RECOMMENDATION ITU-R BS.598-1*

Factors influencing the limits of amplitude-modulation sound-broadcasting coverage in band 6 (MF)

(1982-1990)

The ITU Radiocommunication Assembly,

considering

a) that amplitude-modulation sound-broadcasting coverage within a given frequency band cannot be improved beyond a certain limit imposed by physical and technical factors;

b) that improved coverage within a given frequency band is directly related to improved spectrum-utilization efficiency;

c) that improved spectrum-utilization efficiency can only be achieved by:

– maximizing the useful effects of all transmitters belonging to the network considered;

– minimizing the interference effects of all transmitters of that network;

– selecting an appropriate channel width;

– arranging frequency channels in such a way that interference throughout the network is minimized;

d) that a coverage factor can be defined in a way that it is representative of spectrum-utilization efficiency;

e) that among the factors influencing the limits of broadcasting coverage in band 6 (MF) there are:

– the minimum usable field strength;

– the power level in the network;

– the radio-frequency protection ratios;

– the distance between transmitters sharing the same channel;

– the channel spacing;

– the bandwidth of emission;

– wave propagation and the factors by which propagation is influenced;

– the channel distribution,

recommends

that in frequency planning and for the solution of frequency assignment problems in band 6 (MF) advantage should be taken of existing knowledge of the interrelations between the various factors influencing the limits of broadcasting coverage as they are described in Annex 1.

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

The information contained in Annex 1 was derived from studies based on regular lattices and linear channel distributions and takes account of omni-directional transmitting antennas only.

Practical aspects of MF coverage are given in Annexes 2, 3, 4 and 5.

ANNEX 1

1 Introduction

In the decade preceding the LF/MF Broadcasting Conference for Regions 1 and 3, Geneva, 1974-75, the factors influencing the limits of sound-broadcasting coverage in band 6 (MF) and their interrelations were extensively studied in various countries. The results obtained so far permit a deep insight into the complex problem and may even appear to provide a conclusive answer to it.

For obvious reasons, it was assumed in the studies, that because of the limited MF broadcasting band available, no channel would be assigned exclusively to one transmitter throughout the world. The assignment, however, of the same frequency channel to more than one transmitter supposed to be sufficiently distant from one another inevitably led to co-channel interference problems.

2 Definition of coverage factor

It is first assumed that in an infinitely extended area all transmitters (infinite in number) are operating on the same frequency with an equal power *p* (kW). The distance between neighbouring transmitters is *D* (km). The highest density in this co-channel transmitter network can be obtained when three neighbouring transmitters each form an equilateral triangle of the sidelength *D* (see Fig. 1), and it is supposed that under these conditions spectrum utilization is almost optimal. In the presence of noise and interference from the surrounding co-channel stations the coverage range *R* (km) of each individual transmitter depends on:

– the frequency;

– the propagation characteristics affecting the field strength of the wanted (E_w) and unwanted (E_i) signals;

– the minimum usable field strength (E_{min});

– the radio-frequency protection ratios a_i.

The coverage range is that distance from the wanted transmitter at which field strength of the wanted transmitter is equal to the usable field strength E_u:

$$E_u = E_w = \sqrt{E_{min}^2 + \sum_{i=1}^{n} (E_i \times a_i)^2} \qquad \text{(see Report ITU-R BS.945)}$$

NOTE – Where field strengths or protection ratios are expressed in dB(µV/m) or dB, respectively, the conversion can be made by means of the following formulae:

$$\underline{E}\,(\mu\text{V/m}) = 10^{\frac{E\,(\text{dB}(\mu\text{V/m}))}{20}} \qquad a = 10^{\frac{A\,(\text{dB})}{20}}$$

In the absence of noise or when interference is by far predominant, the coverage range does not depend on the transmitter power level, whereas in the opposite case it does.

Quite generally, the coverage factor, c, may be defined to be the ratio of the sum of all areas, S_n, covered by the individual transmitters operating on the same frequency in a very extensive area to the total area, S:

$$c = \sum S_n / S$$

For the determination of the coverage factor in the theoretical case of a regular network the infinitely extended area is subdivided into unit areas, each of which consisting of two equilateral co-channel triangles having one side in common. Under these conditions each unit area corresponds to just one of the co-channel transmitters (see Fig. 1). Thus, the coverage factor (per channel) may be defined as:

– either the ratio of the coverage area πR^2 to the unit area $1/2 \sqrt{3}\, D^2$ (area coverage):

$$c = \frac{2\pi}{\sqrt{3}} \left(\frac{R}{D}\right)^2 \times 100 \qquad (\%)$$

– or the ratio of the population in the aforementioned two areas (population coverage).

The concept of area coverage will be retained for the remainder of Annex 1 because additional information on population distribution would be required if the concept of population coverage were to be used. However, studies of a general nature would be difficult for the latter case.

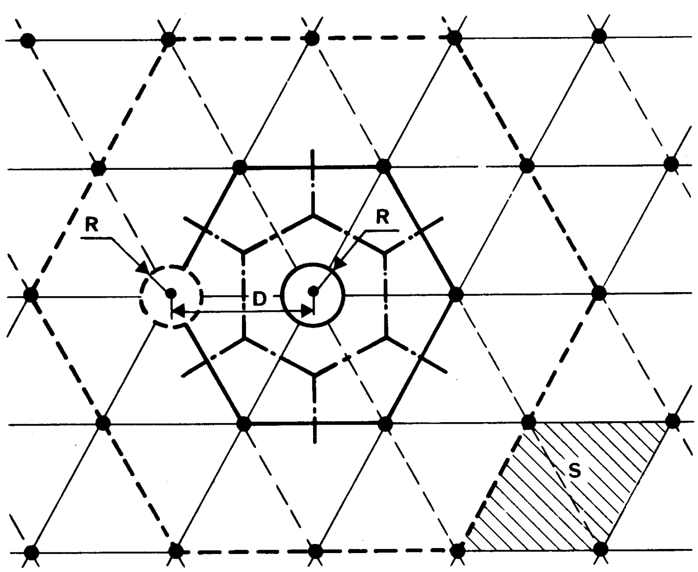

FIGURE 1 – *Regular lattice of transmitter sites*

D: co-channel distance
R: coverage radius
S: unit area

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The influence of the remaining channels as potential sources of interference (e.g. adjacent channels, second channel) should also be considered. In principle, in a unit area, each channel can be assigned to one transmitter only. Depending on whether an even coverage is wanted or not, the channels will either have to be distributed evenly over the unit area in a geometrically regular manner and according to an appropriate (e.g. linear) channel distribution scheme or – in the case of irregular coverage – will have to be arranged differently, maintaining however, sufficiently large distances between transmitters that may cause or suffer interference.

The coverage factor *c* is normally expressed as a percentage. If the area coverage obtainable by means of all the channels available in band 6 (MF) exceeds unity (100%), this number represents, on the average, the number of programmes that can be received at any location throughout the whole area under consideration.

3 Coverage factor *c* as a function of the distance *D* between co-channel transmitters

3.1 General

To establish curves showing the dependence of the coverage factor *c* on the distance *D* between co-hannel transmitters under varying conditions for the remaining parameters two different approaches, A and B, were made, however with the following common bases:

– transmitters of equal power *p*;

– ground-wave propagation curves of Recommendation ITU-R P.368;

– sky-wave propagation curves of Recommendation ITU-R P.1147, see also ITU-R Handbook – The ionosphere and its effects on radiowave propagation;

– radiation constant in all azimuthal directions and at all angles of elevation.

The two approaches, A and B, differ with respect to the following parameters:

Approach A (results shown in Fig. 2):

– the power level remains unchanged ($p = 1$ kW);

– there is no noise limitation ($E_{min} = -\infty$ dB);

– the radio-frequency protection ratio varies, in steps of 5 dB, between the limits $A = 20$ dB and $A = 45$ dB;

– the ground conductivity is $\sigma = 3 \times 10^{-3}$ S/m.

Approach B (results shown in Figs. 3 and 4):

– the power level varies, in steps of 5 dB, between the limits $p = 1$ kW and $p = 1\,000$ kW;

– the minimum usable field strength is $E_{min} = 60$ dB (µV/m);

– the radio-frequency protection ratio values are $A = 40$, 30 or 27 dB;

– the ground conductivity values are $\sigma = 10^{-3}$, 3×10^{-3} or 10^{-2} S/m.

As a matter of fact, the rigorous and systematic use of directional antennas was also studied for approach B. The results obtained indicated that no substantial improvement in spectrum utilization efficiency can be expected under such conditions. This does not mean, however, that no advantage can be gained when directional antennas having horizontal patterns suitably adapted to the individual interference and coverage problem are used to a large extent (see Annex 2).

3.2 Results obtained for a plane Earth model

The curves in Figs. 2, 3 and 4 are given as examples. They show the dependence of the coverage factor c on the co-channel distance D for a frequency of 1 MHz under varying conditions. The Figures take account of the interfering co-channel stations on the two nearest hexagons surrounding the wanted transmitter (see Fig. 1). Thus, interference from 18 stations, i.e. 6 stations at the distances D, $D\sqrt{3}$ or 2 D was included in the computation. For reasons of symmetry the coverage range was determined as the root mean square of the values obtained for two significant azimuthal directions:

– direction towards interfering stations at the distances D and 2 D,

– direction towards interfering station at the distance $\sqrt{3}\,D$.

In particular, Fig. 2 shows the results obtained with approach A and is valid when ground-wave coverage is limited by sky-wave interference and when, in the absence of noise, there is no power dependency. The parameter indicated on the curves is the radio-frequency protection ratio A. Also shown in decibels relative to 1 µV/m is the field E_1, of the wanted transmitter at the limit of the coverage area, for a transmission power of 1 kW with a short vertical antenna. For instance, the points of intersection on a curve shown by alternating dots and dashes, for $E_1 = 40$ dB, and the curves $c = f(D)$, for $A = 20$ dB derived for interference by sky waves of type 1 (shown by a full line) or of type 2 (shown by dashes), mean that if the co-channel distance is D (abscissae of the points of intersection, i.e. 2 800 km or 4 800 km, respectively) and for a protection ratio $A = 20$ dB, the field at the limit of the area, where the radio-frequency protection ratio is ≥ 20 dB, is 0.1 mV/m.

Figure 2 shows that:

– the coverage factor increases with decreasing values of radio-frequency protection ratio, regardless of the type of propagation of the interfering sky-wave signals;

– the general shape of the curves varies considerably with the type of propagation;

– for distances beyond about 1 500 km the coverage factor increases when the interfering sky-wave propagation is of type 1;

– the coverage factor is largely independent of the co-channel distance with propagation of type 2;

– there is no pronounced optimum separation between co-channel transmitters as long as there is no limitation by noise.

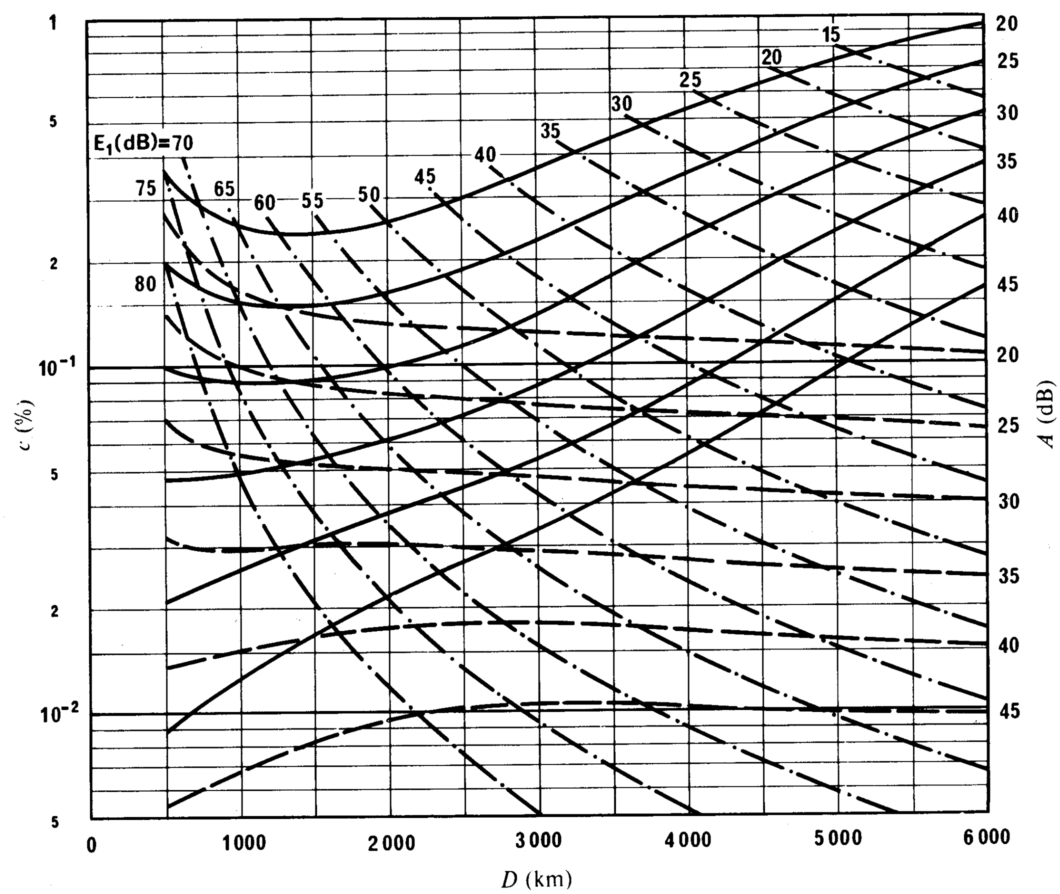

FIGURE 2 – *Coverage factor per channel (c) as a function of distance between co-channel transmitters (D) for various propagation conditions*

Parameters: – radio-frequency protection ratio *A*
– field of the wanted transmitter at the limit of the coverage area E_1; (p = 1 kW)

Propagation conditions:
– wanted signal: ground wave ($\sigma = 3 \times 10^{-3}$ S/m), Recommendation ITU-R P.368
– unwanted signals: sky wave: Recommendation ITU-R P.1147

No coverage limitation by noise

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The curves of Figs. 2, 3 and 4 presenting the results obtained with approach B show the influence of the power *p* (which is the parameter indicated on the curves) in the presence of noise for the three protection-ratio values mentioned above. The coverage factor *c* is represented on a logarithmic scale to facilitate, in each of the Figures, a comparison between the five examples shown:

– ground-wave service interfered with by ground-wave signals (day-time conditions): group A of curves;

– ground-wave service interfered with by sky-wave signals (night-time conditions) for the two types of sky-wave propagation curves under study: groups B_1 and B_2 of curves;

– sky-wave service interfered with by sky-wave signals (night-time conditions) for the two types of sky-wave propagation curves under study: groups C_1 and C_2 of curves.

Figures 3 and 4 show that in the presence of noise:

– the optimum separation between transmitters using the same channel varies considerably with transmitter power;

– the optimum separation is completely different under day-time and night-time conditions;

– the lowest coverage will result when a ground-wave service is interfered with by the sky-wave signals of the unwanted transmitters.

Moreover, the Figures show that at co-channel distances below the optimum distance interference is predominant so that an increase in power is only of limited use and that a power reduction may result in no loss in coverage.

When the sky wave is of type 1 it can, moreover, be seen that:

– the optimum separations between transmitters using the same channel are not very different, under night-time conditions, both for a ground-wave or a sky-wave service;

– at least with high-power transmitters ($p \geq 30$ kW), a sky-wave service would give a coverage similar to that of ground-wave service in the day-time.

The results are remarkably different, however, when the sky-wave propagation is of type 2. In this case:

– the optimum separations, if any, between transmitters using the same channel are noticeably different, under night-time conditions, for a ground-wave and a sky-wave service;

– the coverage of a sky-wave service would be more or less inferior to that of a ground-wave service in the day-time.

Finally, depending on the ground conductivity, the ground-wave coverage during night-time may increase at short distances with decreasing co-channel distance. This effect results in higher coverage at lower co-channel distances whereas the service ranges decrease to a few kilometres only.

The influence on coverage of the radio-frequency protection ratio can be derived from Figs. 3a and 3b, whereas a comparison of Figs. 3b, 4a and 4b permits the influence of the ground conductivity to be ascertained.

As may be expected an increase in the protection ratio leads to reduced coverage which can, at least partly, be compensated for if the co-channel distance is increased. This loss in coverage is particularly pronounced for the night-time sky-wave service obtained with the curves of type 2.

Similarly, decreasing ground conductivity leads to decreasing ground-wave coverage at both the day and the night-time. This can be remedied to some extent by a reduction of the co-channel distance, however, under day-light conditions only. There is, of course, no effect of the ground conductivity on sky-wave coverage.

3.3 Results obtained for a spherical Earth model

For interference from sky-wave signals either to a ground-wave or to a sky-wave service, suitable co-channel distances are of the order of the radius of the Earth, so that the spherical nature of the Earth must be taken into account. This has been done where only a sky-wave service is considered and where potential interference from the nearest co-channel transmitters, all equally spaced, has been taken into account.

An attempt has been made, therefore, to cover a sphere with a network of equilateral spherical triangles. It can be shown that this can be done by approximating the sphere to a polyhedron. A tetrahedron, octahedron and icosahedron provide surfaces consisting of 4, 8 and 20 equilateral triangles, respectively. These triangles may be developed on to a plane and it is then possible to apply, without difficulty, a linear channel distribution to this development.

However, when reconstituting the polyhedron, some of the triangles will share sides or apices with other triangles, from which they were separated in the plane development. In those groups of triangles the channel distribution will then no longer necessarily be linear, and consequently restrictions on the use of the channels shown on these triangles will occur. The proportion of these (unusable) triangles with respect to the total number will be at most 40% in the case of the icosahedron, 25% in the case of the octahedron and 50% in the case of the tetrahedron. On the other hand, these triangles may be ignored to a large extent by making use of the fact that dry land occupies only one third of the Earth's surface. It is, therefore, still possible to utilize the results that have already been obtained by considering networks on a plane surface.

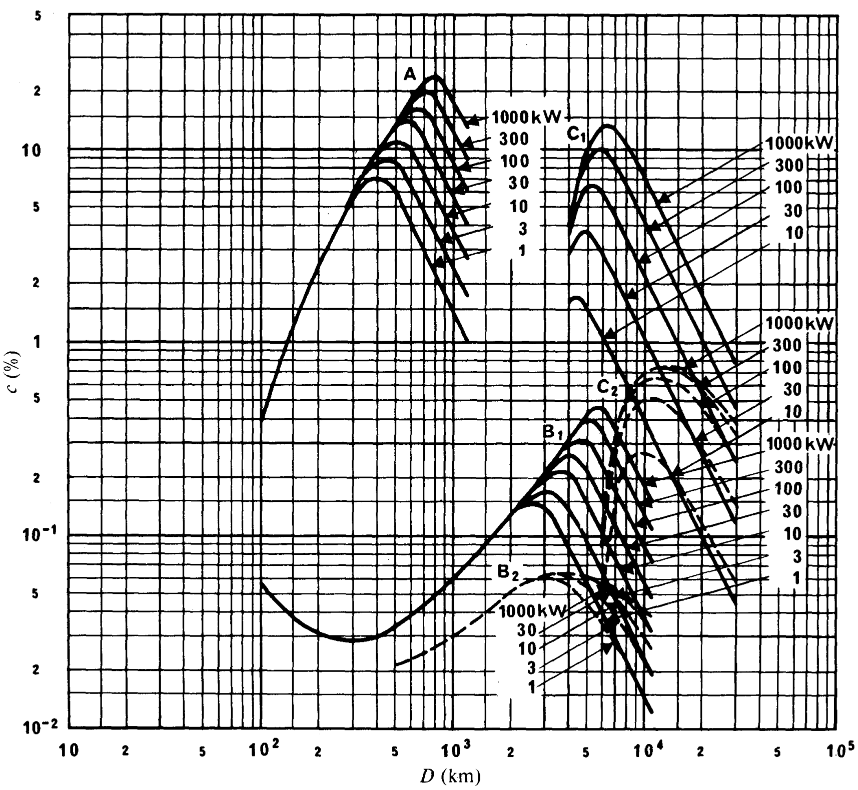

FIGURE 3a – *Coverage factor per channel (c) as a function of distance between co-channel transmitters (D) for various propagation conditions*

Parameter: transmitter e.m.r.p., *p* (kW), (*p* is kept constant at all angles of elevation)

Family of curves (*f* = 1 MHz):

A: ground-wave service under day-time conditions
B: ground-wave service under night-time conditions
C: sky-wave service under night-time conditions

Propagation conditions:

– ground wave: Recommendation ITU-R P.368
– sky-wave: Recommendation ITU-R P.1147

Minimum usable field strength: E_{min} = 60 dB(μV/m)
Ground conductivity: $\sigma = 10^{-2}$ S/m
Protection ratio: A = 40 dB

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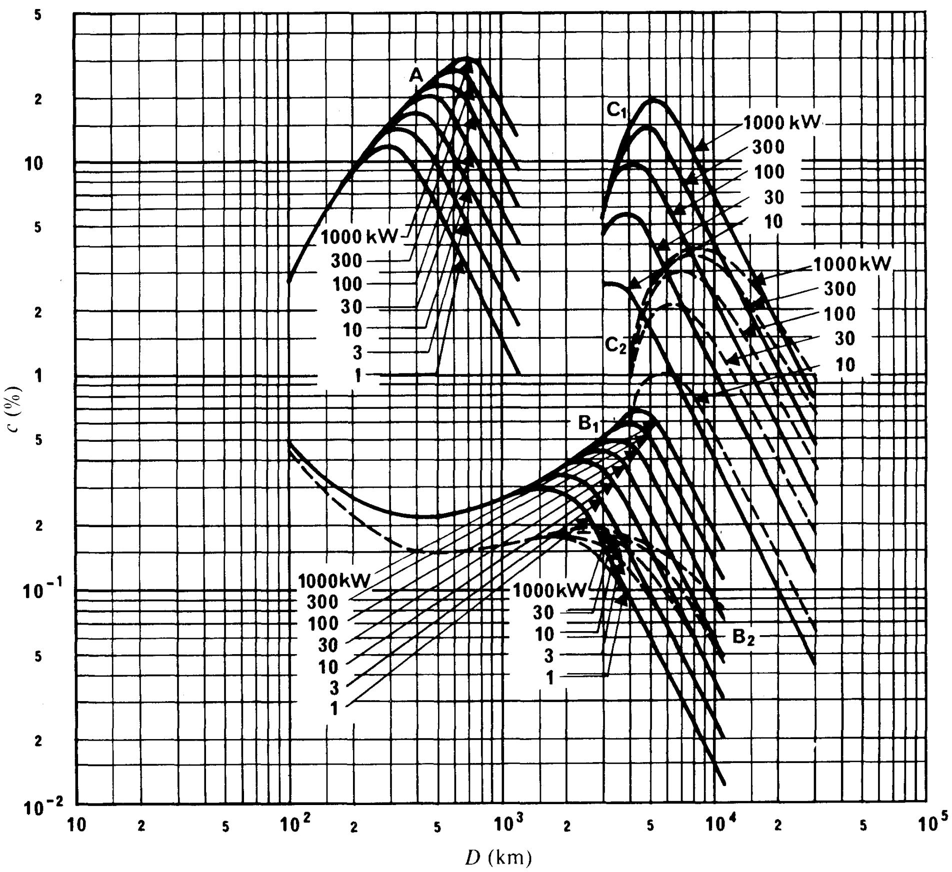

FIGURE 3b – *Coverage factor per channel (c) as a function of distance between co-channel transmitters (D) for various propagation conditions*

Parameter: transmitter e.m.r.p., *p* (kW), (*p* is kept constant at all angles of elevation)

Family of curves (f = 1 MHz):

A: ground-wave service under day-time conditions
B: ground-wave service under night-time conditions
C: sky-wave service under night-time conditions

Propagation conditions:

– ground wave: Recommendation ITU-R P.368
– sky-wave: Recommendation ITU-R P.1147

Minimum usable field strength: E_{min} = 60 dB(μV/m)
Ground conductivity: $\sigma = 10^{-2}$ S/m
Protection ratio: A = 30 dB

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If it is assumed that for the coverage of the land masses about 50% of the triangular surfaces will in fact be used and if account is taken of the fact that two triangular surfaces each carry the total number of channels available, it is evident that under these circumstances each channel can be used precisely 0.25 times the number of existing triangular planes. It is worth noting that this restriction to the use of any channel is exclusively due to the size and properties of the Earth's surface and that the co-channel distances resulting from the choice of the polyhedron would be about 12 740 km, 10 000 km and 7 050 km for a tetrahedron, octahedron and icosahedron, respectively. Smaller co-channel distances and, consequently, a larger number of co-channel transmitters can be obtained by subdivision of the equilateral spherical triangles into smaller triangles which, however, would no longer be equilateral except after development on to a plane.

It is now possible to show as a final result, in one single diagram, the full relationship between:

– the number of transmitters b using one channel;

– the co-channel distance D;

– the necessary transmitter power P and;

– the coverage factor c that can be obtained.

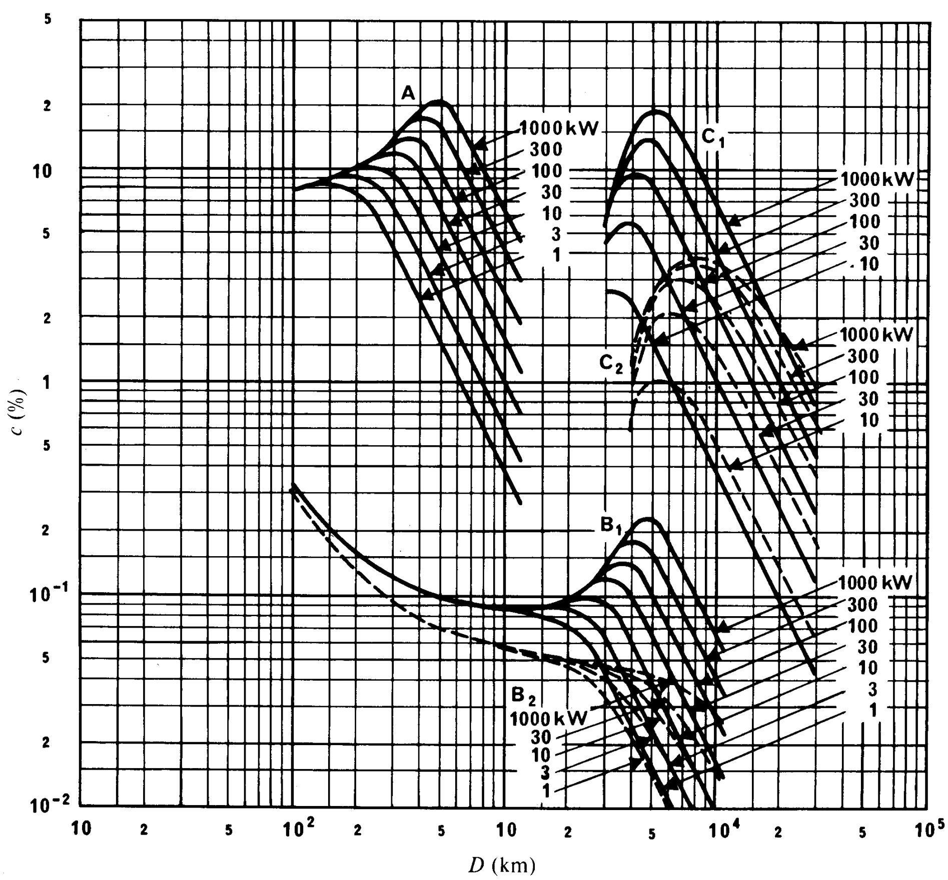

FIGURE 4a – *Coverage factor per channel (c) as a function of distance between co-channel transmitters (D) for various propagation conditions*

Parameter: transmitter e.m.r.p., p (kW), (p is kept constant at all angles of elevation)

Family of curves (f = 1 MHz):

A: ground-wave service under day-time conditions

B: ground-wave service under night-time conditions

C: sky-wave service under night-time conditions

Propagation conditions:

– ground wave: Recommendation ITU-R P.368

– sky-wave: Recommendation ITU-R P.1147

Minimum usable field strength: E_{min} = 60 dB(μV/m)

Ground conductivity: $\sigma = 3 \times 10^{-3}$ S/m

Protection ratio: A = 30 dB

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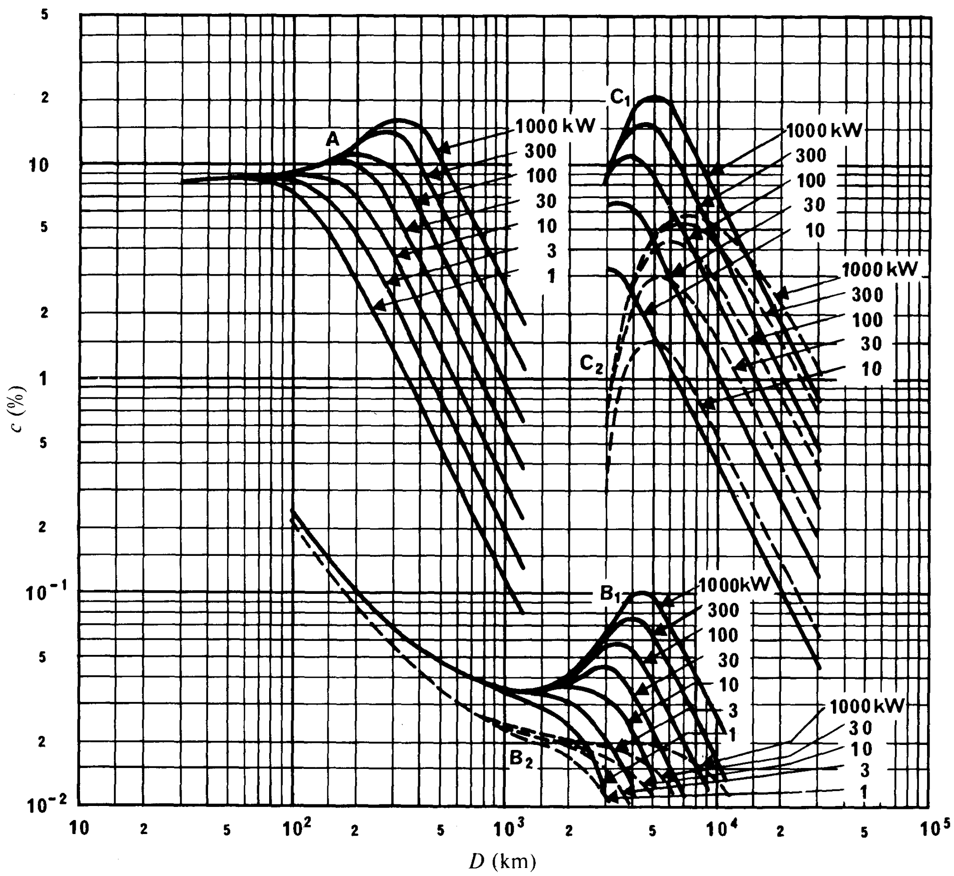

FIGURE 4b – *Coverage factor per channel (c) as a function of distance between co-channel transmitters (D) for various propagation conditions*

Parameter: transmitter e.m.r.p., *p* (kW), (*p* is kept constant at all angles of elevation)
Family of curves (f = 1 MHz):
A: ground-wave service under day-time conditions
B: ground-wave service under night-time conditions
C: sky-wave service under night-time conditions
Propagation conditions:
– ground wave: Recommendation ITU-R P.368
– sky-wave: Recommendation ITU-R P.1147

Minimum usable field strength: E_{min} = 60 dB(μV/m)
Ground conductivity: $\sigma = 10^{-3}$ S/m
Protection ratio: A = 27 dB

Figure 5 shows this result. It should be noted that the absolute value fixed for any one of these parameters determines the values of all the others. When using Fig. 5 it should be borne in mind that it can only give an estimation of these relationships.

In an additional study the influence of the radio-frequency protection ratio on the coverage factor was calculated using the same assumptions as stated previously. The results are shown in Fig. 6 and indicate that the coverage factor increases more rapidly with decreasing values of radio-frequency protection ratio when the distance between co-channel transmitters is relatively small. For a distance of 3 000 km, for example, the coverage factor is 100 times higher when the radio-frequency protection ratio is 20 dB instead of 40 dB.

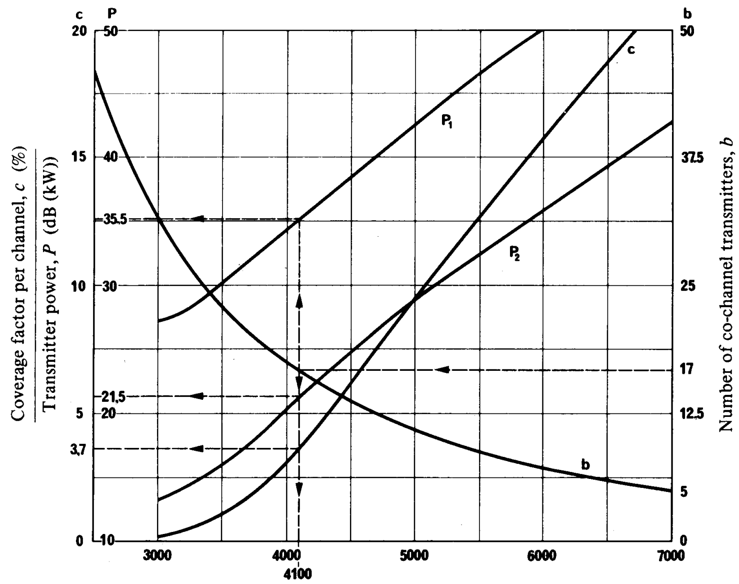

FIGURE 5 – *Number of transmitters, b, transmitter power P and coverage factor per transmitter, c, as functions of the separation between co-channel transmitters, D*

Curves P_1: transmitter power (dB (1 kW)) for E_{min} = 74 dB(μV/m)
P_3: transmitter power (dB (1 kW)) for E_{min} = 60 dB(μV/m)
b : number of co-channel transmitters
c : percentage coverage factor per channel
Radio-frequency protection ratio: 40 dB
Frequency f: 1 MHz

Example:

If the number of transmitters sharing the same channel is taken as b = 17, then the co-channel transmitter separation is D = 4100 km, the coverage factor per channel is c = 3.7% and the e.m.r.p. necessary for all transmitters to make interference rather than noise the coverage limiting factor is:

P = 21.5 (dB (1 kW)) for E_{min} = 60 dB(μV/m)
or
P = 35.5 (dB (1 kW)) for E_{min} = 74 dB(μV/m)

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4 Coverage factor as a function of channel spacing

The influence of the channel spacing on MF area coverage for both ground-wave and sky-wave services at night was investigated by the EBU and in Japan for channel spacings between 5 and 10 kHz. The studies were based on regular channel distributions and on the RF protection-ratio curve of Recommendation ITU-R BS.560. Moreover, it was assumed that the number of transmitters N on a given area remains constant when the channel spacing is varied and the area considered was that of the combined European and African Broadcasting Areas (about 42×10^6 km^2). Similar studies were carried out in the U.S.S.R. based, however, on an RF protection ratio curve obtained from high-quality receivers having adjustable bandwidths which are in wide-spread use in the U.S.S.R. The total area coverage was calculated under various assumptions and some of the results obtained by the EBU and in Japan are presented in Fig. 7 (ground-wave service) and Fig. 8 (sky-wave service) showing the coverage factor as a function of channel spacings between the limits quoted and for various numbers of total frequency assignments as a parameter.

Figures 7 and 8 show that the maximum of coverage is obtained with a channel separation of about 8 kHz, almost independently of the various assumptions made and, in particular, of the number of assignments within the given area. However, the absolute value of coverage does not depend strongly on the number of assignments when the service is provided by the ground-wave (Fig. 7) whereas it depends strongly on this parameter in the case of a sky-wave service (Fig. 8).

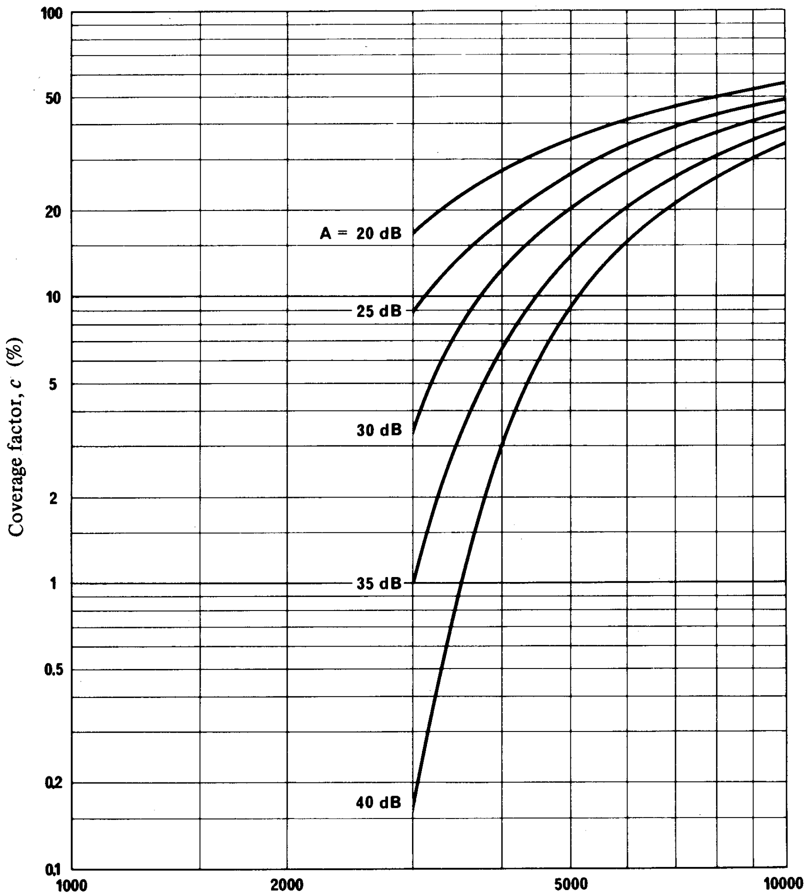

FIGURE 6 – *Coverage factor, c, for a spherical Earth, as a function of separation between transmitters, D, with protection ratio, A, as a parameter.*

Frequency: 1 MHz

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The results obtained in the U.S.S.R. indicate that maximum coverage is to be expected with a channel separation of about 9 kHz. As the technical bases of the studies carried out in the various parts of the world were nearly identical except for the RF protection-ratio curve it is obvious that the difference in the results is solely a consequence of the different shapes of the RF protection ratio curves used.

The fact that there is only one specific optimum value for either set of basic conditions, i.e. 8 kHz or 9 kHz respectively, can best be explained with the help of Fig. 9.

If *N* frequency assignments in band 6 (MF) to transmitters (or synchronized groups) are required in a given area *S* and if co-channel interference only has to be taken into account, the coverage improves with decreasing channel spacing, thus increasing the number of channels available. It is obvious that, in such a case, the average co-channel distance will also increase (curve A of Fig. 9) and that interference will be reduced by this measure. Low values of channel spacing would, in this case, be preferable.

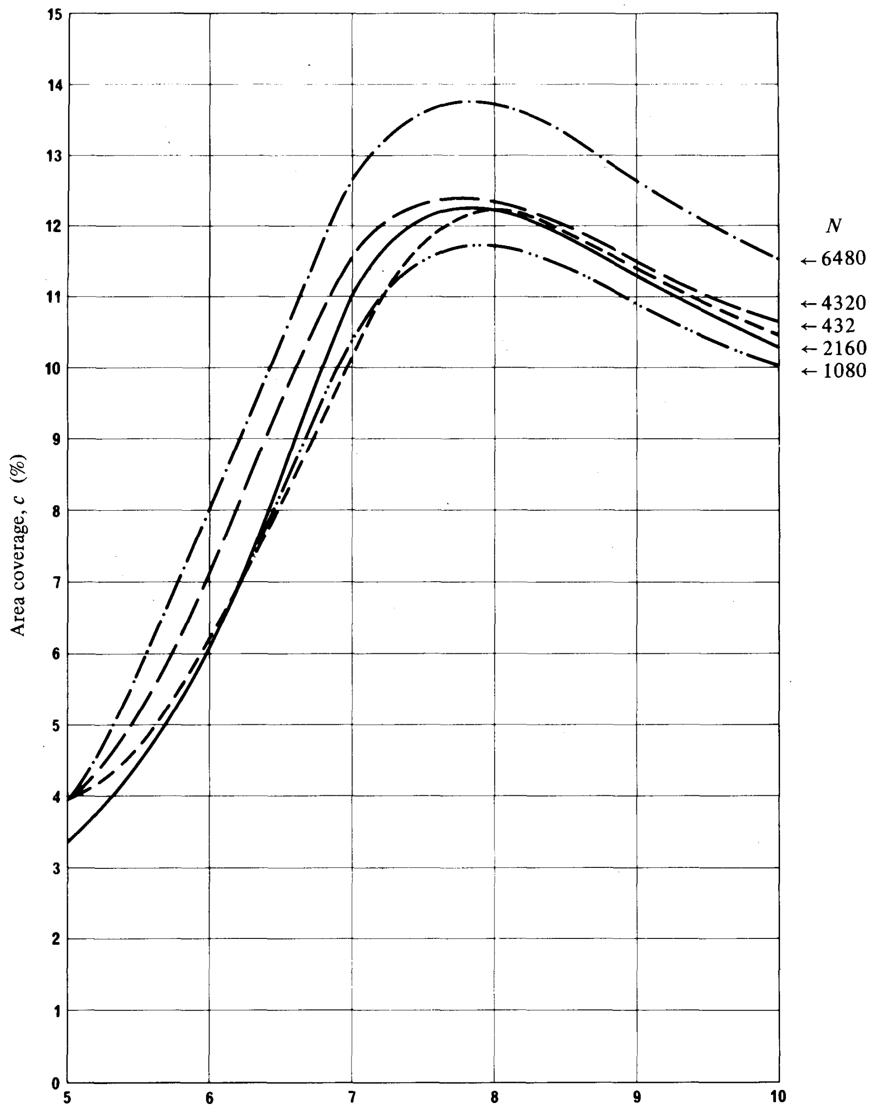

FIGURE 7 – *Coverage, c, obtainable using a 1080 kHz band with N stations in an area of 42×10^6 km² by a ground-wave service under night-time conditions*

Propagation curve used:

Ground-wave:	Recommendation ITU-R P.368 ($\sigma = 3 \times 10^{-3}$ S/m) at 1 MHz
Sky-wave:	Recommendation ITU-R P.1147
Protection ratio, *A*:	26 dB
Adjacent channel protection ratio curve:	Recommendation ITU-R BS.560, curve A

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If, however, adjacent-channel instead of co-channel interference had to be taken into account, the rest of the parameters remaining unchanged, interference would increase and, hence coverage would decrease with decreasing channel spacing (curve B of Fig. 9). High values of channel spacing would, therefore, be desirable in this case.

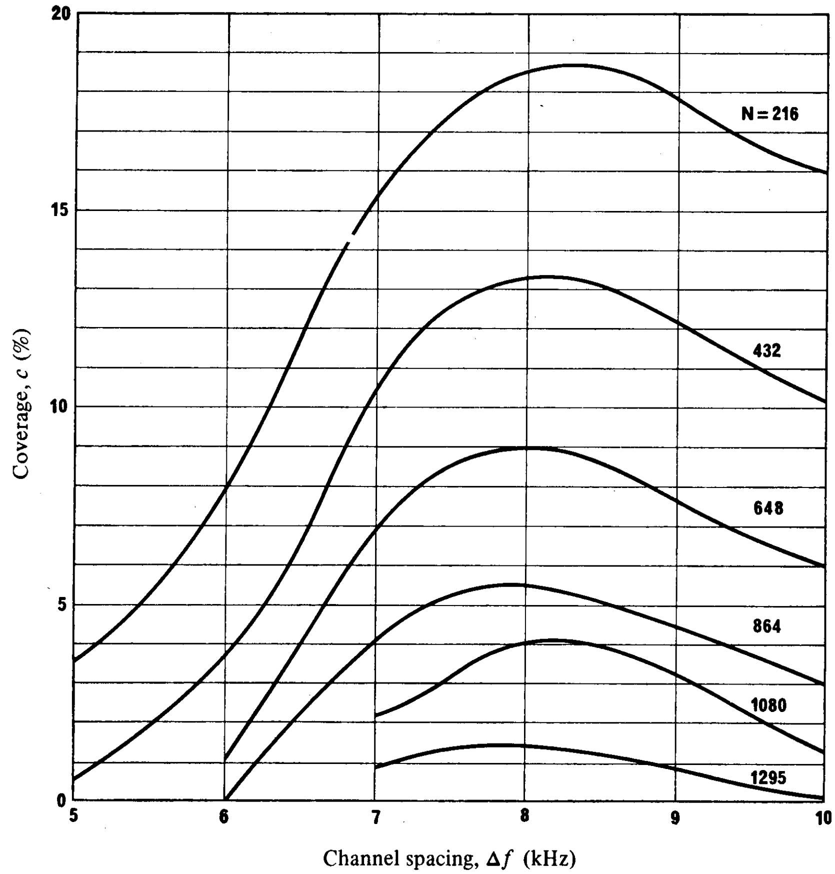

FIGURE 8 – *Coverage, c, obtainable by the sky-wave with all channels in band 6 (MF)*

Parameter: number of frequency assignments, *N*

Basic assumptions:
- total area: 42×10^6 km^2
- co-channel protection ratio for the median field: 27 dB
- relative protection ratios: Curves of Recommendation ITU-R BS.560
- each wanted transmitter interfered with by three co-channel and three adjacent-channel transmitters
- sky-wave propagation curves: Recommendation ITU-R P.1147

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In practice, however, both types of interference have to be considered and it is obvious that the resulting coverage curve, as a function of frequency spacing, will be situated below the two curves discussed above.

Furthermore, from the shape of the two limiting curves, it is very probable that the resulting curve will have a maximum and, in fact, there is a maximum (curve C of Fig. 9) which is, however, relatively flat.

It has been shown in a further study that the optimum channel spacing corresponding to maximum coverage depends mainly on the relative RF protection-ratio curve and, more precisely, corresponds roughly to a value of about $A_{rel} = -20$ dB. Hence, the differing results obtained in the various parts of the world are by no means inconsistent and rather confirm, to some extent, the usefulness of this additional study.

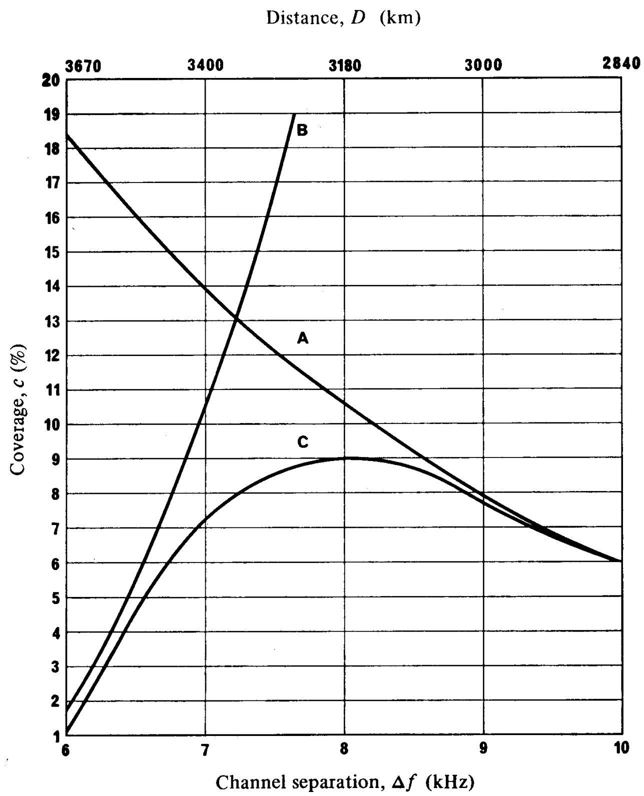

FIGURE 9 – *Limits for area coverage (radio-frequency protection ratio: 27 dB)*

Curve A: area coverage in the presence of co-channel interference (three transmitters)

Curve B: area coverage in the presence of adjacent-channel interference (three transmitters)

Curve C: area coverage obtainable in the presence of co-channel and adjacent-channel interference

Protection ratio *A*: 27 dB

Number of frequency assignments *N*: 648

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The family of curves in Fig. 10 provides a simple but efficient means for the determination of the optimum channel spacing for a given RF protection-ratio curve. Figure 10 shows the coverage factor as a function of the channel spacing, where both co-channel and adjacent channel interference are taken into account. However, for the particular purpose the adjacent-channel protection-ratio values are used as a parameter which is independent of the channel separation. Thus, the curves of Fig. 10 can be used in conjunction with either Fig. 1 of Recommendation ITU-R BS.560 or any other pertinent relative RF protection-ratio curve for the purpose envisaged. If in Fig. 10, at each channel spacing, the pertinent curve representing the actual relative RF protection ratio is marked, e.g. by a little circle (in Fig. 10 this has been done for the relative RF protection-ratio curve C of Recommendation ITU-R BS.560) or a little square (representing relative RF protection-ratio values obtained from U.S.S.R. high-quality receivers having a wide pass band) the sequence of these little circles or squares shows the real dependence of the coverage factor on the channel spacing and in fact indicates, as can be seen from the Figure, a maximum at a spacing of about 8 kHz or 9 kHz, respectively.

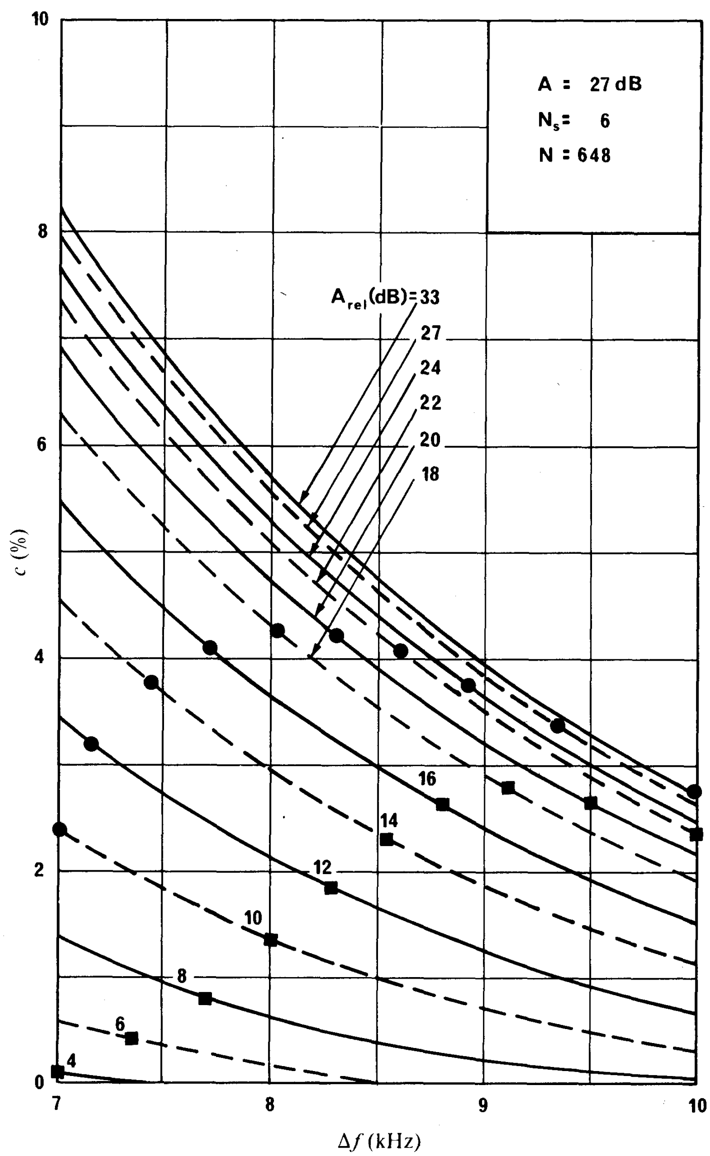

FIGURE 10 – *Coverage factor (c) as a function of channel spacing*

Parameter: relative radio-frequency protection ratio (A_{rel})

● : specific value of A_{rel}, see Recommendation ITU-R BS.560, Fig. 1 curve C

■ : specific value of A_{rel}

N : total number of frequency assignments

N_S : number of groups of interfering transmitters each consisting of one co-channel and one adjacent-channel transmitter

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It should not be overlooked, however, that the results showing the superiority of a specific value of channel spacing were obtained in studies based on regular transmitter lattices and linear channel distributions. If in particular, the distance between adjacent-channel transmitters varies over a wide range throughout the planning area including in many cases, relatively short distances, the effect of adjacent-channel interference will become more severe than in the theoretical case. In such conditions it may be necessary to select channel spacings in excess of the theoretical optimum.

5 Conclusions

The coverage that can be obtained in band 6 (MF) is mainly determined by the distance between any two transmitters sharing the same channel, i.e. the co-channel distance, and by the frequency spacing between adjacent channels.

The optimum co-channel distance depends on many parameters, namely the frequency, the power level of the transmitter network, the radio-frequency protection ratio, the minimum usable field strength, and the propagation properties of the ground wave and the sky wave, as the case may be. The choice of an adequate co-channel distance immediately and irrevocably determines the number of transmitters that may operate in the same channel and vice-versa. This relationship is shown, among others, in Fig. 5.

The optimum channel separation depends on the relative radio-frequency protection-ratio curve taken to be representative of receivers in the area to be planned.

It should be noted, however, that coverage can be considerably improved beyond the limits derived in this Annex by (see Annex 2):

– use of directional transmitting antennas suitably adapted to the particular situation;

– the use of synchronized transmitter networks;

– transmitter powers carefully adapted to the individual coverage problem.

ANNEX 2

Practical aspects of MF broadcasting coverage

1 Day-time coverage

The following results are based on the ground-wave propagation curves of Recommendation ITU-R P.368.

Due to the strong absorption of the sky-wave in band 6 during the day-time, only the ground-wave can be used for coverage. The coverage radius (see Annex 3) depends upon the frequency and the electrical characteristics of the soil within the coverage area; this radius for higher transmitter powers is about 100 km. A transmitter network optimized for day-time coverage could be based on very low co-channel distances, i.e. on a considerably higher transmitter density than that existing at present. For example, a day-time network based on an average co-channel distance of roughly 500 km would provide at any location, about ten radio programmes with good quality of reception.

Coverage during the day-time therefore does not represent a technical problem.

2 Night-time coverage

With the onset of darkness the absorption of the sky-wave is greatly reduced and high values of field strength may build up during a period of one or two hours at distances of thousands of kilometres. This produces interference and limits the ground-wave coverage range. In general, the sky-wave has been regarded mainly as a source of interference, and the systematic use of the sky-wave for coverage purposes has been envisaged for special cases only.

At night-time, the presence of the sky-wave gives rise to complicated technical problems and necessitates planning methods for very large areas based on internationally agreed rules.

To obtain a clear picture of the possibilities of providing radio programmes in band 6 under various basic assumptions, a great number of frequency-assignment exercises have been carried out within the EBU, and the coverage factors obtained have been calculated. These studies were made for the European and African broadcasting areas.

These exercises were made on the basis of rather evenly distributed transmitters with equal power radiated from omnidirectional antennas, the sites of which, however, coincided with real or planned sites in Europe and Africa. The coverage areas were calculated using a statistical method and taking into account only the interference caused by the other transmitters. This method enables a valid comparison to be made between the results of two different exercises, but the absolute values of the results should not be used without due care.

For the purpose of the calculations, certain values of radio-frequency protection ratio (as defined in Recommendation ITU-R BS.638) have been adopted. These different values of radio-frequency protection ratio correspond, of course, to different grades of service. It is evident that the coverage areas so calculated are larger for smaller values of this ratio than for the higher values. The increase in coverage area with decreasing value of protection ratio (i.e. with decreasing grade of service) does not imply that better listening conditions will be obtained; the listening conditions do not depend upon the protection ratio, but only on the power and on the configuration of the interfering transmitters.

It should be noted that, when comparing the results of two different exercises the differences may be more or less pronounced depending upon the radio-frequency protection ratio, i.e. the grade of service adopted. Therefore, the calculation results should not be discussed without making mention of the corresponding grade of service.

Finally it should be recalled that, in the calculations, statistical propagation data have been used. In particular, ionospheric field-strength prediction curves have been taken, which represent median values (i.e., values for 50% of the time) for an average frequency of 1 000 kHz.

It can be assumed, therefore, that the results obtained are reasonably suitable for representing the average situation for the whole of the spectrum covered by band 6.

Some of the results are summed up hereafter.

2.1 Ground-wave coverage at night

The total amount of ground-wave coverage depends in the first place on the co-channel distance, i.e. on the transmitter density. For a given transmitter power, the ground-wave coverage increases with increasing co-channel distance. Thus, for 300 kW transmitters, and assuming protection ratios of 40 dB, 33 dB and 27 dB, the following percentages of the combined surface areas of Europe and Africa can be covered by the employment of the 121 channels now available in band 6:

TABLE 1

Co-channel distance (km)	Ground-wave coverage					
	Radio-frequency protection ratio (dB)					
	40		33		27	
	Number of programmes	Area coverage (%)	Number of programmes	Area coverage (%)	Number of programmes	Area coverage (%)
2700	1	6	1	11	1	21
3500	1	8	1	15	1	25
4100	1	9	1	17	1	28

These coverage factors can possibly be improved by the use of synchronized networks and of directive antennas. Moreover, the population coverage can be made superior to the surface coverage by appropriate transmitter siting. Little numerical information is available on these possible improvements.

The question of the transmitter power which provides the greatest possible ground-wave coverage for a given transmitter density, has been the subject of detailed studies from which a sufficiently accurate answer may be derived. Furthermore, it should be recalled that night-time ground-wave coverage is also limited by interference between the ground-wave and the sky-wave from the same transmitter, but this effect has been ignored in the calculation of the approximate service ranges as given in Annex 4.

2.2 Sky-wave coverage

Under the same assumptions as those made in § 2.1 (300 kW transmitters, 40 dB, 33 dB or 27 dB protection ratio) the sky-wave would provide coverage of the combined surface areas of Europe and Africa, using the entire band 6 as follows (see Table 2).

It can be seen that at night the sky-wave coverage depends far more than the ground-wave coverage on the transmitter density adopted: for high transmitter densities (i.e. co-channel distances even smaller than 2 700 km) nocturnal coverage decreases rapidly, whereas a co-channel distance of 4 100 km would permit the reception of several programmes at any location within the area considered. The majority of these programmes would, of course, be originated far from the reception point. Moreover, the fact should not be overlooked that it is impossible, contrarily to the ground-wave, to achieve consistently good quality by means of the sky-wave. Account should also be taken of the fact that, in practice, the area covered at night will not be continuous, for there will be an annulus embracing ranges in the region between 100 km and 200 km in which severe selective fading will be caused by interference between the ground-wave and the sky-wave. This effect has been neglected in the studies made so far. Examples for approximate coverage ranges are given in Annex 4. The fact remains that the utilization of the sky-wave would allow better use to be made of the spectrum in respect to area coverage, because the ratio between the coverage area and the area of interference is more favourable. Finally, it should be recalled that, conditions yielding satisfactory night-time ground-wave coverage, will also normally result in a reasonable amount of sky-wave coverage.

TABLE 2

Co-channel distance (km)	Sky-wave coverage					
	Radio-frequency protection ratio (dB)					
	40		33		27	
	Number of programmes	Area coverage (%)	Number of programmes	Area coverage (%)	Number of programmes	Area coverage (%)
2700	negligible		1	30	6.1	100
3500	1	15	7.4	100	23.3	100
4100	2.5	100	14.9	100	31.6	100

2.3 Combination of ground-wave and sky-wave coverage

It can be concluded from § 2.1 and 2.2 that good results for both types of coverage may be obtained if the high-power co-channel transmitters are sufficiently widely spaced.

3 Combination of day-time and night-time coverage

As shown in § 1 and 2, transmitter networks devised for good coverage during the day-time differ fundamentally from those set up for good coverage at night; the co-channel distances would, for example, be about 500 km for day-time and about 4 000 km for night-time. As the corresponding total number of transmitters for these networks would have a ratio equal to the square of the ratio of the co-channel distances, the coexistence of both networks would mean that, in this example, only one out of every 64 transmitters could be operated after sunset. In this example, two extreme cases of optimum coverage conditions are compared, neither of which corresponds to present practice. Any network wherein all transmitters remain in operation day and night will reduce the coverage, either by day or by night, or, in the case of a network based on a compromise between the two types of network, will reduce coverage during day and night.

On the other hand, the transition from efficient day-time operation to efficient night-time operation would lead to some problems of an operational and administrative nature. In fact, as shown, the majority of the day-time transmitters would have to be closed down at sunset, to avoid unacceptable interference during the hours of darkness. The time of close-down itself may then depend on the season and the latitude, especially at high and medium latitudes. Moreover, because of the comparatively slow build-up of the sky-wave after sunset, there will always be a period when either the ground-wave network suffers interference (if all transmitters are still in operation) or the sky-wave signals are still too weak. Although the difficulties mentioned above appear to make the general use of such a mode of operation impracticable, its potential advantages are such that a further study is desirable, particularly in respect to certain special cases.

The assignment standards used by the Regional Administrative MF Broadcasting Conference (Region 2) (Rio de Janeiro, 1981) may serve as an example for combined day-time and night-time coverage.

Three classes of stations are provided, A, B and C. Class A are generally permitted 100 kW maximum power day-time and 50 kW night-time, Class B, 50 kW for either operation, and Class C 1 kW, except that in the tropical noise zone 2, Class C are permitted a maximum 5 kW day-time power. Class A are intended to provide extensive secondary (sky-wave) service areas, Class B relatively large primary (ground-wave) service areas, and Class C small local primary service areas.

The night-time coverage, based upon *26 dB co-channel* protection of ground-wave service areas from multiple sky-wave interfering sources, is afforded on the basis of an RSS addition of interfering signals. However, only the major contributors enter the determination of usable field strength (E_u). With the interfering signals listed in order of magnitude, any contributor whose signal is less than half the arithmetic value of the *RSS total of interfering fields* calculated using all greater contributions is not deemed to cause interference. The process applies only where the E_u is greater than the nominal usable field strength (E_{nom}). Typically, only two or three interfering stations contribute to the E_u despite the presence of numerous co-channel stations in the Region. New stations must contribute less than half the value of existing E_us, and must contribute less than the smallest contributor considered to interfere so as not to displace that contributor.

4 Population coverage

While the area coverage is important, another aspect, namely, of population coverage is also of importance. Studies on the problems of population coverage have been initiated in some countries, but further study is required on this point.

5 Improvements of coverage

5.1 Synchronized networks

A synchronized network is a group of transmitters intended primarily for a ground-wave coverage radiating the same programme at a common frequency.

In most European countries, the use of synchronized networks to replace single transmitters of equivalent power leads to better adaptation of coverage to population distribution, and thereby increases total population coverage. Annex 5 shows some examples of the results obtained in various countries. The use of synchronized groups is most effective in those countries where there are widely spread areas of high population density.

It should be emphasized:

– that acceptable reception quality of the sky-wave signal is more likely in those areas where the sky-wave of one transmitter of the synchronized group predominates;

– that the interference from a synchronized group is equivalent to that from a single transmitter sited at the centre of gravity of the group, with a power equivalent to the total power of the group, provided that the average distance between the group of transmitters is not more than about one-tenth of the distance to the nearest co-channel transmitter;

– that synchronized networks are of less value in small countries;

– that the use of directional transmitting antennas improves the coverage from synchronized networks;

– that the use of product demodulators decreases the non-linear distortion due to interference between the transmitters of a synchronized network; this would increase the coverage obtained.

On the other hand, transmitters of a synchronized network may radiate different programmes during daylight hours, if the transmitters are sufficiently widely spaced.

It is obvious that investment and operational costs are higher for a synchronized network than for a single transmitter; nevertheless, the use of synchronized networks should be envisaged in each case where the advantages quoted are to be expected.

5.2 Antenna directivity

5.2.1 Vertical diagram of vertically-polarized transmitting antennas

An antenna may be designed to have a particular vertical radiation pattern so that the power is concentrated in the particular vertical segment or segments which will achieve the type of coverage required.

By concentrating the power in the *horizontal plane* it is possible to improve the ground-wave day-time coverage or to use a lower transmitter power for the same coverage. Where the onset of fading, and not co-channel interference, is the factor limiting ground-wave coverage, an anti-fade antenna will improve ground-wave coverage. This improvement is only likely to be obtained with frequencies at the lower end of band 6, in situations where ground conductivity is better than average. Finally, although such antennas may lead to a reduction in ionospheric cross-modulation, they provide a poorer sky-wave coverage, for the same interference, at shorter ranges (distances less than 2 000 km).

By concentrating the power away from the horizontal plane, the sky-wave coverage is improved, but ground-wave coverage becomes less good and the risk of ionospheric cross-modulation is greater.

5.2.2 Horizontal diagram of vertically-polarized transmitting antennas

By concentrating the radiated power in given horizontal directions particular coverage requirements can be met. Although the general use of directional antennas in a frequency plan does not lead to an overall improvement of coverage, the use of directional antennas will be advantageous when considering the coverage within individual countries, mainly because it may lead to a better adaptation to specific wanted coverage areas and also to a reduction of interference in specific cases. In a particular case, the employment of an antenna which is directional in the horizontal plane will allow a frequency channel to be used in a given zone where this frequency could not be used with an omnidirectional antenna. The use of such a directional antenna can reduce the interference in the coverage area of another co-channel transmitter and as a result permit the reduction of the co-channel distance. This is the principal advantage of an antenna with a horizontal directional pattern.

5.2.3 Economic considerations

In general any antenna, the vertical or horizontal radiation characteristics of which are designed to fulfil specific requirements, will cost more than a non-directional antenna. Special requirements for the vertical radiation pattern normally lead to higher structures, and the cost of a vertical structure increases rapidly with height.

Special requirements for the horizontal radiation pattern lead to multi-element antenna arrangements and therefore to the use of more extensive sites.

The cost of any antenna design will be lower at the higher-frequency end of band 6. Local weather conditions will be an important factor influencing the cost.

5.2.4 Improving MF coverage by the use of directional antennas

To minimize interference between MF stations, directional transmitting antennas have been used in the USA since the mid-1930s. At present more than 1500 are in use. Other countries are also using such antennas for similar purposes.

The use of directional antennas for transmitters operating on the same channel within a country, but not in synchronism, can lead to a substantial increase in coverage. Generally speaking, the more directional antenna operations employed, the greater the improvement in coverage efficiency.

Directional antennas are particularly effective at night, and are also helpful for day-time operations. Directional antennas are also useful in reducing interference to the transmissions of other countries. Another advantage of operating transmitters with directional antennas in the same channel, but not in synchronism, is that it permits independent local programming.

5.3 Relative merits of antennas with horizontal and vertical radiating elements

A conventional vertical transmitting antenna will provide a useful ground-wave coverage for a limited range and a sky-wave coverage at night at greater ranges. At an intermediate range there is a zone where fading is more severe because the ground- and sky-wave field strengths are nearly equal.

The use of a horizontal radiating element or an array of such elements, which is practicable in band 6 (MF), has certain advantages when the main purpose is to provide a night-time, sky-wave coverage, but it is not suitable for providing a day-time coverage by ground-wave.

The main advantage is that it can be designed to provide a nearly constant sky-wave field strength from the transmitter out to the edge of the service area. The design may provide for a coverage range up to the feasible maximum (about 1 000 km) or may be designed for a more limited coverage range (e.g., about 500 km). Nevertheless, very close to the transmitter (within a few kilometres) there may be degradation of quality because of interference between the small unavoidable ground-wave and the sky-wave. If this area is required to have a good service, a small "fill-in" transmitter using a different frequency and vertical polarization may be necessary.

Calculations which take account of the differing directivities and polarization-coupling losses for the case of a single horizontal dipole in place of a short vertical antenna, have been presented. The importance is stressed, of allowing for the effects of imperfect ground conductivity, which not only reduces the low-angle radiation from vertical antennas but also increases the low-angle radiation from horizontal antennas in certain directions. In the latter context, the reduction of co-channel interference from low-angle propagation modes expected from the use of a horizontal transmitting antenna, (if used in place of a vertical antenna), may be over-estimated by as much as 20 dB, particularly if perfectly conducting ground is assumed when in practice the ground conductivity is poor.

The results of the theoretical studies show that, for a given transmitter power, where reflections are confined to the E region, the use of a horizontal dipole in place of a short vertical antenna can reduce the level of co-channel interference by 10 to 15 dB for typical ground characteristics. More recent studies and practical measurements at temperate latitudes have, however, shown that for frequencies and times at which high-angle F-region reflections occur, the advantage is much reduced, because of the strong excitation of multi-hop propagation modes.

A disadvantage of the use of a horizontal antenna is that it is necessary to change over to a vertical antenna for day-time service, but in general, a comparable coverage area may not be obtained without the use of many transmitters. Here also, there is a problem of change-over as discussed already under § 3. Another disadvantage, is that the cost of transmitting antenna may be large, particularly for the lower frequencies in band 6.

In general, it will be necessary to limit the radiated power to suitable values as a function of the angle in the vertical plane, to avoid causing serious ionospheric cross-modulation. (See Annex 1 to Recommendation ITU-R BS.498). This requirement may be more difficult to fulfil with horizontal antenna systems than for a vertical antenna.

It has recently been suggested that a horizontal antenna should consist of one or more pairs of crossed dipoles appropriately fed to transmit elliptically-polarized waves in the wanted directions so as to excite the ordinary wave more strongly than the extraordinary wave. The main advantage over a system radiating linearly-polarized waves is that since ionospheric cross-modulation is caused mainly by the extraordinary wave, less cross-modulation should in theory result for a given transmitter power. A further advantage would be a reduction of polarization coupling loss.

In conclusion, it can be stated that vertical radiation from horizontally-polarized antennas can be valuable in certain special cases. Its general introduction into a frequency-assignment plan, however, cannot be recommended as a means of obtaining a higher density of assignments on the basis of the information available now.

Measurements have been carried out in the People's Republic of Poland to compare the effectiveness of vertical and horizontal polarization for ground-wave coverage using frequencies in the upper part of band 6 (MF). Measurements were made at distances of up to 20 km from the transmitter, the transmission paths being over built-up areas as distinct from open country, and the results indicate that the attenuation of horizontally-polarized waves appears to be considerably less than would be expected from the theory of ground-wave propagation over a smooth Earth.

With regard to the reduction of sky-wave in broadcasting in band 6 (MF), studies have been carried out in Australia to investigate a method of sky-wave field strength reduction which exploits the high absorption of extraordinary waves for transmission frequencies near the gyro-frequency. The transmitting antenna for this system is required to radiate a signal polarized in such a manner that waves entering the ionosphere do so exclusively through extraordinary modes. The system is termed orthogonal transmission.

Propagation tests conducted in 1965 and 1967 indicate that the median value of the sky-wave field strength from a broadcasting transmitter operating in band 6 (MF) may be reduced by 16 dB on paths to the north in the southern hemisphere, when conventional vertically-polarized transmission is replaced by orthogonal transmission. No significant change in this reduction was evident on south-north paths extending from 243 km to 695 km. The reduction decreased on paths with eastward or westward components due to features in the design of the transmitting antenna, which did not provide the polarization ellipse tilt required on such paths. A field-strength reduction of 13 dB was measured on paths which were 19° to the east or west of the bearing of the target area (magnetic North).

This method using mainly extraordinary modes cannot be recommended for all classes of power because of ionospheric cross-modulation effects especially caused by the extraordinary wave (see above).

5.4 Low-power stations

The purpose of low-power transmitters is to cover limited areas, such as towns, where the field strength of the main transmitters is insufficient, or possibly for the transmission of local programmes.

For an efficient service these stations must be included in the plan. It seems that in practice they can only operate with a usable field strength well above that of other stations (in particular at night).

Apart from low-power transmitters which are part of a synchronized network (see § 5.1), these transmitters may use:

– either channels allocated to transmitters of different powers;

– or one or several special channels (formerly called International Common Frequencies (ICF)).

In the first case, the sites of the stations and their other characteristics must be clearly determined in the plan, and any later addition would be dangerous. In the second case, it would be sufficient to state the geographical areas where these transmitters may be sited (taking into account the adjacent-channel interference) and, in addition, to indicate the number of transmitters per area and the maximum power which may be used.

Studies already made show that the present number of ICFs is quite insufficient, and that a total of five to ten would be preferable.

From a technical point of view, these transmitters would be more efficient if their frequencies were in the lower part of band 6, but in practice some of them would no doubt have to use channels throughout the spectrum. Moreover, the maximum power admissible and the number of low-power transmitters depend on the frequency.

ANNEX 3

Approximate day-time coverage ranges

Day-time coverage ranges have been calculated in the absence of interference from unwanted transmitters by using the propagation curves given in Recommendation ITU-R P.368. For the limitation of the coverage ranges tentative values of the minimum field-strength have been assumed:

2.2 mV/m (67 dB (μV/m)) for the lower third of band 6 (MF) (525 kHz to 900 kHz approximately);

0.8 mV/m (58 dB (μV/m)) for the upper third of band 6 (MF) (1 250 kHz, approximately, to 1 605 kHz).

Three values of ground conductivity are assumed:

– good conductivity ($\sigma = 10 \times 10^{-3}$ S/m)

– average conductivity ($\sigma = 3 \times 10^{-3}$ S/m)

– poor conductivity ($\sigma = 1 \times 10^{-3}$ S/m)

When considering the figures so obtained, it should be borne in mind that the average situation of transmitting sites in many countries by no means corresponds to a ground conductivity of $\sigma = 3 \times 10^{-3}$ S/m; moreover, the fact that many such sites are situated on hilly or mountainous terrain would normally lead to coverage ranges below the figures quoted in the following sections.

The e.m.r.p. in the horizontal plane is supposed to be 500 kW (c.m.f.: 6 700 V).

TABLE 3

Frequency (kHz)	Service range (km)		
	$\sigma = 1 \times 10^{-3}$ (S/m)	$\sigma = 3 \times 10^{-3}$ (S/m)	$\sigma = 10 \times 10^{-3}$ (S/m)
Lower third of band 6			
525		180	310
900	80	130	
Upper third of band 6			
1 250		105	180
1 605	60	90	

ANNEX 4

Approximate night-time coverage ranges

The following assumptions are made for the calculation of the night-time coverage ranges:

– two transmitters on the same frequency at a distance of 3 500 km and radiating the same power, this power being such that mutual interference is the only factor determining the coverage range*; the interference between the ground-wave of the wanted transmitter and its own sky-wave has been ignored;

* The trend shown in Table 4 also appears for other cases of interference (more than two transmitters, different distances, etc.).

– ground-wave propagation according to Recommendation ITU-R P.368;
– ground conductivity: $\sigma = 3 \times 10^{-3}$ S/m;
– sky-wave propagation according to Recommendation ITU-R P.1147;
– protection ratio: 27 dB, 33 dB and 40 dB.

TABLE 4

Protection ratio (dB)	Service range (km)	
	525 kHz	1 605 kHz
Ground-wave service		
27	170	90
33	135	70
40	95	55
Sky-wave service		
27	635	850
33	420	660
40	< 300 (1)	450

(1) The curves used in the study are not valid for distances of less than 300 km.

ANNEX 5

Coverage obtained from synchronized transmitters

Table 5 shows the result of studies where the day-time and night-time coverage of existing groups of synchronized transmitters was compared with the coverage that would have been obtained by a hypothetical single transmitter suitably placed and having a total power equivalent to the total power of the synchronized group.

TABLE 5

Ratio of the coverage obtained by a synchronized group of transmitters and a single transmitter

Origin	Frequency (kHz)	Number of transmitters	Total power (kW)	Coverage ratio			
				Day		Night	
				Surface	Population	Surface	Population
O.R.F.	1025	4	300	1.45	1.68		1.83
B.B.C.	1214	16	270		1.26		3.2 (1) 3.0 (2)
RAI	1367	14	85	2.12	3.84	1.39 (3) 1.18 (4) 0.81 (5)	6.24 (3) 7.39 (4) 17.74 (5)

(1) Including interference from transmitters not belonging to the synchronized group.

(2) Interference between the transmitters of the synchronized group only.

(3) Co-channel protection ratio 20 dB against transmitters not belonging to the synchronized group.

(4) Co-channel protection ratio 25 dB against transmitters not belonging to the synchronized group.

(5) Co-channel protection ratio 40 dB against transmitters not belonging to the synchronized group.