RECOMMENDATION ITU-R F.1191-1

BANDWIDTHS AND UNWANTED EMISSIONS OF DIGITAL RADIO-RELAY SYSTEMS*

(Question ITU-R 119/9)

(1995-1997)

The ITU Radiocommunication Assembly,

considering

a) that the definitions of necessary and occupied bandwidth and allocated band are reported in Nos. 146, 147 and 17 of the Radio Regulations (RR) respectively;

b) that the definitions of unwanted, out-of-band and spurious emissions are reported in RR Nos. 140, 138 and 139 respectively;

c) that it is necessary to give guidance for the application of these definitions to digital radio-relay systems (DRRS);

d) that it is relatively unlikely that out-of-band emissions from DRRS will cause significant interference into systems operating in adjacent bands, because:

– the power spectrum of a DRRS decays rapidly outside the occupied bandwidth;

– the e.i.r.p. of line-of-sight DRRS is low or medium;

– trans-horizon DRRS employing a high e.i.r.p. are not widely used;

e) that from the viewpoint of interference into other systems sharing the same frequency band, interference due to out-of-band emissions will be, in general, less significant than that due to emissions within the necessary bandwidth;

f) that intra-system interference related problems, which may be caused by unwanted emissions, are normally taken into account by DRRS designers;

g) that bands are allocated to radio-relay fixed services on a primary or co-primary basis, where a radio-frequency channel arrangement has been established by a relevant ITU-R Recommendation or by a National Regulatory Authority;

h) that transmitter frequencies should be determined so that out-of-band emissions do not cause harmful interference outside the allocated band in accordance with RR No. 343 (S4.5); the transmitters on the radio-frequency channels at the allocated band edges should comply with the general occupied bandwidth compatibility criteria as required by RR No. 147;

j) that at the allocated band edges, radio-frequency bands *ZS*, as defined in Recommendation ITU-R F.746, are given by the relevant ITU-R Recommendations in order to control power spill-over into adjacent allocated bands;

k) that it is not always possible or convenient to make the occupied bandwidth of DRRS smaller than or equal to the bandwidth of the radio-frequency channel provided by the relevant radio-frequency channel arrangement established for the allocated band by ITU-R or by a National Regulatory Authority;

l) that within the allocated band, coordination between various radio-relay systems used on the basis of a radio-frequency channel arrangement is covered by an efficient concept summarized by Recommendation ITU-R F.746 and by the statistical propagation behaviour reported in Recommendation ITU-R P.530 and Recommendation ITU-R F.1093;

m) that DRRS, with suitable scrambling applied, have in general a transmitted spectral density and unwanted emissions with power peak factors that may be conservatively considered noise-like;

n) that DRRS have unwanted emissions composed of both noise-like and discrete components, made up of out-of-band and spurious emissions, which are not easy to distinguish one from the other;

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* This Recommendation should be brought to the attention of Radiocommunication Study Group 1 (TG 1/5).

o) that Recommendation ITU-R SM.329 gives the limits and the reference bandwidth for spurious emissions of all services, including the fixed service;

p) that Recommendation ITU-R SM.329 defines the frequency boundary between spurious and out-of-band emissions as ±250% of the necessary bandwidth; however allowance is given for different definitions, and this frequency boundary may be dependent on the type of modulation used, the maximum bit rate in the case of digital modulation, the type of transmitter, and frequency coordination factors. For example, in the case of some digital systems, the frequency boundary may need to differ from the ±250% factor (see Note 3);

q) that, in fixed service applications, different emissions with different modulation formats and necessary bandwidth may co-exist in the same channel separation; it is therefore convenient, for ease of frequency coordination and for regulatory purposes, to consider the 250% of the constant channel separation as the boundary between out-of-band and spurious emissions, instead of the various different necessary bandwidths of any specific system (see Note 3),

recommends

1 that the following general definitions apply to DRRS:

1.1 Occupied bandwidth

The width of a frequency band such that, below the lower and above the upper frequency limits, the mean powers emitted are each equal to a specified percentage $\beta/2$ of the total mean power of a given emission (RR Article 1, No. 147).

1.2 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 Article 1, No. 146).

1.3 Allocated frequency band

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 radiocommunication services or the radioastronomy service under specific conditions. This term shall also be applied to the frequency band concerned (RR Article 1, No. 17).

For DRRS the allocated frequency band may be considered as the overall frequency band allocated to the FS on a primary or co-primary basis.

1.4 Radio-frequency channel separation

Bandwidth equal to the frequency separation, defined in Recommendation ITU-R F.746, of adjacent channels of the relevant radio-frequency channel arrangement established within the allocated frequency band.

1.5 Guardband

Bandwidth equal to the frequency separation, defined in Recommendation ITU-R F.746 as *ZS*, between the nominal centre frequency of the outermost channel of a radio-frequency channel arrangement and the limit of the allocated band.

1.6 Unwanted emissions

Consist of spurious emissions and out-of-band emissions (RR Article 1, No. 140).

For DRRS an example of a typical scenario is reported in Fig. 2.

1.7 Out-of-band emission

Emission on a frequency or frequencies immediately outside the necessary bandwidth which results from the modulation process, but excluding spurious emissions (RR Article 1, No. 138).

1.8 Spurious emission

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 Article 1, No. 139);

2 that the following specific design objectives and definitions be used for DRRS; an illustration of those objectives and definitions can be found in Fig. 1;

2.1 that, for DRRS, the value of percentage $\beta/2$ should be taken as 0.5%;

2.2 that, for DRRS, the necessary bandwidth is to be considered to have the same value as the occupied bandwidth;

2.3 that, according to the type of the utilized radio-frequency channel arrangement (see Note 1), the capacity and the modulation format of the transmitted signal, similar DRRS could have a necessary bandwidth which is no more than 20% wider than the radio-frequency channel separation (see Note 1); however, since dissimilar systems operating in the same band could give rise to certain incompatibilities, the relationship between the RF channel separation and the necessary bandwidth requires further study;

2.4 that the determination of occupied bandwidth should be done with a spectrum analyser method described in Recommendation ITU-R SM.328 or, whenever possible, by numerical evaluation or integration of the actual emitted spectrum as reported in Annex 1;

2.5 that when burst transmission is used (e.g. for TDMA DRRS) the evaluation of bandwidths and emissions should be done averaging the power over burst duration;

2.6 that DRRS should use suitable scrambling circuitry in order to maintain all the spectral emissions (both wanted and unwanted) independent from the input data stream;

2.7 that any unwanted emission which falls at frequencies separated from the centre frequency of the emission by less than 250% of the relevant channel separation, where the system is intended to be used, will generally be considered out-of-band emission (see Notes 3 and 4);

2.8 that any unwanted emission which falls at frequencies separated from the centre frequency of the emission by 250% or more of the relevant channel separation, where the system is intended to be used, will generally be considered spurious emission (see Notes 3 and 4);

2.9 that, above and below the limits of the necessary bandwidth, the permissible mean power level of unwanted emission should be less than or equal to 0.5% of the total transmitted mean power taken at the radio antenna port (see Note 2);

2.10 that, from the viewpoint of the international regulations, it is presently not necessary to establish any additional limitation on the spectral shape of unwanted emissions from DRRS;

2.11 that the levels of spurious emissions, the frequency range to their measurement and the reference bandwidth in which levels are specified should be those defined by ITU-R Recommendation SM.329 as detailed in Annex 2 (see Notes 3 and 5);

2.12 that, without other specific agreement between administrations sharing the same band edge, the digital radio-relay transmitters operating on the outermost channel frequencies of a radio-frequency channel arrangement should have an occupied bandwidth so that the outermost half of it, when added to the absolute value of the frequency tolerance (see Note 6), results in a bandwidth smaller than or equal to the value of *ZS* as defined in § 1.5.

NOTE 1 – See Recommendation ITU-R F.746 for definitions of alternated, co-channel mode band re-use and interleaved mode band re-use radio-frequency channel arrangements. Channel separation is defined as *XS*/2 for alternated frequency channel arrangements and *XS* for co-channel and interleaved frequency channel arrangements.

NOTE 2 – Due to possible compatibility problems, caution should be exercised when applying this Recommendation to high capacity systems, bands which have dissimilar systems in adjacent channels, and bands which are shared with other services.

NOTE 3 – As Recommendation ITU-R SM.329 allows for boundary values different than ±250%, the following is provisionally recommended for DRRS operating above 1 GHz with channel separation less than 2 MHz:

– that the boundary between the spurious and out-of-band emissions is established as ±500% of the channel separation;

– that the reference bandwidth is 100 kHz in the frequency range between this boundary and ±20 MHz of the nominal centre frequency;

and also for DRRS operating above 1 GHz with transmitter power 20 watts or more and with channel separation between 2 MHz and 14 MHz:

– that the boundary between the spurious and out-of-band emissions is established as ±250% of the channel separation;

– that the reference bandwidth is 100 kHz in the frequency range between this boundary and ±70 MHz of the nominal centre frequency.

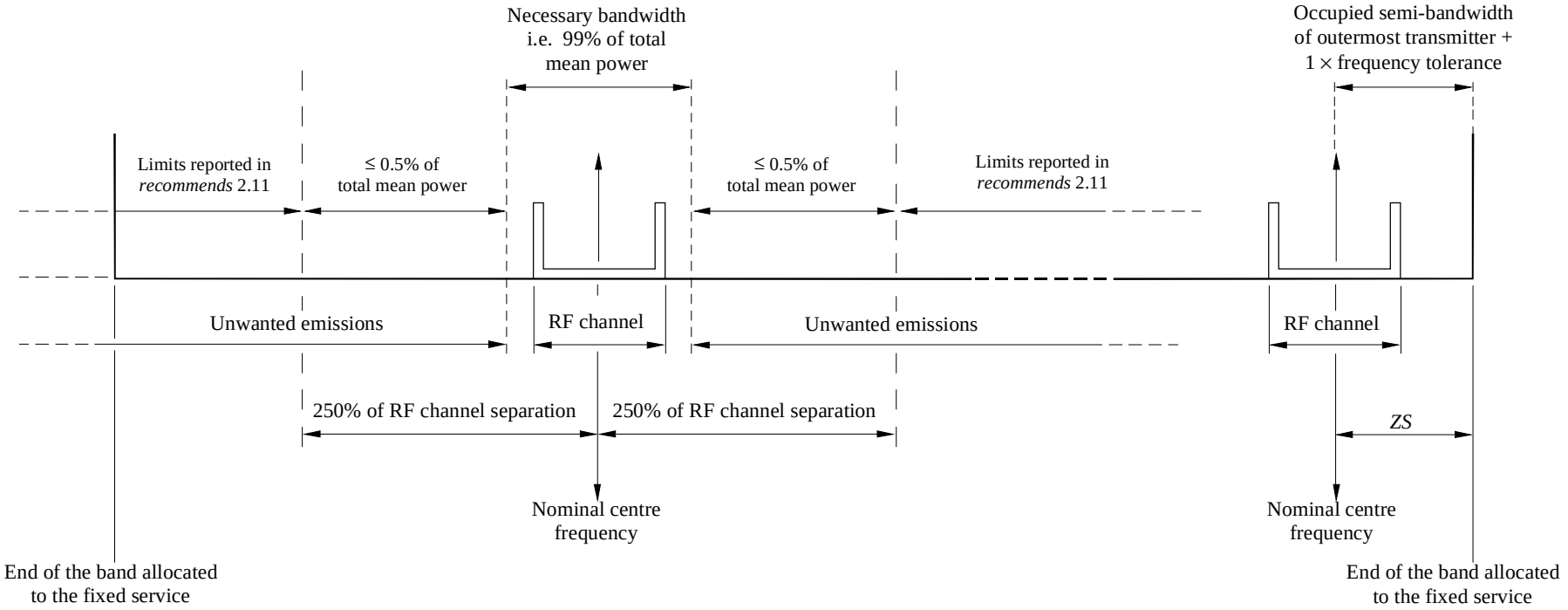
NOTE 4 – When the radio-relay system is intended for use in a frequency band where an RF channel arrangement has not been established, the necessary bandwidth should be used, instead of channel separation, in evaluating the 250% boundary.

NOTE 5 – It is recognized that the reference bandwidth of 1 MHz may result in spectral density requirement of up to 24 dB more stringent than with the 4 kHz bandwidth given in the previous version of this Recommendation. Applicability of these new limits to the existing systems will be subject to national regulations or regulations eventually established by World Radiocommunication Conference, (Geneva, 1997) (WRC-97).

NOTE 6 – The precise specification of frequency tolerance values is left to the National Regulatory Authorities.

FIGURE 1

Unwanted emission attenuation objectives and bandwidth definitions of DRRS



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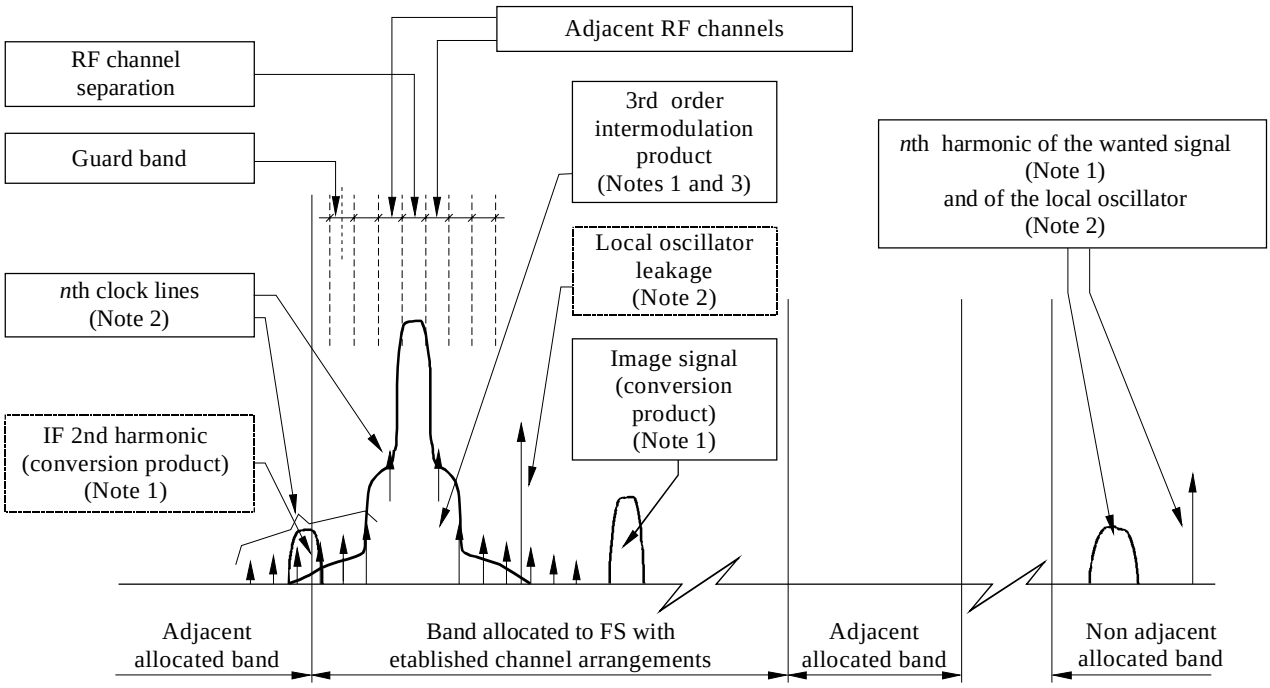
ANNEX 1

1 Typical emission scenario of a digital radio-relay system

Figure 2 shows the typical scenario based on typical and most important emissions of a heterodyne digital radio-relay transmitter. Other emissions (e.g. other conversion products and residual components of the carrier generation) are not shown. For directly modulated radio-frequency transmitters, some unwanted emissions (e.g. conversion products and local oscillator leakage) are not applicable.

FIGURE 2

Frequency bands and unwanted emissions of a digital radio-relay system (typical scenario)



Note 1 – Example of noise-like component of unwanted emissions.

Note 2 – Example of discrete component of unwanted emissions.

Note 3 – Non-linearity due to transmitter results in out-of-band emission which is immediately adjacent to the necessary bandwidth, due to odd order intermodulation products.

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2 Calculation of occupied bandwidth

Generally, a normalized power spectrum $W(f)$ of a modulated carrier of a DRRS can be expressed as follows:

$$W(f) = S(f) \left(\frac{\sin(\pi f T)}{\pi f T} \right)^2 \quad (1)$$

where:

$S(f)$: frequency response of the shaping filter located in the transmitter

f: frequency separation from the carrier

T: pulse width.

Therefore, the occupied bandwidth, B_0, can be calculated as follows:

$$\int_{-B_0/2}^{+B_0/2} W(f)\ \mathrm{d}f = 0.99 \int_{-\infty}^{+\infty} W(f)\ \mathrm{d}f \tag{2}$$

2.1 Case of phase and amplitude modulated signals with ideal square root cosine roll-off shaping

In many cases shaping filters of a square root cosine roll-off type are employed at the transmitter side and the ideal frequency response is given by:

$$S(f) = \begin{cases} \left(\dfrac{\pi f T}{\sin(\pi f T)}\right)^2 & \text{for} \quad |f| \le \dfrac{1-\alpha}{2T} \\ \dfrac{1}{2}\left(1 - \sin\left[\dfrac{\pi T}{\alpha}\left(|f| - \dfrac{1}{2T}\right)\right]\right)\left(\dfrac{\pi f T}{\sin(\pi f T)}\right)^2 & \text{for} \quad \dfrac{1-\alpha}{2T} < |f| \le \dfrac{1+\alpha}{2T} \\ 0 & \text{for} \quad \dfrac{1+\alpha}{2T} \le |f| \end{cases} \tag{3}$$

where α is the roll-off factor between 0 and 1.

Substitution of equation (3) into equations (1) and (2) gives the ideal occupied bandwidth as follows:

$$B_0 = 2\,K(\alpha) / T \tag{4}$$

where $K(\alpha)$ is a function of α and is calculated as shown in Table 1.

Thus, the occupied bandwidth can be calculated by using equation (4) and Table 1.

TABLE 1

The values of $K(\alpha)$

α	$K(\alpha)$
0.1	0.510
0.2	0.537
0.3	0.567
0.4	0.600
0.5	0.634
0.6	0.669
0.7	0.705
0.8	0.742
0.9	0.779
1.0	0.816

2.2 Case of phase and amplitude modulated signals with other shaping filters

Different practical implementations and other types of shaping filters are sometimes used. These cases need more complex numerical evaluations of equation (2) and are under study.

2.3 Case of frequency and phase modulated signals

These cases are under study.

3 Occupied bandwidth for multiple sub-carriers operation

In some cases, a digital radio-relay transmitter may carry multiple sub-carriers amplified by a common amplifier. The occupied bandwidth B_0 for such operation should be calculated as follows:

$$B_0 = b_0 + (m - 1)\,\Delta F \tag{5}$$

where:

b_0: occupied bandwidth of a single sub-carrier

m: number of sub-carriers

ΔF: frequency spacing between centre frequencies of adjacent sub-carriers.

The formula (5) assumes that the multiple sub-carriers are homogeneous and equally spaced. It should be noted that in this case the value of percentage $\beta/2$ for the total power of all sub-carriers is $0.5/m$ %.

ANNEX 2

Recommendation ITU-R SM.329 references

ITU-R Recommendation SM.329 requires levels of spurious emissions, frequency range of their measurement and reference bandwidth in which levels are specified as follows:

1 Frequency range of spurious emission measurement

In the relevant Recommendation ITU-R SM.329 states that the frequency range of the measurement of spurious emissions is from 9 kHz to 110 GHz or the second harmonic if higher. However for practical measurements spurious emissions up to the fifth harmonic of the fundamental frequency should be measured, provided that this does not exceed 26 GHz. For those systems with a fundamental frequency above 13 GHz, spurious emissions up to only the second harmonic should be measured. Systems utilizing a wave guide section as an antenna connector do not require spurious emission measurements below the waveguide cut-off frequency;

2 Reference bandwidth in which levels are specified

In the relevant Recommendation ITU-R SM.329 states that a reference bandwidth is a bandwidth in which spurious emission levels are specified. The following reference bandwidths are recommended:

– 1 kHz between 9 and 150 kHz

– 10 kHz between 150 kHz and 30 MHz

– 100 kHz between 30 MHz and 1 GHz

– 1 MHz above 1 GHz.

3 Levels of spurious emissions

In the relevant Recommendation ITU-R SM.329 states that the limits for spurious emissions will be optionally divided into three categories:

Category A: Recommended maximum spurious emission power levels intended for use with radio equipment for all Administrations; these limits are given in Table 2;

Category B: Recommended maximum spurious emission power levels intended for Administrations that may need to adopt more stringent limits than those given in Category A;

Category C: Radiation limits for information technology (IT) equipment specified by International Special Committee on Radio Interference (CISPR);

Table 2 indicates the recommended maximum permitted levels of spurious emissions, in terms of power as indicated in the table, of any spurious component supplied by a transmitter to the antenna transmission line for Category A equipment.

Spurious emission from any part of the installation other than the antenna and its transmission line should not have an effect greater than would occur if this antenna system were supplied with the maximum permitted power at that spurious emission frequency.

TABLE 2

Spurious emission limits – Category A

Category A: Recommended attenuation values used to calculate maximum permitted spurious emission power levels intended for use with radio equipment by all countries	
Service category in accordance with RR Article 1, or equipment type(1)	Attenuation (dB) below the power (W) supplied to the antenna transmission line
Fixed service	43 + 10 log(*P*), or 70 dBc, whichever is less stringent

P: mean power (W) at the antenna transmission line, in accordance with RR S1.158. When burst transmission is used, the mean power *P* and the mean power of any spurious emissions are measured using power averaging over the burst duration.

dBc: decibels relative to the unmodulated carrier power of the emission. In the cases which do not have a carrier, for example in some digital modulation schemes where the carrier is not accessible for measurement, the reference level equivalent to dBc is decibels relative to the mean power *P*

(1) In some cases of digital modulation and narrow-band high power transmitters for all categories of services, there may be difficulties in meeting limits close to ±250% of the necessary bandwidth.

Table 3 indicates the maximum permitted levels of spurious emissions, in terms of power level, of any spurious component supplied by a transmitter to the antenna transmission line for Category B equipment.

TABLE 3

Category B limits *

Category B: Recommended maximum spurious emission power levels intended for Administrations that may need to adopt more stringent limits than those given in Category A	
Type of equipment	Limits
Fixed Service	−50 dBm 30 MHz ≤ f < 21.2 GHz(1) −30 dBm 21.2 GHz ≤ f < (see § 1 of this Annex) (1)
Fixed Service – Terminal station (out station with subscriber equipment interfaces)	−40 dBm 30 MHz ≤ f < 21.2 GHz(1) −30 dBm 21.2 GHz ≤ f < (see § 1 of this Annex) (1)

* These limits are widely used by European and other countries. However, some other countries indicate these limits require further study.

f: frequency of the spurious.

(1) For digital systems, Category B limits should be applied on both sides of the emission from 250% of the necessary bandwidth +56 MHz. Up to this point, Category A limits should apply, unless a more detailed transition is agreed by administrations.

Table 4 contains Category C limits for Classes A (industrial) and B (domestic) information technology equipment. Category C equipment is defined as that which combines IT equipment with a radio transmitting function. If the IT portion can be detached and still operate independently, then each part should be tested separately in conformity with the pertinent ITU-R spurious emission limit or the CISPR limit. If the IT portion cannot be independently operated, then the ITU-R Category A or B limits should be applied while testing in the transmitting mode and the CISPR limits should apply in the standby or idle mode. Values are taken from CISPR Publication 22 for frequencies below 1 GHz. Limits for frequencies above 1 GHz are under consideration within CISPR.

TABLE 4

Category C limits

Category C: Radiation limits for IT equipment specified by CISPR			
Frequency (MHz)	E_{max} (dB(μV/m))	Distance of measurement (m)	Corresponding e.i.r.p. (dBm)
Class A: applicable to IT equipment intended for industrial environment			
30-230	40	10	−49
230-1 000	47	10	−42
Class B: applicable to IT equipment intended for a domestic environment			
30-230	30	10	−59
230-1 000	37	10	−52

Conversion in terms of equivalent isotropic radiated power (e.i.r.p.) is provided for information by assuming that the maximum field-strength is to be measured in a semi-anechoic chamber or in open area test site according to CISPR measurement method. This is approximately 4 dB above a measurement with free-space condition (this value is in agreement with CISPR studies).