RECOMMENDATION ITU-R BS.560-4*

Radio-frequency protection ratios in LF, MF and HF broadcasting

(1978-1982-1986-1990-1997)

The ITU Radiocommunication Assembly,

recommends

that the radio-frequency (RF) protection ratios for sound broadcasting in bands 5 (LF), 6 (MF), and 7 (HF) as given in § 1 and 2 should be applied.

1 RF protection ratio in bands 5 (LF) and 6 (MF)

The RF protection ratio (as defined in Recommendation ITU-R BS.638) for co-channel transmissions (±50 Hz) should be 40 dB when both the wanted and the unwanted signals are stable (ground wave).

When the wanted signal is stable and the unwanted signal fluctuates (including short-term fluctuations), the RF protection ratio should be 40 dB at the reference time (see Annex 1 to Recommendation ITU-R P.1147) for at least 50% of the nights of the year. This protection ratio corresponds to the ratio of the wanted field strength and the annual median value of the hourly medians of the interfering field strength at the reference time.

The protection so defined is provided:

– for 50% of the nights at the reference time;

– for more than 50% of the nights at times other than the reference time;

– for 100% of the days during daylight hours.

The RF protection ratio values specified above will permit a service of excellent reception quality. For planning purposes, however, lower values may be required. In this respect, proposals have been made by some countries and organizations (see Annex 3).

NOTE 1 – The minimum usable field strength to which this protection ratio of 40 dB applies varies in the different regions and also with frequency. Within the European zone, this minimum is of the order of 1 mV/m.

NOTE 2 – A co-channel protection ratio of 26 dB was used by the Regional Administrative MF Broadcasting Conference (Region 2) (Rio de Janeiro, 1981) for both ground-wave and sky-wave services. Region 2 has two noise zones, 1 and 2, the former for most of the Region, the latter for a defined tropical area. In noise zone 1, the nominal usable field strength is 100 μV/m daytime and 500 μV/m night-time for Class A stations which have secondary service areas. It is 500 μV/m daytime for Classes B and C, and 2 500 and 4 000 μV/m respectively, night-time.

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

In noise zone 2, these values are generally 2.5 times more than the above figures.

Night-time protection, computed for two hours after sunset, is afforded for 50% of the nights of the year, except that the countries of North America agreed to protection from each other for 90% of the nights.

NOTE 3 – Co-channel protection ratios of 30 and 27 dB were used by the Regional Administrative LF/MF Broadcasting Conference (Regions 1 and 3) (Geneva, 1975), for ground-wave and sky-wave services, respectively.

2 Relative RF protection ratio curves in bands 5 (LF), 6 (MF) and 7 (HF)

The relative RF protection ratio is the difference (dB) between the protection ratio when the carriers of the wanted and unwanted transmitters have a frequency difference of Δf (Hz or kHz) and the protection ratio when the carriers of these transmitters have the same frequency.

Once a value for the co-channel RF protection ratio (which is equal to the audio-frequency protection ratio) has been determined, then the RF protection ratio, expressed as a function of the carrier frequency spacing, is given by the curves of Fig. 1 (see also Annex 1):

– curve A is applicable when a limited degree of modulation compression is applied at the transmitter input, such as in good quality transmissions, and when the bandwidth of the audio-frequency modulating signal is of the order of 10 kHz;

– curve B is applicable when a high degree of modulation compression (at least 10 dB greater than in the preceding case) is applied by means of an automatic device and when the bandwidth of the audio-frequency modulating signal is in the order of 10 kHz;

– curve C is applicable when a limited degree of modulation compression (as in the case of curve A) is applied and when the bandwidth of the audio-frequency modulating signal is in the order of 4.5 kHz;

– curve D is applicable when a high degree of modulation compression (as in the case of curve B) is applied by means of an automatic device and when the bandwidth of the audio-frequency modulating signal (see Note 1) is in the order of 4.5 kHz.

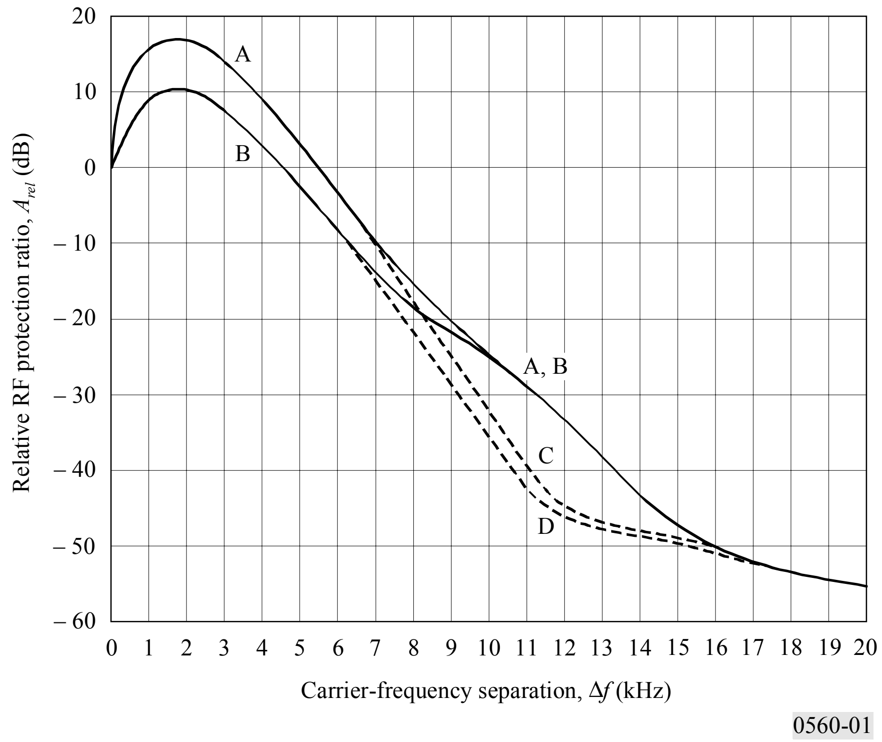
NOTE 1 – The second session of the World Administrative Radio Conference for the Planning of HF Bands Allocated to the Broadcasting Service (Geneva, 1987) (WARC HFBC-87) decided that the upper limit of the audio-frequency band (at –3 dB) of the transmitter shall not exceed 4.5 kHz and the lower limit shall be 150 Hz, with lower frequencies attenuated at a rate of 6 dB/octave.

If audio-frequency signal processing is used, the dynamic range of the modulating signal shall be not less than 20 dB.

The curves A, B, C and D (see also Annex 1) are valid only when the wanted and unwanted transmissions are compressed to the same extent. They have been obtained mainly from measurements and calculations using a reference receiver representative of good quality receivers used for reception in bands 5 (LF) and 6 (MF). The overall frequency response curve of the European Broadcasting Union (EBU) reference receiver used passes through –3 dB, –24 dB and –59 dB at 2 kHz, 5 kHz and 10 kHz respectively.

FIGURE 1

Relative value of the RF protection ratio as a function of the carrier-frequency separation



ANNEX 1

The shape of the relative RF protection ratio curves depends upon the receiver selectivity, the bandwidth of the audio-frequency modulating signal and the ratio of the energy of the carrier to that of the sidebands. This latter phenomenon is most important between 250 Hz and 5 kHz approximately, where the disturbance is essentially due to the whistle produced by the carrier frequency beat. The shape of the curves in Fig. 1 therefore depends upon the average modulation depth and upon the dynamic compression of the modulation signals.

Curve A represents average values derived from calculations and from tests made with various receivers mainly designed for reception in band 5 (LF) and band 6 (MF), with modulation compression typical of that currently applied in the studio, i.e. with compression permitting a maximum dynamic range of at least 30 dB.

Curve B applies to the use of compression, as could be applied by an automatic device, of at least 10 dB higher than in the preceding case.

Both curves A and B, as distinct from curves C and D, apply to a bandwidth of the audio-frequency modulating signal having a bandwidth in the order of 10 kHz.

Curves C and D apply to the use of compression of the same order of magnitude as in the cases of curves A and B, respectively. The bandwidth of the audio-frequency modulating signal, is, however, restricted to about 4.5 kHz. This degree of bandwidth limitation reduces interference from adjacent channels without leading to any significant degradation of the reception quality in practice.

It should be noted that, in some circumstances, listeners are able to reduce the interfering effect of an unwanted transmission, spaced by more than approximately 3 kHz, by adjusting their receivers (slight detuning, selectivity control, tone control, etc.). Under these conditions, the curves of Fig. 1 are no longer applicable. However, the practice of detuning leads to distortion and cannot be used when two interfering emissions of approximately equal strength are present, on both sides of the wanted carrier frequency. Moreover, many receivers are not equipped with a selectivity control or tone control.

NOTE 1 – In addition to the relative RF protection ratios given in this Recommendation there are other factors of importance in determining optimum frequency spacings.

NOTE 2 – Caution should be exercised when relative values of RF protection ratios beyond –50 dB are obtained from the curves because, in practice, non-linear distortion originating in the transmitter may lead to less protection than indicated.

ANNEX 2

Presentation of experimental results

Whenever possible, the results of measurements of the radio-frequency protection ratio between two broadcast signals should be presented in terms of the following characteristics and parameters:

– type of modulation;

– separation between the carrier frequencies (kHz) (this should lie between 0 and at least 10 kHz);

– modulation depth of both signals;

– occupied bandwidth;

– modulation processing (compression and pre-emphasis);

– type of programmes carried by the wanted and unwanted signals;

– characteristics of fading, if present;

– radio-frequency input voltage of the wanted signal (the RF input voltage should be chosen in such a way so as to ensure that the protection ratios are not significantly affected by non-linearities within the RF and intermediate frequency stages of the receiver);

– passband of the receiver before demodulation;

– overall audio frequency response curve of the receiver, including the loudspeaker;

– the grade of listener satisfaction aimed at, and the statistical distribution of such grades;

– the measuring method (subjective or objective).

ANNEX 3

Protection ratios used in the LF, MF and HF broadcasting

1 Introduction

This Annex is a summary of the information available concerning protection ratios for amplitude modulation sound-broadcasting services. It is confined, however, to results obtained since 1948.

Agreed values of protection ratios are essential for the solution of frequency assignment problems in the amplitude modulation sound broadcasting service. Moreover, they may serve as basic reference data for the evaluation of the relative merits and the effectiveness to be expected with various amplitude modulation transmission systems.

The protection ratios quoted refer, in all cases, to the ratios at the input to the receiver, no account having been taken of the effect of using directional receiving antennas.

Protection ratios depend on a multiplicity of parameters, among which transmission standards and receiver characteristics play an important role. Apart from technical factors there are others of a physiological and psychological nature which have to be respected. It is, therefore, extraordinarily difficult to determine generally agreed values of protection ratios, even if both the transmission standards and the receiver characteristics are given (see Recommendation ITU-R BS.559).

It is well known that the RF protection ratios for transmitters working in the same channel and transmitting the same programme can be improved considerably by synchronizing techniques, thereby increasing the coverage areas of these transmitters (see also ex-CCIR Report 616 (Dubrovnik, 1986)). Actual values for these protection ratios depend upon various factors, including the synchronization method (see § 10). A value of 8 dB was laid down at the Regional Administrative LF/MF Broadcasting Conference (Regions 1 and 3) (Geneva, 1975).

2 Audio-frequency protection ratio

The audio-frequency protection ratio is the agreed minimum value of the audio signal-to-interference ratio considered necessary to achieve a subjectively defined reception quality (see Recommendation ITU-R BS.638).

This ratio may have different values according to the type of service desired. It depends greatly upon the type of wanted and unwanted programmes. It is therefore essential to carry out a considerable number of subjective listening tests, before a minimum value of the audio frequency signal-to-interference ratio can be agreed upon.

It must clearly be stated that, due to physiological and psychological effects, it is impossible to specify sensible values for the audio-frequency protection ratio by methods other than subjective testing.

3 RF protection ratio

The RF protection ratio is the value of the RF wanted-to-interfering signal ratio that, under specified conditions, enables the audio-frequency protection ratio to be obtained at the output of a receiver.

The RF protection ratio may, thus, be determined by means of subjective tests, as in the case of the audio-frequency protection ratio. When proceeding in this way the number of parameters to be taken into account and, hence, the amount of work to be done, will prove to be far greater than in the preceding case. Comparable results can only be obtained if the test conditions are similar.

However, the assessment of RF protection ratios can be considerably facilitated, once the audio-frequency protection ratio has been determined. Due to the fact that the majority of physiological and psychological effects only influence the audio-frequency protection ratio, it is possible to derive, under specified technical conditions and for a given value of the audio-frequency protection ratio, values of RF protection ratios, either by objective measuring methods or by graphical or numerical methods (see Recommendation ITU-R BS.559).

It must be emphasised that the last three methods mentioned for the establishment of RF protection ratios are based on the same basic ideas. They should lead, therefore, in principle, to the same results and will, provided the three methods are used with sufficiently high precision.

The lack of suitably reliable values for RF protection ratios in the past was mainly a consequence of the very complicated relationship between the RF protection ratio and the overall amplitude/frequency response of the receivers. The latter depends on the selectivity of the RF and the intermediate-frequency stages, the selectivity of the demodulator and the amplitude/frequency response of the audio-frequency stages. This difficulty has been overcome partly by the establishment of the objective two-signal measuring method.

Numerical methods previously mentioned may be used to relate data on receiver selectivity characteristics, as provided by the receiver manufacturers, to values of RF protection ratios. Although the calculations are complicated and need electronic aids, they make possible (in contrast to the objective measuring method), the determination of the overall frequency response of the receiver for a given RF protection ratio curve.

4 General principle of non-subjective methods

All non-subjective methods assume the use of standardized conditions at both the transmitting and the receiving end of the transmission system, as described in Recommendation ITU-R BS.559.

In all interference problems, there are two different types of annoyance:

– that due to the cross-talk from the interfering channel into the wanted channel, caused by modulation; and

– that due to the beat-note produced by both carriers.

For the majority of receivers in use the beat-note predominates in annoyance when the carrier-frequency separation is between about 0.25 and 5 kHz.

5 RF protection ratios for ground-wave services

5.1 Stable wanted and interfering signals (ground-wave signal interfered with by another ground-wave signal)

In § 1 of this Recommendation, a value of 40 dB is given for use in bands 5 (LF) and 6 (MF) for co-channel transmissions.

With this value of RF protection ratio, high quality reception is possible. For planning purposes however, it may be necessary to adopt lower values. This problem has been studied by the EBU and in Japan. The values that have been proposed are 30 and 26 dB, respectively, and in fact, a value of 30 dB was agreed by the Regional Administrative LF/MF Broadcasting Conference (Regions 1 and 3) (Geneva, 1975), whereas 26 dB was used by the Regional Administrative MF Broadcasting Conference (Region 2) (Rio de Janeiro, 1981).

Relative values of RF protection ratios as a function of the separation between the carrier frequencies of the wanted and interfering signal are given in the form of curves (see § 2). These curves are based partly on measurements made in accordance with the objective two-signal method of measurement and partly on computations (see Recommendation ITU-R BS.559).

The influence of dynamic compression and audio-frequency bandwidth limitation can also be seen from these curves. It should be noted, however, that the full improvement in protection resulting from bandwidth limitation, can only be obtained when the non-linearity of the transmitter is small.

5.2 Stable wanted and fluctuating interfering signal

5.2.1 Short-term fading

Short-term fading of the interfering signal modifies the character of the disturbance experienced by the listener: if, for a given audio-frequency signal-to-interference ratio, the interfering signal is made to fluctuate, the disturbance is subjectively felt to be more severe. Some publications indicate that, to obtain the same degree of listener satisfaction, the protection must be increased by about 5 dB.

In § 1 of this Recommendation, the value for short-term fading has been incorporated in the RF protection ratio.

5.3 Long-term field-strength variations

Detailed information is contained in Recommendations ITU-R P.842 and ITU-R P.1147.

6 RF protection ratios for sky-wave services

A characteristic of the sky-wave service, especially when reception is being made with envelope detectors, is that propagation effects usually bring about a degradation of the received signal quality, for example, distortion in the case of selective fading. Because of this fact, it is considered that lower values of protection ratios should be applied to a sky-wave service as compared with a ground-wave service, the precise values depending upon whether the service is a primary one, as for broadcasting in band 7 (HF), or a secondary one, as for broadcasting in bands 5 (LF) and 6 (MF), where the primary service is provided by the ground wave.

No value is recommended for use when the service is provided by the sky wave.

6.1 Bands 5 (LF) and 6 (MF)

As a result of the studies carried out by the EBU, in bands 5 (LF) and 6 (MF), a co-channel RF protection-ratio value of 27 dB has been proposed and in fact adopted, by the Regional Administrative LF/MF Broadcasting Conference (Regions 1 and 3) (Geneva, 1975).

6.2 Band 7 (HF)

In band 7, following the studies carried out in India, the United States of America, the USSR and in the EBU, the RF protection ratio to be used for co-channel transmission (±10 Hz, see Note 1) should be in the range of 27-40 dB for steady state conditions. According to the subjective assessments of reception quality carried out in Japan and in the People's Republic of China, a co-channel protection ratio of 27 dB for steady-state conditions, a carrier frequency difference of 100 Hz or less, corresponds to grade 4 of the five-grade impairment scale (see Recommendation ITU-R BS.562).

NOTE 1 – The permissible difference in carrier frequencies in band 7 (HF) can be as high as 600 Hz and is applicable to transmitters working at 20 MHz until January 1990, according to Appendix 7 of the Radio Regulations. After this date, this value will only apply to transmitters of 10 kW e.r.p. or less. For all other transmitters, the permissible frequency tolerance will be 10 Hz.

For planning purposes, a minimum value of 27 dB for stable conditions and a frequency difference of ≤ 100 Hz between carriers is proposed.

For the determination of appropriate fading allowances, some information can be found in Recommendations ITU-R P.842 and ITU-R P.533. It should be noted, however, that other factors, such as the correlation between the fading of the wanted and the unwanted signal, need to be taken into account.

We may conveniently distinguish between two types of within-the-hour fade: short-term fades due to interference between individual signal components with a correlation period of up to a few seconds, long-term phenomena in which the signals averaged over a few minutes and fade in periods of up to tens of minutes.

Interference-type within-the-hour wanted signal fades affect only the subjective signal quality, which is significantly improved by receiver automatic gain control (AGC). A suitable duration for purposes of quality evaluation is 1 min.

For the evaluation of fading margins or channel reliability, we may conveniently apply the statistical data for within-the-hour fades, characterized by periods of a few minutes or longer. The standard deviation of this type of fade may vary within wide limits depending on the ionospheric conditions, the location of the path, the path length and its direction. This applies equally to the wanted and interfering signals.

7 Data available on protection ratios

Annex 1 to Recommendation ITU-R BS.639 deals with the effect of a limitation of the bandwidth of emission on RF protection ratios. Additional data for broadcasting in band 7 (HF) are contained in Recommendation ITU-R BS.411. The curves reproduced in Report ITU-R BS.302 represent the data currently available on the subject of Question ITU-R 67/10 and refer principally to the protection ratios required to provide an acceptable broadcasting service in the Tropical Zone in the shared bands.

8 Measurement results

Measurement of protection ratios for stable signals was carried out in the USSR. The following quality criteria were used as the basis of the experiment:

– perceptibility of interference in the background of the wanted programme;

– tolerance to interference while listening to the wanted speech programme.

Quantitative assessments using these criteria were made by a number of experts subjectively assessing a given fragment of the programme against a predetermined criterion.

The results of these measurements are given in Figs. 2, 3 and 4.

Figure 2 shows the results of the co-channel protection ratio measurements. The value of K denotes the proportion of the experts who found the interference tolerable. The interfering programme was modern dance music. The shaded parts correspond to a change of passband from wide to narrow.

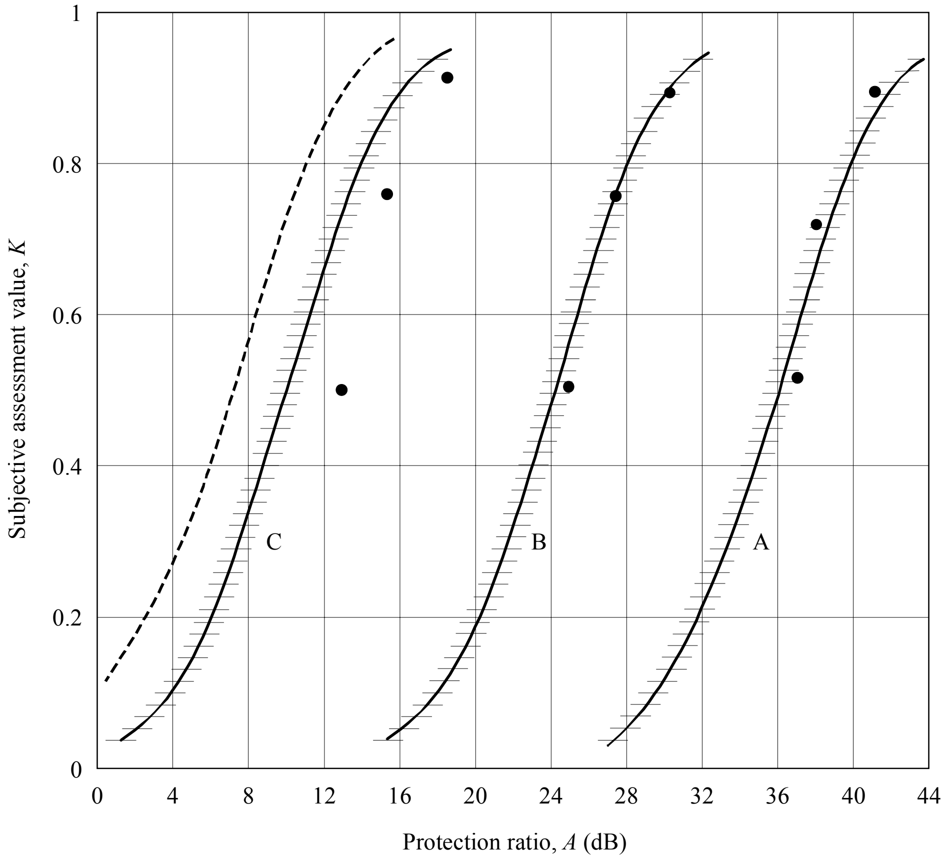
Figure 3 shows the values of protection ratio, A, as a function of the wanted and interfering carrier-frequency spacing for $K = 0.9$. Shaded parts of the curves correspond to the scatter determined by the receiver passband.

Figure 4 gives the receiver selectivity curves, where the shaded parts indicate the dispersion of curves for receivers of different classes. Also shown in Fig. 4 is the selectivity curve of the EBU MBF receiver.

In addition, the effect of the modulating signal bandwidth on protection ratios was studied for the highest-class receiver. The modulating frequency bandwidths of both the wanted and interfering signals were limited using two identical switched filters with the cut-off frequencies $f = 10$, 6.8 and 3.4 kHz and with frequency response slopes of 90 dB/decade. The results of measurements showed that a change of modulating signal bandwidths has no pronounced effect on protection ratios.

FIGURE 2

Co-channel protection ratio measurements



● Measured values

------ Worst case, wanted and interfering programmes broadcast in one language with wide dynamic range, no band constraints and voices similar in tone colour

Curves A: wanted speech programme with wide dynamic range
B: wanted speech programme with small dynamic range
C: wanted music programme with small dynamic range

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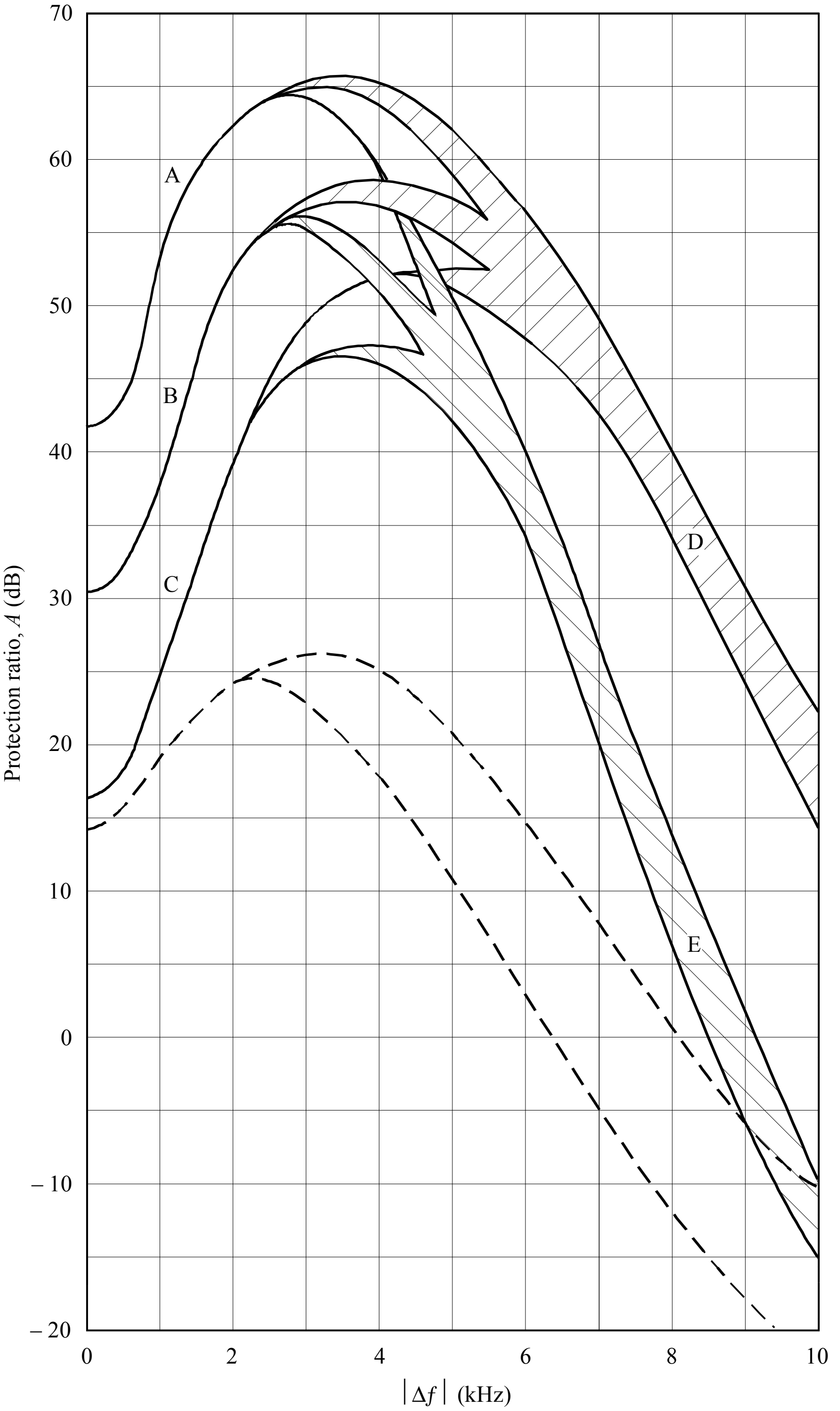
FIGURE 3

Protection ratio as a function of carrier spacing



– – – – Worst case, wanted and interfering programmes broadcast in one language with wide dynamic range, no band constraints and voices similar in tone colour

Curves A: wanted speech programme with wide dynamic range
B: wanted speech programme with small dynamic range
C: wanted music programme with small dynamic range
D: wide-band
E: narrow-band

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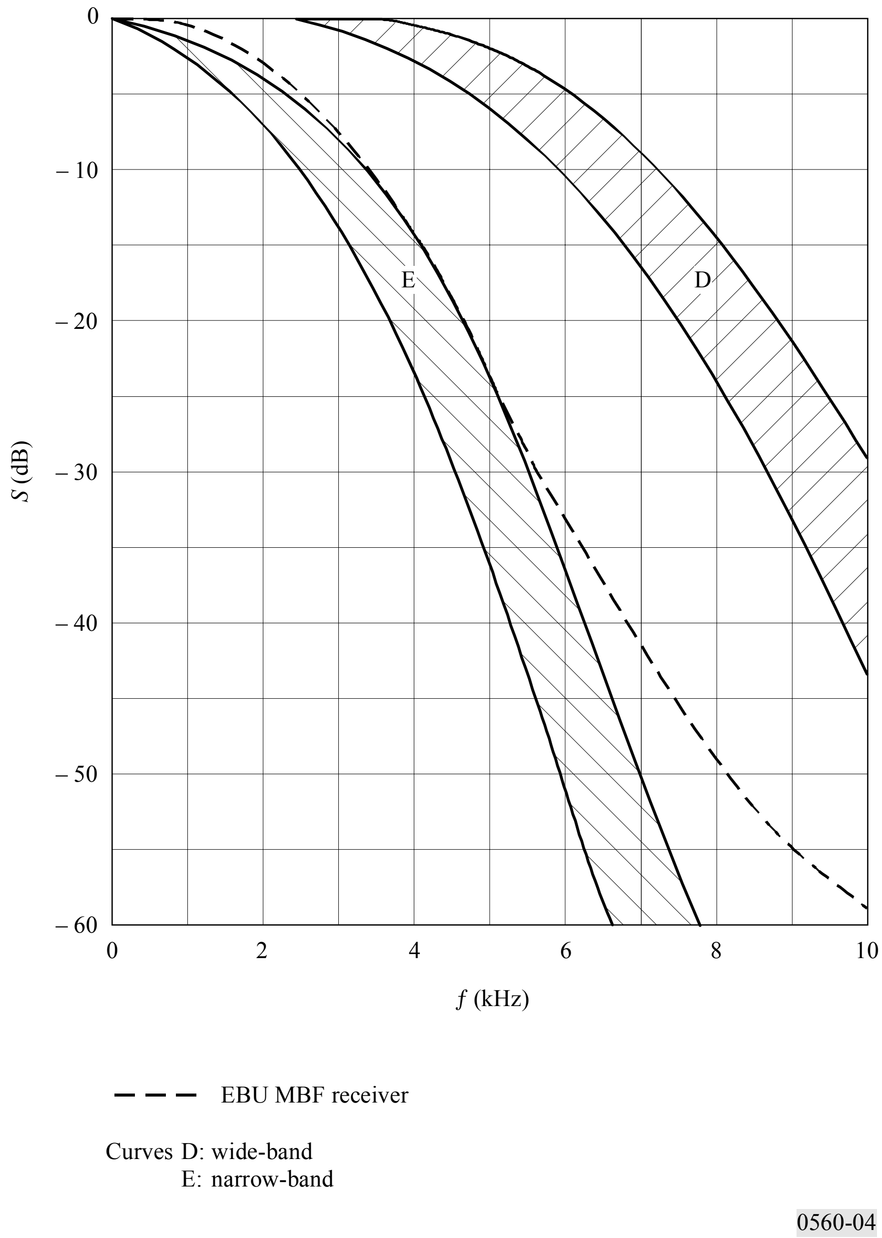
FIGURE 4

Receiver selectivity curves



9 Subjective assessment of the quality of reception

9.1 Investigations carried out in the USSR

Statistical and subjective tests on the effects of distortion and interference in a broadcast channel were carried out in the USSR.

The tests were performed using a statistically based subjective method, using special equipment which enabled a comparison to be made between an undistorted sound programme and a second programme, into which predetermined levels of distortion had been injected.

The objective of these experiments was to determine the perceptibility of distortion by the following groups of listener:

– qualified experts (sound-broadcasting producers);

– observers without special musical education and without training in the observation of distortion.

The results of these experiments were published in the form of graphs, showing the percentage perceptibility as a function of the level of the distortion or interference injected.

All these tests were made on the basis of a large amount of statistical data. The correctness of the data obtained was checked by the methods of mathematical statistics. The results were given in terms of:

– linear distortion of different types (at various levels and for different frequency ranges);

– non-linear distortion (cubic, quadratic and "central cut-off" types);

– background noise (sinusoidal);

– white noise.

A comparison of the reception quality determined by the objective method or subjective tests shows differences in the necessary protection ratio. This difference may reach 10 dB for a frequency spacing of 9 kHz.

9.2 Investigations carried out in Japan

Results of a subjective assessment carried out in Japan concerning the relationship between reception quality and RF wanted-to-interfering signal ratio is shown in Fig. 5a) for co-channel interference, and Fig. 5b) for adjacent-channel interference. Listening tests were made by ten experts using three receivers (A, F, H).

10 RF protection ratios for synchronized broadcasting transmitters

10.1 Investigations carried out in the USSR

These investigations were carried out to determine values of signal-to-interference ratio applicable to reception of transmissions from synchronized transmitter groups comprising two or three transmitters. Both phase and frequency synchronization methods were considered.

10.1.1 Explanation of the term "RF protection ratio"

The term "protection ratio" in this context means the ratio of the field strength of the strongest signal from one of the transmitters in the synchronized group to the resultant field strength of the remaining transmitters in the same group.

10.1.2 Determination of the protection ratio

For the purpose of determining the protection ratio, use was made of a statistical method based on subjective impressions of reception quality from a transmitter in a synchronized group, compared with reception quality of a single unsynchronized transmitter station. Twenty-six experts were employed – all of whom were technical and/or scientific broadcasting staff.

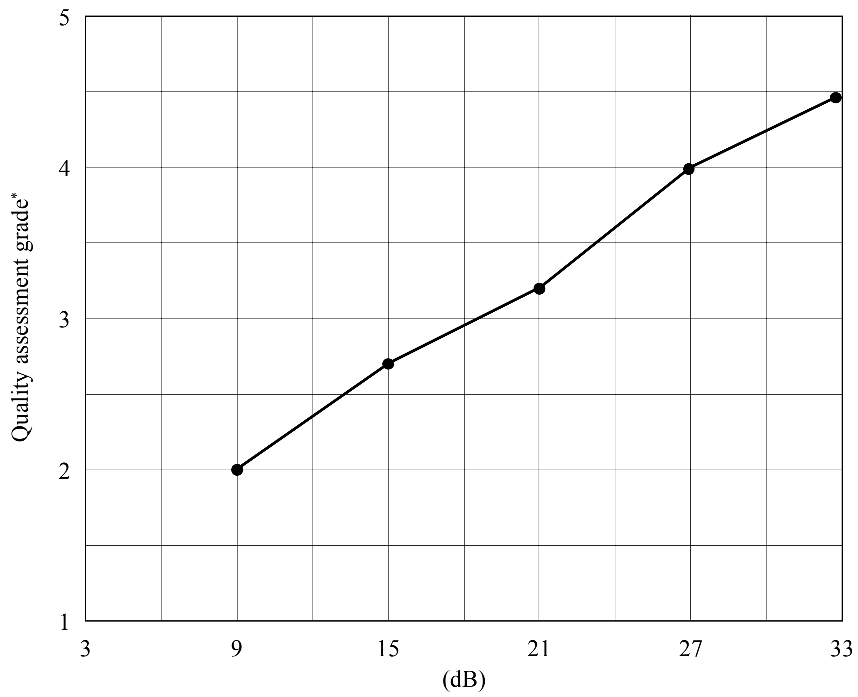
Protection ratio values for non-fading signals were determined under laboratory conditions and later verified under operational conditions.

For fading signals only operational tests using a synchronized network were carried out.

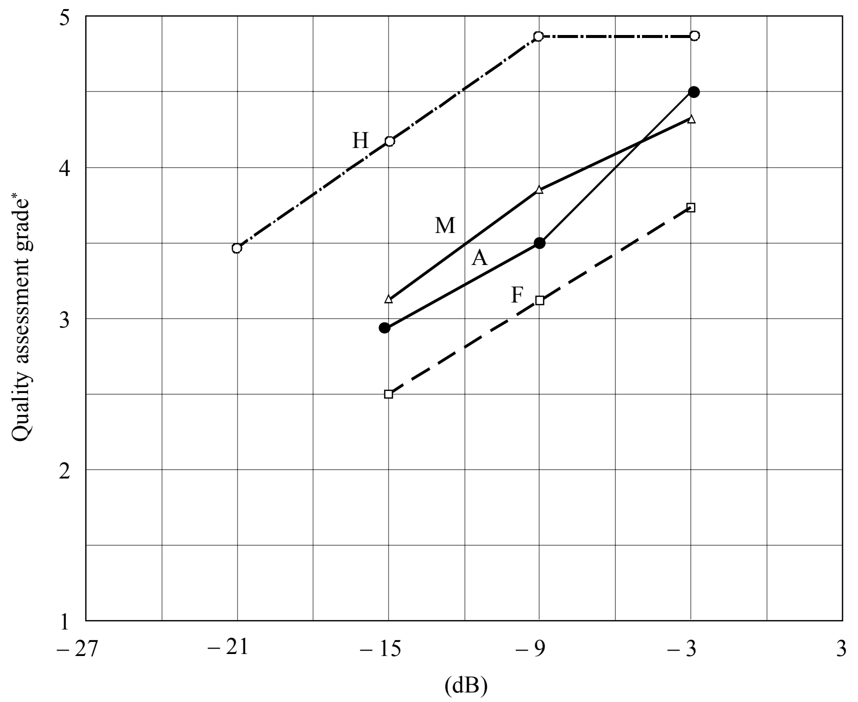
For all these tests the depth of maximum modulation was 90%.

FIGURE 5

Relationship between reception quality and RF wanted-to-interfering signal ratio



a) In case of co-channel interference



b) In case of adjacent-channel (10 kHz spacing) interference

M: results for average of three receivers

* See Recommendation ITU-R BS.562.

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Figure 6 shows the variations in protection ratio as a function of the phase difference between the carriers of two stations during daytime in the absence of fading. The parameter used in these curves is the percentage of experts who rate the total signal as being at least satisfactory. This figure shows that for non-fading signals, with two synchronized stations, a protection ratio of 4 dB was required in order to satisfy 90% of the listeners.

FIGURE 6

Quality of speech and music transmissions as a function of the phase difference between the carriers of two transmitters (non-fading conditions)

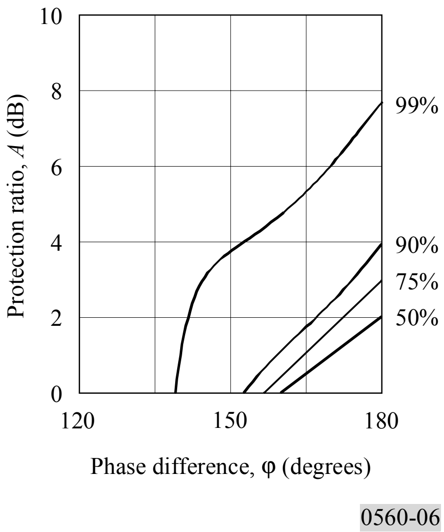


Figure 7 shows the variation in protection ratio as a function of the difference in frequency between two synchronized transmitters for the percentage of experts who found the reception quality to be satisfactory. This figure shows that, for non-fading signals with two synchronized transmitters and a protection ratio of 4 dB, it is necessary to have synchronization accurate to between 0.015 and 0.02 Hz, in order to satisfy 90% of listeners. With a frequency difference of 0.1 Hz the protection ratio has to be increased to 6 dB.

Figure 8 contains similar results for phase synchronized operation of three transmitters. To satisfy 90% of the listeners the protection ratio should not be less than 3.1 dB. (The standard value is 4 dB.)

It is concluded that when reception is affected by fading it will be necessary to increase the protection ratio to 7 or 8 dB in the case of two synchronized transmitters, and to 6 dB in the case of three transmitters.

FIGURE 7

Quality of speech and music transmissions as a function of difference in frequency of two transmitters (non-fading conditions)

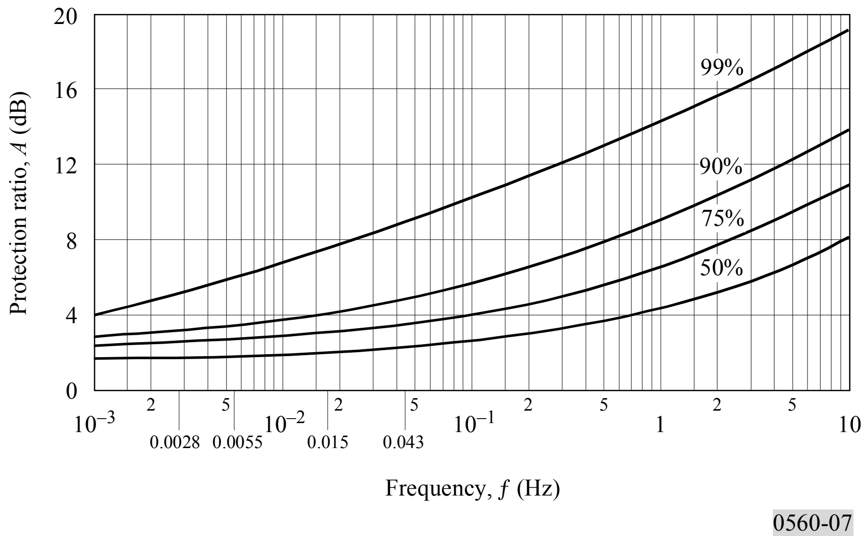
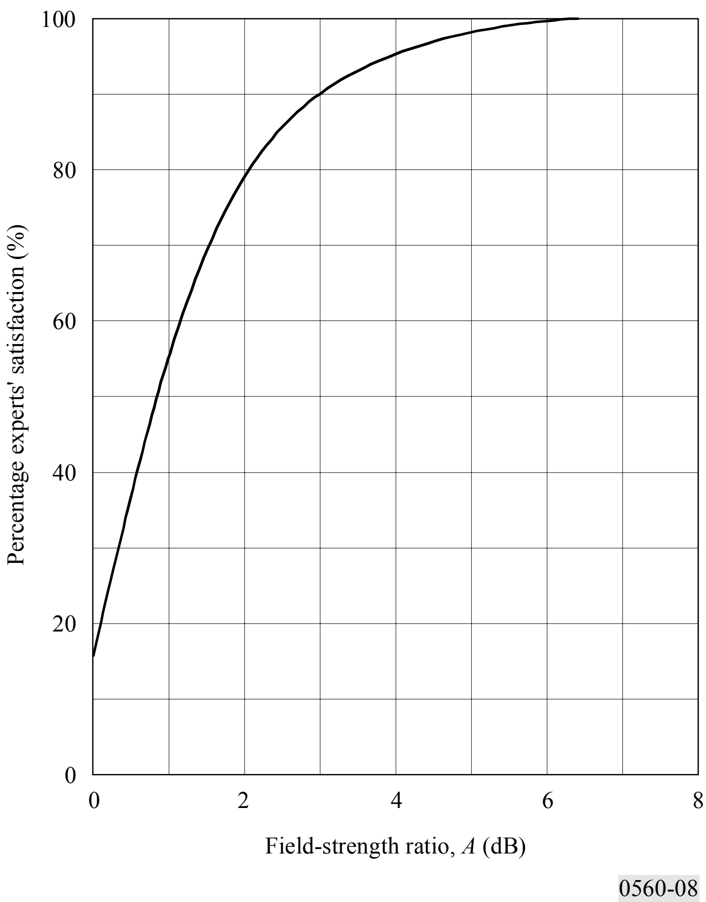


FIGURE 8

Quality of speech reception and of music transmissions as a function of the field-strength ratios of three transmitters synchronized in phase



10.2 Investigations carried out within the EBU

Synchronizing techniques as developed up to 1964 in several countries, notably, Austria, France, Federal Republic of Germany, Italy, the Netherlands, Norway, Sweden, United Kingdom, Australia and the United States of America are in most cases still in use.

10.3 Investigations carried out within the OIRT

It was found that in practice it is possible to simulate all the essential effects of synchronized or unsynchronized common channel systems (same programme) by a model. Such a model was developed by the Rundfunk- und Fernsehtechnisches Zentralamt of the Deutsche Post, Berlin. That model offers both economical and operational advantages, when carrying out studies on reception problems in the area, where the ground waves of synchronized transmitters interfere; i.e., without taking into account ionospheric fading effects.

With the use of the above-mentioned model system, it is possible to study synchronized or unsynchronized common channel systems in the laboratory. If the carrier frequencies differ by only about 0.1 Hz and if the delay times of the sound signals between the studio and the transmitters of this system have been equalized, the following advantages will result:

– decrease of the interference zone to almost zero;

– decrease of the selective fading effects, so that only amplitude fading effects still remain, which are entirely compensated for by the automatic gain control of the receiver, without unacceptable distortion.

In conclusion, it can be said that these effects permit a protection ratio of 0 dB for daytime reception.

These theoretical results have been confirmed in field tests by using two transmitters of 20 kW operating in band 6 (MF) with a spacing of about 80 km.

10.4 Investigations carried out in the United Kingdom

10.4.1 Equalization of modulation delay

Laboratory tests conducted by the BBC to study the effect of modulation delay in a common-channel, same-programme system gave the results shown in Table 1 which are applicable to two carriers, with the order of 0.1 Hz frequency difference, modulated by a music programme. The impairment was slightly less severe when using a speech programme.

Given the field-strength contours for a two-transmitter situation, the results of Table 1 can be used to assess the improvement that modulation delay equalization could provide to daytime reception over any affected region. In most cases, improvement is gained over the greatest area if the modulation delays are equated at the point where the equal-field-strength locus crosses the straight line joining the two transmitters. It may be preferable, however, to equate the modulation delays at some other point, for example, near a highly populated part of the affected region, in order to improve daytime reception for the greatest number of listeners.

TABLE 1

Carrier-amplitude ratio (dB)	Subjective grade of impairment(1) exceeded for 10% of the time for modulation-delay inequality of:					
	0	30 μs	50 μs	84 μs	250 μs	1 ms
0	4	3	2	1	1	1
3	5	5	4.5	2.5	1	1
6	5	5	5	5	3.5	2
9	5	5	5	5	5	5

(1) 5-grade subjective impairment scale (see Recommendation ITU-R BS.562).

A nine-month field trial between the BBC medium wave transmitters (1 214 kHz) at Brookman's Park (50 kW, directional antenna) and Droitwich (30 kW, omni-directional antenna), which are 145 km apart, largely confirmed the results of Table 1 and showed the arrangement to be practicable, stable and to impose very little demand operationally. The trial revealed the following practical aspects:

– It was found practicable to achieve and maintain phase equalization to within ±30° over the modulation band 50 Hz to 4 kHz at the chosen receiving point.

– After inserting the phase equalization in regions where the two field strengths differed by less than 1.5 dB, the residual distortion was nevertheless still significant in practice; in other words, a protection ratio of 1.5 dB is still required for good reception.

10.4.2 Carrier phase locking

A system of carrier phase locking has been introduced in the United Kingdom for three common frequency transmitters on 200 kHz. The transmitters in question are situated in Droitwich in the centre of England, at Westerglen near Edinburgh and at Burghead in North-East Scotland. The phase locking is used in conjunction with audio delay equalization (see § 10.4.1) so that the signals received in the approximately equal field strength areas between adjacent stations (i.e. between Droitwich and Westerglen and between Westerglen and Burghead) are maintained with carriers in phase and with the timings of the modulation envelopes equalized. Furthermore, the three transmitters are driven with rubidium standard units of high frequency stability. In the critical areas, therefore, the standing wave patterns remain fixed and distortion is minimized and a stable, unvarying situation is provided for listeners. Receivers with ferrite-rod antennas may experience poor reception only on or near lines joining the transmitters. Elsewhere the magnetic fields act in different directions and do not cancel.

Experience to date indicates that the system is providing a good nationwide service.

Consideration is being given to the application of the technique to MF broadcasting.

10.5 Investigations carried out in India

Subjective tests were carried out in India with a view to determining the protection ratios applicable to synchronized transmitter groups in band 7 (HF). These tests indicated that a large majority of the listeners did not observe any degradation in the quality of programme even in a zone where the field strength of the synchronized transmitters differed only by 2-3 dB at a distance of approximately 2 000 km from the transmitters. It has therefore been concluded that in the case of synchronized transmitters in band 7, the appropriate co-channel protection ratio would be as low as 3 dB if the transmitters are driven by a common oscillator and operate with antennas of similar vertical radiation characteristics.

10.6 Investigations carried out in Japan

A synchronized network composed of seven MF transmitters has been operated in Okayama, Japan, since January 1984, using an identical carrier frequency in the MF broadcasting band. It is necessary that the following conditions are met, in order to improve the quality of signals received in the interference zones:

– transmitters comprising the network have an identical carrier frequency and are phase-locked to each other, using a synchronizing signal transmitted via radio-relay links between the broadcasting transmitters. In addition, the phase of the two carrier signals is maintained in the area where both carrier signals propagate in the same direction;

– the field strength of each transmitter is set at not less than 1 mV/m in the interference zones where the number of listeners is large;

– the phase difference of modulation signals is maintained within 5° over the frequency band from 80 Hz to 4 kHz in the interference zone.

Seven transmitters utilizing an identical carrier frequency (1 494 kHz) having a total power of 9.2 kW offer a coverage area of about 80 km by 90 km which corresponds approximately to the area (for the Okayama district) that a single high-power transmitter of 150 kW at the main station would provide. When the above three conditions are satisfied, a received signal of sufficient quality is obtained in the interference zones, as long as the S/I ratio is not less than 1 dB (see Fig. 9).

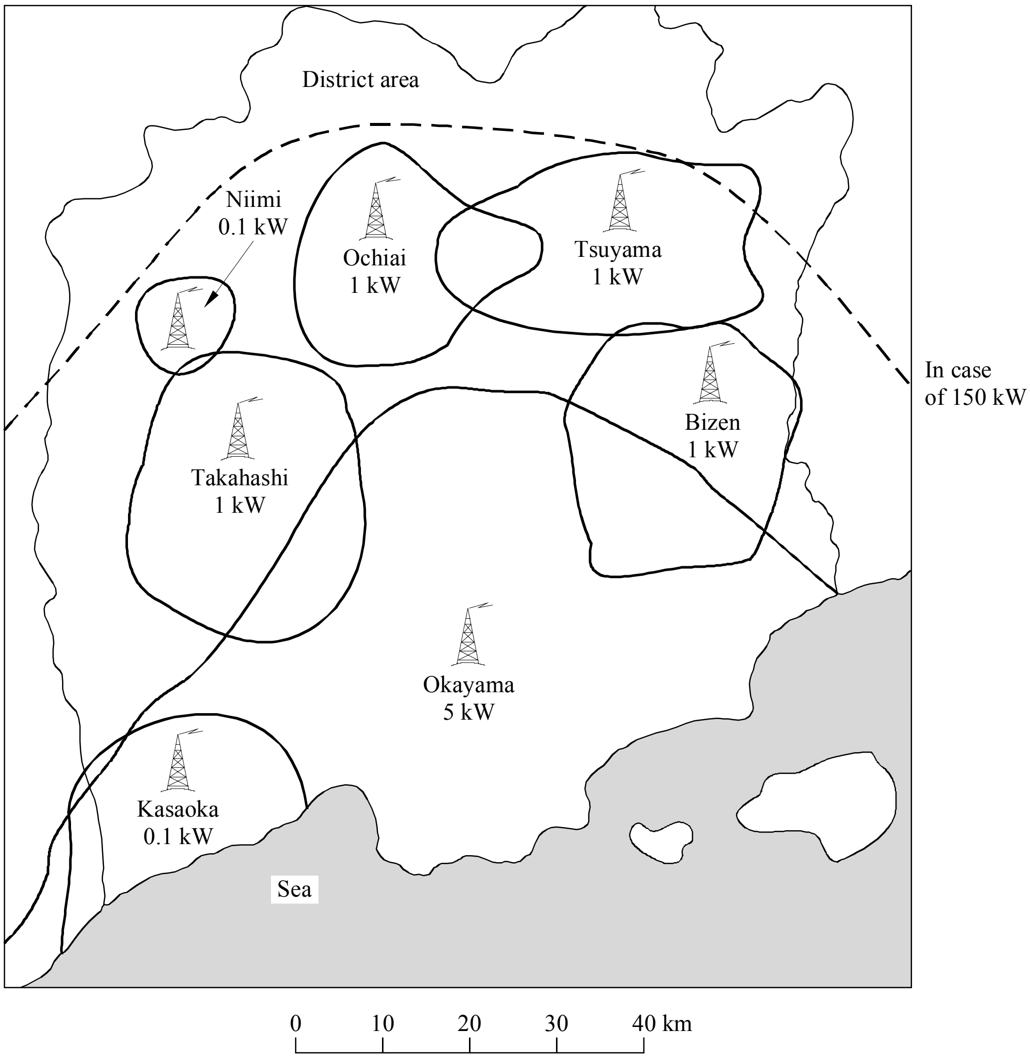
Due to its size, no interference due to short-range fading or multipath propagation was experienced in the coverage area. However, in large coverage areas this type of interference may lead to some difficulty in achieving the same results.

10.7 Investigations carried out in the People's Republic of China

Experiments and research on synchronized MF broadcasting have been carried out in the People's Republic of China since the late 1960s. One method, phase synchronization, is subject to random interference and phase jitter of the standard frequency signal transmitted, resulting in a loss of benefits expected of synchronization. To correct for this, an adaptive phase synchronization system has been developed which employs adaptive tracking based on the quality and presence or absence of the standard frequency signal. It tracks only the accuracy of long-term statistics of the standard frequency signal, rather than its rapid phase change and random jitter. As a result, even when the standard frequency signal is interrupted, frequency accuracy is maintained.

FIGURE 9

Synchronization of the MF transmitter chain on 1 494 kHz



All subsidiary stations: audio phase equalized to principal station
Contour: 1 mV/m
Population in the district area: 1 871 000

0560-09

During the period from 1986 to 1990, digital and intelligent synchronized MF broadcasting exciters were introduced. In 1992, a technical plan for synchronized MF broadcasting using adaptive phase synchronization was implemented. Tests have verified the improved coverage effect of the single-frequency network using the adaptive phase synchronization method. This technique has been put into widespread practice in the People's Republic of China with the following results:

– a synchronized, single frequency MF broadcasting network has been implemented using frequency generators locked to the 1 MHz frequency standard transmitted by China Central TV (CCTV). The RF protection ratio between synchronized transmitters approaches 0 dB;

– the fluctuation of the resultant field strength measured within the field-strength contour is less than ±1 dB over a long period of time, and satisfactory reception can be obtained by common receiver sets without fading and distortion. Although slight fading and distortion of the wanted signal may be perceptible near the valley points of the standing wave field, these will disappear as soon as the direction of receiving antennas is adjusted;

– when the standard frequency signal is interrupted, for 5 min or less, the exciting unit of the intelligent synchronization system will adapt by switching to frequency synchronization mode without any degradation of the received signal.

It is therefore believed that synchronized MF broadcasting using adaptive phase synchronization method has reached a mature state.

ANNEX 4

Planning parameters in band 7 (HF) considered by the WARC HFBC-87

The WARC HFBC-87 considered that RF protection ratios, minimum usable field strengths and signal fading allowances are basic planning parameters which may be improved as a result of further studies and recommended that the ex-IFRB should use the following parameters in its Technical Standards.

1 RF protection ratios

1.1 Protection ratio for unsynchronized transmissions

The WARC HFBC-87 Planning System shall endeavour to satisfy the requirements with a minimal co-channel RF protection ratio of 17 dB without taking into account the fading allowances and multiple interference entries. In cases of congestion this ratio may be lowered until the congestion is resolved.

1.2 Protection ratio for synchronized transmissions

The co-channel protection ratio between synchronized transmissions in the same network should be:

Distance, *L*, between synchronized transmitters (km)	Protection ratio (dB)
$L \leq 700$	0
$700 < L \leq 2\,500$	4
$2\,500 < L$	8

1.3 Relative RF protection ratios

The relative RF protection ratios, α, for carrier frequency separations (see Note 1) (Δ*f*) with reference to the co-channel protection ratio, should be:

Δ*f* (kHz)	α (dB)
0	0
±5	–3
±10	–35
±15	– 49
±20	–54

NOTE 1 – Frequency separations of Δ*f* < –20 kHz and Δ*f* > +20 kHz need not be considered.

2 Minimum usable field strength

The minimum usable field strength should be determined by adding 34 dB to the greater of:

– the field strength due to atmospheric radio noise as contained in Recommendation ITU-R P.372;

– 3.5 dB(μV/m), which is the intrinsic receiver noise level.

3 Signal fading allowance

3.1 Short-term (within the hour) fading

The upper-decile amplitude deviation from the median of a single signal is to be taken as 5 dB and the lower-decile is to be taken as – 8 dB.

3.2 Long-term (day-to-day) fading

The magnitude of the long-term fading, as determined by the ratio of the operating frequency to the basic MUF, is given in Table 2 of Recommendation ITU-R P.842.

For synchronized transmissions, the fading allowance associated with the predominant signal should be used. In cases where the contributing wanted field strengths are equal and Note 1 of Table 2 of Recommendation ITU-R P.842 applies to at least one of the paths, the values for geomagnetic latitudes ≥ 60° should be used.

3.3 Combined distribution of fading applicable to wanted and unwanted signals

The fading allowances for 10% and 90% of the time are each taken to be 10 dB, except where the provisions of the following Notes apply. In the latter case, 14 dB is to be used.

NOTE 1 – If any point on that part of the great circle which passes through the transmitter and the receiver, and which lies between control points located 1 000 km from each end of the path, reaches a corrected geomagnetic latitude of 60° or more, the values for ≥ 60° must be used.

NOTE 2 – These values relate to the path of the wanted signal only.

NOTE 3 – For synchronized emissions, the fading allowance associated with the predominant wanted signal is to be used. For those conditions where the constituent wanted field strengths are equal and Note 1 above applies to at least one of the paths, the value of 14 dB is to be used for the decile values.