RECOMMENDATION ITU-R S.1557

Operational requirements and characteristics of fixed-satellite service systems operating in the 50/40 GHz bands for use in sharing studies between the fixed-satellite service and the fixed service*

(Question ITU-R 250-1/4)

(2002)

The ITU Radiocommunication Assembly,

considering

a) that the band 37.5-42.5 GHz is allocated to the fixed service and the fixed-satellite service (FSS) (space-to-Earth) on a co-primary basis;

b) that some FSS systems plan to provide data rates ranging from synchronous transfer mode 1 (STM-1) or higher, up to 10 STM-4;

c) that most FSS systems propose using small earth station antennas, less than 1 m in diameter for the user link, to provide end-to-end link availability of at least 99.7%;

d) that FSS systems may need to use larger earth terminal antennas, of up to 3 m in diameter, for gateway applications involving individually-coordinated earth stations at geographically dispersed hubs or fibre access points (FAPs) and that these applications will require the end-to-end link availability of at least 99.9%;

e) that the feasibility of using larger antennas having a diameter greater than 2.4 m ($D/\lambda >> 300$), given the effects of main reflector distortion, surface roughness, radome attenuation and auto tracking facilities capable of minimizing pointing loss in this band, remains to be determined;

f) that some proposed FSS systems operating in this band use on-board processing for small earth terminal users, and use a transparent transponder for gateway or hub/FAP applications;

g) that the propagation impairments are very severe in this frequency range;

h) that most FSS systems plan to provide a clear-air bit error ratio (BER) of the order of 1×10^{-7} to 1×10^{-10};

j) that current planned FSS systems use quadrature phase shift keying (QPSK) modulation, and future FSS systems may use higher order modulation schemes such as 8-PSK or quadrature amplitude modulation, 16-QAM,

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* This Recommendation should be brought to the attention of Radiocommunication Study Groups 7, 8 and 9 and Joint Working Party 4-9S.

recommends

1 that FSS system design and sharing studies in the band 37.5-42.5 GHz should take into account the operational requirements in Annexes 1 and 2;

2 that FSS characteristics in Annexes 3 through 6 which contain technical information on some FSS systems operating in the 37.5-42.5 GHz band, should be taken into consideration when conducting sharing studies between the 50/40 GHz FSS service and co-frequency, co-primary services;

3 that administrations planning modifications to these systems or proposing future satellite networks in the 50/40 GHz bands should submit FSS network technical characteristics to ITU-R to update the Annexes.

ANNEX 1

Required downlink parameters of FSS systems operating in the 37.5-42.5 GHz band

1 Introduction

This Annex presents data on the required downlink power flux-density (pfd) in the 37.5-42.5 GHz band to allow FSS systems operating in this band to operate with various earth terminal antenna sizes. The study is based on the proposed FSS operating in the 50/40 GHz bands.

Based on the ITU filing, a considerable number of FSS systems, planned to operate within the bands 37.5-42.5 GHz and 47.2-50.2 GHz, have been received. These systems plan to provide data rates ranging from video-conferencing quality through very high speed transmission of STM-1 (155 Mbit/s) or higher, up to 10 STM-1, to earth terminal antennas ranging in size from 1 m to 3 m. Most FSS systems propose using small earth terminals, less than 1 m in diameter, to provide 99.7% link availability, and the systems using bigger earth terminal antenna sizes, from 1.5-3 m for gateway-to-gateway or hub-to-hub applications, will require higher link availability. Because the propagation impairments are very severe in the 40/50 GHz bands, most proposed systems will provide service at higher minimum elevation angles than FSS systems operating in frequency bands below 30 GHz. The typical minimum operational elevation angle at 40/50 GHz is 20°; however, some systems, like the GSO SV plan to provide service at a 15° minimum elevation angle. Technical characteristics of several proposed FSS systems planning to operate in these bands have been included in Recommendation ITU-R S.1328.

The purpose of this Annex is to provide additional technical characteristics of the FSS systems operating in the 40/50 GHz bands for use in future sharing studies in ITU-R.

2 Required earth terminal antenna size vs. downlink pfd

This section contains computations of the downlink pfd levels that are required to allow the FSS satellite networks operating in the 40/50 GHz band to operate with various earth terminal antenna sizes and desired link availabilities.

The pfd at the Earth's surface can be shown as:

$$pfd = S - G_{rxE/S} + 21.45 + 20\log(f) + 10\log\left(\frac{1}{BW = sps}\right)$$

where:

- pfd: power flux-density (dB(W/(m^2 · MHz))
- S: receive signal strength (dBW)
- BW: transmit bandwidth (necessary bandwidth) (MHz)
- sps: symbol rate (Msymbols)
- f: frequency (GHz)
- $G_{rxE/S}$: on-axis gain of receiving earth station (dBi).

The received $E_b/(N_0 + I_0)$ at the receiver can be computed as:

$$\frac{E_b}{(N_0 + I_0)_\downarrow} = \frac{S}{N_0 + I_0} - 10\log(bps)$$

and

$$\left(\frac{S}{N_0 + I_0}\right) = S - (N_0 + I_0) = S - G_{rxE/S} + (20.4 + 20\log(D) + 20\log(f) + 10\log(\eta)) - (N_0 + I_0)$$

and

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

where:

- N_0 = –228.6 + 10 log(T) (dB(W/Hz)), thermal noise power density
- T: earth station receiver noise temperature + noise temperature increases due to rain (K)
- I_0: self interference + interference from other FSS systems operating in the same band (dB(W/Hz))
- D: earth station antenna diameter (m)
- f: frequency (GHz)
- η: earth station antenna efficiency
- bps: bit rate.

It is important to note that the FSS downlink must satisfy the pfd limits at all slant ranges and elevation angles, while the E_b/N_0 of interest to a designer is the minimum E_b/N_0 over all slant ranges, elevation angles, and positions within a beam. Also the calculated pfd at the Earth's surface is based on the free-space propagation conditions. The received downlink E_b/N_0 at the FSS receiver, can be shown as:

$$\left(\frac{E_b}{N_0+I_0}\right)_{\downarrow} = pfd + 10\log\left(\frac{sps}{bps}\right) + 20\log(D) + 10\log(\eta) - (N_0+I_0) - 61.05 - L_{atm/scin} - L_p - EOC - M_{fade} - M_{system}$$

where:

- $L_{atm/scin}$: atmospheric loss and scintillation loss. In this band, the atmospheric and scintillation loss are about 1.2 dB
- L_p: depending on antenna size (dB)
- EOC: edge of coverage, typically 3.5 dB
- M_{fade}: required rain fade margin to achieve its link availability (dB)
- M_{system}: system margin (2 dB is allocated to system margin).

From the above expressions the receive earth terminal antenna size in metres can be shown as:

$$D = 10^{\left(\frac{1}{20}\right)\left(\left(\frac{E_b}{N_0+I_0}\right)_{\downarrow} - pfd - 10\log\left(\frac{sps}{bps}\right) - 10\log(\eta) + (N_0+I_0) + 61.05 + L_{atm/scin} + L_p + EOC + M_{fade} + M_{system}\right)}$$

2.1 Downlink $E_b/(N_0 + I_0)$

The required receive $E_b/(N_0 + I_0)$ depends on the modulation (QPSK, 8-PSK, 16-QAM, etc.), BER, coding and implementation loss. Most of the proposed systems in these bands plan to use QPSK modulation and to provide a BER of the order of 1×10^{-7} to 1×10^{-9}. The required $E_b/(N_0 + I_0)$, including the implementation loss, is in the range from 7 dB to 9 dB depending on the coding. If the higher modulations such as 8-PSK, 16-QAM, etc. are used, the required $E_b/(N_0 + I_0)$ is significantly higher. In this study, both QPSK and 8-PSK modulations are used.

The required downlink $E_b/(N_0 + I_0)$ depends on whether the satellite payload functions as an on-board processor (OBP) or a transparent transponder (bent-pipe (BP)). In the case of an OBP, the downlink $E_b/(N_0 + I_0)$ is the same as the required $E_b/(N_0 + I_0)$ to achieve its BER. When the satellite payload functions as a transparent transponder, the downlink $E_b/(N_0 + I_0)$ can be computed as:

$$\left(\frac{E_b}{N_0+I_0}\right)_{\downarrow} = -10\log\left(10^{\left((-0.1)\frac{E_b}{N_0+I_0}\right)_{required}} - 10^{\left((-0.1)\frac{E_b}{N_0+I_0}\right)_{\uparrow}}\right)$$

In this study, the downlink $E_b/(N_0 + I_0)$ is assumed to be equal to uplink $E_b/(N_0 + I_0)$. Therefore the downlink $E_b/(N_0 + I_0)$ is 3 dB higher than the required receive $E_b/(N_0 + I_0)$.

2.2 Thermal noise density, N_0 and interference noise density, I_0

Thermal noise density, N_0, can be shown as:

$$N_0 = -228.6 + 10 \log(T_{rx} + T_{rain}) \qquad \text{dB(W/Hz)}$$

where:

T_{rx}: earth station receive system noise temperature (K). Typical ground antenna system temperature is 800 K (antenna noise temperature = 70 K, Receiver noise figure = 4.5 dB, filter/diplexer = 0.7 dB and cable loss = 0.3 dB)

T_{rain} can be computed as:

$$T_{rain} = 280\,(1 - 10^{-0.1\,(rain\ fade\ margin)})$$

For example, if the rain fade margin is 18 dB, the noise temperature increase due to rain is 275 K.

Interference noise density, I_0: Calculated interference noise density should include intra- and inter-system noise density. In this study, 1.5 dB is allocated to the intra-system interference. Calculated inter-system interference from other FSS systems operating in the same frequency band depends on the earth station antenna roll-off and the downlink pfd from other FSS systems. In this study, all FSS systems are assumed to operate at the same pfd and the geostationary-satellite orbit (GSO) is assumed to be populated at 4° intervals. For example, if all GSO FSS systems operate at a downlink pfd of –105 dB (W/(m^2 · MHz)), the received interference noise density of 1 m earth terminal operating in the 40 GHz band is –203.44 dB(W/Hz).

2.3 Required rain fade margin

As mentioned above, most proposed systems plan to provide 99.7% link availability to the very small aperture terminal (VSAT) users and provide higher link availability to gateway-to-gateway or hub-to-hub users. The required rain fade margin is shown in Fig. 1. In the calculation, 99.7% link availability and a 25° elevation angle are assumed. Figure 2 shows the link availability of FSS systems operating in the 40 GHz band with an 18 dB rain fade margin.

Figure 2 shows that the 18 dB rain fade margin will not achieve the 99.7% link availability for most locations around world. In addition, the systems that plan to provide service at elevation angles less than 25° must use mitigation techniques, such as variable data rates, site diversity, frequency diversity, heavy coding, etc. to achieve the desired link availability.

FIGURE 1

Required rain fade margin
(Frequency band = 40 GHz; elevation angle = 25°; link availability = 99.7%)

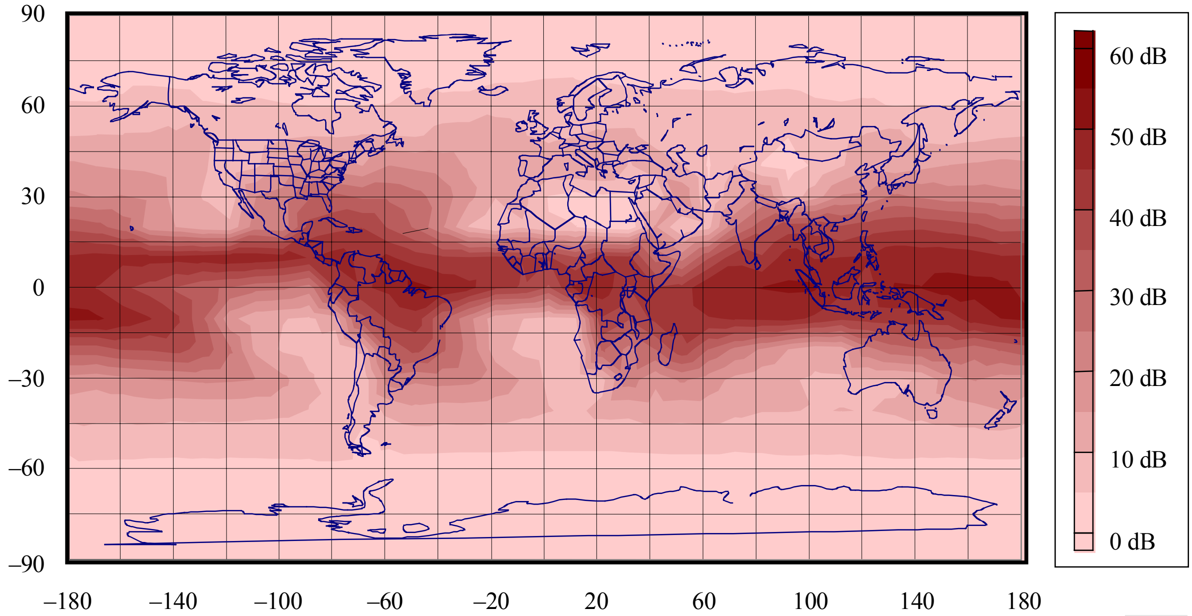

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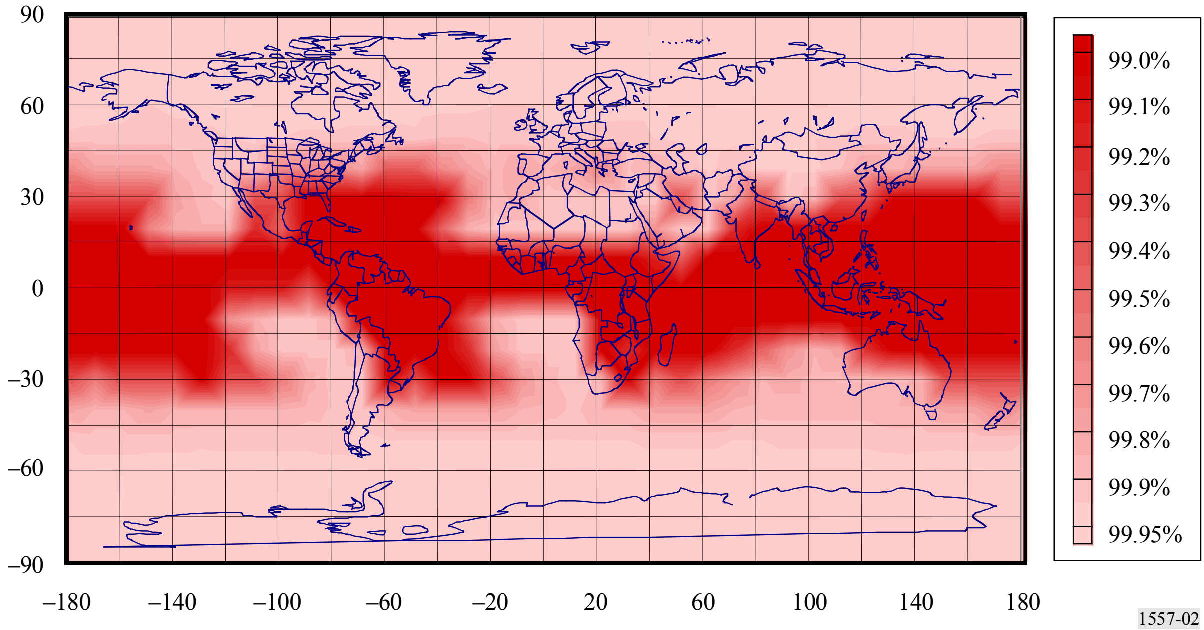
FIGURE 2

Link availability
(Frequency band = 40 GHz; elevation angle = 25°; rain fade margin = 18 dB)



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2.4 Pointing loss

The off-axis antenna pointing loss (dB) for an idea uniformly-illuminated circular aperture can be derived from physical optics:

$$Loss = 10 \log \left(\frac{2 J_1(x)}{x} \right)^2$$

where:

$$x = \frac{\pi\, f\, D}{c} \sin(\varphi)$$

and

f: frequency

D: antenna diameter

c: speed of light

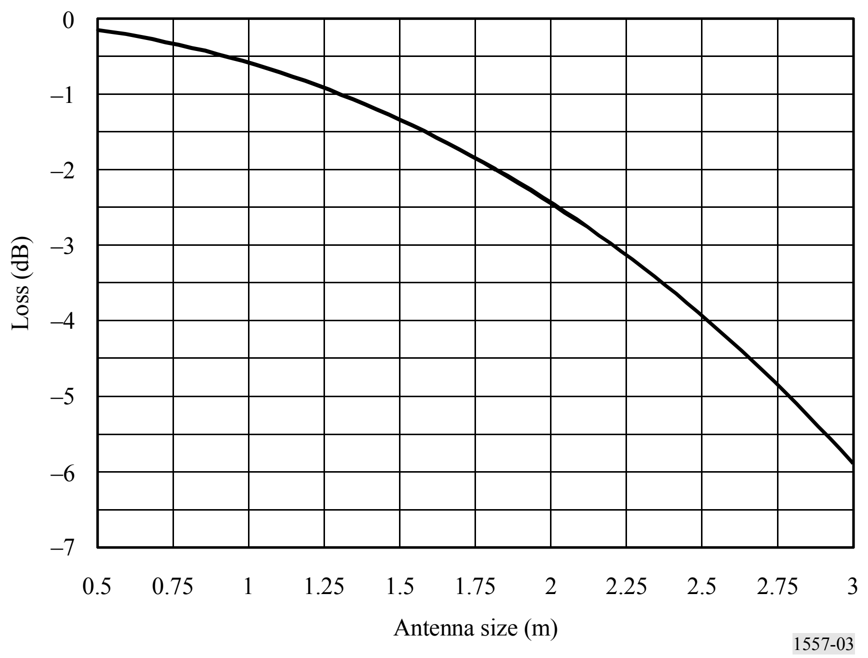
φ: off-axis angle

$J_1(x)$: first order of Bessell function.

For an off-axis angle of 0.1° the pointing loss versus earth terminal antenna size is shown in Fig. 3. In this study, 0.7 dB is allocated to earth terminal antenna pointing loss.

FIGURE 3

Antenna pointing loss vs. antenna size (off-axis angle = 0.1°)



2.5 Results

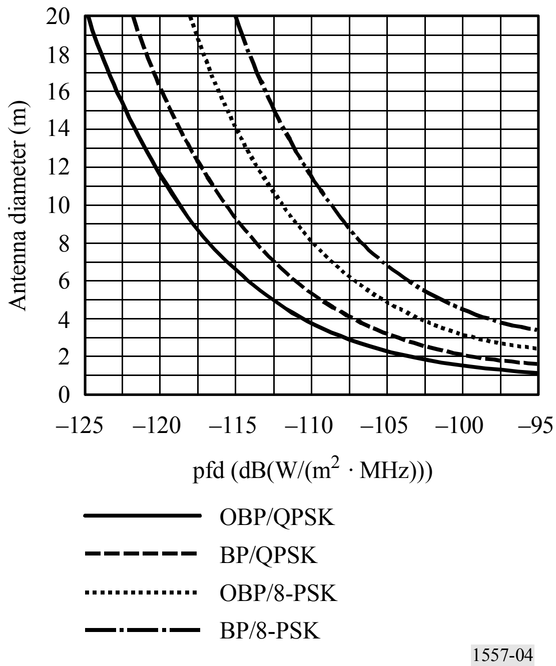
Figure 4 shows the required earth terminal antenna size versus the downlink pfd level. The calculation is based on the following assumptions:

– Rain fade margin = 18 dB
– Earth terminal receive noise temperature = 800 K
– Pointing loss = 0.7 dB
– Atmospheric and scintillation loss = 1.2 dB
– Degradation due to self-interference = 1.5 dB
– EOC = 3.5 dB
– Antenna efficiency = 70%
– Frequency = 40 GHz
– System margin = 2 dB

– Required E_b/N_0:
  - OBP:
    - QPSK = 7.0 dB
    - 8-PSK = 10.5 dB
  - BP (transparent transponder):
    - QPSK = 10.0 dB
    - 8-PSK = 13.5 dB.

FIGURE 4

Earth terminal antenna size vs. downlink pfd levels



3 Discussion of results

Most proposed FSS systems operating in the 40/50 GHz bands use OBP for VSAT users, and use a transparent transponder or BP for gateway-to-gateway or hub-to-hub users. The typical antenna diameter of VSAT users is in a range from 0.5 m to 1 m, and the antenna diameter of gateway-to-gateway or hub-to-hub users is in a range from 1 m to 3 m. Most proposed FSS systems in the 40/50 GHz do not plan to use earth terminal antennas bigger than 3 m because the complexity of an auto track antenna capable of minimizing pointing loss in these frequency bands is very high.

Figure 4 shows that for a QPSK system a downlink pfd level of –95 dB(W/($m^2 \cdot$ MHz)) will allow the use of a 1 m user terminal VSAT operating in this band. The 3 m gateway-to-gateway antenna size may close the link with a pfd level of –105 dB(W/($m^2 \cdot$ MHz)). If the smaller antenna size is used, the pfd must be greater than –95 dB(W/($m^2 \cdot$ MHz)) for VSAT and –105 dB(W/($m^2 \cdot$ MHz)) for gateway users. However, required downlink pfd levels can be different depending on the rain region. Furthermore, if higher modulations, such as 8-PSK, 16-QAM are used, the required downlink pfd levels will be significantly increased.

4 Summary

This Annex shows that, for the example system described, in order to allow 3 m gateway-to-gateway or hub-to-hub users to operate in the 40/50 GHz band, the downlink pfd level must be greater than or equal to –105 dB (W/(m^2 · MHz)). This Annex also show that the downlink pfd level must be greater than or equal to –95 dB (W/(m^2 · MHz)) in order to operate a 1 m VSAT in the same band. Even with these levels, it is shown that even with an 18 dB rain fade margin, the FSS systems still would not be able to achieve their desired 99.7% link availability for all locations around the world. However, required downlink pfd levels can be different, depending on the rain region. Finally, a system that plans to operate at higher-order modulations and/or low elevation angles and/or smaller antennas, would need to either operate at higher pfd levels or use mitigation techniques, such as site diversity or frequency diversity, in order to achieve its link availability.

ANNEX 2

Examination of Table 21-4 of the Radio Regulations (RR) pfd values required for the GSO satellites in the FSS to operate viable downlinks into gateway earth stations in the 37.5-40 GHz and 42-42.5 GHz frequency bands

1 Introduction

This study examines the constraints imposed by both downlink pfd and the effect of elevation angle of the receiving gateway FSS earth station in the 37.5-40 GHz and the 42-42.5 GHz bands. FSS downlinks, all meeting the pfd limits from RR Table 21-4, having various forms of modulation and coding characteristics are examined by calculating link availabilities on GSO FSS downlinks to gateway earth stations ranging from 1.8 to 3 m in diameter over a range of elevation angles over a range of rain rates. Furthermore, it is noted that further studies are required to determine, in accordance with *invites ITU-R* 7 of Resolution 84 (WRC-2000), the conditions under which the pfd limits will provide acceptable levels of protection to the fixed service.

2 GSO FSS system parameter assumptions

It is anticipated that GSO FSS systems using the 37.5-40 GHz and 42-42.5 GHz frequency bands would have basic system parameters within the range of the minimum and maximum values of the parameters listed in Table 1.

TABLE 1

GSO FSS system parameters and assumptions used in analysis

System parameter	Parameter value and units			
Elevation angle to GSO spacecraft (degrees)	17.5	20.0	22.5	25.0
Spacecraft antenna spot-beam size (degrees)	0.3	0.4	0.5	0.5
Power flux spectral density at centre of beam (dB(W/(m^2 · MHz)))	−111.5	−109	−107	−105.5
Transponder configuration	Transparent BP or remodulating OBP			
Data rates	Various			
Modulation, forward error correction (FEC)	QPSK, rate 5/6 with Reed-Solomon (RS) (BP) or 8-PSK rate 2/3 with 188,204 RS OBP			
Demodulator *C*/*N* performance threshold	7.1 dB (QPSK, rate 5/6, 188,204 RS) 9.3 dB (8-PSK, rate 2/3, 188,204 RS)			
User-to-gateway link – BER performance and minimum availability due to fading on the space-to-Earth path (desirable/marginal)	Quasi-error-free (corresponding to BER $\leq 2 \times 10^{-4}$ before RS decoding) better than 99.95/99.90% of the time			
Receive earth station diameter (parabolic main reflector assumed) (m)	1.8; 2; 2.4 and 3(1)			
Antenna efficiency (%)	64			
Feed losses (dB)	2.5			
Assumed off-axis antenna pattern (for the purpose of estimation of adjacent satellite interference)	$32 - 25 \log \varphi$ $(2° < \varphi < 8°)$			
Antenna tracking accuracy (degrees)	± 0.05			
Link noise contribution(2)	Actual relative contribution depends on a number of factors such as receive antenna size and whether the link or transparent or remodulating. C/I_{Link} = 20 dB (transparent) C/I_{Link} = 30 dB (remodulating)			
Uplink noise contribution	$C/(N+I)_{Total}$ = 20 dB (transparent) $C/(N+I)_{Total} \rightarrow \infty$ (remodulating)			
System noise temperature (elevation angle dependent)	460 K (typical at 25° elevation) with 3 dB noise figure LNA/LNB			

LNA: low noise amplifier.

LNB: low noise block.

(1) See § 4.1.

(2) The link noise includes cross-polarization, adjacent channel and intermodulation product contributions.

The geostationary space station in the FSS was assumed to have an antenna pattern conforming with the following:

Gain (dB) relative to main beam:

$$-12\,(\varphi/\varphi_0)^2 \qquad \text{for } 0 \leq (\varphi/\varphi_0) \leq 1.45$$

$$-(22 + 20\log(\varphi/\varphi_0)) \qquad \text{for } 1.45 < (\varphi/\varphi_0) < 4.5$$

where:

φ: off-axis angle (degrees)

φ_0: half-power beamwidth (degrees).

2.1 Link budget assumptions

The following common assumptions were used in all link calculations in the case of both transparent transponder satellites as well as remodulating transponder satellites:

– The gateway earth station is assumed to be located at the edge of the satellite spot beam which is 2 dB down from the centre-of-beam.

– The same downlink frequency is used by a total of four other beams on the satellite have the same polarization. There is sufficient geographic isolation between each beam such that the *C*/*I* due to each co-frequency/co-polarized beam is 30 dB and the aggregate is 24 dB.

– All links beams on the satellite are circularly polarized.

– The terrestrial interference allocation assumes that the contribution from the terrestrial interference is just sufficient to reduce the system margin such that the link availability is impaired to the extent that the unavailability in the presence of terrestrial interference is 10% greater than the unavailability would be if there were no terrestrial interference.

– In the rain faded condition, on the slant path from the satellite, only the *C*/*N* thermal is affected. In the faded condition, the *C*/*N* thermal is reduced by the sum of:

  – the rain fade A_p (dB) as determined by Recommendation ITU-R P.618, and

  – the degradation to the thermal noise during a rain fade of A_p.

In the case of the link noise allocations, C/I_{Link}, the transparent transponder and the remodulating transponder cases were treated differently. In the transparent transponder case, it was assumed that the received carrier was one of many in a frequency division multiple access (FDMA) transponder. To model this situation, a downlink link noise allocation of 20 dB *C*/*I* was assumed given that intermodulation products would dominate the downlink. Also, assuming that small user antennas would be transmitting with just sufficient clear-sky margin to facilitate the use of uplink power control, the total uplink *C*/*I* would not likely be much better than 20 dB. In the remodulating transponder case, it was assumed that the satellite was transmitting toward the gateway earth stations using a single carrier-per-transponder. To model this situation, a downlink link noise allocation of 30 dB *C*/*I* was assumed. Given that in the case of remodulating transponders, the uplink does not contribute to the C/N_{Total} a large value (100 dB) was assigned to the total uplink *C*/*I* to represent this situation.

3 Pfd limit mask used in analysis

The pfd mask used as the basis for limiting the maximum pfd achievable with a spot beam from GSO toward a point on the Earth's surface for intended reception by a gateway earth station. A spot beam was positioned toward a point from which the angle of arrival of that satellite to the point was assumed to be a minimum value within the intended service area and thus forming an EOC scenario. The RR Table 21-4 pfd limit mask is repeated in Table 2. Although no analysis was conducted using the RR Table 21-4 pfd limits applicable to the 40.5-42.0 GHz band, given that the over the elevation angle range considered in the analysis, the pfd limits in RR Table 21-4 are very similar and thus similar performance is expected for a given size earth station having a given elevation angle at a given location.

TABLE 2

Pfd limit masks considered in analysis

RR Table 21-4 pfd mask for 37.5-40 GHz and 42-42.5 GHz bands	
Spectral pfd (dB(W/(m² · MHz)))	**Angle of arrival δ above the horizontal plane**
−127	0 ≤ δ ≤ 5°
−127 + (4/3) (δ − 5)	5° ≤ δ ≤ 20°
−107 + (2/5) (δ − 20)	20° ≤ δ ≤ 25°
−105	25° ≤ δ

In all cases the earth station was assumed to be at 45° latitude and the rain model used in calculating the availability was that of Recommendation ITU-R P.618. Other common elements to the groups of links are listed below:

Frequency: 38.75 GHz

Latitude: 45° N

Earth station height: 0 m above mean sea-level

Barometric pressure: 1018.9 hPa

0° mean isotherm under rainy conditions (h_R): 2.45 km (consistent with geographic locations in North America and West of 60° E in Europe as per Recommendation ITU-R P.839).

Noise figure of LNA/LNB on earth station antenna: 3.0 dB

Atmospheric absorption: Recommendation ITU-R P.676 was used. Given that the water vapour density can take a wide range of possible values at 45° N latitude, it was assumed that regions having wetter climates (i.e. higher rain rates) would have higher water vapour concentrations. In addition, higher temperatures are necessary to support higher water vapour densities. As the purpose of this analysis is to demonstrate the effect of varying atmospheric parameters (and other parameters) on link availability, the following values were chosen:

Air temperature, water vapour density (rain rate exceeded for 0.01% of the time):

Dry climate: 15° C, 5 g/m^3 (for $R_{0.01}$ = 25 mm/h)

Medium climate: 18° C, 7.5 g/m^3 (for $R_{0.01}$ = 37.5 mm/h)

Wet climate: 21° C, 10 g/m^3 (for $R_{0.01}$ = 50 mm/h)

3.1 Pfd mask used

In all the cases studied, the RR Table 21-4 pfd limits were used. The pfd levels are produced from spot beams ranging in size from 0.3° to 0.5° (55 to 50.5 dBi in gain respectively). These spot-beam sizes are typical of some of the higher gain beams of 50/40 GHz GSO FSS systems which are being contemplated for use and for which RR Appendix 4 data has been filed with the ITU. Figure 11 shows the pfd levels emitted from a space station using spot beams of 0.3°, 0.4°, 0.5° and 0.6° in size positioned at angles of arrival of 17.5°, 20°, 22.5° and 25° respectively. It should be noted that the lower the elevation angle of the spot beam to a gateway antenna, the smaller the size that the spot beam needs to be in order to meet the RR Table 21-4 pfd limit at low angles of arrival.

Given the constraints imposed by the RR Table 21-4 pfd mask, link budgets were calculated for downlinks to gateway antennas ranging from 1.8 to 3.0 m for elevation angles of 25° down to 17.5° in 2.5° steps for each of the three different climatic parameter set. The calculated availability results for the 25 mm/h, 37.5 mm/h and 50 mm/h cases are plotted in Figs. 5, 6 and 7 respectively for all four antenna sizes for the transparent transponder case. Similarly, the results for the remodulating transponder case have been plotted in Figs. 8, 9 and 10. Note that for Figs. 5, 6 and 7, the modulation is QPSK, and for Figs. 8, 9 and 10 the modulation is 8-PSK.

FIGURE 5

Transparent transponder, rain rate = 25 mm/h

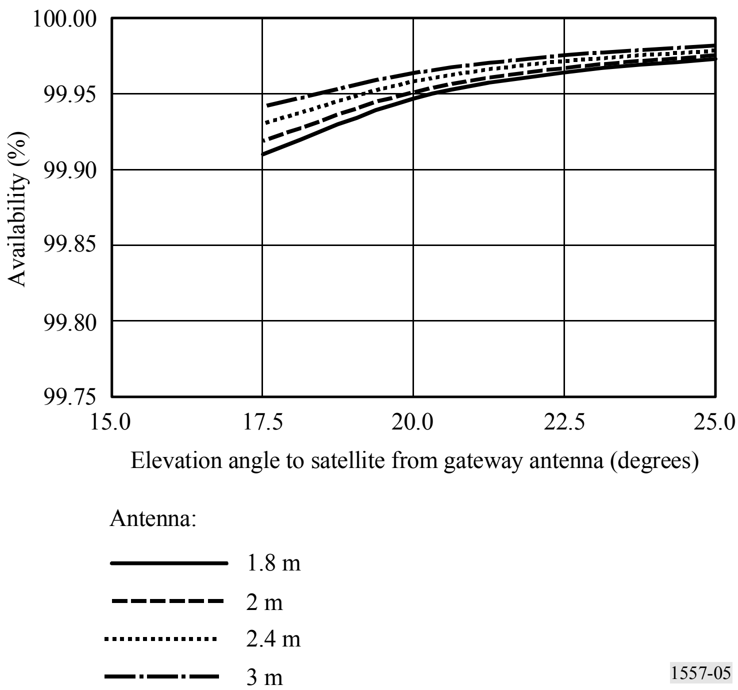


FIGURE 6

Transparent transponder, rain rate = 37.5 mm/h

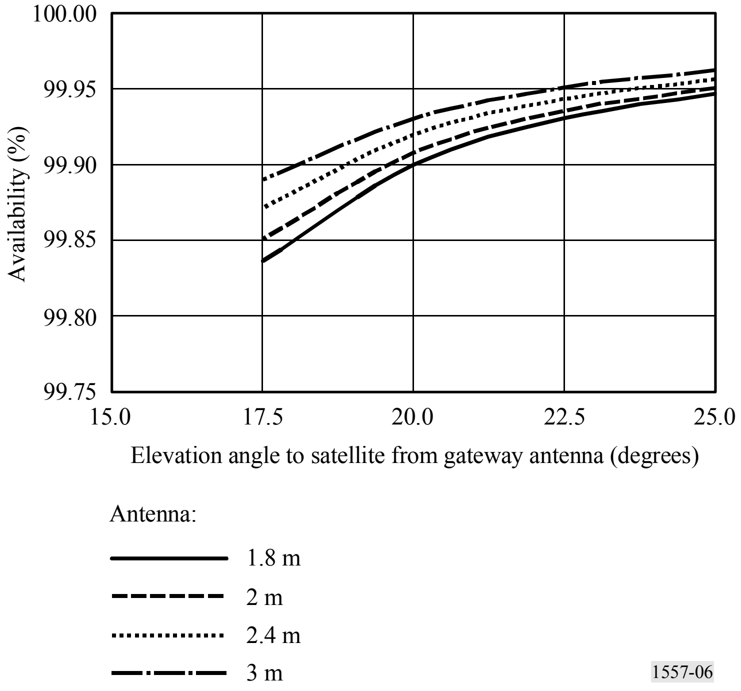


FIGURE 7

Transparent transponder, rain rate = 50 mm/h

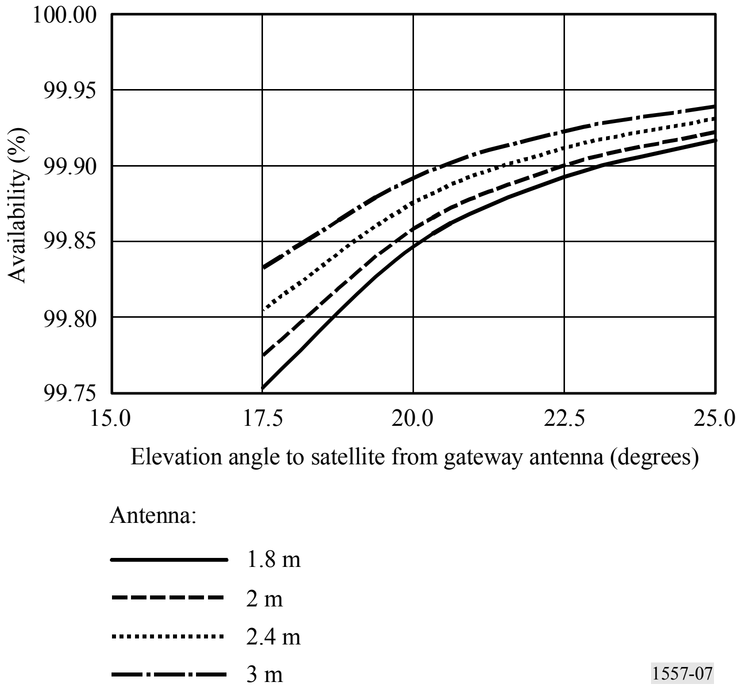


FIGURE 8

Remodulating, rain rate = 25 mm/h

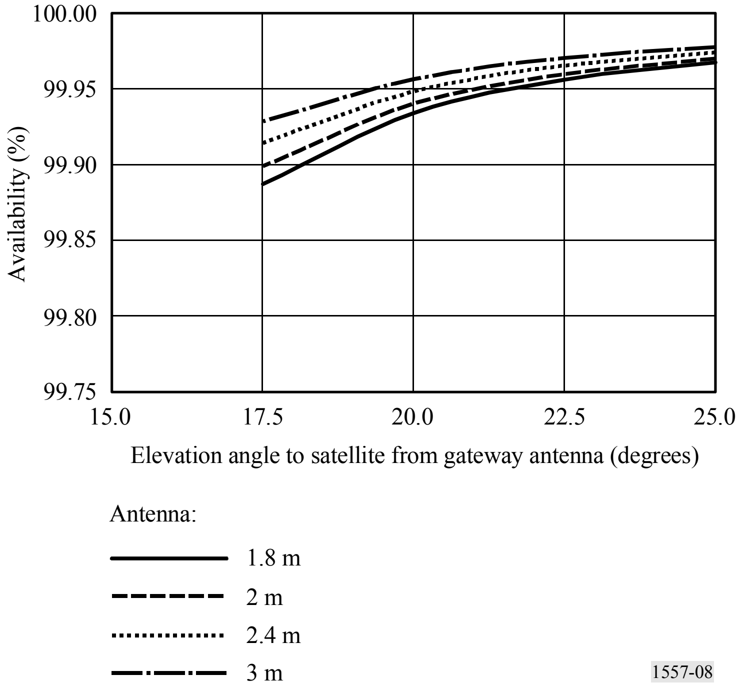


FIGURE 9

Remodulating, rain rate = 37.5 mm/h

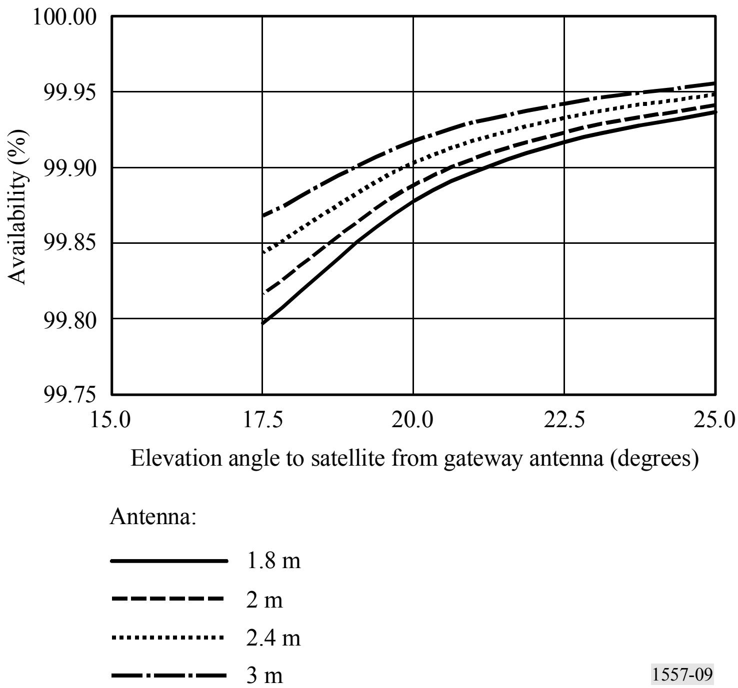


FIGURE 10

Remodulating, rain rate = 50 mm/h

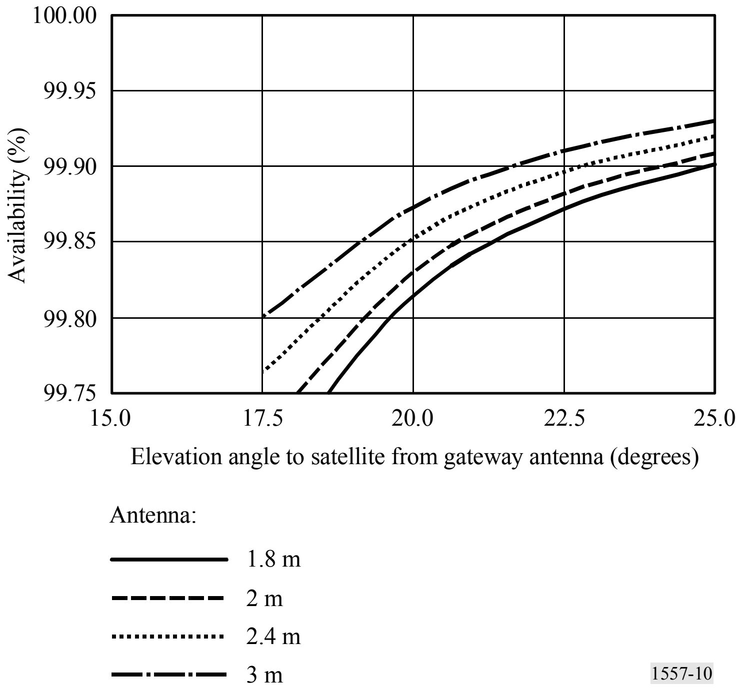
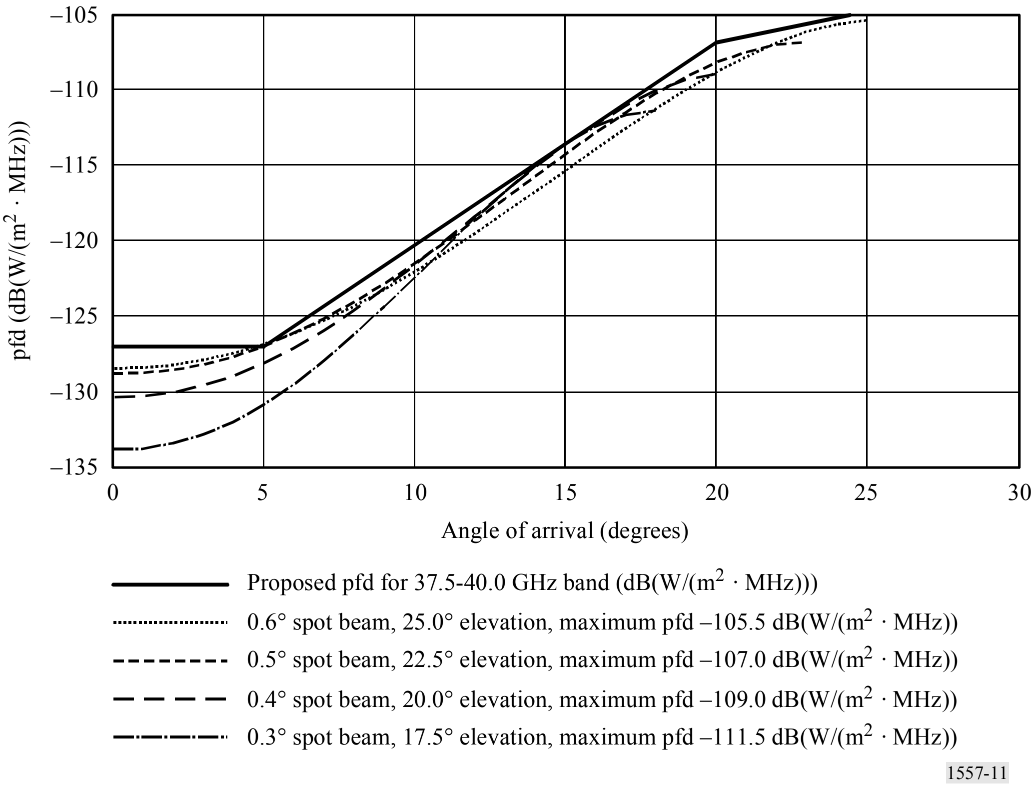


FIGURE 11

GSO FSS downlink beam sizes and associated maximum pfd levels meeting proposed pfd limit in the 37.5-40.0 GHz band



4 Areas requiring further technical studies

4.1 Earth station antenna size in the 50/40 GHz frequency band

The feasibility of using larger antennas (i.e. $D > 2.4$ m where $D/\lambda >> 300$) at frequencies above 30 GHz requires further study on the effects of main reflector distortion, surface roughness and the precision of a step-tracking system on antenna performance. An increase in antenna gain to improve the clear-sky C/N will be partially offset by the increase in earth station antenna pointing error implementing the typical 0.05° tracking precision.

The feasibility of using what is a very large antenna at these frequencies remains to be studied. At a receive frequency of 39 GHz, a 3.7 m diameter antenna, for example, would have a diameter-to-wavelength ratio of 481. Furthermore, assuming the antenna would be transmitting at 49 GHz, the 3 dB beamwidth of this antenna would be 0.11° and the diameter-to-wavelength ratio would be 605.

4.2 Requirement for a radome and potential impact on clear weather performance

Due to the rain droplet size in the 50/40 GHz frequency bands being greater than 1/4 of a wavelength, rain scattering losses will be significant. The use of hydrophobic reflector coatings would eliminate the need for radomes and thus offer better clear-weather performance. The attenuation of the wanted signal under clear-sky conditions resulting from use of a radome at these frequencies is unknown. The link budgets presented assume that no radome is used.

5 Discussion of results

Tables 3-8 summarize and compare the conditions under which varying levels of downlink performance can be achieved. Tables 3, 4 and 5 correspond to Figs. 5, 6 and 7 and Tables 6, 7 and 8 correspond to Figs. 8, 9 and 10. The following guide below can be used to obtain a coarse comparison of the downlink availabilities that are possible over the range of antenna size, elevation angle and climatic parameters examined for each of the transparent transponder (Tables 3-5) and the remodulating transponder (Tables 6-8) cases.

Guide for interpretation of results

Quality of received signal according to downlink availability

0: Availability < 99.90% (unacceptable)

1: 99.90% ≤ Availability < 99.925% (marginal)

2: 99.925% ≤ Availability < 99.95% (fair)

3: 99.95% ≤ Availability < 99.975% (acceptable)

4: Availability > 99.975% (exceeds objective).

TABLE 3

BP transponders (QPSK, Rate 5/6, 188,204 RS (rain rate = 25 mm/h))

Elevation angle (degrees) \ Gateway receiving antenna diameter (m)	1.8	2	2.4	3
17.5	1	1	2	2
20	2	3	3	3
22.5	2	3	3	4
25	3	3	4	4

TABLE 4

BP transponders (QPSK, Rate 5/6, 188,204 RS (rain rate = 37.5 mm/h))

Elevation angle (degrees) \ Gateway receiving antenna diameter (m)	1.8	2	2.4	3
17.5	0	0	0	0
20	0	1	1	2
22.5	2	2	2	3
25	2	3	3	3

TABLE 5

BP transponders (QPSK, Rate 5/6, 188,204 RS (rain rate = 50 mm/h))

Elevation angle (degrees) \ Gateway receiving antenna diameter (m)	1.8	2	2.4	3
17.5	0	0	0	0
20	0	0	0	0
22.5	0	1	1	1
25	1	1	2	2

TABLE 6

Remodulating transponders (8-PSK, Rate 2/3, 188,204 RS (rain rate = 25 mm/h))

Elevation angle (degrees) \ Gateway receiving antenna diameter (m)	1.8	2	2.4	3
17.5	0	0	1	2
20	2	2	2	3
22.5	3	3	3	3
25	3	3	3	4

TABLE 7

Remodulating transponders (8-PSK, Rate 2/3, 188,204 RS (rain rate = 37.5 mm/h))

Elevation angle (degrees) \ Gateway receiving antenna diameter (m)	1.8	2	2.4	3
17.5	0	0	0	0
20	0	0	1	1
22.5	1	1	2	2
25	2	2	2	3

TABLE 8

Remodulating transponders (8-PSK, Rate 2/3, 188,204 RS (rain rate = 50 mm/h))

Elevation angle (degrees) \ Gateway receiving antenna diameter (m)	1.8	2	2.4	3
17.5	0	0	0	0
20	0	0	0	0
22.5	0	0	0	1
25	1	1	1	2

5.1 Interpretation of summary results

Using the RR Table 21-4 pfd mask, it is possible to achieve downlink availabilities of the order of 99.95% for elevation angles as low as 20° using antenna sizes ranging from 1.8 m to 3 m. The size of antenna required to achieve acceptable performance is dependent upon the climatic zone and the elevation angle. Marginally acceptable availability is possible on downlinks having elevation angles as low as 17.5° in dryer climatic zones only when larger antennas are used. Acceptable performance will only be possible using a 1.8 m antenna in drier climates and when associated with higher elevation angles. The feasibility of using of FSS earth station antennas larger than 2.4 m in the 50/40 GHz bands requires further study (see § 4.1).

Comparing the results from the transparent transponder satellites with those for the remodulating transponder satellites, it is evident that achieved performance for satellites using remodulating transponders is less sensitive to antenna size. This is due to the fact that there is a lower contribution from other link noise. In the case of remodulating transponders, however, there is an increased sensitivity to the rain rate due to the higher demodulator threshold (9.3 dB compared with 7.1 dB) associated with the higher order modulation scheme employed by the satellite network using remodulating transponders. There is a noticeable reduction in signal quality as the rain rate increases.

Overall, marginal to acceptable levels of performance should be attainable using antennas ranging in size from 2 m to 2.4 m in climatic zones having rain rates of less than 37.5 mm/h.

ANNEX 3

Technical characteristics of GSO V1 FSS system

The GSO V1 system plans to use the 37.5-40.0 GHz and 42.0-42.5 GHz bands for a small number of individually-coordinated gateway applications at geographically dispersed hubs of FAP. The GSO V1 system will provide the end-to-end link availability of at least 99.9% to the gateway or hub links. Depending on the Hub/FAP locations, the receive antenna diameter may be as large as 3 m. The system plans to provide data rates ranging from video-conferencing quality through very high speed transmission of STM-1 (155 Mbit/s) to 10 STM-4 (6.22 Gbit/s). The propagation impairments in this band are very severe. In order to achieve the desired link availability while not exceeding the pfd levels specified in RR Table 21-4 and in *resolves* 2 of Resolution 84 (WRC-2000), an adjustable data rate, modulation and coding will be used in the GSO V1 system. The severity of the propagation impairments, together with the fixed service protection requirements in the 37.5-40 GHz and 42-42.5 GHz bands, will affect the ability to implement FSS systems with all of the parameters that would otherwise be ideal.

The GSO V1 system plans to use the band 40.0-42.0 GHz for deploying ubiquitous VSATs. The end-to-end availability of the user VSAT link is at least 99.7%. The antenna diameter of user VSAT users is in the range from 0.5 m to 1.0 m. The receive data rate is in the range from STM-1 (155 Mbit/s) to 4 × STM-1 (4 × 155 Mbit/s) depending of the user location, antenna size and link availability. The BER of these links in clear-air is of the order of 1×10^{-7} to 1×10^{-10}.

The downlink system parameters of the proposed GSO V1 FSS system operating in the 37.5-42.5 GHz band are given in Tables 9 and 10.

TABLE 9

Downlink parameters of the GSO V1 system operating in the 37.5-40.0 GHz and 42.0-42.5 GHz (downlink)

Paramètre	Hub	
	Nominal operating condition	Using downlink fade compensation techniques
Frequency (GHz)	37.5-40 et 42-42.5	
Payload	Transparent transponder	
Link availability (%)	End-to-end up to 99.9	
Data rate(1)	$N \times$ 622 Mbit/s; N = 1 to 10 Up to 6.22 Gbit/s (single carrier)	$N \times$ 155 Mbit/s; N = 1 to 10 Up to 1.55 Gbit/s (single carrier)
Access method	FDMA/TDM or TDM	
Modulation	8-PSK	Offset QPSK (OQPSK)
Coding	RS	Concatenated code
Code rate	0.90	0.45
Channel bandwidth	250 MHz for each 622 Mbit/s; 2.5 GHz for 10 × 622 Mbit/s 2.5 GHz for 1 × 6.22 Gbit/s	250 MHz for each 155 Mbit/s; 2.5 GHz for 10 × 155 Mbit/s 2.5 GHz for 1 × 1.55 Gbit/s
Receive antenna gain (dBi)	58.57	
Antenna beamwidth (degrees)	0.19	
Polarization	Circular	
Receive noise temperature (K)	800	
Interference degradation/allocation (dB)(2)	1.5	
Other losses (dB)(3)	2.0	
System margin (dB)	1.0	
BER	1×10^{-9} or better	
Required receive E_b/N_0 (dB)(4)	9.37	4.88
Required downlink E_b/N_0 (dB)(5)	12.37	7.88

TDM: time division multiplexing

(1) N is selected based on propagation condition, or adjust the transmit data rate to achieve the desired link availability.

(2) Degradation due to intra-system and inter-system interference.

(3) Including pointing loss, atmospheric loss, scintillation loss.

(4) Including implementation loss.

(5) Uplink C/N (or E_b/N_0) is assumed to be equal to downlink C/N (or E_b/N_0). Therefore, the downlink E_b/N_0 must be 3 dB higher than the required E_b/N_0.

TABLE 10

Downlink parameters of the GSO V1 system operating in the 40.0-42.0 GHz band

Parameters	FSS system parameters operating in the 40.0-42.0 GHz band			
	Transparent transponder		Processing payload	
Modulation	8-PSK	OQPSK	8-PSK	OQPSK
Frequency (GHz)	41		41	
Edge of coverage (dB)	3.5		3.5	
Link availability (%)(1)	99.7 or higher		99.7 or higher	
Data rate (Mbit/s)(2)	Up to 622	Up to 465	Up to 622	Up to 465
Access method	TDM		TDM	
Coding/code rate(3)	Concatenated code/adjustable code rate			
Channel bandwidth	250 MHz for 622 Mbit/s	250 MHz for 155 Mbit/s	250 MHz for 622 Mbit/s	250 MHz for 155 Mbit/s
Antenna diameter (m)(4)	0.5		0.5	
Receive antenna gain (dBi)	45		45	
3 dB beamwidth (degrees)	0.98		0.98	
Polarization	Circular		Circular	
Receive noise temperature (K)	800		800	
Other loss (dB)(5)	2.0		2.0	
Interference degradation (dB)(6)	2.0		2.0	
System margin (dB)	1.0		1.0	
BER	1×10^{-10}		1×10^{-10}	
Required E_b/N_0 (dB)(7)	9.36	7.0	9.36	7.0
Required downlink E_b/N_0 (dB)(8)	12.36	10.0	9.36	7.0

(1) Depending on user's location.

(2) Depending on user's location, rain rate.

(3) Depending on the required rain fade margin.

(4) The actual antenna size depends on the user location, the required data rate and link availability.

(5) Degradation due to intra-system and inter-system interference.

(6) Including pointing loss, atmospheric loss, scintillation loss.

(7) Including implementation loss.

(8) Uplink C/N (or E_b/N_0) is assumed to be equal to the downlink C/N (or E_b/N_0). Therefore, the required downlink E_b/N_0 must be 3 dB greater than the required E_b/N_0.

ANNEX 4

User terminal: technical characteristics of MULTIMEDIASAT GSO FSS system

In the 37.5-42.5 GHz band, the MULTIMEDIASAT system plans to deploy ubiquitous VSATs to provide various types of applications (video-on-demand, IP access, data broadcasting, …). The end-to-end availability of the user (VSAT) link is at least 98%. The antenna diameter of VSAT users is either 0.3 m or 0.6 m. The receive data rate is in either 25.4 Mbit/s, taking into account the impact of propagation impairments, or 38.1 Mbit/s in clear-sky conditions. The adaptability of these bits rate to transmission conditions enables some data to remain constant under nearly all rain conditions: thus, the BER of these links is 1×10^{-10}, the channel bandwidth is also constant and the E_b/N_0 is kept at 7.0 dB. The minimum operational elevation angle taken into account for this system is 25°.

TABLE 11

Downlink parameters of the MULTIMEDIASAT system operating in the 37.5-42.5 GHz band

Parameters	Hub station			
	Nominal operating condition		**Rainy conditions**	
Frequency (GHz)	37.5-42.5			
Payload	Transparent transponder			
Link availability (%)	End-to-end up to 98			
Data rate (Mbit/s)	38.1		25.4	
Access method	FDMA/TDM or TDM			
Modulation	8-PSK		4-PSK	
Coding	RS and FEC			
Codes rates	(204,188) for RS code and 1/2 for FEC one			
Channel bandwidth (MHz)	36			
Antenna diameter (m)	0.3	0.6	0.3	0.6
Receive antenna gain (dBi)	40	46	40	46
Antenna beamwidth (degrees)	1.65	0.82	1.65	0.82
Polarization	Linear (horizontal and vertical)			
Receive noise temperature (K)	350			
Inter- and intra-system degradation (dB)	4.1	5.2	2.3	4.3
Other losses (dB)(1)	2.0			
System margin (dB)	1.0	1.7	1.0	4.0
BER	1×10^{-10}			
Required E_b/N_0 (dB)(2)	7.0			

(1) Including pointing loss, atmospheric loss, scintillation loss.

(2) The E_b/N_0 value takes into account the equivalent isotropically radiated power (e.i.r.p.) variations during the day.

It should be noted that the operational pfd levels are compliant with RR Table 21-4, and that possible use of lower pfd limits (e.g. reduced by 12 dB) would make the system unusable in all kinds of conditions.

ANNEX 5

User terminal: technical characteristics of high-density GSO FSS system

The system parameters of a GSO FSS system dedicated to high-density satellite services are presented in Table 12. This system is designed to provide a regional service area including Europe, the Middle East and North Africa. In the design the service area is covered by geostationary satellite with a multibeam antenna (72 spot beams) with a beamwidth of 0.65° for each spot beam. Link budgets were calculated for a forward link and the user terminal location was chosen in two different sites in Europe (West France for case 1 and South Italy for case 2). Results are presented in Table 13. The system is designed taking into account the pfd limitations included in RR Table 21-4 in the band 37.5-42.5 GHz for geostationary satellites.

TABLE 12

System parameters (GSO, user terminal)

Orbit	Geostationary
Altitude (km)	35 785.8
Coverage	Regional coverage including Europe, Middle East and North Africa
Number of beams	72 per satellite
Beam size (degrees)	0.65 diameter
Uplink frequency (GHz)	47.2 to 50.2
Downlink frequency (GHz)	37.5 to 42.5
Inter-satellite link (yes or no)	No
Payload	On-board processing
Service availability (%)	99.50
Useful data rate (Mbit/s)	2 × 55 per beam
Satellite capacity	72 × 2 × 55 MHz = 7.92 Gbit/s
Forward link access method	TDM carriers
Return link access method	MF-TDMA
Modulation	QPSK
Coding	Turbo coding
Channel bandwidth (MHz)	60
Number of active transponders	144
TWTA saturated power (W)	120
Transmit antenna gain (maximum) (dBi)	48.8
Satellite e.i.r.p. at saturation (dBW)	61 at the edge of the beam
User terminal receive antenna gain at 41 GHz	50.4 dBi for 1 m diameter (edge of coverage) 44.4 dBi for 0.5 m diameter (centre of coverage)
Antenna receive 3 dB beamwidth at 41 GHz	0.48° for 1 m diameter 0.95° for 0.5 m diameter
Polarization	Linear
User terminal receive noise temperature (K)	532 in clear sky
BER	1×10^{-9}
Required downlink $E_b/(N_0 + I_0)$ (dB)	4.5

TWTA: travelling wave tube amplifier

TABLE 13

Link budget parameters (GSO, user terminal 0.5 m), availability 99.5%

		Case 1 West France	**Case 2 South Italy**
	Clear sky	**With rain**	**With rain**
Downlink frequency (GHz)	41.0	41.0	41.0
Satellite e.i.r.p. (dBW)	68.0	68.0	68.0
Spatial dispersal (dB/m^2)	162.6	162.6	162.6
Information bit rate (Mbit/s)	55.0	36.0	20.0
Modulation ratio (QPSK)	2	2	2
Coding rate	3/4	3/4	3/4
Transmission rate (Msymbols)	40.7	26.7	14.8
pfd (dB(W/m^2))	–96.6	–106.2	–108.6
Spectral pfd on earth station (dB(W/(m^2 · MHz)))	–112.7	–120.5	–120.3
Maximum spectral pfd (dB(W/(m^2 · MHz)))	–110.7	–108.9	–106.3
E_b/N_0 (dB)	16.2	7.8	7.9
E_b/I_0 (dB)	14.3	14.3	14.3
$E_b/(N_0 + I_0)$ (dB)	11.1	5.9	6.0
Modem implementation margin (dB)	0.8	0.8	0.8
Required E_b/N_0 (dB)	4.5	4.5	4.5
Margin (dB)	5.8	0.6	0.7
Noise spectral pfd (dB(W/(m^2 · MHz)))	–121.9	–114.8	–112.3
Total spectral pfd (dB(W/(m^2 · MHz)))	–110.4	–107.9	–105.4

ANNEX 6

Gateway: technical characteristics of non-GSO FSS system

The system is a medium Earth orbit (MEO) equatorial constellation that provides to the backhaul gateways a quasi-permanent 155 Mbit/s trunking connection between one beam to another anywhere on the Earth through high data rate inter-satellite link (ISL) ring and with broadcast capability. Each satellite can provide to five independent spot beams focused on the major worldwide urban areas. The parameter of the proposed non-GSO FSS system operating in the downlink in the 37.5-42.5 GHz band are given in Table 14.

TABLE 14

System parameters (non-GSO, gateway = 3 m)

	Clear sky
Orbit	MEO (equatorial)
Altitude (km)	12 000
Coverage (degrees)	±56
Number of satellites	7
Number of beams	35 (5 per satellite)
Frequency (GHz)(1)	37.5-42.5
ISL	Yes
Payload	Transparent transponder
Service availability (%)	99.95
Data rate (Mbit/s)(2)	$N \times 155$ per beam ($N = 1$ to 6)
Satellite capacity (without ISL) (Gbit/s)(2)	4.65
Access method	FDMA
Modulation	QPSK
Coding	3/4 Convolutional and RS
Channel bandwidth (MHz)	160
Number of transponder (except ISL)(2)	15 (active)
TWTA saturated power (W)	100
Transmit antenna gain (maximum) (dB)	44.9
e.i.r.p. (dBW)	61.2
Receive antenna gain	47.5 dB at 49 GHz and 45.6 dB at 38 GHz
Antenna receive 3 dB beamwidth	0.476° at 49 GHz
Polarization	Linear
Receive noise temperature (K)	700
System margin (dB)(3)	0.5
BER	1×10^{-9}
Required end-to-end E_b/N_0 (dB)	5
Required downlink E_b/N_0 (dB)(4)	8

(1) Uplink: 42.5-43.5 GHz and 47.2-50.2 GHz.

(2) Data based on 1.1 GHz in Tx and 1.1 GHz in Rx.

(3) 0.6 dB if raining condition.

(4) Uplink C/N (or E_b/N_0) is assumed to be equal to downlink C/N (or E_b/N_0). Therefore, the downlink E_b/N_0 must be 3 dB higher than the required end-to-end E_b/N_0.