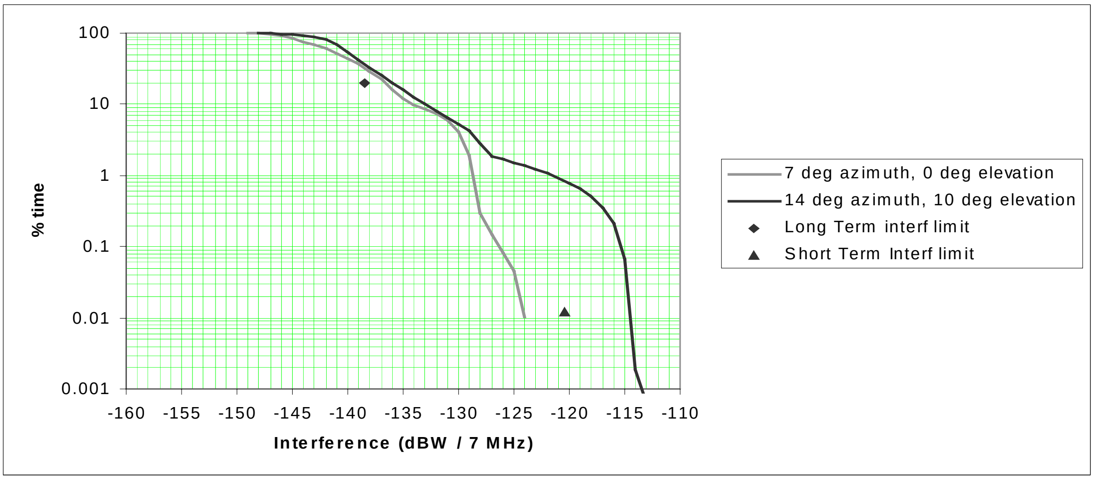
It is clear that the Teledesic based system poses a significantly greater long term interference threat than any of the currently filed systems, however in view of the very narrow spot beams achievable at these frequencies and the high traffic capacity requirements of broadband satellite networks, such constellations can not be ruled out in the future. Further interference simulations for elevated FS antenna angles have therefore been carried out with a Teledesic based interferer, although simulations were also conducted with the MSTAR system for comparison purposes.

6.1.2.7 MSTAR Interferer, with FS antenna elevated at 10^o (worst case azimuth)

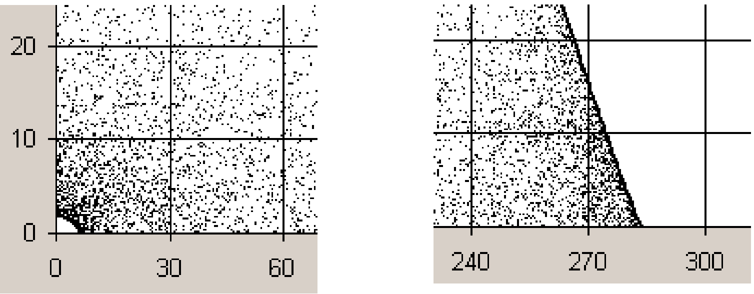


It can be seen that raising the FS antenna elevation angle to 10^o causes a significant increase in the short term interference, which now exceeds the criterion by 6 dB. This is a direct consequence of the much lower atmospheric attenuation at this elevation angle. Because the short term interference is essentially a function of a the direct alignment of a single satellite and the FS receiver, the criterion is likely to be exceeded by a similar margin for any NGSO interferer, albeit for different time percentages depending upon the number of satellites in the NGSO system. The implication is that a reduction in the PFD limit at 10^o elevation will be necessary to obtain sufficient protection for the FS. Note that long term interference in this case is acceptable.

6.1.2.8 Teledesic based interferer, with FS antenna elevated at 10^o



In this case, both the long term and short term interference criteria are exceeded (note that at the worst case azimuth the long term criterion was exceeded even for a horizontally aligned FS antenna). This phenomenon can be explained by considering the satellite visibility at the horizon at the worst case azimuth angle. As the figure below illustrates, the Teledesic constellation has a greater concentration of visible satellites very low on the horizon at the worst case azimuth, whereas MSTAR has similar concentrations at both elevation angles, albeit at slightly different azimuths.



Teledesic MSTAR

Fig 6.2 Teledesic and MSTAR satellite visibility at worst case azimuths

6.1.2.9 Application of Revised PFD limits

Because the maximum elevation angle of the FS receivers is relatively low on the horizon (10^{o}), it should be sufficient to tighten the PFD limit at arrival angles up to and in the vicinity of 10^{o}. This would enable the FSS to operate normally at higher elevation angles providing emissions at lower angles are sufficiently curtailed to protect the FS. In practice such a constraint should not adversely affect the FSS as rain attenuation effectively prohibits operation at low elevation angles.

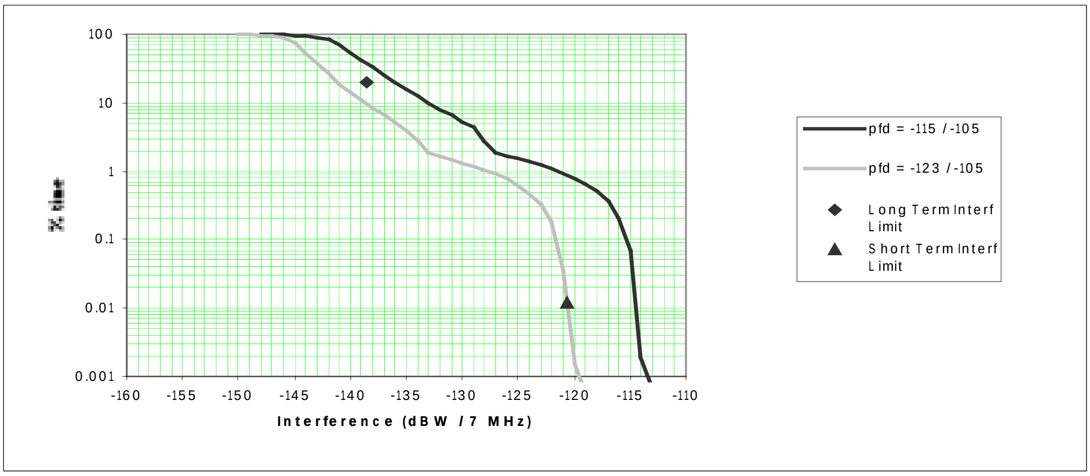
The most serious problem with the current PFD limits is short term interference, where the criterion is exceeded by 6 dB for substantially any NGSO interferer. It is therefore necessary to tighten the PFD limit at 10^{o} elevation by this amount. This can be achieved by tightening the current low arrival angle ($\theta \leq 5^{o}$) by 8 dB.

A simulations was therefore carried out for a Teledesic based interferer with each satellite operating at the following PFD limits:

-123 dBW/MHz/m^2 for $\theta \leq 5^{o}$

-123 + 0.9(θ - 5) dBW/MHz/m^2 for $5^{o} < \theta \leq 25^{o}$

-105 dBW/MHz/m^2 for $25^{o} < \theta \leq 90^{o}$:



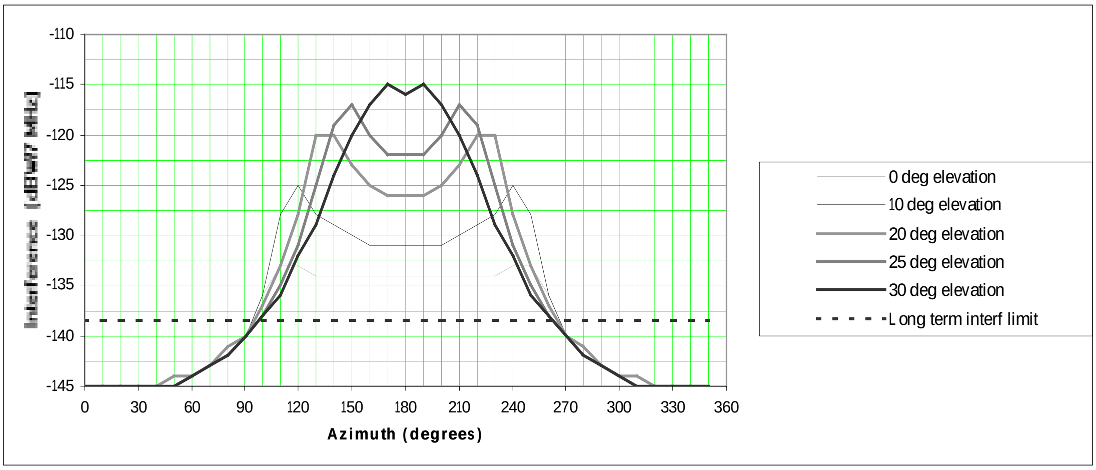
It can be seen that both the long term and short term criteria are now met. It is therefore proposed to modify the PFD limits for NGSO FSS systems in the 37.5-40.0 GHz band accordingly. Note that these limits are somewhat less stringent than those proposed for GSO systems, because the worst case "direct alignment" scenario applies only to short term interference for NGSO systems.

The above limits have been submitted to ITU-R for consideration.

6.2 40.5 – 42.5 GHz Band

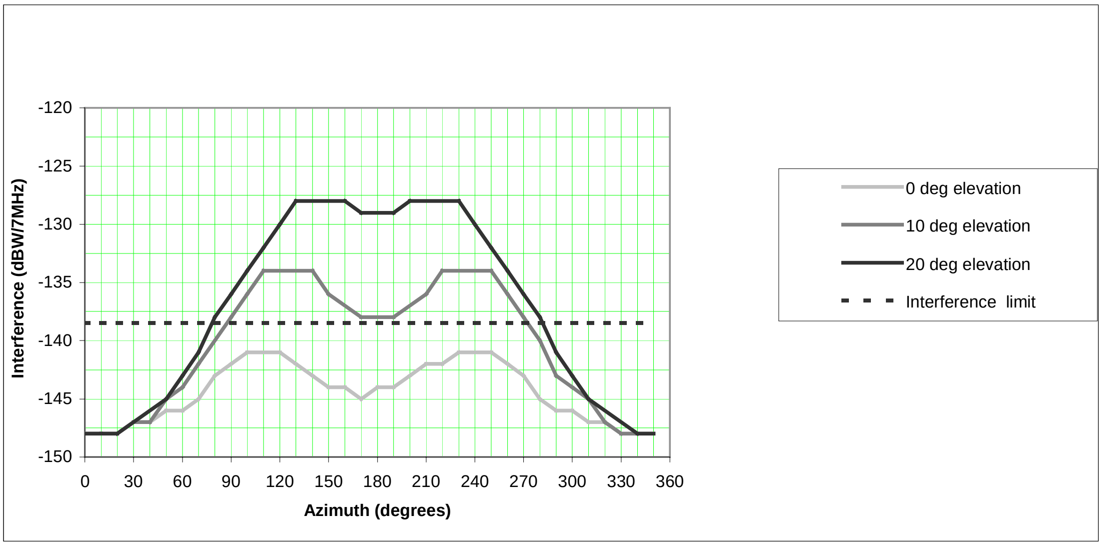
6.2.1 GSO Interferer

6.2.1.1 Fully Populated GSO interference into Directional antenna based on MPT 1560



It is clear from this result that the interference limit will be exceeded for substantially any FS receiver facing south of due east or due west. For elevated antennas, the situation is worse, the limit being exceeded by as much as 24 dB at the worst case azimuths. Interference is worst for FS systems operating at elevation angles between 25 ^{o} and 30 ^{o}, where satellites are operating at the highest PFD. At elevations above 30 ° an FS antenna located in the UK will no longer intercept the GEO arc and interference will diminish (note that this will not be the case at lower latitudes however).

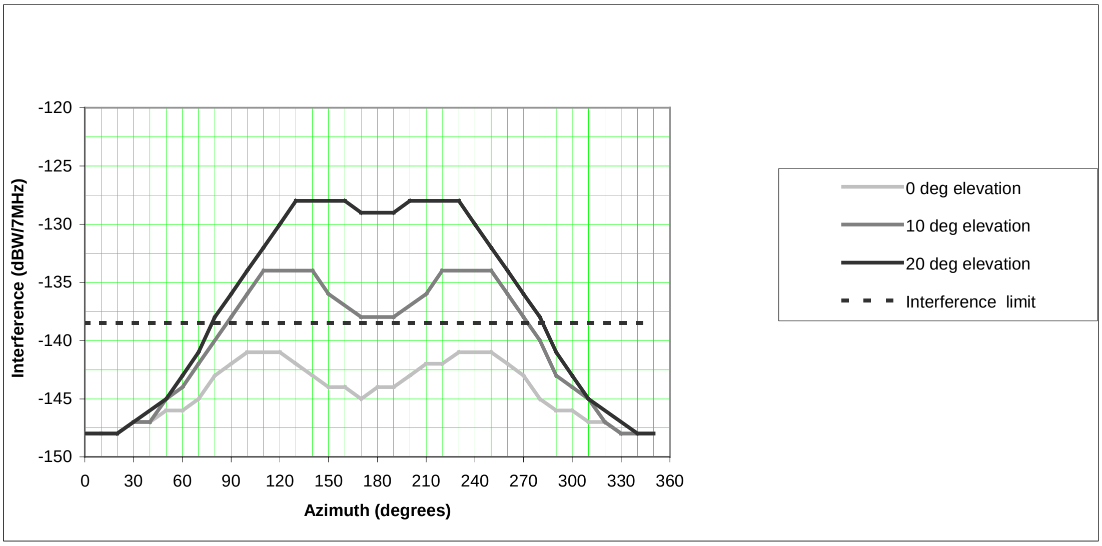
6.2.1.2 Fully Populated GSO interference into Sectoral antenna based on MPT 1560



In this case, the interference criterion is met at zero elevation but is exceeded by a significant margin at higher elevation angles (up to 11 dB at 20°).. However, it is clear from this result that, assuming antennas based on MPT 1560, directional stations are more susceptible to interference from GSO systems than sector stations and that PFD limits should be based on the protection requirements of the former.

6.2.1.3 Effect of applying a modified PFD limit

Because the GSO interference is always present, the S21 PFD limits must be modified to bring the cumulative GSO interference down to below the FS long term interference criterion. Unlike the 37.5 – 39.5 GHz band, the relatively low antenna directivity and the possibility of very high FS elevation angles limits the influence of the low arrival angle PFD value. This is confirmed by the plot below which shows that even reducing the low arrival angle PFD (<5 °) by 25 dB and the high arrival angle limit (>25 °) by 5 dB reduces interference by 7 dB , only 2 dB more than a flat rate PFD reduction of 5 dB would achieve. The plots assume a FS antenna elevation angle of 20°



The implication is that to provide protection in all possible FS scenarios, the PFD at all arrival angles must be reduced by the same margin as the long term interference limit is exceeded at the worst case azimuth, i.e. 24 dB. However, It should be borne in mind that in PMP networks angles above 20^o are likely to apply only to subscribers very close to hub stations, where the link margin will be relatively high, whilst in mesh networks route diversity will provide a degree of additional resilience to interference. On this basis it is considered that a 20 dB reduction in current S21 PFD limits would provide adequate protection from GSO interferers for terrestrial MWS systems.

The proposed PFD limits for GSO FSS systems in the 40.5-42.5 GHz band are therefore:

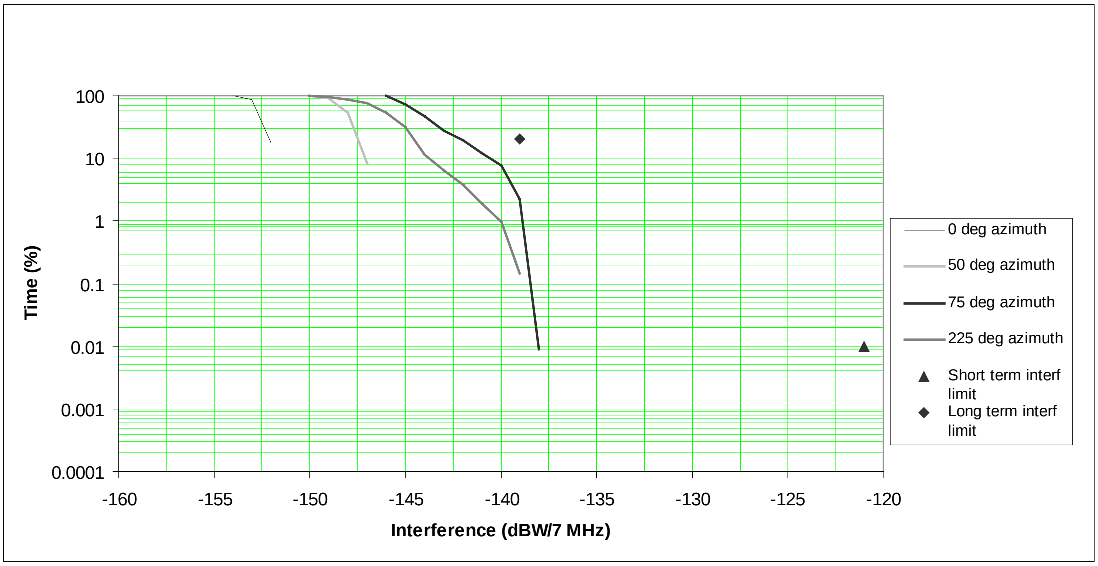
-135	dBW/MHz/m^2	for	$\theta \leq 5^o$
$-135 + 0.5(\theta - 5)$	dBW/MHz/m^2	for	$5^o < \theta \leq 25^o$
-125	dBW/MHz/m^2	for	$25^o < \theta \leq 90^o$.

These limits have been submitted to ITU-R for consideration.

6.2.2 NGSO Interferers

Only one proposed NGSO system has so far been notified in this band, namely the French LEO 3192 system. Simulations were therefore carried out with this system and with a 288 satellite system based on the Teledesic Ka band system orbit characteristics.

6.2.2.1 LEO 3192 Interferer into MPT 1560 directional antenna



Once again it can be seen that interference varies widely with azimuth, reflecting the visibility statistics of the satellites over the course of the simulation (see diagram below).

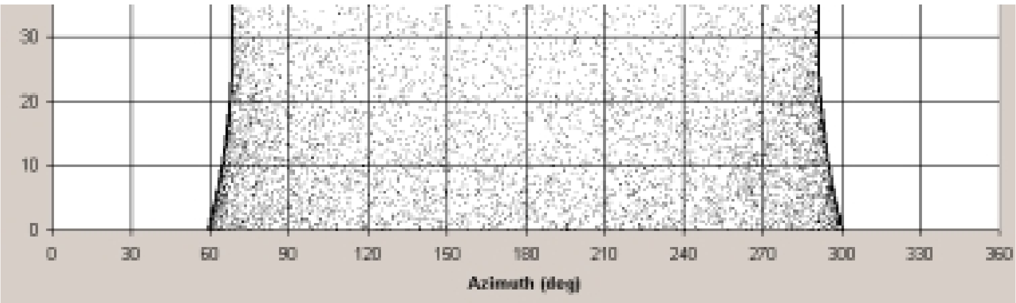
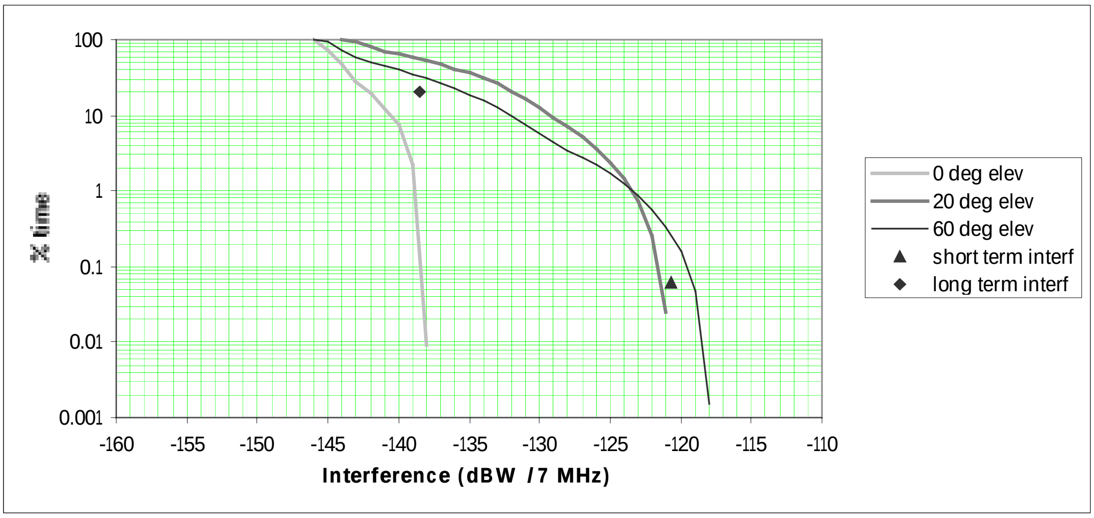


Fig 6.3. LEO 3192 Visibility distribution

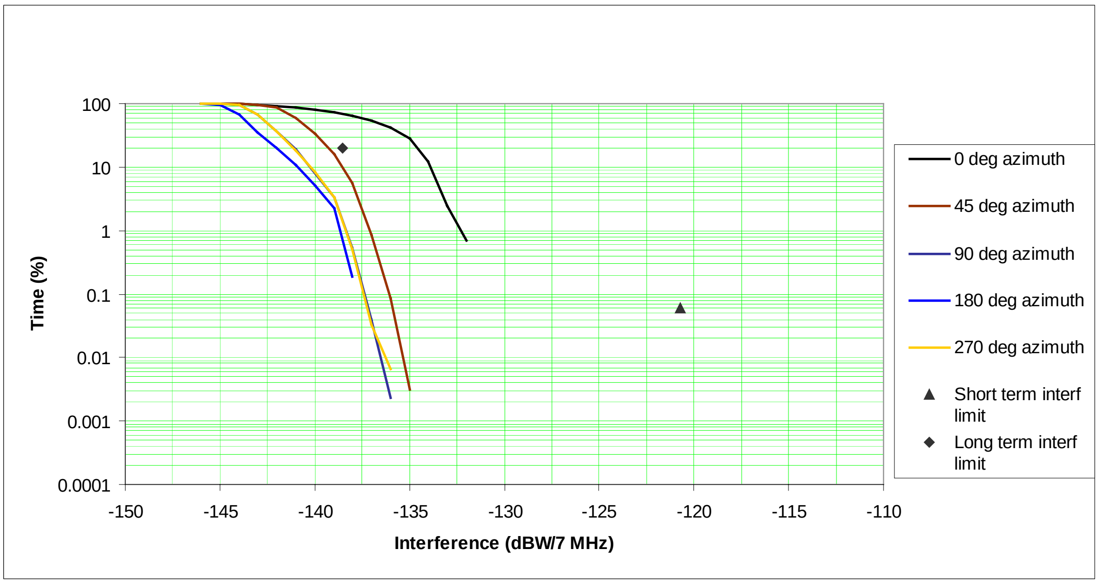
At azimuths north of 60^o or 300^o, no satellites appear in the FS antenna main beam and interference levels fall away rapidly due to the relatively low inclination of the FSS system (55^o) Hardly any interference is detectable at 0^o.

The following plot shows the effect of increasing the FS antenna elevation to 10^o and 20^o, at the worst case azimuth angle (75^o)

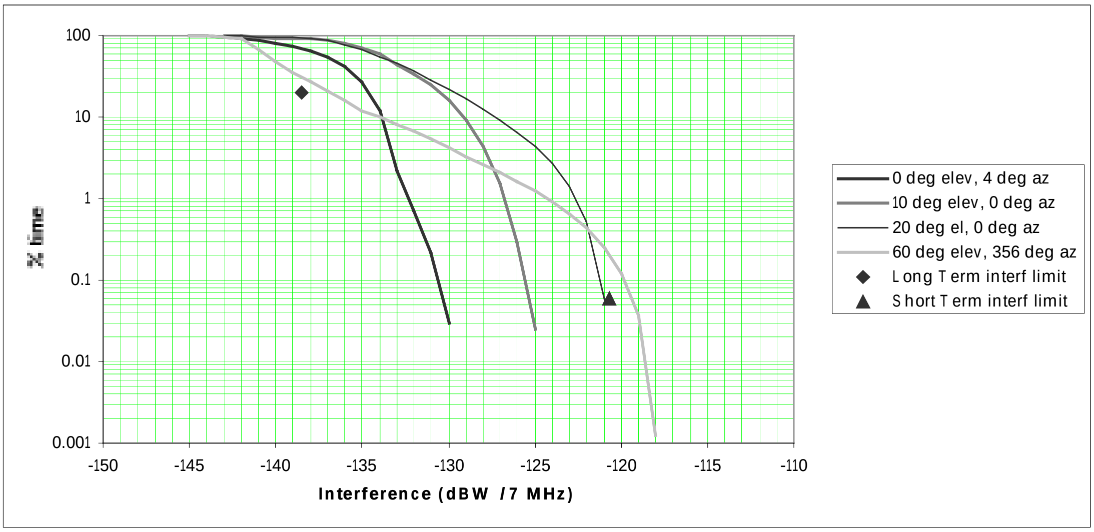


Note that the long term interference level is greater at 20 ° than at 60 °, reflecting the higher probability of satellite visibility at the lower elevation. The criterion is exceeded in both cases however. Short term interference is higher at 60 ° due to the higher PFD limit which applies above 25 °. Because of the potential for very high FS antenna elevation angles, a tightening of the PFD limits at all arrival angles will be necessary to reduce interference to an acceptable level.

6.2.2.2 Teledesic based interferer into directional MPT 1560 antenna

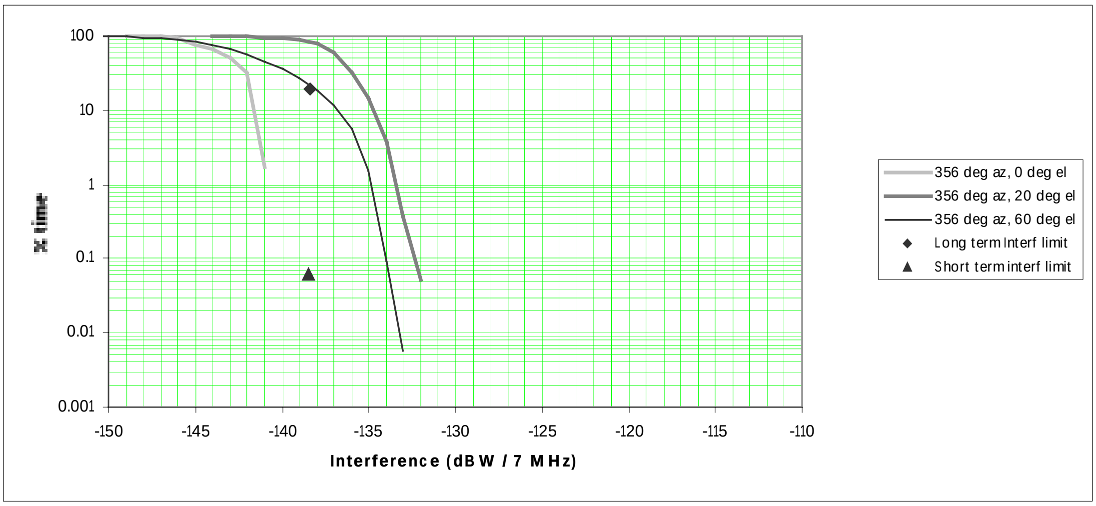


This plot shows the cumulative interference level into a horizontally aligned FS receiver at various azimuths. Interference is markedly worse at 0 °, reflecting the higher probability of satellite visibility in this direction (see fig 6.1). In this direction, the long term criterion is exceeded by 4 dB, even at zero antenna elevation. As would be expected, interference is significantly worse at higher elevations, due to reduced atmospheric loss, the higher PFD limit and the greater number of side lobe interference entries:



Long term interference is at its worst in the range 10-20 °, reflecting the increasing PFDs, much reduced atmospheric attenuation and relatively high visibility probability at these elevations. At higher elevations short term interference is higher (due principally to the higher PFD) but long term interference is lower because there is a lower probability of satellite visibility at higher elevation angles.

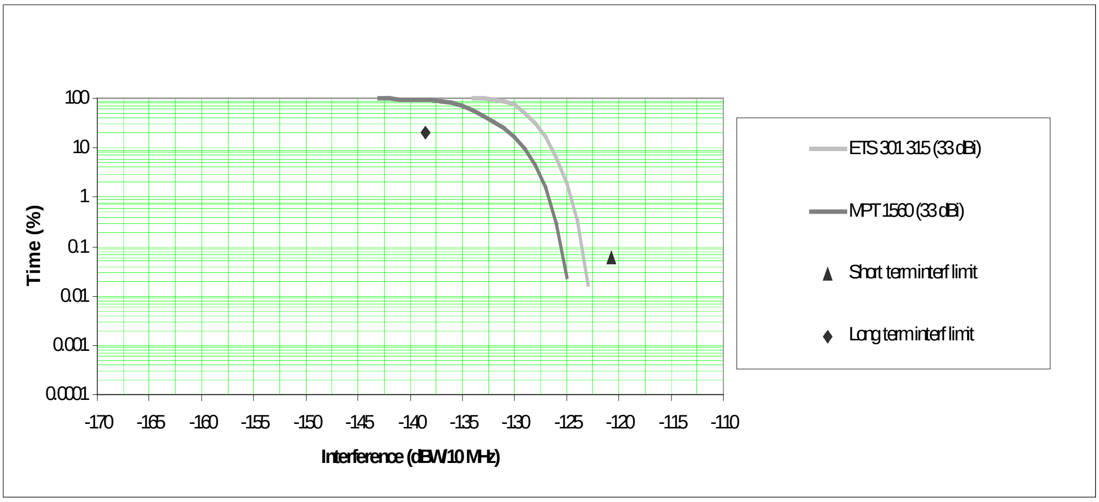
6.2.2.3 Teledesic based interferer into MPT 1560 sectoral antenna.



In this case, actual interference levels are lower due principally to the lower gain of the FS antenna, however the long term interference is still exceeded at 20 ° FS antenna elevation. Moreover, because the wide FS antenna beamwidth means correlated fading of wanted and interfering signals can not be assumed, enhanced levels of short term interference can not be tolerated, hence the short term criterion is identical to the long term in this case.

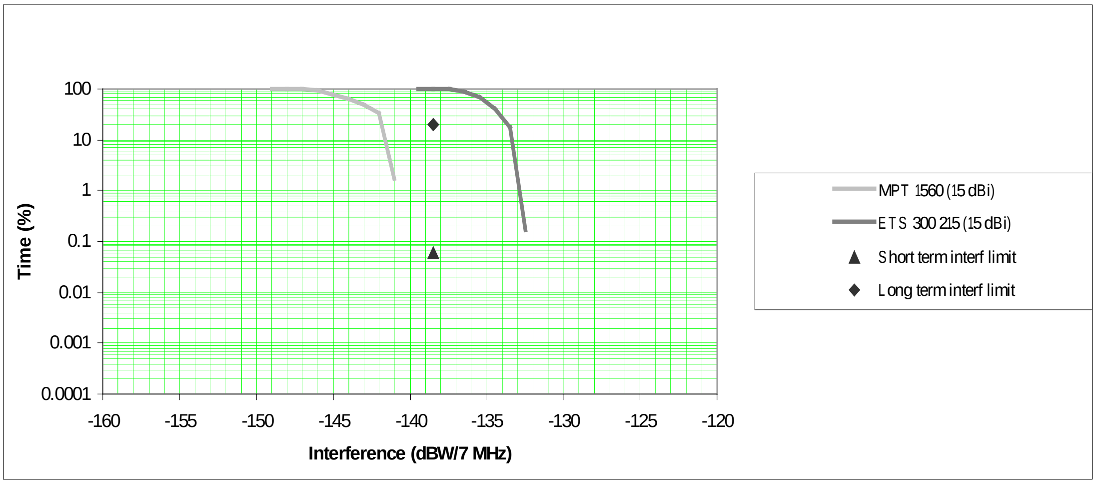
6.2.2.4 Teledesic based interferer into a 33 dBi ETS 301 315 directional MWS antenna, compared with a 33 dBi MPT 1560 directional antenna (both

antennas oriented at 0^{o} azimuth, 10^{o} elevation

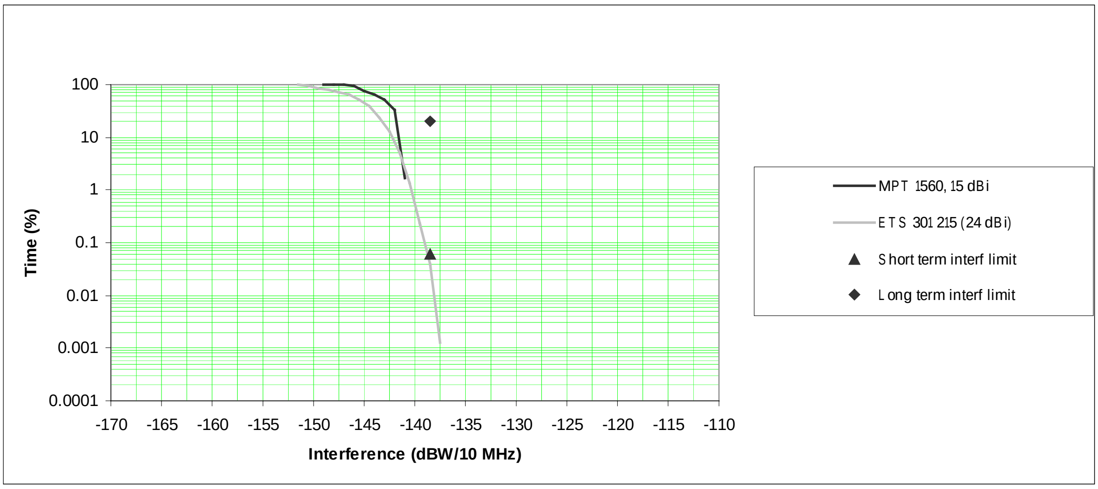


This plot illustrates the effect of the lower off-axis discrimination of the ETSI antenna pattern, which is to increase cumulative interference levels by c. 3 dB.

6.2.2.5 Teledesic interferer into ETS 301 315 MWS sector antenna (15 dBi gain)



This result once again illustrates the effect of the lower off-axis discrimination, however in this case the effect is magnified because of the scale of the difference between the two masks. In practice it is doubtful whether the ETSI pattern would provide adequate off-axis discrimination for deployment in a dense MWS network, however this result shows the importance of antenna design in protecting against co-channel interference. This is even more evident in the next plot which shows the interference into a high performance sector antenna with 24 dBi gain and a 90^{o} beam width:

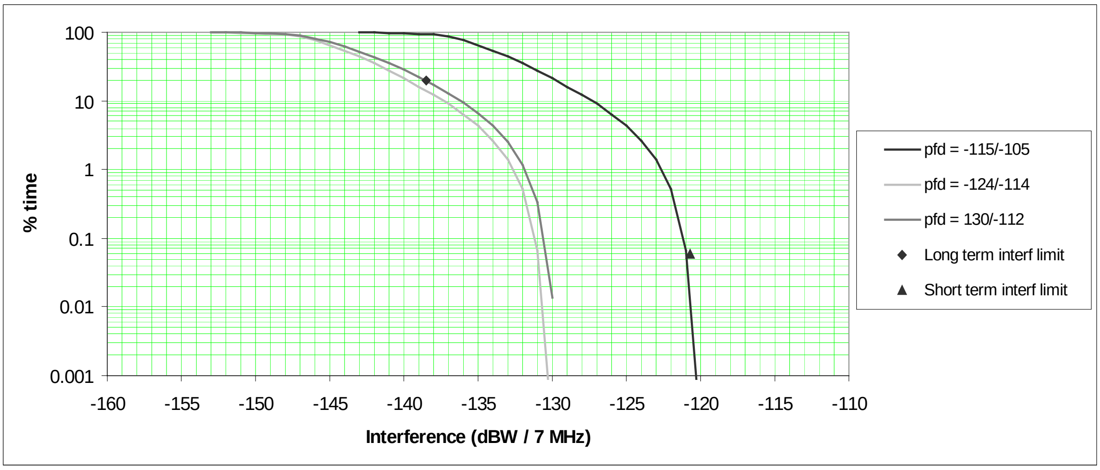


Here, the same generic ETS 301 215 antenna radiation pattern has been used, but the 3 dB elevation beamwidth has been reduced from 18^{o} to 2^{o}. The attraction of such an approach to FS operators is that by pointing the antenna so that the narrow elevation main beam is directed to the edge of the desired coverage area, full advantage may be taken of the higher gain, whilst subscribers closer to the base station who may lie below the narrow main beam of the antenna will still receive service because the reduced off axis gain is offset by the reduced free space path loss.

The reduction in elevation beamwidth significantly reduces the number of satellites which lie within the antenna beam, hence the lower level of cumulative interference compared to a lower gain ETS antenna. It can be seen from the plot that, despite the significantly higher gain, the long term interference is lower than that for the MPT 1560 antenna.

6.2.2.6 Derivation of appropriate PFD limits

In the NGSO case, long term interference is exceeded by a much smaller margin than in the GSO case, because of the dynamic nature of the satellite interferers. This means that significantly less tightening of the PFD limits is required. A reduction of 9 dB at all arrival angles would be sufficient to reduce interference to an acceptable level, however if a further tightening of the low arrival angle limit can be tolerated, a correspondingly lower reduction in the high arrival angle limit is feasible. The plot below shows that a 7 dB reduction at angles above 25^{o} is sufficient if the limit below 5^{o} is reduced by a 15 dB:



The following PFD limits are therefore proposed for NGSO FSS systems operating in the 40.5 – 42.5 GHz band:

-130	W/MHz/m^2	for	$\theta \leq 5^o$
-130 + 0.9(θ - 5)	dBW/MHz/m^2	for	$5^o < \theta \leq 25^o$
-112	dBW/MHz/m^2	for	$25^o < \theta \leq 90^o$,

It should be noted that these PFD limits are based on the assumption that antennas conforming to the UK specification MPT 1560 are used. As illustrated in 6.2.2.4 and 6.2.2.5 above, deployment of antennas with inferior off-axis discrimination may result in a significant increase in interference to the FS receiver. This should be borne in mind in developing antennas for MWS applications.

These limits have been submitted to ITU-R for consideration.

7 Conclusions

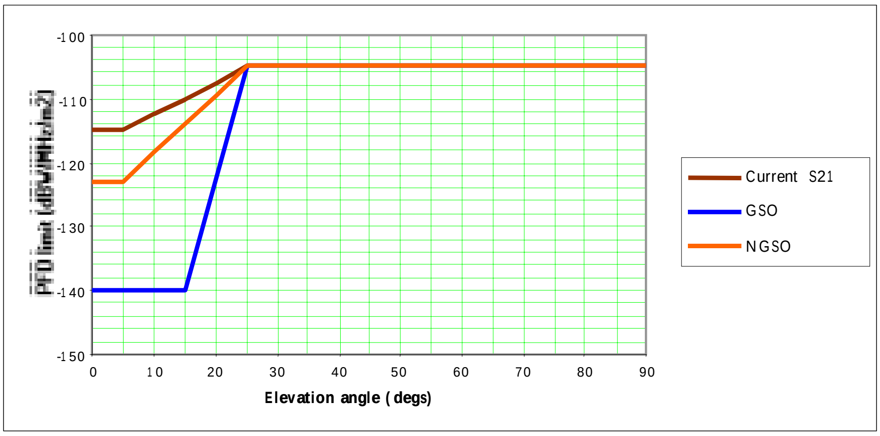
This study has established that the current PFD limits defined for FSS systems operating in `the 37.5 – 40.0 GHz and 40.5 – 42.5 GHz bands are insufficient to protect terrestrial FS systems when all likely operational scenarios are taken into account. Revised PFD limits are therefore proposed for the 37.5 – 40.0 GHz bands, along with separate limits for the 40.5 – 42.5 GHz band which is not currently addressed by Article S21. In both bands, GSO FSS systems (assuming fully populated GSO arc with 2^0 spacing) present the greater source of potential interference because the types of FS application make it impractical to avoid direct alignment between the FS receive antenna and the GSO arc. Different PFD limits have therefore been proposed for GSO and NGSO FSS systems in each band.

In the 37.5 – 40.0 GHz band, the proposed PFD limit is tightened only at low arrival angles ($<25^o$), which should enable sharing between the FS and carefully planned FSS systems. In the 40.5 – 42.5 GHz band, significantly tighter limits are proposed, principally to protect the high density MWS systems which are likely to be deployed in the band and which will not deploy the highly directional antennas found in lower FS frequency bands. The tighter limits apply even to high arrival angles, due principally to the potentially high elevation angles (20^o or more) which may be encountered in MWS systems, but also a further consequence of the more limited antenna directivity. As in the 37.5 – 39.5 GHz band, GSO systems pose the greater interference risk and the proposed PFD limits may rule out co-service sharing in the same geographic region.

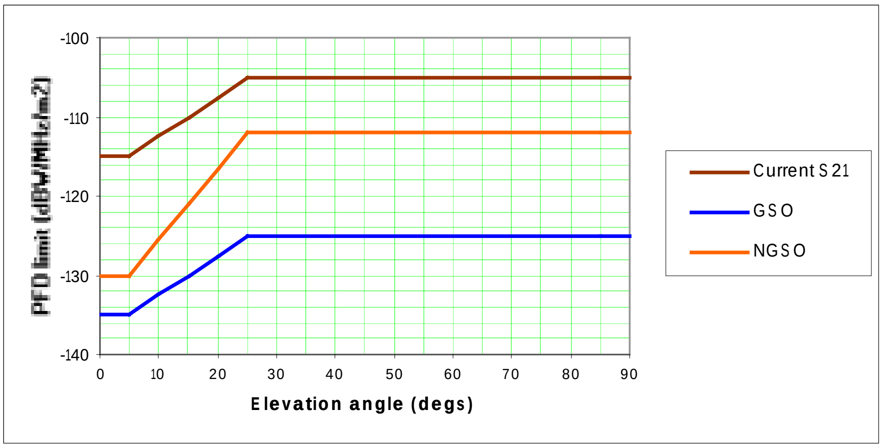
In the 40.5 – 42.5 GHz band, it has also been shown that the interference potential of co-primary FSS systems is highly dependent upon the type of antenna deployed in the FS receivers, in particular the degree of off-axis discrimination. It should be noted that the results presented here are based on type approval specification limits for antenna radiation patterns which may be exceeded by a considerable margin in practice. However, it should also be borne in mind the that the current ETSI standard covering frequencies below 30 GHz could, if extrapolated to the 40.5 – 42.5 GHz band, lead to a significant increase in interference potential relative to FS systems deploying MPT 1560 compliant antennas.

Improvements in MWS receiver technology leading to lower noise figures than today’s point to point FS systems may also increase the potential for interference from other co—primary services. Some proponents of MWS systems are claiming noise figures as low as 5 dB for future systems, compared to the 10 dB figure assumed in the simulations, however this does not appear to include any allowance for other receiver or antenna losses. Nevertheless, it may be necessary to re-visit the sharing criteria for this band in the future, when there is greater clarity about the types of FS system likely to be deployed.

Figure 7.1 below shows the proposed PFD limits in graphic form and compares them with the current Article S21 limits:



37.5 – 40.0 GHz



40.5 – 42.5 GHz

Fig 7.1 Proposed PFD limits for FSS systems in the 37.5 – 40.0 and 40.5 – 42.5 GHz frequency bands