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Foreword

This ETSI Technical Report (ETR) has been prepared by the Satellite Earth Stations (SES) Technical Committee of the European Telecommunications Standards Institute (ETSI).

ETRs are informative documents resulting from ETSI studies which are not appropriate for European Telecommunication Standard (ETS) or Interim European Telecommunication Standard (I-ETS) status.

An ETR may be used to publish material which is either of an informative nature, relating to the use or application of ETSs or I-ETSs, or which is immature and not yet suitable for formal adoption as an ETS or I-ETS.

Introduction

The number of earth stations and radio equipment working in the frequency range above 1 GHz will increase significantly. The mass production of equipment is already underway or will start soon.

Examples are:

- Television Receive Only (TVRO) satellite earth stations (11/12 GHz bands);
- receive only Very Small Aperture Terminals (VSATs) for data distribution (11/12 GHz-bands);
- transmit/receive VSATs (11/12/14 GHz-bands);
- Land Mobile Satellite Earth Stations (LMSES) providing Low Bit Rate Data Communications (LBRDC) (11/12/14 GHz-bands);
- radio relay systems for the transmission of digital signals (11/14/23/38/50 GHz bands).

Increasingly "non-radio communications" systems may radiate spurious signals in these bands.

Undisturbed operation of stations is usually only possible, if no significant interference from other stations or other equipment exists.

The radio communication stations work in frequency bands allocated exclusively to the given service or shared with other services. Methods have been developed by the International Radio Consultative Committee (CCIR) (see CCIR Recommendations [4], and CCIR Reports [5]) to co-ordinate services operating in shared frequency bands. However, these co-ordination methods only cover radiation inside the necessary bandwidth.

The reduction of spurious radiation below permissible limits is not always technically possible, and unreasonably stringent limits could prevent the implementation of low cost equipment.

It is therefore necessary to determine the maximum allowable spurious radiation limits in such a way that, on the one hand, it is technically feasible to meet the requirements with acceptable costs and, on the other hand, harmful interference due to spurious radiation occurs only in very exceptional situations. These cases need to be solved on a case by case basis, therefore Clause 9 is devoted to "conflict resolution".

The Satellite Earth Stations (SES) Technical Committee of ETSI was tasked to develop ETSs for VSATs and TVROs (see ETS 300 157 [7], ETS 300 158 [8], and ETS 300 159 [9]). Due to the lack of applicable existing recommendations or standards for the frequency range above 1 GHz, appropriate limits had to be developed from scratch. During this process, much controversial discussion took place.

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1 Scope

This ETR presents methods which have been used to derive limits for spurious radiation from TVRO and VSAT earth stations. Additions to the report will be published concerning other types of earth station (e.g. Satellite News Gathering (SNG), mobile etc.) when work currently in progress has been completed. It is shown that the derived limits are appropriate and that only in very exceptional cases would harmful interference from spurious radiation be expected.

The report focuses on:

- frequencies above about 1 GHz; special considerations are given to the interference which may occur in frequency bands allocated to the Fixed Satellite Service (FSS);
- radiation outside the allocated frequency band in which the transmitting equipment is designed to work. Generally, this radiation cannot be covered by planning or site co-ordination procedures prior to operation. However, the principles described in this ETR may also be applicable to radiation inside the allocated frequency band but outside the assigned frequency channel or nominated bandwidth.

The report does not cover:

- co-ordination aspects between different satellite services operating in the same frequency bands (e.g., co-ordination between applications of the FSS working in the 11/12/14 GHz frequency band);
- co-ordination aspects between different services sharing the same frequency bands (e.g., co-ordination between FSS and Fixed Service (FS) in the 14,25 to 14,5 GHz band);
- aspects of electromagnetic immunity (e.g. malfunction of equipment caused by interfering electromagnetic fields with frequencies outside the bandwidth of the interfered system).

The methods and interference models described in this ETR are based on contributions to ETSI Technical Sub-Committee (STC) SES 2.

This ETR also clarifies some useful terms and summarises some general considerations which have been discussed in the process of deriving adequate limits.

This ETR is addressed to all bodies involved in the development of requirements or recommendations for equipment which may pollute the radio frequency spectrum in the frequency range above 1 GHz.

2 References

[1] ITU, Radio Regulations, Edition of 1990.

[2] ITU, Recommendations of the CCIR, 1990, Volume IV, Part 1, Fixed-Satellite Service.

[3] ITU, Reports of the CCIR, 1990, Annex to Volume IV, Part 1, Fixed-Satellite Service.

[4] ITU, Recommendations of the CCIR, 1990, Volume IV and IX, Part 2, Frequency Sharing and Co-ordination between Systems in the Fixed-Satellite Service and Radio-Relay Systems.

[5] ITU, Reports of the CCIR, 1990, Annex to Volume IV and IX, Part 2, Frequency Sharing and Co-ordination between Systems in the Fixed-Satellite Service and Radio-Relay Systems.

[6] ITU, CCIR Recommendations (New and revised as of March 1992), RS Series, Fixed Satellite Service.

[7] ETS 300 157: "Receive-only Very Small Aperture Terminals (VSATs) used for data distribution operating in the 11/12 GHz frequency bands".

[8] ETS 300 158: "Television Receive Only (TVRO) Satellite Earth Stations operating in the 11/12 GHz FSS bands".

[9] ETS 300 159: "Transmit/receive Very Small Aperture Terminals (VSATs) used for data communications operating in the Fixed Satellite Service (FSS) 11/12/14 GHz bands".

[10] CCIR Study Groups, Document 4-2/4-E, 30 November 1990: "Out of Band Spurious Emissions for VSAT" (French working paper describing the statistical interferer model in order to justify the proposed limits).

NOTE: Also distributed as Document ETSI /STC-SES 2 (91) 4.

[11] CCIR Study Groups, Document 4-2/25-E, 31 May 1991: "Simplified Interference Model for the Determination ..." (Swiss working paper describing the single interferer model and proposing to use it as alternative method to determine adequate limits).

[12] CCIR Study Groups, Document 4-2/19-E, 18 April 1991, Annex 2.2: "Out-of Band Spurious Emissions" Contribution from Japan.

[13] ETSI/STC-SES 2 (92) 13, February 7, 1992: "VSAT on-axis and out of band spurious emission limits", France Telecom contribution.

[14] ETSI/TC-SES (92) 043, March 11, 1992: "Considerations on the Spurious Limits for VSATs", Contribution from NEC Corporation.

[15] CISPR Publication No.22 (1985): "Limits and methods of measurement of radio interference characteristics of information technology equipment".

3 Definitions, abbreviations and units

3.1 Definitions

For the purposes of this ETR the following definitions extracted from the Radio Regulations [1] apply.

NOTE: References to the corresponding paragraphs of Article 1 in the RR [1] appear in brackets.

Allocation (of a frequency band): Entry in the Table of Frequency Allocations of a given frequency band for the purpose of its use by one or more terrestrial or space radio communication service or the radio astronomy service under specified conditions. This term shall also be applied to the frequency band concerned. (RR 17)

Allotment (of a radio frequency or radio frequency channel): Entry of a designated frequency channel in an agreed plan, adopted by a competent conference, for use by one or more administrations for a terrestrial or space radio communication service in one or more identified countries or geographical areas and under specified conditions. (RR 18)

Assignment (of a radio frequency or radio frequency channel): Authorisation given by an administration for a radio station to use a radio frequency or radio frequency channel under specified conditions. (RR 19)

Station: One or more transmitters or receivers or a combination of transmitters and receivers, including the accessory equipment, necessary at one location for carrying on a radio communication service, or the radio astronomy service.

Each station shall be classified by the service in which it operates permanently or temporarily (RR 58)

Terrestrial Station: A station effecting terrestrial radio communication.

In these Regulations, unless otherwise stated, any station is a terrestrial station. (RR 59)

Earth Station: A station located either on the Earth's surface or within the major portion of the Earth's atmosphere and intended for communication:

- with one or more space stations; or

- with one or more stations of the same kind by means of one or more reflecting satellites or other objects in space. (RR 60)

Space Station: A station located on an object which is beyond, is intended to go beyond, or has been beyond, the major portion of the Earth's atmosphere. (RR 61)

Radiation: The outward flow of energy from any source in the form of radio waves. (RR 131)

Emission: Radiation produced, or the production of radiation, by a radio transmitting station. (RR 132)

Out-of-band Emission (in French: "Emission hors bande"): Emission on a frequency or frequencies immediately outside the necessary bandwidth which results from the modulation process, but excluding spurious emissions. (RR 138)

Spurious emission (in French: "Rayonnement non essentiel"): Emission on a frequency or frequencies which are outside the necessary bandwidth and the level of which may be reduced without affecting the corresponding transmission of information. Spurious emissions include harmonic emissions, parasitic emissions, intermodulation products and frequency conversion products, but exclude out-of-band emissions. (RR 139)

Unwanted Emissions (in French: "Rayonnement non désirés"): Consist of spurious emissions and out-of-band emissions. (RR 140)

Necessary Bandwidth: For a given class of emission, the width of the frequency band which is just sufficient to ensure the transmission of information at the rate and with the quality required under specified conditions. (RR 146)

Equivalent Isotropically Radiated Power (e.i.r.p.): The product of the power supplied to the antenna and the antenna gain in a given direction relative to an isotropic antenna (absolute or isotropic gain). (RR 155)

Effective Radiated Power (e.r.p.) (in a given direction): The Product of the power supplied to the antenna and its gain relative to a half-wave dipole in a given direction. (RR 156)

Interference: The effect of unwanted energy due to one or a combination of emissions, radiations, or inductions upon reception in a radiocommunication system, manifested by any performance degradation, misinterpretation, or loss of information which could be extracted in the absence of such energy (RR 160)

Permissible Interference: Observed or predicted interference which complies with quantitative interference and sharing criteria contained in the Radio Regulations or in CCIR Recommendations or in special agreements as provided for in these Regulations. (RR 161)

3.2 Other definitions

For the purposes of this ETR the following additional definitions applicable to VSATs apply.

Nominated bandwidth; The bandwidth (e.g. of a VSAT radio frequency transmission) is nominated by the manufacturer. The nominated bandwidth shall encompass all close-in spectral elements of the transmission which have a density greater than the specified spurious levels (e.g. for transmit/receive VSATs). The nominated bandwidth shall be wide enough to take account of the transmit carrier frequency stability.

NOTE: It can be assumed, that the nominated bandwidth is equal or smaller than the width of an assigned frequency channel for a given station in a satellite transponder. This definition is used in ETS 300 159 [9].

Spurious Radiation: Spurious emission and any radiation from equipment which is not intended to radiate.

NOTE: This term is used in this ETR to make clear that any kind of equipment is involved. The term "Spurious emission" may be considered to be applicable for radio transmitting stations only.

3.3 Abbreviations

For the purposes of this ETR the following abbreviations apply.

BER	Bit Error Ratio
CCIR	International Radio Consultative Committee
CCIR SG	CCIR Study Group
CDMA	Code Division Multiple Access
CISPR	International Special Committee on Radio Interference
DAMA	Demand Assigned Multiple Access
EIRP	Equivalent Isotropically Radiated Power (see subclause 4.1)
ERP	Effective Radiated Power (see subclause 4.1)
ETS/prETS	European Telecommunication Standard/provisional ETS
ETSI	European Telecommunications Standards Institute
ETSI/TC-SES	ETSI Technical Committee Satellite Earth Stations
ETSI/STC-SES 2	ETSI/TC-SES Technical Subcommittee 2, responsible for radio frequency aspects
FEC	Forward Error Correction
FDM/FM	Frequency Division Multiplex/Frequency Modulation
ITU	International Telecommunication Union
LNA	Low Noise Amplifier
PFD	Power Flux Density
QPSK	Quadrature Phase Shift Keying
RR	Radio Regulations
SCPC	Single Channel Per Carrier
TVRO	Television Receive Only
VSAT	Very Small Aperture Terminal
WARC	World Administrative Radio Conference

3.4 Units for power values

In this ETR, the values for power and EIRP are generally given in dBpW. For an easy comparison, the table below shows the relation to other units:

Table 1: Comparison of power units

EIRP		EIRP (dBW)	EIRP (dBm)	EIRP (dBpW)	ERP (dBpW)	Field strength (dBµV/m at 10 m) *)	PFD (dBW/m^2 at 10 m) *)
10^{-15}	(1 fW)	- 150	- 120	- 30	- 32,15	- 35,23	- 181
10^{-12}	(1 pW)	- 120	- 90	0	- 2,15	- 5,23	- 151
10^{-9}	(1 nW)	- 90	- 60	30	27,85	24,77	- 121
10^{-6}	(1 µW)	- 60	- 30	60	57,85	54,77	- 91
10^{-3}	(1 mW)	- 30	0	90	87,85	84,77	- 61
1	(1 W)	0	30	120	117,85	114,77	- 31

*) NOTE: Since the distance of 10 m is usually in the near field for the frequencies considered the given relations may not be accurate (see also subclause 6.3.1).

4 Existing recommendations and reports from the International Telecommunications Union (ITU) and its associated bodies

The RR [1], Appendix 8 gives some guidance for the maximum mean power level of spurious components at the antenna transmission line. The limits given for the frequency range 960 MHz to 17,7 GHz range from - 10 to + 20 dBm and are between 40 and 60 dB below the mean power within the necessary bandwidth. These limits are not applicable to systems using digital modulation techniques. It is also stated, that specific services may demand more stringent limits. For frequencies above 17,7 GHz, no values are given.

Recommendation No. 66 of the RR [1] revised at Rev. WARC-92 recommends that the CCIR studies as a matter of urgency the question of spurious emissions resulting from space service transmissions. Also the aspects not yet covered by RR [1] Appendix 8 have to be studied.

NOTE: This task has been assigned to CCIR Study Group 1.

The CCIR has started some studies in the domain of this report in Study Group 4 through question 25/4, which resulted in report 713-1 [3]. This report is an overview of the problem area, but does not contain any recommendation for spurious radiation limits.

The CCIR approved in 1992 CCIR Recommendation 726 [6]. The limits in this recommendation have largely been influenced by the work of ETSI/STC-SES 2.

5 General considerations

5.1 Effects of spurious radiation on receiving stations

The effect of spurious radiation depends on the nature of the spurious signal and on the nature of the wanted signal.

Spurious signals may be characterised by:

- their spectra:
    - single tone signals (e.g. local oscillator leakage);
    - modulated signals (e.g. image frequency leakage, intermodulation products generated in power amplifiers);
    - noise like signals (e.g. thermal noise generated by the power amplifiers);
- their occurrence in time:
    - continuous (e.g. due to the continuous transmission of a signal);
    - periodic (e.g. due to the periodic transmission of bursts, as in a Time Division Multiple Access (TDMA) system);
    - random (e.g. due to the random transmission of bursts, as in an ALOHA or slotted ALOHA access system);
    - temporary (e.g. due to the transmission of signals on demand, as in SCPC-DAMA systems);
    - transient (e.g. due to the switching on of an equipment or to the carrier frequency acquisition phase);
- their power level.

The spurious radiation received may result in:

- degradation of the wanted signal quality;
- reduction of the availability margin;
- loss of synchronisation;
- malfunction.

The occurrence in time of these effects is generally the same as the occurrence in time of the spurious signals (see above).

The interfering signal upon reception at the receiving station may be perceived as:

- an apparent increase of the thermal noise;
- an additional modulation (amplitude and/or phase) of the wanted carrier;
- a disturbance of the clock or carrier recovery circuits.

The same interfering signal may have different effects, which depend on its level, on the characteristics of the wanted signal, and on the receiving station characteristics.

When the interfering signal is perceived as an apparent increase of the thermal noise the interfering signal is said to be noise-like.

The interference may, in general, be considered noise-like when the interference is due to a large number of interfering signals of similar power, and, also in the case of a single interfering signal, when its bandwidth is much larger than the bandwidth of the wanted signal. When the interfering signal bandwidth is narrower than the bandwidth of the wanted signal its effect is, in the large majority of cases, less perturbing, by a few dBs, than the effect of a noise-like interference having the same power.

To specify limits for spurious emissions of equipment placed in various locations it is not possible to consider specific receiving equipment and signals. Due to its simplicity, and based on the above considerations, the noise-like assumption was retained in order to estimate the effect of spurious radiation interference.

NOTE: Under certain conditions, this approach (the treatment of an interfering spurious signal in the same way as thermal noise) may be too optimistic. Measurements on a burst mode demodulator have shown, that malfunctions occur if the interferer is a single tone signal at the centre frequency of the demodulator or at the centre frequency ± the symbol clock frequency. These malfunctions occur in the carrier and clock recovery circuits and may happen in very particular situations with interferer levels which are about 10 dB below typical noise levels.

The effect of a noise-like interference signal with the level I can be treated as an apparent increase, (I+N)/N, of the thermal noise, N, of the receiver. The composite effect of various noise-like interferences can, usually, be evaluated by adding the power of the various interfering signals falling inside the receiver bandwidth.

The following conversion table 2 shows the apparent noise increase (I+N)/N as a function of the spurious signal level at the receiver input (I) related to the thermal noise power of the receiver (N).

Table 2: Conversion table

I/N (dB)	/N (dB)	Noise increase (percent)
0	3	100
- 2,3	2	58
- 5,9	1	26
- 9,1	0,5	12
- 11,5	0,3	7
- 13,3	0,2	5
- 16,4	0,1	2,3
- 19,4	0,05	1,2

5.2 Sources of spurious radiation, physical units and measuring bandwidth

5.2.1 Sources of spurious radiation

Spurious signals can be originated in:

- data processing equipment;
- modulators;
- frequency generation stages;
- frequency converters;
- amplification equipment, e.g. high power amplifiers.

Limits for spurious radiation have been defined for frequencies ranging from 30 MHz to 40 GHz. For frequencies below the cut-off frequency of the waveguide connected to the antenna, the spurious radiation is radiated by the connection cable between the indoor and outdoor unit and by the equipment housing. Generally these spurious radiations result from leakages. Above the cut-off frequency, the energy outflow from the antenna is usually the main contributor to spurious radiation.

5.2.2 Physical units

Above 1 GHz the limit of spurious radiation from a given equipment which will be placed anywhere at any distance from other equipment may be expressed as an EIRP value in a specified bandwidth.

The reasons for this choice are:

- wanted emissions are defined in EIRP values as well, and therefore a comparison with unwanted radiations is easy to perform;
- this value is independent of the distance (except for near field effects);
- practical for conformance tests.

However, this does not imply that direct measurement of the EIRP is required.

Conversely the limit of the spurious radiation received by an equipment (i.e. the maximum permissible interfering power due to spurious radiation) may be expressed as the sum of the powers received simultaneously in a specified bandwidth from every spurious generating equipment having various characteristics and frequencies, and which are placed around the interfered station at different positions and with different orientations.

5.2.3 Exclusion of the main beam direction from interference considerations

Earth stations are generally equipped with high directivity antennas, and work at high elevation angles, providing considerable isolation towards the horizontal directions. It is therefore unlikely that spurious radiation through the antenna with their main beam EIRP would cause harmful interference to other terrestrial services. Furthermore the interference potential within the main beam of the earth station is in general due to the high level of the transmitted signal rather than from the spurious radiation.

NOTE: The protection of space radio stations in the geostationary orbit is covered by other specifications.

Consequently, taking into consideration that the large majority of the satellite earth stations work usually at elevation angles greater than 7° (at least in the 11/12/14 GHz-band), limits were derived for directions more than 7° away from the main beam axis.

For earth station antennas complying with the recommended antenna gain patterns given in the VSAT ETSs (see ETS 300 157 [7] and ETS 300 159 [9]), the maximum antenna gain from 7° to 9,2° away from the main beam axis is 8 dBi. At larger angles the gain is lower.

Situations where a station (e.g. a radio relay station) is inside the 7° cone of an earth station antenna may occur under some special circumstances, particularly within cities. Such situations are considered exceptional and have to be treated on a case by case basis if problems occur.

5.3 Considerations on measuring procedures

For the purpose of conformance testing, measuring procedures have to be defined. The appropriate procedures depend on the nature of the equipment (e.g. it is obvious that a procedure which is applicable to a handheld mobile telephone terminal, is probably not applicable to a satellite earth station).

The measuring procedures should:

- be reproducible;

  NOTE 1: Different test houses should measure the same values for a specific parameter.

- be fast and easy to perform;

  NOTE 2: For manufacturers (and for customers) it is desirable, that the costs for conformance testing are not too high.

- show that a requirement is met with an adequate level of confidence.

Below, some remarks are given for specific measuring principles and parameters.

5.3.1 EIRP value, Power Flux Density (PFD) or electric field strength

For the measurement, a measuring receiver and a measuring antenna with a known gain is necessary. This equipment may be calibrated in PFD units or in field strength. With the distance between the equipment under test and the measuring antenna, the EIRP value can easily be calculated.

The EIRP is a far field parameter. The minimum far field distance d is commonly given by:

$$d = 2\,D^2 / \lambda$$

where D is the diameter of the radiating antenna and λ is the wavelength of the signal.

Often measurements are not practicable in the far field (for a 1,2 m antenna working at 14 GHz, the near field region is about 140 m). Measurements at lower distances may be affected by near field effects.

The relationship between the EIRP value and the measured PFD in a given distance and under far field conditions is:

$$EIRP = PFD \times 4\pi r^2$$

where r is the distance between the point of radiation and the measuring antenna.

The electric field strength is a parameter which is commonly used for the definition of radiation limits for frequencies below about 1 GHz, especially for non radio equipment. Implicitly, this parameter is usually perceived as a near-field parameter. The following relationship between the measured electric field strength value and the EIRP value is only valid in the far-field.

$$EIRP = E^2 \times 4\pi r^2 \; / \; Z_o$$

with: E = electric field strength;
Z_o = free space impedance (377 Ω).

The measurement of the EIRP values in any direction, in any polarisation and for any frequency may be very time consuming. However, for conformance testing, it is only necessary to know the values for significant spurious signals in the direction of maximum EIRP in their main polarisation planes.

5.3.2 Measurement at antenna ports

Satellite earth stations and radio relay stations are usually equipped with accessible ports at the antenna (i.e. antenna flange). For these kind of stations, the spurious signals can generally be measured at these ports.

The port measurements offer considerable advantages:

- the power of the spurious signals is independent of the directions in which they will be radiated by the antenna;

- the test time is short compared with a radiation measurement which has to be made in several directions and orientations;

- the measuring equipment consists mainly of a spectrum analyser and the associated calibration arrangement;

- a particular test range or an anechoic chamber is not required;

- the test results will not be affected by electromagnetic disturbances.

If the port measurement is applied to VSATs the following facts have to be taken into consideration:

- radiation from equipment housing and cables is not covered;

- if the antenna port is a waveguide interface the measurement includes all frequencies above the cut-off frequency of this waveguide;

- the measurement is accurate if the antenna port is a coaxial interface. If the antenna port is a waveguide interface, spurious components far away from the nominal frequency are not easy to measure (waveguide-to-coaxial transitions, which are normally used for this measurement, have relatively narrow pass bands);

- the calculation of the EIRP value, using the level at the antenna port, for frequencies far away from the nominal frequency is usually not possible, because the antenna gain is not known at these frequencies;

- the fundamental signal has to be rejected by a filter;

- in compact and/or low cost equipment, the antenna is an integral part of the equipment and an antenna port may not exist.

5.3.3 Measuring bandwidth

Spurious radiation may have different spectra as described in subclause 6.1. On the other hand the disturbing effect of spurious radiation depends on the part of its power which is falling into the bandwidth of the interfered receiver. The given measurement bandwidth in a specification for spurious radiation limits should be typical of the most important, or the most sensitive, service which could suffer interference in the specified frequency range, e.g.:

- 4 kHz for analogue Frequency Division Multiplex (FDM)/Frequency Modulation (FM);

- 40 kHz for 64 kbit/s Quadrature Phase Shift Keying (QPSK) with rate 3/4-Forward Error Correction (FEC);

- 20 MHz for radio relay systems.

For frequencies below about 1 GHz the accepted measuring procedure is contained in CISPR Publication No.22 [15], which specifies a measurement bandwidth of 120 kHz. For frequencies above about 1 GHz the measurement bandwidth of 100 kHz was selected to comply more closely with the features of "state of the art" spectrum analysers.

Which ever bandwidth is specified, the following aspects are to be considered:

- for a measuring equipment, the measuring bandwidth to be considered is the equivalent noise-bandwidth of the filter used;

- this equivalent noise-bandwidth needs to be determined carefully;

- due to the different available bandwidth ranges and bandwidth steps in test equipment it should be permissible to use a lower bandwidth than that specified;

  NOTE 1: If this is the case, and if the measured spurious signal has a bandwidth greater than the used measuring bandwidth, the measured values have to be converted to the specified bandwidth in such a way that the result is equal to the result which would be obtained with a direct measurement using the specified bandwidth.

  NOTE 2: If the measured signal has a bandwidth smaller than the actually used bandwidth no conversion has to be carried out.

- in order to make faster measurements, it might be permissible to measure with a bandwidth greater than the specified bandwidth, but only if the measured values are below the specified value (without conversion) and if the internal noise of the measuring equipment is well below the specified limits.

5.3.4 Operating conditions

Spurious radiation measurements have to be performed during conditions similar to actual operations in order to detect all possible sources such as sidebands, harmonics, intermodulation etc.

6 Interference models

A practicable way for the determination of adequate values for spurious radiation limits is the use of theoretical models which are based on assumptions and an objective.

The assumptions may range from "worst case situations" to "representative or typical situations". Related to this, the objective may also range from "no conflict situation shall occur under any circumstance" to "the probability of conflict situations shall be below a certain value under representative assumptions".

The application of an interference model may show that it is technically not feasible to have zero conflict situations under worst case assumptions. In this case, a compromise has to be found between the number of occurrences of conflicts and the increase of the technical expense of the equipment in order to limit spurious radiation.

To find such a compromise is probably the most controversial step in the process of determining adequate limits.

However, after practical experience in the use of a certain number of stations or equipment and after examination of conflict situations, if any, the limits may be changed.

The general assumptions which normally will be applied to an interference model may not always satisfy the specific demands of a particular radio system. In such cases, additional studies may be necessary to cope adequately with the unique technical features of the particular radio system under investigation, in order to avoid unduly stringent limits.

A widely known interference model is described in RR [1] Appendix 28 "Method for the determination of the co-ordination area around an earth station in frequency bands between 1 GHz and 40 GHz shared between space and terrestrial radio communication services". This model covers transmissions inside the necessary bandwidth and considers distances above 100 km. It is therefore not applicable for the determination of adequate values for spurious radiation limits.

6.1 Physical relationships and main parameters

6.1.1 Relevant characteristics of interfered station

The following relevant characteristics can be identified:

a) characteristic of the antenna, which allows the determination of the antenna gain Gr in the directions from which the interfering signals are coming;

b) thermal noise level N at the receiver input. This value is used when the maximum permissible interference level is defined in relation to thermal noise or as an equivalent increase of thermal noise.

   The thermal noise level N at the receiver input is:

$$N = k \times T \times B \quad (W)$$

   where:

   k = Boltzmann's constant (1,38 x 10^{-23} J/K);
   T = equivalent noise temperature of the receiving system (K);
   B = receiver bandwidth (Hz).

c) as an alternative to b) the level of the wanted signal may be of relevance, when the maximum permissible interference level is defined in relation to the wanted signal level.

6.1.2 Relevant characteristics of interfering station

The following relevant characteristics can be identified:

a) spurious emission level as an EIRP value in the direction of interfered station; or

b) the characteristic of the antenna and the spurious emission level as a power level at the antenna port.

6.1.3 Propagation

a) Line of sight propagation can be characterised as "Free Space Loss" L, if the receiving antenna is characterised by its antenna gain Gr:

$$L = 20 \log (4 \pi d f/c) \ \ (dB)$$

where:

d = distance between the stations (m);
f = frequency of the interfering signal (Hz);
c = speed of light = 3×10^8 m/s.

b) other propagation effects on the interfering signals, such as:

- reflections;
- refractions;
- rain attenuation;
- multipath propagation;
- rain scattering;

may be considered for some interference models. Some of these effects are often defined with a probability of occurrence in time. These effects are not considered in the models described below.

6.2 Statistical interferer model

This interference model was originally proposed by France to CCIR Task Group 4-2 in document 4-2/4-E [10]. The assumptions for this model are:

- a random distribution of interfering stations;
- a given density of interfering stations per km^2;
- all considered interfering stations are transmitting a spurious signal inside the receiving bandwidth of the receiving station;
- all interferers have the same spurious radiation levels;
- line of sight propagation between the interfering stations and the interfered station;
- the antenna gain pattern recommended by CCIR for the interfered station.

The objective is a given maximum noise level increase at the receiver input.

6.3 Single interferer model

The single interferer model consists of one interfering station and an interfered receiving station with a given antenna gain in the direction of the interfering station. It is assumed, that no obstacles are between these two stations (i.e. line of sight propagation) and that the frequency of the spurious signal is inside the receiving bandwidth of the receiving station.

With a given maximum allowable spurious level at the receiver input of the interfered station, the maximum permissible spurious EIRP of the interfering station towards the receiving station can be determined as a function of distance taking into account the antenna gain and the feeder loss.

Alternatively, for a given spurious radiation EIRP from the interfering station, the spurious level at the receiver input can be determined as a function of distance taking into account the antenna gain and the feeder loss.

This model has been proposed to CCIR Task Group 4-2 in document 4-2/25-E [11], to be used as a simplified model for the determination of spurious radiation limitations.

7 Evaluation of spurious radiation limits for VSATs (based on the statistical interferer model)

This interference model was originally proposed by France to CCIR Task Group 4-2 in document 4-2/4-E [10] and is described in Annex A. The specific assumptions for the determination of the maximum allowable spurious EIRP for this model are:

- a random distribution of interfering stations in a ring of radius between 200 m and 2 km;
- a density of 8 to 25 sources per km^2;
- all interferers having the same spurious radiation levels whose frequencies lie within the receiving bandwidth of the interfered station;
- line of sight propagation between the interfering stations and the interfered station;
- the antenna gain pattern recommended by CCIR Recommendation 465-3 [2] for the interfered station.

With the objective of a maximum noise level increase of 0,1 dB at the receiver input, the maximum allowable spurious EIRP has been calculated.

The maximum allowable spurious EIRP from each interfering station is then:

$$EIRP(i)_{dBW} = -92 + 20 \log(f_{GHz});$$

$$EIRP(i)_{dBpW} = 28 + 20 \log(f_{GHz});$$

therefore:

EIRP(i) = 48 dBpW at 10 GHz;

EIRP(i) = 54 dBpW at 20 GHz;

EIRP(i) = 60 dBpW at 40 GHz.

7.1 Adjustment of the derived limits for VSATs in ETSs and in CCIR Recommendation 726

The French contribution to CCIR Task Group 4-2 in document 4-2/4-E [10] has been studied thoroughly by STC-SES 2 and SES 4, and by CCIR Task Group 4-2 and the derived limits were accepted after some amendments and finally approved by TC-SES and by CCIR Study Group 4.

7.1.1 Receive-only VSAT in ETS 300 157 and in CCIR Recommendation 726

A minor amendment was made to the original text. The frequency boundaries have been chosen according to the frequency allocations of the Radio Regulations [1].

The limits are mainly given for the radiation from the receive local oscillators.

7.1.2 Transmit/receive VSATs in ETS 300 159 and in CCIR Recommendation 726

Limits are given for two cases: the carrier-off and the carrier-on cases. The distinction is justified due to the following reasons:

a) The carrier-off case:

- covers mainly the radiation from the local oscillators of the transmit/receive VSATs. Usually VSATs which are transmitting into the same transponder satellite channel use the same oscillator frequency;

- the oscillator leakage powers of identical frequencies may result in an accumulation of interference powers at the disturbed receiver input. However, different VSATs systems usually employ different frequencies;

- the statistical model which has been applied to TVROs and receive-only VSATs may be too pessimistic for transmit/receive VSATs;

- in a given area, TVROs may be numerous and they use the same local oscillator frequency;

- in a given area VSATs will not be so numerous as TVROs. They will transmit through different satellite channels, so accumulation of interference power from local oscillators from different VSATs may be a pessimistic assumption when using the statistical approach for narrow band receivers.

b) In the carrier-off case:

- spurious radiation from the VSAT transmitter is greatly suppressed, since a carrier-on/off switch is usually provided in the RF amplifier stage. Therefore, for the carrier off case of the transmit/receive VSAT, the same limits were applied as for the receive only VSAT. Up to 1st January 1994 a higher limit of 63 dBpW was accepted for the frequency range 13,6 to 14,9 GHz;

c) In the carrier-on case:

- only one VSAT within the entire coverage area of the satellite beam can transmit its signal in a specific frequency channel at a specific time irrespective of the total number of VSATs in that satellite network. An exception is the case of Code Division Multiple Access (CDMA) systems in which several VSATs can transmit simultaneously in the same frequency band;

- the frequency of most of the significant spurious radiation varies with the carrier frequency and therefore the spurious radiation from different VSATs which are transmitting in different frequencies will not add up on the same frequency channel.

From the considerations under c) above it was apparent that further studies had to be performed in order to derive adequate limits for spurious radiation from the transmit/receive VSATs in the carrier on case.

7.2 Spurious radiation assessment studies on transmit/receive VSATs for the carrier on case

Studies on the subject are contained in Reference [12], [13] and [14].

The contribution from Japan to CCIR Task Group 4-2 in document 4-2/19-E [12] presents:

- a compilation of existing standards;
- a compilation of CCIR Recommendations and Reports;
- a compilation of national regulations (Japan, USA) which may be applicable, relevant or can be referred to;
- a discussion of document [10] identifying assumptions which could be subject to change in order to adapt the model more closely to the features of transmit/receive VSATs. In particular the basic assumption where, for every VSAT, an equal spurious EIRP is radiated in any off-axis direction, is a pessimistic assumption.

Then document 4-2/19-E [12] presents the characteristics of spurious radiation of an existing transmit/receive VSAT which is in operation all over the world in great numbers. The equipment has been designed according to the RR [1] Appendix 8 which allows spurious radiation power of up to 80 dBpW at the antenna port (which corresponds to an EIRP of up to 88 dBpW for off beam angles greater than 7°), for transmitter power below 10 W.

Finally a set of limits was presented allowing considerably higher spurious radiation (up to 20 dB) compared with the limits proposed in document 4-2/4-E [10].

The contribution from France Telecom in ETSI/STC-SES2 (92) 13 [13] responded to the limits contained in document 4-2/19-E [12] and addressed two areas of concern:

- for the out-of-band emissions toward the satellites with improved G/T ratio, the limit of 4 dBW - 10 log N in any 4 kHz band is no longer relevant;

- disturbance of terrestrial microwave links by the spurious radiation EIRP of 80 dBpW at angles greater than 7° away from the main beam axis may occur especially if the interfering station is located close to the radio relay link path.

For the first point, the study arrived at the conclusion that the bandwidth of the limit should be changed from 4 kHz to 100 kHz in order to allow undisturbed VSAT operation.

NOTE: Subclause 4.2.2 of ETS 300 159 [9] was changed accordingly.

For the second point it was demonstrated that along the line of a radio relay link there exists an area where VSATs may significantly disturb the link. Annex B is a reproduction of the relevant part of [13]. In order to reduce this area the following limits for the spurious radiation EIRP were proposed by France Telecom:

$$75 \text{ dBpW} \quad \text{for } B_r = 20 \text{ MHz and } N/(N+I) = 0{,}1 \text{ dB}$$

where B_r is the bandwidth of the receiver of the radio relay.

For systems with a receiver bandwidth of 2 MHz the limit should be 10 dB lower, but most of the affected radio relay systems have a receiver bandwidth of 20 MHz.

This study was considered in depth in a contribution from NEC Corporation in ETSI/TC-SES (92) 043 [14]. It was assumed that there is a low probability that the performance of the terrestrial radio link will be degraded by a VSAT that is located within the main beam. In conclusion, a limit of 78 dBpW was agreed.

Finally, in ETS 300 159 [9] for the carrier on case of transmit/receive VSATs, the following limits have been specified:

49 dBpW in any	100 kHz	band in the range	960 MHz	to	3,4 GHz	
55 dBpW in any	100 kHz	band in the range	3,4 GHz	to	10,7 GHz	
61 dBpW in any	100 kHz	band in the range	10,7 GHz	to	13,6 GHz	
78 dBpW in any	20 MHz	band in the range	13,6 GHz	to	14,9 GHz	*)
61 dBpW in any	100 kHz	band in the range	14,9 GHz	to	21,2 GHz	
67 dBpW in any	100 kHz	band in the range	21,2 GHz	to	28,0 GHz	
78 dBpW in any	20 MHz	band in the range	28,0 GHz	to	29,0 GHz	*)
67 dBpW in any	100 kHz	band in the range	29,0 GHz	to	40 GHz	

*) Prior to 1st January 1994, a limit of 88 dBpW shall be applied.

Bearing in mind the great number of existing VSATs which are designed to comply with a limit of 88 dBpW and which do not create any known interference situation, a grace period, up to 1st January 1994, was introduced before the equipment should be redesigned in order to meet the 78 dBpW limit.

8 Calculation examples for typical cases with a single interfering station for illustration purpose

Clause 7 describes how the limits for spurious radiation for ETS 300 157 [7] and ETS 300 159 [9] have been determined.

In this Clause, using these limits and assuming more or less pessimistic situations, the effects of an interfering source towards a VSAT and towards a radio relay station are calculated in terms of spurious power level at the receiver input, as a function of the distance. The comparison of this level with the equivalent thermal noise at the receiver input (under consideration of an acceptable noise level increase) allows estimation to be made of the distance above which critical situations can be excluded, and the distance below which unacceptable interference may occur.

8.1 Examples of station parameters

As a basis for calculation, examples of typical parameters for different kind of stations are listed in subclauses 8.1.1, 8.1.2 and 8.1.3.

8.1.1 Receive only VSATs used for data distribution

System noise temperature	150 - 200 K (clear sky condition) about 500 K (rain fade condition)
Receiver bandwidth	64 kHz
Equivalent noise level (under rain fade conditions)	- 33,5 dBpW
Required C/N for BER = 10^{-7}	7,8 dB (QPSK with rate 1/2 FEC)
Antenna sidelobe peak gains as recommended in ETS 300 157 [7] and CCIR Recommendation 726 [6]	29 - 25 log Φ (dBi) for $2{,}8° \leq \Phi \leq 7°$ 8 (dBi) for $7° < \Phi \leq 9{,}2°$ 32 - 25 log Φ (dBi) for $9{,}2° < \Phi \leq 48°$ - 10 (dBi) for $\Phi > 48°$
Average sidelobe gains (based on measurements on a typical 1,8 m antenna)	+ 10 to -20 (dBi) for $1° \leq \Phi \leq 20°$ approx. linearly decreasing - 20 dBi for $20° \leq \Phi \leq 120°$ - 10 dBi for $120° \leq \Phi \leq 170°$ (spillover region)
Specified limits on spurious radiation	see ETS 300 157 [7] and CCIR Recommendation 726 [6]

8.1.2 Transmit/receive VSATs used for data communication

System noise temperature	180 - 260 K (clear sky condition) about 550 K (rain fade condition)
Receiver bandwidth	64 kHz
Equivalent noise level (under rain fade conditions)	- 33,1 dBpW
Required C/N for BER = 10^{-7}	7,8 dB (QPSK with rate 1/2 FEC)
Antenna sidelobe peak gains	as for Receive only VSATs (see subclause 8.1.1)
Average sidelobe gains (based on measurements on a typical 1,8 m antenna)	as for Receive only VSATs (see subclause 8.1.1)
Specified limits on spurious radiation	see ETS 300 159 [9] and CCIR Recommendation 726 [6]

8.1.3 Radio relay systems for the transmission of digital signals

System noise temperature	600 to 1 500 K
Receiver bandwidth	20 MHz for a 34 Mbit/s system
Carrier level at receiver input	- 73 dBm for 34 Mbit/s
Equivalent noise level at receiver input	- 7,8 to - 3,8 dBpW
Antenna sidelobe peak gain according to ETS 300 198 (standard performance)	+ 12 dBi for $10° \leq \Phi \leq 20°$ + 12 to -7 dBi for $20° \leq \Phi \leq 100°$ linearly decreasing -7 to - 10 dBi for $100° \leq \Phi \leq 180°$ linearly decreasing
Existing limits on spurious radiation (according ETS 300 198), level at the antenna flange	30 dBpW from 1 GHz to 21,2 GHz 60 dBpW from 21,2 GHz to 55 GHz

8.2 Interference level at a receiver input caused by one interferer versus the distance

Based on the assumptions which have also been defined for the single interferer model, the interference level I at a receiver input can be calculated as a function of the distance.

$$I = I_s - L + G_r - L_F$$

where:

I_s = Spurious radiation level (EIRP) in the direction of the interfered station;

L = Free Space Loss;

G_r = gain of receiving station antenna in direction of interferer;

L_F = Feeder Loss.

This interference level can be compared with the equivalent thermal noise level N at the receiver input and it is possible to calculate or estimate the noise level increase.

8.2.1 Interference level at a VSAT receiver input versus distance

For the calculation shown in figure 1, the following assumptions have been made:

a) frequency = 12,5 GHz;

NOTE 1: This is a typical down link frequency (satellite to earth) for VSAT.

b) the spurious signal falls inside the bandwidth of the interfered receiver;

NOTE 2: This is a very pessimistic assumption.

c) the interfering station (also a VSAT station) transmits the spurious signal with the maximum allowed EIRP towards the interfered station (see ETS 300 157 [7], ETS 300 159 [9] i.e. 61 dBpW in the carrier on case and 54 dBpW in the carrier off case);

NOTE 3: This is a pessimistic assumption, because this EIRP value would occur at 7° off axis angle but the actual EIRP value in the direction of the interfered station will be several dB lower.

d) the system noise temperature of the interfered station is 500 K, and the receiver bandwidth is 64 kHz;

NOTE 4: This results in an equivalent thermal noise level of - 33,5 dBpW at the receiver input. This value is shown with a solid line in figure 1.

e) a noise level increase of 0,1 dB can be accepted;

NOTE 5: This corresponds to an interference level of about 17 dB below thermal noise level. The value "Thermal noise level minus 17 dB" is shown in figure 1 with a dashed line.

f) the antenna gain of the interfered station in the direction of the interferer is **-** 10 dBi;

NOTE 6: This corresponds to the average value in the spillover region.

g) the feeder loss L_F is negligible.

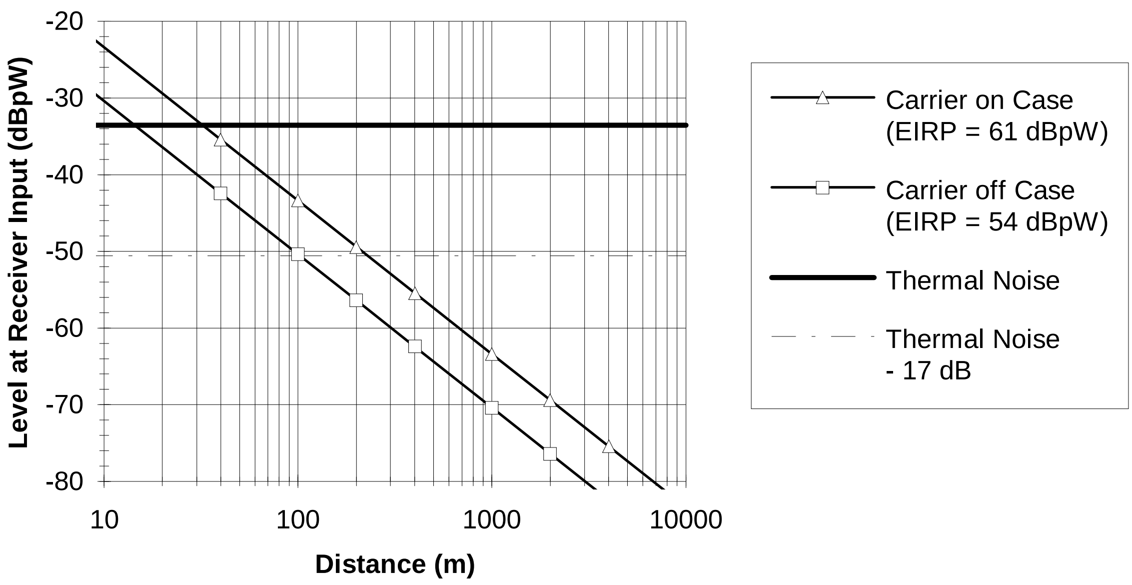


Figure 1: Receiver input level versus distance for a VSAT

With the results shown in figure 1 the following comments can be made:

- for the carrier-off case, if the distance is greater than 100 m, acceptable interference levels are not exceeded (see assumption e) above);

- for the carrier-off case, if the distance is less than 14 m, the interference level is above the thermal noise level. The equivalent noise increase is more than 3 dB. This usually decreases the availability of the interfered service (due to reduction of margin) or causes other disturbing effects;

- for the carrier-on case, the corresponding distances are greater than 230 m (not critical) and less than 32 m (usually unacceptable).

  NOTE: For the evaluation of the spurious radiation limits using the statistical model (see Clause 7), a minimum distance of 200m has been assumed.

8.2.2 Interference level at a radio relay station receiver input vs. distance

For the calculation shown in figure 2, the following assumptions have been made:

a) frequency = 14,3 GHz;

   NOTE 1: This is a frequency which can be assigned to a radio relay system and for which relatively high spurious radiation limits for VSATs are specified.

b) the spurious signal is falling inside the bandwidth of the interfered receiver;

   NOTE 2: This is a pessimistic assumption.

c) the interfering station (also a VSAT Station) transmits the spurious signal with the maximum allowed EIRP towards the interfered station;

   NOTE 3: According to ETS 300 195 [9], this is 78 dBpW in the carrier on case and prior to 1st January 1994, a limit of 88 dBpW is applicable. This is a pessimistic assumption, because this EIRP value would occur at 7° off axis angle but the actual EIRP value in the direction of the interfered station will be several dB lower.

d) the system noise temperature of the interfered station is 800 K and the receiver bandwidth is 20 MHz as a typical value for the transmission of a 2 MBit/s signal;

NOTE 4: This results in equivalent thermal noise level of - 6,6 dBpW at the receiver input. This value is shown with a solid line in figure 2.

e) a noise level increase of 0,1 dB can be accepted;

NOTE 5: This corresponds to an interference level of about 17 dB below thermal noise level. The value "Thermal noise level minus 17 dB" is shown in figure 2 with a dashed line.

f) the antenna gain of the interfered station in the direction of the interferer is assumed to be - 10 dBi and 30 dBi;

NOTE 6: The gain of 30 dBi may be valid if the interferer is positioned close to the main beam direction of the radio relay antenna (e.g. close to the far end station of the radio relay link).

g) the feeder loss L_F is negligible.

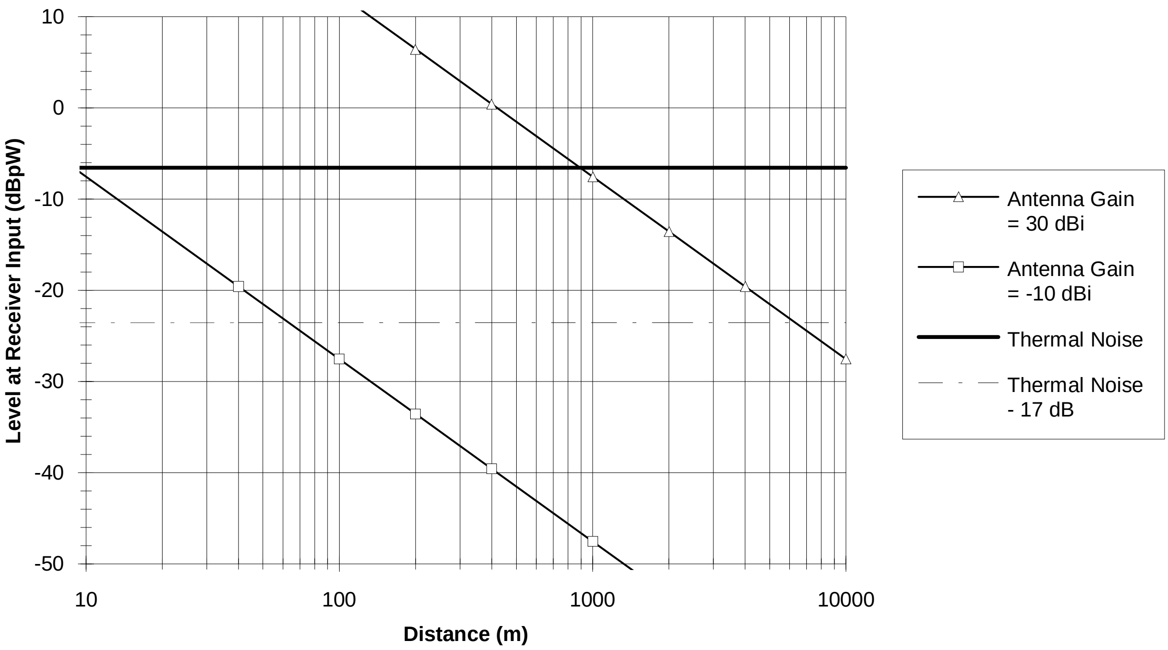


Figure 2: Receiver input level versus distance for a radio relay station

With the results shown in figure 2 the following comments can be made:

a) if the VSAT is located at the rear of the radio relay station and if the distance is less than 9 m, the interference level is above the thermal noise level. The equivalent noise increase in the radio relay receiver is more than 3 dB which is usually unacceptable;

b) the same is valid, if the VSAT is located close to the main beam direction of the radio relay station and if the distance is less than 900 m;

c) if the VSAT is located at a distance of more than 63 m in the rear and more than 6,3 km close to the main beam direction, acceptable interference levels are not exceeded (see assumption e) above).

NOTE 7: See also Annex B.

9 Conflict resolution

The spurious limits in the VSAT ETSs have been determined so that conflict situations will be exceptional. However, as shown in Clause 8 they can not be excluded.

If an interfering signal is causing an effect as described in subclause 5.1, it may be necessary:

a) to detect the exact malfunction or to determine the reduction of the availability of the receiving system;

b) to investigate whether the malfunction is caused by an equipment failure;

c) to identify the interferer;

d) to check whether the interferer meets the applicable limits of the ETSs for spurious radiation levels.

NOTE: Interference situations resulting from inappropriate frequency planning are outside the scope of this ETR.

Whether or not the applicable limits are exceeded the conflict should be resolved by mutual agreement or by an agreement in accordance with the directives of the regulatory authority.

The following measures help to resolve a conflict:

a) change of the operating frequencies;

b) installation of an additional screen (absorbing or reflecting) in the interference propagation path;

c) change of the location of one of the stations or both stations to obtain additional shielding e.g. by existing buildings or natural obstacles;

d) improvement of the interfering station radiation characteristics.

10 Conclusions and aspects for further considerations

a) The limits on spurious radiation in the ETSs for VSATs and TVROs have been chosen in such a way, that on the one hand, harmful interference to other services should occur in very exceptional cases only, and, on the other hand, it is technically feasible to meet these requirements with acceptable additional costs.

b) The basis for the determination of adequate limits were the known characteristics of earth stations, mainly VSATs. Adjustments have been made taking into account the parameters of radio relay systems.

c) The limits of the spurious radiation levels for different frequency ranges reflect mainly the frequency dependence of the free space loss. The limits for higher frequencies are higher, because the free space loss is higher. This fact is a result of the chosen interference model.

   An alternative approach would be, to evaluate the spurious radiation limits for each frequency range, depending on the most susceptible service which has an allocation in this frequency range. This means that, in certain frequency ranges (e.g. bands designated for Industrial Scientific and Medical (ISM) applications, in which radio services have to accept harmful interference anyway), less stringent limits could be applied. Consequently, equipment manufacturers could design their equipment in such a way that significant spurious radiation fall in such uncritical bands only.

d) The evaluation of adequate limits for spurious radiation in ETSI/TC-SES was a very time consuming process. There is still a lack of any commonly accepted suitable recommendation, set of limits or standard in this area. Bearing in mind that more and more equipment is operating in the GHz frequency range, for which an adequate limitation of spurious radiation is indispensable, the development of a Generic Standard by an appropriate body is urgently necessary. Such a Generic Standard should be used as a basis for any standardisation activity, regardless of whether components, radio equipment or radio systems are concerned. Furthermore, a Generic Standard should cover EMC requirements as well as spectrum utilisation aspects. Careful consideration should be given to the question, whether the specification and measurement of far field characteristics are necessary.

e) The ETSs on VSAT and TVRO also contain procedures for the measurement of spurious radiation. However, these methods may be improved. The development of test methods by an appropriate body, applicable also for other kinds of equipment (e.g. radio relay) may harmonise testing and may therefore reduce the costs for conformance testing. Such test procedures should also clarify some old problems, such as the interpretation of measuring results close to transition frequencies.

Annex A (informative): Evaluation of spurious radiation limits for VSATs, based on a statistical interferer model

A.1 Discussion

The method used for determining the level of spurious emissions is presented hereafter with:

- determination of the maximum level of acceptable interference power received by a radio equipment; and
- computation of the interferer EIRP under the assumption of various populations of interference sources.

The sources are assumed to radiate continuously.

A.1.1 Determination of the level of acceptable interference

The level I of interference in a frequency band B_r where the interfering system is not allowed to transmit shall be as low as possible. Considering various systems of the fixed satellite and mobile services and the trend to digitalisation of the transmissions, it can be estimated that a signal to noise ratio for the interfered system of 10 dB is a reasonable value:

$$(C/N)_{(dB)} \approx 10 \text{ dB}$$

where:

- C = the power of the received signal;
- N = the noise power at the input of the receiver.

Consequently, a degradation of this ratio of 0,1 dB, by interfering signals which were not expected to be there, appears to be a maximum which should not be exceeded.

$$((C/N) / (C/(N+I)))_{(dB)} \leq 0{,}1 \text{ dB}$$

or:

$$((N+I)/N)_{(dB)} \leq 0{,}1 \text{ dB}$$

where:

- I = the power of the received interferences from all sources.

This is equivalent to an interfering signal power at about 17 dB below the equivalent thermal noise level of the interfered system:

$$(I/N)_{(dB)} \leq 17 \text{ dB}$$

A.1.2 Evaluation of the noise floor of the interfered services

For the more susceptible equipment like an earth station, the following values are proposed:

- bandwidth B_r of the interfered system = 100 kHz;

  NOTE: This value is at the lower end for fixed satellite services and corresponds approximately to SCPC carriers at 64 kbit/s with 1/2 FEC but it is clearly above the mobile satellite service.

- equivalent thermal noise level N of the interfered system:

  N = k x (Tr + Ta) x B

  where:

  - Tr = the noise temperature of the receiver:

    Tr = 300 K;

  - Ta = the noise temperature of the antenna, under rainy conditions, at frequencies above 10 GHz:

    Ta = 300 K;

  - k = is the Boltzmann constant : $k_{(dBW/Hz/K)}$ = - 228,6

Under these assumptions, it is possible to ignore the effects of intersystem interferences (i.e. intermodulation noise, frequency utilisation).

Then the spectral density of the noise power becomes:

$(N/B_r)_{(dB)}$ = - 151 dBW / 100 kHz

and the maximum level of acceptable interference, received from all sources, is:

$(I/B_r)_{(dB)} \leq$ - 168 dBW / 100 kHz.

A.1.3 Values given in CCIR Report 713-1

This maximum level of acceptable interference, received from all sources, has to be compared with the values proposed by the CCIR.

In the case where, the spectral density is constant in the frequency band B_r, then the limit of - 168 dBW/100 kHz is equivalent to:

- 182 dBW/4 kHz;
- 178 dBW/10 kHz;
- 158 dBW/1 MHz;
- 148 dBW/10 MHz;
- 132 dBW/400 MHz.

Hereafter follows the values of the CCIR Report:

a) interferences caused to radio relay stations by earth stations:

The values vary between:

- 171 dBW/4 kHz for analogue radio relay systems at 6 GHz; and
- 154 dBW/MHz for digital radio relay systems at 30 GHz.

b) interferences caused to trans-horizon stations by earth stations:

- 160 dBW/4 kHz for 0,01 % of the time.

c) interference caused to earth stations of the Fixed Satellite Service by earth stations:

- 166 dBW/MHz for frequencies between 1 and 10 GHz;
- 160 dBW/MHz for frequencies between 10 and 40 GHz.

d) interference caused to radio astronomy stations by earth stations:

- measurement of the continuous part of the spectrum:
  - from - 207 dBW/10 MHz at 2,7 GHz to - 192 dBW/400 MHz at 24 GHz;
- measurement of spectral lines from - 222 dBW/10 MHz at 1,7 GHz to - 209 dBW/100 kHz at 22 GHz.

A.1.4 Conclusion

Without considering the extreme case of the radio astronomy stations which are usually located in isolated areas, it appears that the proposed value (- 168 dBW/100 kHz) is reasonable and quite consistent with those given in the CCIR report. In addition, it is worth noting that this level of interference will cause problems to the signals of certain satellite mobile services such as INMARSAT C and M, for which the signal levels are between - 166 and - 158 dBW at the antenna port.

A.2 Evaluation of the total level of interferences

The total level I of the interfering signals at the input of the receiver of the interfered system is given by:

- $I = \sum_i I(i) = \sum_i (EIRP(i) \times ((lambda)^2/(4\pi di)^2) \times Gr(i))$

where:

- EIRP(i) = the EIRP of the interfering source i;
- Gr(i) = the gain of the antenna of the interfered system in the direction of the interfering source i.

When assuming an equal EIRP, EIRP(i), of the spurious emissions for each of the interfering sources, it becomes:

$$I_{(dBW)} = + EIRP(i)_{(dBW)} + 20 \log(lambda_{(m)}(1GHz)/(4\pi))$$

$$- 20 \log(f_{(GHz)}) + 10 \log(\sum_i (Gr(i)/di_{(m)}{}^2))$$

$$I_{(dBW)} = + EIRPi_{(dBW)} - 32.4 - 20 \log(f_{(GHz)})$$

$$+ 10 \log(\sum_i (Gr(i)/di_{(m)}{}^2)) \qquad (1)$$

The quantity $10 \log(\sum i\ (Gr(i)/di_{(m)}{}^2))$ may be evaluated either by statistical simulations or by probabilistic computations.

A.2.1 Statistical determination of 10 $10 \log(\sum i(Gr(i) / di_{(m)^2}))$

Statistical simulations have been carried out under the following assumptions:

- population of interfering sources variable between 8 and 25 per km², randomly distributed around the interfered system antenna in its horizontal plane;
- distance between the interfered system antenna and the interfering sources, uniformly distributed between 200 m and 2 km;
- gain Gr(i) of the interfered system antenna as follows:

  $32 - 25 \log(\Phi)$ dBi if $9{,}2° < \Phi < 48°$

  $- 10$ dBi if $48° \leq \Phi$

where:

Φ is the angle between the main beam axis and the direction of the source i.

The antenna gain of the interfered system is usually 4 to 7 dB lower than these CCIR limits. This antenna pattern is not applicable for mobile satellite service.

The population which has been chosen corresponds, for satellite TVRO stations, to a penetration rate of the number of homes of only 0,5% to 1,5 %.

For different elevation angles θ of the interfered system antenna, 1 000 random selections of the positions of the interfering sources were made.

Example:

The following results were obtained for an elevation angle of 20° and a density of 8 sources per square kilometre.

10 log(∑i(Gi/di²)(dB)	**Number of occurrences**
-47,09	3
-46,39	18
-45,69	79
-44,99	176
-44,29	239
-43,59	226
-42,89	146
-42,19	83
-41,49	26
-40,79	4

When varying the elevation angle θ and the number γ of sources per km², the following mean values were obtained:

θ (°)	γ	10°	20°	30°	40°
E(GoD2)(dB)	8	- 40,3	- 43,6	- 45,1	- 45,8
E(GoD2)(dB)	16		- 40,5		
E(GoD2)(dB)	25		- 38,7		

It is therefore proposed to use the value of - 43 dB as an average:

$$10 \log \sum i\ (G(i)/di^2) = - 43 \text{ dB}.$$

A.2.2 Probabilistic computation $10 \log(E(\sum i(Gr(i) / di_{(m)^2})))$

General

For a given number of sources N, the expected value of $\sum_i(Gr(i)/di^2))$ can be computed by a probabilistic method.

Let GoD2 (G over D square) value:

$$GoD2 = \sum_i(Gr(i)/di^2)$$

then the expected value of GoD2 is:

$$E(GoD2) = N \times E(Gr) \times E(1/d^2)$$

If γ is the average number of sources per km², in a ring (dMin, dMax) around the interfered equipment, then:

$$N = \gamma (\pi (dMax^2 - dMin^2))$$

and:

$$E(GoD2) = \gamma \times E(Gr) \times D2$$

where:

$$D2 = \pi (dMax^2 - dMin^2) \times E(1/d^2)$$

A.2.3 Computation of the expected value of the antenna gain E(Gr)

The gain Gr of the interfered system antenna is as follows:

$$32 - 25 \log(\Phi) \quad \text{dBi} \quad \text{if} \quad 9{,}2° < \Phi < 48°$$

$$-10 \quad \text{dBi} \quad \text{if} \quad 48° \leq \Phi$$

or:

$$(10\text{\^{}}3{,}2) / (\Phi\text{\^{}}2{,}5) \quad \text{if} \quad 9{,}2° < \Phi < 48°$$

$$1/10 \quad \text{if} \quad 48° \leq \Phi$$

where Φ is the angle between the main beam axis and the direction of the source. Then:

$$E(Gr) = + (10\text{\^{}}3{,}2)\ E((1/ (\Phi\text{\^{}}2{,}5) \mid 9{,}2°<\Phi<48°)\ Pr(9{,}2°<\Phi<48°)$$

$$+ (1/10)\ Pr(\Phi>48°) + E(Gr(\Phi)|\Phi<9{,}2°)\ Pr(\Phi<9{,}2°)$$

The angle Φ, the elevation angle θ of the main beam axis, and the azimuth a of the source are linked by the following relation:

$$\cos(\Phi) = \cos(\theta) \times \cos(a)$$

and:

$$\Phi \geq \theta$$

Then:

$$Pr(\Phi < 9{,}2° \mid \theta > 9{,}2°) = 0$$

The sources are uniformly distributed in any direction in the plane. Then the probability density of a is:

$$p_A(a°) = 1/360$$

For various values of the elevation angle θ, E(Gr) has been computed and also:

$$GMoy = E(Gr(\theta))$$

$$\sigma_G = \sqrt{var[Gr(\theta)]}$$

$GMin = GMoy - 2.5 \times \sigma_G/\sqrt{N}$ for N = 100

$GMax = GMoy + 2.5 \times \sigma_G/\sqrt{N}$ for N = 100

$$R_G = \sigma_G/GMoy$$

θ (°)	10°	20°	30°	40°	50°	60°	70°	80°
GMin(dB)	- 7,60	- 8,82	- 9,56	- 9,92	- 10,01	- 10,05	- 10,05	-10.07
GMoy(dB)	- 3,96	- 7,48	- 9,01	- 9,76	- 10,00	- 10,01	- 10,01	-10.01
GMax(dB)	- 2,01	- 6,46	- 8,53	- 9,61	- 9,99	- 9,96	- 9,96	-9.96
RG (dB)	3,56	0,26	- 3,26	- 8,49	- 19,61	- 13,77	- 14,17	-13.01

For a radio relay, the elevation angle θ is usually close to 0. In that case, for that kind of computation, the antenna gain for off-axis angles Φ lower than 9,2°, need to be known. The mean value GMoy may be increased by several times 10 dB.

For a 2 m diameter parabolic antenna, at 14 GHz, a simple model of the antenna gain has been used:

$Gr(\Phi) = Gr(0) \times (Cos(\Phi/2)^2) \times (2 \times J_1(z)/z)$ for $\Phi < 9{,}2°$

where:

$$z = \pi D\ Sin(\Phi)/Lambda$$

$$Gr(0) = (\pi D/Lambda)^2$$

$$D = 2\ m$$

J1(z) is the first order Bessel function, of index 1

the following results have been obtained:

θ (°)	0,0°	0,2°	0,4°	0,6°	0,8°	2°	4°	8°
GMoy(dB)	24,42	12,08	8,32	3,42	3,02	- 3,90	- 4,95	- 4,77

A.2.4 Computation of the expected value of the $E(1/d^2)$

For sources uniformly distributed in the ring (dMin, DMax), in the horizontal plane, the probability density of the distance d to the interfered station is:

$$p_D(d) = 2 \pi d/(\pi (dMax^2 - dMin^2)) = 2 d/(dMax^2 - dMin^2)$$

then:

$$E(1/d^2) = 2 Ln(dMax/dMin)/(dMax^2-dMin^2)$$

$$D2 = 2 \pi Ln(dMax/dMin)$$

dMin	20 m	200 m	200 m
dMax	2 km	2 km	20 km
dMax/dMin	100	10	100
D2(dB)	14,61	11,60	14,61

For sources uniformly distributed along the radius of the ring (dMin, DMax), in the horizontal plane, the probability density of the distance d to the interfered station is:

$$p_D(d) = 1 / (dMax - dMin)$$

then:

$$E(1/d^2) = 1 / (dMax \times dMin)$$

$$D2 = \pi \, ((dMax / dMin) - (dMin / dMax))$$

dMin	20 m	200 m	200 m
dMax	2 km	2 km	20 km
dMax/dMin	100	10	100
D2(dB)	24,97	14,93	24,97

A.2.5 Sources density

For various density of sources per km²:

γ Source/km²	8	10	16	20	25
γ (dBSource/km²)	9	10	12	13	14
γ (dBSource/m²)	- 51	- 50	- 48	- 47	- 46

A.2.6 Combination of the parameters

The combination of the elevation angle θ, the source density γ, and the range of the ring (dMin, DMax) leads to the following results for the expected value E(GoD2) of $\sum_i(Gr(i)/di^2)$:

For a uniform distribution of the sources in the ring (200 m, 2 km):

θ (°)	γ	10°	20°	30°	40°	50° to 90°
E(GoD2)(dB)	8	- 43,36	- 46,88	- 48,41	- 49,16	- 49,40
E(GoD2)(dB)	16	- 40,36	- 43,88	- 45,41	- 46,16	- 46,40
E(GoD2)(dB)	25	- 38,36	- 41,88	- 43,41	- 44,16	- 44,40

For a uniform distribution of the sources along the radius of the ring (200 m, 2 km):

θ (°)	γ	10°	20°	30°	40°	50° to 90°
E(GoD2)(dB)	8	- 40,03	- 43,55	- 45,08	- 45,83	- 46,07
E(GoD2)(dB)	16	- 37,03	- 40,55	- 42,08	- 42,83	- 43,07
E(GoD2)(dB)	25	- 35,03	- 38,55	- 40,08	- 40,83	- 41,07

The values obtained previously by simulation are identical to those obtain by computation.

A.2.7 Maximum Spurious EIRP

From equation (1) and the limits proposed, - 168 dBW/100 kHz, for the maximum level of interfering power, it can be concluded that the maximum spurious EIRP should be:

$$EIRP(i)_{(dBW)} = -92 + 20\log(f_{(GHz)})$$

$$EIRP(i)_{(dBpW)} = 28 + 20 \log(f_{(GHz)})$$

f (GHz)	1	10	20	40
EIRP(i)(dBpW)	28	48	54	60

Remarks:

- an equal spurious radiation EIRP in any off-axis direction is a pessimistic assumption;
- in a large range of frequencies around the carrier frequency, the antenna gain of the interfering stations are below the CCIR limit: 32 - 25 log(Φ) dBi;
- with this limit, the antenna gain is maximum at 9,2° and it is equal to 7,9 dB. For VSATs or TVROs pointing in the same direction, towards the geostationary orbit, the statistical model has shown that the mean value of the antenna gain is 15,4 dB to 16,9 dB lower, between - 7,5 dB and - 9,0 dB, for elevation angles of 20° to 30°.

A.3 Recommendation for VSATs and TVROs outside the main beam

For spurious radiation transmitted outside of the main beam of the antenna, the EIRP radiated from an earth station should be:

from	30 MHz	to	230 MHz:	35 dBpW	| CISPR 22 specification
from	230 MHz	to	1 000 MHz:	42 dBpW	| at 10 m (Class B)
from	1 GHz	to	10 GHz:	48 dBpW	
from	10 GHz	to	20 GHz:	54 dBpW	
from	20 GHz	to	40 GHz:	60 dBpW	

These limits are for off-axis angles greater than 7°.

Annex B (informative): Protection of microwave radio links

B.1 General

NOTE: This annex is a concentrated reproduction of that part of ETSI/STC-SES2 (92) 13 [13] (contribution from France Telecom) which covers the aspect of protection of microwave radio links.

The frequency band from 14,25 GHz to 14,50 GHz is allocated to both, the Fixed Satellite Service (FSS) and the Fixed Service (FS). In France, it is used for numerous microwave radio links.

When a VSAT is transmitting in the lower Ku band from 14,00 GHz to 14,25 GHz which is allocated exclusively to the FSS, spurious emission falling in the FS band may disturb radio relay links.

This annex contains a calculation example showing the area around a typical radio relay station from which a VSAT with a given spurious EIRP may cause interference. The calculation is made for a frequency of 14,25 GHz.

B.2 Definitions and assumptions

Parameters with subscript (dB) are expressed in dB relative to the unit in the International System.

EIRPi: EIRP of the spurious radiation from the VSAT in the direction of the radio relay station. It is assumed that the spurious signal is falling inside the bandwidth Br.

d: distance between the VSAT and the radio relay station.

L: free space loss between the VSAT and radio relay station:

$$L_{(dB)} = 115{,}52 + 20 \cdot \log(d_{(km)}) \quad \text{at } 14{,}25 \text{ GHz.}$$

Gr(r): off axis gain of the radio relay receiving antenna. Φr is the angle between the main beam direction and the direction of the interfering VSAT.

B_r: bandwidth of the receiver of the radio relay station:

$$B_r = 20 \text{ MHz (typical value for a 34 Mbit/s link).}$$

k: Boltzmann constant : $k_{(dB)} = -228{,}6$ dBW/K/Hz

F: noise figure of the radio relay receiver:

$$F_{(dB)} \approx 7 \text{ to } 8 \text{ dB}$$

Tr: equivalent radio relay receiver noise temperature:

$$Tr = F \cdot 290 \text{ K} \approx 1\,500 \text{ K}$$

N: equivalent thermal noise power at the radio relay receiver input:

$$N_{(dB)} = k_{(dB)} + Tr_{(dB)} + Br_{(dB)} \approx -123{,}84 \text{ dBW} = -93{,}83 \text{ dBm}$$

I: power of the spurious signal at the radio relay receiver input:

$$I_{(dBW)} = EIRP(i)_{(dBW)} + Gr(\Phi r)_{(dB)} - L_{(dB)}$$

Then the interferer to noise ratio (I/N) at the radio relay receiver input is:

$$(I/N)_{(dB)} = EIRP(i)_{(dBW)} + Gr(\Phi r)_{(dBi)} - L_{(dB)} - N_{(dBW)}$$

$$(I/N)_{(dB)} = EIRP(i)_{(dBW)} + Gr(\Phi r)_{(dBi)} - (115{,}52 + 20 \log(d_{(km)})) - (-123{,}84)$$

$$(I/N)_{(dB)} = EIRP(i)_{(dBW)} + Gr(\Phi r)_{(dBi)} - 20 \log(d_{(km)}) + 8{,}32 \qquad (1)$$

The link budgets of the radio links at this frequency are calculated with tight margins taking into account the existing and known disturbing stations. The global effect of all additional disturbing stations should not increase the noise level by more than 0,5 dB, otherwise the link has to be improved. In some cases, it may be necessary to change to a bigger antenna and to reinforce the tower. The method may not be generalised.

Assuming that a margin of 0,1 dB is allowable for one disturbing VSAT:

$$(C/N)_{(dB)} - (C/(N+I))_{(dB)} = (I + N) / N \leq 0{,}1 \text{ dB}$$

then:

$$(I/N)_{(dB)} \leq -16{,}33 \text{ dB}$$

inserted in formula (1) for I/N above:

$$-16{,}33 \geq EIRP(i)_{(dBW)} + Gr(\Phi r)_{(dBi)} - 20 \log(d_{(km)}) + 8{,}32$$

or:

$$EIRP(i)_{(dBW)} + Gr(\Phi r)_{(dBi)} - 20 \log(d_{(km)}) \leq 24{,}65$$

The condition necessary, that the equivalent noise increase at the radio relay receiver is less or equal to 0,1 dB is:

$$EIRPi_{(dBpW)} + Gr(\Phi r)_{(dBi)} - 20 \log(d_{(km)}) \leq -95{,}35 \qquad (2)$$

B.3 Antennas presently used for radio relay systems

The diameters and the gains of the antennas presently used are:

Diameter D	**Gain Gr(0)**
Horn	24,0 dBi
60 cm	35,0 dBi
1,10 m	40,5 dBi
2,00 m	45,9 dBi
3,00 m	≈48 dBi

The calculation in Clause B.4 is based on a 2 m diameter radio relay antenna with gain Gr(0)=45,9 dBi at 14,25 GHz. The antenna gain pattern is assumed to be as follows:

$Gr(\Phi r)_{(dBi)} = Gr(0) - 2{,}5 \times 10^{-3} (D/\lambda\ \Phi)^2$ for $0 \leq \Phi < \Phi m$

$Gr(\Phi r)_{(dBi)} = 30 - 12{,}8 \log \Phi$ for $\Phi m \leq \Phi < 15°$

$Gr(\Phi r)_{(dBi)} = 74 - 50 \log \Phi$ for $15° \leq \Phi < 30°$

$Gr(\Phi r)_{(dBi)} = 0$ for $30° \leq \Phi$

where: Gr(0) = 45,9 dBi

Antenna diameter D = 2 m

$\lambda = c / f = 3 \times 10^8$ m/s / $14{,}25 \times 10^9$ Hz = 21 mm

$D/\lambda = 95$

$\Phi m = 0{,}8°$ (valid for 2m antenna with Gr(0) = 45,9 dBi)

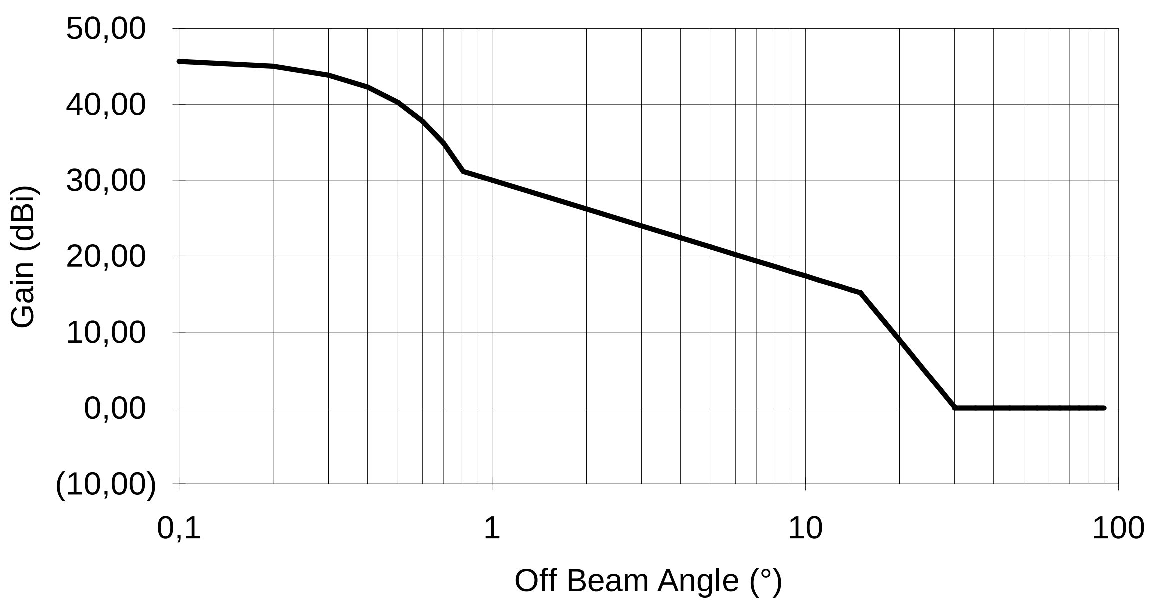


Figure B.1: Assumed radiation pattern of a 2 m radio relay antenna at 14,25 GHz

B.4 Critical positions of VSATs relative to a radio relay station

For most of these radio relay stations the heights of the antennas are between 0 and 10 m above the roofs of the buildings.

For simplicity let us assume that the VSAT and the radio relay link are in a same horizontal plane.

The distance d from where the VSAT causes an equivalent noise level increase of 0,1 dB in the radio relay receiver can be evaluated from the following formula which is based on (2):

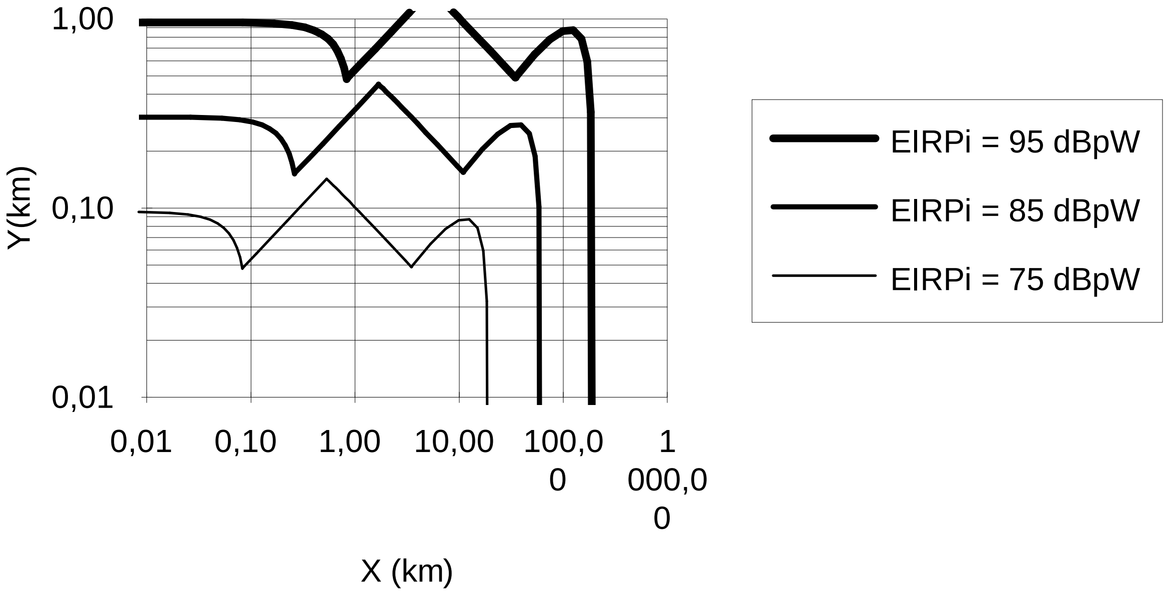
$$20 \cdot \log(d_{(km)}) = EIRP(i)_{(dBpW)} - 95{,}35 + Gr(\Phi r)_{(dBi)} \qquad (3)$$

The co-ordinates of these points in an horizontal plane are:

X = d x cos(Φr)

Y = d x sin(Φr)

Figure B.2 shows the co-ordinates of the positions, from where an interfering VSAT may cause an equivalent noise increase of 0,1 dB at the radio relay receiver input.



X corresponds to the on axis direction of the radio relay station.

Y is the distance of the interfering VSAT from the radio relay link path.

Figure B.2: Coordinates of the positions, from which an interfering VSAT may cause an equivalent noise increase of 0,1 dB at the radio relay receiver input

B.5 Conclusion

Each time a VSAT is set-up in any place, already existing stations in the neighbourhood have to be taken into consideration. Figure B.2 shows the critical distances from the radio relay link path for different spurious levels of the interfering VSAT. In order to limit the number of conflict situations, this critical distance should not be higher than about 50 m to 150 m. Therefore it is necessary that the EIRP of the spurious radiation of a VSAT (EIRP(i)), in direction of a radio relay station, should be below 75 dBpW.

History

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