RECOMMENDATION ITU-R BS.80-3*

Transmitting antennas in HF broadcasting

(1951-1978-1986-1990)

The ITU Radiocommunication Assembly,

considering

a) that a directional transmitting antenna should be used whenever appropriate, both to obtain adequate coverage of an intended service area and to minimize unwanted radiation, and potential interference, elsewhere;

b) that the design and installation of a wide variety of directional HF antenna types of improved performance are feasible using current technology;

c) that directional transmitting antennas can radiate significant power in unwanted directions;

d) that comprehensive and detailed information on the theoretical radiation characteristics of HF antennas is given in Part 1 of Annex 1 to Recommendation ITU-R BS.705;

e) that information regarding the differences between the theoretical and practical performance of HF antennas is given in Part 2 of Annex 1 to Recommendation ITU-R BS.705,

recommends

1 that Annex 1 and Annex 2 should be used to give guidance on the choice of a suitable HF transmitting antenna;

2 that side-lobe radiation should be maintained at the lowest practical value;

3 that in practical operating conditions, for purposes of calculating interference, the field strength in other azimuths at angles of elevation corresponding to those of the main lobe, cannot be assumed to be less than 222 mV/m at a distance of 1 km for 1 kW of power supplied to the antenna, in the case of high gain antennas. A lower value of interfering field strength may need to be considered in the case of low gain antennas;

4 that Annex 1 to Recommendation ITU-R BS.705 should be used as a source for more detailed information.

NOTE – The World Administrative Radio Conference for the Planning of HF Bands Allocated to the Broadcasting Service (WARC HFBC(1)), Geneva, 1987 has adopted for use, calculated values of minimum radiation which in some cases are lower than that given above (see Annex 2).

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

ANNEX 1*

1 The use of non-directional and directional antennas

In HF broadcasting the antenna is the means by which the radio-frequency energy is directed towards the required service area. The selection of the right type of antenna will enhance the signal in this area, while reducing radiation in unwanted directions. This will protect other users of the radio-frequency spectrum operating on the same channel or adjacent channels in another service area. The use of directional antennas with well defined radiation patterns is thus recommended as far as possible.

Non-directional antennas can be used when the transmitter is located within the required service area. In this case the required service area as seen by the transmitter extends over an azimuthal angle greater than 180°.

Directional antennas serve a double purpose. The first is to prevent interference to other users of the spectrum by means of their directivity. The second is to provide sufficient field-strength for satisfactory reception by means of their power gains.

A chart in Fig. 1 gives some general guidelines for the choice of optimum antennas for a given type of service according to the required distance range. Two different categories are considered: short distance and medium/long-distance services.

A short distance service is understood here to have a range of up to about 2 000 km. The corresponding area can be covered with either a non-directional or a directional antenna whose beamwidth can be selected according to the sector to be served. In the case of directional antennas, both horizontal dipole curtain and logarithmic-periodic antennas can be employed.

Medium and long distance services can be considered to reach distances greater than approximately 2 000 km. Such coverage can be provided by antennas whose main lobe elevation angle is small (6°-13°) and whose horizontal beamwidth – depending on the area to be served – is either wide between 65° and 95° (generally 70°) or narrow between 30° and 45° (generally 35°).

The value of the field strength in the reception area is influenced by the radiation characteristics of the antenna, which depends upon the type of array. Antennas of extremely narrow horizontal and vertical beamwidth should not be used because variations of the ionosphere could change the location of the coverage area.

Although rhombic antennas are used for broadcasting, their use should be discouraged because of the size and number of their sidelobes, which could create unnecessary interference.

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[*] Nomenclature is explained in Annex 1 to Recommendation ITU-R BS.705 and in Annex 2 to the present Recommendation.

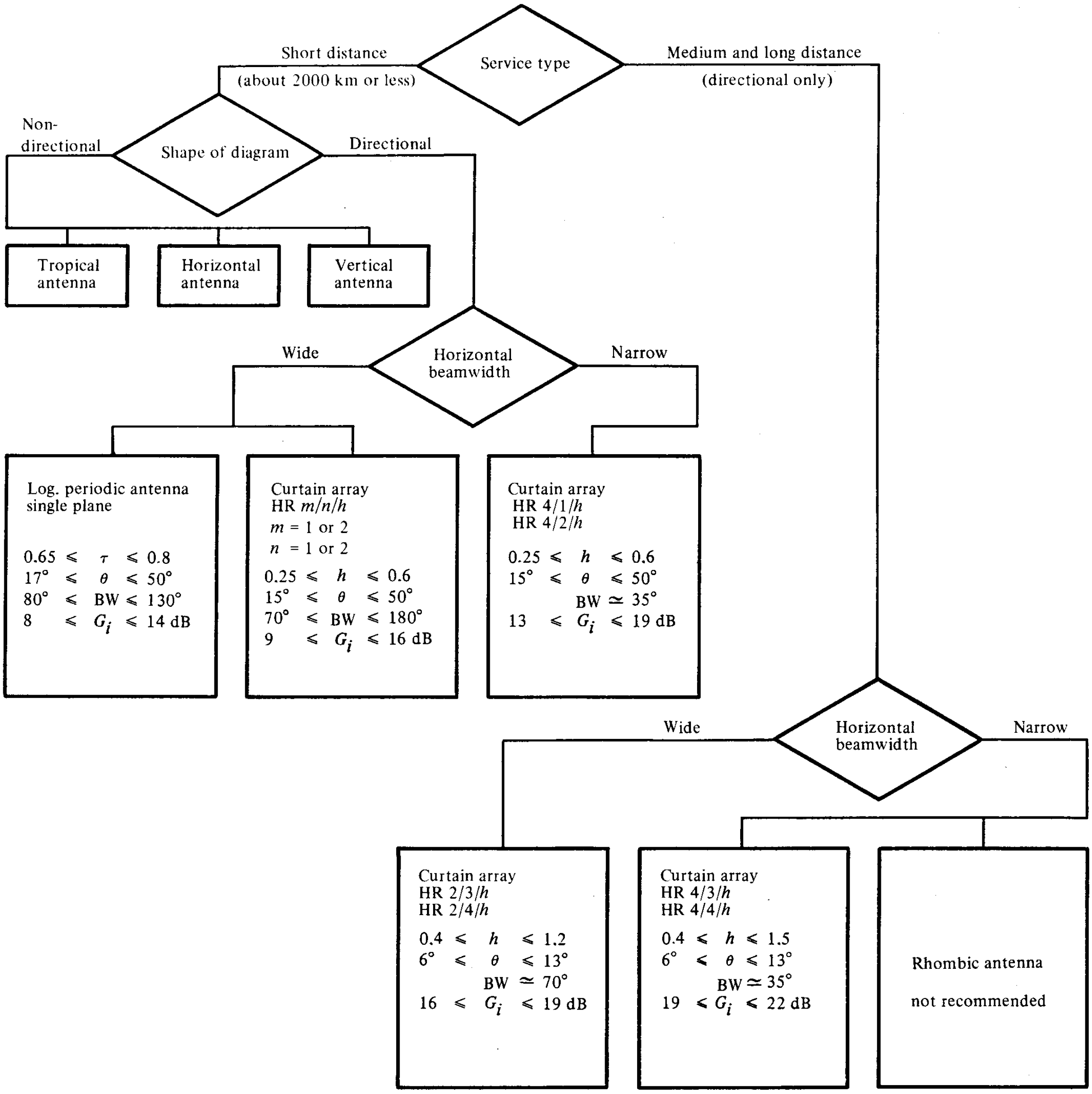

FIGURE 1 – *Antenna selection chart*

θ: elevation angle
G_i: gain (dB) relative to an isotropic antenna isolated in space } **of maximum radiation of the main beam**
G_d: gain (dB) relative to a half-wave dipole isolated in space ($G_i = G_d + 2.2$ dB) } **of maximum radiation of the main beam**
BW: total horizontal beamwidth (−6 dB relative to maximum)
HR: horizontal dipole curtain antenna with reflector curtain
m: number of half-wave elements in each row
n: number of half-wave elements in each stack (one above the other)
h: height above ground in full wavelengths of the bottom row of elements
τ: taper ratio of log. periodic antenna

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2 Reduction of subsidiary lobes

For the purpose of avoiding interference in frequency sharing, the reduction of subsidiary lobes in high-frequency broadcasting directional antenna systems is of utmost importance. This interference is generally caused by the radiation pattern of the transmitting antenna having subsidiary lobes in unwanted directions, or by scatter of the energy of the main lobe, due to propagation anomalies. Reduction in intensity of the subsidiary lobes is possible by correct antenna design, while the propagation scatter in unwanted directions presents a complex problem, and its effect should be treated statistically.

HF curtain antennas constructed of horizontal dipole elements are made unidirectional by the addition of a reflector screen. This screen can be comprised of either:

– an identical array of dipoles tuned to provide an optimum front-to-back ratio over the range of operating frequencies. In general no power is applied to this type of reflector, which is known as either a "tuned dipole" or a "parasitic" reflector; or

– a screen consisting of horizontal wires which act as an untuned reflector. This type of reflector is known as an "aperiodic screen".

The maximum slew values obtained in practice for different antenna types are given in Table 1 of Annex 2.

While slewing does not appreciably affect the horizontal width of the main lobe of radiation, it does increase its asymmetry and at the same time produces a principal subsidiary lobe of considerable intensity. In slewing, the gain of main lobe decreases with the increase of the slewing angle and side lobe radiation increases. As a consequence the field strength created by the side lobes will substantially increase.

Practical experience in the People's Republic of China has confirmed the possibility of obtaining satisfactory slewing by using the value of current phase differences determined by a successive approximation method of calculation.

Tests in Italy have shown that with an antenna of the type HRS 5/4/1.5 it is possible to reduce the amplitude of subsidiary lobes significantly when feeding the five stacks of dipoles separately. This property is maintained when the main beam is slewed.

A special feature of some type HR 4/4 antennas manufactured in France is that the reflector is fed, an arrangement which makes it possible to adjust accurately the current amplitudes and phases in the back and front of the arrays. Measurements of the pattern, using a helicopter, showed that it resembled the theoretical patterns very closely (nulls about 40 dB). Compared with systems with passive reflectors, the new arrays have a larger bandwidth and are more easily adjusted.

Calculations in France have also shown that, for multiband antennas of the type HR $2/n/h$ extension of the frequency ratio to a value of f_{max}/f_{min} close to 3 would result in satisfactory theoretical radiation patterns without significant development of subsidiary lobes.

Although it is possible to achieve a substantial degree of suppression of side lobes for curtain arrays, the methods so far employed introduce mechanical difficulties and increase the cost.

3 Verification of radiation patterns

The RAI in Italy and the Vatican City State have made a series of field-strength measurements to investigate and verify the effective radiation pattern of a variety of types of HF antennas. The measurements have been performed by using airborne equipment. The results of these measurements on non-obstructed antennas confirm that the radiation patterns of the main beam are in good agreement with the theoretical values as calculated applying the methodology described in Recommendation ITU-R BS.705. Detailed studies by several administrations confirm the validity of these theoretical values. Furthermore it is shown that in the case of a practical horizontal dipole antenna with an aperiodic screen reflector the back radiation and that in the principal minimum in the forward direction is about 20 dB below the maximum of the main lobe. It can be concluded that the methodology of measuring antenna patterns by helicopter described in Part 2 of Annex 1 to Recommendation ITU-R BS.705 is a reliable and valuable means of evaluating the performance of transmitting antennas.

4 Discrimination obtained in practice by directional antennas

Extensive measurement campaigns have been carried out in different countries, to evaluate the field strength of co-located transmitters and of transmitters on different transmitting sites using directional antennas directed to geographically separated service areas. These results were used to derive antenna discrimination values, that is, the reduction in field strength, relative to the main beam value, at angles of azimuth and elevation other than those of the main beam. The discrimination obtained in practice was consistent with the limiting value given in this Recommendation. The discrimination deduced from theoretical antenna considerations (see Part 1 of Annex 1 to Recommendation ITU-R BS.705) would in most cases have been much higher than that actually measured. These measurement campaigns are reported by the United Kingdom and India.

ANNEX 2

HF antenna patterns for system design and planning

1 A set of reference antenna characteristics

The formulae and the associated software for the calculation of antenna patterns and values of maximum gain are given in Recommendation ITU-R BS.705 for a wide range of HF antenna types. A limited set of reference HF antenna characteristics using the patterns of horizontal dipole antennas was adopted by WARC HFBC-87. Patterns of horizontal dipoles were used because it was found that these were the most commonly used antenna type. An examination of the variation in performance of this set of antennas forms a useful introduction to the range of antenna characteristics found in practice.

The principal characteristics of this reference set of patterns are summarized in Table 1, containing 24 types of directional antenna together with a simplified pattern of a non-directional antenna (type 25). This set of antennas was selected so that a relatively wide range of characteristics is represented with only small changes between types. It also includes multiband operation and slewing.

TABLE 1

Set of reference HF antenna types

Principal characteristics at design frequency

Antenna reference No.	Antenna type HR(S) *m*/*n*/*h*	Max. gain G_i (dBi)	Elevation angle of maximum radiation (degrees)	Azimuthal beamwidth (–6 dB) (degrees)	Maximum slew (degrees)
01	HR (S) 4/4/1.0	22.3	7	36	
02	HR (S) 4/4/0.8	22.1	8	36	(A) Multiband 30
03	HR (S) 4/4/0.5	21.5	9	36	(T) Multiband 30
04	HR (S) 4/3/0.5	20.5	12	36	(T) Dual band 30
05	HR (S) 4/2/0.5	19.1	17	36	(TE) Single band 15
06	HR (S) 4/2/0.3	18.1	20	36	
07	HR (S) 2/4/1.0	19.7	7	66	
08	HR (S) 2/4/0.8	19.4	8	68	
09	HR (S) 2/4/0.5	18.8	9	68	(A) Multiband 15
10	HR (S) 2/3/0.5	17.9	12	68	(T) Multiband 15
11	HR (S) 2/2/0.5	16.5	17	68	(T) Dual band 15
12	HR (S) 2/2/0.3	15.5	20	70	
13	HR (S) 2/1/0.5	14.5	27	72	
14	HR (S) 2/1/0.3	13.4	40	80	
15	HR 1/2/0.5	14.1	17	108	
16	HR 1/2/0.3	13.1	20	110	
17	HR 1/1/0.5	11.8	27	116	
18	HR 1/1/0.3	9.6	44	148	
19	H 2/1/0.5	10.8	28	78	
20	H 2/1/0.3	8.5	47	106	
21	H 1/2/0.5	11.2	17	114	
22	H 1/2/0.3	10.2	21	116	
23	H 1/1/0.5	8.9	28	124	
24	H 1/1/0.3	6.9	47	180	
25	ND	3.9	47	360	

H: horizontal dipole curtain antenna
R with reflector
S: slewable antenna
m : number of collinear elements in each horizontal row
n : number of parallel elements in each vertical stack
h : height above ground of lowest row of element(s) in wavelengths at the design frequency
(A): aperiodic screen reflector centre-fed elements
(T): tuned dipole reflector centre-fed elements
(TE): tuned dipole reflector end-fed elements
ND: non-directional antenna.

The characteristics given in Table 1 apply to a design frequency of 10 MHz and ground of average conductivity. The characteristics for dual band and multiband antennas are frequency dependent. Information regarding typical expected changes in performance with frequency is given in § 3.

Information is given regarding:

- the maximum directivity gain of the main lobe of radiation in dB relative to an isotropic antenna;
- the elevation angle at which maximum radiation occurs;
- the azimuthal beamwidth to the –6 dB points;
- information regarding the practical slewing capabilities for the cases where the radiator/reflectors are one of the following:
  - (A): aperiodic screen reflector with centre-fed elements;
  - (T): tuned dipole reflector with centre-fed elements;
  - (TE): tuned dipole reflector with end-fed elements.

Types 1-6 are arrays having four collinear dipoles in each row, with from two to four parallel rows of dipoles stacked one above the other, and using one of the types of reflectors listed above, and have been extended to include multiband operation and slewing.

As the number of elements stacked above one another is decreased or the height of the lowest row of dipoles is decreased, it can be seen that:

- the maximum gain decreases;
- the elevation angle of the maximum of the main lobe increases;
- the azimuthal beamwidth does not change.

The main beam of multiband and dual band antennas with centre-fed elements can be slewed to a maximum of ±30° before the secondary lobes have maximum gain values approaching –6 dB relative to the main beam maximum.

NOTE – The elevation and the azimuthal characteristics will change with operating frequency for multiband and dual band antennas (see § 3).

Types 7-14 have two collinear dipoles in each row with from one to four rows of dipoles stacked one above the other. The same trends are observed, as for the previous group, except that the azimuthal beamwidth widens significantly for the antennas with very few elements.

Slewing of the main beam should normally be restricted to a maximum of ±15° to avoid secondary lobes having maximum gain values approaching –6 dB relative to the main beam maximum.

Types 15-18 are arrays with a single dipole in each row, and using a reflector. These unidirectional antennas have the maxima of their elevation patterns at higher angles and have a comparatively wide azimuthal beamwidth between the –6 dB points.

Types 19-24 include arrays with one or two elements stacked above one another, all without reflectors. The characteristics are generally similar to those in the previous group except that the radiation patterns are bidirectional because no reflector is used. The non-directional antenna, type 25, has an elevation pattern similar to that of type 24.

2 Comparisons of ITU-R data with practical performance

Comparisons between the data produced by the ITU-R computer program, the values obtained from the reference data and that according to this Recommendation are illustrated in Fig. 2, for azimuthal patterns (HR 2 and HR 4) and Fig. 3 for vertical patterns (HR *m*/2/0.5) and (HR *m*/4/0.5).

Annex 1 refers to measurements which show that radiation to the rear of the antenna and in the minima may be no more than 20 dB below the maximum for a typical HR 4/4/*h* antenna.

Further studies are needed to verify the practical performance of low gain antennas particularly regarding the attenuation achieved, in practice, in directions other than those of the main lobe.

3 Multiband and dual band antennas

Multiband antennas may be operated over a frequency range of approximately 2:1, i.e. from about 0.6 to 1.4 times the ratio of the operating frequency to the design frequency (Fr). Dual band antennas can only be operated over a frequency range of 0.9 to 1.1 times Fr.

Table 2 gives details of the maximum gain, the elevation angle at which this occurs and the vertical attenuation at intervals of 3° of elevation angle for ratios of Fr from 0.6 to 1.4 for multiband antenna types HR(S) 4/4/0.5 ($m = 4$) and HR(S) 2/4/0.5 ($m = 2$). The vertical characteristics given show that the elevation angle of maximum radiation decreases and the main beam of the antenna becomes narrower as Fr is increased.

Table 3 gives the values of azimuthal attenuation at intervals of 5° in azimuth for these two types of antenna for values of Fr from 0.6 to 1.4.

Table 4 gives the values of azimuthal attenuation for a HR(S) 4/4/0.5 multiband antenna fitted with an aperiodic screen reflector operating at the design frequency, in the unslewed condition and for slew angles in 5° steps up to a maximum of 30°.

4 Equivalent antenna elevation patterns

The elevation pattern characteristics of HF antennas are dependent upon the height of the lowest row of elements, h, the number of parallel elements stacked above one another, n, and the conductivity of the ground. Elevation patterns are calculated using a ground reflection function which depends upon the spacing between the radiating elements and their images in the ground. This function can be simplified by using half this distance i.e. the mean height, h_m, of the radiating elements, illustrated for 2-stack and 4-stack antennas in Fig. 4a.

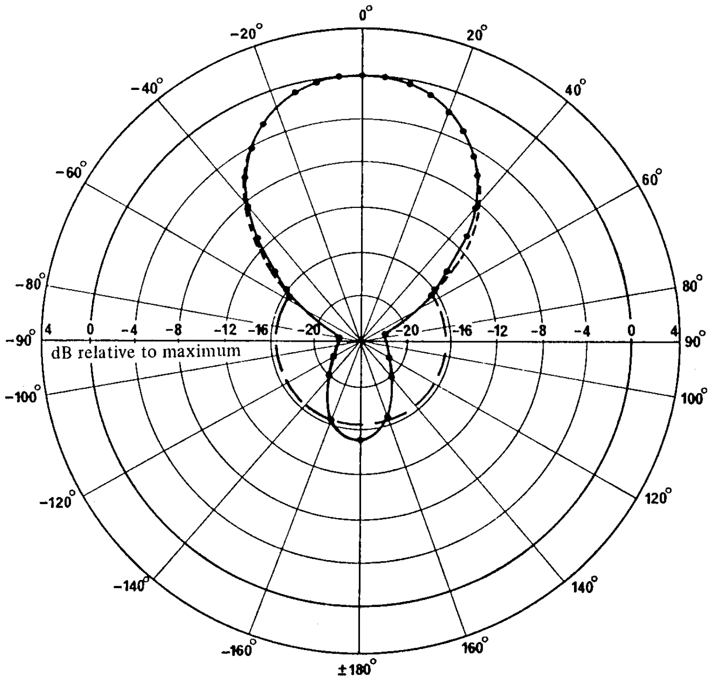
The elevation angle at which the maximum of the first main lobe occurs is then given approximately by:

$$\theta_{max} = \arc \sin (1/4.5 \times h_m)$$

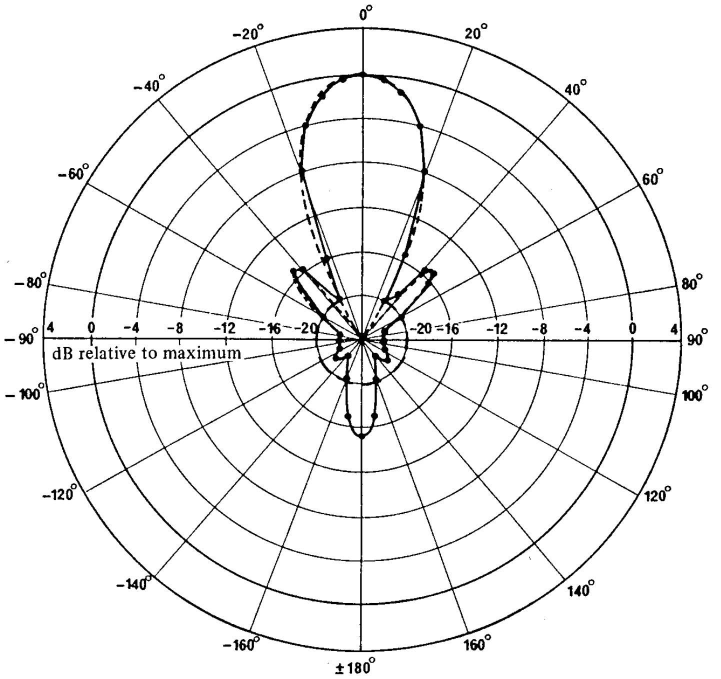
where:

$$h_m = h + 0.25 (n - 1),$$

h and n are defined in Table 1.



a) Azimuthal pattern HR 2/4/0.5, maximum gain 19 dBi



b) Azimuthal pattern HR 4/4/1, maximum gain 22 dBi

FIGURE 2 – *Azimuthal patterns*

—●—●— Representative data

– – – – ITU-R data

— —— Recommendation ITU-R BS.80

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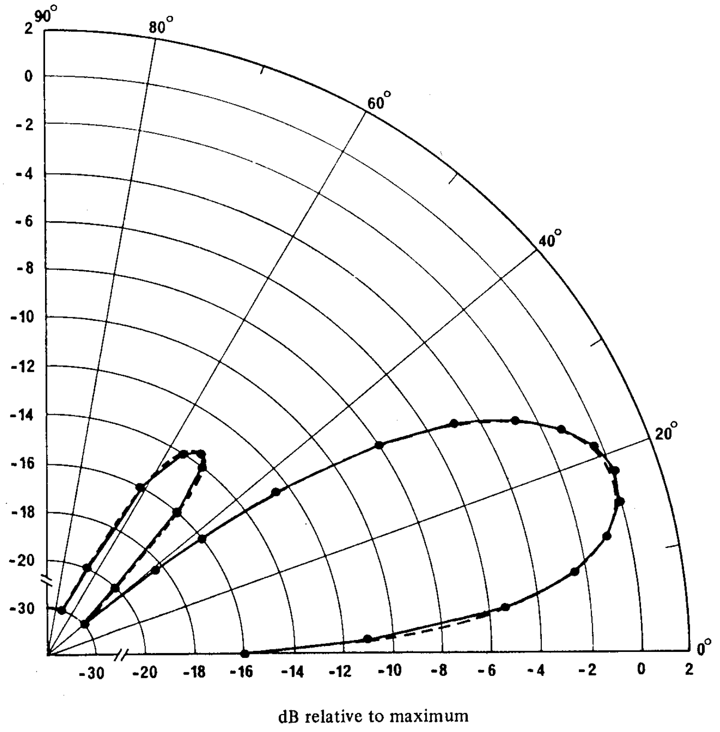
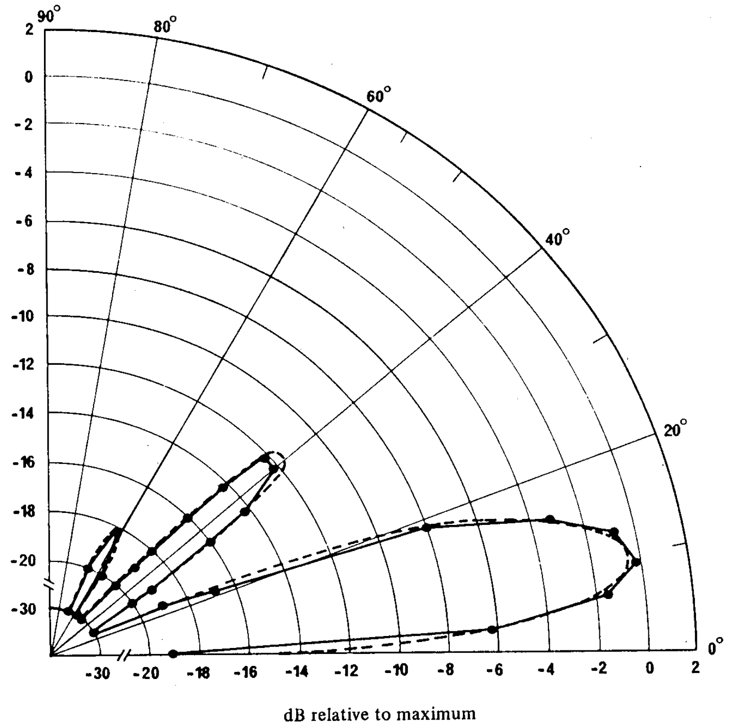


a) Vertical pattern HR *m*/2/0.5



b) Vertical pattern HR *m*/4/0.5

FIGURE 3 – *Vertical patterns*

—●—●—●— Representative data

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TABLE 2

Vertical characteristics of antenna types HR(S) 4/4/0.5 and HR(S) 2/4/0.5

Frequency ratio		0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4
G_i max (dB)	$m = 4$	17.8	18.9	19.9	20.7	21.5	22.2	22.8	23.3	23.5
	$m = 2$	16.1	16.9	17.5	18.2	18.8	19.4	20.0	20.4	20.7
Elevation angle of maximum (degrees)		15	13	11	10	9	8	8	7	7
Elevation angle (degrees)		Vertical attenuation (dB)								
0		30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
3		9.9	8.7	7.7	6.8	6.0	5.3	4.7	4.1	3.6
6		4.4	3.4	2.5	1.9	1.3	0.8	0.5	0.3	0.1
8		2.4	1.6	0.9	0.5	0.2	0.0	0.0	0.1	0.3
9		1.7	1.0	0.4	0.1	0.0	0.0	0.2	0.6	1.1
12		0.4	0.1	0.0	0.3	0.8	1.6	2.7	4.2	6.1
15		0.0	0.2	0.8	1.9	3.5	5.6	8.6	12.7	19.0
18		0.3	1.2	2.8	5.2	8.6	13.6	22.4	30.0	23.9
21		1.3	3.2	6.2	10.8	18.4	30.0	24.2	25.3	30.0
24		2.9	6.2	11.4	21.3	28.7	23.8	30.0	23.5	15.2
27		5.2	10.5	20.5	28.0	24.3	30.0	19.6	13.5	11.2
30		8.3	17.0	30.0	24.3	30.0	18.8	13.1	11.5	12.7
33		12.5	28.9	24.4	30.0	20.2	13.5	11.9	13.8	21.5
36		18.4	27.4	27.2	24.6	14.8	12.3	14.1	22.6	20.3
39		27.8	24.8	30.0	17.4	13.0	13.7	21.0	21.6	15.7
42		30.0	27.5	23.4	14.5	13.3	18.2	25.3	16.6	18.0
45		26.2	30.0	18.3	13.7	15.7	27.5	18.4	17.4	30.0
48		25.9	29.5	15.9	14.3	20.4	22.9	17.3	23.7	22.1
51		28.4	22.8	15.1	16.2	28.3	19.0	19.5	30.0	18.1
54		30.0	19.8	15.3	19.5	25.5	18.5	26.3	21.8	19.6
57		30.0	18.3	16.2	24.5	21.6	20.2	30.0	19.7	25.0
60		30.0	17.7	17.9	30.0	20.4	24.0	25.4	21.0	20.4
63		27.8	17.9	20.2	28.9	20.8	30.0	22.5	25.1	15.6
66		25.7	18.5	23.1	26.0	22.3	30.0	22.4	27.1	13.6
69		24.8	19.6	26.7	24.9	24.7	30.0	23.9	23.1	13.1
72		24.7	21.0	30.0	25.0	28.0	28.6	26.7	20.6	13.7
75		25.3	22.8	30.0	25.9	30.0	28.1	30.0	19.8	15.2
78		26.5	25.1	30.0	27.5	30.0	29.0	30.0	20.2	17.3
81		28.6	27.9	30.0	29.9	30.0	30.0	30.0	21.7	20.2
84		30.0	30.0	30.0	30.0	30.0	30.0	30.0	24.7	24.1
87		30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
90		30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0

TABLE 3a

Azimuthal attenuation of unslewed antenna type HR(S) 4/4/0.5

Frequency ratio	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4
Azimuthal angle	Azimuthal attenuation (dB)								
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.2	0.2	0.3	0.4	0.5	0.5	0.6	0.7	0.8
10	0.8	1.0	1.2	1.5	1.8	2.2	2.6	3.0	3.5
15	1.8	2.3	2.9	3.5	4.3	5.3	6.3	7.6	9.1
20	3.2	4.1	5.3	6.6	8.3	10.5	13.3	17.6	25.3
25	5.1	6.6	8.7	11.3	15.2	21.8	30.0	21.5	16.4
30	7.5	9.9	13.5	19.4	30.0	22.6	16.9	14.1	12.7
35	10.4	14.4	21.6	30.0	20.4	16.0	14.1	13.4	13.7
40	14.0	20.7	30.0	21.3	16.8	15.0	14.8	15.8	18.6
45	18.5	30.0	24.4	18.6	16.5	16.3	17.7	21.7	30.0
50	24.5	30.0	21.6	18.5	17.9	19.2	23.3	30.0	25.1
55	30.0	27.5	21.4	19.8	20.5	24.0	30.0	28.3	20.9
60	30.0	26.5	22.7	22.2	24.4	30.0	30.0	24.7	20.9
65	30.0	27.5	25.0	25.6	29.4	30.0	30.0	25.0	22.9
70	30.0	29.8	28.3	29.8	30.0	30.0	30.0	27.4	26.6
75	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
80	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
85	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
90	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
95	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
100	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
105	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
110	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
115	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
120	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
125	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
130	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
135	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
140	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
145	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
150	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	29.4
155	28.3	29.4	30.0	30.0	30.0	30.0	30.0	30.0	30.0
160	26.7	27.1	27.7	28.4	29.3	30.0	30.0	30.0	30.0
165	25.4	25.4	25.4	25.4	25.4	25.4	25.4	25.5	25.7
170	24.6	24.2	23.9	23.4	22.9	22.3	21.6	20.8	19.9
175	24.0	23.5	22.9	22.3	21.5	20.6	19.6	18.4	17.1
180	23.9	23.3	22.7	21.9	21.0	20.1	19.0	17.7	16.2

TABLE 3b

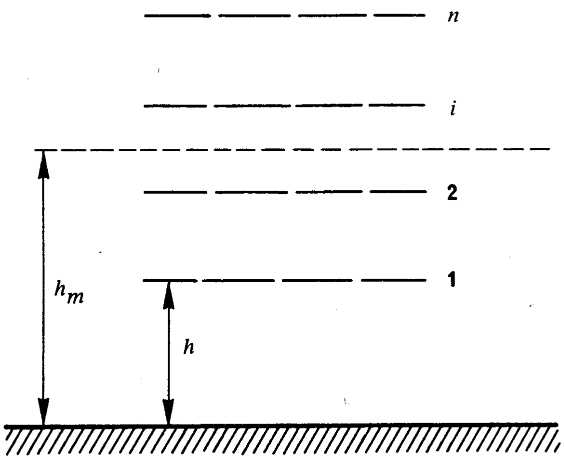
Azimuthal attenuation of unslewed antenna type HR(S) 2/4/0.5

Frequency ratio	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4
Azimuthal angle	Azimuthal attenuation (dB)								
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2
10	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7
15	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.7
20	1.4	1.6	1.7	1.9	2.1	2.3	2.6	2.8	3.1
25	2.2	2.4	2.7	3.0	3.3	3.7	4.1	4.6	5.1
30	3.2	3.5	3.9	4.4	4.9	5.5	6.1	6.9	7.9
35	4.4	4.9	5.4	6.0	6.8	7.7	8.8	10.1	11.8
40	5.8	6.4	7.1	8.0	9.1	10.4	12.1	14.5	18.1
45	7.5	8.2	9.2	10.3	11.8	13.8	16.5	21.3	30.0
50	9.4	10.3	11.5	13.0	15.0	18.0	22.9	30.0	24.9
55	11.6	12.7	14.2	16.1	18.9	23.5	30.0	28.2	20.1
60	14.1	15.5	17.3	19.7	23.4	30.0	30.0	24.1	19.0
65	17.1	18.7	20.8	23.8	28.9	30.0	30.0	23.7	19.7
70	20.5	22.5	25.0	28.6	30.0	30.0	30.0	25.3	21.8
75	24.8	27.0	29.9	30.0	30.0	30.0	30.0	28.6	25.5
80	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
85	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
90	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
95	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
100	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
105	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
110	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
115	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
120	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
125	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
130	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
135	29.0	29.4	30.0	30.0	30.0	30.0	30.0	30.0	30.0
140	27.9	28.1	28.5	28.9	29.5	30.0	30.0	30.0	30.0
145	27.0	27.0	27.1	27.3	27.4	27.7	28.1	28.7	29.5
150	26.2	26.1	25.9	25.8	25.7	25.6	25.5	25.4	25.3
155	25.5	25.2	24.9	24.6	24.3	23.9	23.4	22.9	22.2
160	24.9	24.5	24.1	23.7	23.1	22.5	21.8	20.9	19.9
165	24.4	24.0	23.5	22.9	22.2	21.4	20.5	19.5	18.3
170	24.1	23.6	23.0	22.3	21.6	20.7	19.7	18.5	17.1
175	23.9	23.4	22.7	22.0	21.2	20.2	19.1	17.9	16.4
180	23.9	23.3	22.7	21.9	21.0	20.1	19.0	17.7	16.2

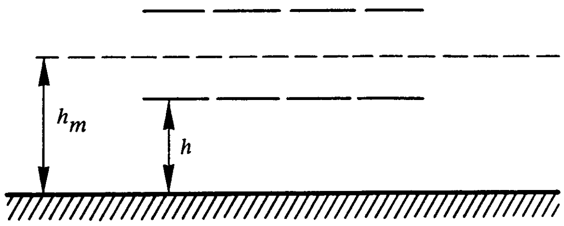
TABLE 4

Azimuthal attenuation of slewed antenna type HR(S) 4/4/0.5

Frequency ratio: 1.0							
Slew =	0	5	10	15	20	25	30
Az max. =	0	4	9	13	17	22	26
–6 dB =	18	23	27	32	37	42	46
–6 dB =	–18	–13	–9	–4	0	5	9
Width =	36	36	36	36	37	37	37
s_{eff} =	0	5	9	14	18	23	27
Angle	Azimuthal attenuation (dB)						
0	0.0	0.4	1.5	3.5	6.8	12.7	30.0
5	0.5	0.0	0.3	1.3	3.1	6.1	11.2
10	1.8	0.5	0.0	0.2	1.0	2.6	5.3
15	4.3	2.0	0.7	0.1	0.1	0.8	2.1
20	8.3	4.5	2.2	0.8	0.1	0.0	0.5
25	15.2	8.4	4.7	2.4	0.9	0.2	0.0
30	30.0	14.7	8.5	4.9	2.6	1.1	0.3
35	20.4	29.7	14.2	8.5	5.1	2.9	1.4
40	16.8	23.8	24.9	13.6	8.5	5.4	3.2
45	16.5	19.0	29.7	21.8	13.2	8.7	5.7
50	17.9	18.4	22.2	30.0	19.7	12.9	9.0
55	20.5	19.5	21.0	27.2	30.0	18.4	13.0
60	24.4	22.0	22.0	24.9	30.0	25.9	17.8
65	29.4	25.4	24.3	25.7	30.0	30.0	23.7
70	30.0	29.9	27.9	28.2	30.0	30.0	30.0
75	30.0	30.0	30.0	30.0	30.0	30.0	30.0
80	30.0	30.0	30.0	30.0	30.0	30.0	30.0
85	30.0	30.0	30.0	30.0	30.0	30.0	30.0
90	30.0	30.0	30.0	30.0	30.0	30.0	30.0
95	30.0	30.0	30.0	30.0	30.0	30.0	30.0
100	30.0	30.0	30.0	30.0	30.0	30.0	30.0
105	30.0	30.0	30.0	30.0	30.0	30.0	30.0
110	30.0	30.0	30.0	30.0	30.0	30.0	30.0
115	30.0	30.0	30.0	30.0	30.0	30.0	30.0
120	30.0	30.0	30.0	30.0	30.0	30.0	30.0
125	30.0	30.0	30.0	30.0	30.0	30.0	30.0
130	30.0	30.0	30.0	30.0	30.0	30.0	28.5
135	30.0	30.0	30.0	30.0	30.0	28.7	25.8
140	30.0	30.0	30.0	30.0	28.9	25.8	23.7
145	30.0	30.0	30.0	29.1	25.7	23.5	22.1
150	30.0	30.0	29.3	25.7	23.4	22.0	21.2
155	30.0	29.4	25.6	23.3	21.9	21.1	20.9
160	29.3	25.5	23.2	21.8	21.1	21.0	21.5
165	25.4	23.0	21.7	21.1	21.1	21.9	23.2
170	22.9	21.6	21.1	21.2	22.1	23.7	26.3
175	21.5	21.1	21.3	22.3	24.1	27.1	30.0
180	21.0	21.4	22.5	24.5	27.9	30.0	30.0
185	21.5	22.7	24.9	28.4	30.0	30.0	30.0
190	22.9	25.1	28.9	30.0	30.0	30.0	30.0
195	25.4	29.1	30.0	30.0	30.0	30.0	30.0
200	29.3	30.0	30.0	30.0	30.0	30.0	30.0
205	30.0	30.0	30.0	30.0	30.0	30.0	30.0
210	30.0	30.0	30.0	30.0	30.0	30.0	30.0
215	30.0	30.0	30.0	30.0	30.0	30.0	30.0
220	30.0	30.0	30.0	30.0	30.0	30.0	30.0
225	30.0	30.0	30.0	30.0	30.0	30.0	30.0
230	30.0	30.0	30.0	30.0	30.0	30.0	30.0
235	30.0	30.0	30.0	30.0	30.0	30.0	30.0
240	30.0	30.0	30.0	30.0	30.0	30.0	30.0
245	30.0	30.0	30.0	30.0	30.0	30.0	30.0
250	30.0	30.0	30.0	30.0	30.0	30.0	30.0
255	30.0	30.0	30.0	30.0	30.0	30.0	30.0
260	30.0	30.0	30.0	30.0	30.0	30.0	30.0
265	30.0	30.0	30.0	30.0	30.0	30.0	30.0
270	30.0	30.0	30.0	30.0	30.0	30.0	30.0
275	30.0	30.0	30.0	30.0	30.0	30.0	30.0
280	30.0	30.0	30.0	30.0	30.0	30.0	30.0
285	30.0	30.0	30.0	30.0	30.0	30.0	30.0
290	30.0	30.0	30.0	28.7	27.2	27.9	30.0
295	29.4	30.0	30.0	26.4	24.0	23.7	25.7
300	24.4	30.0	30.0	25.8	22.0	20.7	21.3
305	20.5	24.4	30.0	27.9	21.3	18.7	18.1
310	17.9	19.8	25.5	30.0	22.7	18.1	16.2
315	16.5	16.7	19.4	27.5	29.2	19.3	15.6
320	16.8	15.0	15.8	19.2	30.0	24.5	16.8
325	20.4	15.1	13.9	15.0	18.9	30.0	21.8
330	30.0	18.3	13.9	12.9	14.2	18.3	30.0
335	15.2	30.0	16.7	12.8	12.0	13.2	17.2
340	8.3	15.4	30.0	15.7	12.0	11.1	12.1
345	4.3	8.2	15.3	30.0	15.0	11.2	10.2
350	1.8	4.1	7.8	14.8	30.0	14.7	10.6
355	0.5	1.7	3.8	7.4	13.9	30.0	14.8



4 stack array



2 stack array

FIGURE 4a

Fig. 4b shows elevation angles of maximum radiation obtained from the ITU-R antenna calculations plotted against mean height, h_m, and the curve obtained from the formula above. Figure 4c illustrates h_m at the design frequency and the variation in the value of h_m for the multiband antennas listed in Table 1.

An HR 4/6/0.5 antenna has a mean height of 1.75 wavelengths at the design frequency, and will, as can be seen from Fig. 4c, have the same mean height and therefore a similar elevation angle of maximum radiation to that of an HR 4/4/1.0 antenna.

5 Horizontally slewed antennas

The angle of slew is the difference between the azimuth of the normal to the dipoles, i.e., the direction of the maximum of the unslewed beam, and the azimuth of the slewed radiation. The actual angle of slew of the maximum of the slewed beam may vary with operating frequency.

Slewing is usually effected by phase-shifting the feeds of the horizontally displaced radiating elements. As a result, if the slew is such that the azimuth of the main beam is increased, then the azimuths of the rearward directed side-lobes will decrease.

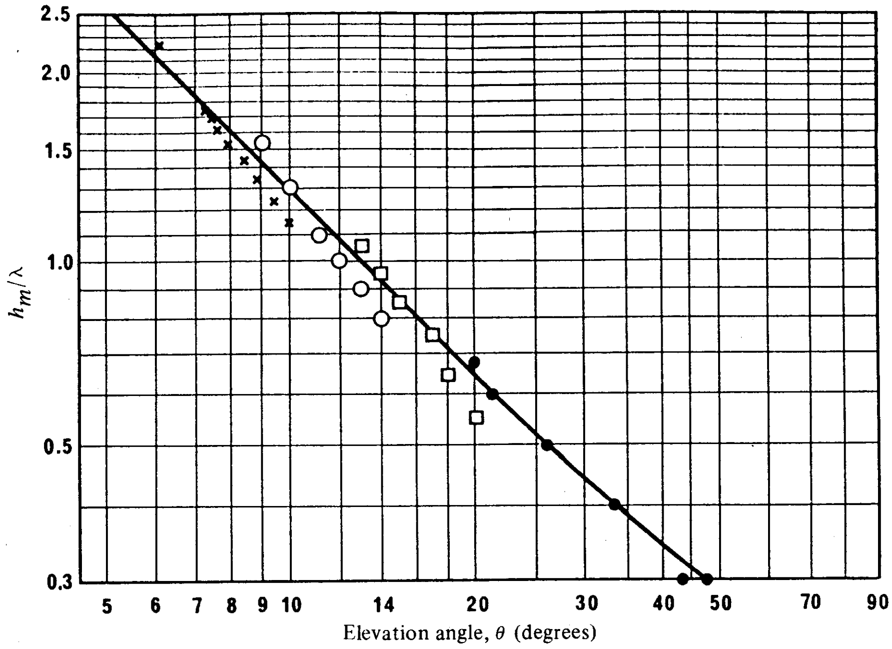


FIGURE 4b – *Angle of maximum radiation v. mean height* (h_m)

× Elements per stack 4
○ Elements per stack 3
□ Elements per stack 2
● Elements per stack 1

D05-sc

For example, if the maximum of the unslewed beam was 90° E of N and the beam was slewed to 110° E of N, the corresponding azimuths of a single lobe of rearward radiation would be 270° and 250° E of N respectively. This is illustrated in Fig. 5.

When an antenna is slewed horizontally, the horizontal radiation pattern is not symmetrical with respect to the azimuth of maximum radiation. The degree of the asymmetry increases as the magnitude of the slew increases.

It should also be noted that the slew angle, s, does not always precisely define the centre of the horizontal pattern given by the mean of the angles at which the maximum gain in the forward radiation pattern is reduced by 6 dB. The mean value is called the "effective slew", s_{eff}. This parameter more accurately reflects the reality of the performance of the slewed antennas, particularly multi-band antennas. The adoption of the term "effective slew", as defined above would help to reduce the ambiguities often found in descriptions of slewed antenna radiation patterns.

Because there is a strong possibility of confusion when dealing with slewed antennas, particularly when reference is made to a slew angle, it is recommended that the azimuths of maximum radiation for the unslewed and slewed antenna should be quoted in all documentation.

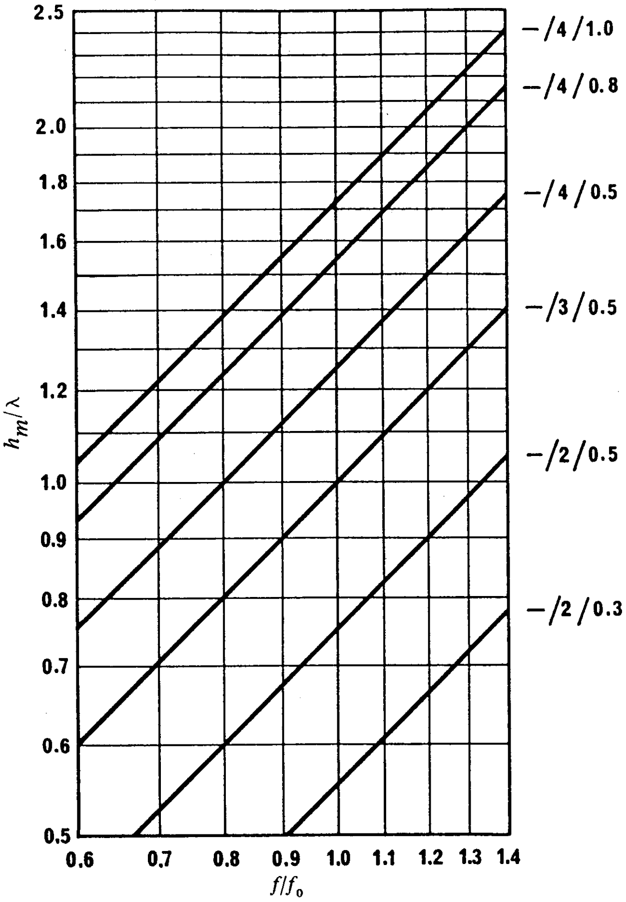


FIGURE 4c – *Variation in mean height* (*h_m*) *for typical multiband antennas*

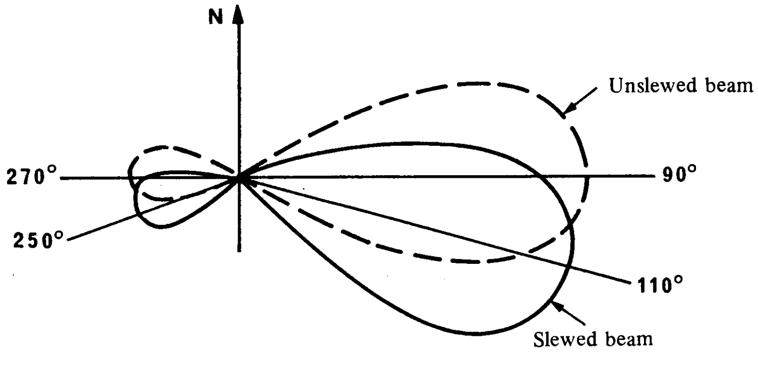


FIGURE 5 – *Pattern for slewed and unslewed antenna*