The information contained within Appendix C is taken from the CCIR Report to the 1st Session of the Regional Administrative MF Broadcasting Conference, (Region 2), held in Geneva, 1979.

CHAPTER 2

SKY-WAVE PROPAGATION

2. Sky-wave field strength prediction method for the frequency range 520 to 1600 kHz in Region 2

2.1 General

This Chapter sets out a method for the prediction of sky-wave field strengths at MF for planning purposes, for the use of the Regional Administrative MF Broadcasting Conference (Region 2). This method is based on the information contained in CCIR Recommendation 435-3, and has been carefully considered in the light of measurements made in Region 2, in particular the information contained in the Final Report of the Fifth Meeting of the Working Group on Radiobroadcasting, Inter-American Telecommunications Conference, Brasilia, 9-13 July 1979. It will be noticed that this present method while being compatible with the basis of the above mentioned Final Report now offers reliable and complete treatment of the entire Region without discontinuities, and contains several important simplifications in the application of the Recommendation 435-3 data considered appropriate for use in the development of a Region 2 plan. These simplifications are based on direct contributions from Region 2 to the meeting of CCIR Interim Working Party 6/4, Geneva, October 2-5, 1979.*

This method of prediction suggested for use in Region 2 for planning purposes is similar to but not identical with that of CCIR Recommendation 435-3. In all cases of inter-Regional interference predictions involving Region 2, the use of the entire method set out in the latest version of Recommendation 435 is considered appropriate.

2.2 List of symbols

c_1, c_2: Sea-gain corrections defined in § 2.4.3.

d: Ground distance between transmitter and receiver (km).

F: Annual median field strength for a given cymomotive force (c.m.f.), M**, at the reference time defined in § 2.4.1.

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* In order that this CCIR planning data be continually refined, Administrations of Region 2 are specifically requested to contribute additional information on this subject to Study Group 6 of the CCIR.

** A cymomotive force of 300 V is equivalent to a field strength of 300 mV/m at 1 km, which is the field strength due to an ideal short vertical monopole radiating 1 kW (an e.m.r.p. of 1 kW).

F_0: Annual median of half-hourly median field strengths (dB(μV/m)) for a transmitter cymomotive force of 300 V at the reference time defined in § 2.4.1.

f: Frequency (kHz).

G_0: Sea gain for a terminal on the coast (dB), see § 2.4.3.

G_H: Transmitting antenna gain factor due to horizontal directivity (dB), see § 2.4.2.

G_S: Sea gain for a terminal near the sea (dB), see § 2.4.3.

G_V: Transmitting antenna gain factor due to vertical directivity (dB), see § 2.4.2.

h: Transmitting antenna height, see fig. 33.

I: Magnetic dip angle, N or S (degrees), see § 2.4.4.

k: Basic loss factor, see § 2.4.6.

L_p: Excess polarisation coupling loss (dB).

P: Radiated power (dB(1 kW)).

p: Slant propagation distance (km), see § 2.4.5.

r_1, r_2: Parameters defined in § 2.4.3.

s_1: Distance of terminal from sea, measured along great-circle path (km), see § 2.4.3.

s_2: Distance of terminal from next section of land, measured along great-circle path (km), see § 2.4.3.

M: Transmitter cymomotive force (dB(300 V)) , see § 2.4.2.

α: Geographic latitude of terminal, degrees positive in the northern hemisphere, negative in the southern hemisphere, see § 2.4.6.

β: Geographic longitude of terminal, degrees, positive east of Greenwich meridian, see § 2.4.6.

θ: Direction of propagation relative to magnetic East-West (degrees), see § 2.4.4.

λ: Wavelength, see fig. 33.

Φ: A geomagnetic latitude parameter, see § 2.4.6.

Φ_T: Geomagnetic latitude of transmitter

Φ_R: Geomagnetic latitude of receiver

} degrees, positive for northern geomagnetic latitudes, negative for southern geomagnetic latitudes, see § 2.4.6.

2.3 Introduction

This method of prediction gives the night-time sky-wave field strength produced for a given power radiated from one or more vertical antennae, when measured by a loop antenna at ground level aligned in a vertical plane along the great-circle path to the transmitter. It applies for paths of lengths up to 12 000 km but should be used with caution for geomagnetic latitudes greater than 60°. It applies to the period when solar activity is least and field strengths are greatest and is suitable for planning purposes at all periods of solar activity. It gives the median field strength two hours after sunset (see § 2.4.1). The field strength exceeded for 10% of the time at this hour is 8 dB greater (see § 2.5).

Figs. 33 and 34 are an essential part of the prediction method. Geomagnetic maps are included for convenience in figs. 40, 41 and 43. The remaining figs. 35, 36, 37, 38, 39, 42, 44 and 45 provide additional information to simplify the use of the method when using manual calculations.

2.4 Annual median night-time field strength

The predicted sky-wave field strength is given by:

$$F = M + F_0 = M + G_S - L_P + 103 - 20 \log p - 10^{-3} kp \qquad (1)$$

where,

F: annual median of half-hourly median field strengths (dB(μV/m)) for a given transmitter cymomotive force, M*, at the reference time defined in § 2.4.1,

F_0: annual median of half-hourly median field strengths (dB(μV/m)) for a transmitter cymomotive force of 300 V* at the reference time defined in § 2.4.1,

M: transmitter cymomotive force, dB above a reference cymomotive force of 300 V*, see § 2.4.2,

G_S: sea-gain correction, (dB), see § 2.4.3,

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* A cymomotive force of 300 V is equivalent to a field strength of 300 mV/m at 1 km, which is the field strength due to an ideal short vertical monopole radiating 1 kW (an e.m.r.p. of 1 kW).

L_P: excess polarization-coupling loss, (dB), see § 2.4.4,

p: slant-propagation distance, (km), see § 2.4.5,

k: basic loss factor incorporating effects of ionospheric absorption, focusing and terminal losses, and losses between hops on multi-hop paths, see § 2.4.6.

To facilitate calculation, figs. 35 and 36 show F_0 as a function of ground distance, d, for various geomagnetic latitudes when G_S and L_P are zero. Curves for 1 kW radiated from a short vertical monopole would be identical at distances greater than 1000 km.

2.4.1 Reference time

The reference time is taken as two hours after the time at which the Sun sets at a point S on the surface of the Earth. For paths shorter than 2000 km, S is the mid-point of the path. On longer paths, S is 750 km from the terminal where the Sun sets last, measured along the great-circle path. Fig. 45 facilitates the determination of sunset time.

2.4.2 Cymomotive force

The cymomotive force (c.m.f.) is expressed in volts; it corresponds numerically to the field-strength in mV/m at a distance of 1 km* (see CCIR Recommendation 561).

The cymomotive force M (in dB with respect to 300 V) is given as:

$$M = P + G_V + G_H \tag{2}$$

where,

P: radiated power, dB above 1 kW,

G_V: transmitting antenna gain factor, dB, due to vertical directivity, given in fig. 33 for omnidirectional antennae,

G_H: transmitting antenna gain factor, dB, due to horizontal directivity.

For omnidirectional antennae, $G_H = 0$. For directional antennae G_H and G_V vary with azimuth and ground distance and may be determined collectively from the antenna radiation patterns.

For ground distances greater than 2000 km, $G_V + G_H$ is approximately equal to the antenna gain in the horizontal plane.

2.4.3 Sea gain

G_S is the additional signal gain when one or both terminals are situated near the sea, but it does not apply to propagation over fresh water. G_S for a single terminal is given by:

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* A cymomotive force of 300 V, which is the reference level used in this Section corresponds to an effective monopole radiated power (e.m.r.p.) of 1 kW.

$$G_S = G_0 - c_1 - c_2 \quad \text{for} \quad (c_1 + c_2) < G_0 \tag{3}$$

$$G_S = 0 \quad \text{for} \quad (c_1 + c_2) > G_0 \tag{4}$$

where,

G_0: gain when the terminal is on the coast and the sea is unobstructed by further land;

c_1: correction to take account of the distance between the terminal and the sea,

c_2: correction to take account of the width of one or more sea channels, or the presence of islands.

If both terminals are near the sea, G_S is the sum of the values for the individual terminals.

G_0 is given in fig. 34 as a function of d.

G_0 = 10 dB when $d > 6500$ km.

The correction c_1 is given by

$$c_1 = \frac{s_1}{r_1} G_0 \tag{5}$$

where,

s_1: distance of terminal from sea, measured along great-circle path (km),

r_1: $10^3 \, G_0^{\,2} \,/\, 1.4 \, f$ (km),

f: frequency in kHz.

The correction c_2 is given by

$$c_2 = G_0 \left(1 - \frac{s_2}{r_2}\right) \quad \text{for} \quad s_2 < r_2 \tag{6}$$

$$c_2 = 0 \quad \text{for} \quad s_2 > r_2 \tag{7}$$

where,

s_2: distance of terminal from next section of land, measured along great-circle path,

r_2: $10^3 \, G_0^{\,2} \,/\, 1.2 \, f$ (km).

Equation (6) applies if there is only one sea channel, or if more than half the distance between s_2 and a great-circle distance equal to r_2 is occupied by land. If less than half the distance between s_2 and r_2 is occupied by land, $c_2 = 0$.

To facilitate calculation, fig. 37 shows r_1, the greatest distance from the sea for which sea gain has to be calculated, and fig. 38 shows r_2, the greatest distance to the next section of land for which the correction c_2 is required, for various frequencies.

2.4.4 Polarization coupling loss

L_P is the excess polarization coupling loss. L_P for a single terminal is given by one of the following two formulae:

$$\left.\begin{array}{ll} \text{If } I \leqslant 45^\circ : & L_p = 180\,(36 + \theta^2 + I^2)^{-\frac{1}{2}} - 2 \quad (\text{dB}) \\ \text{If } I > 45^\circ : & L_p = 0 \end{array}\right. \qquad (8)$$

where I is the magnetic dip, N or S, in degrees at the terminal and θ is the path azimuth measured in degrees from the magnetic E-W direction, such that $|\theta| \leqslant 90^\circ$ as shown in fig. 39. L_P should be evaluated separately for the two terminals, because of the different θ and I that may apply, and the two L_P values added. The most accurate available values of magnetic dip and declination (e.g. see figs. 40 and 41) should be used in determining θ and I.

Fig. 39 shows values of L_P calculated from equation (8).

2.4.5 Slant propagation distance

For paths longer than 1000 km, p is approximately equal to the ground distance d (km). For shorter paths

$$p = (d^2 + 4 \times 10^4)^{\frac{1}{2}} \qquad (9)$$

Equation (9) may be used for paths of any length with negligible error.

2.4.6 Loss factor

The basic loss factor k is given by:

$$k = 0.067\,|\Phi| + 0.2 + 3\tan^2(\Phi+3) \qquad (10)$$

If $\Phi > 59^\circ$, equation (10) is evaluated for $\Phi = 59^\circ$. If $\Phi < -59^\circ$, equation (10) is evaluated for $\Phi = -59^\circ$. If equation (10) gives a value of $k < 3$, then $k = 3$. Fig. 42 shows values of k calculated from equation (10) according to these rules.

For paths shorter than 3000 km:

$$\Phi = 0.5\,(\Phi_T + \Phi_R) \qquad (11)$$

where Φ_T and Φ_R are the geomagnetic latitudes at the transmitter and receiver respectively, determined by assuming an Earth-centred dipole field model with northern pole at 78.5° N, 69° W geographic co-ordinates. Φ_T and Φ_R are taken as positive in the northern hemisphere and negative in the southern hemisphere (see fig. 43), and are given by the equation

$$\Phi_T \text{ or } \Phi_R = \arcsin\left[\sin\alpha \sin 78.5^\circ + \cos\alpha \cos 78.5^\circ \cos(69^\circ + \beta)\right] \qquad (12)$$

where α and β* are the latitude and longitude of the terminal respectively. Paths longer than 3000 km are divided into two equal sections which are considered separately. The value of Φ for each half-path is derived by taking the average of the geomagnetic latitudes at one terminal and at the mid-point of the whole path, the geomagnetic latitude at the mid-point of the whole path being assumed to be the average of Φ_T and Φ_R. As a consequence:

$$\Phi = 0.25\ (3\Phi_T + \Phi_R) \text{ for the first half of the path and} \qquad (13)$$

$$\Phi = 0.25\ (\Phi_T + 3\Phi_R) \text{ for the second half.} \qquad (14)$$

The values of k calculated from equation (10) for the two half-paths are then averaged and used in equation (1).

2.5 The accuracy of the field-strength prediction method for Region 2, proposed in this Chapter

In Section 2.3 above, it is stated that the field strength exceeded for 10% of the time near to two hours after sunset is 8 dB greater than the median field strength. Although this figure is suitable for planning purposes, it should be noted that in regions of high geomagnetic latitude the 10% field strength will tend to be up to 2 dB higher, and at lower geomagnetic latitudes up to 2 dB lower, than this figure.

Field strengths decrease with increasing solar activity, especially at high geomagnetic latitudes.

Field strengths vary during the night and at sunrise and sunset. Fig. 44 shows the average variation which has been observed in Europe and Australia, and it is reasonable to assume that this curve also applies in Region 2. The horizontal scale shows the time in hours relative to the sunrise or sunset reference times as appropriate. These are taken at the ground at the mid-path position for $d < 2000$ km, and at 750 km from the terminal where the Sun sets last or rises first for longer paths. The vertical scale shows the correction which should be applied to the prediction for two hours after sunset.

Fig. 45 shows sunset and sunrise times for a range of geographic latitudes.

The method predicts the field strength which is likely to be observed if the transmitter and receiver are situated on ground of average conductivity, typically 3 to 10 mS/m. If the ground conductivity is an order of magnitude smaller, as it is in some parts of Region 2, then the field strength will be up to 10 decibels smaller; the amount of attenuation is a function of path length and is greatest for waves approaching grazing incidence.

Information on non-reciprocal sky-wave propagation is to be found in the Annex to this Chapter.

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* See § 2.2 for sign convention.

2.6 Illustration of Chapter 2 method of prediction of sky-wave field strengths

Case 1: Transmitter XEW, Mexico City, Mexico, 19°19' N, 99°07' W, f = 900 kHz, P = 250 kW, $\Phi_T = 29.1^\circ$, and antenna height (assumed) 0.25λ.

Receiving site Kingsville, USA, 27°26' N, 97°53' W, $\Phi_R = 37.3^\circ$, d = 910 km.

Calculation:

Step	Item	Equation or figure used	Contribution to equation (1)
1	$G_V = 0.2$ dB	Fig. 33	-
2	M	Equation (2)	24.2
3	$G_S = 0$	(Path is over land)	0
4	$L_P = 0$	$(I > 45^\circ$, both terminals)	0
5	103	-	103
6	p = 931.7 km	Equation (9)	-
7	- 20 log p	-	-59.4
8	$\Phi = 33.2^\circ$	Equation (11)	-
9	k = 4.03	Equation (10)	-
10	-10^{-3} kp	-	-3.7
11	F	Equation (1)	63.9 dB(μV/m)

Case 2: Transmitter WLS, Chicago, USA, 41°33' N, 87°51' W, f = 890 kHz, P = 50 kW, $\Phi_T = 52.3^\circ$, and antenna height = 0.53λ (178 m), omni.

Receiving site Portland, USA, 45°32' N, 122°40' W, $\Phi_R = 51.4^\circ$, d = 2821 km.

Calculation:

Step	Item	Equation or figure used	Contribution to equation (1)
1	$G_V = 2.6$ dB	Fig. 33	-
2	M	Equation (2)	19.6
3	$G_S = 0$	(Path is over land)	0
4	$L_P = 0$	$(I > 45^\circ$, both terminals)	0
5	103	-	103
6	-20 log p	p = d = 2821	-69
7	$\Phi = 51.9^\circ$	Equation (11)	-
8	k = 9.75	Equation (10)	-
9	-10^{-3} kp	-	-27.5
10	F	Equation (1)	26.1 dB(μV/m)

Case 3: Transmitter, Buenos Aires, Argentine, 34°27' S, 58°34' W, $f = 1070$ kHz, $P = 100$ kW, $\Phi_T = -23.1°$, antenna height = 0.5λ, omni.

Receiving site, Recife, Brazil, 8°06' S, 34°53' W, $\Phi_R = 1.5°$, $d = 3800$ km.

Calculation:

Step	Item	Equation or figure used	Contribution to equation (1)
1	$G_V = 2.3$ dB	Fig. 33	-
2	M	Equation (2)	22.3
3	$G_S = 5.4$ dB	Equations (3) to (7) and fig. 34 $G_0 = 9.2$ dB At transmitter: $s_1 = 4$ km, $r_1 = 67$ km, $c_1 = 0.5$ dB; $s_2 = 50$ km, $r_2 = 78$ km, $c_2 = 3.3$ dB; $G_S = 5.4$ dB At receiver: $G_S = 0$	5.4
4	$L_P = 4.5$ dB	Equation (8), figs. 40 and 41 At transmitter: $I = 33°S$, $\theta = 43°$, $L_P = 1.3$ dB At receiver: $I = 12°S$, $\theta = 32°$, $L_P = 3.2$ dB	-4.5
5	103	-	103
6	$-20 \log p$	($p = d = 3800$ km)	-71.6
7	Φ	Equations (13) and (14) $\Phi = -17.0°$ for first half of path; $\Phi = -4.7°$ for second half of path;	
8	$k = 3$	Equation (10), but $k = 3$ for both halves of path	
9	$-10^{-3}\,kp$	-	-11.4
10	F	Equation (1)	43.2 dB(µV/m)

ANNEX TO CHAPTER 2

NON-RECIPROCAL SKY-WAVE PROPAGATION

1. Introduction

A recent paper* describes an analysis of measurement made in the United States of America which indicates that sky-wave propagation in the MF broadcasting band is non-reciprocal on east-west paths, the transmission loss being greater on paths from east to west. The paper says that these differences should be considered in any frequency assignment process intended to make optimum use of the MF broadcasting band.

2. General

A theoretical paper** has shown that non-reciprocal transmission losses are to be expected on east-west multihop paths due to the change in polarization occurring at the intermediate ground reflection. The paper shows that greater transmission losses are expected on paths from east to west and that the difference between the two directions of propagation is greatest at magnetic-dip latitudes of about 60°, and increases as the frequency increases. The difference between the two directions of propagation is likely to be most pronounced on paths which are just beyond the range of the one-hop mode and where the intermediate reflection point is on land; at this distance (2000 to 2500 km) the two-hop mode is reflected at angles near the Brewster angle. Little difference between the two directions of propagation is to be expected when the intermediate reflection point falls on sea water.

If non-reciprocal propagation is confined to east-west multi-hop paths over land at about 60° dip latitude it will be significant only within a small part of Region 2. The conditions for non-reciprocal propagation can be satisfied in Canada and the United States of America, and here it appears to have been confirmed by measurements. In Central and South America, two-hop paths with intermediate reflection points on land are possible only at dip latitudes less than 30°, where the non-reciprocal effect is unimportant.

3. Conclusion

In common with the field strength prediction method described in Annex I to CCIR Recommendation 435-3, with all of the earlier methods described in CCIR Report 575-1 and with methods based on the FCC curves, the method recommended here for planning purposes in Region 2 does not take account of non-reciprocal propagation. Any method would become very complicated if such a correction were to be properly applied, while in most parts of Region 2 the improvement in accuracy of the predictions would be small.

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* CROMBIE, D.D. /‾1979_7 Comparison of measured and predicted signal strengths of night-time medium frequency signals in the USA. IEEE Trans. on Broadcasting, BC-25, 86-89.

** KNIGHT, P. /‾1973_7 MF propagation: non-reciprocal ionospheric propagation on multi-hop paths. British Broadcasting Corporation Research Report 1973/17.

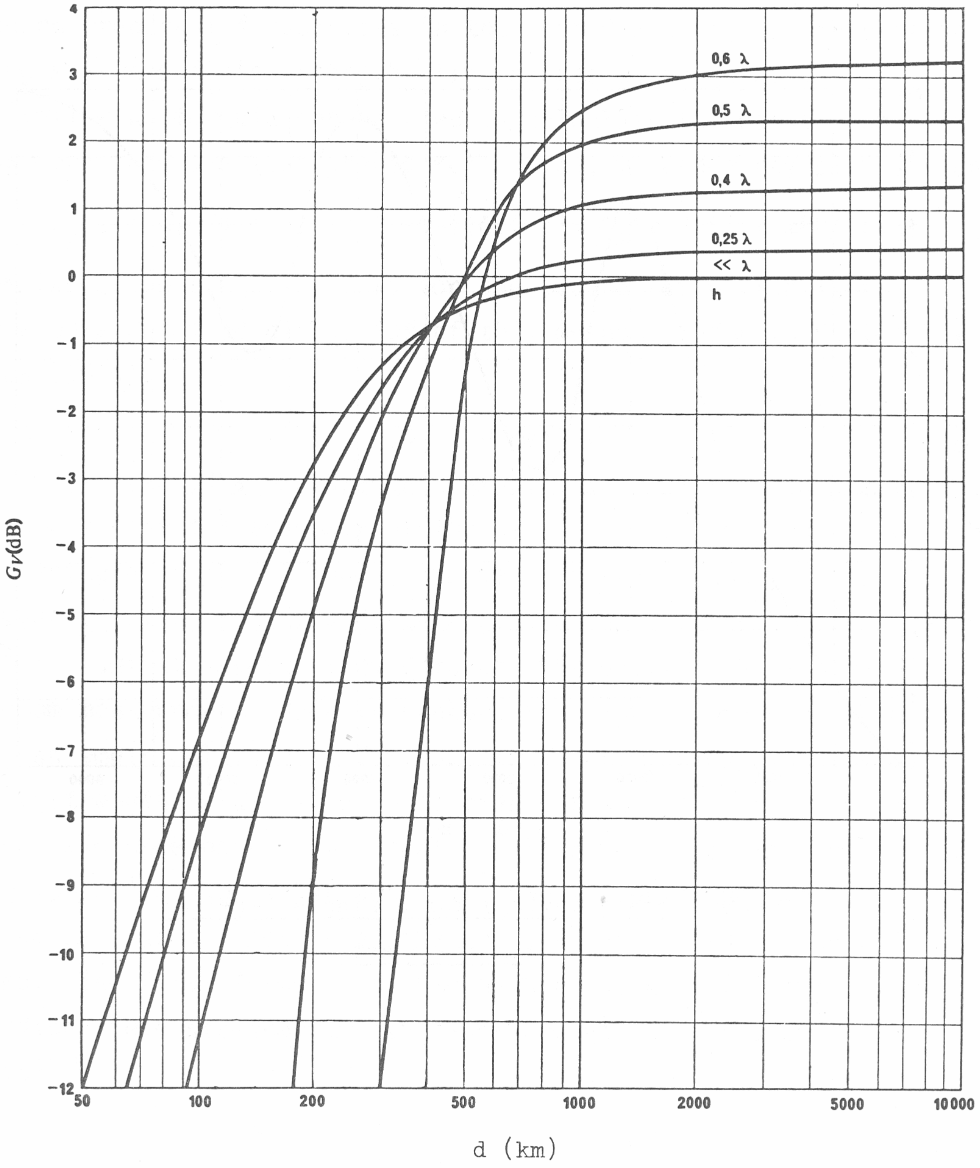

Fig.33 - Transmitting antenna gain factor for single monopoles (G_V)

h= height of antenna

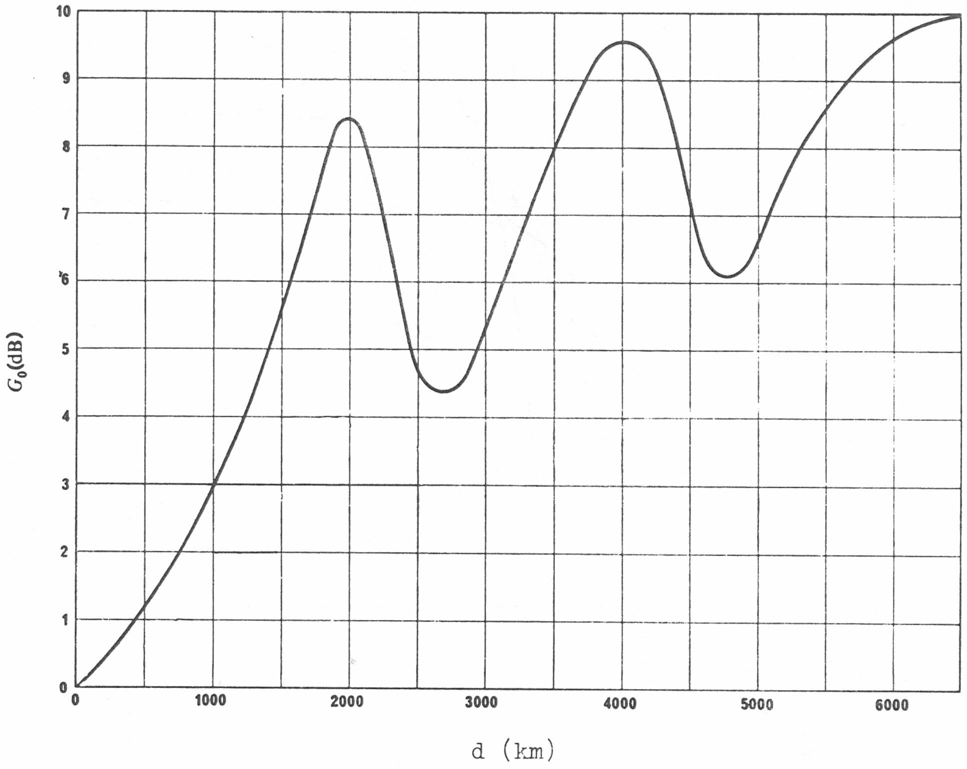

Fig.34 - Sea gain (G_0) for a single terminal on the coast

(G_0 = 10 dB for d>6500km)