RECOMMENDATION ITU-R BS.498-2*

Ionospheric cross-modulation in the LF and MF broadcasting bands

(1974-1978-1990)

The ITU Radiocommunication Assembly,

considering

that excessive radiation towards the ionosphere may result in ionospheric cross-modulation and hence harmful interference,

recommends

that the maximum permissible radiation at any angle of elevation should be such that annoyance due to ionospheric cross-modulation does not exceed that agreed for co-channel interference (see Recommendation ITU-R BS.560).

ANNEX 1**

The effects of ionospheric cross-modulation in bands 5 (LF) and 6 (MF) may become a problem of increasing severity as the power of transmitters continues to increase.

1 Detailed experiments on this subject have been carried out within the framework of the EBU in several countries, notably in the United Kingdom, in the Federal Republic of Germany and in the People's Republic of China. From these experiments which were carried out with conventional amplitude-modulation double-sideband transmissions, the following results may be deduced:

1.1 The percentage of cross-modulation increases practically linearly with the power of the interfering transmitter and also increases with the depth of modulation.

NOTE – The percentage of cross-modulation is the percentage by which the carrier of the wanted transmitter is modulated by the modulating frequencies of the interfering transmitter.

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* Radiocommunication Study Group 6 made editorial amendments to this Recommendation in 2002 in accordance with Resolution ITU-R 44.

** This Annex is given for information.

1.2 Cross-modulation depends primarily on the power radiated by the interfering transmitter in the direction of the reflection point of the wanted signal in the ionosphere.

Cross-modulation of percentages less than 10% are directly proportional to the power; an increase of 3 dB in the interfering transmitter power therefore, increases the cross-modulation levels by 6 dB. The percentage of cross-modulation is also directly proportional to the depth of modulation of the interfering transmitter.

1.3 The percentage of cross-modulation decreases as the modulating frequency of the interfering transmitter increases. Laboratory experiments have shown that the subjective effect of cross-modulation can be related to co-channel interference. To produce a given subjective grade of impairment, interference resulting from ionospheric cross-modulation requires 6 dB less input signal-to-interference ratio than does co-channel interference, providing that the cross-modulation is referred to a modulation frequency of 300 Hz.

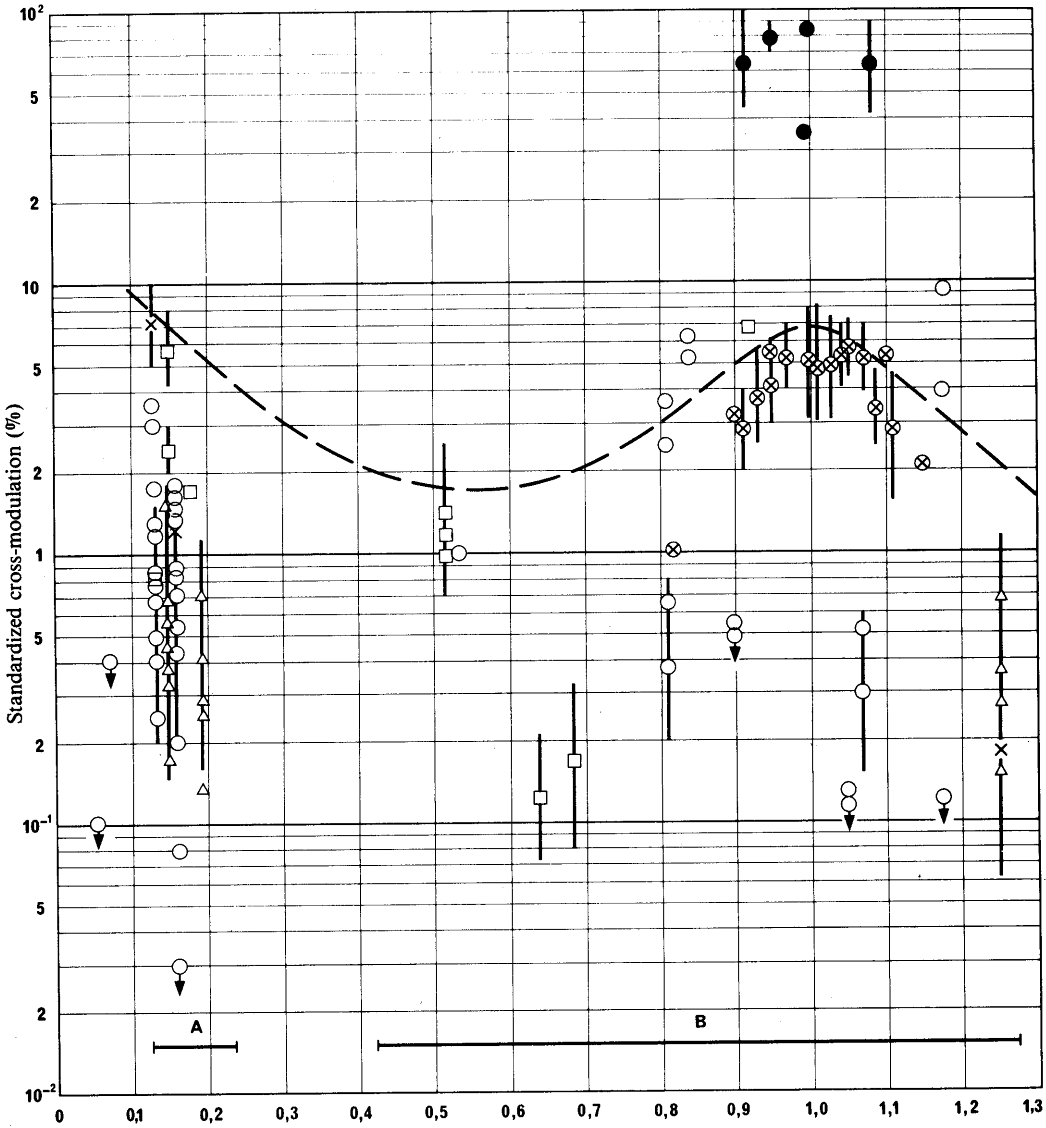
1.4 It should be noted that the studies on the problem of ionospheric cross-modulation are summarized in Recommendation ITU-R P.532.

2 Figure 1 shows the percentages of cross-modulation measured in many experiments. Each measurement has been standardized to the value which would have been observed if the interfering transmission had been radiated from a short vertical antenna with a carrier power of 100 kW and amplitude modulated at 300 Hz to a depth of 80%.

Figure 1 includes a semi-empirical curve which shows the greatest percentage of cross-modulation, averaged over a short period, likely to be observed; the condition for this is that the wanted signal should traverse the region of the ionosphere most strongly illuminated by the interfering transmitter. Figure 1 shows that cross-modulation rises to a second maximum when the frequency of the interfering transmitter is close to the gyromagnetic frequency. Figure 5 shows a map giving the value of the gyromagnetic frequency for different parts of the world.

3 The effects of cross-modulation should be taken into account not only for sky-wave reception, but also for ground-wave reception at the edge of the service area when at night the sky-wave is no longer negligible. However, the effect of cross-modulation is reduced approximately in the ratio of the wanted signal levels, ground-wave to sky-wave, at the receiving point.

4 The percentages of ionospheric cross-modulation have been calculated for LF and MF and their dependence on the powers of the wanted and unwanted transmitter has been determined. Results of theoretical studies and practical experiments have been compared.



Normalized frequency of interfering transmitter relative to the gyromagnetic frequency, f_i/f_G

FIGURE 1 – *Measurements of ionospheric cross-modulation at medium latitudes*

□ : measurements before 1945

○ : measurements at Cambridge and Birmingham

● : measurements in Italy

⊗ : measurements in Australia

△ : measurements in Western Europe after 1945

× : other measurements

— — — : semi-empirical upper limit

A : band 5 (LF)

B : band 6 (MF)

Note – The vertical lines represent a range of median values measured during the course of a night, or on different nights. The arrows pointing downwards indicate measured values which are less than the value indicated.

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5 Preliminary conclusions

Examples may be given of the power-flux levels, or the transmitter power as a function of the angle of elevation, which can cause disturbance to wanted transmissions.

For this purpose, an assumption is first made regarding the tolerable level of the percentage of cross-modulation. According to Recommendation ITU-R BS.560 and Recommendation ITU-R P.1147, a radio-frequency protection ratio of approximately 30 dB is agreed for 10% of the time in the case of a fluctuating unwanted signal. Ignoring the effect mentioned in § 1.3, the same disturbing effect is produced by 3% cross-modulation for 10% of the time. It has been shown that for frequencies at the upper end of the MF broadcasting band 6 (MF) this level of cross-modulation may be produced by a power flux within the E region of the ionosphere of about 2 $\mu W/m^2$ (-57 dB(W/m^2)), which corresponds to a maximum field strength of 27 mV/m (89 dB(μV/m)).

Assuming a height of 100 km of the reflecting layer (E region), it is possible to calculate the power radiated from various types of antenna which would produce this power flux within the E region. The vertical transmitting antennas that are commonly used show a vertical radiation pattern which depends in a well-defined fashion on the height (expressed in fractions of the wavelength, λ). In particular, such vertical antennas do not radiate at an angle of elevation of 90°. Table 1 indicates, for a number of vertical transmitting antennas at different heights the transmitter powers to be fed into these antennas to meet the above-mentioned requirements.

TABLE 1

Length of vertical antenna	< 0.25 λ	0.25 λ	0.5 λ	0.55 λ	0.64 λ	0.64 λ (1)
Transmitter carrier power (kW)	320	340	560	670	370	840

(1) First side lobe compensated.

It is possible to calculate the dependence of the radiated power on the angle of elevation required to produce the same power flux, covering the whole range from 0° (horizontal radiation) to 90° (vertical radiation). The results are given in Table 2.

Tables 1 and 2 give only approximate values because it is known, from theory, that ionospheric cross-modulation may be influenced by several parameters, such as the frequencies of the wanted and of the interfering transmitter (in particular seen in their relationship to the gyro-frequency) and the polarization of emission.

The powers given in Tables 1 and 2 are examples based on a small number of measurements at a frequency near the top end of band 6 (MF); they make no allowance for the change of cross modulation with carrier frequency of the disturbing signal, nor do they include the effect of reduced cross-modulation at the higher audio frequencies which permits interfering-transmitter powers to be increased by 3 dB.

TABLE 2

Angle of elevation	0°	10°	20°	30°	40°	45°	50°	60°	70°	80°	90°
e.m.r.p. (dB (1 kW)) or c.m.f.[1] (dB (300 V))	39.5	32	27.5	24.3	22.5	22	21.5	20.2	19.3	18.7	18.5
e.m.r.p. (kW)	9000	1600	570	230	190	160	140	105	85	75	70

[1] e.m.r.p.: effective monopole radiated power; c.m.f.: cymomotive force. } See also Recommendation ITU-R BS.561

It may be noted that services other than broadcasting have also suffered degradations due to ionospheric cross-modulation.

The results of many other measurements of ionospheric cross-modulation have been compared and Fig. 1 shows that 100 kW radiated from a short vertical antenna at frequencies in the lower part of the broadcast band 6 (MF) produces cross-modulation which may exceed 2% for 50% of the time. It may be shown that this corresponds to a cross-modulation level of 3% exceeded for 10% of the time. The power of 100 kW may therefore be directly compared with the power of 320 kW given in Table 1. The greater power in Table 1 arises because the series of measurements on which it was based appear to give lower cross-modulation than the estimated worst-case values shown by the curve in Fig. 1.

Figure 1 also shows that cross-modulation levels caused by disturbing transmitters, operating either at frequencies in band 5 (LF) or at frequencies close to the gyromagnetic frequency, may be 10 dB greater than levels arising at frequencies in the lower part of band 6. A 5 dB reduction of disturbing-transmitter power reduces the cross-modulation level by 10 dB. Allowing for the modulation-frequency effect we conclude that, depending on the disturbing frequency in bands 5 (LF) and 6 (MF), transmitter powers in a range varying from the values in Tables 1 and 2 down to 7 dB lower may, at worst, give interference to a sky-wave service comparable with co-channel interference for 30 dB protection ratio.

Somewhat greater disturbing-transmitter powers may be radiated if ground-wave services, rather than sky-wave services, are to be protected from the effects of ionospheric cross-modulation, because the disturbing transmitter influences only the sky-wave component of the received signal. If the limit of the ground-wave service area is defined as the line where the ground-wave field strength exceeds the median sky-wave field strength by 10 dB; the median cross-modulation of the resultant signal will be 14 dB less than the median cross-modulation of the sky-wave. Disturbing-transmitter powers may therefore be greater than the equivalent powers when the sky-wave is being protected.

6 Practical application of the conclusions

The EBU has investigated the consequences on the planning of broadcasting networks in bands 5 (LF) and 6 (MF) to be drawn from the preliminary conclusions summarized in § 5 of this Annex. The most urgent problem is that of setting limits for the maximum effective monopole-radiated power as a function of the angle of elevation and type of antenna if a certain amount of interference caused by ionospheric cross-modulation is not to be exceeded. The conclusions drawn so far from these studies are set out hereafter.

It is recommended that the annoyance due to cross-modulation should not exceed that resulting from co-channel interference with a protection ratio of 30 dB. However, cross-modulation, unlike co-channel interference, decreases with increasing modulation frequency, so that subjective experiments are necessary to relate the two effects. Such experiments have been carried out, and have shown that the maximum percentage of cross-modulation could be 6.3% when the interfering transmitter is 80% modulated by 300 Hz tone. It is recommended that this should be regarded as the maximum acceptable limit of cross-modulation.

The results of subjective assessment of the degree of annoyance by cross-modulation carried out in China under normal transmission of sound broadcasting programmes and a co-channel protection ratio of 27 dB for sky-wave service show that the quality grade of 4 is achieved and the interference is perceptible but not annoying, when the percentage of cross-modulation is 8.9%.

Taking into account the dependance of cross-modulation on the carrier frequency of the unwanted emission and the height of the reflecting layer, Fig. 2 (curve A) shows the maximum effective monopole-radiated power (dB (1 kW)) or cymomotive force (dB (300 V)) directed vertically upwards which would produce, for 50% of the time, the percentage of cross-modulation specified above. The abscissa is the ratio of the unwanted carrier frequency f_i to the gyro-frequency f_G (about 1.25 MHz in Europe). This curve is based on a large number of measurements in Europe and Australia as described in § 5 and Fig. 1, taking the observed values of cross-modulation as representing the worst values likely to occur over the most unfavourable geographical path.

In practical cases, account must be taken of the vertical radiation pattern of the antenna and of the increasing distance between the antenna and the reflecting point in directions other than vertical. Fig. 3 shows the permissible increase in e.m.r.p. in directions other than vertical, allowed by the increasing distance only. An additional increase or decrease in power resulting from the vertical diagram of the antenna has to be taken into account. For practical application, the influences of increasing distance to the reflecting point and of the vertical radiation pattern of the antenna have been combined into one single correction factor ΔP which has to be added to that read from Fig. 2. This correction factor has been calculated for vertical antennas of different electrical length $\chi \approx l/\lambda$ and horizontal dipoles 0.5 λ long, at different heights $\chi \approx h/\lambda$ above ground, assuming a height of 85 km for the region of the ionosphere in which cross-modulation should occur. The result of this calculation is given in Fig. 4.

In a ground-wave service which is to be protected against cross-modulation at night, it may be assumed that the sky-wave field strength of the wanted transmitter is 10 dB below the ground-wave field strength at the service limit. Since only the sky-wave component is subject to cross-modulation, an increase of 5 dB in radiation is permissible if only ground-wave services need be considered. This leads to curve B of Fig. 2.

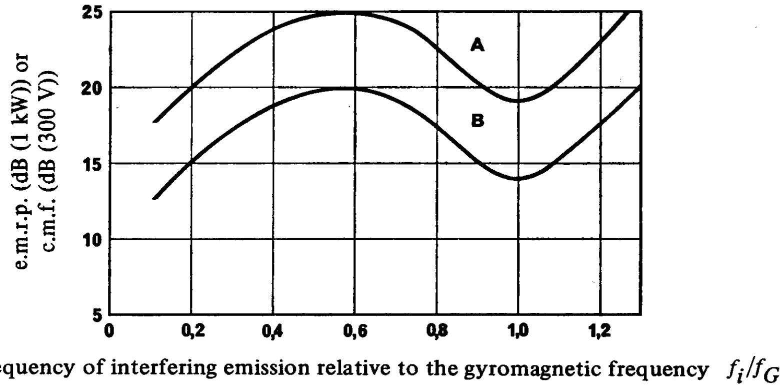

FIGURE 2 – *Vertically-incident radiation giving a quasi-maximum of 6.3% cross-modulation at 300 Hz*

Curve A: for protection of ground-wave services
Curve B: for protection of sky-wave services

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As a practical example, consider a short vertical antenna in band 5 (LF) (f_i/f_G = 0.2). Figure 2 shows that to protect a ground-wave service, the maximum e.m.r.p. in a vertical direction would be 20 (dB (1 kW)) i.e. 100 kW. However, a short antenna produces a maximum value of field strength in the ionosphere at an angle elevation of 45°; Fig. 3 shows that an increase of 3 dB is permitted at that angle, giving an e.m.r.p. of 200 kW. However, it is more convenient to specify the e.m.r.p. in the horizontal direction; for a short antenna this is 3 dB greater than at 45°, i.e. 400 kW.

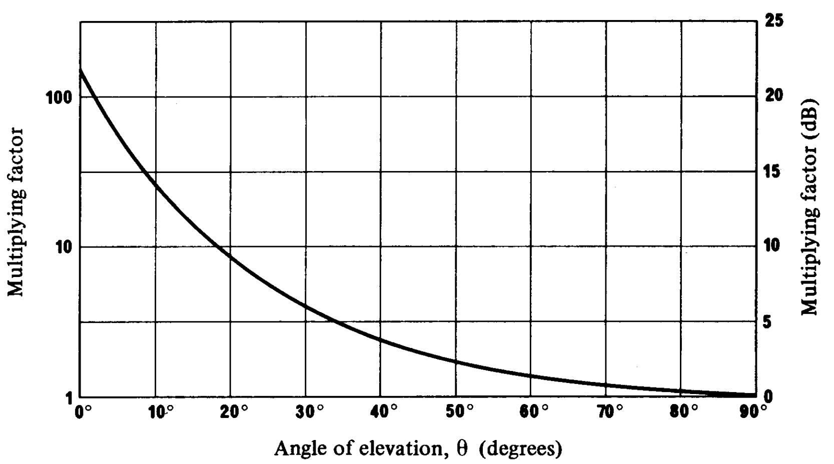

FIGURE 3 – *Variation of permissible radiation with angle of elevation*

(Curvature of the Earth taken into account, assuming that cross-modulation takes place at a height of 85 km)

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Accordingly, in this case, for a short vertical antenna (L/λ << 0.1), the value of $\Delta P = +6$ dB can be read from curve A in Fig. 4, which results in a total power fed to the antenna of $P = +26$ dB (1 kW) i.e. ≈ 400 kW.

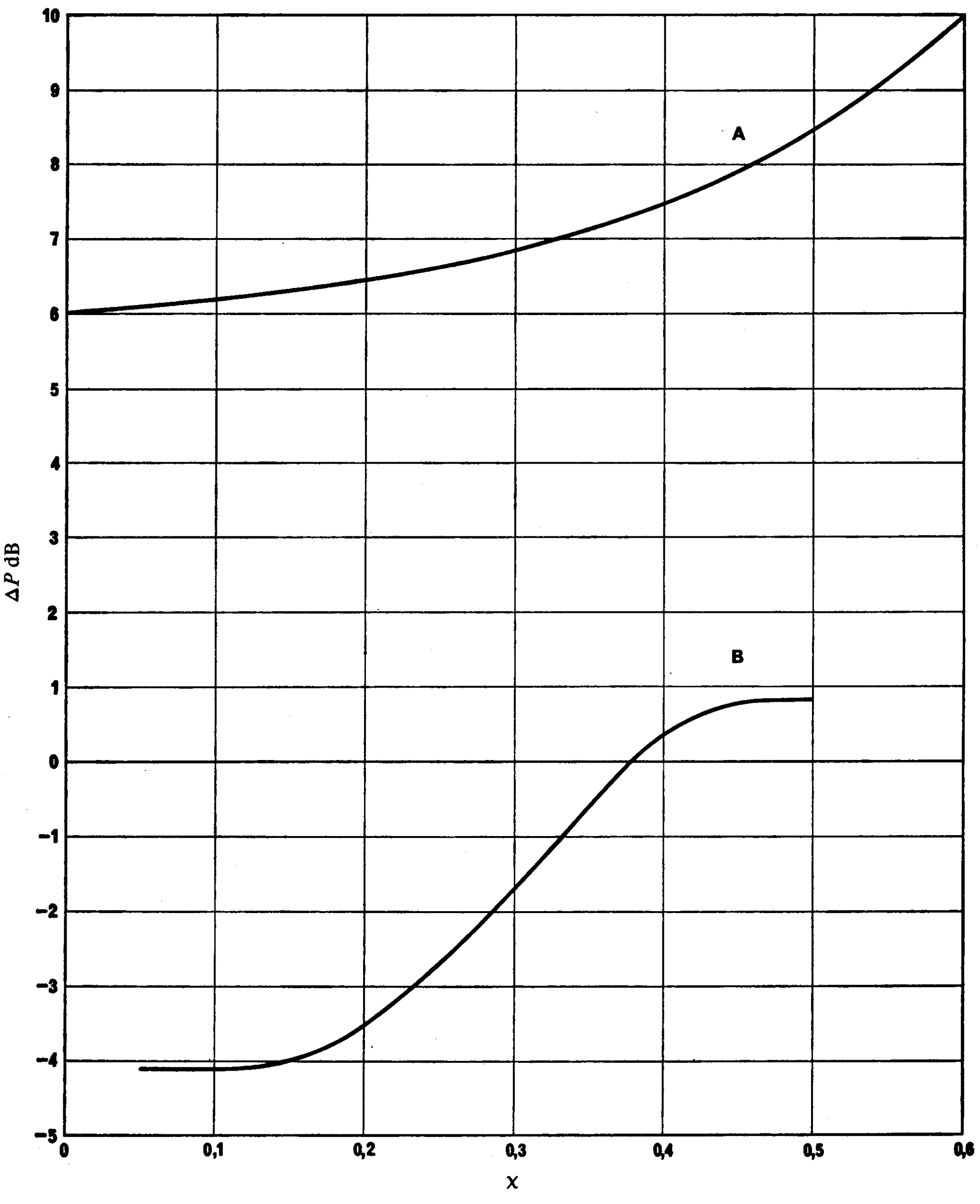

FIGURE 4 – *Correction factor, ΔP, for different types of antenna*

Curve A: vertical antenna
x: relative length of antenna, l/λ

Curve B: horizontal dipole ($l = 0.5\lambda$)
x: relative height above ground, h/λ

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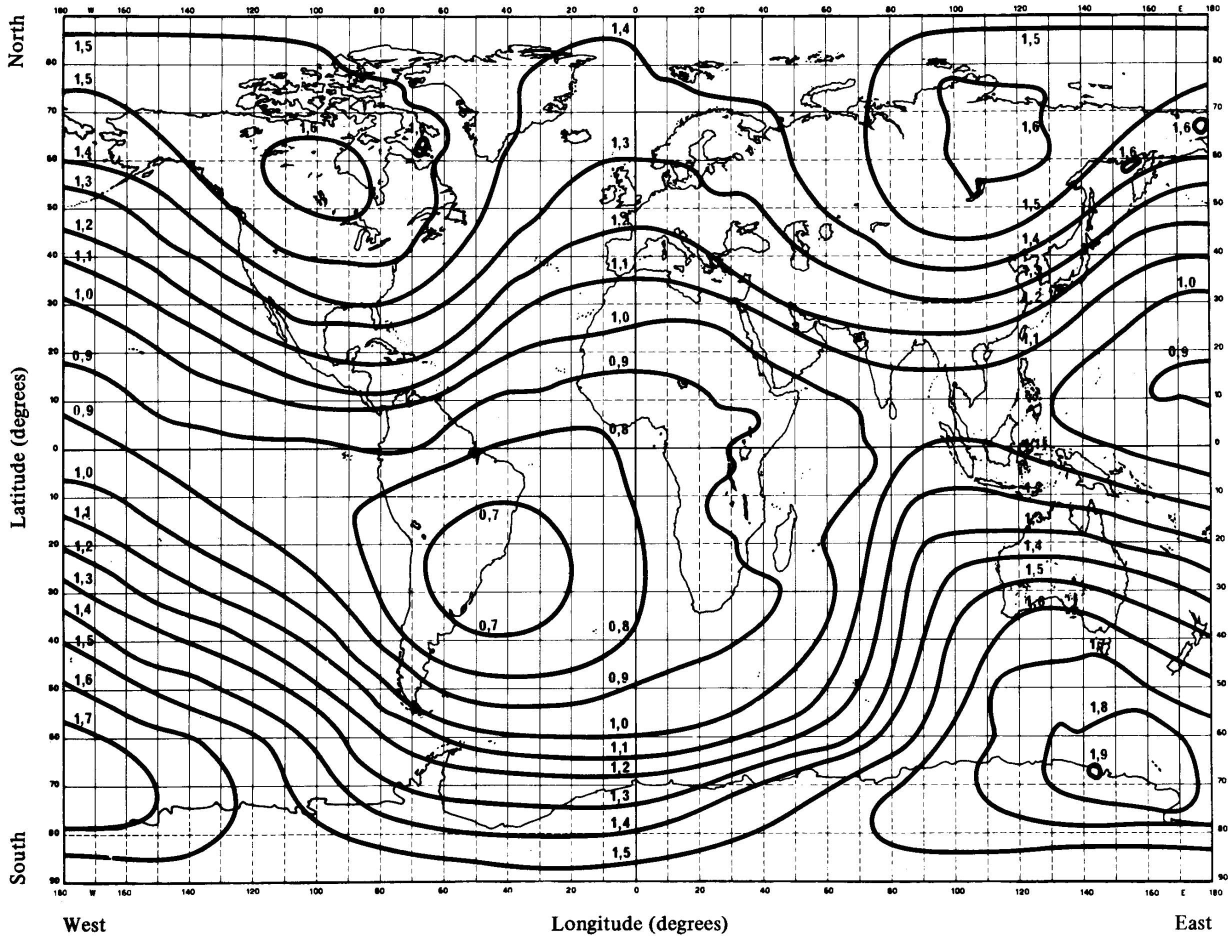

FIGURE 5 – *World-wide distribution of gyro-frequency (MHz)*

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Curves showing the relationship between the depth of cross-modulation at the point of reception and the field strength at the point of reflection in the ionosphere are given in Fig. 6. They have been obtained following investigations carried out in China. These curves may be used to evaluate the percentage of cross-modulation at a given reception point for different values of interfering field strength at the point of reflection in the ionosphere and to calculate approximately the zone of influence of cross-modulation.

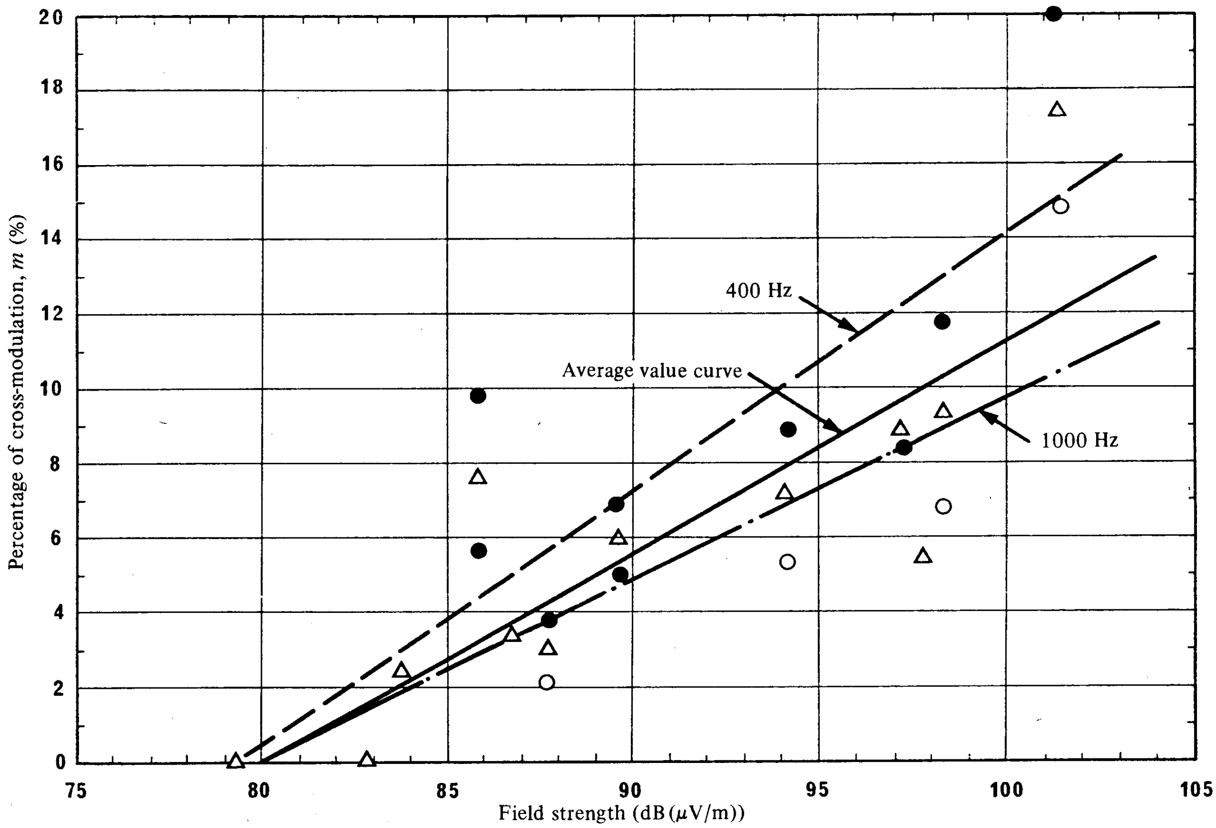

FIGURE 6 – *Relationship between the depth of cross-modulation and the field strength at the point of reflection in the ionosphere*

(correlation coefficient r = 0.84 for the curves)

● 400 Hz measured value
○ 1000 Hz measured value
△ average of measured value

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