RECOMMENDATION ITU-R S.524-5

MAXIMUM PERMISSIBLE LEVELS OF OFF-AXIS e.i.r.p. DENSITY FROM EARTH STATIONS IN THE FIXED-SATELLITE SERVICE TRANSMITTING IN THE 6 AND 14 GHz FREQUENCY BANDS*

(Questions ITU-R 48/4 and ITU-R 70/4)

(1978-1982-1986-1990-1992-1994)

The ITU Radiocommunication Assembly,

considering

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

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

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

d) 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;

e) that networks in the FSS may receive interference into the space station receiver;

f) that the use of antennas with the best off-axis performance will lead to the most efficient use of radio-frequency spectrum and the geostationary-satellite orbit (GSO);

g) that progress in the development of reduced side-lobe antennas indicates that improved performance antennas will be widely available in the next few years;

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;

j) that Annex 1 describes the basis on which the limits in this Recommendation were derived,

recommends

1. that networks in the FSS operating in the 6 GHz frequency band be designed in such a manner that at any angle, φ, which is 2.5° or more off the main lobe axis of an earth station antenna, the e.i.r.p. density in any direction within 3° of the GSO should 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*
$2.5° \leq \varphi < 48°$	$(35 - 25 \log \varphi)$ dB(W/4 kHz)
$48° \leq \varphi \leq 180°$	–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*
$2.5° \leq \varphi < 48°$	$(42 - 25 \log \varphi)$ dB(W/40 kHz)
$48° \leq \varphi \leq 180°$	0 dB(W/40 kHz);

* Except where providing feeder links to the broadcasting-satellite service in accordance with Appendix 30A of the Radio Regulations (RR).

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

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

2. for new antennas of an earth station using emissions other than those considered in § 1.2 and 1.3, after 1988 the e.i.r.p. density should not exceed the following values:

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

3. that earth stations operating in networks in the FSS operating in the 14 GHz frequency band (which are not providing feeder links to the broadcasting-satellite service in accordance with RR Appendix 30A be designed in such a manner that at any angle, φ, which is 2.5° or more off the main lobe axis of an 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*
$2.5° \leq \varphi \leq 7°$	$(39 - 25 \log \varphi)$ dB(W/40 kHz)
$7° < \varphi \leq 9.2°$	18 dB(W/40 kHz)
$9.2° < \varphi \leq 48°$	$(42 - 25 \log \varphi)$ dB(W/40 kHz)
$48° < \varphi \leq 180°$	0 dB(W/40 kHz);

4. that the following Notes should be regarded as part of this Recommendation.

Note 1 – Values in § 1.2 above are based on a mean power noise analysis. Possible subjective effects of interference into an SCPC-FM carrier by a very narrow bandwidth emission have not been considered. Further studies are required on this matter.

Note 2 – Limits in § 1.2 above apply to normal operation of voice telephony in a 4 kHz baseband.

Note 3 – The values contained in § 1.1 above have been derived mainly from an analysis of FM systems used for analogue television or multi-channel telephony. It is not known at the present time whether telecommand and ranging systems operating in the emission band and some types of SCPC system different from those mentioned in § 1.2 and 1.3, comply with these provisions. Studies should be undertaken in order to determine how these systems could comply with the limits above.

Note 4 – Enhanced orbit utilization and easier coordination would be attained with lower side-lobe e.i.r.p. values, and therefore, administrations are encouraged to achieve lower values where practicable.

Note 5 – Wherever practicable, existing earth stations should comply with the values above.

Note 6 – The provisional values contained in § 2 have been derived from advanced, low side-lobe antenna patterns, taking into account the principles of Note 3. Further studies of earth station antenna performance at angles close to the main beam, and particularly in respect of the validity of 7° as a value up to which it is reasonable to recommend this 3 dB tightening of the off-axis e.i.r.p. density limit, are urgently needed. These studies should also include consideration of the impact of the values in § 2 on antennas with operating bandwidths greater than 500 MHz.

Note 7 – It may be necessary, in frequency planning, to avoid situations where television transmissions in one network use the same frequencies as SCPC telephony transmissions in a network using a nearby satellite.

Note 8 – When up-link power control is used and rain fades make it necessary, the limiting values stated in § 3 may be exceeded for the duration of that period. In rain climates N and P in the case when up-link power control is not used, the limits given in § 3 may be exceeded by *y* dB. The value of *y* dB needs to be determined by further studies based on reliable propagation data to establish fade margins with adequate accuracy. Table 2 provides further guidance on this subject.

Note 9 – Administrations operating earth stations in the 14 GHz band are encouraged to reduce the off-axis e.i.r.p. density by increasing the required antenna diameter, employing improved antenna side-lobe performance or, in the case of FM-TV, to use an appropriate form of energy dispersal, if applicable.

Note 10 – For FM-TV transmissions, administrations are encouraged to reduce interference to other networks by using either programme material or appropriate test patterns, together with energy dispersal, at all times.

Figure 1 provides an example of typical spectral distribution of a FM-TV carrier modulated by programme material, together with energy dispersal.

Note 11 – The use of reduced satellite spacing will require further study of the e.i.r.p. limit for off-axis angles below 2.5°.

Note 12 – FM-TV emissions with energy dispersal in the 14 GHz band may exceed the limits in § 3 above by up to 3 dB provided the off-axis total e.i.r.p. of the emitted FM-TV carrier does not exceed the following values:

Angle off-axis	*Maximum e.i.r.p.*
$2.5° \leq \varphi \leq 7°$	$(53 - 25 \log \varphi)$ dBW
$7° < \varphi \leq 9.2°$	32 dBW
$9.2° < \varphi \leq 48°$	$(56 - 25 \log \varphi)$ dBW
$48° < \varphi \leq 180°$	14 dBW

Note 13 – For FM-TV carriers in the 14 GHz band which operate without energy dispersal, such carriers should be modulated at all times with programme material or appropriate test patterns. In this case, the off-axis total e.i.r.p. of the emitted FM-TV carrier should not exceed the following values:

Angle off-axis	*Maximum e.i.r.p.*
$2.5° \leq \varphi \leq 7°$	$(53 - 25 \log \varphi)$ dBW
$7° < \varphi \leq 9.2°$	32 dBW
$9.2° < \varphi \leq 48°$	$(56 - 25 \log \varphi)$ dBW
$48° < \varphi \leq 180°$	14 dBW

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 up-link 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 geostationary-satellite orbit (GSO) should not exceed the following values:

Angle off-axis	*Maximum e.i.r.p. per 4 kHz*
$2.5° \leq \varphi \leq 25°$	$(E - 25 \log \varphi)$ dB(W/4 kHz)
$25° < \varphi \leq 180°$	$(E - 35)$ 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. $\varphi \leq 7°$) 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: single-channel-per-carrier (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.)

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°.

TABLE 1

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

	FDM-FM 1 332 channels 36 MHz RF bandwith	FM-TV	FM-TV broadcasting satellite up-link	SCPC global
Satellite *G*/*T* (dB($K^{–1}$))	–7	–17	0	–17
Up-link *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
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.

While Case 4 indicates a similar value for off-axis e.i.r.p. density radiations, other factors must be considered. Single channel per carrier (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 up link and 13 dB on the down link. 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 down link 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 up and down links. 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 single channel per carrier 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 single channel per carrier 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:

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

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 up-link 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:

$$I = 10 \log (kTB) - \Delta \tag{2}$$

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 $L_R = 0$:

$$E - 25 \log \varphi = 10 \log kB + L_{FS} + L_{CA} - (G/T)_s - \Delta \tag{3}$$

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:

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

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 up-link rain margins is shown in Table 2a.

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 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}).

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;
– up-link availability better than 99.9%;
– 14 GHz operation.

3.2 Factors affecting E

In addition to the rain margin included in the interfering up-link 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 up link 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” up-link 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” up-link 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 up links 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