RECOMMENDATION ITU-R SM.337-6*

Frequency and distance separations

(1948-1951-1953-1963-1970-1974-1990-1992-1997-2007-2008)

Scope

This Recommendation provides the procedures for calculating distance and frequency separations for an acceptable interference level.

Keywords

Interference level, receiver selectivity, channel, frequency separation, protection ratio

The ITU Radiocommunication Assembly,

considering

a) that, in the more usual cases, the primary factors which determine appropriate frequency or distance separation criteria include:

– the signal power and spectral distribution required by the receiver;

– the power and spectral distribution of the interfering signals and noise intercepted by the receiver;

– the distance dependence of the transmission losses of the radio equipments;

b) that transmitters, in general, emit radiations outside the frequency bandwidth necessarily occupied by the emission;

c) that many factors are involved, among which are the properties of the transmission medium (which are variable in character and difficult to determine), the characteristics of the receiver and, for aural reception, the discriminating properties of the human ear;

d) that trade-offs in either frequency or distance separations of the radio equipment are possible,

recommends

1 that the frequency-distance (FD) separations of radio equipment should be calculated by the following method:

1.1 determine the power and spectral distribution of the signal intercepted by the receiver;

1.2 determine the power and spectral distribution of the interfering signals and noise intercepted by the receiver;

1.3 determine the interactive effects among wanted signals, interference and receiver characteristics for various frequency or distance separations by using the basic equations given in Annex 1 along with, if necessary, simple approximations to the integral expressions and the concept described in Annex 2;

1.4 determine, from these data, the degree of frequency or distance separation that will provide the required grade of service and the required service probability. Account should be taken of the fluctuating nature both of the signal and of the interference, and, whenever appropriate, the discriminating properties of the listener or viewer;

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* Radiocommunication Study Group 1 made editorial amendments to this Recommendation in the years 2018 and 2019 in accordance with Resolution ITU-R 1.

1.5 determine the appropriate ITU-R propagation model to be used;

2 that, at every stage of the calculation, comparison should be made, as far as possible, with data obtained under controlled representative operating conditions, especially in connection with the final figure arrived at for the frequency or distance separation among radio equipment.

Annex 1

Basic equations

This Annex describes basic equations which quantify the interactive effects among wanted signals, interference, and receiver characteristics for various frequencies and FD separations. The measures are:

– frequency dependent rejection (FDR) which is a measure of the rejection produced by the receiver selectivity curve on an unwanted transmitter emission spectra;

– FD which is a measure of the minimum distance separation that is required between a victim receiver and an interferer as a function of the difference between their tuned frequencies;

– relative radio-frequency protection ratio *A* (see Recommendation ITU-R BS.560) which is the difference (dB) between the protection ratio when the carriers of the wanted and unwanted transmitters have a frequency difference of Δf and the protection ratio when the carriers of these transmitters have the same frequency.

The FD and FDR are measures of the interference coupling mechanism between interferer and receiver and are the basic solutions required for many interference evaluations. They aid in the solution of co-channel frequency sharing and adjacent band or channel interference problems by providing estimates of the minimum frequency and distance separation criteria between interferer and receiver which are required for acceptable receiver performance.

The interference level at the receiver is a function of the gains and losses the interference signal will incur between the source and the receiver and is expressed by:

$$I = P_t + G_t + G_r - L_b(d) - FDR(\Delta f) \qquad \text{dBW} \tag{1}$$

where:

P_t: interferer transmitter power (dB)

G_t: gain of interferer antenna in direction of receiver (dBi)

G_r: gain of receiver antenna in direction of interferer (dBi)

$L_b(d)$: basic transmission loss for a separation distance *d* between interferer and receiver (dB) (see Recommendation ITU-R P.341)

and

$$FDR(\Delta f) = 10 \log \frac{\int_0^\infty P(f)\,\mathrm{d}f}{\int_0^\infty P(f)\,\left|H(f+\Delta f)\right|^2\,\mathrm{d}f} \qquad \text{dB} \tag{2}$$

where:

$P(f)$: power spectral density of the interfering signal equivalent intermediate frequency (IF)

$H(f)$: frequency response of the receiver

$$\Delta f = f_t - f_r$$

where:

f_t: interferer tuned frequency

f_r: receiver tuned frequency.

The FDR can be divided into two terms, the on-tune rejection (OTR) and the off-frequency rejection (OFR), the additional rejection which results from off-tuning interferer and receiver.

$$FDR(\Delta f) = OTR + OFR(\Delta f) \qquad \text{dB} \tag{3}$$

where:

$$OTR = 10 \log \frac{\int_0^\infty P(f)\,\mathrm{d}f}{\int_0^\infty P(f)\,|H(f)|^2\,\mathrm{d}f} \qquad \text{dB} \tag{4}$$

$$OFR(\Delta f) = 10 \log \frac{\int_0^\infty P(f)\,|H(f)|^2\,\mathrm{d}f}{\int_0^\infty P(f)\,|H(f+\Delta f)|^2\,\mathrm{d}f} \qquad \text{dB} \tag{5}$$

The on-tune rejection also called the correction factor, can often be approximated by:

$$OTR \approx K \log \left(\frac{B_T}{B_R} \right) \qquad B_R \le B_T \tag{6}$$

where:

B_R: interfered receiver 3 dB bandwidth (Hz)

B_T: interferer transmitter 3 dB bandwidth (Hz)

$K =$ 20 for non-coherent signals

$=$ 20 for pulse signals.

Annex 2

Methodology to determine frequency and distance separation for radio systems

1 Introduction

It is well known that FD rules are an important part of the frequency management process in most radio services. In channelized services, these rules take the following form: co-channel transmitters must be separated by at least d_0 (km), the adjacent channel transmitters must be separated by at least d_1 (km), transmitters separated by two channels must be at least d_2 (km) away and so on. For older technologies the FD rules are usually well known by now. However, the introduction of new technologies raises the question: what kind of FD rules a spectrum manager should apply when new and old systems occupy the same frequency band? The methodology that is required to determine FD separation rules between both similar and dissimilar systems is given below.

2 Methodology

The development of a new FD rule requires the computation of the level of interference at the input of the victim receiver, and also requires the definition of an acceptable interference criterion.

2.1 Interference computation

This depends on two primary factors: a spectral factor and a spatial factor.

The *spectral factor* depends on the spectral characteristics of the interfering transmitter and the frequency response of the victim receiver. For computational purposes one must have accurate knowledge of the power spectral density of the interfering signal which depends on factors such as the underlying modulation technique and the bandwidth of the information signal for analogue systems and the transmitted data rate in the case of digital systems.

As far as the victim receiver is concerned, one must know the equivalent IF frequency response characteristics of the receiver. Manufacturer's specifications such as the 6 dB and the 40 dB bandwidth of the IF stage may be used as a basis for modeling the receiver's IF frequency response.

The spectral factor is represented by the off-channel-rejection factor OCR(Δf), which is defined by the following relationship:

$$\mathrm{OCR}(\Delta f) = -10 \log \frac{\int_{-\infty}^{+\infty} P(f) \left| H(f + \Delta f) \right|^2 \mathrm{d}f}{\int_{-\infty}^{+\infty} P(f) \mathrm{d}f} \quad \text{dB} \qquad (7)$$

where:

- $P(f)$: power spectral density of the interfering signal in (W/Hz)
- $H(f)$: equivalent IF frequency response of the victim receiver
- Δf: frequency separation between the victim receiver and the interfering transmitter.

Note that equation (7) is not different from equation (2), even though the lower limits of integration are different.

It is evident from equation (7) that OCR(Δf) is strongly dependent on the extent of overlapping between the receiver passband and the power spectrum of the interfering signal. As Δf increases, the extent of overlapping diminishes, thus resulting in lower interference power or, equivalently, higher values for OCR(Δf).

The *spatial factor* of the methodology is concerned with the computation of the distance related signal attenuation; it is closely related to the propagation model to be used and to the statistical distribution of the interfering signal at the front end of the victim receiver. An appropriate propagation model as recommended by ITU-R should be used.

The propagation model to be used with this procedure is of course dependent on the system configuration as well as the operating frequency band and the geographical environment surrounding the service area and the system bandwidth.

2.2 Interference criterion

This usually is a simple relationship based on which one judges the interference as harmful or tolerable. Such a criterion should ideally be tied to the level of performance degradation the victim receiver may be capable of tolerating. This however is not practical at least from the point of view that there are many different types of systems and technologies that may not be capable of dealing with interference the same way. A more generic criterion based on a protection ratio α (dB) is therefore adopted. The interference will be considered tolerable if the following inequality is satisfied:

$$P_d - P_i \geq \alpha \tag{8}$$

where:

P_d: desired signal level (dBW)

P_i: interfering signal level (dBW)

α: protection ratio (dB).

2.3 Procedure

The procedure for developing a FD separation rule can now be summarized as follows:

Step 1: Determine the desired signal level P_d (dBW) at the victim receiver front end.

Step 2: Calculate the resulting level of interference at the victim receiver's front end using the formula:

$$P_i = P_t + G_r - L_p - \text{OCR}(\Delta f) \tag{9}$$

where:

P_t: equivalent isotropically radiated power (e.i.r.p.) of the interfering transmitter (dBW)

G_r: gain of the receiving antenna with respect to an isotropic antenna (dBi)

L_p: propagation path loss

OCR(Δf): off-channel-rejection factor for a frequency separation Δf as expressed by equation (7).

The OCR values used in this paper are assumed. The purpose of this Recommendation is to present the methodology rather than the development of OCR values.

Step 3: Substitute P_d and P_i of steps 1 and 2 above into equation (8) to derive or numerically compute a relationship between the frequency separation Δf and the distance separation d such that the interference is considered tolerable.

2.4 Alternative procedure

In the real environment, the received signal at the victim receiver experiences shadow fading which is represented by log-normal distribution. To compensate for this fading effect, the received signal level should be higher than the sensitivity level. An alternative procedure for determining a required isolation between the victim and the interferer, reflecting the shadowing effect, is presented as follows:

Step 1: Calculate the required isolation in order to prevent the interferer from causing radio interference to the victim using the formula:

$$L_I = P_t + G_r - (P_{min} - \alpha) - \text{OCR}(\Delta f) - 10\log(10^{N/10} - 1) \tag{10}$$

where:

- L_I: isolation required between the interferer and the victim to ensure tolerable interference (dB)
- P_t: equivalent isotropic radiated power (e.i.r.p.) of the interfering transmitter (dBW)
- G_r: gain of the receiving antenna with respect to an isotropic antenna (dBi)
- P_{min}: minimum desired signal level (dBW)
- α: protection ratio (dB)
- OCR(Δf): off-channel-rejection factor for a frequency separation Δf as expressed by equation (7)
- N: log-normal fading margin (dB).

Step 2: Employing an appropriate ITU-R propagation model to equation (10) gives the frequency separation Δf and the distance separation d at which the interference can be tolerable.

2.5 Consideration of antenna isolation

When several different radio systems are co-located, the antenna isolation concept can be brought into consideration in the calculation of interference between them. Figure 1 gives generic examples of antenna arrangements which illustrate the isolations of horizontal (HI), vertical (VI) and slant (SI) antenna configurations.

The antenna isolation is mainly dependent on distance separation and wavelength, λ, (m). The distance separation between two antennas is the distance from the centre of interferer antenna to that of victim receiver antenna[1]. Antenna-to-antenna isolations are normally expressed in terms of dB of attenuation.

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[1] In the practical situation the distance between the interferer antenna and victim receiver antenna may be measured between the nearest edges of both antenna systems for convenience.

The isolation between two dipole antennas can be approximately computed by using the following equations (10a), (10b) and (10c):

$$\mathrm{HI(dB)} \approx 22 + 20 \ \log(x/\lambda) \tag{10a}$$

$$\mathrm{VI(dB)} \approx 28 + 40 \ \log(y/\lambda) \tag{10b}$$

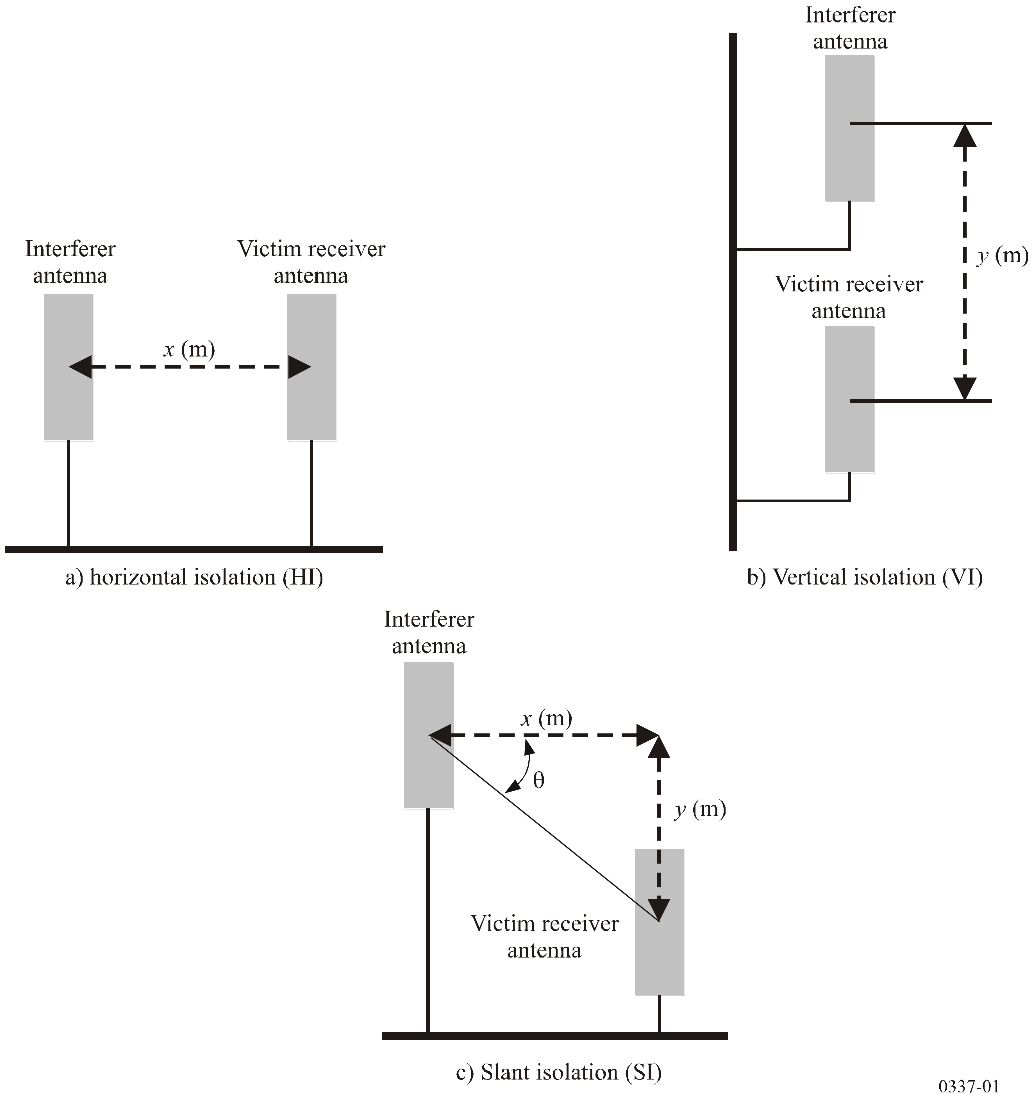
$$\mathrm{SI(dB)} \approx (\mathrm{VI} - \mathrm{HI}) \cdot 2\theta/\pi + \mathrm{HI} \tag{10c}$$

where θ (rad) is $\tan^{-1}(y/x)$, x is the horizontal distance, and y is the vertical distance. The equations are applicable when x is greater than 10λ and y is greater than λ.

These isolations obtained from equations (10a), (10b) and (10c) can be substituted for the basic transmission loss ($L_b(d)$) of equation (1) or the propagation path loss (L_p) of equation (9) when two stations are co-located.

FIGURE 1

Antenna isolation in horizontal, vertical and slant direction



3 Application to land mobile radio systems

To demonstrate the methodology described above, an example using two dissimilar land mobile radio (LMR) systems is described in this section. The two systems considered could be digital or analogue with TDMA or FDMA access techniques. Our computations are based on spectral emission masks and certain receiver selectivity requirements and as such the results are independent of any particular modulation techniques that may be used by either of the two systems. In this example, the receiver selectivity was assumed to have similar characteristics to the spectral emission masks, a consideration which is expected to be the case for digital systems.

The assumptions made for the two systems are summarized in Tables 1 and 2:

TABLE 1

Assumed parameters for the example

Minimum desired signal level, P_{min}	–145 dBW
Required protection ratio, α	18 dB
Base station antenna height, h_b	75 m
Operating frequency, f	450 MHz
Base station e.i.r.p.	20 dBW
Base receiving antenna gain	0 dBi
Equivalent relative permittivity, ε Equivalent conductivity, σ	30 10^{-2} S/m

In LMR systems there are four modes of interference: base-to-base, base-to-mobile, mobile-to-base and mobile-to-mobile. In simplex systems, where the base and the mobiles transmit on the same frequency, all four modes of interference are present. On the other hand, in duplex systems the mobiles and the base transmit on different frequencies and hence only the base-to-mobile and the mobile-to-base modes need to be considered. For the distance of separation analysis purpose however, we only need to look at the worst case; the interference case that demands the greatest isolation distance between systems. In most situations, base stations can be assumed to operate close to 100% of the time and the base-to-base interference mode is the dominant mode demanding the largest distance of separation. For this reason, other modes are not considered herein.

We now proceed to present the propagation models for LMR systems, followed by the numerical results for each of the two system combinations under study.

3.1 Base-to-base interference

The propagation model chosen for the base-to-base mode is the diffraction propagation model (see Recommendation ITU-R P.526). Under this model, the path loss is expressed as:

$$L_{P_{bb}} = L_{FS} - L_{DIF/FS} \tag{11}$$

where:

L_{FS}: path loss (dB), due to free space

$L_{DIF/FS}$: diffraction loss over free space loss (dB) and is defined as follows:

$$L_{DIF/FS} = 20 \log \left(\frac{E_{DIF}}{E_{FS}} \right) = F(X) + G(Y1) + G(Y2) \tag{12}$$

where:

$F(X)$:	gain term dependent on the normalized distance between base stations
$G(Y1)$, $G(Y2)$:	gain terms dependent on the base stations normalized antenna heights
X:	normalized distance between the base stations antennas
$Y1$, $Y2$:	normalized antenna heights and are defined as follows:

$$X = 2.2\beta f^{1/3} a_e^{-2/3} d \tag{13}$$

$$Y = 9.6 \times 10^{-3} \beta f^{2/3} a_e^{-1/3} h_{1.2} \tag{14}$$

where:

$$\beta = \frac{1 + 1.6\,K^2 + 0.75\,K^4}{1 + 4.5\,K^2 + 1.35\,K^4} \tag{15}$$

K: surface admittance of the Earth for vertical polarization:

$$K = 0.36(a_e f)^{-1/3}\left[(\varepsilon = 1)^2 + (18\,000\,\sigma / f)^2\right]^{-1/4}\left[\varepsilon^2 + (18\,000\,\sigma / f)^2\right]^{1/2} \tag{16}$$

where:

ε:	equivalent relative permittivity of the Earth
σ:	equivalent conductivity (S/m) of the Earth
a_e:	equivalent earth radius equal to 4/3 of 6 371 km
d:	distance between the transmitter and the receiver (km)
f:	transmit frequency
h_1 and h_2:	respectively the transmitter and receiver antenna heights (m).

$$F(X) = 11 + 10\log(X) - 17.6X \tag{17}$$

$$G(Y) \cong 17.6\,(Y - 1.1)^{1/2} - 5\log\,(Y - 1.1) - 8 \quad \text{for} \quad Y > 2 \tag{18}$$

$$G(Y) \cong 20\log(Y + 0.1Y^3) \quad \text{for} \quad 10\,K < Y < 2 \tag{19}$$

$$G(Y) \cong 2 + 20\log K + 9\log(Y/K)[\log(Y/K) + 1] \quad \text{for} \quad K/10 < Y < 10\,K \tag{20}$$

$$G(Y) \cong 2 + 20\log K \quad \text{for} \quad Y < K < 10 \tag{21}$$

where K is the normalized surface admittance.

3.2 Numerical results

3.2.1 Spectral aspects

Equation (7) is used to compute the off-channel-rejection factor OCR(Δf) as a function of Δf. In our example, we look at two study cases:

Case 1: A 25 kHz system interfering with a 12.5 kHz system.

Case 2: A 12.5 kHz system interfering with a 25 kHz system.

The numerical assumptions for the two cases are shown in Table 2 in which OCR(Δf) is expressed as a function of the frequency separation Δf (kHz).

TABLE 2

OCR (dB) results for interference between two dissimilar systems

Δf (kHz)	Case 1: OCR(Δf) (dB)	Case 2: OCR(Δf) (dB)
0	≅ 0	≅ 0
12.5	26.4	29
25	57.7	58.8
37.5	57.7	59

3.2.2 Spatial aspects

Based on the assumed parameters as shown in Tables 1 and 2 and assuming a log normal distribution of the power of the desirable received signal, a location variability factor of 17 dB, the 90% coverage for the land mobile system is 32 km. The corresponding desired receiver power level is:

$$P_d = P_{min} + L_{VF} = -128 \text{ dBW}$$

Therefore, the acceptable interference level is: $P_d - \alpha = -146$ dBW.

The required separation distances, D, between base stations for the two cases under study, have been computed based on the procedure presented in this text. A summary of the results is given in Table 3.

TABLE 3

Required separation distance, *D* (km), versus frequency separation, Δf (kHz)

Δf (kHz)	Case 1 and Case 2: D (km)
0	107.5
12.5	72.5
25	33
37.5	33

3.2.3 Fading margin dependent isolation aspects

Using the parameters given in Tables 1 and 2 and the alternative procedure described in § 2.4, we obtain the required isolation L_I in terms of log-normal fading margin as in Table 4.

TABLE 4

Required isolation, L_I (dB) according to log-normal fading margin, N (dB)

Δ*f* (kHz)	**Case 1**		**Case 2**	
	$N = 3$	$N = 10$	$N = 3$	$N = 10$
0	183.02	173.46	183.02	173.46
12.5	156.62	147.06	154.02	144.46
25	125.32	115.76	124.22	114.66
37.5	125.32	115.76	124.02	114.46

Note that the larger the N requires the lower the isolation.

4 An intermodulation FD rule

In addition to co-channel and adjacent-channel interference, land mobile systems are also affected by intermodulation interference through the formation of intermodulation products. In the case of two-signal third-order receiver intermodulation, since two base station transmitters are involved in the formation of an intermodulation product, their minimum acceptable distances from a victim receiver are interrelated.

Based on the assumption that the receiver antenna gain is equal to the receiver total loss, that the average value of the minimum wanted signal level to produce a 12 dB signal-to-interference ratio including noise and distortion (SINAD) in the presence of noise is –145 dBW, that the free-space path loss is used and that all transmitters have the same e.i.r.p. equal to 20 dBW, the FD rule for the 410-470 MHz band can be established to predict interfering power levels at the victim receiver. In this model:

$$P = 2P_N + P_F - 0.57 - 60 \log(\delta f) \tag{22}$$

where:

- P: resulting interfering power level at the victim receiver (dBW)
- P_N: received power (dBW) from the transmitter whose frequency is the nearest to the frequency of the victim receiver
- P_F: received power (dBW) from the transmitter whose frequency is the farthest from the frequency of the victim receiver
- δf: frequency separation between the near and far transmitter frequencies (MHz).

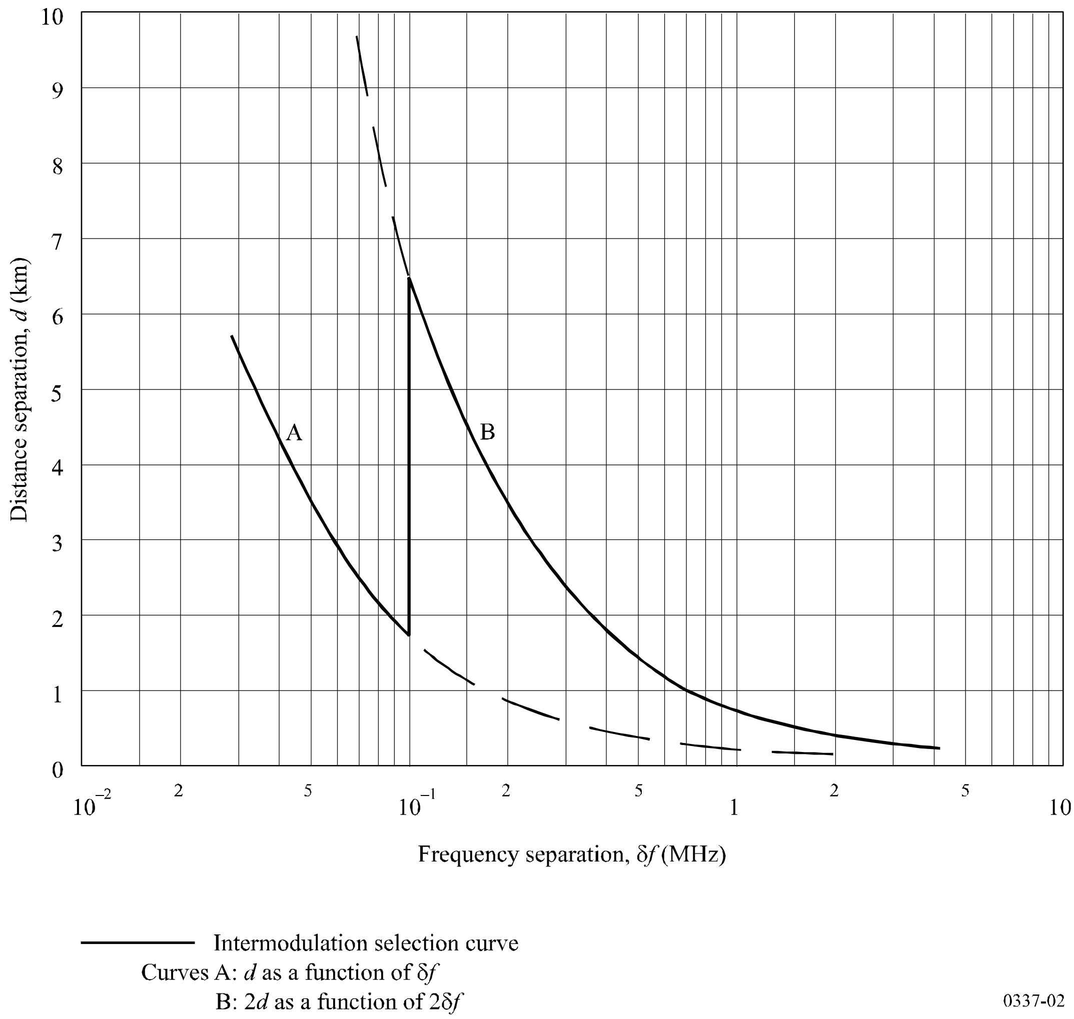
By using a carrier frequency value equal to 460 MHz, the two-signal third-order intermodulation would occur if:

$$d \cdot \delta f \leq 0.17 \tag{23}$$

where d is the distance of an existing station from a proposed station. A protection margin of 6 dB between the interfering power level and the minimum wanted power level has been assumed. Useful information may be found in Recommendation ITU-R SM.1134. Since the proposed station may be involved as a victim receiver, a far transmitter or a near transmitter in an intermodulation product, the curve B has to be used with the curve A in establishing the FD rule which is depicted in Fig. 2. The area above the curve corresponds to permissible interference situations, while that below corresponds to potential interference situations.

FIGURE 2

An FD rule for two-signal third-order receiver intermodulation interference analysis



5 Conclusions

In order to assign a frequency to a proposed new station, co-channel and adjacent-channel interference is first evaluated using the appropriate FD rules. After these rules are satisfied, existing stations which may be involved in intermodulation interference with the proposed station are then examined based on the intermodulation FD rule. A detailed analysis can then follow if these rules are not satisfied. It should be noted that the analyses contained in this Recommendation do not consider man-made or natural obstructions.