

RECOMMENDATION ITU-R BO.1696

Methodologies for determining the availability performance for digital multiprogramme broadcasting-satellite service systems, and their associated feeder links operating in the planned bands

(Question ITU-R 3/6)

(2005)

Scope

This Recommendation proposes methodologies for determining performance objectives for digital systems in the 11.7-12.7 GHz, and sets availability objectives for digital systems that are higher than those for analogue systems. Annex 1 to this Recommendation provides example implementations of the recommended methodologies, as well as exact and approximate solutions.

The ITU Radiocommunication Assembly,

considering

- a) that digital multiprogramme systems are now in use in the broadcasting-satellite service (BSS);
- b) that the performance of digital multiprogramme systems is important to administrations implementing such systems;
- c) that the system availability performance provides an important reference point for evaluating the relative performance of an administration's BSS assignment, should that assignment be implemented with a digital multiprogramme system;
- d) that the reception characteristics of a digital multiprogramme system are significantly different from the reception characteristics of an analogue FM system;
- e) that the existing Appendices 30 and 30A of the Radio Regulations performance objective of maintaining a C/N ratio equal to or better than 14 dB for 99% of the worst month is based on analogue FM transmission;
- f) that, because of these factors, it is desirable to develop an availability performance objective specifically for digital multiprogramme systems;
- g) that a methodology to determine availability performance for digital multiprogramme BSS systems must recognize the wide range of threshold C/N ratios at which these various systems operate;
- h) that the development of a digital multiprogramme performance objective is not only useful for the planned BSS band, but also for other BSS bands, for example, the 17/21 GHz band,

further considering

- a) that the performance of digital multiprogramme systems can be characterized by evaluating the system availability corresponding to the quasi-error-free (QEF) point¹, which corresponds to high-picture quality reception,

recognizing

- a) that although many operational digital multiprogramme BSS links have QEF link availability better than 99.5% of the worst month (or about 99.86% of an average year for most rain zones), the required availability is determined by specific system performance objectives;
- b) that Recommendation ITU-R BO.1516 – Digital multiprogramme television systems for use by satellites operating in the 11/12 GHz frequency range recommends, among other things, that one of the four transmission systems described in Annex 1 of that Recommendation be selected when implementing digital multiprogramme television services via satellite;
- c) that Recommendation ITU-R BO.1516 shows that the QEF C/N ratio values for these systems is spread over a wide range of values, and that trade-offs among primary digital link parameters can be used to meet performance objectives,

recommends

- 1 that administrations should use the methodologies provided in Annex 1 to this Recommendation to determine the system availability performance for digital multiprogramme BSS systems, and their associated feeder links, operating in the planned bands;
- 2 that digital multiprogramme systems should provide, as guidance, QEF performance for at least $X\%$ of the worst month;
- 3 that when implementing digital multiprogramme systems, a target C/N value of (minimum $C/N + Z$) dB should be maintained within the service area or coverage area for at least $X\%$ of the worst month. As guidance, 99.5% can be taken for the default value of X . The values of the minimum C/N are defined in Table 1 (also described in Table 2 of Recommendation ITU-R BO.1516). The value Z is the additional degradation margin².

¹ QEF generally refers to a BER of approximately one bit error per hour or per day. When a digital multiprogramme system is operating at a BER equal to or better than the QEF point, picture quality becomes solely a function of the video compression rates and algorithms in use, and not a function of the channel BER. When a digital multi-programme system is operating at a BER below or worse than QEF, then video quality becomes a function of both the video compression rates and algorithms, and the channel BER.

² The value Z is the sum of Z_1 and Z_2 . In case of System C and System D in Table 1, additional margin Z_1 is needed for hardware implementation and satellite transponder distortions. As guidance, a value of 1.8-2.3 dB, depending on the modulation used can be taken as the default value for Z_1 . Z_2 is the margin taking into account interference from intra and interregional BSS satellites, uplink noise, and interference from other sources. The value of Z_2 needs to be determined for each specific case, taking into account the individual system operational and interference environment.

TABLE 1

Minimum C/N for QEF operation (dB) (quoted from Table 2 of Recommendation ITU-R BO.1516)

Modulation and coding			System A	System B	System C	System D
Modulation modes supported individually and on the same carrier			QPSK	QPSK	QPSK	8-PSK, QPSK, and BPSK
Performance requirement C/N (dB)			C/N for QEF ⁽¹⁾	C/N for QEF ⁽²⁾	C/N for QEF ⁽³⁾	C/N for QEF ⁽⁴⁾
Modes	Inner code					
BPSK	Conv.	1/2	Not used	Not used	No	0.2
QPSK	Conv.	5/11	Not used	Not used	2.8/3.0	Not used
		1/2	4.1	3.8	3.3/3.5	3.2
		3/5	No	Not used	4.5/4.7	Not used
		2/3	5.8	5	5.1/5.3	4.9
		3/4	6.8	Not used	6.0/6.2	5.9
		4/5	Not used	Not used	6.6/6.8	Not used
		5/6	7.8	Not used	7.0/7.2	6.8
		6/7	Not used	7.6	Not used	Not used
		7/8	8.4	Not used	7.7/7.9	7.4
8-PSK	Trellis		Not used	Not used	Not used	8.4

- (1) At a BER $< 10^{-10}$. The C/N values for System A refer to computer simulation results achieved on a hypothetical satellite chain, including input multiplex (IMUX), travelling wave tube amplifier (TWTA) and output multiplex (OMUX), with modulation roll-off of 0.35. They are based on the assumption of soft-decision Viterbi decoding in the receiver. A bandwidth to symbol rate ratio of 1.28 has been adopted. The figures for C/N include a calculated degradation of 0.2 dB due to bandwidth limitations on IMUX and OMUX filters, 0.8 dB non-linear distortion on TWTA at saturation and 0.8 dB modem degradation. The figures apply to BER $= 2 \times 10^{-4}$ before RS (204,188), which corresponds to QEF at the RS coder output. Degradation due to interference is not taken into account.
- (2) At a BER of 1×10^{-12} .
- (3) Theoretical QPSK (2-bit per symbol) E_s/N_0 , i.e. C/N as measured in Nyquist bandwidth (baud rate/2) for normal and truncated spectral shaping, respectively. Does not include hardware implementation margin or satellite transponder loss margin. Two values correspond to System C normal and truncated transmit spectral shaping, respectively.
- (4) These values were derived from computer simulations and regarded as theoretical values. The values apply to BER $= 2 \times 10^{-4}$ before RS (204,188) and using the Nyquist bandwidth. Does not include hardware implementation margin or satellite transponder loss margin.

Annex 1

Methodologies for determining the availability performance for digital multiprogramme BSS systems, and their associated feeder links operating in the planned bands

1 Introduction

1.1 General remarks

Digital multiprogramme transmission systems are now in widespread use in the BSS. This use has been recognized within ITU-R in several areas. In particular, some of the parameters used in the replanning of the Regions 1 and 3 BSS Plan reflect the introduction of such digital multiprogramme transmission systems. One system parameter that has not adequately been defined for digital multiprogramme transmissions is the system availability performance, taking into account feeder link and downlink propagation fade statistics and the particular characteristics of the digital system (e.g. interference environment). As digital multi-programme transmission systems continue to be studied and implemented, this Annex provides the recommended methodologies for calculating threshold availability performance of contemporary digital systems and propagation models.

1.2 Specific characteristics of digital multiprogramme BSS

The performance of an operating digital BSS system can be characterized by looking at two distinct digital modulation performance thresholds. The first, sometimes called the QEF threshold, is characterized by operation at a BER of approximately one bit error per hour or day (BER of 10^{-9} to 10^{-12}). The second, sometimes referred to as the “freeze frame” point, or the point where video picture continuity is lost, occurs when the BER becomes sufficiently high that a video compression decoder becomes unable to build a picture frame. This freeze frame point is typically very close to the complete unlock of the demodulator carrier and bit timing tracking loops.

Above the QEF point, digital picture quality remains essentially constant for all values of C/N . In fact, the video picture quality level in this region is independent of the link C/N , i.e. it is solely dependent on the quality and compression ratio of the compression video encoder being employed, as well as the information bit rate assigned to the video channel.

Video quality rapidly degrades from the QEF point to the freeze frame point because of the avalanching number of bit errors presented to the video decoder that can no longer be mitigated by the concatenated forward error correction. At error correction lock threshold, video stops abruptly, normally resulting in frozen display of the most recent decoded video frame.

As per Note 2 to *recommends* 1.2 in Recommendation ITU-R BO.1444, the difference in C/N between the freeze frame point and the QEF point is assumed to be 1.5 dB unless an administration specifies otherwise. In this Recommendation, threshold availability is calculated at the QEF point.

2 Description of recommended methodologies

2.1 Introduction of relevant parameters

The performance of the digital BSS link is dependent on the technical design of the link, including the choice of digital coding, multiplexing, and modulation methods, the satellite e.i.r.p. and the figure of merit (G/T) of the BSS receiver. Other parameters that will impact system availability include propagation fading, depolarization due to rain, polarization misalignment, receive antenna mispointing, feeder uplink power control (UPC), on-board satellite automatic gain control (AGC) and interference from neighbouring BSS systems.

Table 2 provides the list of ITU-R Recommendations applied in the following sections. Techniques mentioned in Recommendation ITU-R BO.794 to minimize the effect of rain attenuation on the feeder link are considered and in particular UPC and on-board AGC: UPC allows the feeder link to maintain a given power level at the satellite in presence of propagation fading, while on-board AGC maintains the total satellite receive power to a level such that the power amplifier is driven at a constant level, i.e. the satellite maintains the downlink e.i.r.p. level independently of the uplink channel condition. Given that it is common to assume that the uplink interference signals are not faded at the same time as the desired link, the use of on-board AGC results in increase of the uplink interference signal power, which reduces the uplink C/I . Site diversity, also discussed in Recommendation ITU-R BO.794, is addressed fully in Recommendation ITU-R P.618 where a conversion from single link availability to multiple site diversity availability is provided; if applicable, this conversion can be applied to the results obtained using the methodology presented below.

2.2 System performance

The overall system performance is determined by the overall aggregate carrier-to-noise-plus-interference power ratio, $C/(N + I)$, defined by:

$$C/(N + I) = C/(N + I)_u \oplus C/(N + I)_d \quad \text{dB} \quad (1)$$

where:

$$C/(N + I)_u = C/N_u \oplus C/I_u \quad \text{dB} \quad (1a)$$

$$C/(N + I)_d = C/N_d \oplus C/I_d \quad \text{dB} \quad (1b)$$

and

C/N_u : uplink carrier to thermal noise power ratio (dB)

C/I_u : uplink carrier to interference power ratio (dB)

C/N_d : downlink carrier to thermal noise power ratio (dB)

C/I_d : downlink carrier to interference power ratio (dB)

Operator $\oplus$: $A \oplus B = -10 \log (10^{-A/10} + 10^{-B/10})$.

TABLE 2
Relevant ITU-R Recommendations

Recommendation ITU-R	Title	Application
P.618	Propagation data and prediction methods required for the design of Earth-space telecommunication systems	Propagation attenuation
P.676	Attenuation by atmospheric gases	
P.837	Characteristics of precipitation for propagation modelling	
P.839	Rain height model for prediction methods	
P.840	Attenuation due to clouds and fog	
P.841	Conversion of annual statistics to worst-month statistics	
P.838	Specific attenuation model for rain for use in prediction methods	
P.1511	Topography for Earth-to-space propagation modelling	
P.453	The radio refractive index: its formula and refractivity data	
P.835	Reference standard atmospheres	
P.679	Propagation data required for the design of broadcasting-satellite systems	
BO.790	Characteristics of receiving equipment and calculation of receiver figure-of-merit (G/T) for the broadcasting-satellite service	Calculation of receiver figure of merit (G/T)
BO.793	Partitioning of noise between feeder links for the broadcasting-satellite service (BSS) and BSS downlinks	Partitioning of noise
BO.794	Techniques for minimizing the impact on the overall BSS system performance due to rain along the feeder-link path	Rain fade mitigation techniques
BO.1212	Calculation of total interference between geostationary-satellite networks in the broadcasting-satellite service	Calculation of C/I
BO.1516	Digital multiprogramme television systems for use by satellites operating in the 11/12 GHz frequency range	Modulation and coding parameters

2.2.1 C/N_u calculation

The uplink carrier to thermal noise power ratio C/N_u is given by:

$$C/N_u = EIRP_u - L_{su} - A_{pu}(p_u) + UPC(p_u) - BW_{effu} - k + G/T_s \quad \text{dB} \quad (2)$$



where:

$EIRP_u$: uplink effective isotropic radiated power (dBW) in clear sky

L_{su} : uplink free space loss (dB) calculated as:

$$20 \log (4\pi R_u / \lambda_u)$$

where:

R_u : range (m) between feeder-link station and satellite

λ_u : uplink wavelength (m)

$A_{pu}(p_u)$: total uplink propagation loss (dB) exceeded $p_u\%$ of time; defined by ITU-R P.618, § 2.5 as

$$= A_{gu} + A_u(p_u)$$

where:

A_{gu} : uplink gaseous absorption (dB) (Recommendation ITU-R P.676)

$$A_u(p_u) = \sqrt{(A_{ru}(p_u) + A_{cu}(p_u))^2 + A_{su}^2(p_u)}$$

$A_{ru}(p_u)$: uplink rain attenuation (dB) exceeded $p_u\%$ of time (Recommendation ITU-R P.618)

$A_{cu}(p_u)$: uplink cloud and fog attenuation (dB) exceeded $p_u\%$ of time

$A_{su}(p_u)$: uplink scintillation fading (dB) exceeded $p_u\%$ of time

P_u : uplink exceedance or unavailability (%)

$UPC(p_u)$: uplink power control factor (dB) calculated as:

= 0, under clear-sky condition or when uplink power control is not used

= $\min(A_u(p_u), UPC_{max}) - \epsilon$, under faded condition

where:

UPC_{max} : maximum increase in transmit power (dB) in presence of path propagation attenuation

ϵ : uplink power control peak positive error (dB)

Bw_{effu} : effective uplink noise bandwidth (dB/Hz) of digital carrier

k : Boltzmann's constant = -228.6 (dB(W/K · Hz))

G/T_s : satellite receiver figure of merit (dB/K).

2.2.2 C/N_d calculation

With the use of on-board AGC and/or UPC, BSS systems are designed such that the satellite transponder is driven at a constant level up to the point where the uplink $C/(N + I)$ falls below a threshold, creating a system outage independent of the downlink channel condition. Accordingly, the satellite e.i.r.p. is maintained constant and thus the downlink availability performance is, for all practical purposes, decoupled from the uplink performance. Under these conditions, the downlink carrier to thermal noise power ratio C/N_d is given by:

$$C/N_d = EIRP_d - L_{sd} - A_{pd}(p_d) - BW_{effd} - k + G/T_g - Z_1 - dT(p_d) \quad \text{dB} \quad (3)$$

where:

$EIRP_d$: downlink effective isotropic radiated power (dBW)

L_{sd} : downlink free-space loss (dB) calculated as:

$$= 20 \log (4\pi R_d/\lambda_d)$$

where:

R_d : range (m) between satellite and receiver terminal

λ_d : downlink wavelength (m)

$A_{pd}(p_d)$: total downlink propagation loss (dB) exceeded $p_d\%$ of time; defined by Recommendation ITU-R P.618, § 2.5 as

$$= A_{gd} + A_d(p_d)$$

where:

A_{gd} : downlink gaseous absorption (dB)
(Recommendation ITU-R P.676)

$$A_d(p_d) = \sqrt{(A_{rd}(p_d) + A_{cd}(p_d))^2 + A_{sd}^2(p_d)}$$

$A_{rd}(p_d)$: downlink rain attenuation (dB) exceeded $p_d\%$ of time
(Recommendation ITU-R P.618)

$A_{cd}(p_d)$: downlink cloud and fog attenuation (dB) exceeded $p_d\%$ of time

$A_{sd}(p_d)$: downlink scintillation fading (dB) exceeded $p_d\%$ of time

P_d : downlink exceedance or unavailability (%)

BW_{effd} : effective downlink noise bandwidth (dB/Hz) of digital carrier; same as BW_{effu} for “bent pipe” repeater satellite

G/T_g : receiver terminal usable figure of merit (dB/K) under clear-sky condition, i.e. including only gaseous absorption effect (Recommendation ITU-R BO.790, Annex 1, § 1 without rain and cloud attenuation)

Z_1 : adjustment factor (dB) for satellite transponder distortion

$dT(p_d)$: increase in noise temperature (dB/K) due to path attenuation from rain and clouds exceeded $p_d\%$ of time (e.g. difference in G/T when applying Recommendation ITU-R BO.790, Annex 1, § 1 with:

1. path attenuation set to $A_{gd} + A_{rd} + A_{cd}$,
2. path attenuation set to A_{gd} only).

2.2.3 Overall C/I calculation

The overall aggregate carrier-to-interference power ratio, C/I , is given by:

$$C/I = C/I_u \oplus C/I_d \quad \text{dB} \quad (4)$$

where:

C/I_u : uplink carrier to interference power ratio (dB)

C/I_d : downlink carrier to interference power ratio (dB).

Recommendation ITU-R BO.1212 is used to calculate the clear-sky uplink and downlink C/I 's including intra- and inter-BSS system interference. Under channel fading, the inter-system interference signals are assumed to be non-faded. Combined with the use of UPC and/or on-board AGC, the faded inter-system C/I 's are equivalent to the clear-sky C/I 's reduced by the level of channel fading such that:

$$C/I_u = [C/I_{cu} - A_u(p_u) + UPC(p_u)] \oplus C/I_{intra}^u(p_u) \quad \text{dB} \quad (4a)$$

$$C/I_d = [C/I_{cd} - A_d(p_d)] \oplus C/I_{intra}^d(p_d) \quad \text{dB} \quad (4b)$$

where:

C/I_{cu} : clear-sky uplink inter-system C/I (dB) according to Recommendation ITU-R BO.1212 when considering only atmospheric gaseous absorption (Recommendation ITU-R P.676) for both the interfered and wanted links and without consideration of UPC

C/I_{cd} : clear-sky downlink inter-system C/I (dB) according to ITU-R BO.1212 when considering only atmospheric gaseous absorption (Recommendation ITU-R P.676) for both the interfered and wanted links

$$C/I_{intra} = C/I_{intra}^u(p_u) \oplus C/I_{intra}^d(p_d) \quad \text{dB}$$

C/I_{intra} : overall aggregate carrier to intra-system interference ratio (dB)

$C/I_{intra}^u(p_u)$: uplink carrier to intra-system interference ratio (dB) according to Recommendations ITU-R BO.1212 and ITU-R P.618 for the rain depolarization

$C/I_{intra}^d(p_d)$: downlink carrier to intra-system interference ratio (dB) according to Recommendations ITU-R BO.1212 and ITU-R P.618 for the rain depolarization.