International Telecommunication Union

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Radiocommunication Sector of ITU

Recommendation ITU-R BO.1659-1

(01/2012)

Mitigation techniques for rain attenuation for broadcasting-satellite service systems in frequency bands between 17.3 GHz and 42.5 GHz

BO Series

Satellite delivery

International Telecommunication Union

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Note*: This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

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RECOMMENDATION ITU-R BO.1659-1

Mitigation techniques for rain attenuation for broadcasting-satellite service systems in frequency bands between 17.3 GHz and 42.5 GHz

(2003-2012)

Scope

This Recommendation provides techniques to mitigate rain attenuation that should be considered in order to facilitate the introduction of BSS systems in frequency bands between 17.3 GHz and 42.5 GHz. Such techniques include increase in e.i.r.p., hierarchical transmission and broadcasting system assuming storage in receiver.

The ITU Radiocommunication Assembly,

considering

a) that BSS systems using frequency bands from 17.3 GHz onwards have the possibility to deliver wide-RF-band digital multiprogramme services, which may consist of high-definition television (HDTV), audio and data programmes, possibly including interactivity;

b) that, in the future, they can also be the appropriate channels to accommodate the higher bit-rate programmes, such as extremely high resolution imagery whose number of lines is much larger than HDTV, three-dimensional TV and high bit-rate data programmes;

c) that the frequency allocations were made to the BSS by the World Administrative Radio Conference (Geneva, 1979) (WARC-79) in the 42 GHz and 84 GHz band, World Administrative Radio Conference for Dealing with Frequency Allocations in Certain Parts of the Spectrum (Malaga-Torremolinos, 1992) (WARC-92) allocated the band 17.3-17.8 GHz in Region 2 and the band 21.4-22.0 GHz in Regions 1 and 3 to BSS to be implemented after 1 April 2007, and the frequency allocation modification to the BSS from the 84 GHz band to the 74 GHz band was made by the World Radiocommunication Conference (Istanbul, 2000) (WRC-2000);

d) that the atmospheric absorption and rain attenuation in the BSS bands from 17.3 GHz onwards are much larger than those in the 12 GHz band which is widely used for BSS;

e) that the propagation attenuation may place a heavy restriction on service availability and/or system feasibility;

f) that Report ITU-R BO.2007 describes technical information to introduce BSS into the 17/21 GHz band with reference to Resolution 525 (WARC-92). In the Annexes to this Report, detailed information is given such as:

– possible coding and modulation approaches to improve service availability for digital HDTV satellite broadcasting;
– an adaptive satellite e.i.r.p. control method for the 21 GHz band satellite broadcasting;
– bandwidth efficient coding and modulation schemes for wideband HDTV applications supported by satellite and cable networks,

recommends

1 that the use of one of the following techniques to mitigate the rain attenuation or a combination of these techniques should be considered to facilitate the introduction of the BSS systems in frequency bands between 17.3 GHz and 42.5 GHz:

– increase in e.i.r.p. (see Annex 1);

– hierarchical transmission (see Annex 2);

– broadcasting system assuming storage in receiver (see Annex 3).

NOTE 1 – Supplementary information related to the rain attenuation in the BSS bands between 17.3 GHz and 42.5 GHz and some prospective feeder-link bands between 17.3 GHz and 30 GHz is found in Appendix 1.

Annex 1

Increase in e.i.r.p.

1 Concept of variable e.i.r.p. satellite

Adaptive power control is an effective and straightforward method to enhance the service availability under rain fade, while it reduces interference to the other services in the clear-sky condition.

The BSS system normally has a large service area covered by a single beam. The variable e.i.r.p. systems are categorized as to whether the e.i.r.p. can be locally-variable within the service area or not.

1.1 Uniformly-variable e.i.r.p.

In the system, total output power of the beam is controlled, while the antenna pattern is left unchanged. The e.i.r.p. in the service area varies uniformly.

Typically, strong rains occur locally. To compensate for local rain attenuation, the e.i.r.p. is increased for the whole coverage area. Apart from areas with strong rain, the rest of the service area in clear-sky conditions can be overcompensated. It is undesirable from the viewpoint of sharing with the other systems. In this respect, the adaptive power control of such single beam systems is less effective than those of multibeam systems.

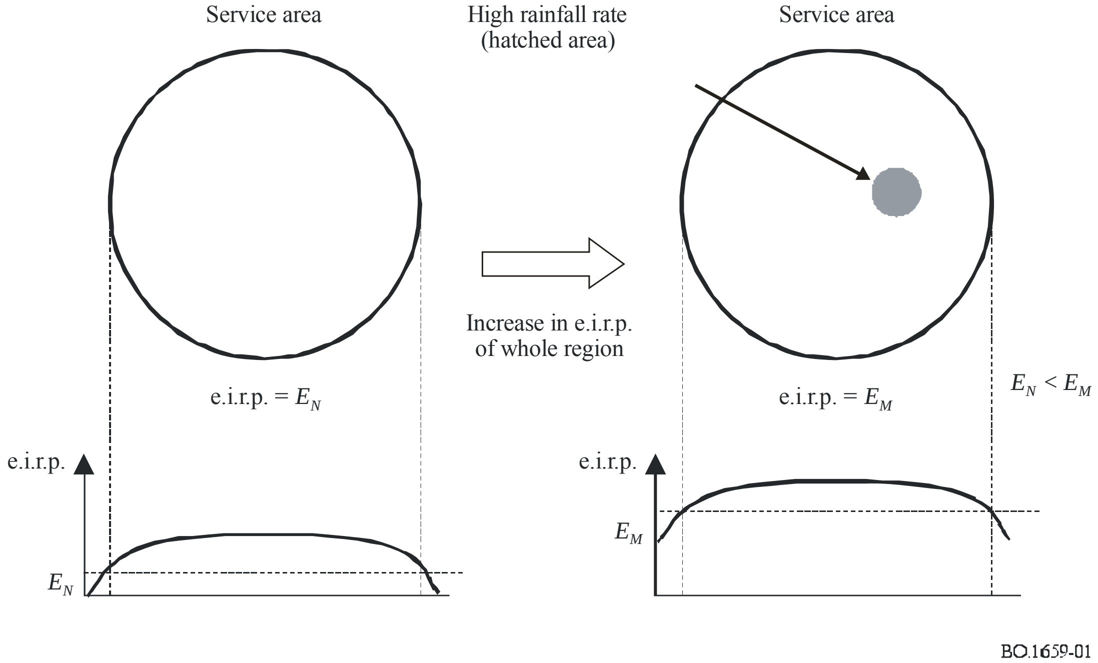
The total required radiation power is high and the increase in radiation power is frequent since the single beam covers the whole region. The concept of the system is shown in Fig. 1. The following parameters are used for the definition of the system:

– e.i.r.p. value E_N with nominal condition in the service area;

– e.i.r.p. value E_M with maximum e.i.r.p. increase in the service area. The e.i.r.p. values in certain areas vary, ranging from E_N to E_M.

FIGURE 1

Concept of uniformly variable e.i.r.p.



Alternatively, the following parameters can be used to define the system from the viewpoint of satellite design:

– nominal power supplied to the input of the antenna;

– maximum power supplied to the input of the antenna;

– gain contour of the antenna.

1.2 Locally-variable e.i.r.p.

The locally-variable e.i.r.p. system varies the distribution of the satellite e.i.r.p. of a beam within the service area locally, in accordance with the local distribution of rain attenuation. Total required radiation power of the satellite is to be reduced compared with a uniformly-variable e.i.r.p. system with the same service availability, because the probability of simultaneous occurrence of strong rain in a large portion of the service area is considered to be substantially low. Therefore a more stringent level of the spurious emission limitation is applied.

While a high e.i.r.p. may be required to compensate for large rain attenuation, the area and the duration of the boost are limited. Since the e.i.r.p. can be lowered for the area and duration with low rain attenuation, it has an advantage over satellite systems with a fixed or uniformly-variable e.i.r.p. in terms of sharing with other systems.

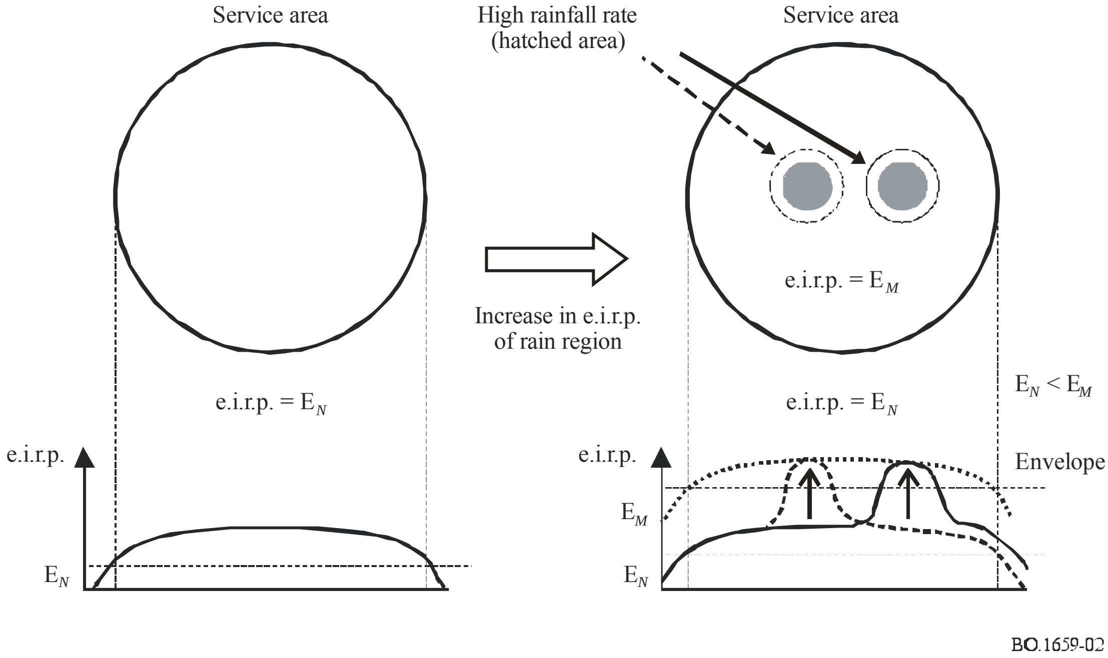
The concept of the system is shown in Fig. 2. The following parameters are used for the definition of the system:

– e.i.r.p. value E_N for the area with nominal condition (E_N);

– e.i.r.p. value E_M for the local area with maximum e.i.r.p. increase (E_M).

FIGURE 2

Concept of locally-variable e.i.r.p.



Alternatively, the following parameters can be used to define the system from the viewpoint of satellite design:

– nominal power supplied to the input of the antenna;

– nominal antenna gain contour;

– maximum power supplied to the input of the antenna;

– examples of antenna gain contour with local increase;

– envelope of maximum antenna gain with the results of all possible movement of intensified e.i.r.p.

2 Satellite technologies

2.1 Satellite technologies for uniformly-variable e.i.r.p.

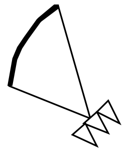
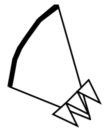
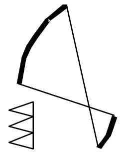
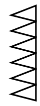
The system may be realized with a combination of a reflector antenna with a horn feeder and a variable-power high power amplifier (HPA). The HPA with considerably higher power will be employed to increase e.i.r.p. in the whole service area. The impact of the power control on the efficiency of the HPA needs to be studied.

2.2 Satellite technologies for locally-variable e.i.r.p.

The satellite antenna configurations shown in Table 1 can be used to realize the function.

TABLE 1

Antenna configurations for locally-variable e.i.r.p. systems

Antenna type	Multi-horn	Phased-array		
		Single reflector	Double reflector	Direct radiation
Schematic diagram				
Range of pattern synthesis	Fixed beam location	Limited beam steering angle	Greater than single reflector	Greatest
Peak gain	High	Lower than double reflector	Lower than multi-horn	High
Gain decrease with beam-steering	Large	Smaller than multi-horn	Smaller than single reflector	Small
Number of element	Small	Medium	Medium	Large
Complexity of structure	Simple	Medium	Complex (sub-reflector)	Complex (feed circuit)

2.2.1 Multi-horn antenna

In the antenna, multiple feed horns are placed at the focal plane of the reflector. Each horn corresponds to one of the beams generated by the antenna. When each beam radiates in phase, the beams form a single shaped beam. By controlling the power provided to the individual horns, a locally-variable e.i.r.p. system can be realized.

The range of power control is limited to the range of the corresponding HPA's output power. The impact of the power control on the efficiency of the HPA needs to be studied. Since the locations of the beams are fixed, the range of possible pattern syntheses is less than those of phased-array antennas.

2.2.2 Phased-array antennas

Compared with the multi-horn antenna, a greater range of pattern syntheses can be obtained using phased-array antennas. The direct-radiation phased-array antenna would show best performance in terms of the range of possible pattern syntheses. On the other hand, the complexity of the configuration may reduce the applicability to the on-board system.

In contrast to the multi-horn antenna, a large number of the radiation elements contribute to the power control of a small area. The minimum diameter of the intensified area is determined by the aperture diameter of the antenna. The performance and feasibility of each configuration should be examined further.

2.2.3 Case study on antenna pattern synthesis with local increase

An example of antenna synthesis is given to explain the feasibility of a locally-variable e.i.r.p. satellite. Its parameters are shown below:

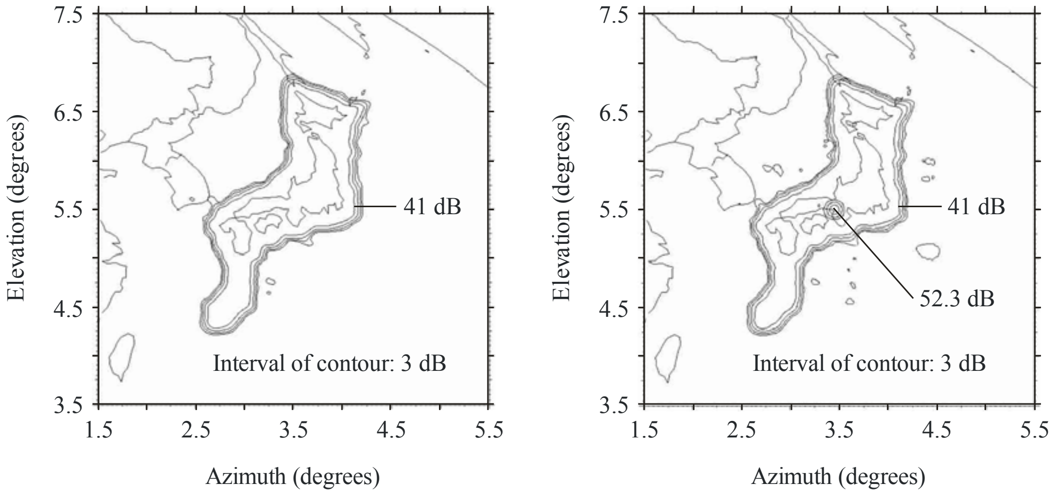
– Antenna configuration: array-fed single reflector antenna
– Aperture diameter of antenna: 10 m
– Frequency: 21.7 GHz
– Number of radiators: 227

– Interval of radiators: 1.5 wavelengths.

The calculated antenna gain contours are shown in Fig. 3. The left-hand Figure shows a radiation pattern under nominal conditions. Taking advantage of the large aperture antenna and the phased-array technique, a radiation pattern with a large gain plateau is obtained. The right-hand Figure is an example of the radiation pattern with a local gain increase. The peak gain increases by more than 10 dB from the nominal value. As a result of the local increase, gains in the remaining area slightly decrease.

FIGURE 3

Example of pattern synthesis (simulation)



a) Nominal gain contour b) Gain contour with local increase

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Antenna parameters such as the diameter and the number of radiators should be determined by taking into consideration the system parameters such as size and shape of the service area, minimum and maximum area to be compensated and required increase level as well as the feasibility of on-board equipment and the cost.

2.3 HPA technologies

Travelling wave tubes (TWTs) and solid state power amplifiers (SSPAs) can be used for the HPA of the satellites. In the 17/21 GHz band, the overall efficiency of a conventional TWT with an output power around 100 W exceeds 60%. On the other hand, the output power and efficiency of SSPAs are lower than those of TWTs. To use TWTs as amplifiers for an active array antenna of locally-variable e.i.r.p. satellites, mini-TWTs, whose cross-sectional dimensions are reduced compared with the conventional one, have been studied. A comparison is shown in Table 2.

TABLE 2

Examples of HPAs for the 17/21 GHz band satellite systems

HPA type	SSPA (including power supply)	TWT	
		Conventional TWT	Mini-TWT
Output power (W)	6	120	10
Efficiency (%)	<10	62	50
Size (mm)	326 × 327 × 36	85 × 63 × 325	15 × 20 × 300
Weight (kg)	4.6	0.9	0.3

Annex 2

Hierarchical transmission

1 Concept of hierarchical transmission

Two or more modulation schemes of different *C*/*N* requirements are time-multiplexed to form a hierarchical transmission signal. The fundamental information, such as minimum quality video signal and audio, is transmitted at a low data-rate by using a robust modulation/channel coding scheme with a low *C*/*N* requirement. On the other hand, the high data-rate signal part, such as for HDTV or 5.1-channel surround sound, is transmitted by using a higher efficiency modulation scheme with a higher *C*/*N* requirement. The receiver chooses the appropriate data stream depending on the actual receiving *C*/*N* condition. Therefore, a hierarchical transmission can be used to realize a stepwise degradation in the digital system that degrade the picture quality gradually in accordance with the decrease in the receiving *C*/*N*.

In the BSS bands from 17.3 GHz onwards, the rain attenuation is considerably higher than that in the 12 GHz band. By applying hierarchical transmission, service interruptions due to rain attenuation can be reduced. Detailed information of the hierarchical transmission is found in Annex 1 to Report ITU-R BO.2007.

The hierarchical transmission scheme can be integrated with the other techniques. For example, the different types of service such as non-real-time broadcasting assuming storage reception described in Annex 3 and ordinary real-time broadcasting, can be transmitted simultaneously using the hierarchical transmission scheme. In this scheme, multi-level modulation signals of BPSK, QPSK, and 8-PSK can be time-multiplexed.

The hierarchical transmission scheme can also be integrated with scalable video coding (SVC) technology. SVC technology generates a scalable video elementary stream with the base and enhancement layers. The scalably encoded video data are processed by a variable coding and modulation (VCM) scheme. In VCM, low-quality data (base layer) can be delivered using a more robust modulation scheme than high-quality data (enhancement layer). Therefore, in a clear-sky condition, both base and enhancement layers can be received and this enables provision of HD services. On the contrary, in a rain-faded condition, only the base layer can be received for low-quality video services.

2 Example of hierarchical transmission

2.1 Hierarchical transmission based on a modulation scheme

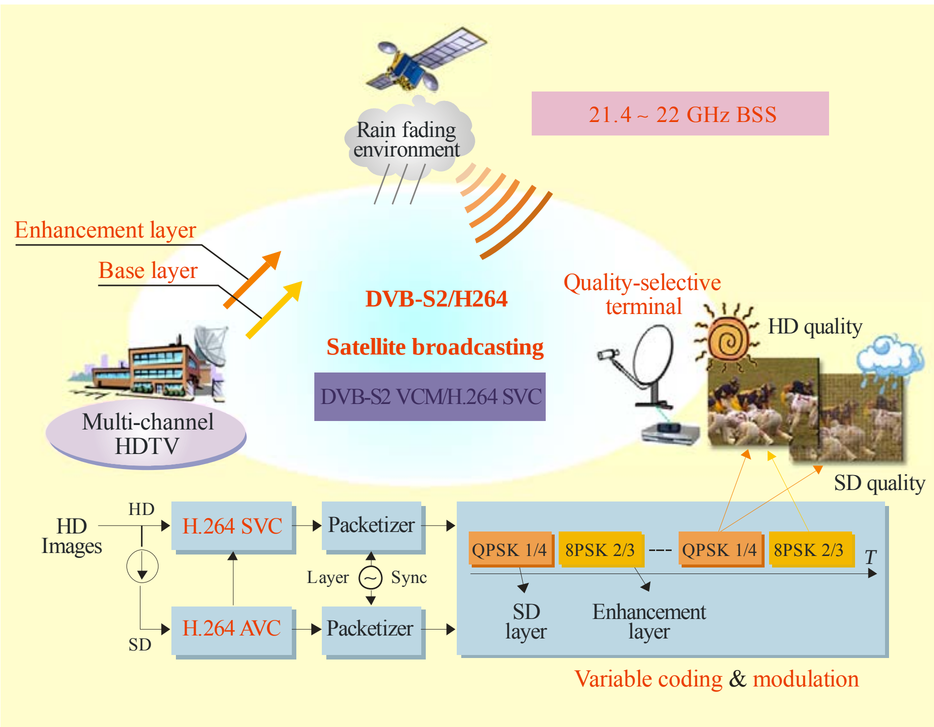
An example of hierarchical transmission is found in Recommendation ITU-R BO.1516 – Digital multiprogramme television systems for use by satellites operating in the 11/12 GHz frequency range. In system D, more than one transmitting signal modulated in BPSK, QPSK and trellis coded 8-PSK (TC8-PSK) can be time-multiplexed. In this system, an 8.2 dB difference in required *C*/*N* between BPSK 1/2 and TC8-PSK is considered to be the maximum gain of the hierarchical transmission.

2.2 Hierarchical transmission based on scalable video coding technology

Figure 4 shows the concept of hierarchical satellite HD broadcasting services provided using the 21 GHz frequency band. Scalably encoded video data are transmitted by VCM. For example, low-quality data is modulated by QPSK, while high-quality data is modulated by 8-PSK. Consequently, the link availability can be improved. This quality-selective service can be achieved by layering at both media source level and transmission level.

FIGURE 4

Hierarchical broadcasting based on SVC technology



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Annex 3

Broadcasting system assuming storage in receiver

1 Concept of non-real-time broadcasting system assuming storage in receiver

In accordance with the increase in capacity and the reduction in price of storage devices such as hard disks, receivers with storage devices have started to appear on the market. Several studies have been undertaken to look at the advantage of storage functions for broadcasting services.

Statistically speaking, rain heavy enough to cause signal interruption occurs only for a short time during a day. Utilizing the characteristics, it is possible to transmit programmes in advance and store them in the receiver to avoid service interruptions during the presentation.

Assuming the storage reception, a long transmission delay is inevitable. The delay depends on the scheme to be adopted and the ability to overcome signal interruptions. Real-time programmes, such as live news programmes, may not be suitable for storage in the receiver systems.

Further study on the service availability of non-real-time broadcasting is needed.

2 Example methods

2.1 Repetitive transmission

An example of BSS transmission schemes utilizing storage to improve service availability is repetitive transmission, in which programmes are transmitted repeatedly to deliver intact data to the storage and thereby avoid the consequences of link disruptions due to rain attenuation.

Since it is possible to obtain a high C/N in a clear-sky condition, the reduction in efficiency due to the repetitive transmission can be compensated by using high frequency-use efficiency modulations such as 16-QAM. System parameters, such as the appropriate number of repetitions, interval and modulation scheme, are left for future study.

2.2 Long block-length data interleaving

Interleaving over very-long intervals can be used to overcome interruption in the receiving signal that might occur for a relatively short time within the interval.

The programme data is spread (i.e. interleaved) over a long transmission interval on the transmission side. The receiver first stores the transmitted signal in the storage, and then uses it to reconstruct (i.e. de-interleave) the original programme. Even if a part of the transmitted data is lost due to rain attenuation, the programme data can be reconstructed by using an error-correction code, since the lost continuous data is dispersed by the de-interleaving in the receiver.

System parameters, such as the appropriate interleave length and modulation scheme are left for future study.

2.2.1 Example for a long block-length data interleaving system

A simulation of long block-length data interleaving was carried out using measured rain attenuation data collected over a one-year period to show the validity of the scheme. A schematic diagram of the simulation is shown in Fig. 5. The right-hand side of the diagram is the conventional digital BSS system with the error correction done by outer-code 1 and inner-code. The left-hand side of the diagram is an additional block of long block-length data interleaving which consists of mass storage and an associated error correction coder and decoder (outer-code 2). The assumed simulation parameters are as follows:

– Receiving location: Tokyo (climate zone K)
– Rain attenuation data used: measured from May 2000 to April 2001 in the 12 GHz band converted to data in the 21 GHz band by means of a frequency scaling formula in Recommendation ITU-R P.618
– Modulation: TC8-PSK
– Satellite pfd: –114.0 dB(W/(m^2 · MHz)).

The performance of the long block-length data interleaving was evaluated from the increase in e.i.r.p., which is defined as the e.i.r.p. of the conventional BSS system without long block-length data interleaving with the same service availability achieved by simulation block with long block-length data interleaving.

The increase in e.i.r.p. as a function of interleaving period is shown in Fig. 6, where the error correction capability of outer-code 2 is set at 20% or 40%. e.i.r.p. increases with the interleaving period, as it would with increasing storage capacity and transmission delay. The larger the error correction capability of outer-code 2 is, the more e.i.r.p. increases with sacrificing transmission information rate. For example, taking 20% as the error correction capability, increasing the interleaving period from one hour to 12 or 24 h is equivalent to increases in e.i.r.p. of 2.4 or 6.2 dB, respectively.

FIGURE 5

Schematic diagram of simulation

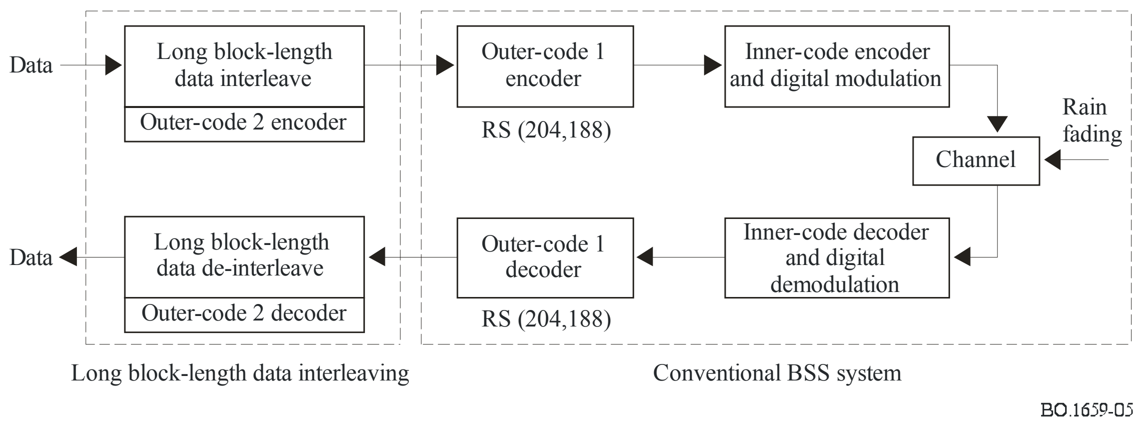
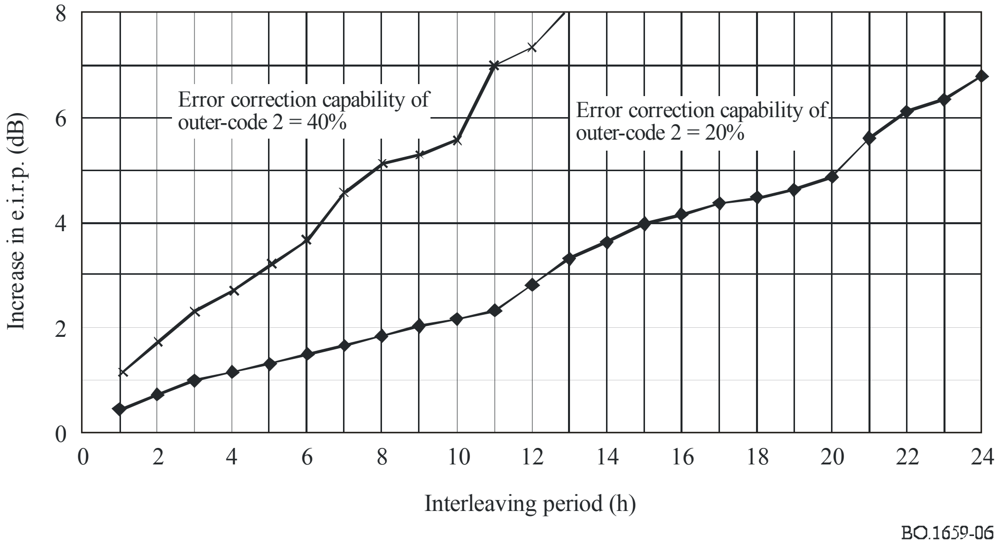


FIGURE 6

Example of long block-length data interleaving performance in terms of the increase in equivalent pfd (simulation)



This simulation is based on data taken over one year at a specific location. Different effects would be observed if the data were for a different location, different satellite pfd or with a longer term. The parameters should be carefully chosen depending on the system requirement.

Appendix 1
to Annex 3

Rain attenuation and absorption due to atmospheric gases in BSS bands between 17.3 GHz and 42.5 GHz and some associated feeder links

1 Introduction

A significant characteristic of the BSS bands between 17.3 GHz and 42.5 GHz is the larger propagation loss in comparison to the 12 GHz band. The elevation angle is a critical factor for both the rain attenuation and the atmospheric absorption in these high frequency bands. Appropriate mitigation techniques may be chosen depending on the propagation loss to be overcome. In this Appendix, a preliminary comparison of the propagation loss is shown in terms of the frequency and the location of the earth stations.

The cities mentioned in the Tables of Appendix 1 to Annex 3 of this Recommendation are selected only as examples.

2 Parameters for the calculation

The following Recommendations are used in the calculation:

– Altitude of receiving station: Recommendation ITU-R P.1511 (database)
– Annual mean surface temperature: Recommendation ITU-R P.1510 (database)
– Surface water vapour density (1% of year): Recommendation ITU-R P.836 (database)
– Atmospheric gaseous attenuation model: Recommendation ITU-R P.676
– Cloud attenuation: Recommendation ITU-R P.840
– Rainfall rate model: Recommendation ITU-R P.837 (database)
– Specific attenuation: Recommendation ITU-R P.838
– Rain height model: Recommendation ITU-R P.839 (database)
– Rain attenuation model: Recommendation ITU-R P.618
– The orbital position of the satellite: Assumed to coincide with those in the 12 GHz BSS Plans for Regions 1, 2 and 3 (see Appendix 30 of the Radio Regulations).

3 Rain attenuation and gaseous absorption in BSS downlink bands

Comparison of rain attenuation and gaseous absorption in the bands with those in the 12 GHz band was carried out for several cities in Regions 1, 2 and 3.

Atmospheric water vapour and oxygen cause absorption, and water vapour density is not constant over the year. In this study, the values exceeded for 1% of the year extracted from the ITU database were used to estimate gaseous absorption.

As shown in Tables 3 and 4, the gaseous absorption at 21.7 GHz is ranging from 1.2 to 2.0 dB compared with about 0.2 dB at 12.0 GHz. The rain attenuation at 21.7 GHz is approximately four times as large as those at 12.0 GHz, in decibels.

TABLE 3

Atmospheric gaseous absorption and rain attenuation in some cities in Region 1

		Moscow		**London**		**Paris**		**Istanbul**	
Longitude/latitude (degrees)		37.6 E/55.8 N		0.1 E/51.5 N		2.3 E/48.9 N		29.0 E/41.0 N	
Satellite orbital position (degrees)		36.0 E		33.5 W		7.0 W		42.0 E	
Elevation angle (degrees)		26.5		23.2		33.2		40.7	
$R_{0.01}$ (mm/h)		31.7		30.8		34.0		38.8	
	Annual time percentage	12.0 GHz	21.7 GHz	12.0 GHz	21.7 GHz	12.0 GHz	21.7 GHz	12.0 GHz	21.7 GHz
Atmospheric absorption	–	0.2 dB	2.0 dB	0.2 dB	2.0 dB	0.2 dB	1.6 dB	0.1 dB	1. 5 dB
Rain attenuation	0.3%	1.0 dB	3.4 dB	1.0 dB	3.4 dB	0.9 dB	3.1 dB	1.0 dB	3.5 dB
	0.1%	1.9 dB	6.4 dB	1.9 dB	6.3 dB	1.7 dB	5.8 dB	1.9 dB	6.5 dB

TABLE 4

Atmospheric gaseous absorption and rain attenuation in some cities in Region 3

		Tokyo		**Kuala Lumpur**		**Seoul**		**Bangkok**	
Longitude/latitude (degrees)		139.8 E/35.7 N		101.7 E/3.2 N		127 E/37.6 N		100.5 E/13.8 N	
Satellite orbital position (degrees)		110.0 E		91.5 E		116.0 E		98.0 E	
Elevation angle (degrees)		38.0		77.4		44.9		73.5	
$R_{0.01}$ (mm/h)		48.0		93.9		50.6		86.7	
	Annual time percentage	12.0 GHz	21.7 GHz	12.0 GHz	21.7 GHz	12.0 GHz	21.7 GHz	12.0 GHz	21.7 GHz
Atmospheric absorption	–	0.2 dB	1.9 dB	0.1 dB	1.2 dB	0.2 dB	1.8 dB	0.1 dB	1.4 dB
Rain attenuation	0.3%	1.5 dB	5.5 dB	3.7 dB	14.7 dB	1.4 dB	5.2 dB	3.0 dB	12.2 dB
	0.1%	2.8 dB	10.0 dB	6.6 dB	24.7 dB	2.7 dB	9.4 dB	5.5 dB	20.9 dB

The propagation losses at 17.5 GHz were compared with those at 12.5 GHz in Table 5 for the cities in Region 2. The rain attenuations at 17.5 GHz were up to 2.5 times larger than those at 12.5 GHz, in decibels.

TABLE 5

Atmospheric gaseous absorption and rain attenuation in some cities in Region 2

		Miami		Rio de Janeiro	
Longitude/latitude (degrees)		80.2 W/25.8 N		43.2 W/22.9 S	
Elevation angle (degrees)		51.8		63.1	
Satellite orbital position (degrees)		101.2 W		45.2 W	
$R_{0.01}$ (mm/h)		89.1		56.5	
	Annual time percentage	12.5 GHz	17.5 GHz	12.5 GHz	17.5 GHz
Atmospheric absorption	–	0.1 dB	0.4 dB	0.1 dB	0.3 dB
Rain attenuation	0.3%	2.7 dB	5.8 dB	2.0 dB	4.4 dB
	0.1%	4.9 dB	10.4 dB	3.7 dB	7.9 dB

The rain attenuations in the 12 GHz band and 17/21 GHz bands were calculated for the capital cities of all ITU member countries for 0.1% and 0.3% time of an average year. Results are shown in Figs. 7, 8 and 9 as histograms for each Region. Compared with Region 1, the rain attenuation in the capital cities in Region 3 is distributed over a wider range at 21.7 GHz.

The band 40.5-42.5 GHz is allocated to the BSS in all three Regions. Atmospheric absorption and rain attenuation at 41.5 GHz are shown in Tables 6, 7 and 8. The rain attenuation in the 42 GHz band is considerably higher than in the 17/21 GHz band.

FIGURE 7a

Rain attenuation for 0.1% of the year in capital cities of Region 1 countries at 12 GHz

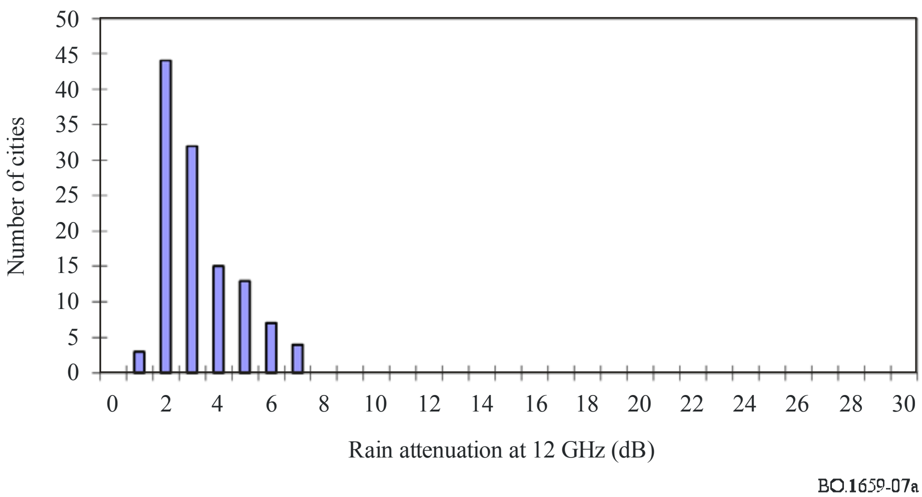


FIGURE 7b

Rain attenuation for 0.1% of the year in capital cities of Region 1 countries at 21.7 GHz

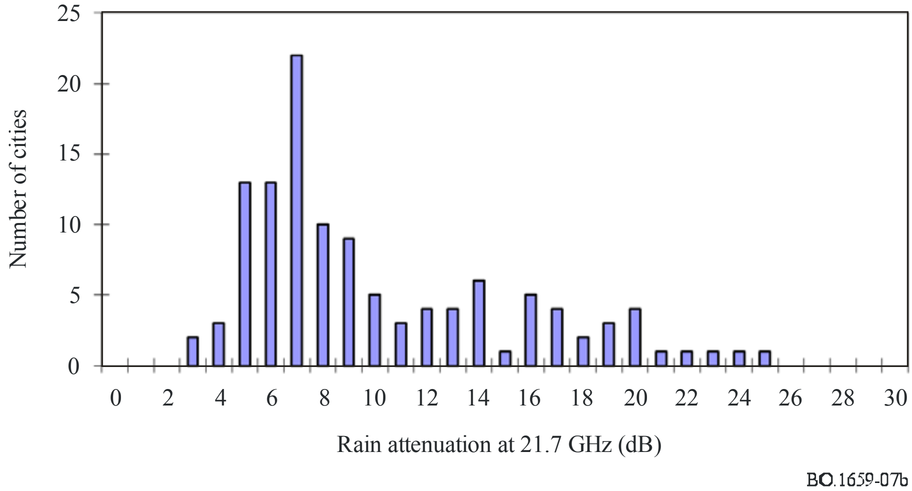


FIGURE 7c

Rain attenuation for 0.3% of the year in capital cities of Region 1 countries at 12 GHz

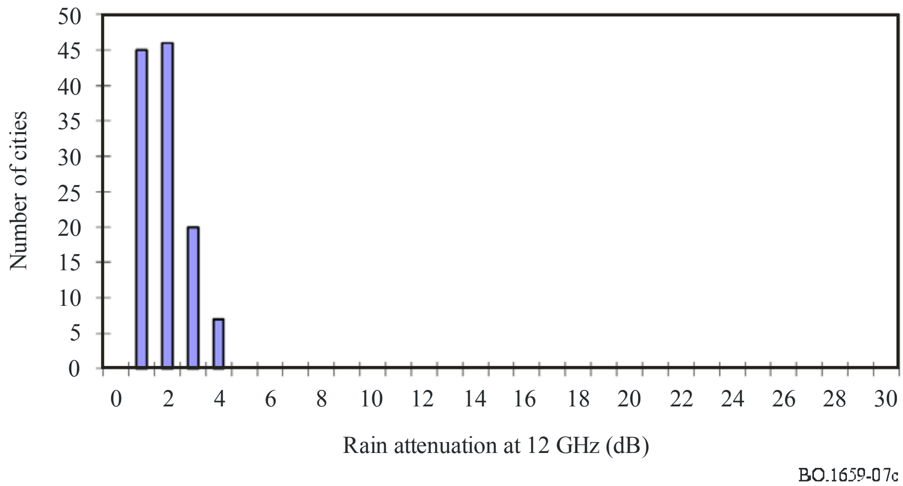


FIGURE 7d

Rain attenuation for 0.3% of the year in capital cities of Region 1 countries at 21.7 GHz

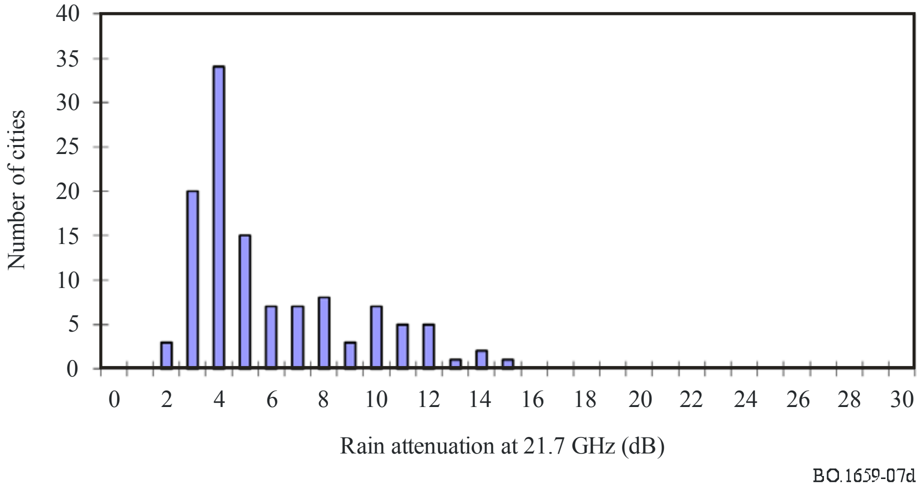


FIGURE 8a

Rain attenuation for 0.1% of the year in capital cities of Region 2 countries at 12.5 GHz

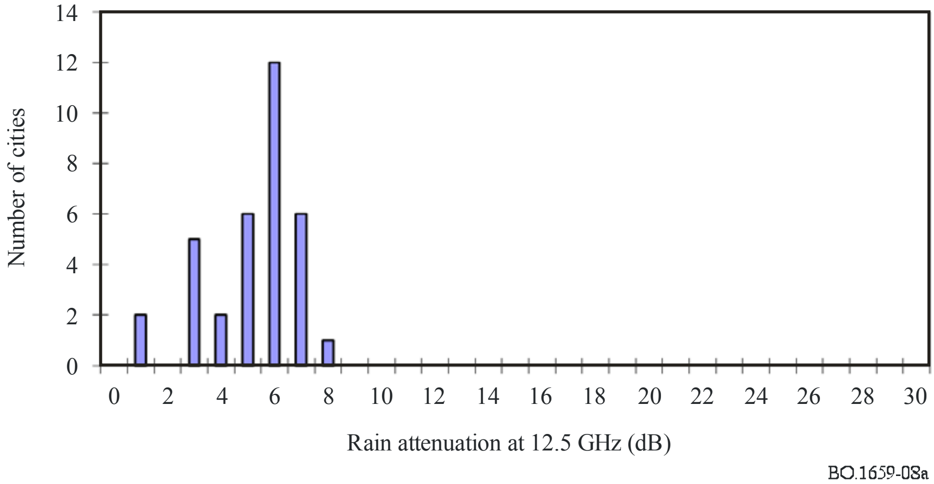


FIGURE 8b

Rain attenuation for 0.1% of the year in capital cities of Region 2 countries at 17.5 GHz

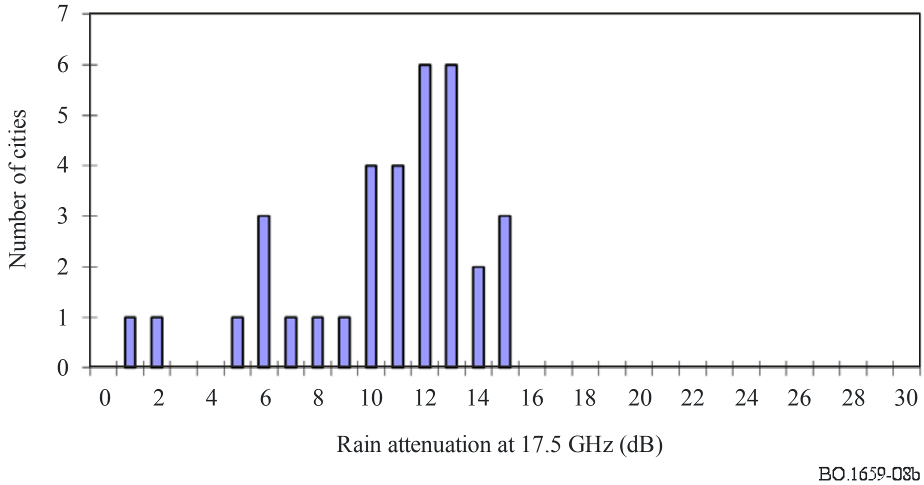


FIGURE 8c

Rain attenuation for 0.3% of the year in capital cities of Region 2 countries at 12.5 GHz

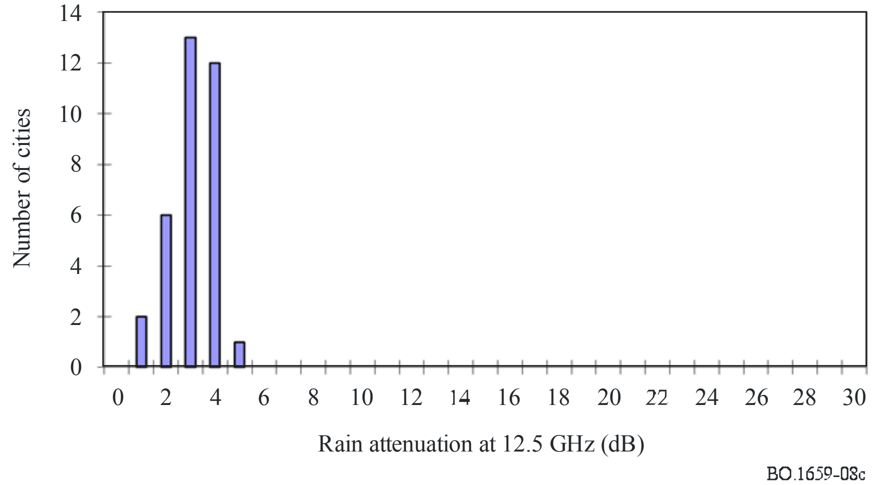


FIGURE 8d

Rain attenuation for 0.3% of the year in capital cities of Region 2 countries at 17.5 GHz

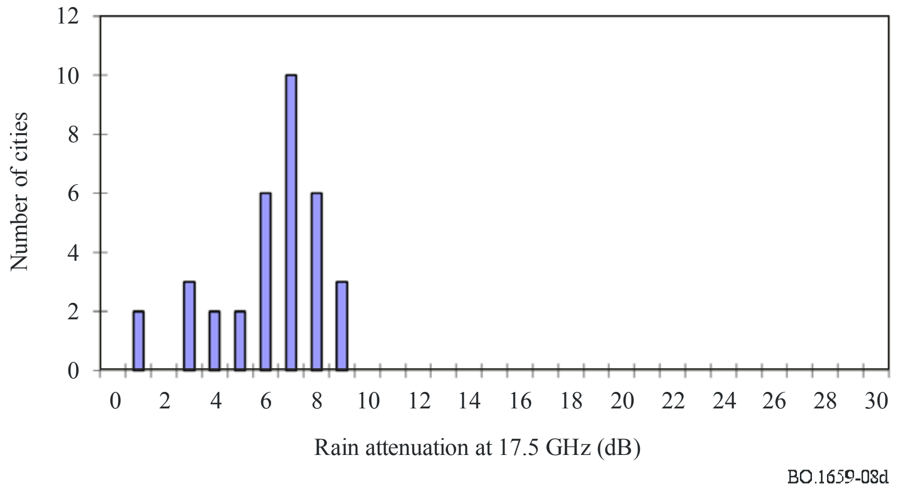


FIGURE 9a

Rain attenuation for 0.1% of the year in capital cities of Region 3 countries at 12 GHz

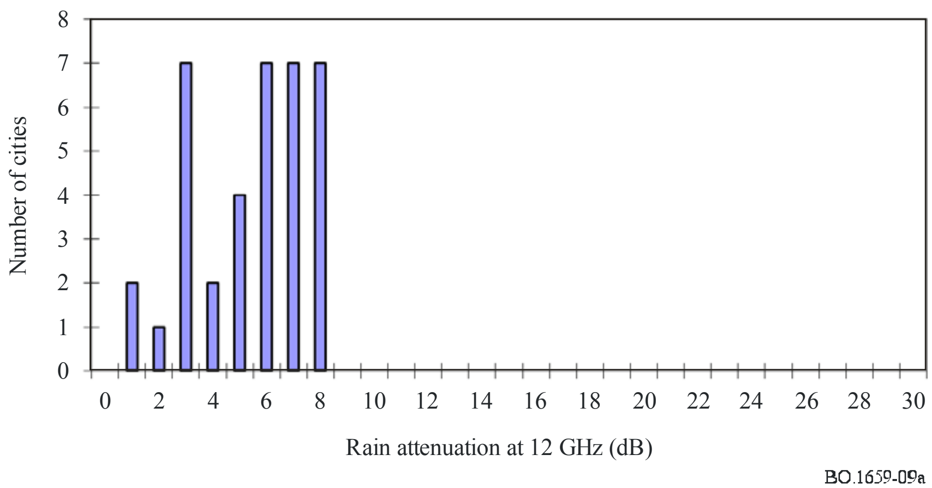


FIGURE 9b

Rain attenuation for 0.1% of the year in capital cities of Region 3 countries at 21.7 GHz

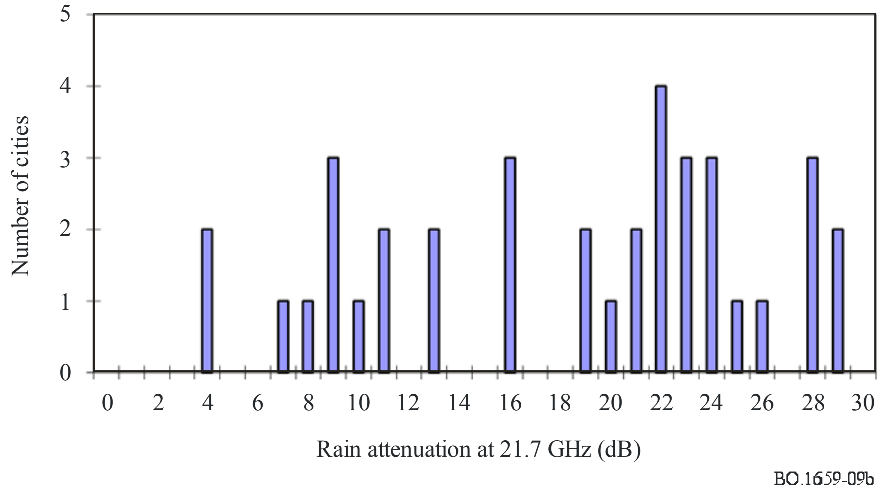


FIGURE 9c

Rain attenuation for 0.3% of the year in capital cities of Region 3 countries at 12 GHz

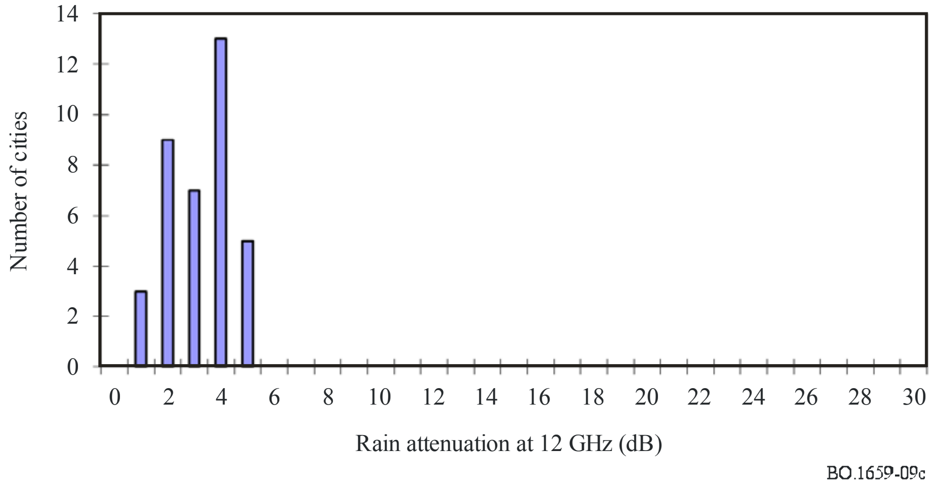


FIGURE 9d

Rain attenuation for 0.3% of the year in capital cities of Region 3 countries at 12 GHz

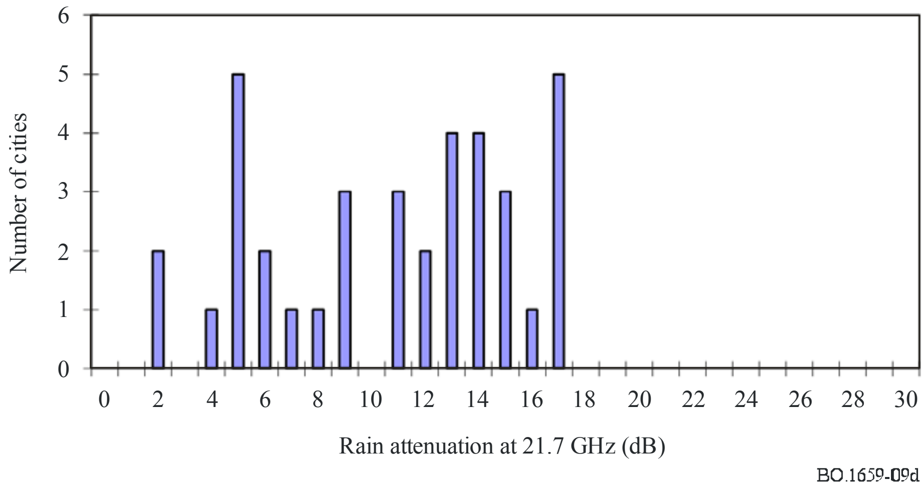


TABLE 6

Atmospheric gaseous absorption and rain attenuation in some cities in Region 1 at 41.5 GHz

	Annual time percentage	Moscow	London	Paris	Istanbul
		41.5 GHz			
Atmospheric absorption	–	1.7 dB	1.7 dB	1.3 dB	1.2 dB
Rain attenuation	3.0%	2.4 dB	2.3 dB	2.1 dB	2.5 dB
	1.0%	4.9 dB	4.8 dB	4.5 dB	5.2 dB
	0.3%	10.1 dB	9.9 dB	9.2 dB	10.6 dB
	0.1%	17.9 dB	17.6 dB	16.4 dB	18.7 dB

TABLE 7

Atmospheric gaseous absorption and rain attenuation in some cities in Region 2 at 41.5 GHz

	Annual time percentage	Miami	Rio de Janeiro
		41.5 GHz	
Atmospheric absorption	–	1.1 dB	1.0 dB
Rain attenuation	3.0%	6.2 dB	4.6 dB
	1.0%	12.5 dB	9.4 dB
	0.3%	27.0 dB	21.6 dB
	0.1%	45.4 dB	36.5 dB

TABLE 8

Atmospheric gaseous absorption and rain attenuation in some cities in Region 3 at 41.5 GHz

	Annual time percentage	Tokyo	Kuala Lumpur	Seoul	Bangkok
		41.5 GHz			
Atmospheric absorption	–	1.4 dB	0.9 dB	1.3 dB	1.0 dB
Rain attenuation	3.0%	4.0 dB	8.0 dB	3.8 dB	7.6 dB
	1.0%	8.1 dB	15.9 dB	7.7 dB	15.2 dB
	0.3%	16.3 dB	45.2 dB	15.5 dB	38.1 dB
	0.1%	28.3 dB	72.6 dB	26.9 dB	62.2 dB

4 Rain attenuation and gaseous absorption in BSS feeder-link bands

A similar calculation was carried out for the 18 and 28 GHz bands, which are candidates for the feeder links in all Regions, as well as for the 25 GHz band, which is another candidate in Regions 2 and 3. The results are shown in Tables 9, 10 and 11.

TABLE 9

Atmospheric gaseous absorption and rain attenuation in some cities in Region 1

	Annual time percentage	**Moscow**		**London**	
		18.1 GHz	27.8 GHz	18.1 GHz	27.8 GHz
Atmospheric absorption	–	0.6 dB	1.1 dB	0.6 dB	1.1 dB
Rain attenuation	0.3%	2.4 dB	5.4 dB	2.4 dB	5.3 dB
	0.1%	4.5 dB	9.8 dB	4.5 dB	9.7 dB
		Paris		**Istanbul**	
		18.1 GHz	27.8 GHz	18.1 GHz	27.8 GHz
Atmospheric absorption	–	0.5 dB	0.9 dB	0.4 dB	0.8 dB
Rain attenuation	0.3%	2.2 dB	4.9 dB	2.5 dB	5.6 dB
	0.1%	4.1 dB	9.0 dB	4.6 dB	10.2 dB

TABLE 10

Atmospheric gaseous absorption and rain attenuation in some cities in Region 2

	Annual time percentage	**Miami**			**Rio de Janeiro**		
		18.1 GHz	25.0 GHz	27.8 GHz	18.1 GHz	25.0 GHz	27.8 GHz
Atmospheric absorption	–	0.5 dB	1.1 dB	0.8 dB	0.4 dB	1.0 dB	0.7 dB
Rain attenuation	0.3%	6.2 dB	12.0 dB	14.6 dB	4.7 dB	9.2 dB	11.3 dB
	0.1%	11.1 dB	20.9 dB	25.1 dB	8.5 dB	16.2 dB	19.6 dB

TABLE 11

Atmospheric gaseous absorption and rain attenuation in some cities in Region 3

	Annual time percentage	Tokyo			Kuala Lumpur		
		18.1 GHz	25.0 GHz	27.8 GHz	18.1 GHz	25.0 GHz	27.8 GHz
Atmospheric absorption	–	0.5 dB	1.4 dB	1.0 dB	0.3 dB	0.9 dB	0.6 dB
Rain attenuation	0.3%	3.8 dB	7.2 dB	8.7 dB	9.9 dB	19.6 dB	24.0 dB
	0.1%	7.0 dB	12.9 dB	15.5 dB	17.0 dB	32.6 dB	39.5 dB
		Seoul			**Bangkok**		
		18.1 GHz	25.0 GHz	27.8 GHz	18.1 GHz	25.0 GHz	27.8 GHz
Atmospheric absorption	–	0.5 dB	1.3 dB	0.9 dB	0.4 dB	1.0 dB	0.7 dB
Rain attenuation	0.3%	3.6 dB	6.8 dB	8.3 dB	8.2 dB	16.3 dB	20.0 dB
	0.1%	6.6 dB	12.2 dB	14.8 dB	14.3 dB	27.6 dB	33.5 dB

5 Downlink service availability in the 21 GHz band

The service availability of the BSS system was calculated assuming various pfd values. A receiving antenna diameter of 45 cm was assumed. DVB-S, DVB-S2 and ISDB-S signal with modulation schemes of QPSK, 8-PSK and 16-QAM are the candidates for the system in this study. The required *C*/*N* of the system has a variation depending on the modulation and coding which involves a trade-off between service availability and frequency-use efficiency.

The time percentages of an average year for which the *C*/*N* exceeds 5.6 dB, 7.5 dB, 10.7 dB and 17.0 dB are shown with an example of pfd equal to −105 dB(W/(m^2 · MHz)), −115 dB(W/(m^2 · MHz)) and −120 dB(W/(m^2 · MHz)) in Table 12 and equal to −105 dB(W/(m^2 · MHz)) in Table 13.

The link budget includes rain attenuation, cloud attenuation, gas attenuation, scintillation and antenna pointing loss.

TABLE 12

Annual service availability of 21 GHz band BSS downlink in some cities in Region 1

		Moscow			London		
Elevation angle (degrees)		26.5			23.2		
pfd (dB(W/(m^2 · MHz)))		–105.0	−115.0	−120.0	–105.0	−115.0	−120.0
Overall C/N	5.6 dB	99.99%	99.96%	99.89%	99.99%	99.97%	99.90%
	7.5 dB	99.99%	99.95%	99.81%	99.99%	99.95%	99.84%
	10.7 dB	99.98%	99.89%	99.38%	99.99%	99.90%	99.53%
	17.0 dB	99.93%	98.48%	NA[1]	99.92%	99.04%	NA[1]
$R_{0.01}$ (mm/h)		31.7			30.9		
Rain attenuation[2] (dB)		6.5			6.6		
		Pretoria			**Istanbul**		
Elevation angle (degrees)		59.9			40.7		
pfd (dB(W/(m^2 · MHz)))		–105.0	−115.0	−120.0	–105.0	−115.0	−120.0
Overall C/N	5.6 dB	99.97%	99.87%	99.69%	99.99%	99.96%	99.88%
	7.5 dB	99.97%	99.84%	99.50%	99.99%	99.94%	99.79%
	10.7 dB	99.95%	99.67%	98.63%	99.98%	99.88%	99.30%
	17.0 dB	99.82%	95.80%	NA[1]	99.94%	98.35%	NA[1]
$R_{0.01}$ (mm/h)		31.8			38.9		
Rain attenuation[2] (dB)		5.8			6.7		
		Alexandria					
Elevation angle (degrees)		35.8					
pfd (dB(W/(m^2 · MHz)))		−105.0	−115.0	−120.0			
Overall C/N	5.6 dB	99.99%	99.99%	99.99%			
	7.5 dB	99.99%	99.99%	99.99%			
	10.7 dB	99.99%	99.99%	99.94%			
	17.0 dB	99.99%	99.60%	NA[1]			
$R_{0.01}$ (mm/h)		5.4					
Rain attenuation[2] (dB)		1.4					

NOTE – The locations presented in Table 12 give only examples of the service availability in Region 1. Service availability is dependent on the elevation angle and also dependent on the location within Region 1. Hence, a pfd value lower than −120 dB(W/(m^2 · MHz)) may also be used in areas with lower rain attenuation than those in Table 12.

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[1] NA: Not applicable because the level of pfd does not permit to achieve the level of C/N required.

[2] Rain attenuation calculated for 99.9% of the year.

TABLE 13

Annual service availability of 21 GHz band BSS downlink in some cities in Region 3

		Tokyo	Kuala Lumpur	Seoul	Bangkok	Wellington
Elevation angle (degrees)		38.0	77.4	44.9	73.5	42.3
pfd (dB(W/(m^2 · MHz)))		–105.0	–105.0	–105.0	–105.0	–105.0
Overall *C*/*N*	5.6 dB	99.98%	99.81%	99.98%	99.88%	99.99%
	7.5 dB	99.97%	99.77%	99.97%	99.85%	99.99%
	10.7 dB	99.95%	99.68%	99.95%	99.78%	99.99%
	17.0 dB	99.80%	99.36%	99.83%	99.44%	99.94%
$R_{0.01}$ (mm/h)		48.0	93.6	50.6	87.1	41.7
Rain attenuation[2] (dB)		10.0	26.3	14.2	21.5	6.4

NOTE – The cities mentioned in Table 13 give only examples of the service availability in Region 3. Service availability is dependent on the elevation angle and also dependent on the location within Region 3.

The more frequency-efficient modulation schemes such as 16-QAM may be applicable to future BSS systems. The required *C*/*N* of the modulation schemes is, however, higher than TC8-PSK. Furthermore, it is susceptible to the non-linearity of the satellite transponders. Tentatively, a required *C*/*N* of 17.0 dB is assumed.

In the BSS, using the 21 GHz band, the much larger rain fade should be compensated to achieve service availability similar to that of the 12 GHz band. In the conventional satellite design, the e.i.r.p. is determined by considering the attenuation as a margin. Therefore the system needs excessively large-scale satellites and high clear sky pfd, which may be considered uneconomical. Thus to implement a BSS with an affordable satellite system in a specific area, effective measures to compensate for rain attenuation are required.

The annual service availability of the 21 GHz BSS band downlink listed in Table 12 for some cities in Region 1, as an example, is considerably greater than the annual service availability for the 12 GHz Plan in Appendix 30 of the Radio Regulations, i.e. 99% of the worst month, equivalent to an annual service availability of 99.7%. Based on satellite operator objectives and service area targeted, if the level of availability with a power flux-density at the Earth's surface equal to −105 dB(W/(m^2 · MHz)) is much greater than the expected availability, it could be envisaged to reduce the power flux-density at the Earth's surface produced by emissions from the space stations in order to reach the required availability. This power reduction could directly impact the satellite design (i.e. more operational transponders with the same power consumption envelope) or the associated cost (i.e. reduction of total power consumption which have a direct impact on the satellite cost).

For Region 1, with respect to a reduced power flux-density at the Earth's surface:

1) For a pfd of −115 dB(W/(m^2 · MHz)) (i.e. 10 dB of reduction), the annual service availability for the *C*/*N* of 7.5 and 10.7 dB for some example cities in Region 1 listed in Table 12 is greater than the annual service availability for some other cities in Region 1 listed in Table 12 with a power flux-density at the Earth's surface of −105 dB(W/(m^2 · MHz)).

2) For a pfd of −120 dB(W/(m^2 · MHz)) (i.e. 15 dB of reduction), the annual service availability for the *C*/*N* of 5.6 dB for some example cities in Region 1 listed in Table 12 is greater than the annual service availability for some other cities in Region 1 listed in Table 12 with a power flux-density at the Earth's surface of −105 dB(W/(m^2 · MHz)).

For Region 1, it would be understood that a power flux-density at the Earth's surface of −105 dB(W/(m^2 · MHz)) is effective to improve the annual service availability for some cities in Region 1 as shown in Table 12. For example, it would be noted that one city with a rainfall rate, $R_{0.01\%}$, below 31 mm/h in Region 1 shows the possibility to consider a pfd at the Earth's surface of −105 dB(W/(m^2 · MHz)) instead of −115 dB(W/(m^2 · MHz)) to increase the annual service availability for the *C*/*N* of 10.7 dB from 99.90% to 99.99%.

As shown in Tables 12 and 13, the required value of power flux-density at the Earth's surface for a specific satellite network is fully linked to several factors (e.g. total link attenuation observed over the targeted area, required availability, modulation scheme, etc.).

6 Conclusion

This Appendix has shown that:

– rain attenuation and atmospheric gaseous absorption in bands between 17.3 GHz and 42.5 GHz are considerably larger than those in the 12 GHz band;

– assuming conventional satellite system design, the e.i.r.p. is determined including the link margin requirements to meet the availability objectives. In some cases, the required e.i.r.p. could be too high to allow for a conventional satellite system;

– given the propagation conditions, appropriate mitigation techniques for rain attenuation may be required to facilitate the introduction of feasible BSS systems in the higher frequency bands.