International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Report ITU-R BO.2071-2

(07/2019)

Broadcasting-satellite service system parameters between 17.3 GHz and 42.5 GHz and associated feeder links

BO Series

Satellite delivery

International Telecommunication Union

Foreword

The role of the Radiocommunication Sector is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services, and carry out studies without limit of frequency range on the basis of which Recommendations are adopted.

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SM	Spectrum management

Note*: This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.*

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REPORT ITU-R BO.2071-2

Broadcasting-satellite service system parameters between 17.3 GHz and 42.5 GHz and associated feeder links

(2006-2011-2019)

Abbreviations/Glossary

Array-fed IRA	Array-fed Imaging Reflector Antenna
APSK	Amplitude phase shift keying
BCH	Bose–Chaudhuri–Hocquenghem codes
BFN	Beam forming network
BPF	Band pass filter
BPSK	Binary phase shift keying
BRF	Band rejection filter
BSS	Broadcasting-satellite service
BW	Band width
BWS	Bandwidth shaping factor (roll-off factor)
C/N	Carrier to noise ratio
DVB-S	Digital Video Broadcasting for Satellite
e.i.r.p.	Equivalent isotropically radiated power
ETSI	European Telecommunications Standards Institute
FEC	Forward error correction
HDTV	High definition television
ISDB-S	Integrated services digital broadcasting for satellite
LDPC code	Low density parity check code
LPF	Low pass filter
pfd	Power flux-density
PSK	Phase shift keying
QPSK	Quadrature phase shift keying
RAS	Radio astronomy service
RMSE	Root means square error
RS	Reed-Solomon coding
SDTV	Standard television
TWTA	Traveling wave tube amplifier
UHDTV	Ultra-high definition television

Related ITU-R Recommendations, Reports and Resolutions

Recommendation ITU-R BO.652-1 – Reference patterns for earth station and satellite antennas for the broadcasting-satellite service in the 12 GHz band and for associated feeder-links in the 14 GHz and 17 GHz bands

Recommendation ITU-R BO.790 – Characteristics of receiving equipment and calculation of receiver figure-of-merit (G/T) for the broadcasting-satellite service

Recommendation ITU-R BO.791 – Choice of polarization for the broadcasting satellite service

Recommendation ITU-R BO.792 – Interference protection ratios for the broadcasting satellite service (television) in the 12 GHz band

Recommendation ITU-R BO.1212 – Calculation of total interference between geostationary-satellite networks in the broadcasting-satellite service

Recommendation ITU-R BO.1293-2 – Protection masks and associated calculation methods for interference into broadcast-satellite systems involving digital emissions

Recommendation ITU-R BO.1295 – Reference transmit earth station antenna off-axis e.i.r.p. patterns for planning purposes to be used in the revision of the Appendix **30A** (Orb-88) Plans of the Radio Regulations at 14 GHz and 17 GHz in Regions 1 and 3

Recommendation ITU-R BO.1408-1 – Transmission system for advanced multimedia services provided by integrated services digital broadcasting in a broadcasting-satellite channel

Recommendation ITU-R BO.1516-1 – Digital multiprogramme television systems for use by satellites operating in the 11/12 GHz frequency range

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

Recommendation ITU-R BO.1776-1 – Reference power flux-density for the broadcasting-satellite service in the band 21.4-22.0 GHz in Regions 1 and 3

Recommendation ITU-R BO.1900 – Reference receiving earth station antenna pattern for the broadcasting-satellite service in the band 21.4-22 GHz in Region 1 and 3

Recommendation ITU-R BT.2020-2 – Parameter values for ultra-high definition television systems for production and international programme exchange

Recommendation ITU-R P.618-10* – Propagation data and prediction methods required for the design of Earth-space telecommunication systems

Recommendation ITU-R P.837-5* – Characteristics of precipitation for propagation modelling

Recommendation ITU-R P.1623-1 – Prediction method of fade dynamics on Earth space paths

Recommendation ITU-R RA.769-2 – Protection criteria used for radio astronomical measurements

Recommendation ITU-R S.524-9 – Maximum permissible levels of off-axis e.i.r.p. density from earth stations in geostationary-satellite orbit networks operating in the fixed-satellite service transmitting in the 6 GHz, 13 GHz, 14 GHz and 30 GHz frequency bands

Recommendation ITU-R SM.1633 – Compatibility analysis between a passive service and an active service allocated in adjacent and nearby bands

Resolution **554 (WRC-12)** – Application of pfd masks to coordination under No. **9.7** for broadcasting-satellite service networks in the band 21.4-22.0 GHz in Regions 1 and 3 for the enhancement of equitable access to this frequency band

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* Recommendations ITU-R P.618-10 and ITU-R P.837-5 are not the latest, but were used in the calculation of the rain attenuation in this Report.

Resolution **739 (Rev.WRC-15)** – Compatibility between the radio astronomy service and the active space service in certain adjacent and nearby frequency bands

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1 Introduction

ITU-R has identified the need to assemble system parameters and system characteristics for the BSS bands between 17.3 GHz and 42.5 GHz and associated feeder links. For that purpose, a Report had been developed on the basis of inputs to ITU-R. An example of the parameters is shown as follows:

a) Service requirements
   – service description, service objective, service availability, bit rate, etc.

b) Feeder-link parameters
   – feeder-link frequency, earth station e.i.r.p., feeder-link transmitting parameters, etc.

c) Modulation, link parameters
   – bandwidth, modulation, coding, polarization, sharing criteria, etc.

d) Satellite parameters
   – satellite e.i.r.p. (pfd), transmitting antenna pattern, etc.

e) Receiver parameters
   – receiving antenna diameter, antenna pattern, etc.

Further contributions are invited for future updates of this Report, which may eventually serve in establishing system parameters of BSS services operating above 17 GHz, including the associated feeder links.

Note that for the specific problem of rain mitigation techniques in the noted bands, ITU-R developed Recommendation ITU-R BO.1659 – Mitigation techniques for rain attenuation for BSS systems in frequency bands between 17.3 GHz and 42.5 GHz.

The BSS systems in the frequency bands between 17.3 GHz to 42.5 GHz have the possibility to deliver wideband RF digital multiprogramme services, which may consist of SDTV, HDTV, audio and data programmes. In addition, it is also possible to implement interactive multimedia and on-demand services. To facilitate the introduction of BSS in the bands, former WP 6S/RG 9 was established to carry out studies on applicable technologies to improve service availability against rain attenuation, and on outlining necessary BSS system characteristics.

In the Radio Regulations, the band 17.3-17.8 GHz in Region 2 and the band 21.4-22.0 GHz in Regions 1 and 3 are allocated to BSS as of 1 April 2007.

Attachment 1 to Annex 1 to this Report contains examples of system parameters of BSS systems and their associated feeder links in frequency bands 17.3-17.8 GHz and 24.75-25.25 GHz, which are allocated for BSS feeder links in Region 2.

The system parameters given in Table 1 are based on information supplied by Canada in accordance with Appendix **4** of the Radio Regulations (RR). The system parameters given in Table 2 are based on information supplied by the United States of America. Using the system parameters provided in Table 1 and information provided in ETSI DVB-S.1 standard (version EN 301 210 V1.1.1) as the minimum satellite system link performance requirements, Attachment 2 to Annex 1 contains a study on the impact of satellite separation on system performance of typical BSS systems. Utilizing the same methodology as provided in Attachment 2, Attachment 3 to Annex 1 re-examines the impact of satellite separation on system performance for BSS systems using information provided in ETSI DVB-S.2 standard (version EN 302 307 V1.1.1). However, it should be noted that it was assumed in these studies that the downlink and uplink e.i.r.p.s (of both the wanted and interfering networks) were scaled with the C/N threshold for the type of modulation used regardless of whether the capability exists for both networks. This has simply been done for comparison purposes to illustrate the effect of the type of modulation employed. The actual RR Appendix **4** data filed for each network and Article 21 pfd limits will ultimately determine the maximum downlink e.i.r.p. regardless of the C/N

threshold for the type of modulation used. The feasibility of using higher order modulation techniques (e.g. higher than 8-PSK) over satellite links remains to be proven in practice.

Annex 2 to this Report shows study results for 21 GHz band broadcasting satellites based on input documents to ITU-R. Measured downlink receiving earth station antenna patterns are shown in § 2. Some examples of BSS systems utilizing the locally-variable e.i.r.p. systems in the 21 GHz band are introduced in § 3.

In § 4, a study of antenna radiation pattern of a variable e.i.r.p. broadcasting-satellite system in the 21 GHz band is described. Section 5 shows a study result of interference from the locally variable e.i.r.p. satellite systems into a conventional satellite system. Section 6 deals with methodology to evaluate unwanted emission from 21 GHz band BSS. Finally, a transmission scheme utilizing the receiver with a storage function is described in § 7.

Annex 1

System parameters of unplanned BSS systems and associated feeder links in frequency bands 17.3-17.8 GHz and 24.75-25.25 GHz

Attachment 1 to Annex 1

Examples of system parameters of unplanned BSS systems and associated feeder links in frequency bands 17.3-17.8 GHz and 24.75-25.25 GHz

Table 1 contains an example summary of the Canadian coordination information submitted to BR (CAN-BSS-95). The system plans to provide TV broadcasting and interactive multimedia services. Furthermore, coordination information submitted by another Region 2 country for providing broadcast services is included in the third column, titled “Other”, of Table 1.

TABLE 1

System characteristics

		CAN-BSS-95	**Other**
Orbit		GEO	GEO
Position		95.0° W	101.0° W
Frequency	Uplink	24.75-25.25 GHz	24.75-25.25 GHz
	Downlink	17.3-17.8 GHz	17.3-17.8 GHz
Broadcast			
Coverage		North America	North America
Assigned channel bandwidth		25 MHz	25-500 MHz

TABLE 1 (*continued*)

	CAN-BSS-95	Other
Uplink		
Satellite receive antenna gain	35 dBi	49.4 dBi
E.S. transmit antenna size	5.6 m, 3.5 m	5-13 m
E.S. transmit antenna gain (maximum)	61.1 dBi, 57.0 dBi	60.5-68.8 dBi
Receiving satellite system noise temperature	730 K	810 K
E.S. transmit antenna pattern	AP 4 A, B, C, D, φ parameters: 29, 25, 32, 25, 7°	Rec. ITU-R S.465
Polarization	Circular left	Circular left
Maximum power supplied to the input of E.S. transmitting antenna	22.2 dBW	21.2-29.5 dBW
Downlink		
Satellite transmit antenna gain	35 dBi	49.4 dBi
E.S. receive antenna size	0.45-1.4 m	0.45-1.2 m
E.S. receive antenna gain	36.1-46.0 dBi	36.5-45.0 dBi
Polarization	Circular right	Circular right
E.S. receive noise temperature	170 K	140 K
E.S. receive antenna pattern	(see Addendum 1 to Attachment 1)	Rec. ITU-R S.465
Maximum power supplied to the input of satellite transmitting antenna	22.2 dBW	14.8-19.1 dBW
E_b/N_0	6.5 dB	No info.
C/N threshold	6.6 dB	No info.
Required C/N (clear-sky)	9.0 dB	Uplink 17.4 dB, Downlink 6-17.6 dB
Multimedia (CAN-BSS-95 only)		
Forward link		
Coverage	Visible earth	
Channel bandwidth	25 MHz	
Uplink		
Satellite receive antenna gain	44.5 dBi	
E.S. transmit antenna size	5.6 m, 3.5 m	
E.S. transmit antenna gain (maximum)	61.1 dBi, 57.0 dBi	
Receiving satellite system noise temperature	730 K	
E.S. transmit antenna pattern	AP 4 A, B, C, D, φ parameters: 29, 25, 32, 25, 7°	
Polarization	Circular left	
Maximum power supplied to the input of E.S. transmitting antenna	18.0 dBW	

TABLE 1 (*end*)

	CAN-BSS-95	Other
Downlink		
Satellite transmit antenna gain	44.5 dBi	
E.S. receive antenna size	0.45-1.4 m	
E.S. receive antenna gain	36.1-46.0 dBi	
Polarization	Circular right	
E.S. receive noise temperature	170 K	
E.S. receive antenna pattern	(see Addendum 1 to Attachment 1)	
Maximum power supplied to the input of satellite transmitting antenna	21.0 dBW	
E_b/N_0	6.5 dB	
C/N threshold	6.6 dB	
Required C/N (clear-sky)	11.0 dB	
Return link		
Coverage	Visible earth	
Channel bandwidth	55 MHz, 113 MHz	
Uplink		
Satellite receive antenna gain	44.5 dBi	
E.S. transmit antenna size	0.45-1.4 m	
E.S. transmit antenna gain (max)	39.2-49.1 dBi	
Receiving satellite system noise temperature	730 K	
E.S. transmit antenna pattern	Rec. ITU-R S.465	
Uplink polarization	Circular left, circular right	
Maximum power supplied to the input of E.S. transmitting antenna	36.4 dBW, 39.7 MHz	
Downlink		
Satellite transmit antenna gain	44.5 dBi	
E.S. receive antenna size	5.6 m, 3.5 m	
E.S. receive antenna gain	58.0 dBi, 54 dBi	
Downlink polarization	Circular right, circular left	
E.S. receive noise temperature	185 K	
E.S. receive antenna pattern	AP 4 A, B, C, D, φ parameters: 29, 25, 32, 25, 7°	
Maximum power supplied to the input of satellite transmitting antenna	21.2 dBW	
E_b/N_0	6.5 dB	
C/N threshold	6.6 dB	
Required C/N (clear-sky)	10.0 dB	

Table 2 contains parameters of another example system that could operate in the 17.3-17.8 GHz and 24.75-25.25 GHz bands. The system has a reconfigurable “bent-pipe” payload capable of providing

TV broadcasting services using fixed beams over North and South America, respectively, or a steerable beam over North America.

TABLE 2

Additional system characteristics

		HDBSS-A (NAF)	**HDBSS-A (SAF)**	**HDBSS-A (NAS)**
Orbit		GEO	GEO	GEO
Position		67.5° W	67.5° W	67.5° W
Frequency	Uplink	24.75-25.25 GHz	24.75-25.25 GHz	24.75-25.25 GHz
	Downlink	17.3-17.8 GHz	17.3-17.8 GHz	17.3-17.8 GHz
Coverage		North America	South America	North America
Assigned channel bandwidth		24 MHz	24 MHz	48 MHz
Uplink				
Satellite receive antenna gain		37 dBi	34.2 dBi	46.1 dBi
E.S. transmit antenna size		6-11 m	6-11 m	6-11 m
E.S. transmit antenna gain (maximum)		61.1-67 dBi	61.1-67 dBi	61.1-67 dBi
Receiving satellite system noise temperature		815 K	815 K	865 K
E.S. transmit antenna pattern		Rec. ITU-R S.465	Rec. ITU-R S.465	Rec. ITU-R S.465
Polarization		Circular left/ circular right	Circular left	Circular left
Maximum power supplied to the input of E.S. transmitting antenna		13.5-20 dBW	13.5-20 dBW	13.5-20 dBW
Downlink				
Satellite transmit antenna gain		34.5 dBi	30.9 dBi	46.1 dBi
E.S. receive antenna size		0.45-1.8 m	0.45-1.8 m	0.45-1.8 m
E.S. receive antenna gain		36.1-48.1 dBi	36.1-48.1 dBi	36.1-63.9 dBi
Polarization		Circular right circular left	Circular right	Circular right
E.S. typical G/T		12.3-24.3 dB/K	12.3-24.3 dB/K	12.3-24.3 dB/K
E.S. receive antenna pattern (For off axis angles up to 20°)		Rec. ITU-R S.465 Rec. ITU-R S.580	Rec. ITU-R S.465 Rec. ITU-R S.580	Rec. ITU-R S.465 Rec. ITU-R S.580
Maximum power supplied to the input of satellite transmitting antenna		21.1 dBW, 23.7 dBW	21.1 dBW, 23.7 dBW	18.6 dBW
E_b/N_0		2.9 dB	2.9 dB	4.9 dB
C/N threshold		4.1 dB	4.1 dB	8.9 dB
Required C/N (clear-sky)		5.6 dB	5.6 dB	10.4 dB

Addendum 1
to Attachment 1
to Annex 1

Reference receiving antenna pattern

Antenna pattern:

$G_{co}(\varphi) = G_{max} = 2.5 \times 10^{-3}\left(\frac{D}{\lambda}\varphi\right)^2$ for $0 \leq \varphi < \varphi_m$ where $\varphi_m = \frac{\lambda}{D}\sqrt{\frac{G_{max} - G_1}{0.0025}}$

$G_{co}(\varphi) = G_1 = 29 - 25\log_{10}\varphi_r$ for $\varphi_m \leq \varphi < \varphi_r$ where $\varphi_r = 95\,\frac{\lambda}{D}$

$G_{co}(\varphi) = 29 - 25\log_{10}\varphi$ for $\varphi_r \leq \varphi < 7°$

$G_{co}(\varphi) = 7.9$ dBi for $7° \leq \varphi < 9.2$

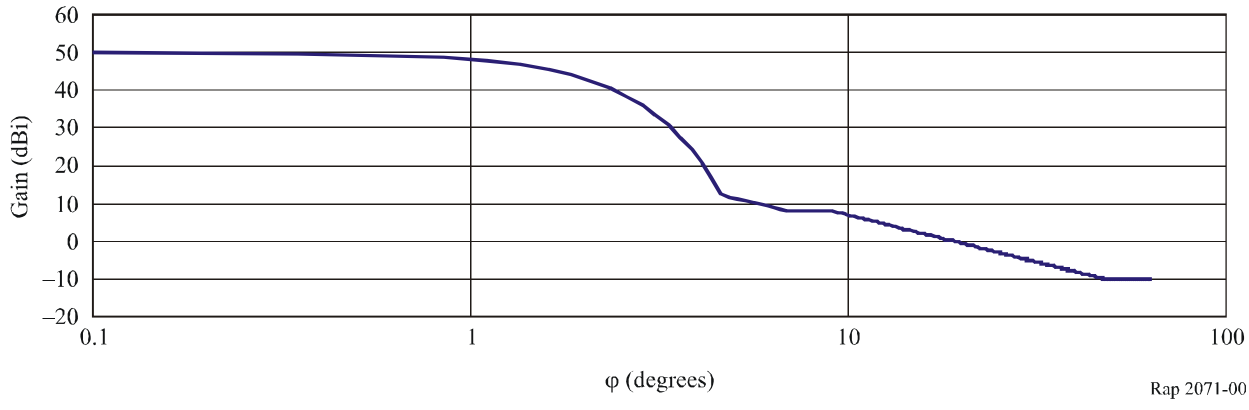
$G_{co}(\varphi) = 32 - 25\log_{10}\varphi$ for $9.2 \leq \varphi < 48°$

$G_{co}(\varphi) = -10$ dBi for $48° \leq \varphi < 180$

where:

- G_{co}: co-polar gain (dBi)
- G_{max}: maximum isotropic gain of the antenna (dBi)
- φ: off-axis angle (degrees)
- D antenna diameter (m)
- λ: wavelength (m).

Reference receiving antenna pattern



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Attachment 2
to Annex 1

A study of orbital separation requirements for the unplanned BSS and associated feeder links in frequency bands 17.3-17.8 GHz and 24.75-25.25 GHz

1 Introduction

This Attachment examines the impact of satellite separation (intersystem interference) on system performance of typical BSS systems operating in frequency bands 17.3-17.8 GHz and 24.75-25.25 GHz.

2 Methodology

The system performance is represented by the system margin, which is defined as:

$$\text{System margin} = \left(\frac{C}{N+I}\right)_{system,\,faded} - \left(\frac{C}{N}\right)_{threshold}$$

where:

$\left(\frac{C}{N+I}\right)_{system,\,faded}$: overall system $\left(\frac{C}{N+I}\right)$ with uplink availability of 99.95% of the year and the downlink availability of 99.8% of the year

$$\left(\frac{C}{N}\right)_{threshold} = \frac{E_b}{N_0} + 10\log\left(\frac{R_b}{BW}\right)$$

$$= \frac{E_b}{N_0} + 10\log\left(\frac{BW \cdot ML \cdot FEC \cdot RS}{BW \cdot BWF}\right)$$

$$= \frac{E_b}{N_0} + 10\log\left(\frac{ML \cdot FEC \cdot RS}{BWF}\right)$$

and

R_b: bit rate (Mbit/s)

BW: channel bandwidth (MHz)

ML: modulation level, e.g., 2 for QPSK and 3 for 8-PSK

FEC: FEC rate

RS: Reed-Solomon coding rate

BWF: bandwidth shaping factor (roll-off factor).

The analysis was performed for two types of interfering systems: homogeneous and inhomogeneous. For the inhomogeneous case, interfering systems with different modulation schemes from the wanted system were examined. Both QPSK and 8-PSK modulation schemes were examined using different FEC rates in order to assess the sensitivity of the satellite separation requirements on these parameters.

2.1 Assumptions

The system characteristics used in the analysis are listed in Addendum 1 to Attachment 2. They are largely based on the attachment to Annex 11 of the March 2003 former WP 6S Chairman's Report. The analysis was carried out on the following assumptions:

a) The interfering satellites are located with equal spacing on both sides of the wanted satellite. Both first and second adjacent interfering satellites were assumed. Co-coverage is assumed for wanted and interfering satellites.

b) Recommendation ITU-R P.618-8 was used to calculate propagation attenuation. The uplink availability is assumed to be 99.95% of the year and the downlink availability is assumed to be 99.8% of the year; this results in an overall system availability of 99.75% of the year.

c) Recommendation ITU-R BO.1212 was used to calculate the total interference.

d) The receiving earth station is located in rain climatic zone "M". (Rain rate = 72.4 mm/h exceeded for 0.01% of the average year.)

e) The wanted and interfering uplink earth stations were assumed to be in the same location, as this represents the worst-case scenario.

f) The minimum required link performance is obtained from ETSI standard EN 301 210 V1.1.1. (DVB; Framing structure, channel coding and modulation for DSNG and other contribution applications by satellite.)[1]

3 Results

3.1 Homogeneous model for interfering system based on wanted system

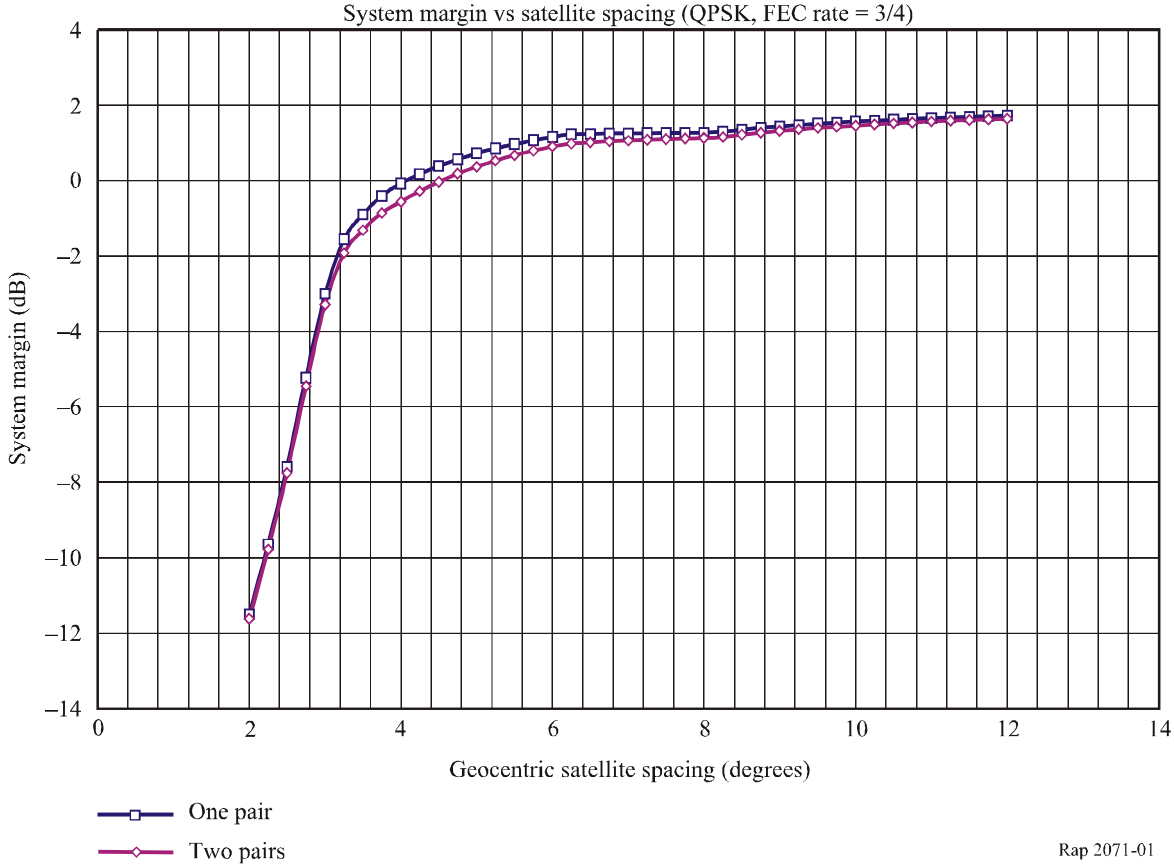
Case 1: using QPSK modulation

Analysis was performed to examine the relationship between system performance and satellite spacing for one pair and two pairs of interfering satellites. It is assumed that an FEC rate of 3/4 is used. The results of the analysis are shown in Fig. 1.

[1] It is noted that ETSI standard EN 301 210 V.1.1.1 will be updated in the near future. Pending on the updated values, the results presented in this document might be changed.

FIGURE 1

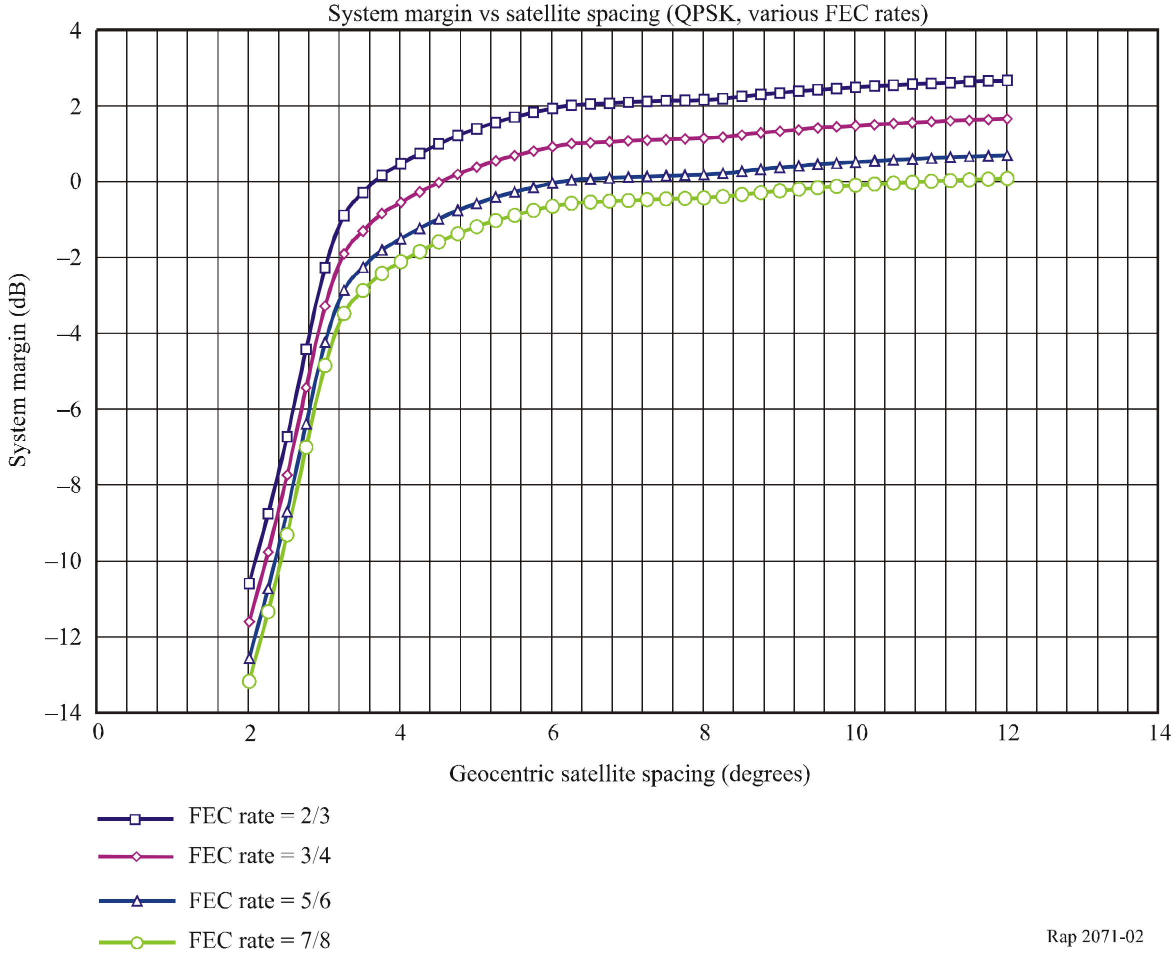
System margin vs. satellite spacing for system using QPSK



In order to study the effect of FEC rate on the system performance, an analysis was performed to determine the relationship between system margin and satellite spacing for systems with various FEC rates. Figure 2 shows the analysis results, which are based on two pairs of interfering satellites.

FIGURE 2

System margin vs. satellite spacing for various FEC rates

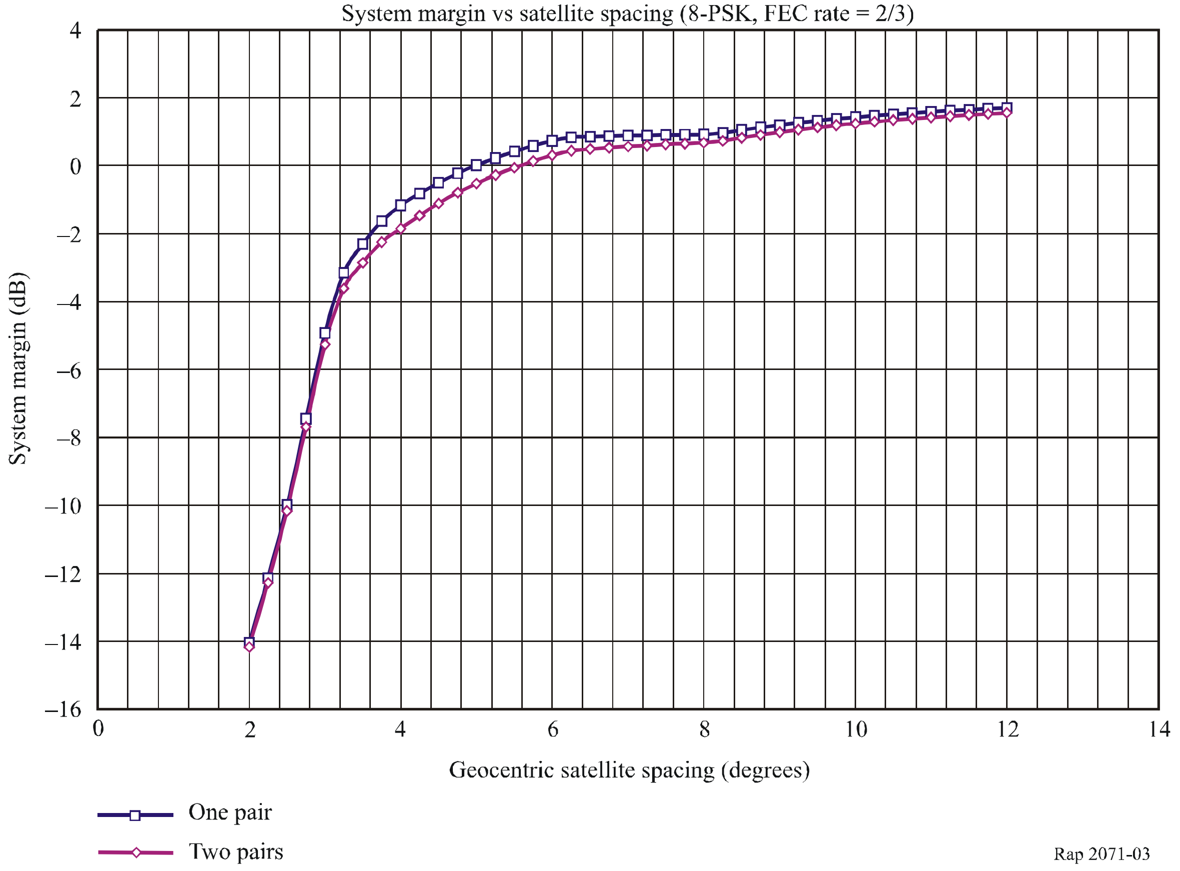


Case 2: using 8-PSK modulation

A similar analysis was performed for systems using 8-PSK modulation and an FEC rate of 2/3. It is expected that, due to change in the modulation scheme, the transmitting satellite power (downlink power) and the transmitting earth station power (uplink power) have to be increased. It is determined that the $(C/N)_{threshold}$ of the 8-PSK system is 3.66 dB higher than that of the QPSK system; therefore, an increase of 3.66 dB is applied to the uplink and downlink powers of the 8-PSK system. Figure 3 shows the relationship between system performance and satellite spacing for a system using 8-PSK modulation.

FIGURE 3

System margin vs. satellite spacing for system using 8-PSK



3.2 Inhomogeneous model for interfering system based on different modulation schemes

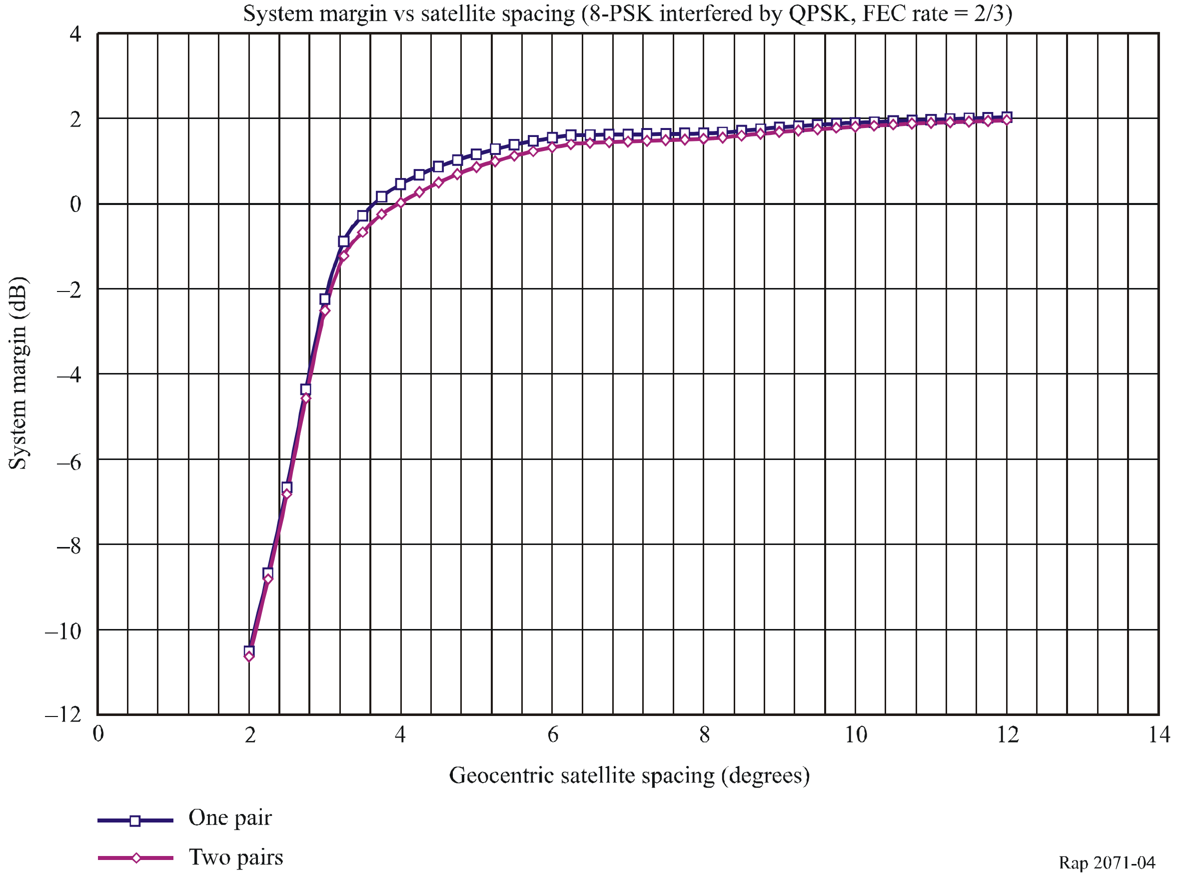
To further study the effect of different modulation schemes on the system performance, analysis was performed for an inhomogeneous model involving systems using QPSK and 8-PSK. It is assumed that the QPSK systems possess the characteristics of the QPSK system in Case 1 of § 3.1 and the 8-PSK system possesses the characteristics of the 8-PSK system in Case 2 of § 3.1.

Case A: wanted system uses 8-PSK and interfering systems uses QPSK

Figure 4 shows the relationship between system performance and satellite spacing for one pair and two pairs of interfering satellites.

FIGURE 4

System margin vs. satellite spacing for 8-PSK interfered by QPSK



Case B: wanted system uses QPSK and interfering systems uses 8-PSK

Figure 5 shows the relationship between system margin and satellite spacing for various FEC rates. The results are shown for two pairs of interfering satellites.

4 Conclusion

Based on the system characteristics given in Addendum 1 to Attachment 2, this Report studies the impact of satellite separation (intersystem interference) on system performance of typical BSS systems operating in frequency bands 17.3-17.8 GHz and 24.75-25.25 GHz. The results of the study are summarized in Table 3.

FIGURE 5

System margin vs. satellite spacing for QPSK interfered by 8-PSK

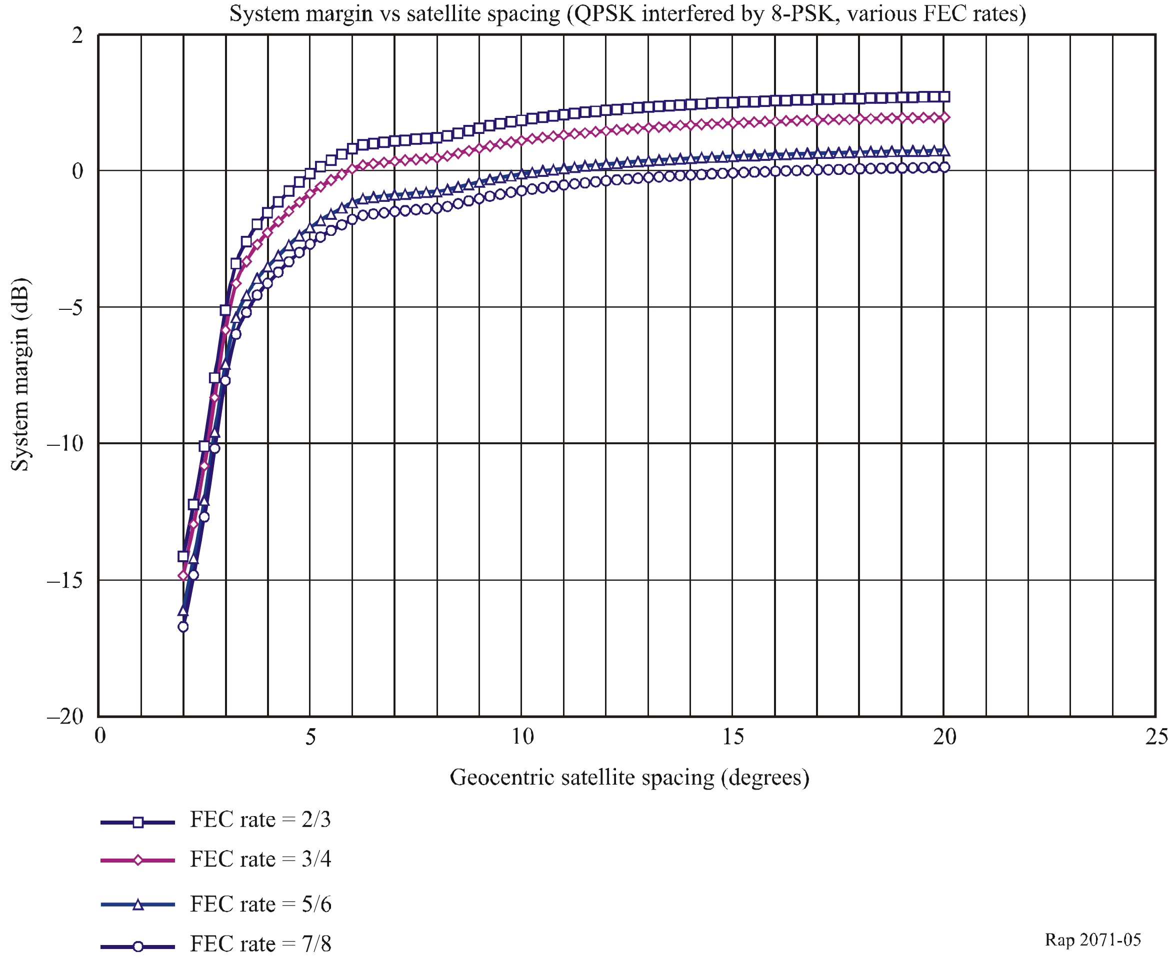


TABLE 3

	Increase in uplink and downlink power (dB)	Satellite spacing to achieve 0 dB system margin (degrees)
Homogeneous interfering model		
QPSK with FEC rate = 2/3	0	3.66
QPSK with FEC rate = 3/4	0	4.54
QPSK with FEC rate = 5/6	0	6.15
QPSK with FEC rate = 7/8	0	11.1
8-PSK with FEC = 2/3	3.66	5.57
Inhomogeneous interfering model		
QPSK with FEC rate = 2/3 interfered by 8-PSK	0	5.13
QPSK with FEC rate = 3/4 interfered by 8-PSK	0	5.96
QPSK with FEC rate = 5/6 interfered by 8-PSK	0	10.7
QPSK with FEC rate = 7/8 interfered by 8-PSK	0	17.25
8-PSK with FEC rate = 2/3 interfered by QPSK	3.66	3.97

Addendum 1
to Attachment 2 to Annex 1

System characteristics

	Wanted	Interfering 1	Interfering 2
Sat. longitude (W: −ve)	–95°	–99°	–103°
Channel bandwidth	25 MHz		
Uplink			
E.S. Tx pointing loss	0.5 dB		
Sat. Rx antenna gain	35 dBi		
Rx Sat system noise temp	730 K		
Availability	≥ 99.95%		
E.S. latitude	43.67°		
E.S. longitude	–79°		
Frequency	25 GHz		
Polarization	Circular		
E.S. Tx antenna size	5.6 m		
E.S. Tx power	22.2 dBW		
Combiner loss to antenna	2 dB		
E.S. Tx antenna gain	61.48 dBi		
E.S. Tx antenna pattern (co-pol)	AP 4 A, B, C, D, φ coefficients: 29, 25, 32, 25, 7°		
E.S. Tx antenna pattern (x-pol)	AP 4 A, B, C, D, φ coefficients: 19, 25, 32, 25, 7°		
Downlink			
E.S. latitude	29.7°		
E.S. longitude	–95.3°		
E.S. receive antenna size	0.45 m		
E.S. Rx antenna gain	36.49 dBi		
E.S. Rx noise temperature	170 K		
E.S. Rx antenna pattern co-pol	Refer to Annex 11 6S/349		
E.S. Rx antenna pattern x-pol	ITU-R BO.1213		
E.S. pointing loss	0.5 dB		
Availability	≥ 99.8%		
Type of modulation	QPSK		
BW shaping factor	1.35		
FEC rate	0.75		
RS coding	RS-188/204		
Frequency	17.55 GHz		
Polarization	Circular		
Sat. Tx power	22.2 dBW		
Sat Tx antenna gain	35 dBi		
Combiner losses to antenna	1 dB		

Addendum 2
to Attachment 2 to Annex 1

Error performance requirements[2]

Modulation	Inner code rate	Spectral efficiency (bit/symbol)	Modem implementation margin (dB)	Required E_b/N_0 (Note 1) for BER = 2×10^{-4} before RS QEF after RS (dB)
QPSK	1/2	0.92	0.8	4.5
	2/3	1.23	0.8	5.0
	3/4	1.38	0.8	5.5
	5/6	1.53	0.8	6.0
	7/6	1.61	0.8	6.4
8-PSK (optional)	2/3	1.84	1.0	6.9
	5/6	2.30	1.4	6.9
	8/9 (Note 3)	2.46	1.5	9.4
16-QAM (optional)	3/4 (Note 3)	2.76	1.5	9.0
	7/6	3.22	2.1	10.7

NOTE 1 – The figures of E_b/N_0 are referred to the useful bit-rate R_u (188 byte format, before RS coding) (so takes account of the factor 10 log 188/204 ≅ 0.36 dB due to the Reed-Solomon outer code) and include the modem implementation margins. For QPSK the figures are derived from EN 300 421.

For 8-PSK and 16-QAM, modem implementation margins which increase with the spectrum efficiency are adopted to cope with the larger sensitivity associated with these schemes.

NOTE 2 – Quasi-error-free (QEF) means approximately less than one uncorrected error event per hour at the input of the MPEG-s demultiplexer. Other residual error rate targets could be defined for “contribution quality” transmissions. The bit error ratio (BER) of 2×10^{-4} before RS decoding corresponds approximately to a byte error ratio between 7×10^{-4} and 2×10^{-3} depending on the coding scheme.

NOTE 3 – 8-PSK 8/9 is suitable for satellite transponders driven near saturation, while 16-QAM 3/4 offers better spectrum efficiency for quasi-linear transponders, in FDMA configuration.

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2 Table 5 from ETSI standard EN 301 210 V1.1.1. (DVB; Framing structure, channel coding and modulation for DSNG and other contribution applications by satellite.)

Attachment 3
to Annex 1

A further study of orbital separation requirements for BSS and associated feeder links in frequency bands 17.3-17.8 GHz and 24.75-25.25 GHz

1 Introduction

Using the same methodology as provided in Attachment 2 to Annex 1, this Attachment re-examines the impact of satellite separation on system performance for BSS systems using information provided in ETSI DVB-S.2 standard (Version EN 302 307 V1.1.1), http://webapp.etsi.org/WorkProgram/Report_WorkItem.asp?WKI_ID=19738.

2 Assumptions

The system characteristics used in the original analysis are listed in Attachment 2 to Annex 1. This analysis was carried out with the following new assumptions, which are obtained from the ETSI standard:

1 FEC encoding:

- Inner code: LDPC
- Outer code: BCH
- Frame length: 64 800 bits.

In this study, the inner code rate will be referred to as FEC rate. Please see Addendum 1 to Attachment 3 for a list of coding parameters.

2 Symbol rate: 27.5 MBd

3 Bandwidth: 35.75 MHz

4 Satellite transponder: dynamic pre-distortion with phase noise

5 In this study, the system uplink and downlink transmit powers are assumed to be the same value.

It should be noted that the draft ETSI DVB-S.2 standard gives error performance in terms of an ideal E_b/N_0, hence when calculating the link budgets an allowance needs to be included, represented as C/N degradation, to account for satellite channel impairments. In the ETSI standard, examples of satellite channel impairments were provided based on computer simulations using realistic satellite channel models. In this study, C/N degradation is taken into account as the modem implementation margin. The required E_b/N_0 is therefore calculated as:

$$\text{Required } E_b/N_0 = \text{Ideal } E_b/N_0 + \text{Modem implementation margin}$$

Please refer to Table 6 which lists the system error performance requirements with their corresponding $\left(\frac{C}{N}\right)_{threshold}$ values.

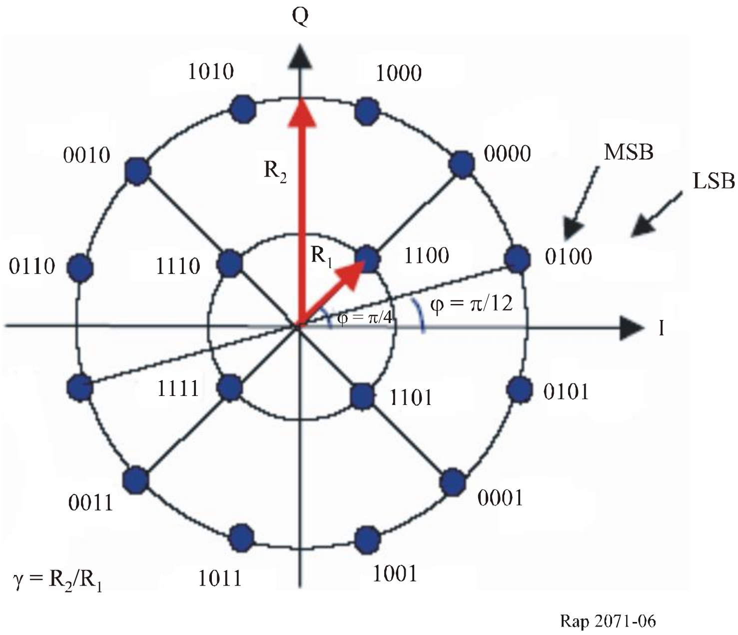
Furthermore, the ETSI DVB-S.2 standard contains two unconventional APSK modulation schemes, which are described below:

16-APSK

The I/Q constellation diagram representing 16-APSK modulation is composed of two concentric rings of uniformly spaced 4 and 12-PSK points, respectively in the inner ring of radius R_1 and outer ring of radius R_2.

FIGURE 6

16-APSK signal constellation

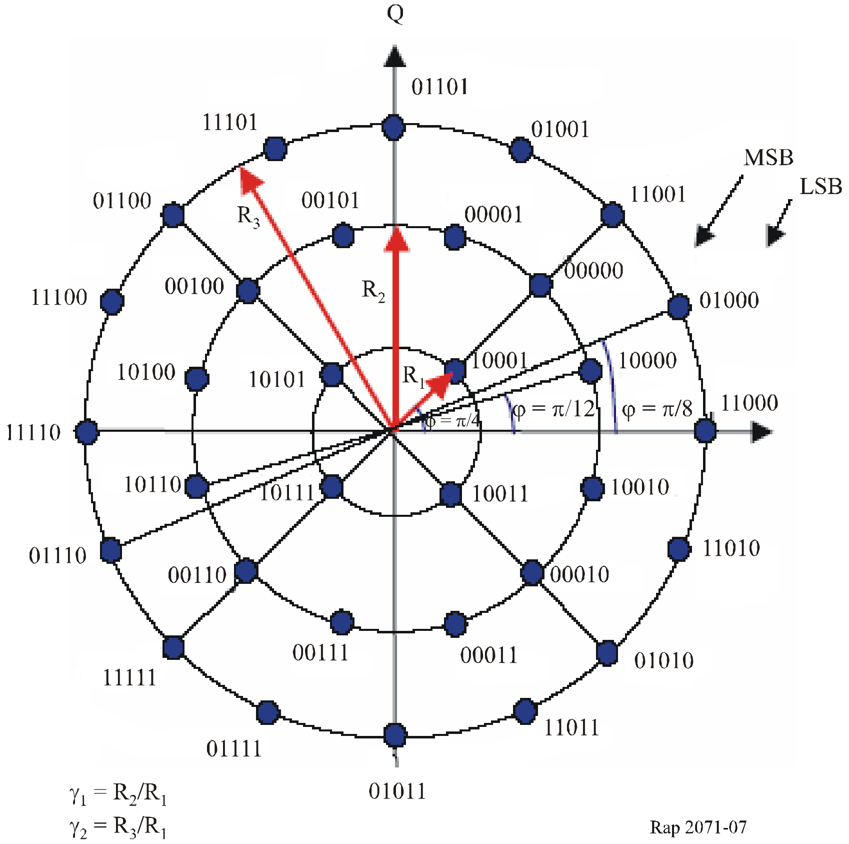


32-APSK

The I/Q constellation diagram representing the 32-APSK modulation is composed of three concentric rings of uniformly spaced 4, 12 and 16-PSK points, respectively in the inner ring of radius R_1, the intermediate ring of radius R_2 and the outer ring of radius R_3.

FIGURE 7

32-APSK signal constellation



3 Results

3.1 Homogeneous model for interfering system based on wanted system

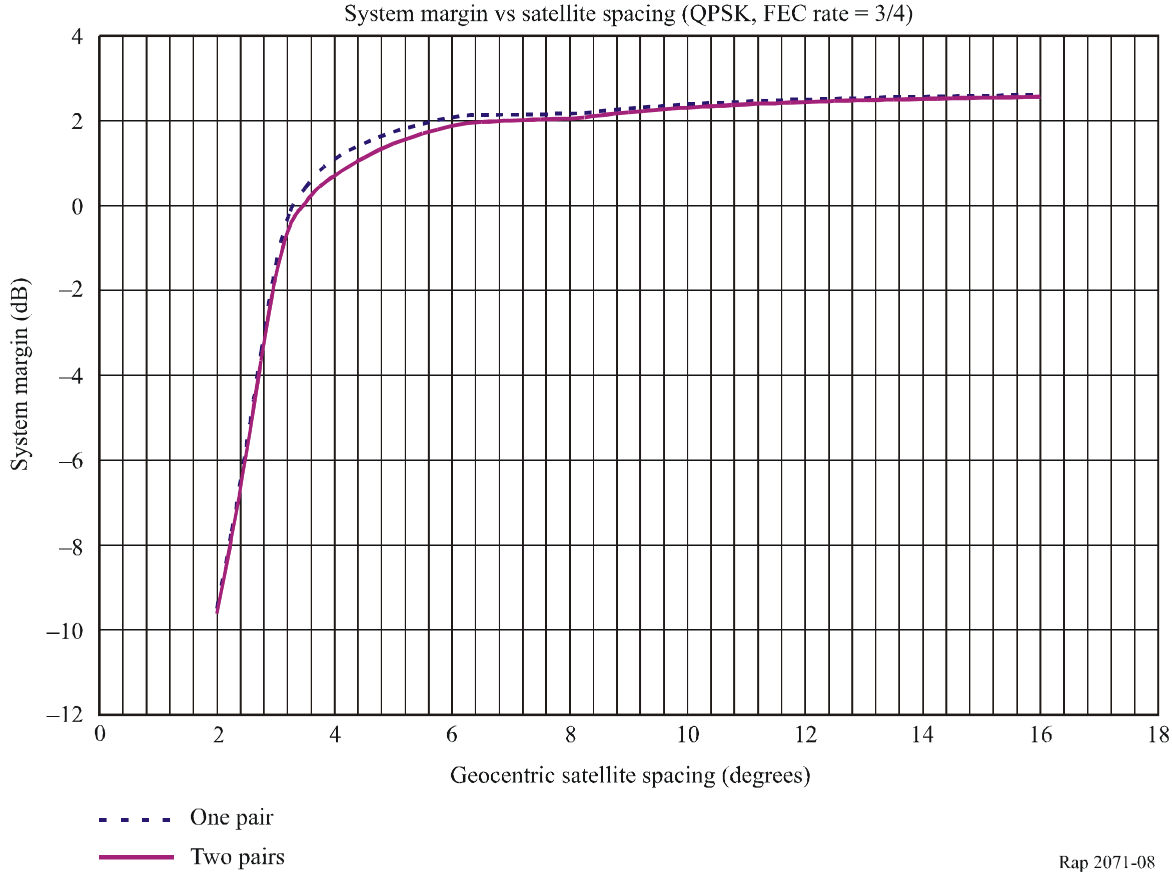
This section analyses the relationship between system performance and satellite spacing for one and two adjacent pairs of interfering satellites. The results are shown in Figs 8, 10 and 12. The system parameters were appropriately adjusted to limit the maximum orbital spacing requirement between satellites of 20°.

3.1.1 Case 1: using QPSK modulation

An FEC rate of 3/4, and a QPSK modulation scheme were used.

FIGURE 8

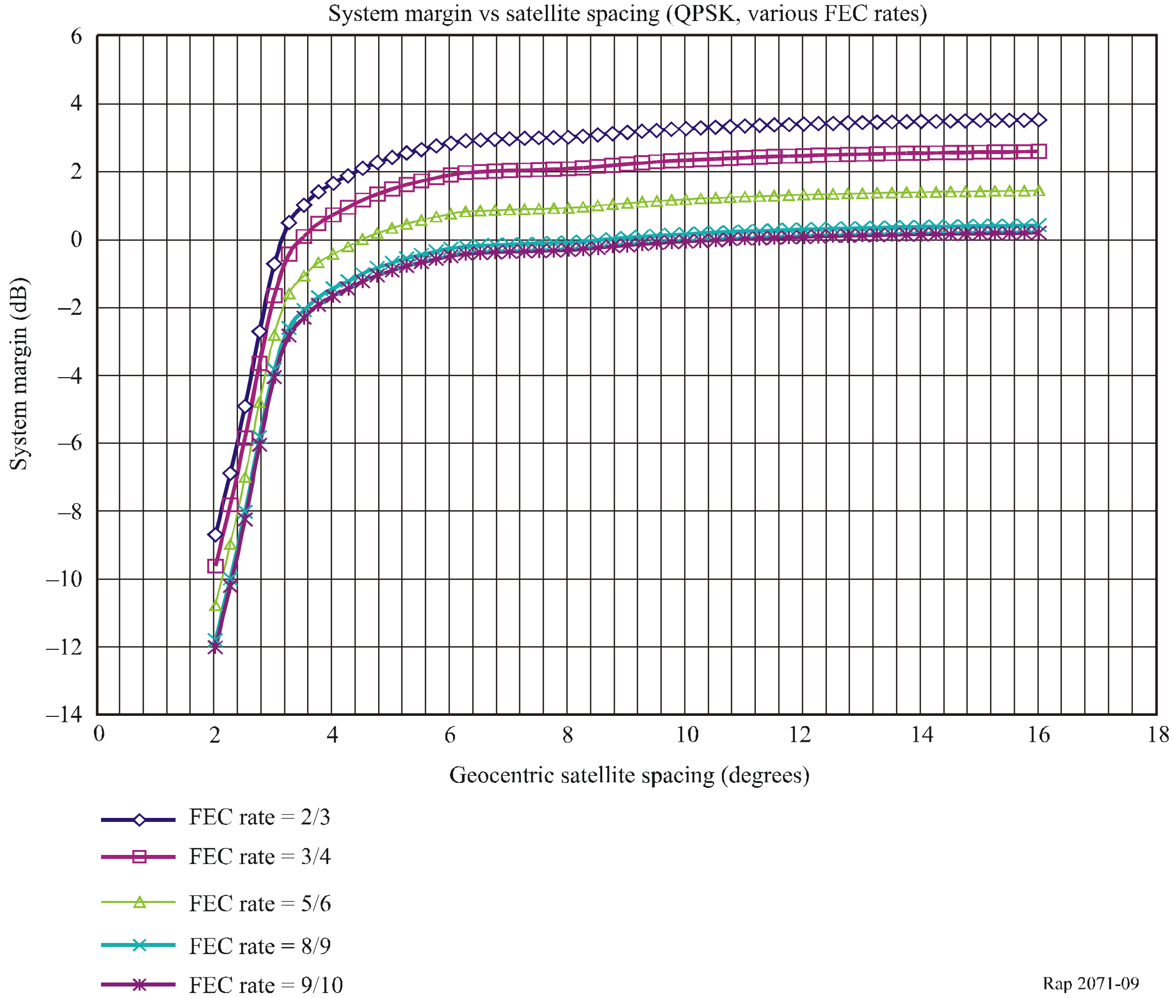
System margin vs. satellite spacing for system using QPSK



In order to study the effect of FEC rate on the system performance, analysis was performed to determine the relationship between system margin and satellite spacing for systems with various FEC rates. Figure 9 shows the analysis results.

FIGURE 9

System margin vs. satellite spacing for various FEC rates



3.1.2 Case 2: using 8-PSK modulation

A similar analysis to that of Case 1 was performed for systems using 8-PSK modulation and an FEC rate of 2/3. Due to the higher $(C/N)_{threshold}$ values resulting from the higher modulation level and maintaining the same receive earth station figure-of-merit, the transmit satellite power (downlink power) and the transmit earth station power (uplink power) have to be increased.

It is determined that the $(C/N)_{threshold}$ of an 8-PSK system is 3.75 dB higher than that of the QPSK system; therefore, an increase of 3.75 dB is applied to both the uplink and downlink powers of the 8-PSK system. Figure 10 shows the relationship between system performance and satellite spacing for a system using 8-PSK modulation, and Fig. 11 shows the effect of FEC rate on the system performance.

Figure 11 shows that for FEC rates of 8/9 and 9/10, the system margin will always be less than 0 dB. Therefore, an additional increase in uplink and downlink powers is needed. For an FEC rate of 8/9, an increase of 1.74 dB is necessary to have 0 dB system margin at 20° satellite spacing. For an FEC rate of 9/10, the transmit power increase is 2.19 dB.

FIGURE 10

System margin vs. satellite spacing for system using 8-PSK

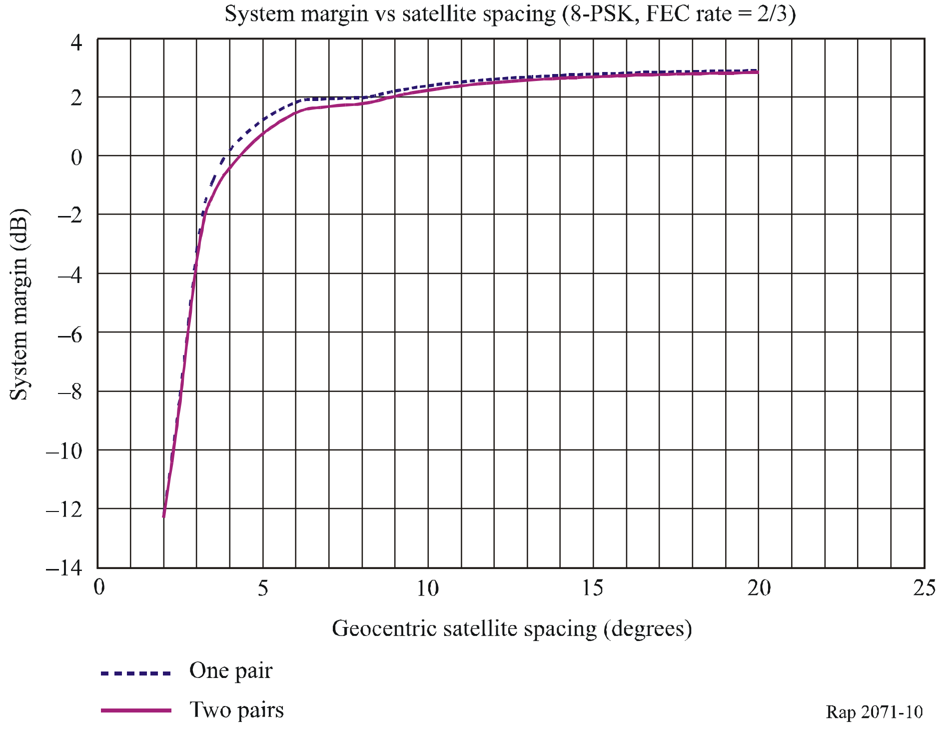
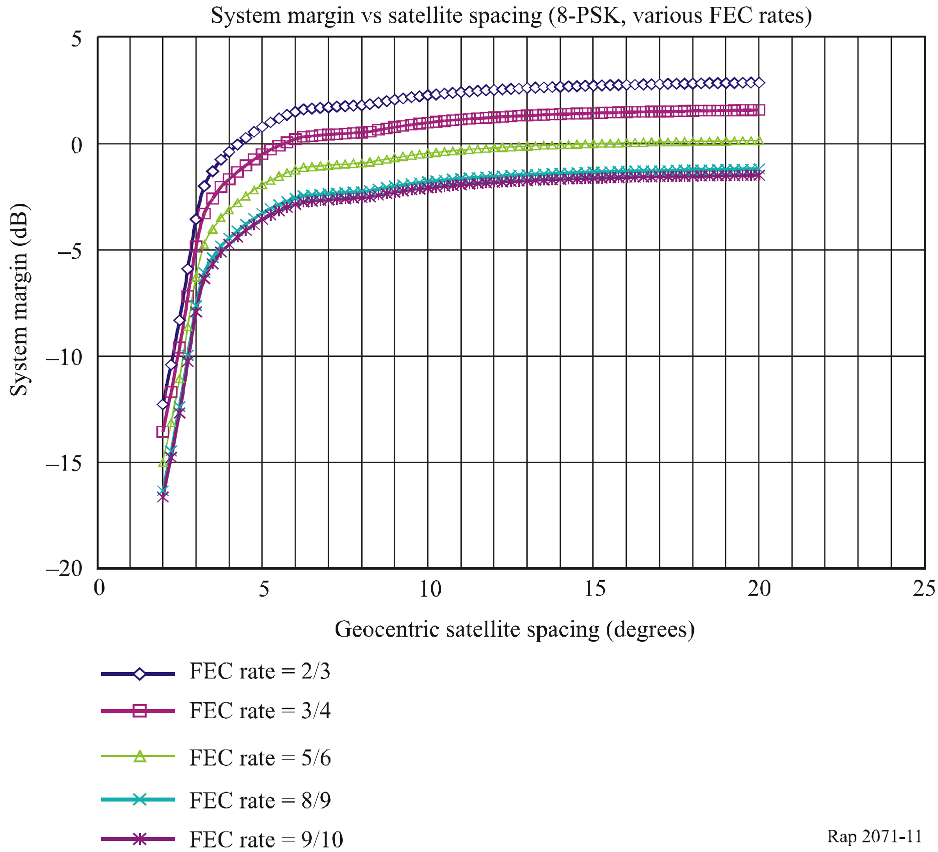


FIGURE 11

System margin vs. satellite spacing for various FEC rates



3.1.3 Case 3: using 16-APSK modulation

Analysis was also performed for systems using 16-APSK modulation and an FEC rate of 2/3. The $(C/N)_{threshold}$ of a 16-APSK system is 7.05 dB higher than that of the QPSK system therefore the uplink and downlink powers for the 16-APSK system were increased by this amount.

Figure 12 shows the relationship between system performance and satellite spacing for a system using 16-APSK modulation, and Fig. 13 shows the effect of FEC rate on the system performance.

From Fig. 13, it can be observed that for FEC rates of 5/6, 8/9 and 9/10, the system margin will always be less than 0 dB. Therefore, for FEC rates of 5/6, 8/9 and 9/10 additional increases of the feeder link and downlink e.i.r.p.s of 1.75 dB, 5.1 dB and 5.99 dB respectively are needed to achieve a 0 dB system margin at 20 degree satellite spacing.

FIGURE 12

System margin vs. satellite spacing for system using 16-APSK

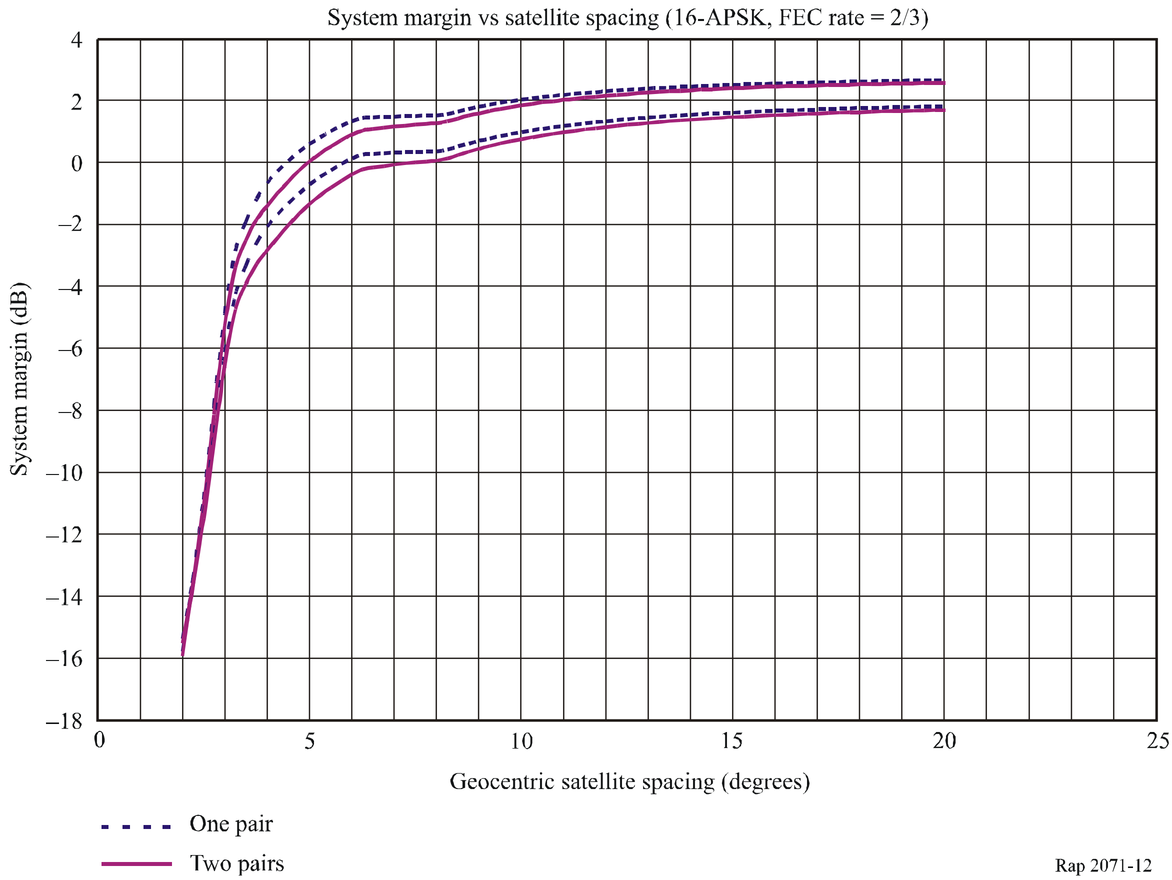
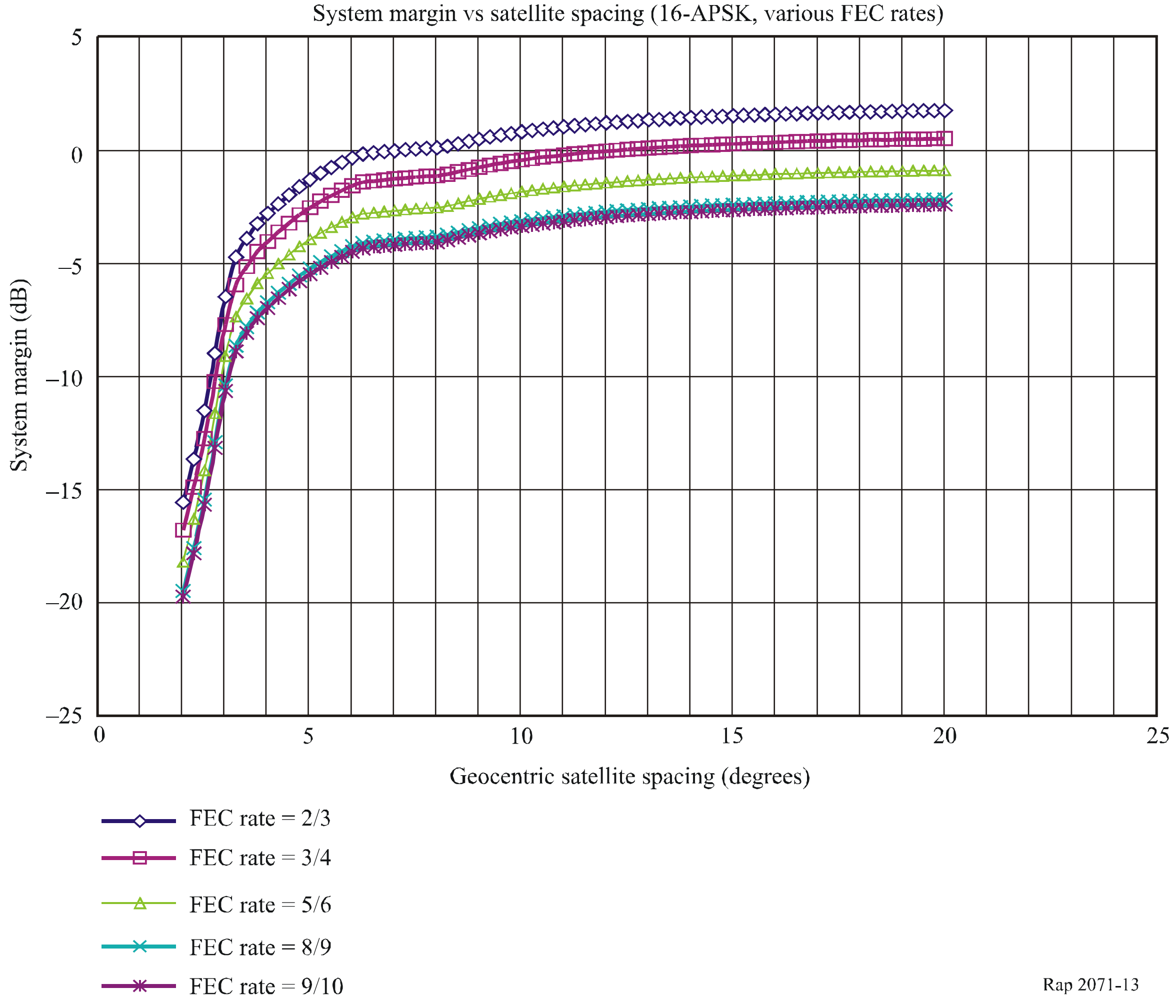


FIGURE 13

System margin vs. satellite spacing for various FEC rates

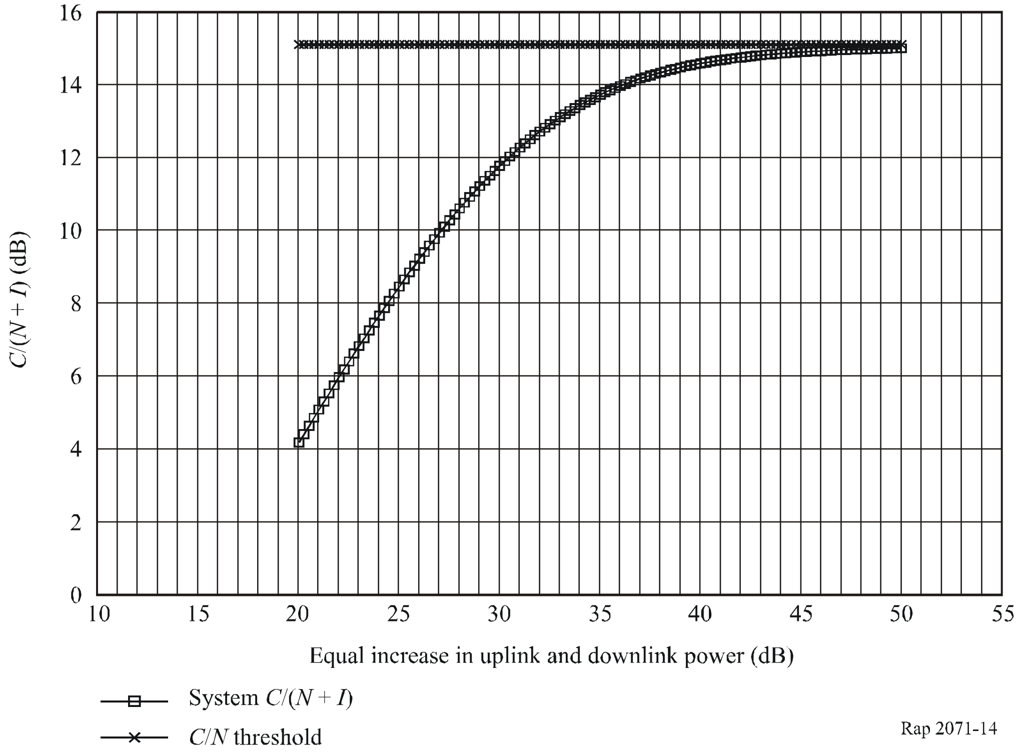


3.1.4 Case 4: using 32-APSK modulation

Similarly, analysis was performed for systems using 32-APSK modulation and an FEC rate of 3/4. However, in this case, it is impossible to achieve 0 dB system margin at 20° separation. As can be seen from Fig. 14, which plots the system $C/(N + I)$ versus uplink and downlink powers, the system $C/(N + I)$ curve is always less than the C/N threshold, even for transmit power increased by 50 dB. Thus, under the assumption of maintaining a fixed receive earth station performance 32-APSK modulation is not feasible. Although there are ways to improve the system $C/(N + I)$ to enable the operation of 32-APSK modulation, for example, improving receive earth station performance by increasing antenna size and/or lowering receiver noise temperature, decreasing the intra-system interference caused by rain depolarization by reducing the amount of frequency reuse, however these techniques go beyond the scope of this study.

FIGURE 14

***C*/(*N* + *I*) vs. uplink and downlink power for 32-APSK**



3.2 Inhomogeneous model for interfering system based on different modulation methods

To further study the effect of modulation method on the system performance, analyses were conducted for an inhomogeneous model involving systems using different modulation methods. Here, the interfering system uplink and downlink transmitting powers are referred to as interfering powers. From the point of view of the effect on the wanted satellite system, the result of changing the interfering system modulation is analogous to changing the transmit powers from the interfering systems. Thus the effect of using different modulation methods on the system performance can be examined by varying the interfering transmit powers and determining the required satellite spacing to achieve a 0 dB system margin. Again two adjacent pairs of interfering satellites are assumed.

The results of the analysis are presented in Figs 15, 16 and 17. The y-axis is the required orbital spacing for a system margin of 0 dB, and the x-axis is the difference between the interfering and wanted transmit power levels. It is assumed that the wanted and interfering systems have the same characteristics as given in § 3.1. Also, for these cases, a maximum orbital spacing of 30° is assumed.

FIGURE 15

Required satellite spacing to achieve 0 dB system margin vs. interfering transmitted power for QPSK

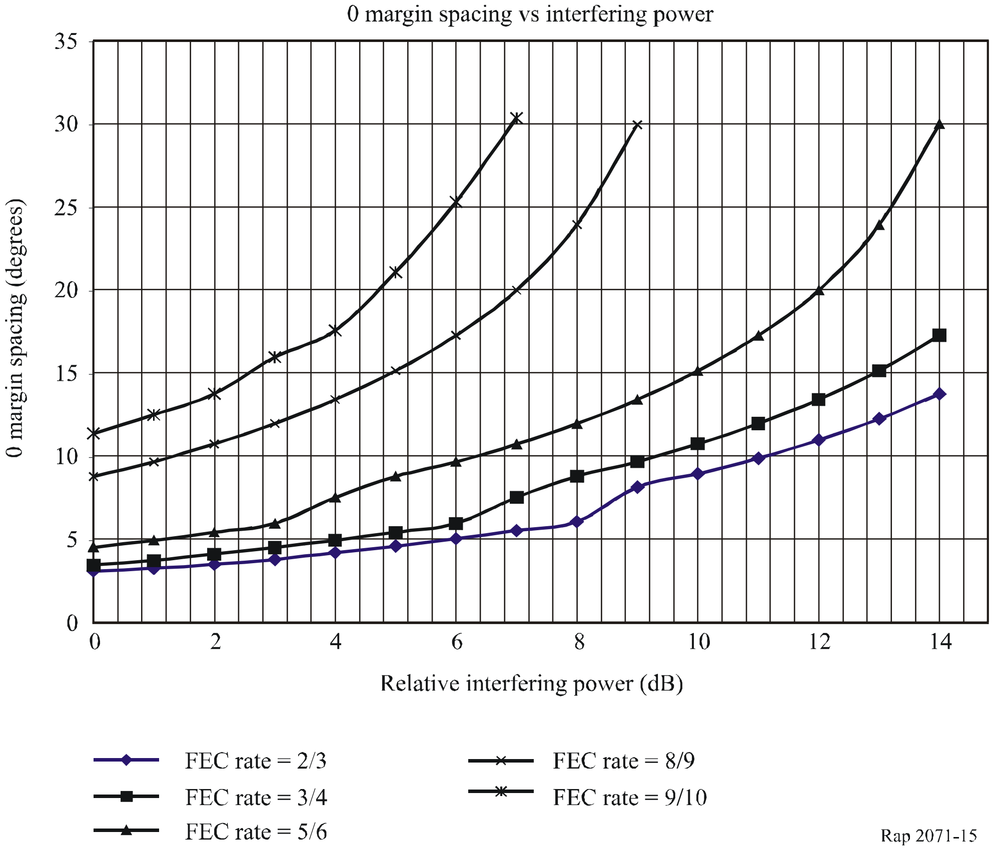


FIGURE 16

Required satellite spacing to achieve 0 dB system margin vs. interfering transmit power for 8-PSK

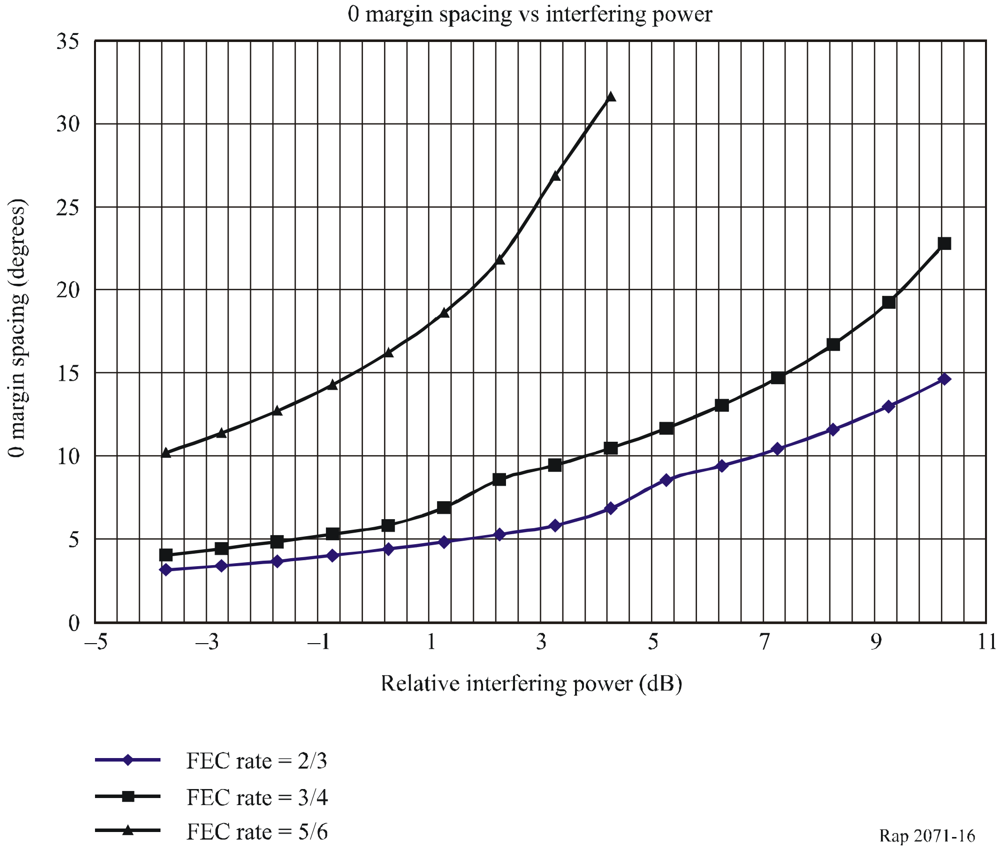
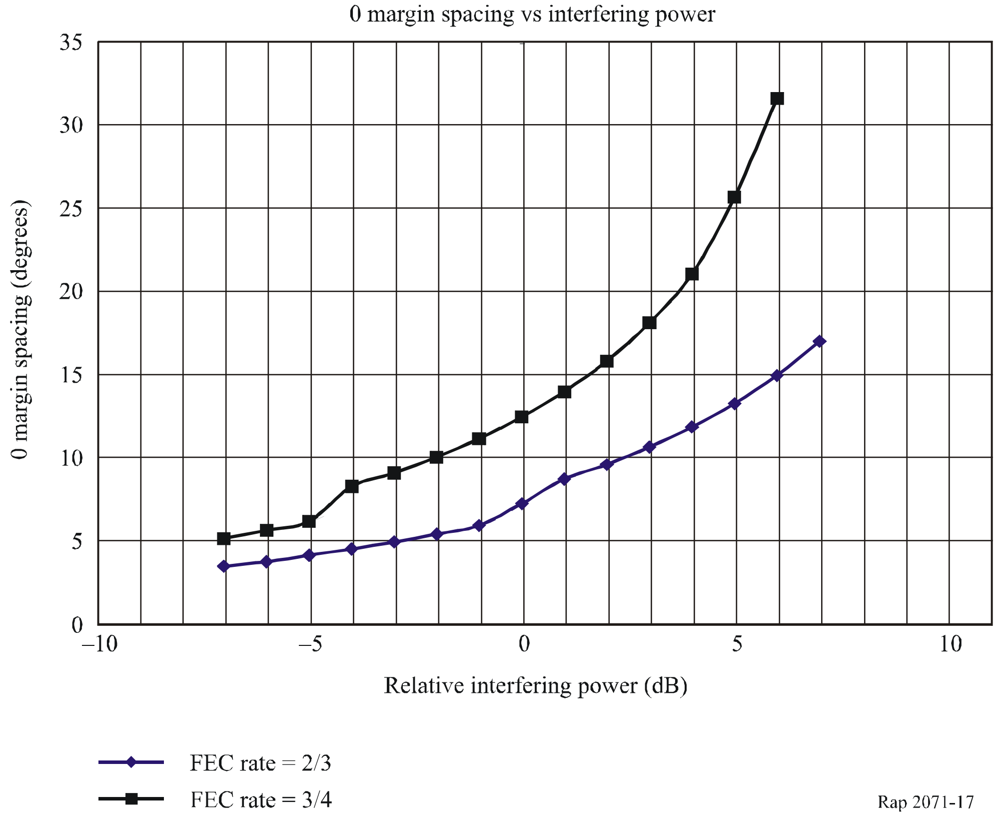


FIGURE 17

Required satellite spacing to achieve 0 dB system margin vs. interfering transmit power for 16-APSK



4 Conclusion

Using the system characteristics specified in the draft ETSI DVB-S.2 standard, this document studies the impact of satellite separation (intersystem interference) on system performance for BSS systems operating in the unplanned frequency band 17.3-17.8 GHz and associated 24.75-25.25 GHz feeder-link band. The results of the study are summarized in the following Figures and Tables.

It is recommended that the following text be included in the Report on system parameters for BSS systems in the unplanned 17.3-17.8 GHz and 24.75-25.25 GHz bands for future reference and review.

TABLE 4

Homogeneous interfering model

	Increase in uplink and downlink power (dB)	**Satellite spacing to achieve 0 dB excess system margin (degrees)**
QPSK		
FEC rate = 2/3	0	3.11
FEC rate = 3/4	0	3.47
FEC rate = 5/6	0	4.53
FEC rate = 8/9	0	8.80
FEC rate = 9/10	0	11.38
8-PSK		
FEC rate = 2/3	3.75	4.31
FEC rate = 3/4	3.75	5.69
FEC rate = 5/6	3.75	15.68
FEC rate = 8/9	5.49	20.00
FEC rate = 9/10	5.94	20.00
16-APSK		
FEC rate = 2/3	7.05	7.35
FEC rate = 3/4	7.05	12.50
FEC rate = 5/6	8.80	20.00
FEC rate = 8/9	12.15	20.00
FEC rate = 9/10	13.04	20.00

FIGURE 18

Case 1: Inhomogeneous interfering model: QPSK

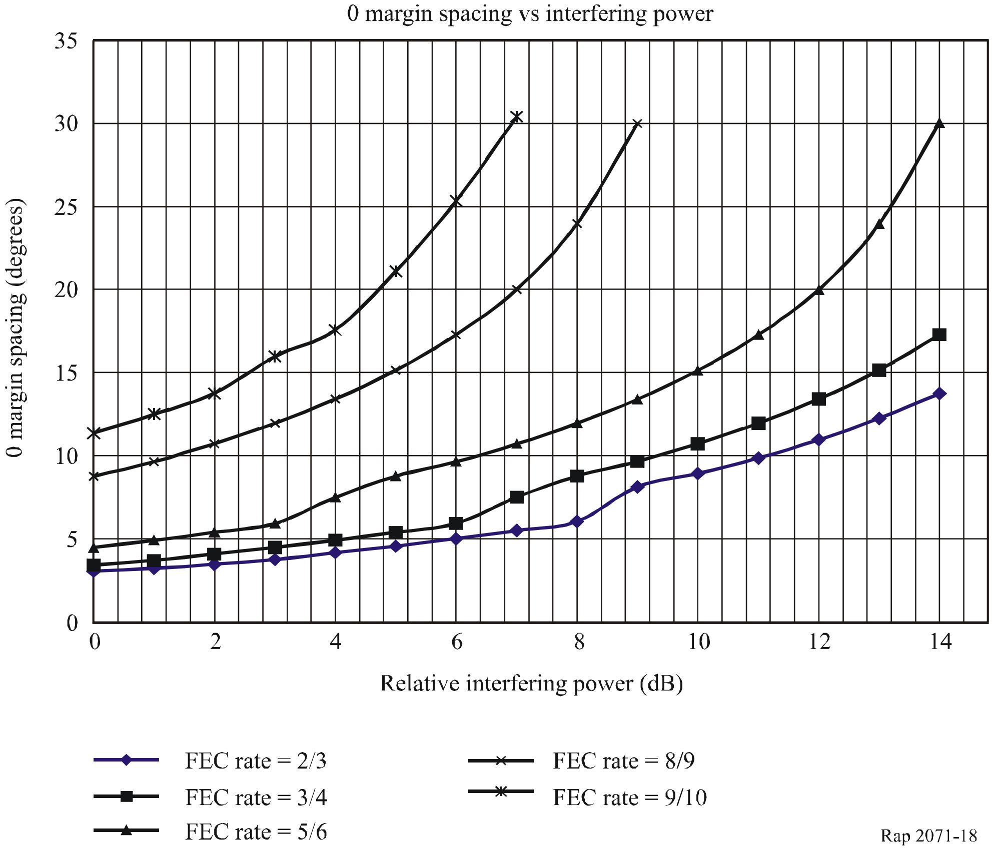


FIGURE 19

Case 2: Inhomogeneous interfering model: 8-PSK

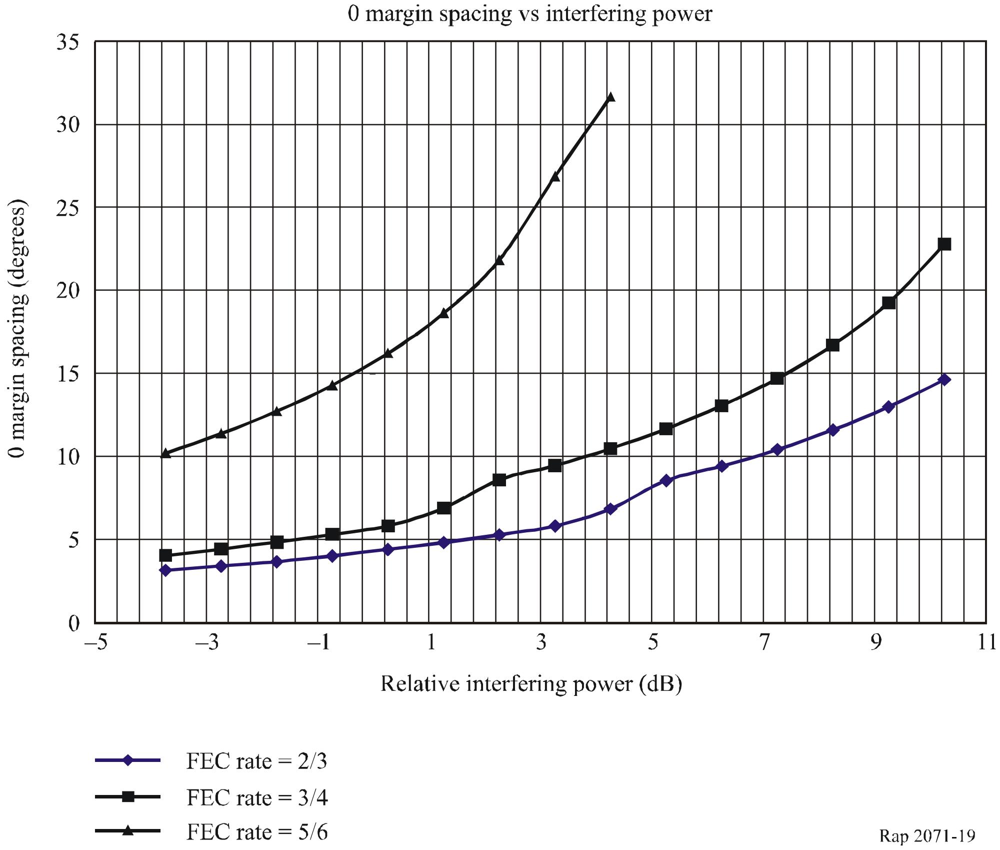


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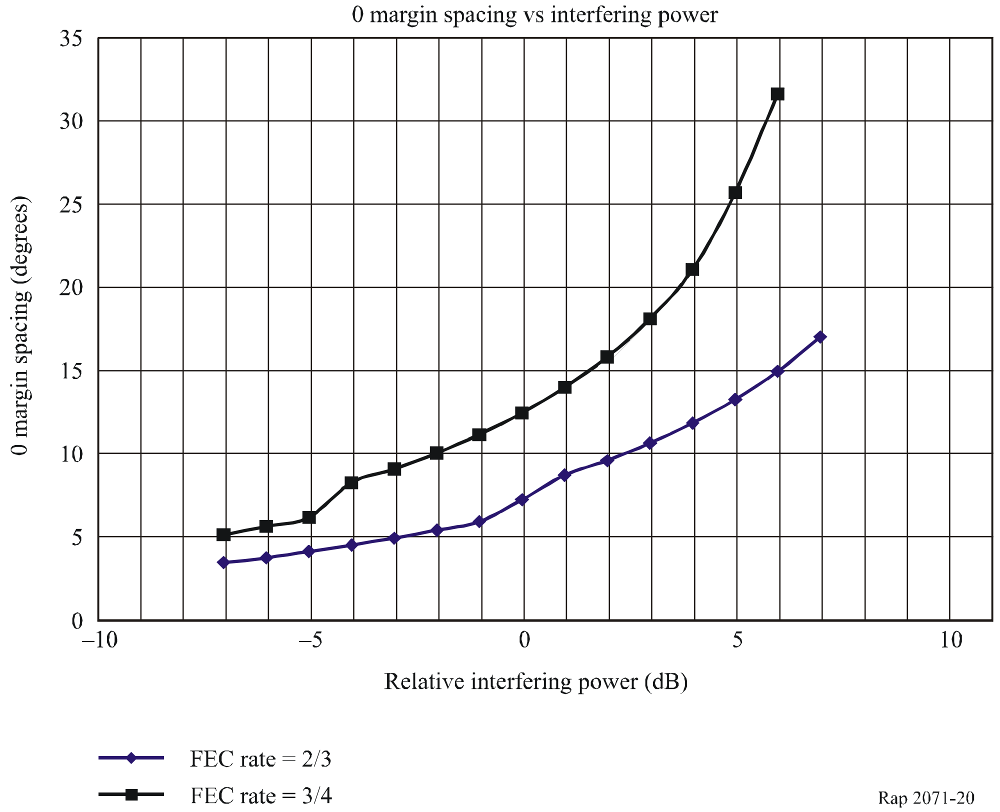
FIGURE 20

Case 3: Inhomogeneous interfering model: 16-APSK



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Addendum 1
to Attachment 3 to Annex 1

TABLE 5

FEC coding parameters*

LDPC code	BCH uncoded block K_{bch}	BCH coded block N_{bch} LDPC uncoded block K_{ldpc}	BCH *t*-error correction	LDPC coded block n_{ldpc}
1/4	16 008	16 200	12	64 800
1/3	21 408	21 600	12	64 800
2/5	25 728	25 920	12	64 800
1/2	32 208	32 400	12	64 800
3/5	38 688	38 800	12	64 800
2/3	43 040	43 200	10	64 800
3/4	48 408	48 600	12	64 800
4/5	51 648	51 840	12	64 800
5/6	53 840	54 000	10	64 800
8/9	57 472	57 600	8	64 800
9/10	58 192	58 320	8	64 800

* Table 5a from ETSI standard draft ETSI EN 302 307 V1.1.1 (Digital Video Broadcasting (DVB); Second generation framing structure, channel coding and modulation systems for Broadcasting, Interactive services, News Gathering and other broadband satellite applications).

Addendum 2
to Attachment 3 to Annex 1

TABLE 6

Error performance requirements*

Modulation	Inner code rate (FEC rate)	Ideal E_b/N_0 (dB)	Modem implementation margin (dB)	Required E_b/N_0 for BER = 10^{-7}	System C/N threshold (dB)
QPSK	2/3	1.8869	0.63	2.5169	2.61
	3/4	2.3055	0.63	2.9355	3.54
	5/6	2.9929	0.63	3.6229	4.69
	8/9	3.7290	0.63	4.3590	5.71
	9/10	3.8948	0.63	4.5248	5.93
8-PSK	2/3	3.6520	0.85	4.5020	6.36
	3/4	4.4306	0.85	5.2806	7.65
	5/6	5.4080	0.85	6.2580	9.09
	8/9	6.4641	0.85	7.3141	10.42
	9/10	6.6999	0.85	7.5499	10.71
16-APSK	2/3	4.7586	1.80	6.5586	9.66
	3/4	5.4872	1.80	7.2872	10.90
	5/6	6.4246	1.80	8.2246	12.30
	8/9	7.4207	1.80	9.2207	13.58
	9/10	7.6066	1.80	9.4066	13.82
32-APSK	3/4	7.0441	3.50	10.5441	15.13
	5/6	8.1315	3.50	11.6315	16.68
	8/9	9.2576	3.50	12.7576	18.08
	9/10	9.5634	3.50	13.0634	18.45

* Based on Table 14 and Table H.1.1 of ETSI standard draft ETSI EN 302 307 V1.1.1 (Digital Video Broadcasting (DVB); Second generation framing structure, channel coding and modulation systems for Broadcasting, Interactive services, News Gathering and other broadband satellite applications).

Annex 2

BSS system parameters in frequency band 21.4-22.0 GHz and associated feeder links

1 Introduction

The BSS systems in the band have the possibility to deliver wide-RF-band digital multiprogramme services of HDTV . In the future, they also can be appropriate channels to accommodate higher bit-rate programmes, such as Ultra-high definition television (UHDTV), three-dimensional TV and high bit-rate data programme. The parameter values for UHDTV systems were described in Recommendation ITU-R BT.2020-2. The 21 GHz band satellite broadcasting is expected to provide advanced services that will prevail in the future.

Taking into account the study results in accordance with Resolution **551 (WRC-07)**, the World Radiocommunication Conference (Geneva, 2012) (WRC-12) has established definitive arrangements for the use of this frequency band in accordance with Resolution **552 (WRC-12)**, Resolution **553 (WRC-12)**, Resolution **554 (WRC-12)** and Resolution **555 (WRC-12)**.

The Recommendation "Mitigation techniques for rain attenuation for BSS systems in frequency bands between 17.3 GHz and 42.5 GHz" was approved as Recommendation ITU-R BO.1659 (December 2003). Recommendation ITU-R BO.1659 includes the following techniques to mitigate the rain attenuation when considering facilitating the introduction of the BSS systems:

– increase in e.i.r.p.;

– hierarchical transmission;

– broadcasting system assuming storage in receiver.

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.

For certain countries having low-rain attenuation for BSS systems in frequency band 21.4-22.0 GHz, implementation of mitigation techniques as described in Recommendation ITU-R BO.1659 may not be required.

The system parameters might be different depending on the BSS systems in the band 21.4-22 GHz. It is encouraged that administrations submit contributions to progress the studies.

2 Downlink receiving earth station antenna patterns

The downlink receiving earth station antenna patterns for the 21 GHz band broadcasting in Regions 1 and 3 were measured and the reference antenna pattern for the broadcasting satellite service in the band 21.4-22 GHz in Region 1 and 3 is described in Recommendation ITU-R BO.1900.

3 Example of the 21 GHz band broadcasting satellites

This section deals with the following items for BSS systems:

– service availability;

– attenuation caused by precipitation and other meteorological factors;

– downlink e.i.r.p. or pfd;

– channel coding.

This section also presents examples of the 21 GHz band BSS utilizing the locally-variable e.i.r.p. system (see Recommendation ITU-R BO.1659) and shows required pfd values to overcome the large rain attenuation. In areas subject to high total link attenuation, the locally-variable e.i.r.p. system can significantly reduce the necessary total RF power compared to conventional systems.

3.1 Service availability for the BSS in the band 21.4-22 GHz

The downlink service availability of the 21 GHz band BSS is desired to be achieved at that of the 12 GHz band. Therefore, a service availability of 99.7-99.9% in a year or more is required for the 21 GHz band BSS to carry out real-time broadcasting.

3.2 Attenuation caused by precipitation and other meteorological factors in the band 21.4-22 GHz

The rain attenuations and atmospheric absorptions for some major cities in Regions 1 and 3 are tabulated in the § 5 of Appendix 1 to Annex 3 of Recommendation ITU-R BO.1659. An example of time percentage of rain attenuation calculated in Osaka and Luxembourg City by Recommendation ITU-R P.618-10 is depicted in Fig. 21A and Fig. 21B, respectively. In Osaka, the rain attenuations at 0.3% and 0.1% of time are 6.0 dB and 10.8 dB, respectively. The gaseous attenuation is 1.7 dB, the attenuation due to clouds is 1.12 dB, and the attenuation due to tropospheric scintillation is 0.42 dB. By using the equation (52) in § 2.5 of Recommendation ITU-R P.618-10, the total link attenuations at 0.3% and 0.1% of time become 8.9 dB and 13.7 dB, respectively. In Luxembourg City, the total link attenuation at 0.3% and 0.1% of time are 3.7 dB and 6.3 dB, respectively.

3.3 Downlink e.i.r.p. or pfd in the band 21.4-22 GHz

The example in Tables 7A and 7B shows the necessary pfd values, in Osaka and Luxembourg city, to achieve a service availability of 99.9% and 99.7% respectively, for various channel codings. The required *C*/*N* in this Table includes some degradations by actual hardware such as non-linear effects of satellite transponder, etc. The peak pfd ranges from -105.3 dB(W/(m^2 · 1 MHz)) to −115.6 dB(W/(m^2 · 1 MHz)) for a service availability of 99.9%, and from −110.4 dB(W/(m^2 · 1 MHz)) to −118.9 dB(W/(m^2 · 1 MHz)) for a service availability of 99.7%.

The downlink e.i.r.p. can be derived from the pfd value in Tables 7A and 7B and the bandwidth. The detail is discussed in the next section.

FIGURE 21A

Example of rain attenuation at 21.7 GHz in Osaka calculated by Recommendation ITU-R P.618-10

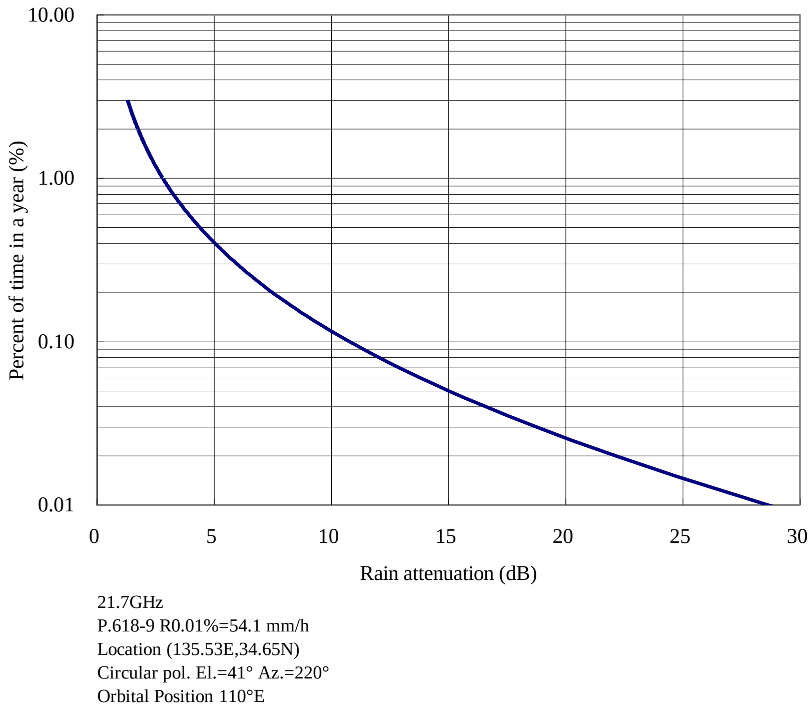
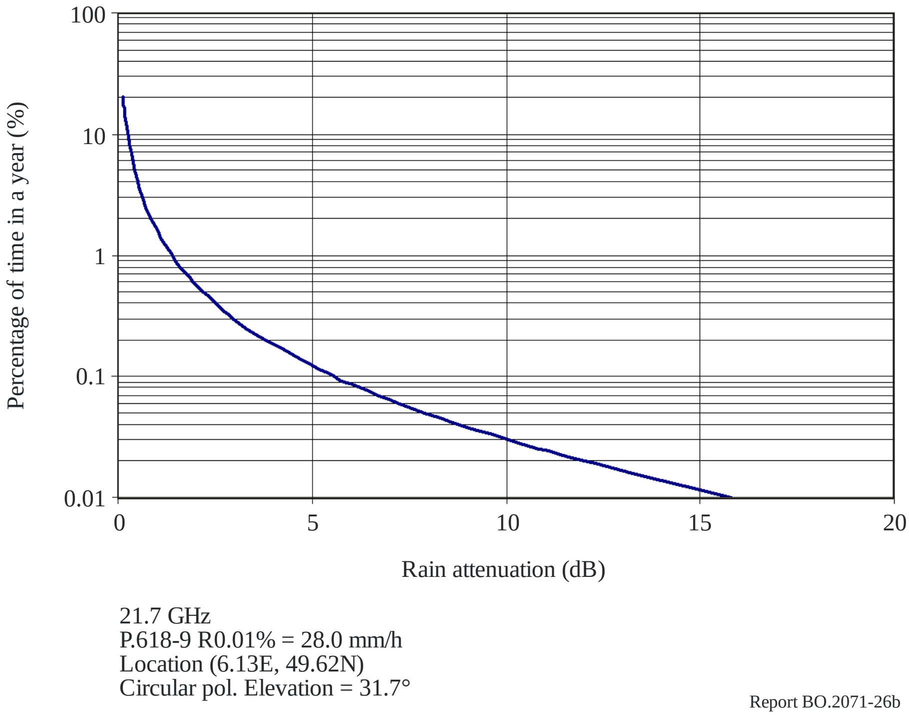


FIGURE 21B

Example of rain attenuation at 21.7 GHz in Luxembourg City calculated by Recommendation ITU-R P.618-10



Report BO.2071-26b

TABLE 7A

Examples of pfd values required to achieve a service availability of 99.9%

Modulation	Required C/N	Osaka		Luxembourg City	
		Edge (–3 dB) pfd values dB(W/(m² · 1 MHz))	Peak pfd values dB(W/(m² · 1 MHz))	Edge (–3 dB) pfd values dB(W/(m² · 1 MHz))	Peak pfd values dB(W/(m² · 1 MHz))
DVB-S QPSK1/2	4.4 dB	−114.8	−111.8	–118.6	–115.6
DVB-S2 QPSK3/4	5.6 dB	−113.6	−110.6	–117.4	–114.4
DVB-S QPSK3/4	7.5 dB	−111.6	−108.6	–115.5	–112.5
ISDB-S TC8-PSK	10.7 dB	−108.3	−105.3	–112.1	–109.1

TABLE 7B

Examples of pfd values required to achieve a service availability of 99.7%

Modulation	Required C/N	Osaka		Luxembourg City	
		Edge (–3 dB) pfd values dB(W/(m² · 1 MHz))	Peak pfd values dB(W/(m² · 1 MHz))	Edge (–3 dB) pfd values dB(W/(m² · 1 MHz))	Peak pfd values dB(W/(m² · 1 MHz))
DVB-S QPSK1/2	4.4 dB	−119.9	−116.9	–121.9	–118.9
DVB-S2 QPSK3/4	5.6 dB	−118.6	−115.6	–120.7	–117.7
DVB-S QPSK3/4	7.5 dB	−116.7	−113.7	–118.7	–115.7
ISDB-S TC8-PSK	10.7 dB	−113.4	−110.4	–115.4	–112.4

3.4 Examples of BSS utilizing the locally-variable e.i.r.p. system in the band 21.4-22 GHz

An array-fed phased-reflector antenna employing TWTs is considered as one of the promising satellite transmitting antenna techniques to achieve the locally-variable e.i.r.p. system (see Recommendation ITU-R BO.1659).

Examples of BSS parameters utilizing a locally-variable e.i.r.p. system are given in the Attachment to Annex 2. In this Attachment, parameters of calculated high performance antenna and manufactured simplified antenna are described in § 1 and § 2, respectively. The required RF powers for these examples are shown in Tables 8A and 8B. In these examples, required RF powers per 1 MHz are presented. Some examples of transmitting antenna gain patterns concerning each Table as follows can be referred to the following Attachment.

TABLE 8A

Required RF power for overcoming the rain attenuation of 11.1 dB

	Locally-variable e.i.r.p. system			**Uniform**
Boosted beam diameter (% vs. nationwide beam)	200 km (2%)	300 km (5%)	400 km (7%)	–
Boosted beam gain (–3 dB)	47.5 dBi	47.3 dBi	46.7 dBi	–
Wide area beam antenna gain	38.8 dBi	38.8 dBi	38.0 dBi	40.2 dBi
	Required specific RF power per MHz			
QPSK1/2	1.1 W/MHz	1.2 W/MHz	1.4 W/MHz	6.1 W/MHz
QPSK3/4	2.3 W/MHz	2.4 W/MHz	2.8 W/MHz	12.5 W/MHz
TC8-PSK	5.0 W/MHz	5.2 W/MHz	6.0 W/MHz	26.8 W/MHz

TABLE 8B

Required RF power for overcoming the rain attenuation of 6.1 dB

	Locally-variable e.i.r.p. system			**Uniform**
Boosted beam diameter (% vs. nationwide beam)	200 km (2%)	300 km (5%)	400 km (7%)	–
Boosted beam gain (−3 dB)	44.7 dBi	45.1 dBi	44.0 dBi	–
Wide area beam antenna gain	39.6 dBi	39.5 dBi	39.2 dBi	40.2 dBi
	Required specific RF power per MHz			
QPSK1/2	0.6 W/MHz	0.6 W/MHz	0.8 W/MHz	1.8 W/MHz
QPSK3/4	1.3 W/MHz	1.2 W/MHz	1.6 W/MHz	3.8 W/MHz
TC8-PSK	2.9 W/MHz	2.6 W/MHz	3.4 W/MHz	8.1 W/MHz

It can be seen from Tables 8A and 8B that by employing a locally-variable e.i.r.p. system, the transmitting power can be reduced by about 4 dB to 7 dB. It should be noted that in the locally-variable e.i.r.p. system, the pfd values of the wide area beam are significantly lower than the peak value. These lower pfd values should be taken into account in the sharing study. Examples of BSS link budget are shown in Table 9A.

3.5 Examples of BSS system in the band 21.4-22 GHz with no mitigation technique

In an area not subject to high total link attenuation, it should not be required to implement some mitigation technique to overcome the rain attenuation. Examples of BSS link budget are shown in Table 9B.

In these examples, the benefit of the limited impact due to the rain attenuation could be used to:

– limit the required RF power;

– reduce antenna size;

– increase information bit rate.

TABLE 9A

Examples of 21 GHz band BSS link budget for the locally variable e.i.r.p. system

Orbital position		110°E	
Uplink			
Uplink $C/(N + I)$		24 dB	
Downlink			
Coverage		Japan	
Tx antenna diameter		4 m	
No. of feed horns		188	
Modulation		TC-8PSK	
Symbol rate		246.7 Mbaud	
Rx antenna	Diameter	45 cm (Effic. = 70%, NF = 1.5 dB)	
	Location	Osaka	
	elevation	41.4 °	
	miss-point	0.5 dB	
Service availability in a year by boosted beam		99.7% (Rain attenuation: 6.0 dB)	99.9% (Rain attenuation: 10.8 dB)
Antenna gain at Boosted beam (−3 dB)		44.0 dBi (Fig. 25C)	46.7 dBi (Fig. 24C)
e.i.r.p. at Boosted beam (−3 dB)		73.1 dBW	78.1 dBW
pfd at Boosted beam (−3 dB)		−113.3 (dB(W/(m^2 · 1 MHz)))	−108.3 (dB(W/(m^2 · 1 MHz)))
Total atmospheric attenuation (dB)		8.9	13.7
Downlink C/N (dB)		11.0	10.9
Overall link C/N (dB)		10.8	10.7
Required C/N (dB)		10.7	
Margin (dB)		0.1	0.0

TABLE 9B

Examples of 21 GHz band BSS link budget with no mitigation technique

Orbital position	19.2°E					
Uplink						
Tx antenna diameter	3 m					
Uplink $C/(N+I)$	24 dB					
Downlink						
Coverage	Europe					
Modulation	DVB-S2 QPSK1/2	DVB-S2 QPSK3/4	DVB-S2 QPSK3/4	DVB-S2 QPSK3/4	DVB-S2 QPSK8/9	DVB-S2 8PSK3/4
pfd (−3 dB contour) (dB(W/(m^2 ・1MHz)))	−120	−120	−117	−120	−115	−115

TABLE 9B (*end*)

RX antenna	diameter (cm)	30	45	45	60	45	60
	Location	Luxembourg					
	elevation	31.7º					
	miss-point	0.5 dB					
Availability		99.70%	99.70%	99.90%	99.90%	99.90%	99.90%
Total link attenuation (dB)		3.7	3.7	6.3	6.3	6.3	6.3
Downlink *C*/*I* (dB)		29.7					
Downlink *C*/*(N*+*I)* (dB)		2.81	6.32	6.06	5.56	8.05	10.52
Overall							
Total *C*/(*N*+*I)* (dB)		2.78	6.25	5.99	5.50	7.94	10.33
Required *C*/*N* (dB)		2.80	5.60	5.60	5.60	7.90	9.80
Margin (dB)		−0.02	+0.65	+0.39	−0.10	+0.04	+0.53

3.6 Conclusion

Annex 2 to this Report presents the relation between pfd values and the service availability values for various channel coding. In order to overcome the large rain attenuation of 10.8 dB or 6.0 dB in Osaka, which corresponds to the service availability of 99.9 or 99.7% in a year, the peak pfd ranges between −105.3 dB(W/(m^2 · 1 MHz)) and −116.9 dB(W/(m^2 · 1 MHz)). For an area not subject to large rain attenuation, the same service availability could be reached with at least 3 dB reductions of the pfd values. It is also shown for the system described in § 3.4, that by employing a locally-variable e.i.r.p. system, the transmitting RF power can be reduced by 4 dB to 7 dB compared to the uniform beam system. For the locally-variable e.i.r.p. system, the minimum pfd values should be taken into account in the sharing study.

Attachment
to Annex 2

Examples of BSS parameters utilizing a locally-variable e.i.r.p. system

1 A locally-variable e.i.r.p. system using high performance antenna (calculated)

1.1 An example of high performance array-fed imaging reflector antenna

Examples of BSS parameters utilizing a locally-variable e.i.r.p. are given in this Attachment for various parameters.

– The service availability: 99.7%, 99.9% of a year.

– The rain attenuation: 6.0 dB for 99.7%, 10.8 dB for 99.9% of service availability.

– The diameter of a boosted beam: 200 km (2%), 300 km (5%), 400 km (7%) (% compared to the nationwide beam).

– Modulation: QPSK1/2, QPSK3/4, TC8-PSK.

In Figure 22, a locally-variable e.i.r.p. system consisting of multiple TWTAs for supplying power to each successive output filter and feed horn was studied. The outputs from each horn are combined in the imaging reflector antenna. The more the number of feed horns are increased, the more the output power and flexibility in reconfiguring the radiation pattern can be achieved. The diameter of onboard antenna is 4 m and the number of feed elements is 188. The radiation patterns are given in Fig. 23 (uniform beam), Fig. 24 (boosted beam has about 9 dB higher gain) and Fig. 25 (boosted beam has about 4 dB higher gain).

BSS system parameters, especially total RF power, are given for three cases as follows:

Case 1 – The diameter of the boosted beam is about 200 km. (Table 10).

Case 2 – The diameter of the boosted beam is about 300 km. (Table 11).

Case 3 – The diameter of the boosted beam is about 400 km. (Table 12).

In these examples, the required total RF powers for transmitting about 40 Mbit/s of information bit rate are given.

For example, the necessary peak pfd values are derived for TC8-PSK as follows:

– for 10.8 dB (99.9% of service availability): −105.3 dB(W/(m^2 · 1 MHz));

– for 6.0 dB (99.7% of service availability): −110.4 dB(W/(m^2 · 1 MHz)).

It is interesting to compare the necessary RF power for the uniform beam system (Fig. 23) and the locally-variable e.i.r.p. system (e.g., Fig. 24A). The antenna gain of the former is 40.2 dBi and the latter is 47.5 dBi and the difference between the two is about 7 dB. That means the necessary RF power differs by 7 dB for attaining the same service availability.

The difference in the antenna gain between the uniform beam system (40.2 dBi in Fig. 23) and the nationwide beam (38.8 dBi in Fig. 24A) is 1.4 dB. It can be said that by adding 1.4 dB more RF power to the uniform beam, 10.8 dB of rain attenuation can be overcome (the 99.9% of service availability can be achieved).

FIGURE 22

A locally-variable e.i.r.p. system consisting of multiple TWTAs studied for 21 GHz BSS

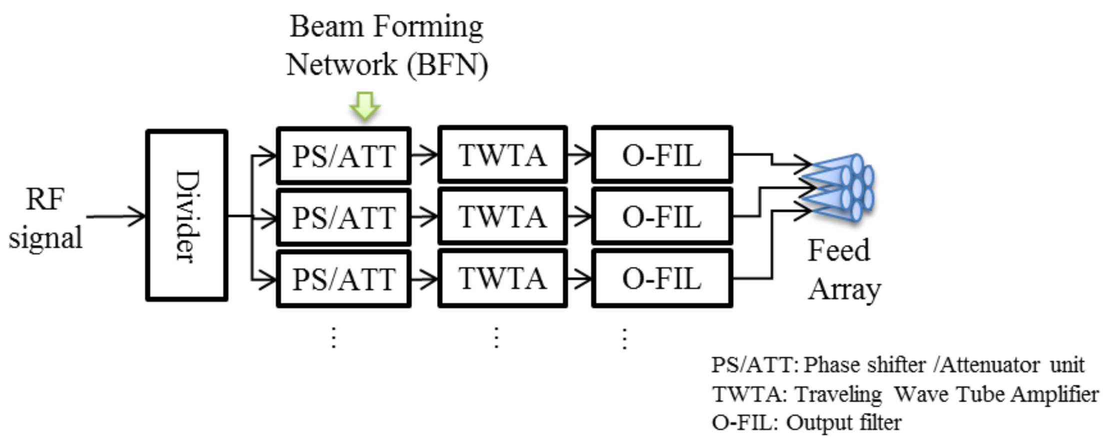


TABLE 10

Examples of 21 GHz band BSS parameters utilizing a locally-variable e.i.r.p. system

Link parameters (1)					
Uplink $C/(N + I)$	24 dB				
Tx antenna diameter	4 m				
Number of feed horns	188				
Receiving antenna	Dia. = 45 cm, Effic. = 70%, NF = 1.5 dB				
Information bit rate	About 40 Mbit/s			About 240 Mbit/s	About 480 Mbit/s
Modulation	**QPSK1/2**	**QPSK3/4**	**TC8-PSK**	**QPSK1/2**	**TC8-PSK**
Required C/N	4.4 dB	7.5 dB	10.7 dB	4.4 dB	10.7 dB
Channel bandwidth (99%)	54.2 MHz	35.4 MHz	26.4 MHz	252.3 MHz	
Symbol rate	45.2 MBd	29.6 MBd	22 MBd	246.7 MBd	
Required pfd (dB(W/(m^2 · 1 MHz))) (2)	−127.1	−123.9	−120.6	−127.1	−120.6
Case 1					
Service availability in a year by boosted beam	99.9% (Rain attenuation: 10.8 dB total attenuation: 13.7 dB)				
Antenna gain (Fig. 24A)	Boosted beam (−3 dB): 47.5 dBi Nationwide beam (min.): 38.8 dBi				
Total RF power (Fig. 26)	56.8 W	76.6 W	122.4 W	264.2 W	1169.5 W
RF power of 0 dB, −3 dB −6 dB, −10 dB elements (Fig. 26)	1.2 W, 0.6 W 0.3 W, 0.1 W	1.6 W, 0.8 W 0.4 W, 0.2 W	2.5 W, 1.3 W 0.6 W, 0.3 W	5.5 W, 2.8 W 1.4 W, 0.5 W	24.3 W, 12.2 W 6.1 W, 2.4 W
e.i.r.p. nationwide	56.3 dBW	57.6 dBW	59.7 dBW	63.0 dBW	69.5 dBW
e.i.r.p. boosted beam (–3 dB)	65.0 dBW	66.3 dBW	68.4 dBW	71.7 dBW	78.2 dBW
Peak pfd (dB(W/(m^2 · 1 MHz)))	−111.8	−108.6	−105.3	−111.8	−105.3
Boosted beam pfd (dB(W/(m^2 · 1 MHz)))	−114.8	−111.6	−108.3	−114.8	−108.3
Nationwide beam pfd (dB(W/(m^2 · 1 MHz)))	−123.5	−120.3	−117.0	−123.5	−117.0

TABLE 10 (*end*)

Case 2					
Service availability in a year by boosted beam	99.7% (Rain attenuation: 6.0 dB total attenuation: 8.9 dB)				
Antenna gain (Fig. 25A)	Boosted beam (−3 dB): 44.7 dBi Nationwide beam (min.): 39.5 dBi				
Total RF power (Fig. 26)	33.5 W	45.2 W	72.2 W	156.0 W	690.4 W
RF power of 0 dB, −3 dB −6 dB, −10 dB elements (Fig. 26)	0.7 W, 0.3 W 0.2 W, 0.1 W	0.9 W, 0.5 W 0.2 W, 0.1 W	1.5 W, 0.8 W 0.4 W, 0.2 W	3.2 W, 1.6 W 0.8 W, 0.3 W	14.4 W, 7.2 W 3.6 W, 1.4 W
e.i.r.p. nationwide	54.9 dBW	56.2 dBW	58.2 dBW	61.5 dBW	68.0 dBW
e.i.r.p. boosted beam (–3 dB)	60.0 dBW	61.3 dBW	63.3 dBW	66.6 dBW	73.1 dBW
Peak pfd (dB(W/(m^2 · 1 MHz)))	−116.9	−113.7	−110.4	−116.9	−110.4
Boosted beam pfd (dB(W/(m^2 · 1 MHz)))	−119.9	−116.7	−113.4	−119.9	−113.4
Nationwide beam pfd (dB(W/(m^2 ·1 MHz)))	−125.0	−121.8	−118.5	−125.0	−118.5

(1) The diameter of the boosted beam is 200 km and the information rate is about 40 Mbit/s, 240 Mbit/s and 480 Mbit/s.

(2) The required pfd overcomes attenuation including propagation losses due to clouds, gas and tropospheric scintillation.

TABLE 11

Examples of 21 GHz band BSS parameters utilizing a locally-variable e.i.r.p. system

Link parameters (1)					
Uplink $C/(N + I)$	24 dB				
Tx antenna diameter	4 m				
Number of feed horns	188				
Receiving antenna	Dia. = 45 cm, Effic. = 70%, NF = 1.5 dB				
Information bit rate	About 40 Mbit/s			About 240 Mbit/s	About 480 Mbit/s
Modulation	**QPSK1/2**	**QPSK3/4**	**TC8-PSK**	**QPSK1/2**	**TC8-PSK**
Required C/N	4.4 dB	7.5 dB	10.7 dB	4.4 dB	10.7 dB
Channel bandwidth (99%)	54.2 MHz	35.4 MHz	26.4 MHz	252.3 MHz	
Symbol rate	45.2 MBd	29.6 MBd	22 MBd	246.7 MBd	
Required pfd (dB(W/(m^2 · 1 MHz))) (2)	−127.1	−123.9	−120.6	−127.1	−120.6
Case 1					
Service availability in a year by boosted beam	99.9% (Rain attenuation: 10.8 dB total attenuation: 13.7 dB)				
Antenna gain (Fig. 24B)	Boosted beam (−3 dB): 47.5 dBi Nationwide beam (min.): 38.8 dBi				
Total RF power (Fig. 26)	59.4 W	80.2 W	128.1 W	276.7 W	1224.7 W
RF power of 0 dB, −3 dB −6 dB, −10 dB elements (Fig. 26)	1.2 W, 0.6 W 0.3 W, 0.1 W	1.7 W, 0.8 W 0.4 W, 0.2 W	2.7 W, 1.3 W 0.7 W, 0.3 W	5.8 W, 2.9 W 1.4 W, 0.6 W	25.5 W, 12.8 W 6.4 W, 2.5 W
e.i.r.p. nationwide	56.3 dBW	57.6 dBW	59.7 dBW	63.0 dBW	69.5 dBW
e.i.r.p. boosted beam (–3 dB)	65.0 dBW	66.3 dBW	68.4 dBW	71.7 dBW	78.2 dBW
Peak pfd (dB(W/(m^2 · 1 MHz)))	−111.8	−108.6	−105.3	−111.8	−105.3
Boosted beam pfd (dB(W/(m^2 · 1 MHz)))	−114.8	−111.6	−108.3	−114.8	−108.3
Nationwide beam pfd (dB(W/(m^2 · 1 MHz)))	−123.5	−120.3	−117.0	−123.5	−117.0

TABLE 11 (*end*)

Case 2					
Service availability in a year by boosted beam	99.7% (Rain attenuation: 6.0 dB total attenuation: 8.9 dB)				
Antenna gain (Fig. 25B)	Boosted beam (−3 dB): 44.7 dBi Nationwide beam (min.): 39.5 dBi				
Total RF power (Fig. 26)	30.6 W	41.2 W	65.9 W	142.3 W	629.7 W
RF power of 0 dB, −3 dB −6 dB, −10 dB elements (Fig. 26)	0.6 W, 0.3 W 0.2 W, 0.1 W	0.9 W, 0.4 W 0.2 W, 0.1 W	1.4 W, 0.7 W 0.3 W, 0.1 W	3.0 W, 1.5 W 0.7 W, 0.3W	13.1 W, 6.6 W 3.3 W, 1.3 W
e.i.r.p. nationwide	54.9 dBW	56.2 dBW	58.2 dBW	61.5 dBW	68.0 dBW
e.i.r.p. boosted beam (–3 dB)	60.0 dBW	61.3 dBW	63.3 dBW	66.6 dBW	73.1 dBW
Peak pfd (dB(W/(m^2 · 1 MHz)))	−116.9	−113.7	−110.4	−116.9	−110.4
Boosted beam pfd (dB(W/(m^2 · 1 MHz)))	−119.9	−116.7	−113.4	−119.9	−113.4
Nationwide beam pfd (dB(W/(m^2 ·1 MHz)))	−125.0	−121.8	−118.5	−125.0	−118.5

(1) The diameter of the boosted beam is 200 km and the information rate is about 40 Mbit/s, 240 Mbit/s and 480 Mbit/s.

(2) The required pfd overcomes attenuation including propagation losses due to clouds, gas and tropospheric scintillation.

TABLE 12

Examples of 21 GHz band BSS parameters utilizing a locally variable e.i.r.p. system

Link parameters (1)					
Uplink $C/(N+I)$	24 dB				
Tx antenna diameter	4 m				
No. of feed horns	188				
Receiving antenna	Dia. = 45 cm, Effic. = 70%, NF = 1.5 dB				
Information bit rate	About 40 Mbit/s			About 240 Mbit/s	About 480 Mbit/s
Modulation	**QPSK1/2**	**QPSK3/4**	**TC8-PSK**	**QPSK1/2**	**TC8-PSK**
Required C/N	4.4 dB	7.5 dB	10.7 dB	4.4 dB	10.7 dB
Channel bandwidth (99%)	54.2 MHz	35.4 MHz	26.4 MHz	252.3 MHz	
Symbol rate	45.2 MBd	29.6 MBd	22 MBd	246.7 MBd	
Required pfd (dB(W/(m^2 · 1 MHz))) (2)	−127.1	−123.9	−120.6	−127.1	−120.6
Case 1					
Service availability in a year by boosted beam	99.9% (Rain attenuation: 10.8 dB total attenuation: 13.7 dB)				
Antenna gain (Fig. 24C)	Boosted beam (–3 dB): 46.7 dBi Nationwide beam (min.): 38.0 dBi				
Total RF power (Fig. 26)	68.2 W	92.1 W	147.1 W	317.7 W	1406.1 W
RF power of 0 dB, −3 dB −6 dB, −10 dB elements (Fig. 26)	1.4 W, 0.7 W 0.4 W, 0.1 W	1.9 W, 1.0 W 0.5 W, 0.2 W	3.1 W, 1.5 W 0.8 W, 0.3 W	6.6 W, 3.3 W 1.7 W, 0.7W	29.3 W, 14.7 W 7.4 W, 2.9 W
e.i.r.p. nationwide	56.3 dBW	57.6 dBW	59.7 dBW	63.0 dBW	69.5 dBW
e.i.r.p. boosted beam (–3 dB)	65.0 dBW	66.3 dBW	68.4 dBW	71.7 dBW	78.2 dBW
Peak pfd (dB(W/(m^2 · 1 MHz)))	−111.8	−108.6	−105.3	−111.8	−105.3
Boosted beam pfd (dB(W/(m^2 · 1 MHz)))	−114.8	−111.6	−108.3	−114.8	−108.3
Nationwide beam pfd (dB(W/(m^2 · 1 MHz)))	−123.5	−120.3	−117.0	−123.5	−117.0

TABLE 12 (*end*)

Case 2					
Service availability in a year by boosted beam	99.7% (Rain attenuation: 6.0 dB total attenuation: 8.9 dB)				
Antenna gain (Fig. 25C)	Boosted beam (–3 dB): 44.0 dBi Nationwide beam (min.): 39.1 dBi				
Total RF power (Fig. 26)	39.4 W	53.1 W	84.9 W	183.3 W	811.2 W
RF power of 0 dB, −3 dB −6 dB, −10 dB elements (Fig. 26)	0.8 W, 0.4 W 0.2 W, 0.1 W	1.1 W, 0.6 W 0.3 W, 0.1 W	1.8 W, 0.9 W 0.4 W, 0.2 W	3.8 W, 1.9 W 1.0 W, 0.4 W	16.9 W, 8.5 W 4.2 W, 1.7 W
e.i.r.p. nationwide	54.9 dBW	56.2 dBW	58.2 dBW	61.5 dBW	68.0 dBW
e.i.r.p. boosted beam (–3 dB)	60.0 dBW	61.3 dBW	63.3 dBW	66.6 dBW	73.1 dBW
Peak pfd (dB(W/($m^2 \cdot$ 1 MHz)))	−116.9	−113.7	−110.4	−116.9	−110.4
Boosted beam pfd (dB(W/($m^2 \cdot$ 1 MHz)))	−119.9	−116.7	−113.4	−119.9	−113.4
Nationwide beam pfd (dB(W/($m^2 \cdot$ 1 MHz)))	−125.0	−121.8	−118.5	−125.0	−118.5

(1) The diameter of the boosted beam is 400 km and the information rate is about 40 Mbit/s, 240 Mbit/s and 480 Mbit/s)

(2) The required pfd overcomes attenuation including propagation losses due to clouds, gas and tropospheric scintillation.

FIGURE 23

Gain contour of onboard satellite antenna (uniform beam)

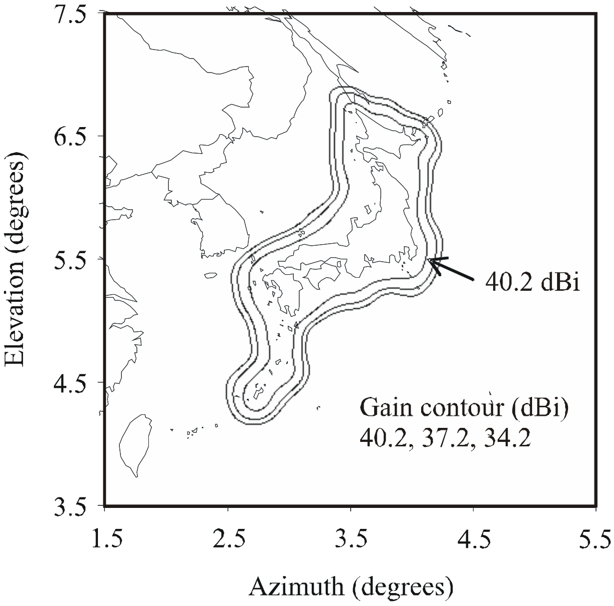


FIGURE 24A

200 km boosted and nationwide beam for service availability of 99.9%

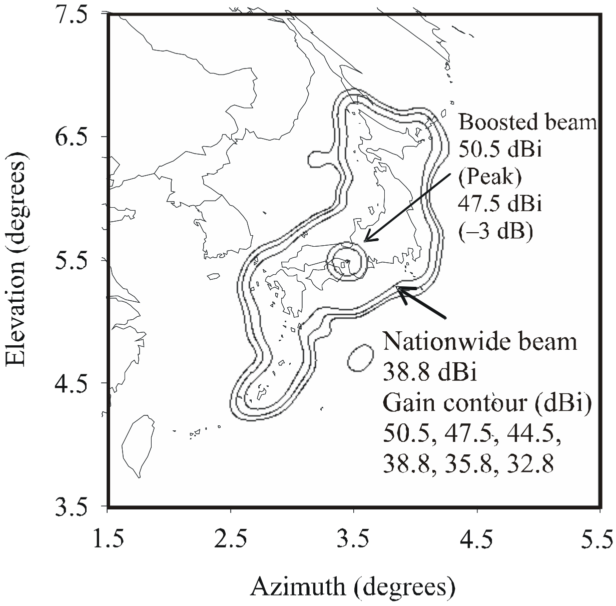


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FIGURE 24B

300 km boosted and nationwide beam for service availability of 99.9%

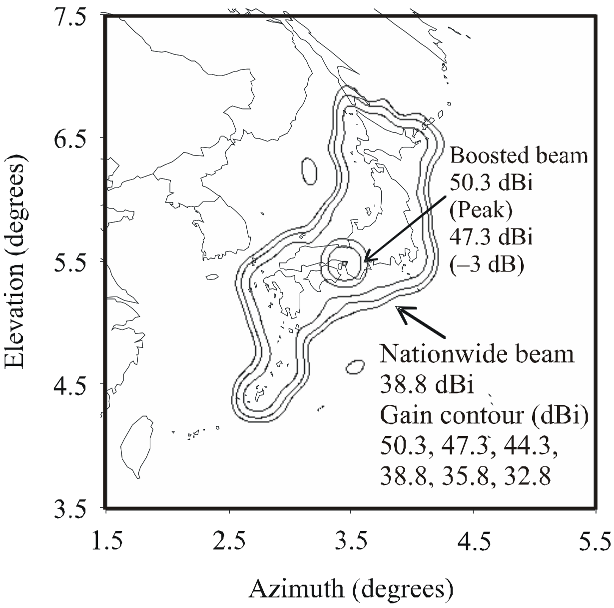

FIGURE 24C

400 km boosted and nationwide beam for service availability of 99.9%

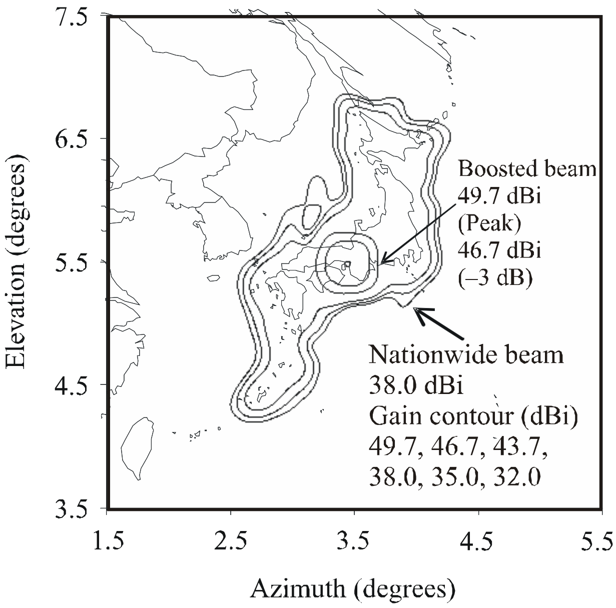

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FIGURE 25A

200 km boosted and nationwide beam for service availability of 99.7%

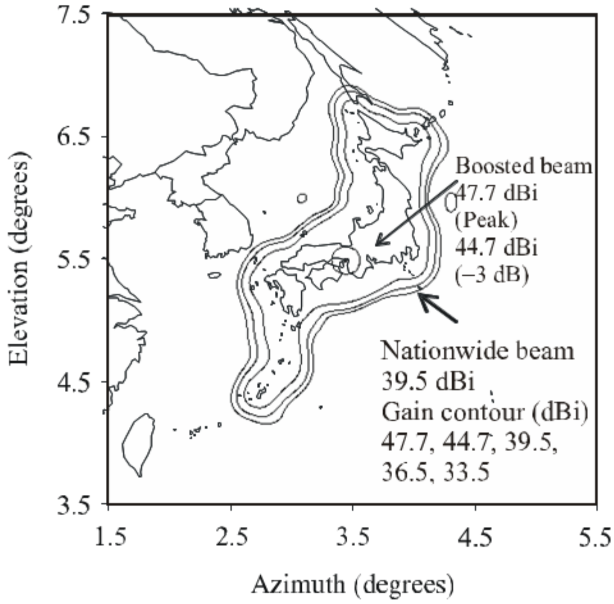
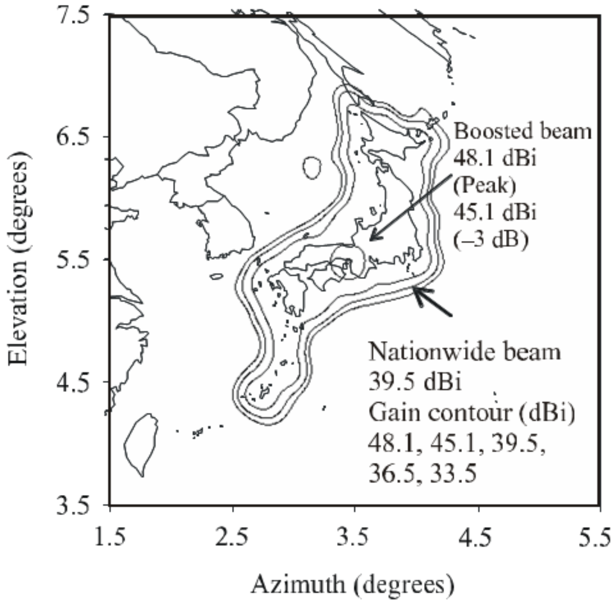


FIGURE 25B

300 km boosted and nationwide beam for service availability of 99.7%



Rap 2071-26a26b

FIGURE 25C

400 km boosted and nationwide beam for service availability of 99.7%

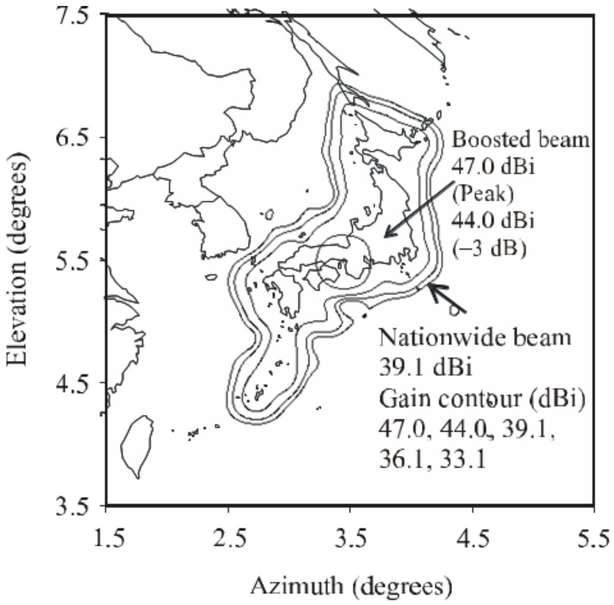
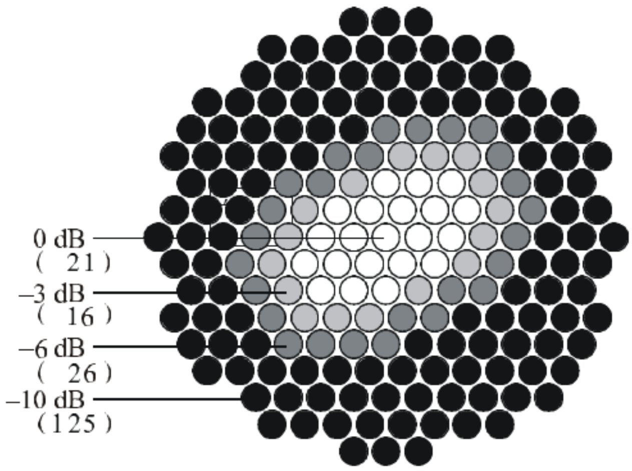


FIGURE 26

Distribution of RF power in the feed array



Rap 2071-26c27

1.2 A study of antenna radiation pattern of a variable e.i.r.p. broadcasting-satellite system in the 21 GHz band

Sidelobe characteristics of satellite transmitting antenna are evaluated to reflect a rain attenuation compensating system with a phased array antenna in the Plan of BSS in the 21 GHz band. To evaluate the characteristics, grid points are set in countries surrounding Japan and the maximum sidelobe level and its location are detected for each country. Furthermore, a radiation pattern that can appear on a cut plane between the location of maximum sidelobe level and the centre of planned beam for Japan used for the Plan of BSS in the 12 GHz band is calculated for each country surrounding Japan.

1.2.1 Simulation of radiation pattern design

The satellite orbital location is assumed 110E. The shape of nationwide beam is approximated like the shape of Japanese territory. Grid points are set in countries surrounding Japan and the maximum sidelobe level and its location are detected for each country. Figure 27 shows constraint points used for the design of radiation pattern of satellite transmitting antenna and cities in Japan where a boosted beam is formed. Figure 28 shows the gain evaluation points to detect sidelobe level. In this simulation, the normal vector to define a zero point for each azimuth and elevation direction points the centre of Earth.

The comparison of the pattern mask in the 12 GHz band and the radiation patterns at a cut plane in this study is conducted in the way prescribed as follows:

a) The gain of radiation pattern of cut plane is corrected to keep the antenna gain for a boosted beam generated for Wakkanai city below the antenna mask level for main beam.

b) The angle for horizontal axis is normalized by a half angle width of the planned beam of the 12 GHz band.

Figure 29 shows the evaluation results. From this Figure, it is found that the radiation pattern does not exceed the antenna mask referred to RR Appendix **30**, Annex 5, § 3.13.3.

FIGURE 27

Constraint points to design the radiation pattern and cities in Japan where a boosted beam is formed

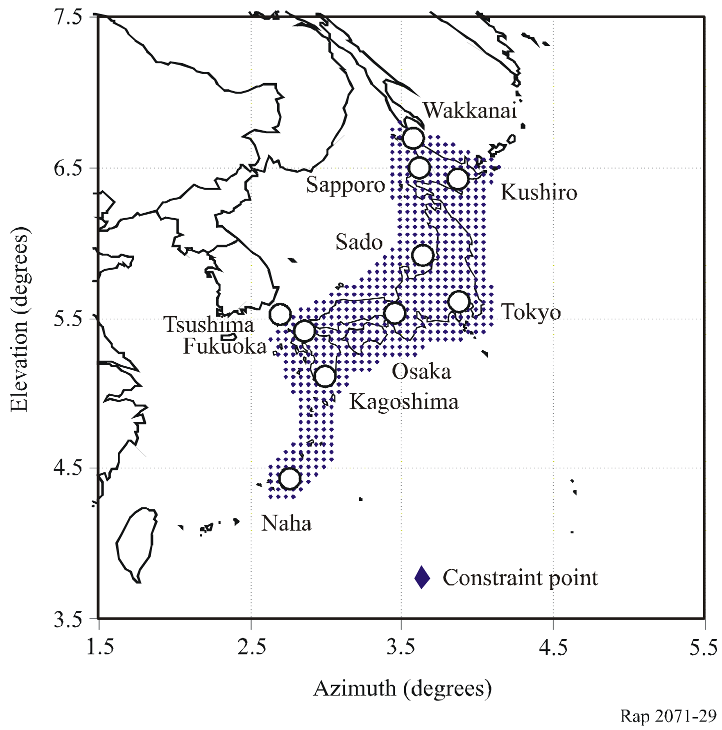
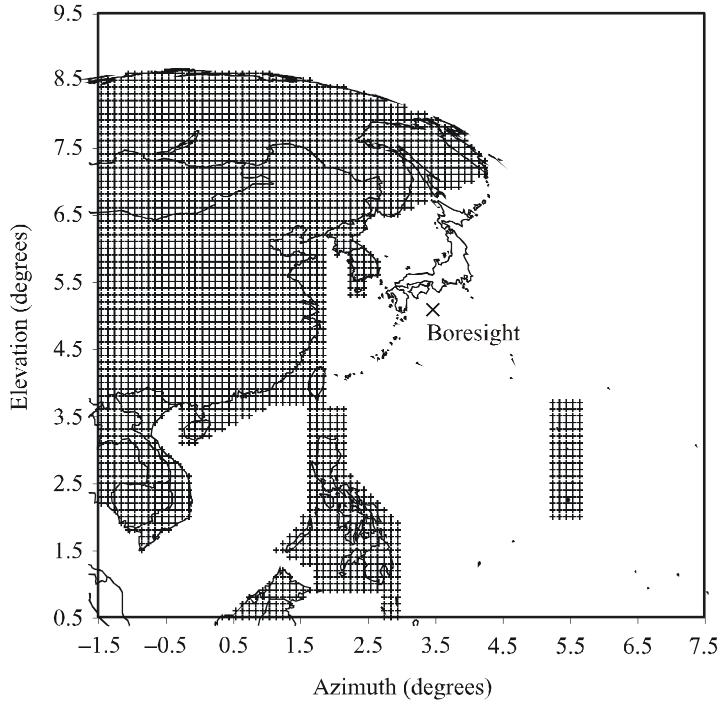


FIGURE 28

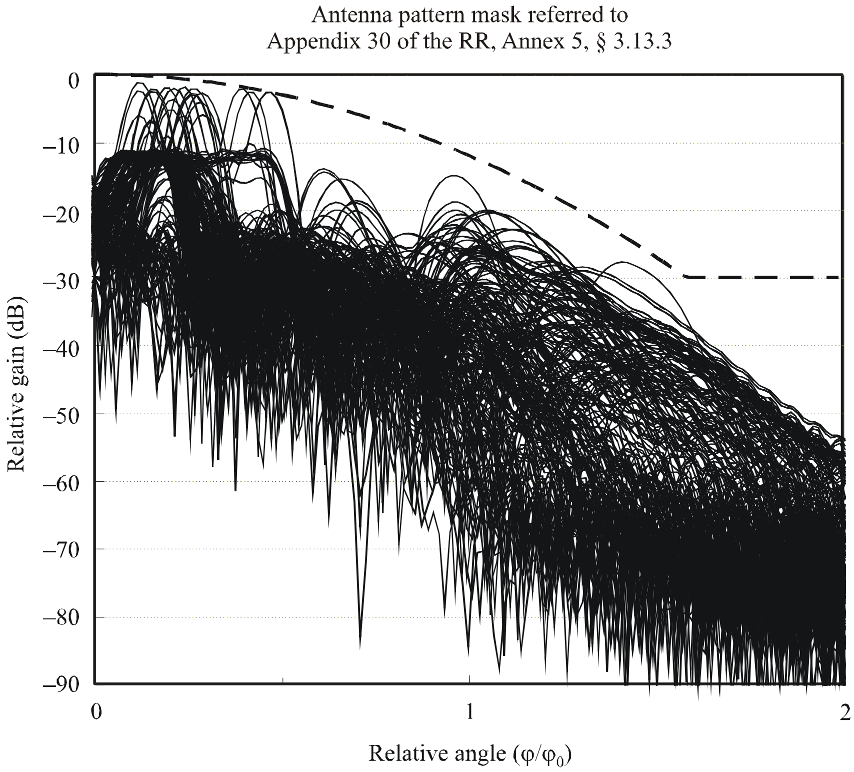
Gain evaluation points to detect sidelobe level



Rap 2071-30

FIGURE 29

Radiation pattern at a cut plane between the location of maximum sidelobe level and the centre of planned beam for Japan



Rap 2071-31

1.2.2 Conclusion

Sidelobe characteristics of satellite transmitting antenna are evaluated by computer simulations to reflect a rain attenuation compensating system with a phased array antenna in the 21 GHz band. It is found that the radiation pattern for variable e.i.r.p. BSS in the 21 GHz band does not exceed the antenna mask in the Plan of BSS that is shown in RR Appendix **30**, Annex 5 § 3.13.3.

2 A locally-variable e.i.r.p. system using simplified antenna (manufactured)

In the previous section, simulated antenna parameters are described. With these parameters, calculated radiation patterns are studied. In this section, a simpler and less expensive prototype antenna is studied. The diameter of the main reflector antenna and the number of the elements were reduced from 4 m to 1.8 m and from 188 to 32, respectively. A phased array antenna, a beam forming network (BFN), a linearized TWTA and an output filter were fabricated. Using these manufactured hardware, radiation patterns were measured. The objectives of the manufactured antenna were to study the feasibility of the reconfigurable radiation pattern as well as the evaluation of the surface accuracy of the reflectors, the accuracy of the phase controlled in the BFN and the degradation of the radiation pattern due to the mutual coupling in the feed array.

2.1 Manufactured array-fed imaging reflector antenna

The manufactured antenna and feed horn array are depicted in Figs 30A and 30B, respectively. The parameters of the antenna are shown in Table 13. The antenna consists of dual parabolic reflectors and feed array (array-fed imaging reflector antenna, IRA). The RF power in the feed array were 0 dB, −3 dB and −6 dB distributed from the centre to the outer bound. The type of the antenna is the same as the simulated antenna parameters in the former section, however the flexibility of the radiation pattern is limited due to the smaller aperture and number of the elements.

The radiation pattern can be altered by controlling only the phase. The feed horns were connected to the BFN, which controlled the phase and amplitude of each input signals. The prototype BFN unit is depicted in Fig. 31. The quantization unit was 5-bits (11.25 deg.) for phase shifters and the minimum amplitude step and dynamic range for the attenuators were 0.5 dB and 7.5 dB, respectively. The attenuators were also equipped with a mute function to calibrate output of each horn. The measured root means square error (RMSE) of each BFN unit is described in Fig. 32.

The measured radiation patterns of the nationwide beam and a boosted area on the nationwide beam are depicted in Figs 33A and 33B, respectively.

FIGURE 30A

Picture of an array-fed IRA

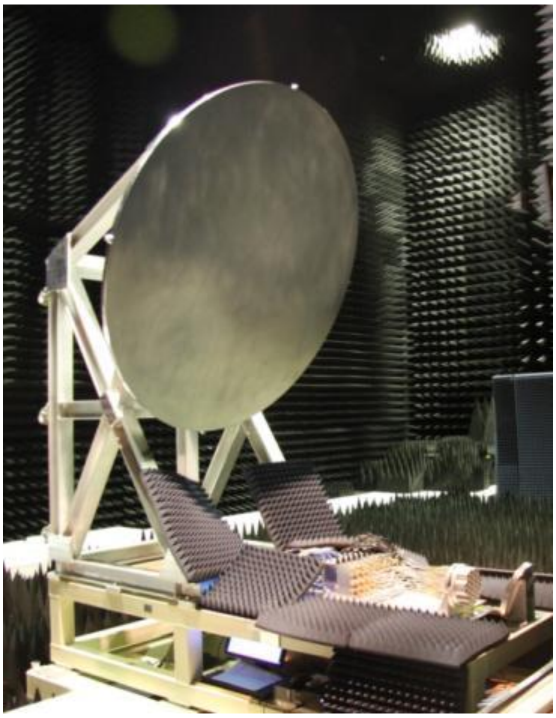


FIGURE 30B

Picture of 32 feed horns array and BFN

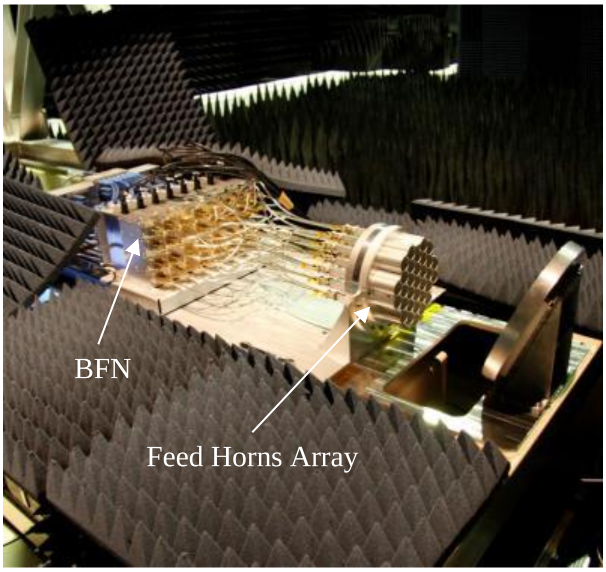


TABLE 13

Parameters of an experimental antenna models of 21 GHz band BSS utilizing a locally variable e.i.r.p. system

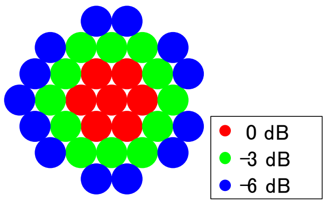
Antenna parameters	
Type of antenna	array-fed imaging reflector antenna (array-fed IRA)
Diameter of main reflector	1.8 m
Main reflector Surface	Paraboloid
Diameter of sub reflector	0.24 m
Sub reflector surface	Paraboloid
Number of elements	32
Element spacing	24.9 mm (1.8 wave lengths)
Distribution of RF power in the feed array	 Numbers of elements: 0 dB: 7 −3 dB: 12 −6 dB: 13

TABLE 13 (*end*)

Beam Forming Network	
Phase quantization	5 bit (11.25 degrees)
Phase error	5.52-6.31 degrees r.m.s
Attenuator min. step	0.5 dB (Dynamic range 7.5 dB)
Mute attenuation	more than 40 dB
Amplitude error	0.66-0.81 dB r.m.s.
Modulation	
Bit rate	250 Mbit/s for QPSK(1/2), 562.5 Mbit/s for 8PSK(3/4)
Frequency	21.7 – 22.0 GHz
Band width	258 MHz
Symbolrate	250 Mbaud

FIGURE 31

A prototype BFN unit

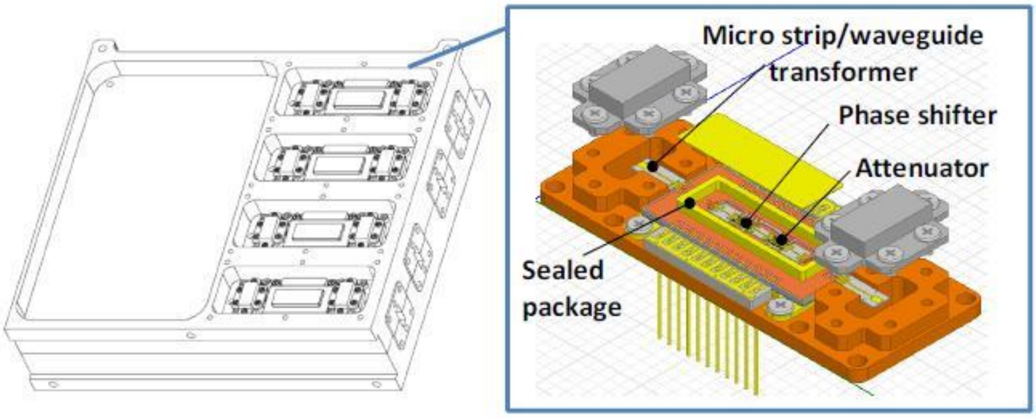


FIGURE 32

RMSE of phase and amplitude for each BFN unit

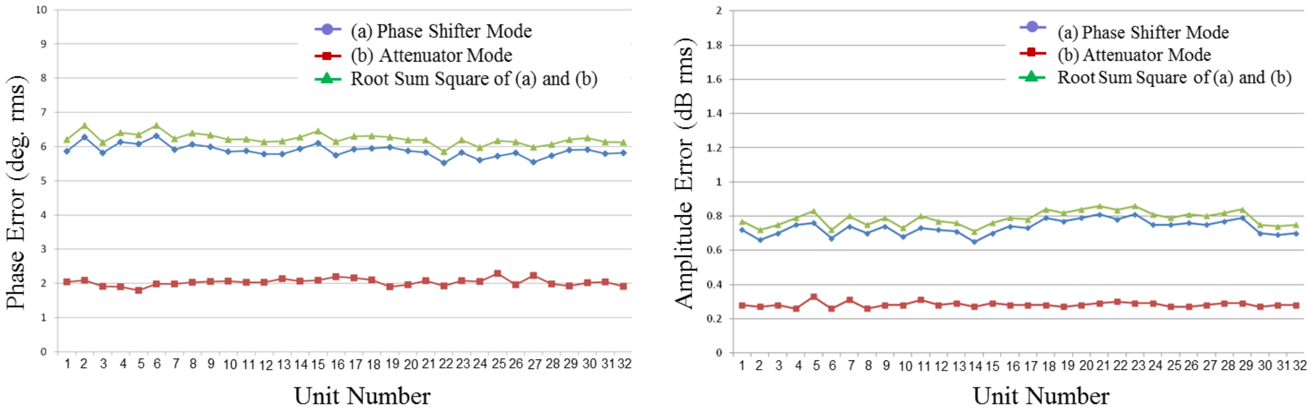


FIGURE 33A

Contour of nationwide beam by array-fed IRA

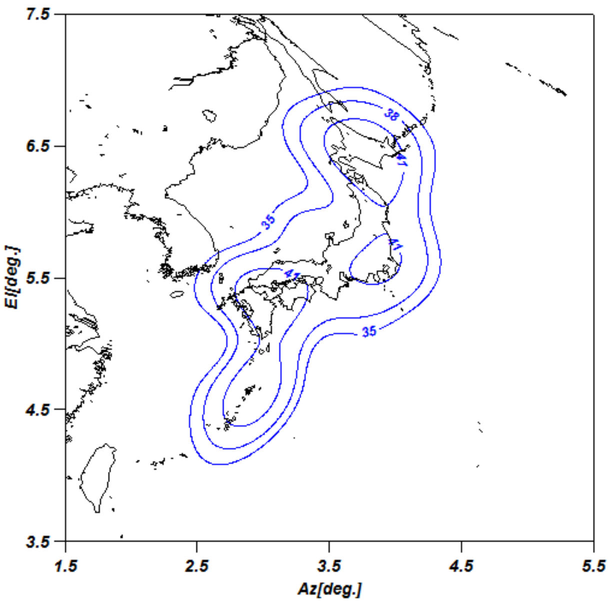
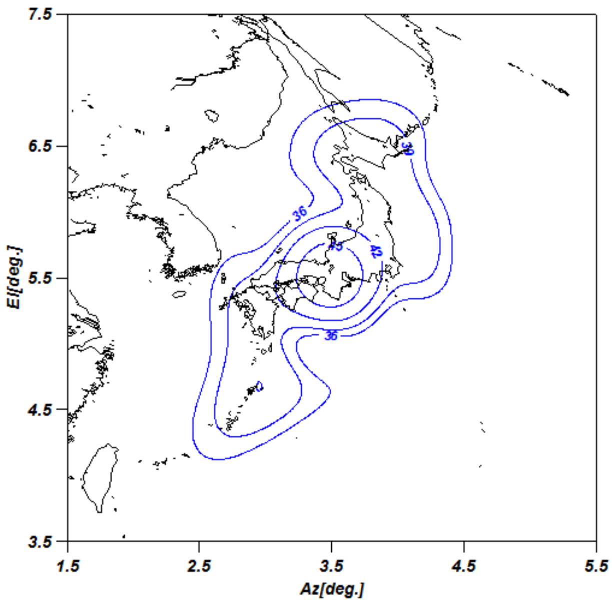


FIGURE 33B

Contour of a boosted beam and the nationwide beam by array-fed IRA



3 Wideband transponder

3.1 Introduction

A wideband transponder has been developed to transmit high-bit-rate programs for future broadcasting using the 21-GHz band BSS. Two 258 MHz channel bandwidths (BW) with channel separation of 287.5 MHz are assumed for the 21.4-22.0 GHz band. Meanwhile, the 22.21-22.5 GHz and 42.5-43.5 GHz bands are allocated to radio astronomy service (RAS) on a primary basis. The pfd threshold for the unwanted emission in the RAS band is regulated in Resolution **739 (Rev.WRC-15)**. Therefore, the output filter should have sufficient electric performances in-band low group delay and low attenuation as well as out-of-band sharp attenuation to suppress unwanted emission in the 22 GHz RAS band, and enough attenuation to suppress unwanted emission in the 2^{nd} harmonic domain close to the 43 GHz RAS band. This chapter provides measurement results of unwanted emission falling into the RAS band by using a TWT manufactured for the 21 GHz band BSS and a manufactured output filter in order to reduce the unwanted emissions in the RAS band.

3.2 Channel allocation

An example of channel allocation for a wideband transponder in the 21 GHz band BSS compared with channels in the 12 GHz band BSS Plan is depicted in Fig. 34. In order to transmit the high-bit-rate programs for future broadcasting, a wideband transponder with a channel BW of 258 MHz, which was 7.5 times as wide as the channel BW of 34.5 MHz for the 12 GHz band, was manufactured. A wideband transponder can transmit not only a high-bit-rate program but also multiple HD- and UHD-TV programs simultaneously with time-division multiplexing access.

The manufactured transponder configuration is depicted in Fig. 35. In Figure 35, the 32-feed horn array is fed by a TWTA by dividing its output power of 100W to 32 ports.

The pfd threshold values for the 21 GHz band BSS in Regions 1 and 3 are described in Resolution **554 (WRC-12)**, and the maximum pfd value is −105 dB(W/(m^2 MHz)), which is 12.9 dB higher than that of −103.6 dB(W/(m^2 27 MHz)) for the 12 GHz band BSS.

FIGURE 34

Channel allocation of wideband transponders in 21 GHz BSS and transponders in 12 GHz BSS Plan in Region 3

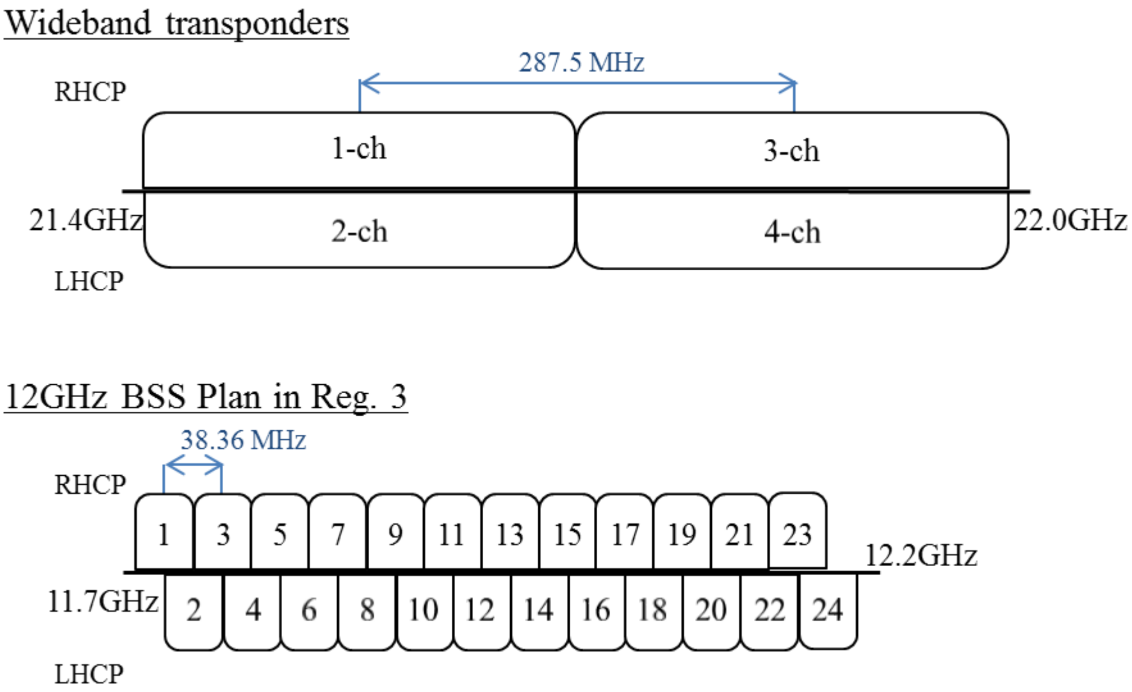
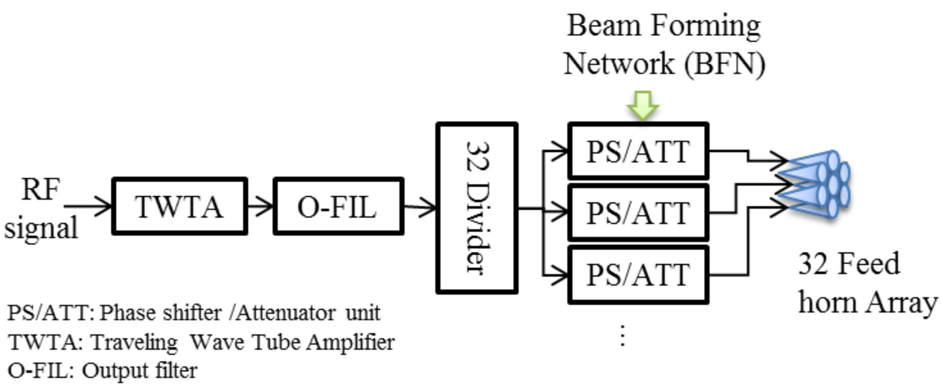


FIGURE 35

Manufactured wideband transponder configuration for 21 GHz BSS



3.3 Wideband modulator and demodulator

Wideband-modulator and -demodulator were developed. The technical specifications are listed in Table 14. Photographs of these two units are shown in Figs 36A and 36B. Considering a simple frequency division of the 21.4–22 GHz band, the symbol rate of the modem was set to 250 Mbaud. As the forward error correction (FEC) of the modem, a concatenation of an inner code of low density parity check (LDPC) and an outer code of Bose-Chaudhuri-Hocquenghem (BCH) was adopted. The length of the concatenated code was 44,880 bits. The error correction capability of the BCH code is 12 bits. In order to correct burst error due to the switching of the radiation patterns, the concatenated code was interleaved and deinterleaved by bit in the modulator and the demodulator, respectively. The modem supported a phase reference burst signal (PRBS) to keep strong robustness under a very low *C*/*N*, like one below 0 dB. A PRBS was π/2-shift binary phase shift keying (BPSK), and four symbols of a PRBS were inserted after 187 symbols of the main signal (QPSK or 8PSK) periodically.

TABLE 14

Technical specifications of wide-band modem

Item	Description
IF-frequency	3.0 GHz
Symbol rate	220 Mbaud – 275 Mbaud
Roll-off factor	0.01 – 1.0 0.01 step
Modulation	QPSK/8PSK
LDPC coding rate	1/2, 3/5, 2/3, 3/4, 4/5, 5/6, 7/8, 9/10
Interleaved memory	More than 1536 Mbit

FIGURE 36A

Wideband modulator

FIGURE 36B

Wideband demodulator

3.4 Suppression of unwanted emission from BSS

3.4.1 Technical items in regard to unwanted emissions

The technical items in regard to unwanted emissions are as follows:

– BSS parameters:
  - transmission characteristics: modulation, symbol rate, bandwidth, center frequency, roll-off factor, etc.;
  - downlink e.i.r.p. (or pfd);
  - other parameters.

– Sources of unwanted emissions (RR No. **1.146**):
  - spectral regrowth of digital-modulated signals due to non-linearity of satellite transponders;
  - uplink spectral regrowth due to non-linearity of uplink transmitter;
  - thermal noise from satellite receivers;
  - noise originating from high power TWT amplifier;

- intermodulation products (in the case of multicarrier transponders);
- other sources.

The BSS parameters in Table 15 were assumed for manufacturing components. The downlink pfd assumed the maximum of −105 dB (W/(m^2 MHz)) to determine the required suppression level for the output filters. The TWTA used in this study is depicted in Fig. 37. TWTAs are widely used as the final stage amplifiers of a BSS satellite because of their high efficiency and high output power capability in spite of relatively noisy characteristics.

The sources of unwanted emissions considered in this section are the spectral regrowth of digital-modulated signals due to the non-linearity of satellite transponders and noise originating from the high-power TWTA (1 and 4 in the list above). Further studies are required for other sources of unwanted emissions.

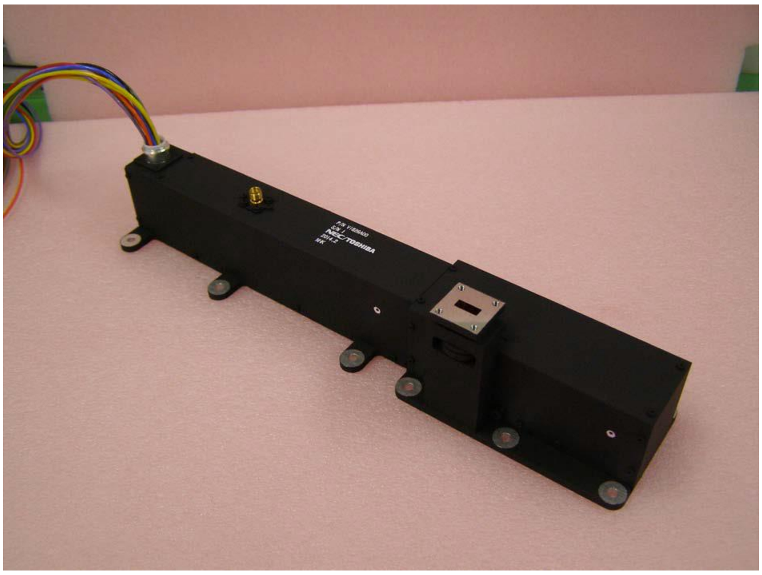
TABLE 15

Parameters assumed for manufacturing components

Number of channels	2
Center frequencies (GHz)	21.55265 / 21.84375
99% power bandwidth (MHz)	258
Symbol rate per channel (MBaud)	250
Channel separation (MHz)	287.5
Modulation	QPSK / 8PSK
Roll-off factor	0.1
TWTA non-linear characteristics	See Fig. 38
Output filter design	Combination of BPF, BRF and LPF (Detailed parameters are described in § 3.4.4)

FIGURE 37

Picture of a manufactured TWT



3.4.2 Measured spectral regrowth for PSK signal

Figure 38 illustrates the power transfer and the phase shift characteristics of the manufactured TWTA depicted in Fig. 37. The measured spectral regrowth from the wideband broadcasting channel signals and noise generated from the transponder components, especially that in the TWTA into the RAS bands (22.21-22.5 GHz and 42.5-43.5 GHz), are depicted in Fig.39. Because spectral regrowth in the RAS band of −25 dB and second harmonics of −32 dB were measured, an output filter with wideband signal transmission characteristics as well as steep suppression of unwanted emission was required. The required suppression level is described in the following section.

FIGURE 38

Non-linear characteristics of manufactured TWTA

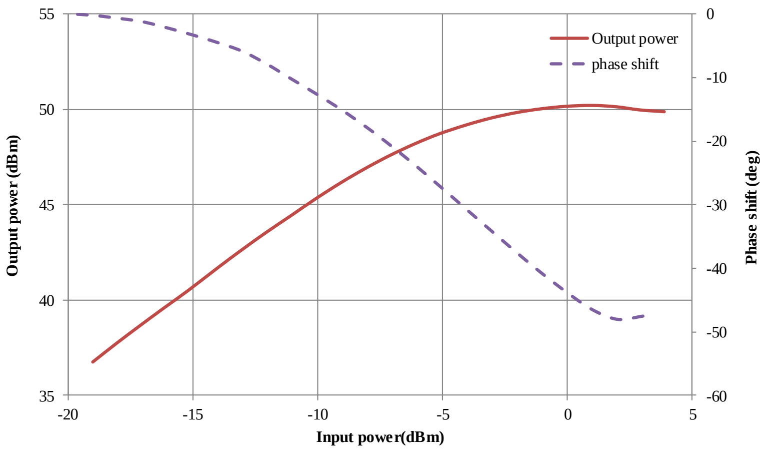
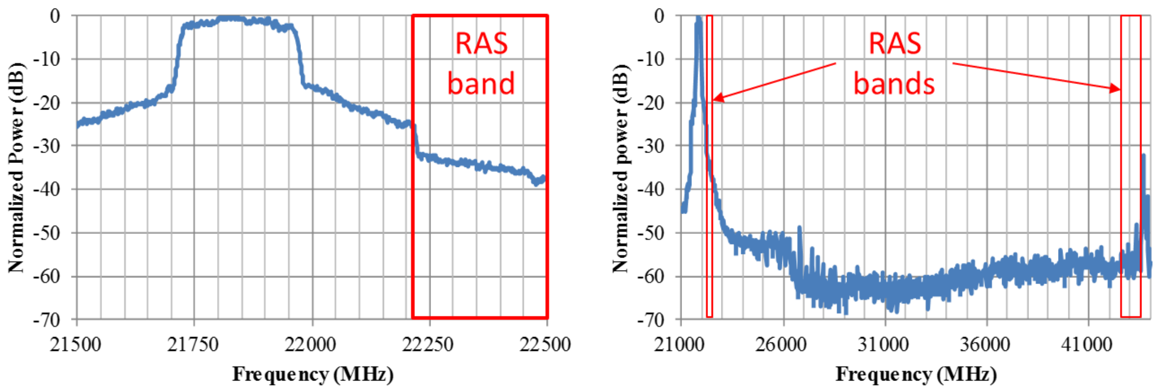


FIGURE 39

Measured spectral regrowth of a wideband modulated signal (8 PSK 3/4)



3.4.3 Requirements for the output filter of the on-board 21 GHz band BSS

The requirements for the on-board 21 GHz band output filter were as follows:

– Wideband single carrier transmission of a 258 MHz BW signal with low loss and a low group delay deviation;

– Suppression of unwanted emission in the adjacent frequency band for other channels of the 21-GHz-band BSS;

– Suppression of unwanted emission in the frequency band for 22 GHz band RAS;

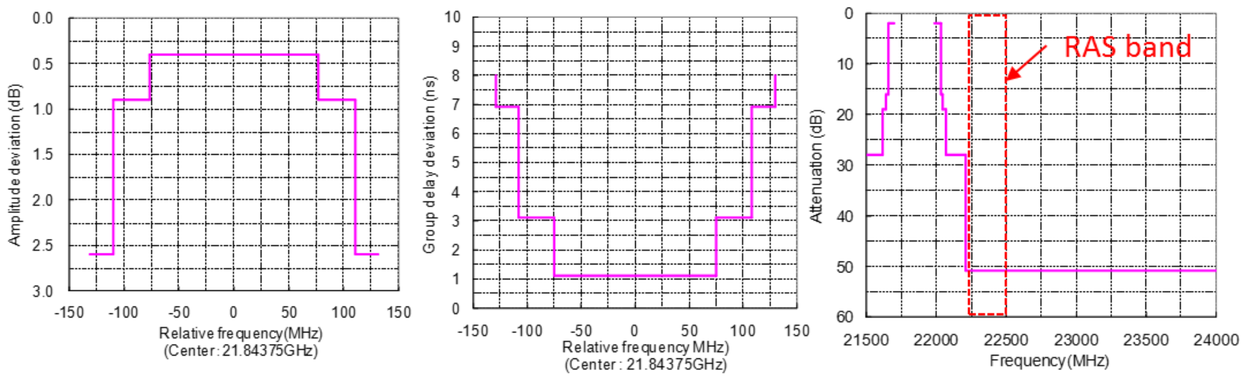
– Suppression of unwanted emission in the spurious domain, especially the 42.5-43.5 GHz frequency band for the 43 GHz band RAS, which will overlap with the second harmonic component of the 21 GHz band broadcasting satellite signal.

In order to transmit a wideband single carrier of a 258 MHz BW signal without severe degradation, the in-band amplitude deviation and group delay deviation were required to be less than 0.4 dB and 1.1 ns, respectively. For preventing unwanted emission from an adjacent higher (or lower) channel, as illustrated in Fig. 40, more than 28 dB of the out-of-band attenuation in the center frequency of the adjacent channel (or ±287.5 MHz) was required. Design objectives for in-band amplitude deviation, group delay deviation, and out-of-band attenuation performances are illustrated in Fig. 40.

For suppression of unwanted emission in the nearby frequency band for 22 GHz and 43 GHz bands RAS, the pfd thresholds for unwanted emission are described in Resolution **739 (Rev.WRC-15)** and Recommendation ITU-R RA.769-2. Table 16 lists the pfd thresholds of 22 GHz band RAS and the required suppressions for the maximum pfd of -105 dB(W/m^2/MHz) of a 21 GHz band BSS. Similarly, Table 17 lists the pfd thresholds of 43 GHz band RAS and the required suppressions

FIGURE 40

Design objectives for 21 GHz band output filter in 21.7-22 GHz band



In-band amplitude deviation In-band group delay deviation Out-of-band attenuation

TABLE 16

pfd threshold of 22 GHz band RAS and required suppression compared with max. pfd of 21 GHz BSS

	pfd threshold (dB (W/m^2))	Reference bandwidth (MHz)	Required suppression (dB)
Single dish continuum observation	−146	290	65.6
Single dish, spectral line observation	−162	0.25	51.0
VLBI	−128	0.25	17.0

TABLE 17

pfd threshold of 43 GHz band RAS and required suppression compared with maximum pfd of 21 GHz BSS

	pfd threshold (dB (W/m^2))	Reference bandwidth (MHz)	Required suppression (dB)
Single dish continuum observation	−137	1,000	61.6
Single dish, spectral line observation	−153	0.5	45.0

3.4.4 Suppression of the out-of-band emission by the output filter

In this Report, an on-board 21 GHz band output filter consisting of a band pass filter (BPF), a band rejection filter (BRF), and a low pass filter (LPF) was designed in order to satisfy the requirements A) to D) described in § 3.4.3 for the on-board 21 GHz band output filter and it was verified by computer simulation that the performance could meet the design objectives shown in Fig. 40.

Band pass filter (BPF)

The BPF has a function that satisfies requirements A) and B) in § 3.4.3. Table 18 lists the technical parameters of the BPF. Considering frequency transition due to thermal variation in the temperature range from –30 to +60 degrees Celsius in a broadcasting satellite transponder, we fabricated the BPF with super invar and also designed the pass-band to be wide enough. The measured electrical performances of the manufactured BPF in a thermal vacuum test is shown in Fig. 41. The measured performance was in good agreement with the design and met the objectives.

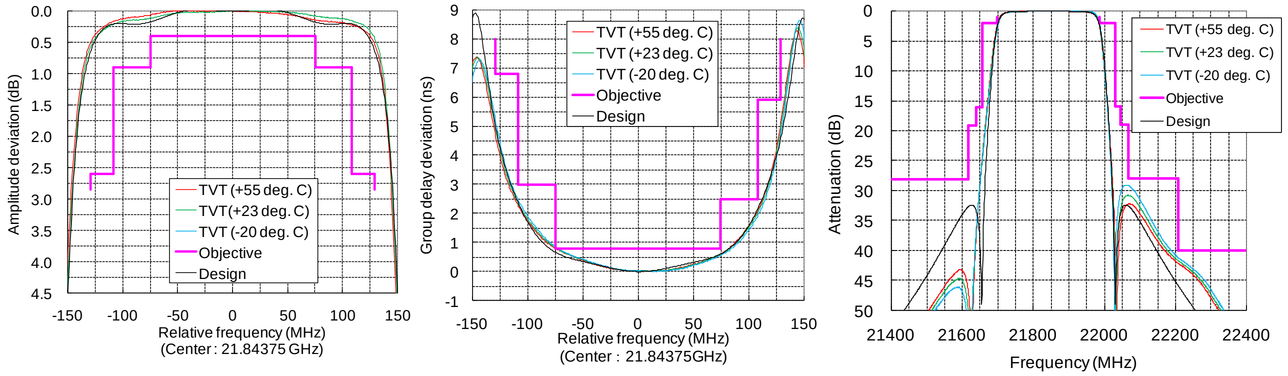
TABLE 18

Technical parameters of BPF

Item	Parameters
Transfer Function	Pseudo-elliptic
Steps	6
Ripple	0.02 dB
Bandwidth	±128.5 MHz
Minimum Attenuation	32 dB
Structure	Cylindrical cavity resonator

FIGURE 41

Measured performance of a BPF in a thermal vacuum test (TVT)



In-band amplitude deviation In-band group delay deviation Out-of-band attenuation

Band rejection filter (BRF)

The BRF has a function that satisfies requirement C) in § 3.4.3. The objective of the BRF is suppression of unwanted emission in the frequency band for 22 GHz band RAS. Table 19 lists the technical parameters of the BRF. The BRF was fabricated with aluminium. Filter made by aluminium changes shape due to thermal variation. Therefore, the stop-band was designed to be wide enough. Figure 42 shows the measured electrical performance of the BRF in a thermal test. The measured performance met the objectives.

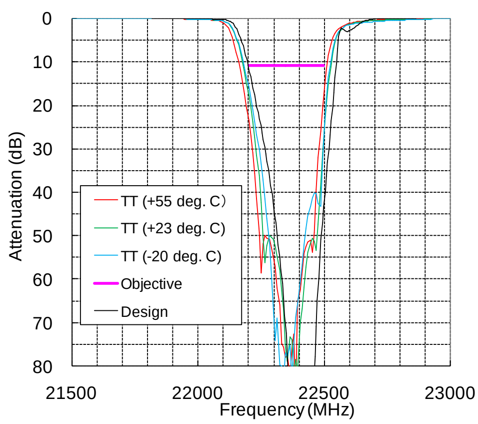
TABLE 19

Technical parameters of BRF

Item	Parameters
Transfer Function	Chebyshev
Steps	5
Ripple (in-band)	L.T. 0.01 dB
Bandwidth	±244.4 MHz
Minimum Attenuation	11 dB
Structure	Rectangular cavity resonator

FIGURE 42

Measured performance of a BRF in a thermal test (TT)



Low pass filter (LPF)

The LPF has a function that satisfies requirement D) in § 3.4.3. The objective of the LPF is suppression of unwanted emission in the frequency band for 43 GHz band RAS. Table 20 lists the technical parameters of the LPF. To achieve sufficient attenuation over a wide frequency range, a waffle-iron structure was applied. The measured electrical performance of the LPF at room temperature is shown in Fig. 43. The measured performance met the objectives.

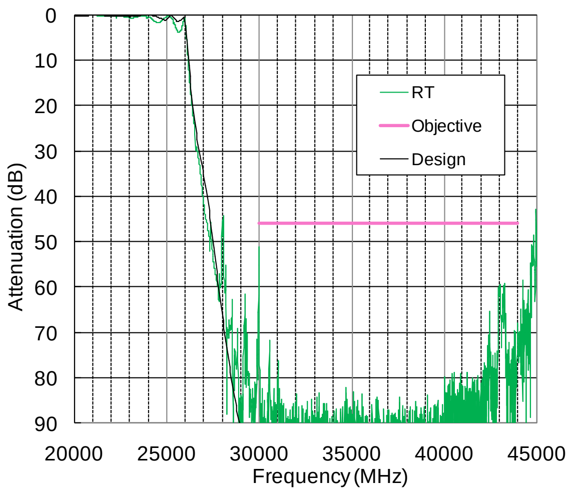
TABLE 20

Technical parameters of LPF

Item	**Parameters**
Ripple (in-band)	L.T. 0.15 dB
Minimum Attenuation	46 dB (30-44 GHz)
Structure	Waffle-iron

FIGURE 43

Measured performance of a LPF at room temperature (RT)



Overall electrical performance

A manufactured output filter consisting of a BPF, a BRF and a LPF is depicted in Fig. 44. The input and output ports were WR-42 rectangular waveguides. The length was about 235 mm. The measured electrical performances of the combined filter in a thermal vacuum test is shown in Fig. 45.

FIGURE 44

Manufactured 21GHz-band output filter

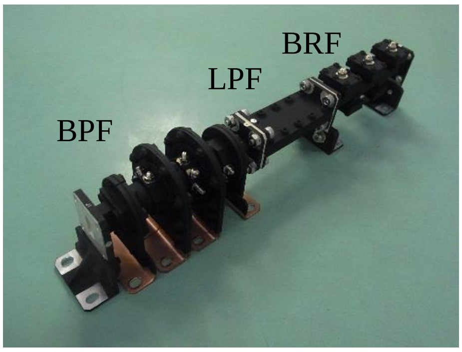
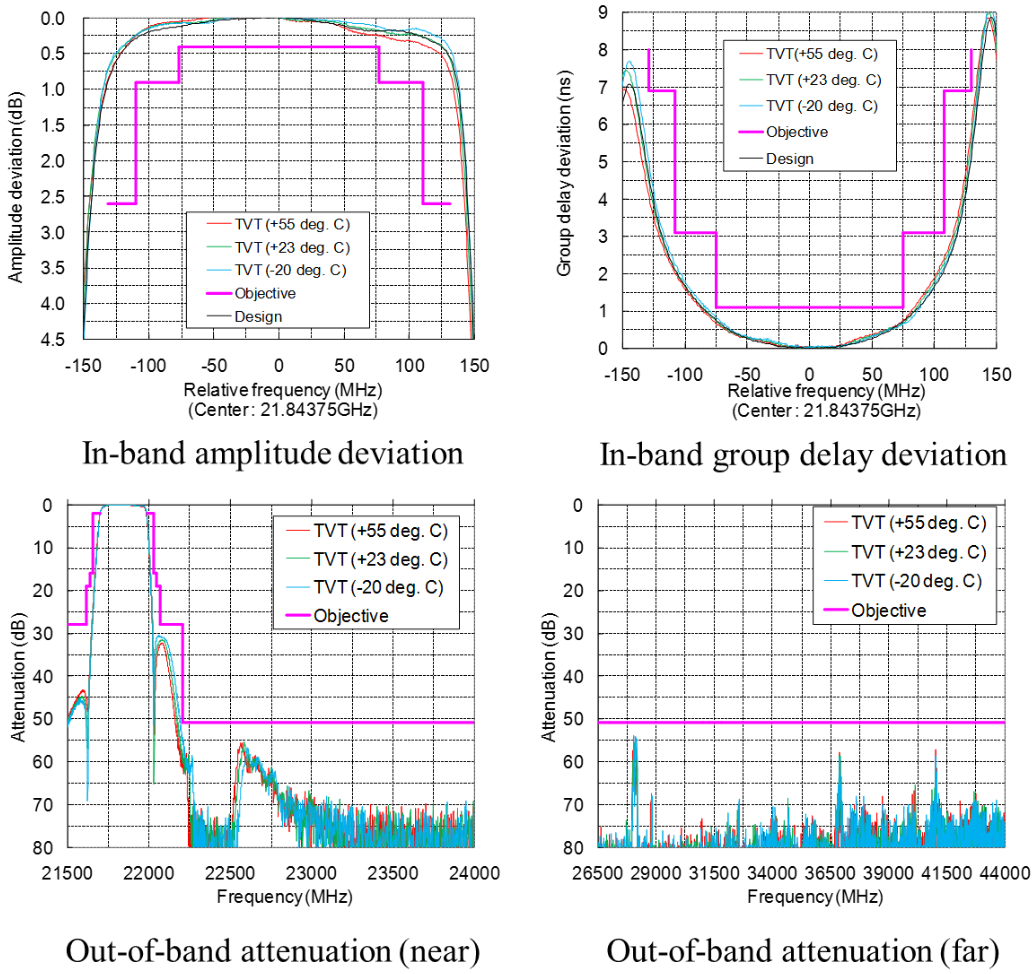


FIGURE 45

Electrical performances of manufactured 21 GHz band output filter measured in thermal vacuum test (TVT)



3.4.5 Evaluation of unwanted emission level with wideband modulated signal

To evaluate the unwanted emission level from the assumed 21 GHz band broadcasting satellite configuration, out-of-band suppression was evaluated with the combined configuration of a TWTA and the output filter using a wideband modulated signal. Figure 46 shows the measured system diagram. The wideband modulator generated a 250 Mbaud PSK signal with roll-off factor of 0.1. The TWTA was operated at a saturated power of more than 100 W. The output filter and TWTA were operated in the vacuum chamber.

The measured normalized power through the output filter using a wideband modulated signal is depicted in Fig. 47. The measured signal level in the 22.21-22.5 GHz band for radio astronomy was under the noise floor of the spectrum analyser, and the attenuation in the band seemed to be more than 64 dB. In Figure 47, the noise floor of the spectrum analyser was approximately −64 dB. The measured spectral regrowth at 22.21 GHz out of the TWTA was less than −25 dB as depicted in Fig. 39; and an attenuation of more than 50 dB was achieved as shown in Fig. 45, therefore, the attenuation of the combined configuration of the TWTA and the output filter in the 22.21-22.5 GHz band for radio astronomy was assumed to be more than 75 dB.

Similarly, the measured signal level in the 42.5-43.5 GHz band for radio astronomy from the 21 GHz band output filter was under the noise floor generated in the spectrum analyser, the attenuation in the band seemed to be more than 53 dB. In Fig. 47, the noise floor of the spectrum analyser was approximately −53 dB. For accurate measurement, further study using an amplifier of high power (more than 100W) is required. The second harmonic component of the 21 GHz band signal was less than −32 dB as depicted in Fig. 39; and an attenuation of more than 50 dB was achieved in the 42.5-43.5 GHz at the output filter as shown in Fig. 45, therefore, the attenuation of the combined configuration of the TWTA and the output filter in the band 42.5-43.5 GHz for radio astronomy assumed to be more than 82 dB.

Compatibility between the RAS bands (22.21-22.5 GHz and 42.5-43.5 GHz) and the BSS band (21.4-22.0 GHz) was confirmed using a manufactured output filter consisting of a BPF, a BRF, and a LPF.

The output filter had sufficient electrical performances in-band low group delay and low attenuation, as well as out-of-band sharp attenuation to suppress unwanted emission in the 22 GHz RAS band, and wideband attenuation to suppress unwanted emission in the 2nd harmonic domain close to the 43 GHz RAS band. This is assuming the maximum pfd level of −105 dB(W/(m^2 · MHz)) meets the requirement for avoiding to excess the threshold interference to RAS described in Resolution **739 (Rev.WRC-15)** and Recommendation ITU-R RA.769-2.

FIGURE 46

Measured system diagram to evaluate unwanted emission level from assumed 21GHz-band broadcasting satellite configuration

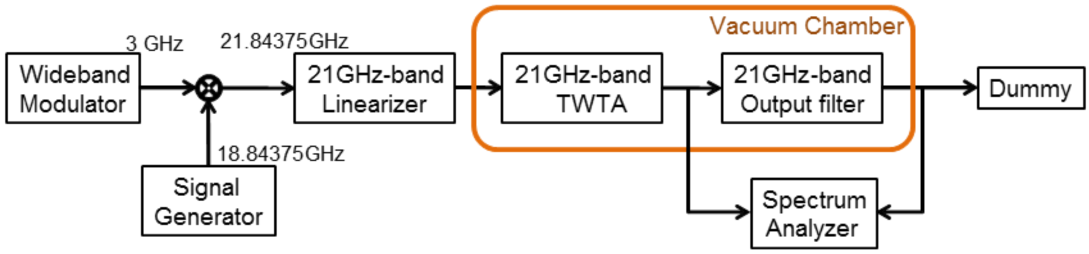
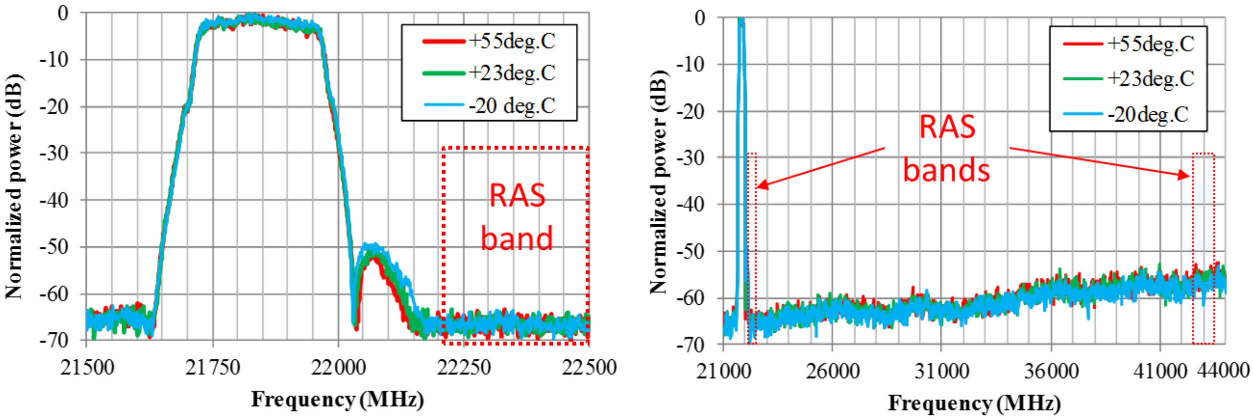


FIGURE 47

Measured normalized power through output filter using a wideband modulated signal



4 An experimental transmission using manufactured 21 GHz band BSS transponder

The feasibility of a 21 GHz band broadcasting-satellite service (BSS) needs to be shown using manufactured components. In this section, the measurement system diagram is introduced at first. Then, this study's transmission experiment dealt with the following items:

– Wideband frequency spectrum of the locally-variable e.i.r.p. system;

– Transmission performance by measuring the carrier to noise ratio (*C/N*) vs. bit error rate (BER);

– 8K UHDTV transmission.

4.1 Wideband transmission measurement

The measurement system diagram of wideband transmission experiment is depicted in Fig. 48. The parameters of the experiment are listed in Table 21. The centre frequency of the modem was set to 3 GHz. The locally-variable e.i.r.p. system mainly consists of an up-converter, travelling wave tube amplifier (TWTA), output filter, BFN, and array-fed imaging reflector antenna (array-fed IRA). The frequency was up-converted to 21.84375 GHz at the input of the system. The TWTA was driven at saturation. The 21 GHz band wideband signal was radiated from the array-fed IRA and received in a compact antenna test range (CATR). The received signal was amplified with the low noise amplifier (LNA) and down-converted to 3 GHz, and the received *C/N* was adjusted using the *C/N* test set, which could control the *C/N* by measuring the input power and by adding additive white Gaussian noise (AWGN). The received signal with AWGN was demodulated and decoded in the demodulator. The BER was measured after FEC decoding. Among the combinations of the modulation and LDPC coding rate, QPSK (1/2), QPSK (3/4), and 8PSK (3/4) were selected.

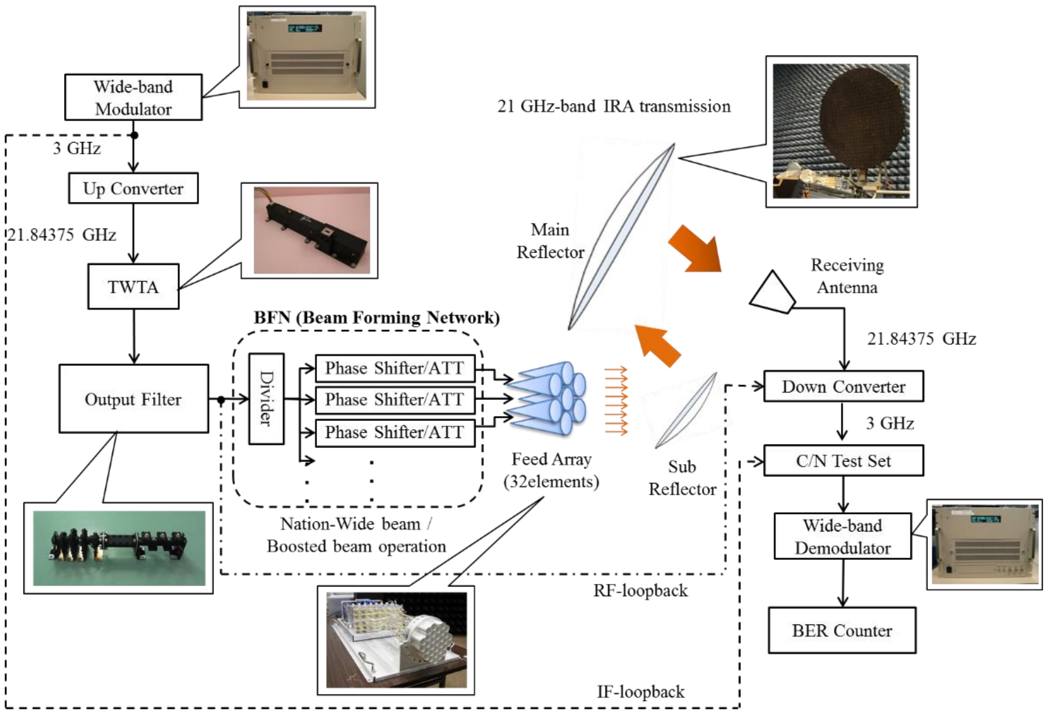
TABLE 21

Parameters of transmission experiment

Item	Description
IF centre frequency	3.0 GHz
RF centre frequency	21.84375 GHz
Symbol rate	250 Mbaud
Modulation	QPSK/8PSK
Roll-off factor	0.1
Information bit rate	245.7 Mbps (QPSK (1/2), 250 Mbaud) 360.4 Mbps (QPSK (3/4), 250 Mbaud) 540.4 Mbps (8PSK (3/4), 250 Mbaud)
Beam pattern	1 Nationwide beam; 2 Boosted beam aimed at: a) Sapporo; b) Tokyo; c) Osaka; d) Fukuoka; e) Naha; while keeping the nationwide beam.

FIGURE 48

Measurement system diagram of wideband transmission experiment



4.2 Wideband frequency spectrum of the locally-variable e.i.r.p. system

Figures 49A and 49B show the received QPSK wide-band frequency spectrums when the receiving point of the signal was assumed at Osaka by adjusting azimuth- and elevation-angles of the CATR. The spectrum of Fig. 49A was measured when the beam pattern was reconfigured the nationwide beam. On the other hand, the spectrum of Fig. 49B was measured when the beam pattern was reconfigured a boost beam aimed at Osaka while keeping the nationwide beam. Overall, 5 dB gain of the received signal corresponded to the calculated value.

FIGURE 49A

Received QPSK frequency spectrum of the nationwide beam

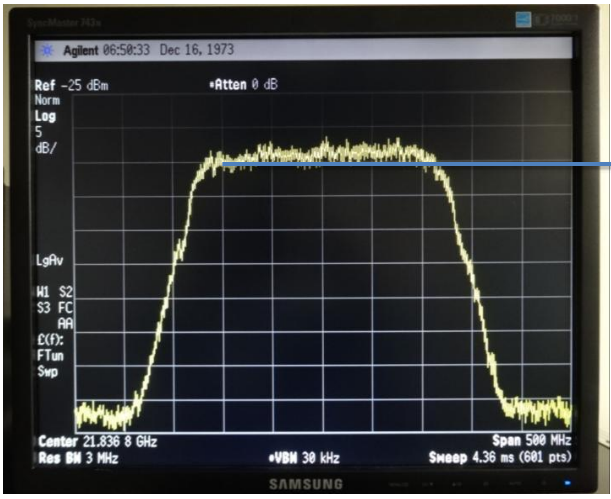
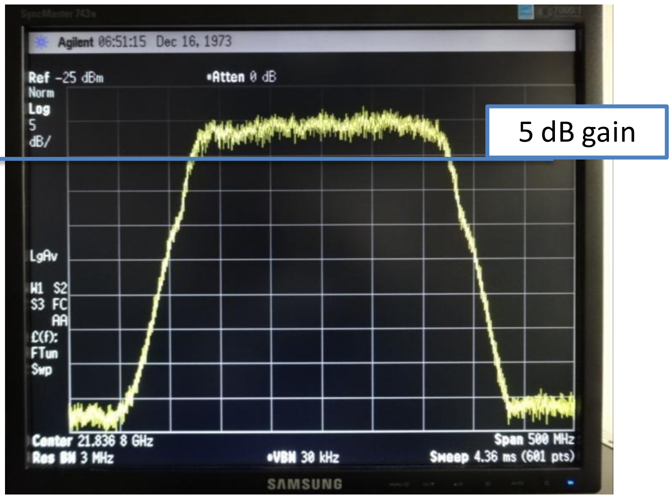


FIGURE 49B

Received QPSK frequency spectrum of a boosted beam at Osaka and the nationwide beam



4.3 Transmission performance

C/N vs. BER measurements were conducted by varying condition of modulation, LDPC coding rate, and beam pattern listed in Table 21. Three transmission paths were defined as follows:

A) IF-loopback (dotted shortcut line in Fig. 48):

The 3 GHz band modulated signal was connected to the *C/N* test set directly;

B) RF-loopback (dash-dotted shortcut line in Fig. 48):

The 21 GHz band modulated and TWTA amplified signal from the output filter was down converted to 3 GHz and connected to the *C/N* test set;

C) 21 GHz band IRA transmission (solid line in Fig. 48):

The 21 GHz band modulated signal went through all of the components. Six beam patterns listed in Table 21 were reconfigured. And *C/N* vs. BER measurements were conducted in each beam pattern, respectively.

The *C/N* vs. BER of QPSK (1/2), QPSK(3/4), and 8PSK(3/4) are shown in Figs 50, 51 and 52, respectively. Those Figures include IF-loopback, RF-loopback, and 21 GHz band IRA transmission by reconfiguring the beam patterns. The required *C/N*[3] of QPSK (1/2), QPSK(3/4), and 8PSK (3/4) are listed in Tables 22, 23 and 24, respectively. Those tables show that the *C/N* degradations by radiation in the 21 GHz band array-fed IRA compared with RF-loopback were less than 0.2 dB and 0.4 dB for using QPSK and 8PSK, respectively. These *C/N* degradations occurred in the amplification of the received low power signal in the CATR as well as in the passing through BFN and array-fed IRA. Furthermore, the transmission degradation by reconfiguring the beam patterns was negligible.

[3] The required *C/N* is defined as the smallest *C/N* at which the bit error rate (BER) is 1×10^{-11}. The noise bandwidth of the *C/N* was set to 250 MHz, equivalent to the symbol rate in units of baud for the experiments.

FIGURE 50

QPSK (1/2) *C*/*N* vs. BER

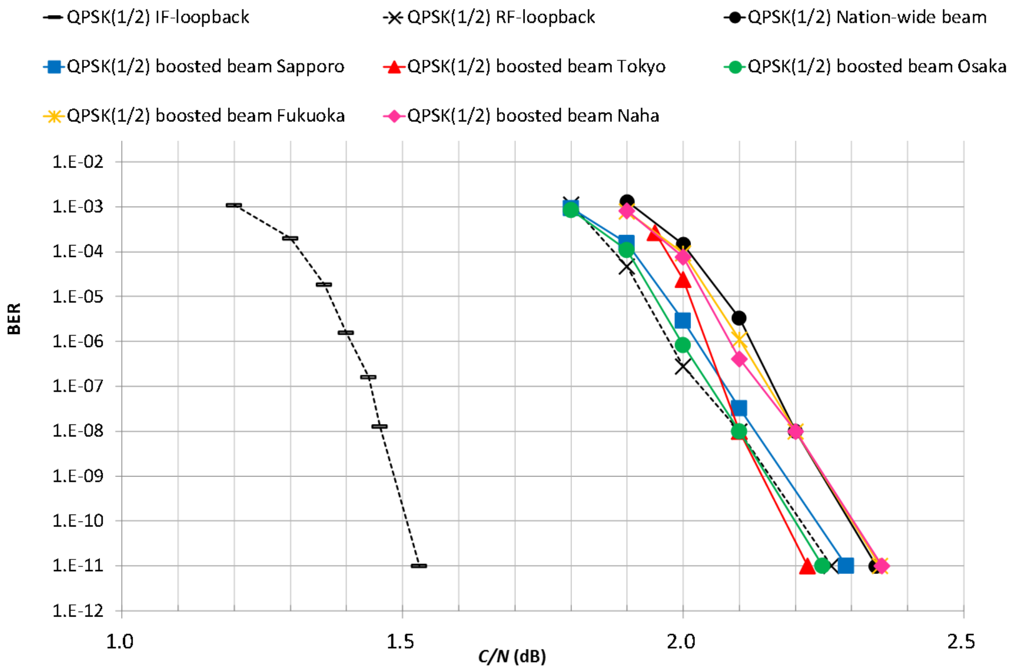


FIGURE 51

QPSK (3/4) *C*/*N* vs. BER

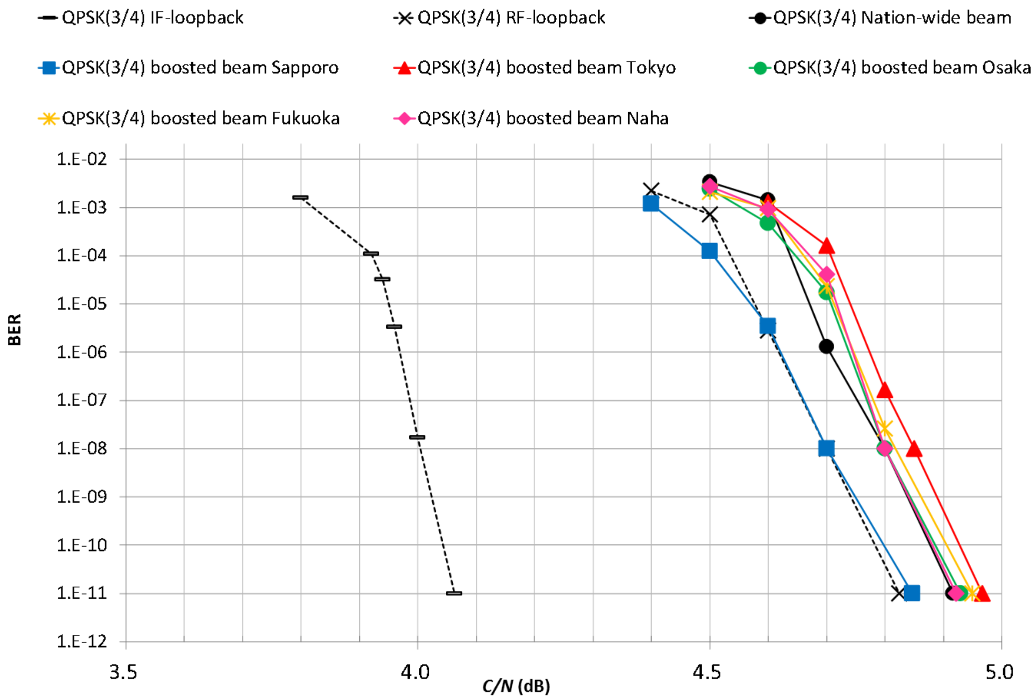


FIGURE 52

8PSK (3/4) *C*/*N* vs. BER

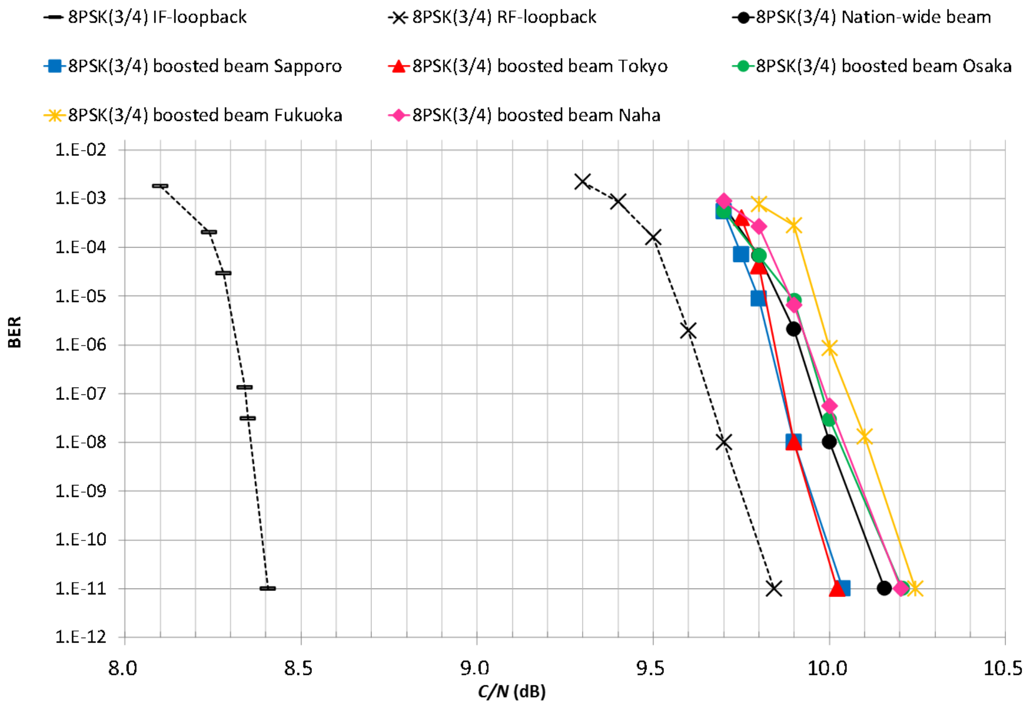


TABLE 22

QPSK (1/2) Required *C*/*N* and transmission degradation

		Required *C*/*N* (dB)	Transmission *C*/*N* degradation from IF-loopback (dB)	Transmission *C*/*N* degradation from RF-loopback (dB)
A) IF-loopback		1.53	-	-
B) RF-loopback		2.26	0.73	-
C) 21-GHz-band IRA transmission	1) Nation-wide	2.34	0.81	0.08
	2-a) Sapporo	2.29	0.76	0.03
	2-b) Tokyo	2.22	0.69	0.04
	2-c) Osaka	2.25	0.72	0.01
	2-d) Fukuoka	2.35	0.82	0.05
	2-e) Naha	2.35	0.82	0.05

TABLE 23

QPSK (3/4) Required *C*/*N* and transmission degradation

		Required *C*/*N* (dB)	Transmission *C*/*N* degradation from IF-loopback (dB)	Transmission *C*/*N* degradation from RF-loopback (dB)
A) IF-loopback		4.06	-	-
B) RF-loopback		4.82	0.76	-
C) 21-GHz-band IRA transmission	1) Nation-wide	4.92	0.86	0.10
	2-a) Sapporo	4.85	0.79	0.03
	2-b) Tokyo	4.97	0.91	0.15
	2-c) Osaka	4.93	0.87	0.11
	2-d) Fukuoka	4.95	0.89	0.13
	2-e) Naha	4.92	0.86	0.10

TABLE 24

8PSK (3/4) Required *C*/*N* and transmission degradation

		Required *C*/*N* (dB)	Transmission *C*/*N* degradation from IF-loopback (dB)	Transmission *C*/*N* degradation from RF-loopback (dB)
A) IF-loopback		8.41	-	-
B) RF-loopback		9.84	1.44	-
C) 21-GHz-band IRA transmission	1) Nation-wide	10.16	1.75	0.31
	2-a) Sapporo	10.04	1.63	0.19
	2-b) Tokyo	10.02	1.62	0.18
	2-c) Osaka	10.21	1.80	0.36
	2-d) Fukuoka	10.24	1.84	0.40
	2-e) Naha	10.20	1.80	0.36

4.4 8K UHDTV transmission

The specifications of the 8K UHDTV transmission are listed in Table 25. The 8K UHDTV reception and receiving systems are shown in Figs 53 and 54, respectively. Stable 8K UHDTV transmission was confirmed. No interruption of the 8K UHDTV image was detected by reconfiguring the beam patterns because the transmitted signal was interleaved. The required bit-interleave time was about 1 000 ms.

TABLE 25

Specifications of 8K UHDTV transmission

Item	Description
RF centre frequency	21.84375 GHz
Symbol rate	250 Mbaud
Modulation	QPSK/8PSK
Roll-off factor	0.1
Information bit rate	245.7 Mbit/s (QPSK (1/2), 250 Mbaud) 360.4 Mbit/s (QPSK (3/4), 250 Mbaud) 540.4 Mbit/s (8PSK (3/4), 250 Mbaud)
Multiplexing	MPEG-2 systems
Video format	7680×4320/59.94 p
Video coding	MPEG-4 AVC/H.264
Audio format	22.2 ch
Audio coding	MPEG-4 AAC
MPEG-2 TS bit rate	182 Mbit/s
Max interleave time	6167.9 ms (QPSK (1/2)) 4211.8 ms (QPSK (3/4)) 2809.4 ms (8PSK (3/4))

FIGURE 53

8K UHDTV reception

FIGURE 54

8K UHDTV receiving system

5 Conclusion

An example of a locally-variable e.i.r.p. system using high performance antenna was introduced. The diameter of the main reflector is 4 m and the number of the elements was assumed to be 188. Radiation patterns of a nationwide beam and a boosted beam while keeping a nationwide beam were calculated. Moreover, sidelobe characteristics of the antenna was evaluated by computer simulation.

A locally-variable e.i.r.p. system using an array-fed imaging reflector antenna was manufactured. The diameter of the main reflector is 4 m and the number of the elements was 32. Radiation patterns varied by the manufactured antenna were measured and evaluated. The feasibility of the variable e.i.r.p. system was confirmed with the manufactured hardware. In addition, the surface accuracy of the reflectors, the accuracy of the phase controlled in the BFN and the degradation of the radiation pattern due to the mutual coupling in the feed array were evaluated.

The system featured of the wideband transmission characteristics. Two 258 MHz channel bandwidths (BW) are assumed for the 21.4-22.0 GHz band. Meanwhile, the 22.21-22.5 GHz and 42.5-43.5 GHz bands are allocated to radio astronomy service (RAS). Therefore, an output filter to suppress unwanted emission was also fabricated and proved to be sufficient performances for wideband transmission of the BSS as well as suppression of unwanted emission in the RAS bands.

An indoor transmission experiment was conducted to show the feasibility of a 21 GHz band BSS. The transmission experiment system was established using a wide-band modem, TWTA, output filter, BFN, and array-fed IRA. The experiment proved that a 5 dB gain increase of the received signal was achieved and agreed with the calculated value. The C/N vs. BER measurement results revealed that transmission degradation occurred in the wideband transmission measurement for the manufactured system was within 0.2 dB for QPSK and within 0.4 dB for 8PSK. And, it showed the transmission degradation by reconfiguring the beam patterns was negligible. Finally, stable 8K UHDTV transmission was confirmed by experiment.

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