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

(Questions ITU-R 70/4 and ITU-R 259/4)

(1978-1982-1986-1990-1992-1994-2000-2001-2003-2006)

Scope

This Recommendation provides maximum off-axis e.i.r.p. levels not to be exceeded by earth stations associated with geostationary-satellite networks operating in the fixed-satellite service and transmitting in the 6 GHz, the 13 GHz, the 14 GHz and the 30 GHz frequency bands. A number of notes provides additional guidelines on the application of the off-axis e.i.r.p. levels.

The ITU Radiocommunication Assembly,

considering

a) that geostationary satellite networks in the fixed-satellite service (FSS) operate in the same frequency bands;

b) that some non-geostationary satellite networks in the FSS may operate in the same frequency bands as some geostationary satellite networks in accordance with the Radio Regulations (RR);

c) that interference between networks in the FSS contributes to noise in the network;

d) that it is necessary to protect a network in the FSS from interference by other such networks;

e) that it is necessary to specify the maximum permissible levels of off-axis e.i.r.p. density from earth stations, to promote harmonization between geostationary satellite networks, and also where applicable to limit interference power from GSO FSS earth stations to uplinks of non-GSO systems;

f) that the contribution of interference from an earth station of an adjacent satellite network into a space station receiver is a function of the earth station off-axis e.i.r.p. density;

g) that the use of antennas with the best off-axis performance will lead to the most efficient use of radio-frequency spectrum and the GSO;

h) that off-axis e.i.r.p. density levels are determined by the side-lobe gain, the transmitter output power level and spectral distribution of that power,

noting

a) that Annex 1 and Annex 2 describe the basis on which certain of the levels in this Recommendation were derived, *recommends*

1 that earth stations operating in GSO networks in the FSS transmitting in the 5 725-7 075 MHz frequency band should be designed in such a manner that at any angle, φ, which is 2.5° or more off the main lobe axis of the earth station antenna, the e.i.r.p. density in any direction within 3° of the GSO does not exceed the following values:

1.1 for emissions in systems other than those considered in § 1.2 and 1.3 below:

Angle off-axis	*Maximum e.i.r.p. per 4 kHz*
2.5° ≤ φ < 48°	(35 – 25 log φ) dB(W/4 kHz)
48° ≤ φ ≤ 180°	–7 dB(W/4 kHz);

1.2 for emissions in voice-activated telephony SCPC/FM systems:

Angle off-axis	*Maximum e.i.r.p. per 40 kHz*
2.5° ≤ φ < 48°	(42 – 25 log φ) dB(W/40 kHz)
48° ≤ φ ≤ 180°	0 dB(W/40 kHz);

1.3 for emissions in voice-activated telephony SCPC/PSK systems:

Angle off-axis	*Maximum e.i.r.p. per 40 kHz*
2.5° ≤ φ < 48°	(45 – 25 log φ) dB(W/40 kHz)
48° ≤ φ ≤ 180°	3 dB(W/40 kHz);

2 for new antennas of an earth station transmitting in the 5 725-7 075 MHz frequency band and installed after 1988, using emissions other than those considered in *recommends* 1.2 and 1.3, the e.i.r.p. density should not exceed the following values:

Angle off-axis	*Maximum e.i.r.p. per 4 kHz*
2.5° ≤ φ ≤ 7°	(32 – 25 log φ) dB(W/4 kHz)
7° < φ ≤ 9.2°	11 dB(W/4 kHz)
9.2° < φ ≤ 48°	(35 – 25 log φ) dB(W/4 kHz)
48° < φ ≤ 180°	–7 dB(W/4 kHz);

3 that earth stations operating in GSO networks in the FSS transmitting in the 12.75-13.25 GHz and 13.75-14.5 GHz frequency bands should be designed in such a manner that at any angle, φ, which is 2.5° or more off the main lobe axis of the earth station antenna, the e.i.r.p. density in any direction within 3° of the GSO does not exceed the following values:

3.1 for emissions in systems other than those considered in *recommends* 3.2:

Angle off-axis	*Maximum e.i.r.p. per 40 kHz*
2.5° ≤ φ ≤ 7°	(39 – 25 log φ) dB(W/40 kHz)
7° < φ ≤ 9.2°	18 dB(W/40 kHz)
9.2° < φ ≤ 48°	(42 – 25 log φ) dB(W/40 kHz)
48° < φ ≤ 180°	0 dB(W/40 kHz).

3.2 for FM-TV emissions with or without energy dispersal, the off-axis total e.i.r.p. of the transmitted FM-TV carrier should not exceed the following values:

Angle off-axis	*Maximum e.i.r.p.*
2.5° ≤ φ ≤ 7°	(53 – 25 log φ) dBW
7° < φ ≤ 9.2°	32 dBW
9.2° < φ ≤ 48°	(56 – 25 log φ) dBW
48° < φ ≤ 180°	14 dBW

FM-TV emissions with or without energy dispersal should be modulated at all times with programme material or appropriate test patterns to reduce interference to other networks. Figure 1 of Annex 1 provides an example of typical spectral distribution of an FM-TV carrier modulated by programme material, together with energy dispersal. In the event that the FM-TV emission is not being modulated, energy dispersal should be used such that the levels in *recommends* 3.1 are exceeded by no more than 3 dB;

3.3 for any direction in the region outside 3° of the GSO, the levels given in *recommends* 3.1 and 3.2 may be exceeded by no more than 3 dB;

4 that earth stations operating in GSO networks in the FSS transmitting in the 27.5-30 GHz frequency band be designed in such a manner that at any angle, φ, which is 2° or more off the main lobe axis of the earth station antenna, the e.i.r.p. density in any direction within 3° of the GSO should not exceed the following values:

Angle off-axis	*Maximum e.i.r.p. per 40 kHz*
2° ≤ φ ≤ 7°	(19 – 25 log φ) dB(W/40 kHz)
7° < φ ≤ 9.2°	–2 dB(W/40 kHz)
9.2° < φ ≤ 48°	(22 – 25 log φ) dB(W/40 kHz)
48° < φ ≤ 180°	–10 dB(W/40 kHz).

For any direction in the region outside 3° of the GSO, the above levels may be exceeded by no more than 3 dB.

Studies are being conducted which may lead to revision of this value;

5 that the following Notes should be regarded as part of this Recommendation:

NOTE 1 – Values in *recommends* 1.2 above apply to normal operation of voice telephony in a 4 kHz baseband and are based on a mean power noise analysis.

NOTE 2 – Enhanced orbit utilization and easier coordination would be attained with lower side-lobe e.i.r.p. density values, and therefore, administrations are encouraged to achieve lower values where practicable (e.g. by using antenna having an improved pattern performance in the GSO plane).

NOTE 3 – The values in *recommends* 1 to 4 are maximal values under clear-sky conditions. In case of systems employing uplink power control, these levels include any additional margins above the minimum clear-sky level necessary for the implementation of uplink power control. When uplink power control is used and rain fades make it necessary, the levels stated in *recommends* 3 and 4 may be exceeded for the duration of that period. When uplink power control is not used and the e.i.r.p. density levels given in the above *recommends* 3 and 4 are not met, different values can be agreed upon through bilateral coordination taking into account the specific requirements (e.g. rain fade effects) and parameters of the satellite networks involved.

NOTE 4 – The e.i.r.p. density levels for off-axis angles less than 2.5° (for the 6 GHz, 13 GHz and 14 GHz ranges) and less than 2° (for the 30 GHz range) may be determined through coordination agreements taking into account the specific parameters of the two satellite networks involved.

NOTE 5– The off-axis e.i.r.p. density levels outside 3° of the GSO do not apply to earth station antennas ready to be in service[1] prior to 2 June 2000 nor to earth stations associated with a satellite network in the FSS for which complete coordination or notification information has been received before 2 June 2000.

The uplinks to non-GSO FSS systems using the bands 12.75-13.25 GHz and 13.75-14.5 GHz should be designed allowing for interference from the earth stations of GSO FSS networks exceeding the off-axis e.i.r.p. density levels in *recommends* 3 within 3º of the GSO by up to 3 dB.

NOTE 6 – For GSO systems in which the earth stations are expected to transmit continuously and simultaneously in the same 40 kHz band, e.g. for the GSO systems employing code division multiple access (CDMA), the maximum off-axis e.i.r.p. density values should be decreased by 10 log(N) dB, where N is the number of earth stations which are in the receive satellite beam of the satellite to which these earth stations are communicating and which are expected to transmit simultaneously on the same frequency.

NOTE 7 – Earth stations operating in the 27.5-30 GHz frequency band should be designed in such a manner that 90% of their peak off-axis e.i.r.p. density levels do not exceed the levels given in *recommends* 4. Further study is needed to determine the off-axis angular range over which these exceedances would be permitted, taking into account the interference level into adjacent satellites. The statistical processing of the off-axis e.i.r.p. density peaks should be dealt with using the method given in Recommendation ITU-R S.732.

NOTE 8 – In the frequency band 29.5-30 GHz, the off-axis e.i.r.p. density levels given in *recommends* 4 do not apply to earth stations associated with GSO networks brought into use before 2 June 2000.

NOTE 9 – The application of *recommends* 4 for earth stations operating with GSO networks in the 27.5-29.5 GHz frequency band requires taking into account existing GSO networks as of 1 July 2003.

NOTE 10 – FSS earth stations operating in the 27.5-30 GHz band, which have lower elevation angles to the GSO will require higher e.i.r.p. levels relative to the same terminals at higher elevation angles to achieve the same power flux-densities (pfds) at the GSO due to the combined effect of increased distance and atmospheric absorption. Earth stations with low elevation angles may exceed the levels of *recommends* 4 by the following amount (see Annex 2):

Elevation angle to GSO (ε)	*Increase in e.i.r.p. density (dB)*
$\varepsilon \leq 5°$	2.5
$5° < \varepsilon \leq 30°$	$3 - 0.1\,\varepsilon$

NOTE 11 – The levels given in *recommends* 3 may be exceeded by telecommand and ranging carriers transmitted to GSO FSS satellites in both normal and emergency modes of telecommand operation. The amount by which these levels may be exceeded when operating in normal mode is 16 dB. For earth stations operating telecommand and ranging carriers in the 27.5-30 GHz band further study is required.

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[1] "Ready to be in service" relates to the case where antennas have been installed but the start of service has been delayed due to *force majeure*.

NOTE 12 – In the frequency range 27.5-29.0 GHz for earth stations whose antenna diameter is less than 65 cm, the off-axis e.i.r.p. density levels given in *recommends* 4 may be exceeded by up to 3 dB provided that the maximum off-axis e.i.r.p. density does not exceed the following values:

Angle off-axis	*Maximum e.i.r.p. per 2 MHz*
$2° \leq \varphi \leq 7°$	(37 – 25 log φ – 10 log M) dB(W/2 MHz)
$7° < \varphi \leq 9.2°$	(16 – 10 log M) dB(W/2 MHz)
$9.2° < \varphi \leq 48°$	(40 – 25 log φ – 10 log M) dB(W/2 MHz)
$48° < \varphi \leq 180°$	(7 – 10 log M) dB(W/2 MHz).

where *M* is the number of earth stations which are in the receive beam of the satellite to which these earth stations are communicating and which are expected to transmit simultaneously in the same 2 MHz band and in the same polarization. It should be noted that for these cases a reduction in e.i.r.p. density, or additional orbital separation, would be required in order to arrive at the same adjacent satellite interference in the Earth-to-space direction as would result from the off-axis e.i.r.p., values as specified in *recommends* 4.

NOTE 13 – The levels in *recommends* 4 applicable to the off-axis angle range from 48° to 180° are intended to account for spillover effects.

Annex 1

1 Introduction

Interference from an earth station transmitter into the satellite receivers of other networks can be related directly to the off-axis spectral e.i.r.p. density of the interfering earth station antenna. This is a function not only of the earth station antenna side-lobe performance but also depends on the transmitter power level and its spectral density which, in turn, will be influenced by the overall satellite system design.

The establishment of a recommended limit for off-axis spectral e.i.r.p. density can be approached from two viewpoints:

– limitation of the interference level entering another satellite taking particular account of interference to networks employing large earth station antennas;

– determination of the on-axis e.i.r.p. requirements for earth stations, particularly those employing relatively small antennas and consideration of the on-axis and off-axis gain that such antennas could be expected to provide.

2 Consideration of an off-axis e.i.r.p. density limit for the 6 GHz band

An examination from both of the viewpoints mentioned above has led to the conclusion that the recommended limit should take the following form for uplink emission at about 6 GHz.

At any angle, φ, 2.5° or more off the main lobe axis of an earth station antenna, the e.i.r.p. per 4 kHz in any direction within 3° of the GSO should not exceed the following values:

Angle off-axis	*Maximum e.i.r.p. per 4 kHz*
2.5° ≤ φ ≤ 25°	(E – 25 log φ) dB(W/4 kHz)
25° < φ ≤ 180°	(E – 35) dB(W/4 kHz)

where the value of E should be within the range 32.0 to 38.5. The value of E should be as small as practicable, and will vary from one frequency band to another. For some satellite system applications, it may be desirable to develop an off-axis e.i.r.p. density limit by using a more stringent value of E (e.g. 32) in the near-in angular region (e.g. φ ≤ 7°) and then to relax the value of E at larger off-axis angles. This type of stepped limit would constrain the off-axis radiation in those angular regions where the value would be more effective in limiting interference to adjacent satellites.

From the viewpoint of tolerable interference into a satellite network with large station antennas, it may be noted that a value of 38.5 for E would permit a maximum e.i.r.p. density of 21.0 dB(W/4 kHz) to be radiated from an earth station at 5° off-axis.

From the viewpoint of the reasonable requirements of earth stations with small antennas, four cases that might be considered are:

Case 1: high density FM carrier – large station;

Case 2: FM-TV – small station (global satellite antenna);

Case 3: FM-TV – broadcast satellite uplink;

Case 4: SCPC – narrow-band.

Assuming the following:

– the satellite noise temperature ≤ 3 000 K;

– the satellite antenna gain ≥ 16 dB;

– the earth-station antenna conforms to Recommendation ITU-R S.465 for off-axis angles less than 25°, but the side-lobe envelope has a constant level of –3 dBi beyond 25°;

– 10 log (earth station noise temperature) ≥ 19.

(Values for the minimum power density at an off-axis angle of 5° are shown in Table 1.)

TABLE 1

Minimum off-axis e.i.r.p. density for typical carriers

	FDM-FM 1 332 channels 36 MHz RF bandwidth	**FM-TV**	**FM-TV broadcasting satellite uplink**	**SCPC global**
Satellite G/T (dB(K^{-1}))	–7	–17	0	–17
Uplink C/T (dB(W/K))	–125	–137	–134	–154
e.i.r.p. (dBW)	82	80	66	63
Earth station antenna transmit gain (dB)	60	53	46	53
RF power input to earth station antenna (dBW)	22	27	20	10

TABLE 1 (*end*)

	FDM-FM 1 332 channels 36 MHz RF bandwidth	**FM-TV**	**FM-TV broadcasting satellite uplink**	**SCPC global**
RF spectral power density input to earth station antenna (dB(W/4 kHz))	–8	0	–4	0
$E_{5°}$ (dB(W/4 kHz)[(1)]	6.5	14.5	10.5	14.5

(1) Radiation at 5° assuming 32 – 25 log φ relationship.

The worst interference would be from Case 2 where a 53 dB gain corresponds to a 10 m diameter antenna. The required transmitter power would be about 500 W. With 27 dB (2 MHz) of spreading advantage, the nominal transmit power density would be 0 dB(W/4 kHz) resulting in an off-axis radiation of 14.5 dB(W/4 kHz) at 5°.

While Case 4 indicates a similar value for off-axis e.i.r.p. density radiations, other factors must be considered. SCPC are low level carriers with a nominal earth station transmit level of 63.5 dB(W/channel). Since TV normally only has spreading at a slow rate (25 or 30 Hz), it is considered that the total carrier power must be considered as pulsed interference. In this case, at 5° the *C*/*I* would be 22 dB on the uplink and 13 dB on the downlink. While criteria for interference in these cases do not exist, an overall *C*/*I* of 20 dB has been adopted in some analyses for such pulsed interference. Recognizing the severe incompatibility of this situation, the conclusion is reached that adequate protection is not reasonably attainable by satellite separation nor by more severe e.i.r.p. restrictions since the downlink is dominant. One solution is to restrict the uses of the two types of signals such that they would also be separated in frequency where the FSS is involved on both uplinks and downlinks. A second solution which might considerably relieve the problem noted above is a different method of carrier energy dispersal for television by transformation of the video signal.

Two examples from the Canadian TELESAT system show that at 6 GHz and an off-beam angle of 5°, a level of unwanted e.i.r.p. density in the approximate range 17-18 dB(W/4 kHz) is associated with SCPC transmissions from a 4 to 5 m diameter antenna and with TV transmissions from a 10 m diameter antenna.

As to Case 4, a study was made in Japan on the off-axis e.i.r.p. density per 4 kHz bandwidth for the SCPC-PSK carrier of the INTELSAT system and SCPC-FM and SCPC-PSK carriers of the MARISAT system. Based on the results of the above studies, it may be concluded that in the case of a transmission between Standard-B earth stations in the INTELSAT system, the worst value of off-axis e.i.r.p. density from the transmitting earth station is 6 dB higher than 35 – 25 log φ (dB(W/4 kHz)).

It should be noted that these figures are only an illustrative example of existing systems. In any event a Recommendation should not be tailored to a specific existing system but on the contrary future systems should be designed to meet the Recommendation in its final form.

Based on the foregoing, it is concluded that the utilization of the GSO at about 6 GHz could be protected, while permitting earth stations with antennas as small as 4 or 5 m in diameter to be used, by applying the following guidelines:

– care should be exercised in frequency planning to ensure that television transmissions in one network do not use the same frequencies as SCPC telephony transmissions in a network using a nearby satellite;

– in all other cases, earth stations should conform to the off-axis e.i.r.p. spectral density limits in the direction of the GSO indicated in the second paragraph of this section, the value of *E* lying within the range 32.0 to 38.5.

3 Consideration of off-axis e.i.r.p. density limit for the 10-15 GHz band

When considering an off-axis e.i.r.p. density limit at 10-15 GHz it is reasonable to assume that the satellite receive antenna will not normally provide wide angle coverage and on this account it may be possible to utilize lower earth-station e.i.r.p.s and hence lower levels of off-axis radiation than in the lower frequency bands. However, this may be counteracted by the fact that rain fading will be more severe.

3.1 Method of calculation of *E*

In general, the interference, *I*, from a transmitting earth station into an interfered-with space station φ° from the intended transmission is given by:

$$I = E - 25 \log \varphi - L_{FS} - L_{CA} - L_R + G_s \quad (1)$$

where:

- E: constant to be determined for a limit formula related to a reference bandwidth
- L_{FS}: free-space loss at the transmitting frequency
- L_{CA}: clear-air attenuation
- L_R: attenuation due to rain (in the worst case $L_R = 0$, in clear-air conditions)
- G_s: gain of the antenna of the interfered-with satellite in the direction of the interfering earth station.

The single entry uplink interference, *I*, may be specified to be constrained to be equal to a fraction of the up-path thermal noise of the interfered-with space station. In that case:

$$I = 10 \log (k\,T\,B) - \Delta \quad (2)$$

where:

- Δ: thermal noise-to-interference power ratio
- T: noise temperature at the satellite receiver input
- B: bandwidth under consideration
- k: Boltzmann's constant.

Then, in the worst case where $L_R = 0$:

$$E - 25 \log \varphi = 10 \log k\,B + L_{FS} + L_{CA} - (G/T)_s - \Delta \quad (3)$$

where $(G/T)_s$: satellite figure of merit (dB(K^{-1})).

If the free-space loss is 207 dB (14 GHz) and the clear-air attenuation is 0.5 dB this simplifies to:

$$E - 25 \log \varphi = -21.1 - (G/T)_s + B - \Delta \quad (4)$$

Thus for given parameters φ, $(G/T)_s$, B and Δ, the parameter *E* which defines the permissible e.i.r.p. density from an earth station at angle φ° off-axis can be determined.

However, other factors should also be taken into account in choosing an off-axis limitation to the e.i.r.p. of emissions from transmitting earth stations in the 10-15 GHz bands. One such factor is the need to consider rain margins in the earth stations' e.i.r.p. budgets at these frequencies; another is that constraining the off-axis e.i.r.p. density values to certain limits may have a significant influence on the earth station antenna diameter. An example of how antenna diameter varies with *E* for three different uplink rain margins is shown in Table 2a.

TABLE 2a

Required earth-station antenna diameters in an assumed television mode of operation to meet specified off-axis e.i.r.p. density values

E **(dB(W/40 kHz))**	**Antenna diameter (m)**		
	Rain margin 0 dB	**Rain margin 3 dB**	**Rain margin 6 dB**
33	12	17	24
36	8	12	17
39	6	8	12
42	4	6	8

Assumptions made in deriving Table 2a:

– TV carrier with 2 MHz peak-to-peak energy dispersal modulation only;

– reference bandwidth for E = 40 kHz;

– earth-station side-lobe gain given by 29 – 25 log φ (dBi);

– earth-station antenna efficiency = 57-65%;

– 14 GHz operation;

– clear-air C/T required at satellite input = –127 dBW(K^{-1});

– satellite G/T = –3 dB(K^{-1}).

The impact on the parameter *E* of the need to take account of adverse propagation conditions, in a region of high rainfall (Brazil) is exemplified in Table 2b.

TABLE 2b

Examples of the increase in off-axis e.i.r.p. density for systems designed to cope with large propagation fades

Carrier	***E*** **(dB(W/40 kHz))**			
	Clear-sky model		**Deep-fade model**	
	A = 29	A = 32	A = 29	A = 32
FM-TV	34	37	47	50

Where earth-station side-lobe gain is A – 25 log φ (dBi).

Assumptions made in deriving Table 2b:

– TV carrier with 2 MHz peak-to-peak energy dispersal modulation only;

– 60° earth-station elevation angle;

– uplink availability better than 99.9%;

– 14 GHz operation.

3.2 Factors affecting *E*

In addition to the rain margin included in the "interfering" uplink design there are a number of variables which impact on the value of *E* for satellite services:

a) *"Interfering" carrier type*

Recognizing that, in transponders amplifying multiple FM carriers, power spectral density, and hence the interference potential, does not vary greatly between carriers of different capacity, consideration can perhaps be limited to cases in which a transponder carries the following signals:

– multiple FDM-FM carriers;
– multiple "high density" FDM-FM carriers;
– a single FDM-FM carrier;
– one PCM-PSK-TDMA carrier;
– SCPC-PCM-PSK multiple carriers;
– FM-TV, single carrier, with 2 MHz carrier energy dispersal;
– SCPC-FM multiple carriers.

The e.i.r.p. spectral density required for the uplink of each of these carriers will further depend on whether it is destined for reception at large or small antenna receiving terminals.

b) *"Interfered-with" carrier type*

A similar range of cases as in a) above should be considered.

c) *Interference objective*

ITU-R studies have considered the possibility of increasing the interference allowance in the interest of decreasing satellite spacing.

d) *Satellite spacing*

In the frequency range 10-15 GHz, spacings of 3° for co-coverage satellites have been implemented, but increased demand for service has prompted consideration of 2° spacing in certain locations.

e) *"Interfered-with" satellite coverage area*

Satellite *G*/*T* values corresponding to typical regional and domestic coverages should be considered.

f) *"Interfering" earth station side-lobe gain characteristic*

As improved designs of earth station antenna are brought into service, off-axis emissions will reduce.

g) *Rain margin included in the "interfered-with" uplink design*

Full consideration of all these factors would involve thousands of combinations, and a correspondingly wide range of *E*.

In deriving this list the assumption is made that the values of earth station antenna diameter and transmitter power required to simultaneously meet the "wanted" uplink e.i.r.p. and the off-axis e.i.r.p. limit will be chosen. There may be circumstances where this is impractical, e.g. small transportable earth stations being used to provide short duration television uplinks from various locations in a satellite's coverage area.

Table 3 gives an example of the inter-relationship between parameter *E* and factors c) to f) inclusive. Both interfering and interfered-with carriers are frequency modulated by television signals and are assumed to be identical. Combinations of earth station antenna size and transmitter power have been chosen which provide the required e.i.r.p. for the wanted carrier whilst just meeting the up-path interference objectives.

It should be noted that this example assumes two identical satellite systems. Wider variations in *E* and in the earth station parameters would result from the inclusion of cases where the satellites in the interfering and interfered-with systems had different *G*/*T* values.

TABLE 3

Optimum *E* values and related parameters for FM-TV to FM-TV interference

Satellite *G*/*T* (dB(K^{-1}))		–3				–5			
Satellite spacing (degrees)		2		3		2		3	
Interference objective (% of up-path thermal noise)		20	50	20	50	20	50	20	50
Earth-station side-lobe gain 32 – 25 log φ	Antenna diameter (m)	10.7	6.8	6.4	4.1	26.9	17.1	16.2	10.3
	Transmitter power (W)	139	342	382	951	3.5	8.6	9.6	23.9
Earth-station side-lobe gain 29 – 25 log φ	Antenna diameter (m)	7.6	4.8	4.6	2.9(1)	19.0	12.1	11.5	7.3
	Transmitter power (W))	287	685	764	1 903(1)	7.0	17.2	19.2	47.8
Earth-station side-lobe gain 26 – 25 log φ	Antenna diameter (m)	5.3	3.4	3.2(1)	2.0(1)	13.4	8.5	8.1	5.1
	Transmitter power (W)	557	1 385	1 517(1)	3 794(1)	14.0	34.8	38.1	95.3
Off-axis e.i.r.p. parameter *E* (dB(W/40 kHz))		28.4	32.4	32.8	36.8	20.4	24.4	24.8	28.8

(1) In these cases, larger antennas and lower transmitter powers would probably be chosen in practice and in these circumstances the interference would be well within the prescribed limits.

Assumptions made in deriving Table 3:

– "interfering" and "interfered-with" earth-stations at 15° elevation;

– 14 GHz operation;

– satellite antenna gain the same for "interfering" and "interfered-with" up paths;

– earth-station antenna efficiency = 65%;

– 3 dB rain attenuation on "interfered-with" up path only;

– up-path *C*/*T* of "interfered-with" TV carrier = –130 dBW(K^{-1});

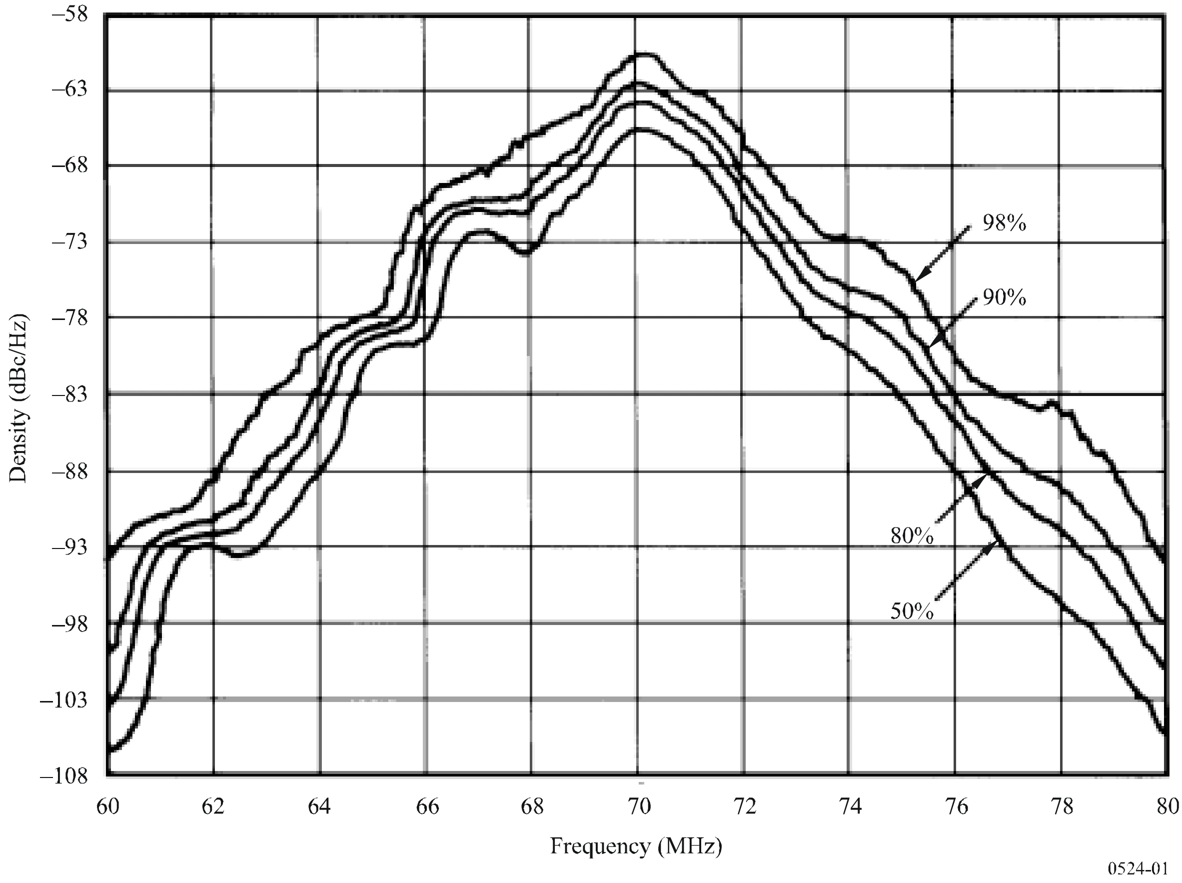
– modulation by energy dispersal signal only, 2 MHz peak-to-peak deviation.

3.3 Spectral distribution of modulated FM-TV carrier

To study the effects of interference into narrow-band carriers due to FM-TV carriers modulated by program material together with energy dispersal, the spectral characteristics of a 20 MHz NTSC TV carrier were measured. Figure 1 shows spectral density distribution of the TV carrier modulated by a live video signal plus energy dispersal causing 1 MHz peak-to-peak deviation, not exceeded for various percentages of time.

FIGURE 1

Spectral distribution of a 20 MHz FM-TV carrier modulated by NTSC live video plus 1 MHz energy dispersal



4 Consideration of off-axis e.i.r.p. density limits for the band 29.5-30 GHz (see Note 1)

4.1 Evidence in supporting of *recommends* 4

At the time of writing there are two sources of data in ITU-R documentation on GSO/FSS carriers using, or planned to use, the 29.5-30 GHz band; one is Recommendation ITU-R S.1328, and the other is the database compiled from the responses by administrations to Circular Letters CR/92 and CR/116 (see Note 2) issued in 1998 and 1999 respectively during the preparation for WRC-2000 (hereafter this is termed the CR/116 database for convenience).

For most of its GSO FSS carriers Recommendation ITU-R S.1328 contains sufficient information to enable the off-axis e.i.r.p. spectral density transmitted by the uplink earth station to be calculated, if realistic assumptions are made for the earth station antenna radiation pattern (e.g. Recommendation ITU-R S.580) for the few carriers where it is missing. There is also enough data to calculate, for each carrier, the degradation in the clear-air $(C/N)\uparrow$ which would be caused by an earth station located near the centre of the "wanted" satellite beam but operating to an adjacent satellite and whose off-axis e.i.r.p. density is equal to the limits in *recommends* 4 of this Recommendation, given reasonable assumptions where necessary for the uplink thermal noise and the internal interference. For the present purpose an uplink thermal noise temperature of 800 K, and an uplink carrier-to-internal interference ratio of 20 dB, were assumed wherever Recommendation ITU-R S.1328 lacks sufficient data for one of these parameters to be deduced.

The information in the CR/116 database on all the links designed to use the 29.5-30 GHz band is fully adequate for the uplink degradation to be calculated. However, the earth station off-axis e.i.r.p. density which would be radiated by the transmitting earth station could not be calculated for any of the CR/116 links because, apart from its on-axis e.i.r.p. and pointing error, no other parameters of that earth station (e.g. peak antenna gain and side-lobe pattern) are included in the database.

The e.i.r.p. spectral density which would be radiated by the transmitting earth station for each of the Recommendation ITU-R S.1328 carriers in the band 29.5-30 GHz, at 2° off-axis, is given in Fig. 2. The degradation in the clear-air total $(C/N)\uparrow$ for each of the Recommendation ITU-R S.1328 carriers, which would be caused by interference from an earth station near the centre of the wanted satellite beam, transmitting to another satellite spaced 2° and 3° respectively from the wanted satellite in the GSO at levels corresponding to the limits in *recommends* 4, is given in Fig. 3. The carrier numbers indicated in Table 4 correspond to the following in Recommendation ITU-R S.1328:

FIGURE 2

e.i.r.p. density produced by 29.5-30 GHz Recommendation ITU-R S.1328 carriers at 2° off-axis

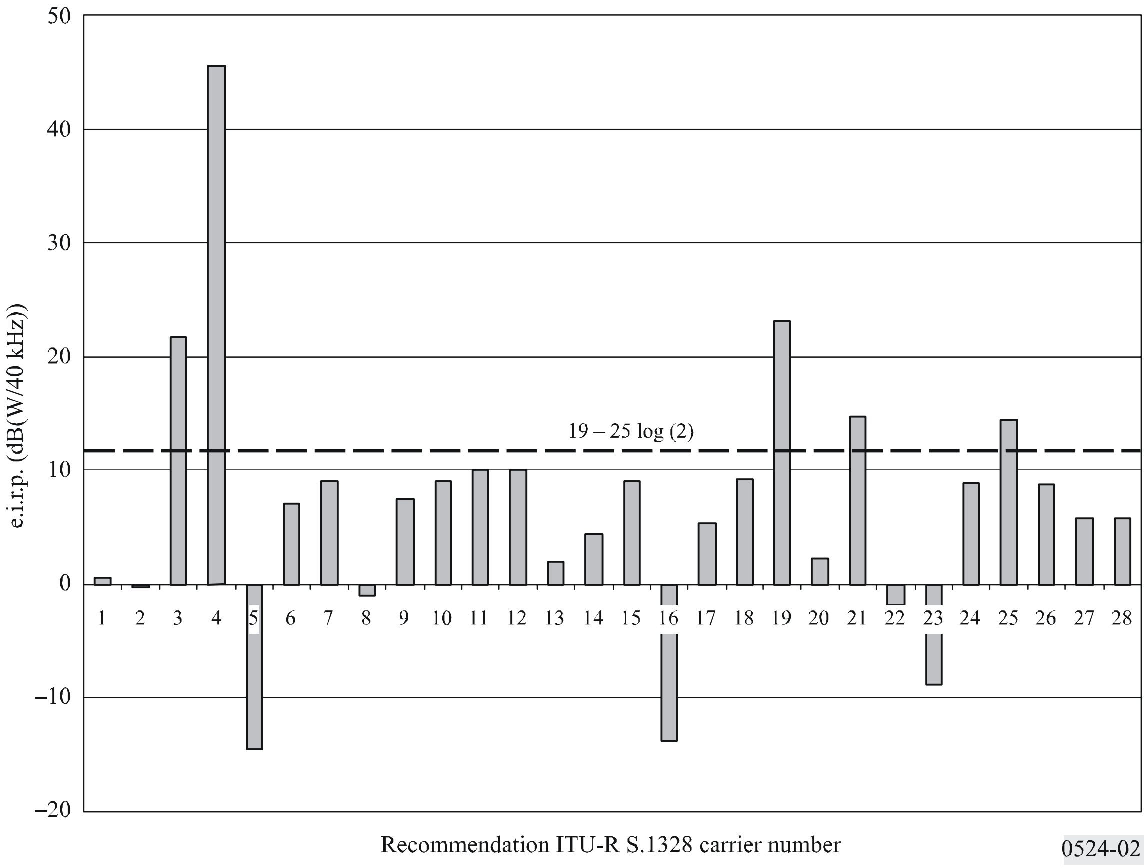


FIGURE 3

Maximum degradation in $(C/N)_{\uparrow}$ of 29.5-30 GHz Recommendation ITU-R S.1328 carriers from single-entry interference at off-axis e.i.r.p. limit level

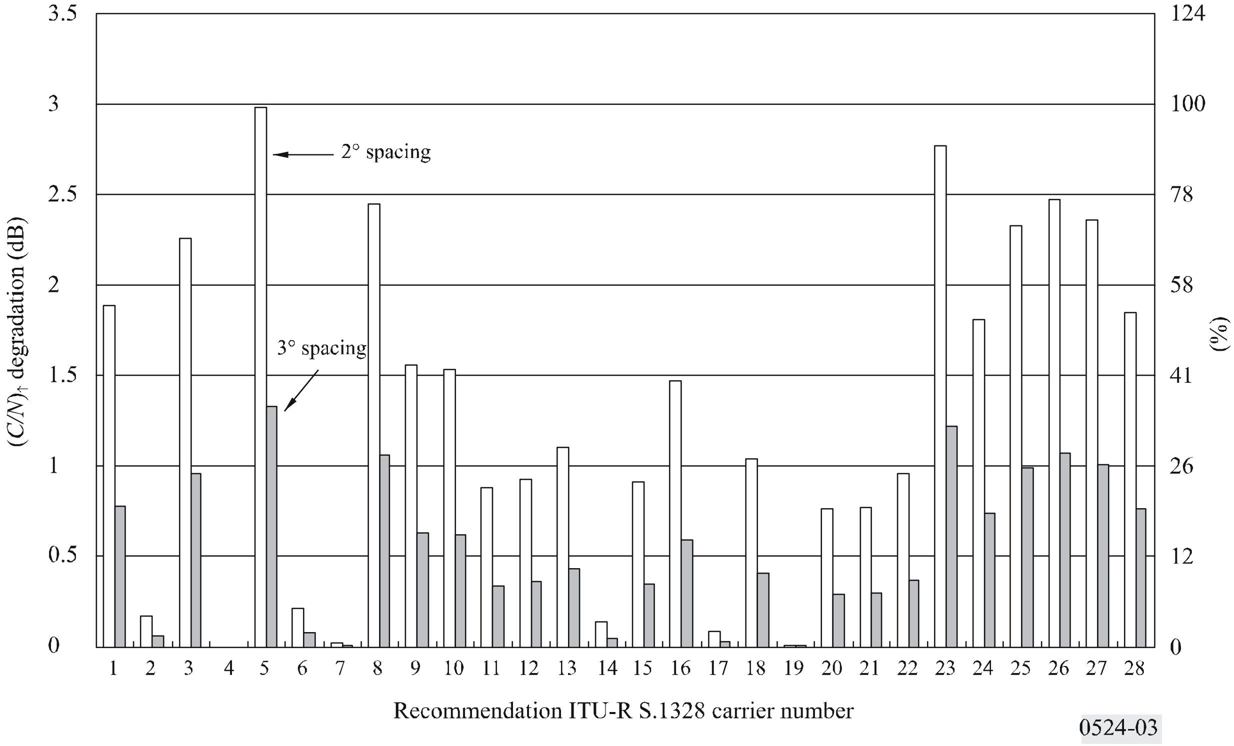


TABLE 4

GSO carrier No.	1	2	3	4	5	6	7	8	9	10
Rec. ITU-R S.1328 table	1	1	1	1	2	3	3	3	4	4
Rec. ITU-R S.1328 system	13 min	13 max	20	30	F	11	12	13	B	J

GSO carrier No.	11	12	13	14	15	16	17	18	19	20
Rec. ITU-R S.1328 table	4	4	4	4	4	4	4	4	4	4
Rec. ITU-R S.1328 system	K	L	M	N	S	T	U	V	W	X (max)

GSO carrier No.	21	22	23	24	25	26	27	28
Rec. ITU-R S.1328 table	4	5	5	5	6	6	6	6
Rec. ITU-R S.1328 system	X (min)	P Ka-1	P Ka-2	P Ka-3	Q Res. min	Q Res. max	Q Bus. min	Q Bus. max

The degradation in the clear-air total $(C/N)\uparrow$ for each of the CR/116 links in the band 29.5-30 GHz, which would be caused by interference from an earth station near the centre of the wanted satellite beam, transmitting to another satellite spaced 2° and 3° respectively from the wanted satellite in the GSO at levels corresponding to the limits in *recommends* 4, is given in Fig. 4. Link numbers shown are those in the database.

FIGURE 4

Maximum degradation in $(C/N)\uparrow$ of 29.5-30 GHz CR/116 links from single-entry interferences at off-axis e.i.r.p. limit level

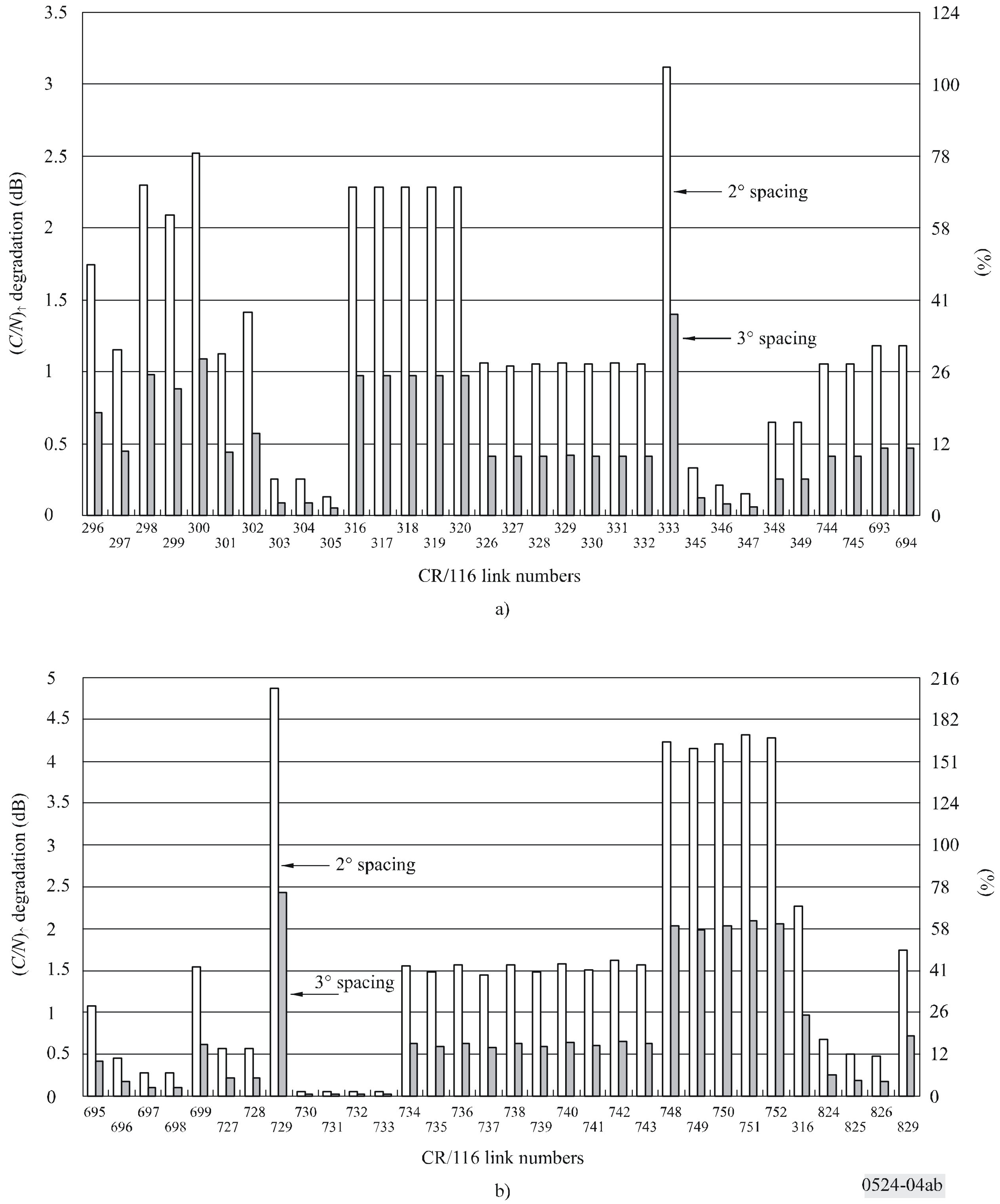
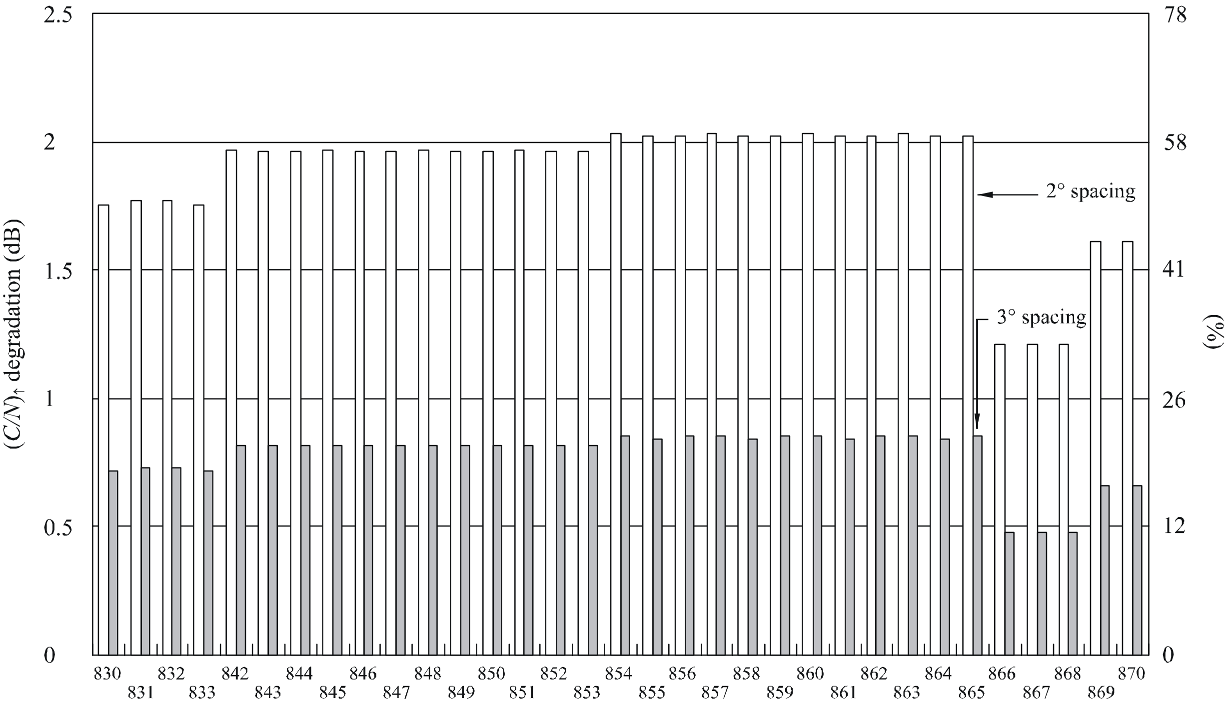


FIGURE 4 (*continued*)



c)

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At 2° off-axis *recommends* 4 prescribes an e.i.r.p. density limit of 11.47 dB(W/40 kHz). Of the 28 carriers included in Fig. 2 it can be seen that 23 – i.e. 82% – would meet that limit, and since the only reference antenna patterns listed in Recommendation ITU-R S.1328 for the 30 GHz carriers are those defined in Recommendation ITU-R S.465 or Recommendation ITU-R S.580, both of which follow 25 log (φ) laws for the near side lobes, this indicates that in the 29.5-30 GHz band most existing and planned GSO earth stations are likely to meet *recommends* 4. It may therefore be concluded that the limits in *recommends* 4 are not an unreasonable restriction on FSS developments in this band.

From Fig. 3 it can be seen that interference at the *recommends* 4 limit, from an earth station operating to a satellite spaced at 2° from the wanted satellite, would degrade the $(C/N)_\uparrow$ by less than 58.5% (i.e. 2 dB) in 75% of the carriers. Similarly Fig. 3 also shows that for 3° satellite spacing the degradation in $(C/N)_\uparrow$ would be 36% (1.33 dB) for the most vulnerable of the Recommendation ITU-R S.1328 carriers, and would be less than 26.0% (1 dB) in 82% of the Recommendation ITU-R S.1328 carriers.

From Fig. 4 it may be deduced that interference at the *recommends* 4 limit, from an earth station operating to a satellite spaced at 2° from the wanted satellite, would degrade the $(C/N)_\uparrow$ no more than 58.5% or less in 84% of the CR/116 links. Similarly, Fig. 4 shows that for 3° satellite spacing the degradation in $(C/N)_\uparrow$ would be 75% (2.4 dB) for the most vulnerable of the CR/116 links, and would degradate the $(C/N)_\uparrow$ by less than 26.0% (1 dB) in 92% of the CR/116 links.

To put the findings of the two preceding paragraphs into perspective four factors should be taken into account:

– that in most of the geostationary orbit the spacing between adjacent co-frequency, co-coverage satellites is a minimum of 3°, and even in crowded arcs that spacing is not normally less than 2°;

– that the off-axis e.i.r.p. density levels in the near-side-lobe region generated by earth stations transmitting the majority of 29.5-30 GHz carriers, except those subject to 10% of side-lobe peaks as mentioned in Note 15 (see § 4.2), will be significantly lower than the limits in *recommends* 4;

– that the 6%-of-noise specified in Recommendations on FSS long-term protection criteria such as Recommendations ITU-R S.523, ITU-R S.735 and ITU-R S.1323 is the coordination trigger level set by the RR;

– that where necessary higher interference levels are often accepted during the coordination process.

Therefore it is considered that the uplink degradation results mentioned above provide evidence that the off-axis e.i.r.p. density limits in *recommends* 4 give acceptable protection to GSO FSS uplinks against interference from other GSO FSS networks and allow to increase the efficient use of the geostationary orbit.

Bearing these factors in mind the above results support the conclusion that the limits in *recommends* 4 are sufficiently tight to allow reasonably close satellite spacing, without requiring individual systems to accept unreasonable levels of uplink interference.

NOTE 1 – The process contained in this section was undertaken to provide evidence in support of the levels of *recommends* 4, but was not used to derive the levels given in *recommends* 4 and is not proposed as a new method for possible use in future revisions of this Recommendation.

NOTE 2 – Circular Letters CR/92 and CR/116 requested administrations to provide data on their GSO FSS links that could have a significant impact on their performance due to interference from non-GSO FSS networks.

4.2 Further factors taken into account

4.2.1 Introduction

In determining the acceptable level of off-axis emissions, it is important to consider two points. First, the maximum permissible levels of off-axis e.i.r.p. density should not constrain the continuing operation of existing GSO/FSS systems and the development of future GSO/FSS systems. Second, off-axis e.i.r.p. densities must include appropriate margins to compensate for the fact that the standard ITU-R approach permits 10% of antenna side lobes to exceed the nominal envelope.

The *recommends* 4 and associated footnotes take account of these two requirements. This Annex provides background information on the factors which were taken into account in the ITU-R studies on this topic, shows the maximum permissible levels of off-axis e.i.r.p. density needed to operate certain existing 30/20 GHz GSO/FSS systems mentioned in this Recommendation and the need for considering grandfathering these existing systems.

4.2.2 Existing and future GSO/FSS systems

Several systems are now in operation in the bands 29.5-30.0/19.7-20.2 GHz and the number is increasing. Many types of services will be provided to meet the many types of expected market demands. Therefore, when considering acceptable levels of off-axis e.i.r.p. density, it is necessary to take into account not only existing systems but also future systems so as not to restrict the variety of services that can be provided by satellite systems.

Four example system types are shown in Table 5. Types 1 and 2 currently exist; the other two are planned. All four types have been or will be in operation in Japan in the 29.5-30.0/19.7-20.2 GHz frequency bands.

TABLE 5

Parameters of existing and future GSO/FSS systems

System	Type 1	Type 2	Type 3	Type 4
Service type	PSTN/ISDN	High-speed data	SNG	ISDN
Availability (%)	99.8/99.6	99.6	99.6	99.6
Required *C*/*N* (dB)	11.5	9.0	8.0	12.8
Required bandwidth (kHz)	25 024	100 000	21 000	8 800
Transmission antenna diameter (m)	4.2	2.4	1.2	3.0
Input power at feed (W)	150	150	15	15
Input power density at feed (dB(W/40 kHz))	–6.2	–12.2	–15.4	–11.7
Maximum input power density at feed in rain condition (dB(W/40 kHz))	–6.2	–12.2	–5.4	–1.7
Maximum off-axis e.i.r.p. densities in clear-sky condition[(1)] (dB(W/40 kHz); $1° \le \varphi \le 20°$)	23 – 25 log φ	17 – 25 log φ	14 – 25 log φ	18 – 25 log φ
Receive antenna diameter (m)	11.5/4.2	2.4	4.2	3.0
Total $C/N + I$ (dB)	22.1/19.9	13.3	11.0	17.9

(1) Values are calculated using 29 – 25 log φ antenna side-lobe pattern.

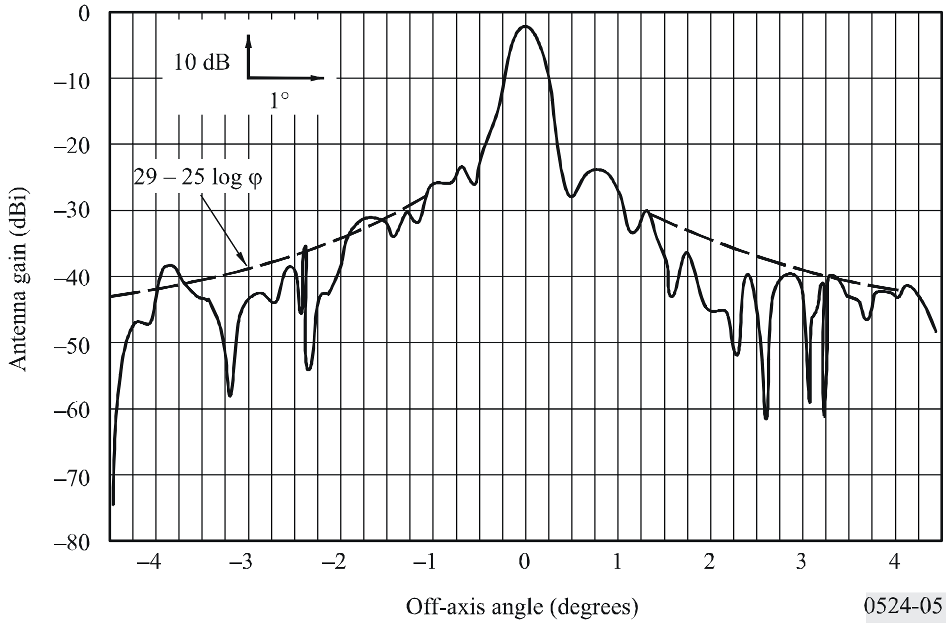
SNG: satellite news gathering.

4.2.3 Margin to the excess of antenna side-lobe gain from side-lobe pattern

A 29 – 25 log φ antenna side-lobe pattern was used to calculate off-axis e.i.r.p. densities shown in Table 5. However, this side-lobe pattern is a design objective in Recommendation ITU-R S.580, which states that the gain of 90% of the side-lobe peaks should not exceed this side-lobe envelope in any direction within 3° of the GSO. Thus, 10% of the side-lobe peaks can exceed this side-lobe envelope even if the earth station antennas comply with this Recommendation. Therefore, it is necessary to take into account some margin to the excess when evaluating actual off-axis e.i.r.p. densities. An example measured radiation pattern in the east/west plane of 2.4 m diameter antenna for 30/20 GHz band usage is shown in Fig. 5. The maximum excess over the Recommendation ITU-R S.580 side-lobe envelope was about 4 dB. This means that at least a 4 dB margin is needed for this antenna to evaluate off-axis e.i.r.p. densities.

FIGURE 5

Exemple measured antenna radiation pattern



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If this 4 dB margin is used with the uplink power control range of 10 dB, for all conditions, the maximum permissible levels of off-axis e.i.r.p. density that do not constrain the operation of the GSO/FSS systems mentioned in the previous section are as follows:

32 – 25 log (φ)	dB(W/40 kHz)	for	2.0° ≤ φ ≤ 7.0°
11	dB(W/40 kHz)	for	7.0° < φ ≤ 9.2°
35 – 25 log (φ)	dB(W/40 kHz)	for	9.2° < φ ≤ 48°
–7	dB(W/40 kHz)	for	φ > 48°

In case of clear-sky condition, the maximum permissible levels of off-axis e.i.r.p. density that do not constrain the operation of the GSO/FSS systems mentioned in the previous section are as follows:

27 – 25 log (φ)	dB(W/40 kHz)	for	2.0° ≤ φ ≤ 7.0°
16	dB(W/40 kHz)	for	7.0° < φ ≤ 9.2°
30 – 25 log (φ)	dB(W/40 kHz)	for	9.2° < φ ≤ 48°
–12	dB(W/40 kHz)	for	φ > 48°

However, further studies are needed to select appropriate margin to the excess, because various types of antennas should be taken into account.

4.2.4 Conclusion

This Annex showed several GSO/FSS system parameters, an example of a measured antenna radiation pattern, and the maximum permissible levels of off-axis e.i.r.p. density that do not constrain the operation of these GSO/FSS systems.

The maximum permissible levels of off-axis e.i.r.p. density should be selected so as not to restrict the variety of services provided by existing and future satellite systems. Furthermore, off-axis e.i.r.p. densities must include appropriate margin to the excess of the actual antenna side-lobe gain from antenna side-lobe design objectives described in Recommendation ITU-R S.580.

Therefore, when defining the permissible levels of off-axis e.i.r.p. density from GSO/FSS earth stations operating in the 29.5-30.0 GHz band in any direction within 3º of the GSO, these GSO/FSS system parameters and the side-lobe envelope should be taken as the minimum conditions which could be adopted. This has been done in Note 7 of the Recommendation.

Where new networks must meet more stringent limits, provision must be made for ensuring that more strigent limits are not imposed to existing networks. This has been done in Notes 8 and 9 of the Recommendation.

Annex 2

1 Introduction

Using the formula given in Note 10 to establish the increase, for low elevation angle terminals, above the maximum off-axis e.i.r.p. level transmitting in the 27.5-30.0 GHz band (see Note 1), the range between the maximum and the minimum pfd received at the GSO (from any point on the Earth's surface from which the elevation angle to the GSO is greater than 5°), would not be more than about 1 dB. Given the proposed model for off-axis e.i.r.p. limits for transmitting earth station terminals having elevation angles 30° or less, the variation in pfd at the GSO, over the range of atmospheric parameters examined, is less than the difference in free space loss alone (1.32 dB), which occurs over the entire range of elevation.

In the 6 GHz or the 14 GHz bands, the off-axis e.i.r.p limits in *recommends* 1 to 3 are independent of elevation angle. Atmospheric absorption even at low elevation angles in these bands is small when compared with the variation in the pfd at the GSO due to free space loss alone. Using the model proposed in Note 10, the variation of pfd received at the GSO will be less than that which occurs due to free space loss alone. Thus, the impact of permitting low elevation angle earth station terminals at 30 GHz to transmit with the additional off-axis e.i.r.p proposed, over the range of atmospheres studied will have very minimal risk to the coordination of co-frequency uplinks to GSO satellite networks. In atmospheres where water vapour density, δ, is greater than about 7.5 g/m^3, the peak pfd at the GSO, due to low elevation angle earth station terminals implementing the proposed uplink power compensation, will be less than that at angles above 30° where no uplink power compensation is used.

Figures 6, 7 and 8 show, using Recommendation ITU-R P.676, the relative levels of pfd received at the GSO as a function of elevation angle. In all three cases examined, a ground elevation of 0 m (amsl) and an atmospheric pressure of 1 013 hPa were assumed.

FIGURE 6

Variation of the pfd received at GSO computed at 29.75 GHz

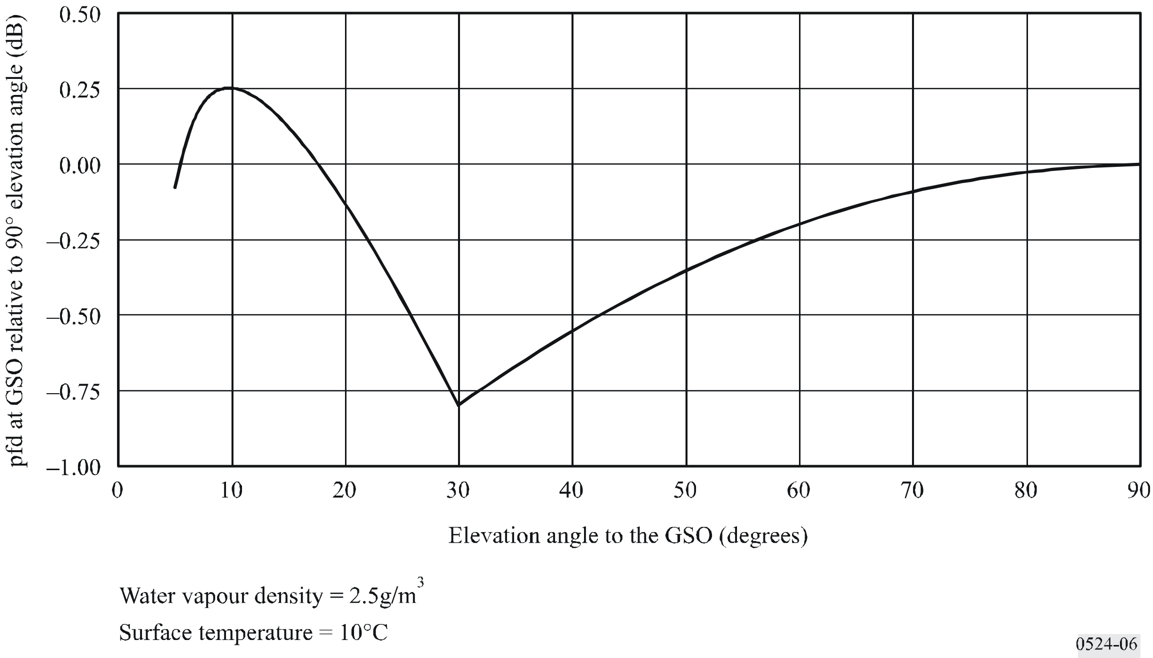

FIGURE 7

Variation of pfd received at the GSO computed at 29.75 GHz

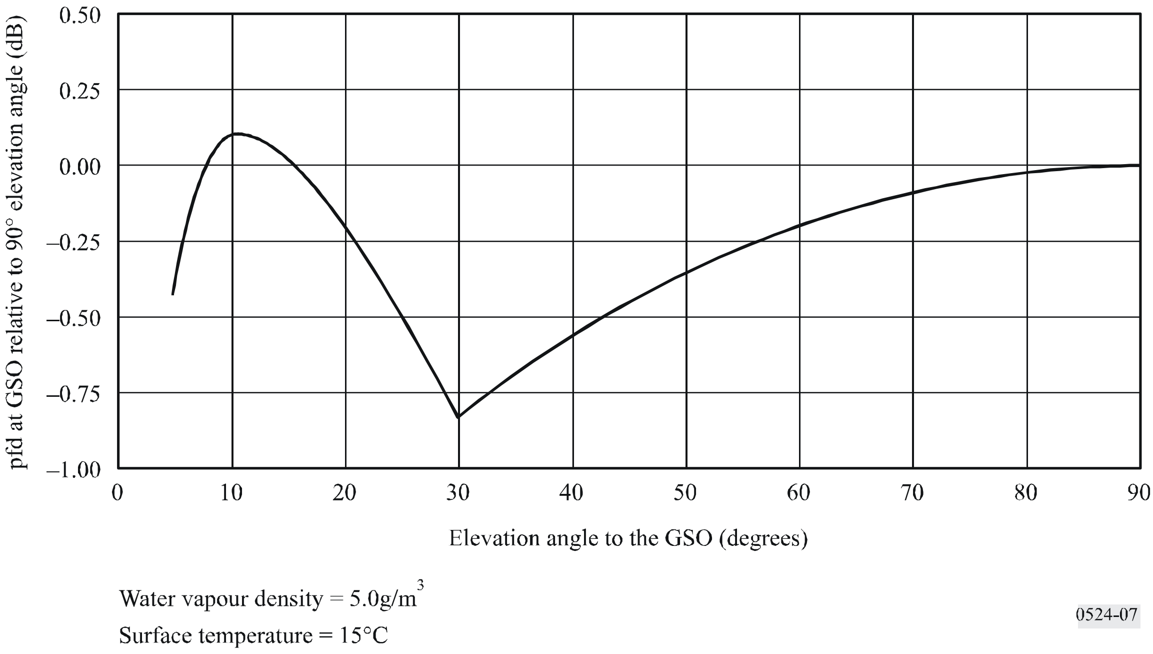

FIGURE 8

Variation of the pfd received at GSO computed at 29.75 GHz