

RECOMMENDATION 598-1*

**FACTORS INFLUENCING THE LIMITS OF AMPLITUDE-MODULATION
SOUND-BROADCASTING COVERAGE IN BAND 6 (MF)**

(Question 44/10, Study Programme 44F/10)

(1982-1990)

The CCIR,

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,

UNANIMOUSLY 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 I.

The information contained in Annex I 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 II, III, IV and V.

* This Recommendation incorporates, in Annexes II to V, the contents of Reports 616-3 (Dubrovnik, 1986) and 461 (Dubrovnik, 1986) which are hereby deleted.

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 :

$$E_u = E_w = \sqrt{E_{min}^2 + \sum_{i=1}^n (E_i \times a_i)^2} \quad (\text{see Report 945})$$

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

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

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):

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

- 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 I 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.

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.

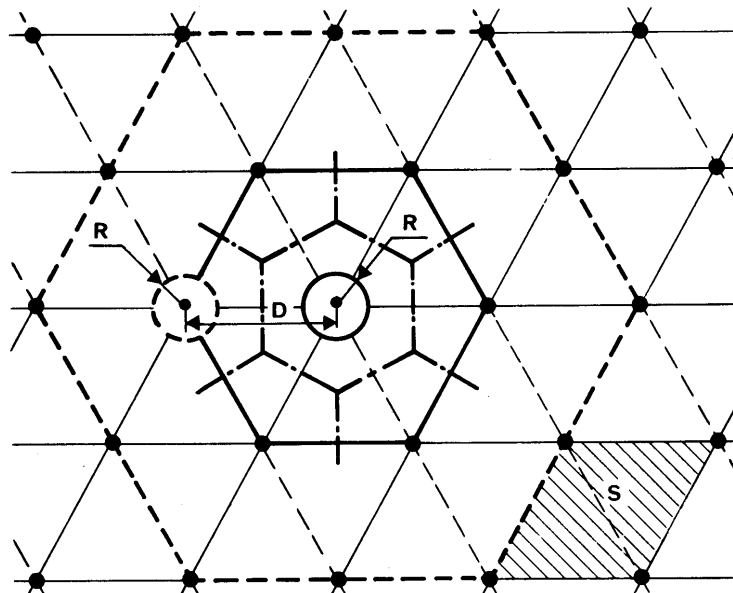


FIGURE 1 – Regular lattice of transmitter sites

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

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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-channel 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 368;
- sky-wave propagation curves of Recommendation 435 (type 1) or Report 575, (type 2);
- 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 $p = 1000$ kW;
- the minimum usable field strength is $E_{min} = 60$ dB ($\mu\text{V/m}$);
- the radio-frequency protection ratio values are $A = 40, 30$ or 27 dB;
- the ground conductivity values are $\sigma = 10^{-3}, 3 \times 10^{-3}$ 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 II).

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 $2D$ 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 $2D$,
- 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 $1 \mu\text{V/m}$ 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. 2800 km or 4800 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 1500 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.

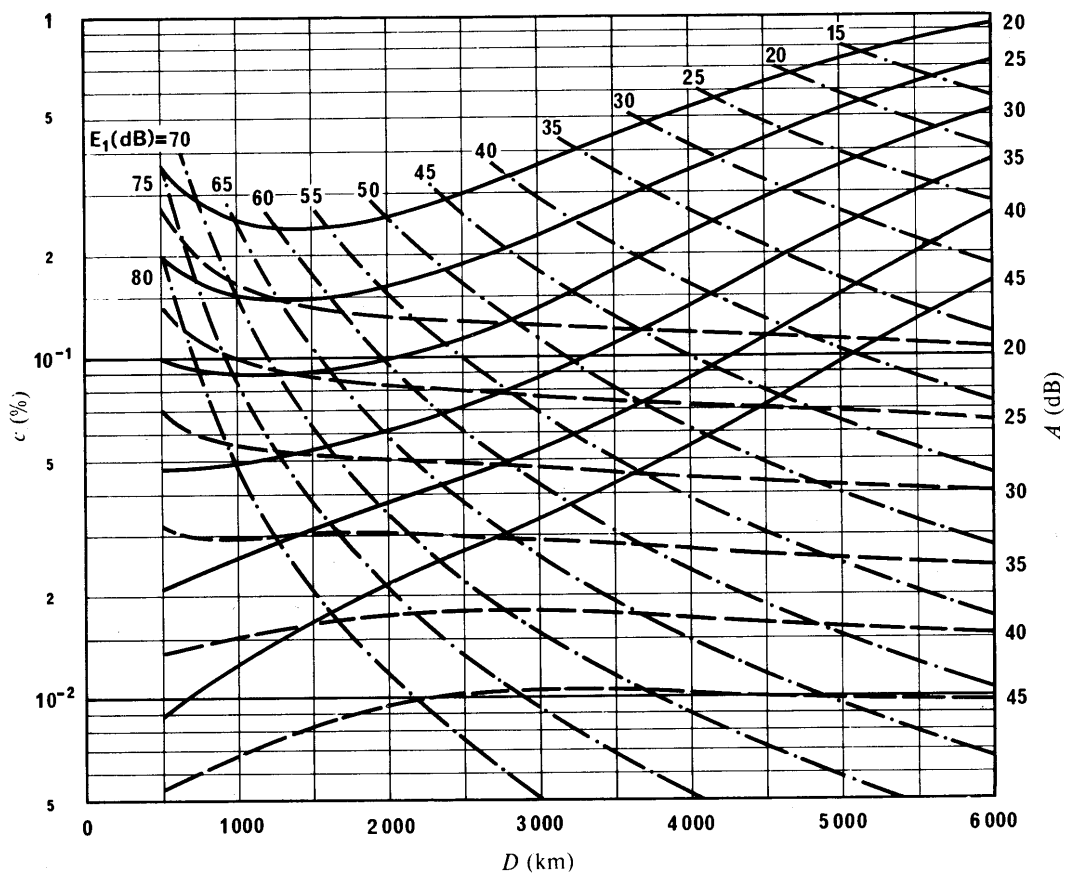


FIGURE 2 – Coverage factor per channel (c) as a function of distance between co-channel transmitters (D) for various propagation conditions

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 368
- unwanted signals: sky wave: type 1 (Recommendation 435)
 type 2 (Report 575)

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 B₁ and B₂ 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 C₁ and C₂ 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 in [Eden and Minne, 1969] 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 utilise the results that have already been obtained by considering networks on a plane surface.

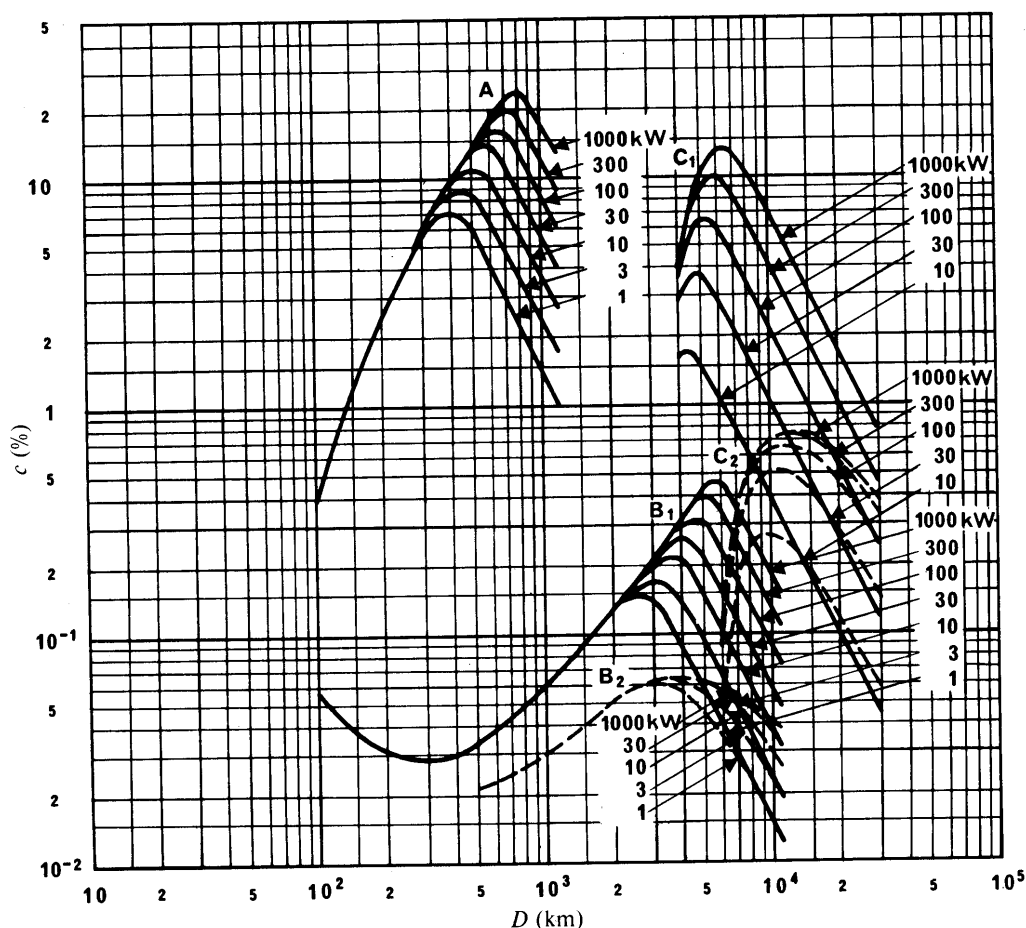


FIGURE 3a – Coverage factor per channel (c) as a function of distance between co-channel transmitters (D) for various propagation conditions

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 368
- sky-wave: type 1 (index 1): Recommendation 435
- type 2 (index 2): Report 575

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

Ground conductivity: $\sigma = 10^{-2}$ S/m

Protection ratio: $A = 40$ 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 7050 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.

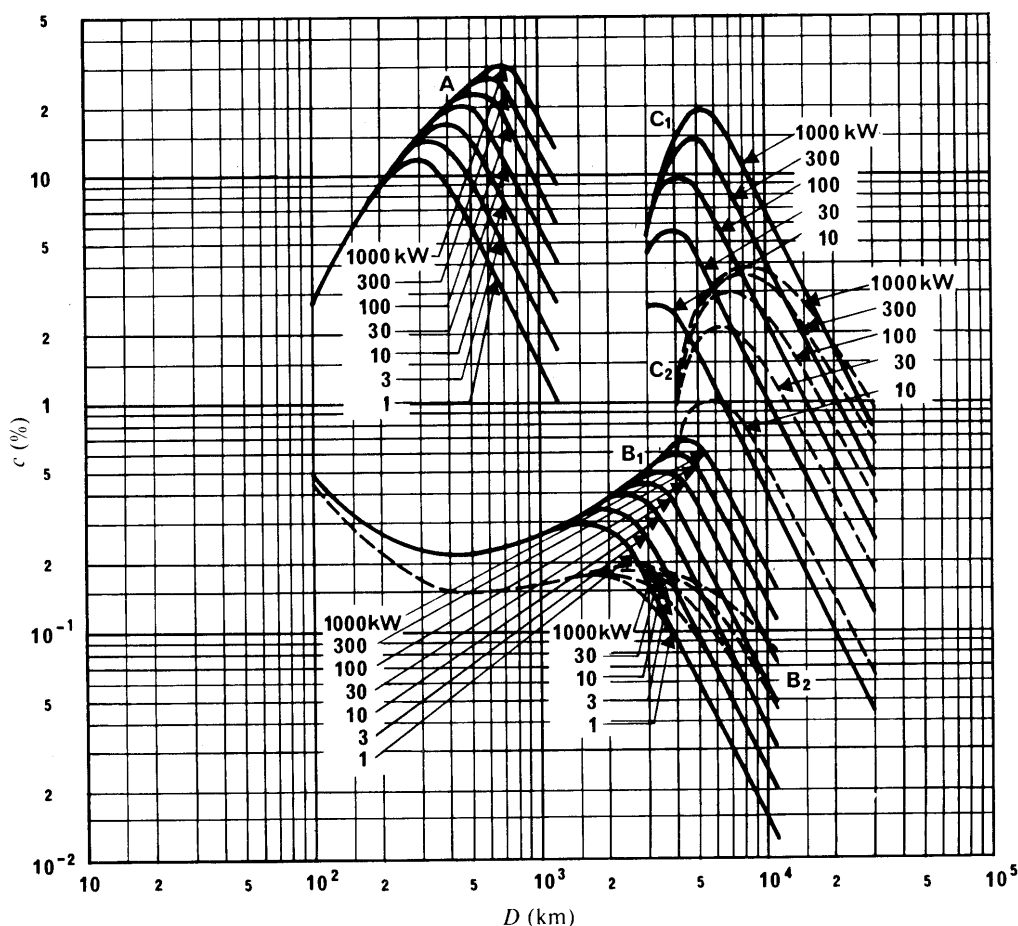


FIGURE 3b – Coverage factor per channel (c) as a function of distance between co-channel transmitters (D) for various propagation conditions

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 368
- sky-wave: type 1 (index 1): Recommendation 435
- type 2 (index 2): Report 575

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

Ground conductivity: $\sigma = 10^{-2}$ S/m

Protection ratio: $A = 30$ dB

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