RECOMMENDATION ITU-R F.162-3*

USE OF DIRECTIONAL TRANSMITTING ANTENNAS IN THE FIXED SERVICE OPERATING IN BANDS BELOW ABOUT 30 MHz

(Question 150/9)

(1953-1956-1966-1970-1992)

The ITU Radiocommunication Assembly,

considering

a) that there is serious congestion in the fixed service bands between 4 and 28 MHz;

b) that occupancy of the radio-frequency spectrum is represented, not only by occupancy in bandwidth and time, but also by the spatial distribution of the radiated power;

c) that radiation outside the directions necessary for the service can be effectively reduced by the use of directional antennas;

d) that Articles S3 and S15 of the Radio Regulations would seem to justify explicit requirements for the use of directional antennas in these bands;

e) that the Panel of Experts, in Recommendation No. 13 of its Final Report, Geneva, 1963, advocates the use of directional antennas for transmission and reception in the fixed service;

f) that the request by the Panel of Experts in Recommendation No. 38 of its Final Report, Question 150/9, ask for specification of reasonable standards of directivity for antennas in the various types of radio services in the bands between 4 and 28 MHz, with due regard to economy of cost;

g) that the adoption of minimum standards for directional antennas would contribute to the solution of frequency sharing problems;

h) that antenna performance materially better than these minimum standards is attainable at economic cost using modern techniques,

recommends

1. that the following definitions should be used in specifying the performance of directional antennas:

1.1 Directivity, G_0**

In a given direction, 4π times the ratio of the intensity of radiation (power per unit solid angle (steradian)), in that direction, to the total power radiated by the antenna.

1.2 Service sector, *S*

The horizontal sector containing the main beam of the antenna radiation and including the direction required for service. It is very close to twice the angular width of the main beam measured to the half-power (–3 dB) points.

* Radiocommunication Study Group 9 made editorial amendments to this Recommendation in 2000 in accordance with Resolution ITU-R 44.

** See No. S1.160 of the Radio Regulations for a definition of power gain.

1.3 Interference sector, I

The horizontal sector outside the main beam

$$I^\circ = 360^\circ - S^\circ$$

1.4 Minimum standard antenna

The antenna having the specified minimum characteristics as regards directivity and service sector at its operating frequency or frequencies.

1.5 Economic standard antenna

The antenna having the specified characteristics as regards directivity and service sector at its operating frequency or frequencies which are justifiable on economic grounds (i.e. by savings in the cost of providing a given transmitter output power).

1.6 Antenna directivity factor, M*

The ratio of the power flux-density in the wanted direction to the average value of power flux-density at crests in the antenna directivity pattern in the interference sector. This is equivalent to the average improvement in signal-to-interference ratio achieved by using the actual antenna in place of an isotropic radiator in free space;

2. that the minimum standard antenna should have a directivity factor given by:

$$M = 0.1\, f^2$$

f being the operating frequency in MHz;

3. that the economic standard antenna should have a directivity factor given by:

$$M = 0.25\, f^2$$

4. that, for a radiated power of 5 kW or greater, the directivity factor, M, of the antenna used should be equal to or greater than that of the minimum standard antenna;

5. that, for a radiated power of 10 kW or greater, antennas having performances not worse than that of the economic standard antenna should be used to the extent practicable;

6. that, for transmitter powers below 5 kW, the power flux-density in the interference sector should not exceed that radiated in this sector from the minimum standard antenna with a total radiated power of 5 kW;

7. that, in the interests of reducing the effects of interference, the directivity factor, M, of the receiving antenna should be equal to or greater than that of the minimum standard antenna and should, as far as practicable, attain that of the economic standard antenna.

Furthermore, when calculated gains, based on constant-current formulae, are used to determine the M-factor, adjustment should be made to allow for the current decay along the actual antenna. Methods of making these adjustments are described in Annex 1.

No preferred polarization or type of antenna is established. Horizontal polarization offers better ground reflection characteristics and, for receiving, some reduction of interference due to man-made noise. Where reflection over sea water or over earth of very high conductivity takes place, the use of vertical polarization can enhance the low-angle performance needed for long paths. This important consideration is reflected in the computation of M, which includes a weighting factor $10/\Delta$, where Δ is the vertical angle of optimum radiation. There is no requirement for the transmitting and receiving antennas to have the same polarization characteristics because of the randomization of the polarization in the ionospheric transmission process.

* The derivation of the directivity factor for any given antenna is explained in Annex 1.

The *M*-factors chosen are largely based upon the measured performance of typical rhombic antennas and typical antenna-arrays. The radiation characteristics of single rhombic antennas in the interference zone are, in general, somewhat inferior to other types of antenna (e.g. half-wave antenna arrays), a fact which is reflected in the *M*-factor. Provided the parameters are correctly chosen, the performance of antennas of differing types possessing the same *M*-factor is comparable;

8. that Annex 1 should be referred to for the values of directivity and service sector;

9. that Annex 2 should be referred to for a detailed explanation of directional antennas;

10. that Annex 3 should be referred to for a description of directional arrays with aperiodic reflector.

ANNEX 1

Values of directivity and service sector

The values of directivity and service sector appropriate to the specified values of M for the minimum standard antenna and the economic standard antenna respectively are given in the following Table 1:

TABLE 1

Operating frequency f (MHz)	Minimum standard antenna			Economic standard antenna		
	M	G_0 (dB)	$S°$	M	G_0 (dB)	$S°$
5	2.5	13.8	54	6.25	17.5	35
10	10	16.6	39	25	20.4	25
15	22.5	18.3	32	57	22.1	21
20	40	19.4	28	100	23.3	18

The antenna gain relative to a half-wave dipole above earth may be obtained by subtracting 8 dB from the value of G_0. It should be noted that the S value is the minimum bound at the directivity specified and has been derived on the assumption that at least 40% of the total power is radiated in the main beam (a value appropriate to many rhombic antennas). Where (as is commonly the case) the (power) gain of the antenna (No. S1.160 of the Radio Regulations) is known, a suitable adjustment should be made to account for the efficiency of the antenna in deriving the directivity.

ANNEX 2

Use of directional antennas in the bands 4 to 28 MHz

1. Introduction

This Annex discusses the problem of specifying reasonable standards for the directivity of antennas in the various types of radio service, and for various distances, in the bands between 4 and 28 MHz with due regard to economy of cost. It is mainly concerned with point-to-point circuits longer than 4 000 km but, with suitable modifications, could be applied to shorter range circuits. The technique discussed requires a knowledge of the gain of the antenna under consideration and the angular widths in zenith and azimuth of its main beam of radiation. With this information a directivity factor is derived which, used in conjunction with certain other factors, for example, transmitter power and provision cost, may be used to assess the suitability of an antenna for any particular application.

2. Proposition

An antenna possessing a given directivity which radiates all its power in a single beam could be regarded as having the best attainable performance of its class. Communication systems using such antennas for emission and reception could operate on a common frequency with a given spatial distribution without risk of mutual interference, the only condition being that each receiving antenna should “see” only the wanted transmitting antenna. With such an ideal arrangement the number of systems sharing the same frequency would increase as a function of the gain of the antennas because of their smaller angular beamwidth.

By making certain simplifying but justifiable assumptions, it can be shown that to a high degree of approximation there is a fixed relationship between the directivity (relative to an isotropic radiator) and the angular widths of this single beam (to the null) as follows:

$$G = \frac{P_0}{P} = \frac{32\,\pi^2}{(\pi^2 - 4)\,\theta_0\,\varphi_0} = \frac{K}{\theta_0\,\varphi_0} \tag{1}$$

(θ_0 and φ_0 are the horizontal and vertical angular widths respectively, in radians and P, P_0 are the total powers radiated from the ideal antenna and the isotropic radiator respectively to produce the same field in the desired direction).

Practical antennas fall some way short of this ideal in that a proportion of the power is radiated (or received) in directions other than in the main beam.

If the directivity of such an antenna is G' and the widths of its main beam are θ_0', φ_0', then from equation (1), the power radiated in the main beam:

$$P' = \frac{P_0\,\theta_0'\,\varphi_0'}{K} \tag{2}$$

If this represents a fraction q of the total radiated power,

$$G' = \frac{P_0\,q}{P'} = \frac{Kq}{\theta_0'\,\varphi_0'} \tag{3}$$

or

$$q = \frac{G'\,\theta_0'\,\varphi_0'}{K} \tag{4}$$

Thus, from the measured or computed characteristics of an antenna it is possible to determine its radiation efficiency, i.e. the fraction of the total radiated power that is directed in the main beam.

The power radiated outside the main beam of a transmitting antenna which is liable to set up interfering signals is given by:

$$\frac{P_0(1-q)}{G'}$$

If this were distributed evenly over the residual hemisphere outside the lunar arc θ_0' the average power flux would be:

$$\frac{P_0(1-q)}{(2\pi-\theta_0')\,G'}$$

Since the maximum flux in the main beam is $P_0/4\pi$, one can write:

$$\frac{\text{Maximum useful signal power flux}}{\text{Average interfering signal power flux}} = \frac{G'\,(2\pi-\theta_0')}{(1-q)\,4\pi} \tag{5}$$

As is well known, the spatial distribution of flux outside the main beam will vary widely and values considerably in excess of the average will be found. It would seem appropriate to express this as a probability distribution in such a way that its effect in degrading the signal-to-interference ratio appears as a term in the directivity factor of the antenna. To do this would require a knowledge of the minor beam flux distributions of a large sample of practical antennas and because insufficient information of this nature is available an alternative approach must be adopted. The method used is to derive an antenna directivity factor based on the assumption that all the misdirected power appears as a number of equi-amplitude secondary beams and to apply an adjustment when individual secondary beam amplitudes are likely to be significant to a particular problem e.g. frequency sharing studies.

If the same power distribution (cosine-squared) as that assumed for the main beam is used then, for the secondary beams:

$$\left(\frac{F_{max}}{F_{average}}\right)^2 = \frac{2\pi^2}{\pi^2-4} = 3.36\ (5.3\ \text{dB})$$

and one can then write:

$$\frac{\text{Maximum useful signal power flux}}{\text{Maximum interfering signal power flux}} = \frac{G'\,(2\pi-\theta_0')}{(1-q)\,4\pi \times 3.36} \tag{6}$$

One further modification to the formula is necessary to take account of what has been called the “propagation match” of the antenna: various studies have shown that for long distances (> 4 000 km), circuit performance improves as the vertical angle of the main beam maximum of the antenna is reduced.

A weighting factor (appropriate for vertical launching angles between about 5° and 25°) allows for this effect and the equation for the antenna directivity factor becomes:

$$M = \frac{G' \left(2\pi - \theta_0'\right)}{(1-q)\, 4\pi \times 3.36} \cdot \frac{10}{\Delta_m}$$

and expressing θ_0', φ_0' in degrees:

$$M = \frac{G' \left(360 - \theta_0'\right)}{241.9\, \Delta_m\, (1-q)} \tag{7}$$

where:

$$q = \frac{G'\, \theta_0'\, \varphi_0'}{176\ 600}$$

G' : directivity of antenna expressed relative to an isotropic radiator (expressed as a ratio unless otherwise stated)

θ_0' : horizontal angular width of main beam (degrees) (to first minimum points)

φ_0' : vertical angular width of main beam (degrees) (to first minimum points)

Δ_m : vertical angle of main beam maximum (degrees).

For distances less than 4 000 km, this factor may be omitted and instead the height of the antenna chosen to match the propagation conditions over the route.

3. Determination of directivity

When the measured characteristics of antennas are available, particularly the (power) gain and angular beamwidths, calculation of the figure of merit, M, is straightforward provided the power efficiency of the antenna is known. In many instances, however, it will be necessary to evaluate paper designs and special care is needed in the case of the rhombic antenna. Although the angular dimensions of the main beam and the vertical angle of the main beam maximum can be predicted with sufficient accuracy by a calculation which assumes constant current in the antenna wires, the gain so calculated is generally optimistic and must be corrected before it can be used in the M factor formula. This correction may be considered in two parts.

3.1 Adjustment for power dissipation in the termination, C_t

This is, in effect, a conversion from measured (power) gain to directivity and is given for various configurations in Figs. 1a) and 3a).

3.2 Adjustment of current decay along the antenna, C_d

This adjustment is necessary to convert (power) gain calculated from constant correct formulae to a value more nearly in conformity with the measured values on actual antennas and is given, for the same configurations, in Figs. 1b) and 3b). For convenience these curves are combined in Figs. 2 and 4, which enables the calculated (power) gain to be converted directly to directivity. The full-line portions of these curves represent the normal design range.

All the curves are derived from measurements made on the power efficiencies of rhombic antennas in which a linearly tapered current decay along the antennas was assumed. The antennas were of 3-wire construction having a surge impedance of 600 Ω. There is an important dependence of radiation efficiency upon surge impedance and the lowest practicable value is desirable. Nevertheless there are constructional problems in reaching a value much below 600 Ω in the HF band.

FIGURE 1

Gain adjustments for rhombic antenna 122 m/40 m

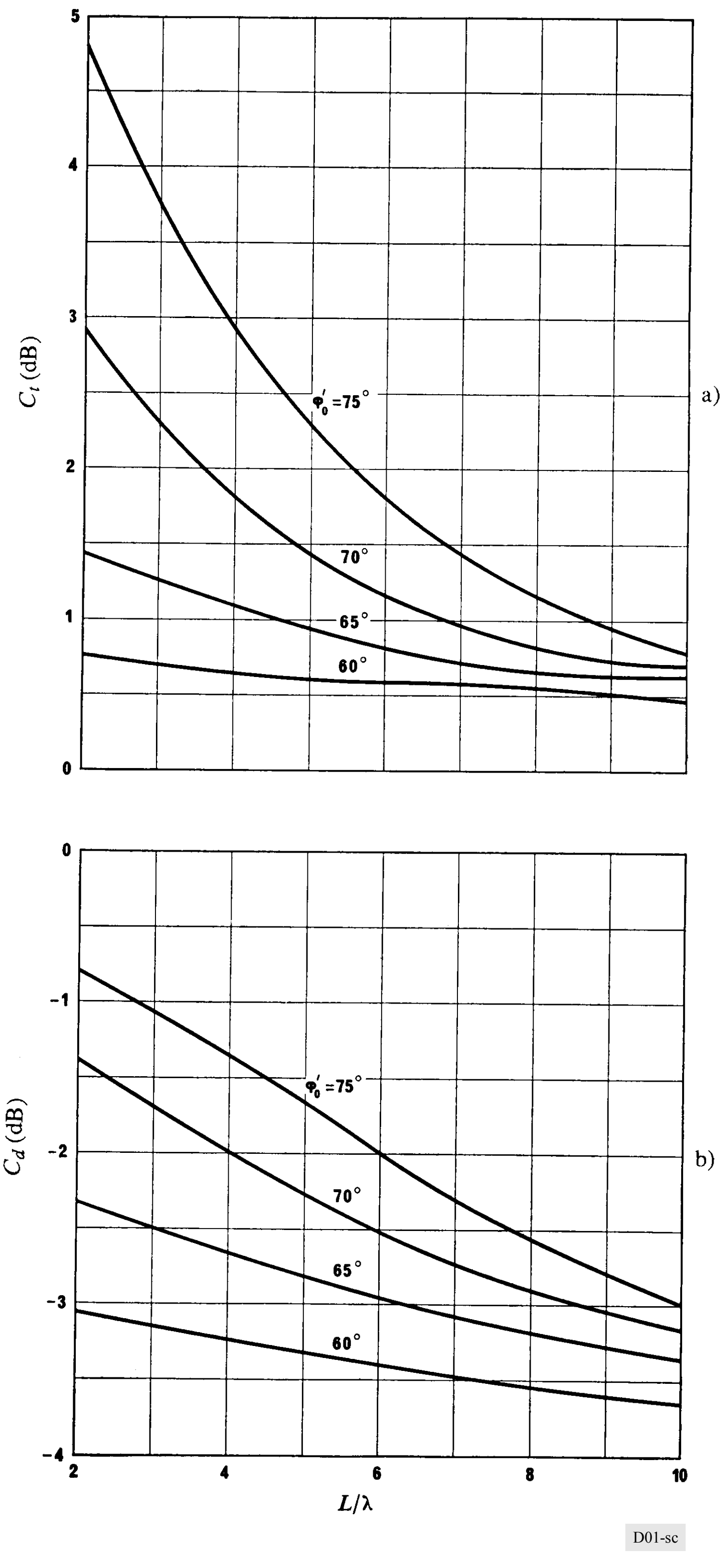
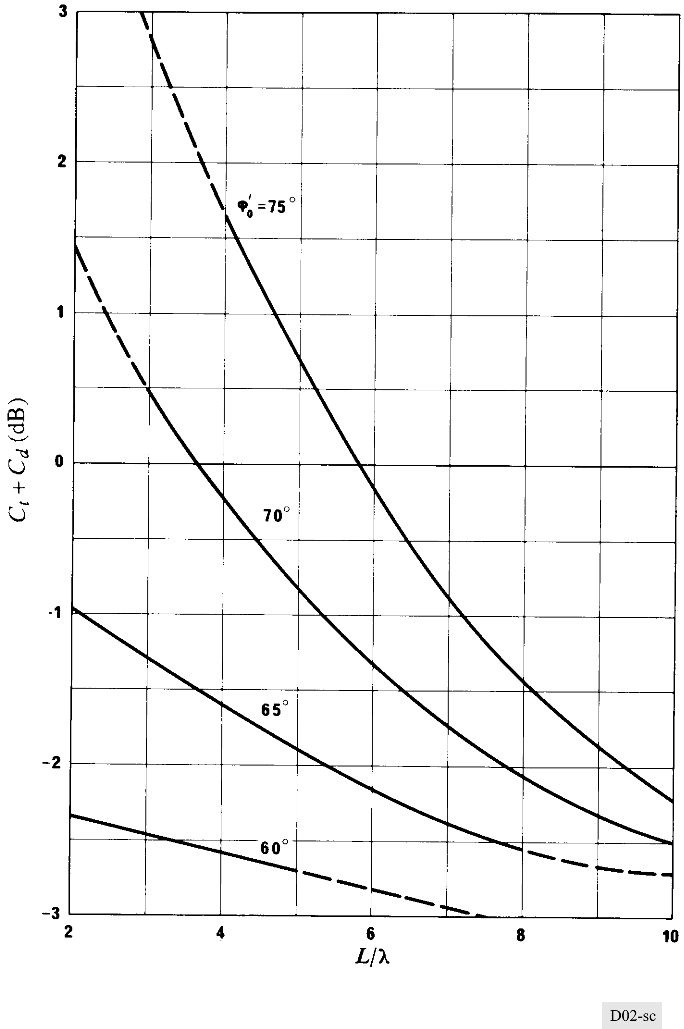


FIGURE 2

Combined gain adjustment for rhombic antenna 122 m/40 m



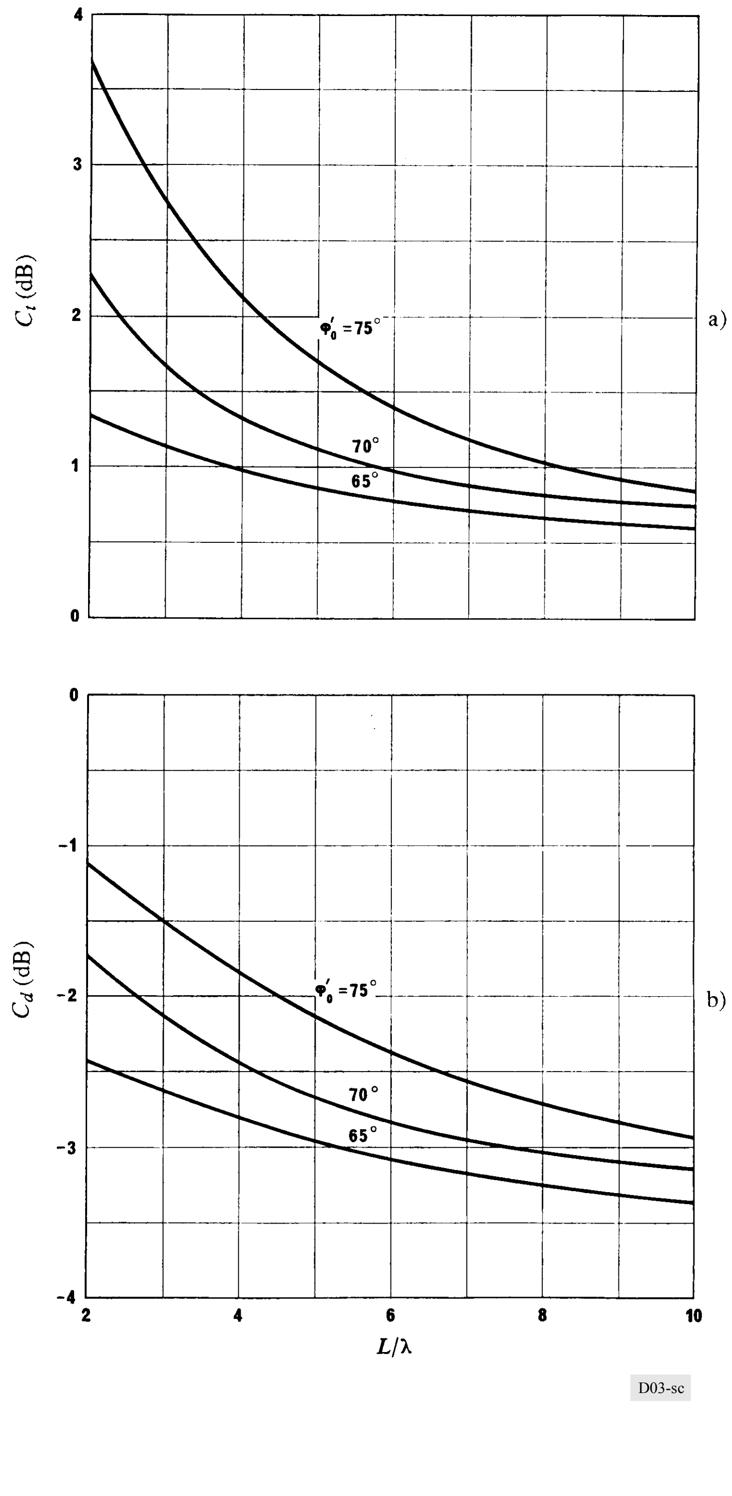
4. Application

M-values for a number of antennas of various types are plotted in Fig. 5 and provide an indication of the variation with frequency of the performance of single antennas and antenna arrays, assessed from both measured (power) gains and from the directivities calculated using the methods described in § 3. Curves, which it is considered represent reasonable standards of performance for these two classes of antenna, have been drawn on the diagram. The lower curve (labelled minimum standard antenna) is a best fit to the available experimental data and may be expressed as $M = 0.1f^2$. This is considered to be representative of the standard of performance to be expected from well-designed single rhombic antennas operated within a frequency band in which the ratio of highest to lowest frequency does not exceed 2.

The upper curve of Fig. 5 (economic standard antenna) which may be similarly expressed as $M = 0.25f^2$ represents a standard of performance which will normally only be achieved with antenna arrays. This higher standard necessarily involves a proportionally greater expenditure on antenna plant but some increase above the current level of expenditure can be economically justified.

FIGURE 3

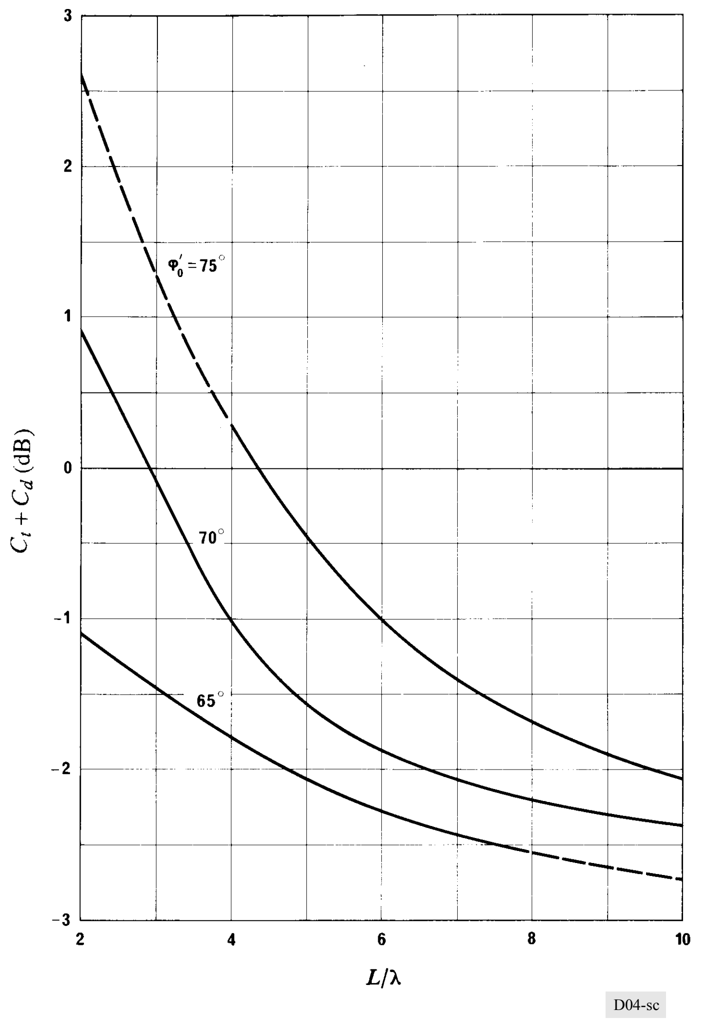
Gain adjustments for rhombic antenna 122 m/23 m



For frequency planning and other allied studies the occurrence frequencies of secondary beams having amplitudes greater than the equi-amplitude crest value may be important. Within the range of *M*-values considered the results of the measurements made on practical antennas indicate that not more than 10% of the secondary beams will exceed the equi-amplitude crest value by 6 dB. Thus for an antenna having an *M* value of 40, the ratio of the levels of the main-beam intensity and the higher secondary beam intensity would be 10 dB. These secondary beams will usually be adjacent to the main beam.

FIGURE 4

Combined gain adjustment for rhombic antenna 122 m/23 m



5. The effect of snow, ice and tides on antenna radiation patterns

This section reports the results of theoretical studies conducted to determine the effect of varying ground thickness of snow and ice on the radiation patterns of a horizontal half-wave dipole antenna and a vertical quarter-wave antenna. Tidal effects on the radiation patterns of these same antennas over sea water were also calculated.

For these studies, flat, homogeneous, and uniformly thick layers of snow, ice, and ground have been assumed.

For a horizontal dipole, the effect of 1 m of snow or ice is negligible. However, the effect of a tidal change of 3 m can result in a shift of about 5° in the angle of maximum radiation in the vertical plane.

A vertical quarter-wave antenna is more noticeably affected by snow or ice, particularly for directions near the horizon where a significant reduction in signal occurs. Corresponding changes in the power transmitted or received are given for 3 angles, at a frequency of 10 MHz, in Table 2.

FIGURE 5

Antenna directivity factor, *M*, based on calculated gains

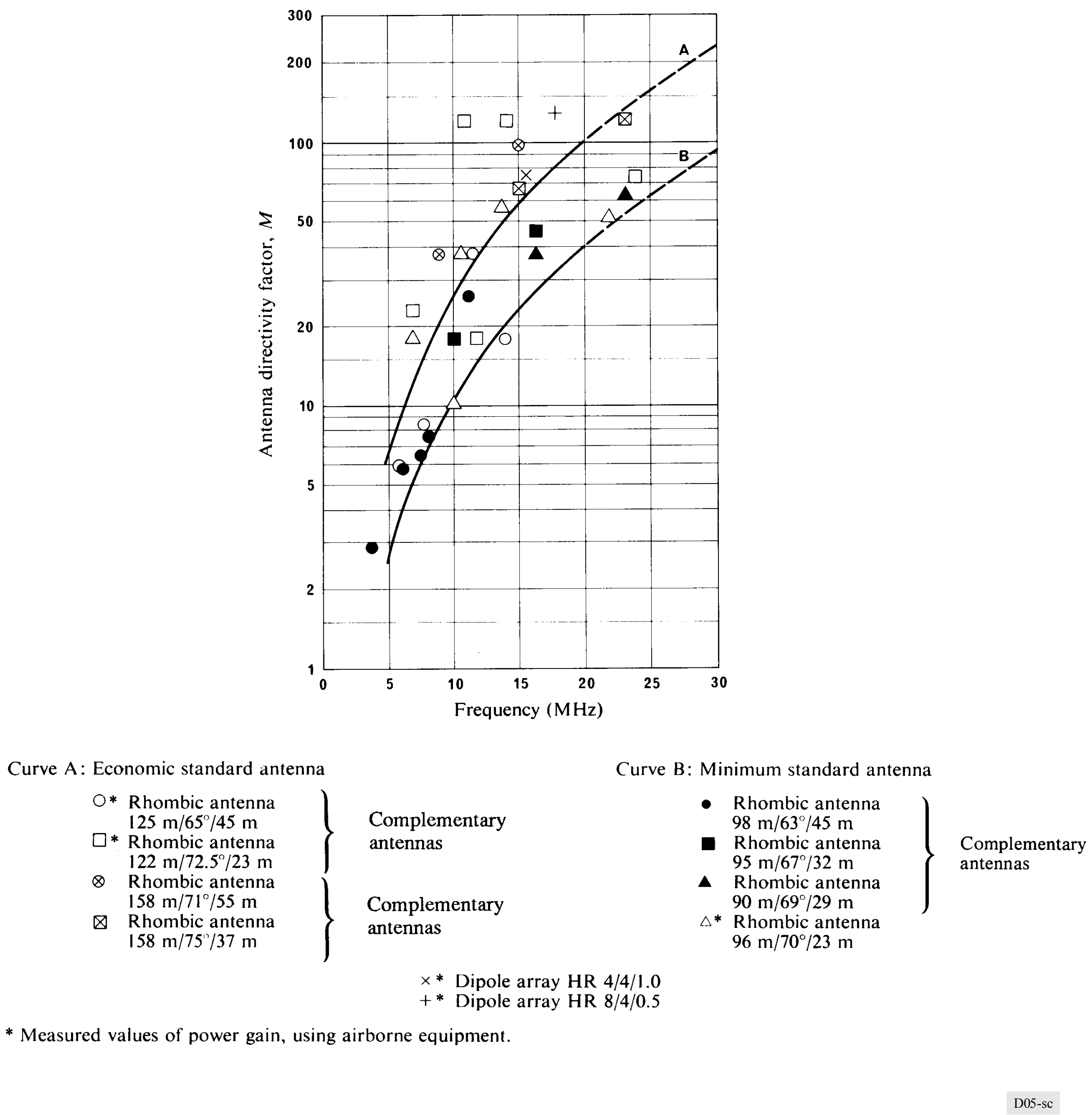


TABLE 2

Relative change (dB) of the transmitted or received power due to a snow, ice or tidal change for 3 zenith angles

(Frequency: 10 MHz)

	Zenith angle		
	45°	75°	85°
Vertical quarter-wave antenna on a ground plane to which 1 m snow (dielectric constant of 1.2, conductivity of 10^{-5} S/m) is added	–0.5	–0.6	–1.3
Vertical quarter-wave antenna over sea water which is displaced by 1 m salt ice (dielectric constant of 6.0, conductivity of 10^{-3} S/m)	–1.7	–3.4	–8.7
Vertical quarter-wave antenna over sea water which drops by 3.0 m	–2.9	–0.4	–0.1

ANNEX 3

Directional arrays with aperiodic reflector

1. Introduction

Frequency sharing between the fixed and broadcasting services at frequencies below 30 MHz is difficult to achieve, owing to the difference in operating methods and usable field strengths of the two services. The use of directional antennas to limit radiation in directions not necessary to the particular service could, in some cases, help alleviate this problem.

2. Directional antennas

Directional antennas used by the broadcasting service for long-distance communication are still generally of two main types: rhombic antennas and dipole antennas. In the fixed service, the use of log-periodic antennas is more general.

Single and dual band arrays of dipoles with tuned reflectors are generally preferred as they have high directivities, with a front-to-back ratio of 10 to 15 dB. Although these antennas have the advantage of permitting the direction of the main lobe to be fairly readily reversed, they also produce a series of subsidiary lobes whose intensity is quite important since they may cause unnecessary interference to other users.

More recently, dipole arrays have been constructed with an aperiodic screen as the reflecting system. These arrays have directivities similar to those of arrays with tuned reflectors and also have the advantages of wider operating bandwidth, a reduced level of subsidiary lobes and simplicity of construction. Provided that the reflecting screen is well designed, the resulting radiation patterns provide front-to-back ratios as high as 20 dB thus reducing the power radiated by the subsidiary lobes and consequently the potential interference in directions other than that of the main lobe.

A disadvantage of this type of array is the fact that the directivity can be significantly reduced at frequencies below the centre frequency of the operating band. The most important advantages are:

– electrical: as it is not necessary to regulate the phases of the currents in the dipole reflectors;

– radio frequency (wideband): these antennas do not require retuning if the working frequency is displaced with respect to that of the centre frequency;

– frequency planning: as the reduction of subsidiary lobes permits better utilization of the spectrum;

– mechanical: as the construction and adjustment is simplified and consequently maintenance is easier.

3. Conclusions

A comparison of the theoretical radiation patterns and those measured by means of a helicopter revealed that dipole arrays with aperiodic screens had a 6 dB better front-to-back ratio than an equivalent dipole array with tuned reflectors.

It is therefore possible that the use of dipole arrays with aperiodic screens, especially in the broadcasting service, may facilitate the sharing of the frequency spectrum with the fixed service.

A more detailed study of the electrical characteristics of dipole arrays with aperiodic screens is necessary to provide sufficient data to demonstrate the advantages of their use to administrations.