The Effect of Metal Support Structures on the Performance of VHF and UHF Antennas

1. General

The true characteristics of a given VHF or UHF antenna are only obtainable when that antenna is located in *free space* which, in this context, is space clear of the earth or other bodies or structures so that radiation from the antenna is propagated by direct path only. The separation between an antenna and any structure must, therefore, be in excess of a predetermined minimum distance – usually defined in wavelengths – unless, of course, the modifying effect of the structure is required to provide a given radiation pattern. Obviously, the lower the frequency and the larger the structure, the greater the separation must be if the effect on the pattern is to be minimal. If, however, the antenna approaches the earth or structure, the effect on the characteristics – in particular, that of the radiation pattern – becomes more and more pronounced; whilst ultimately, at close spacing, changes to the antenna impedance will also become noticeable, with obvious effect on the standing wave performance.

The following paragraphs outline the effect of various types of structure upon normal antennas, and indicate means of minimizing these shortcomings or, alternatively, of using them to modify the antenna radiation pattern to suit a particular application.

2. Basic Patterns Obtained in Free Space

2.1 Half-wavelength Dipole (transmitting and receiving)

This is the simplest form of antenna currently in use at VHF and UHF. The radiation pattern in free space measured in the *far field* takes the form of a 'doughnut' (Fig.1). (The *far field* of an antenna is generally considered as beyond the distance $\frac{2d^2}{\lambda}$, where 'd' is the antenna length and λ the wavelength, all parameters being in the same metric units).

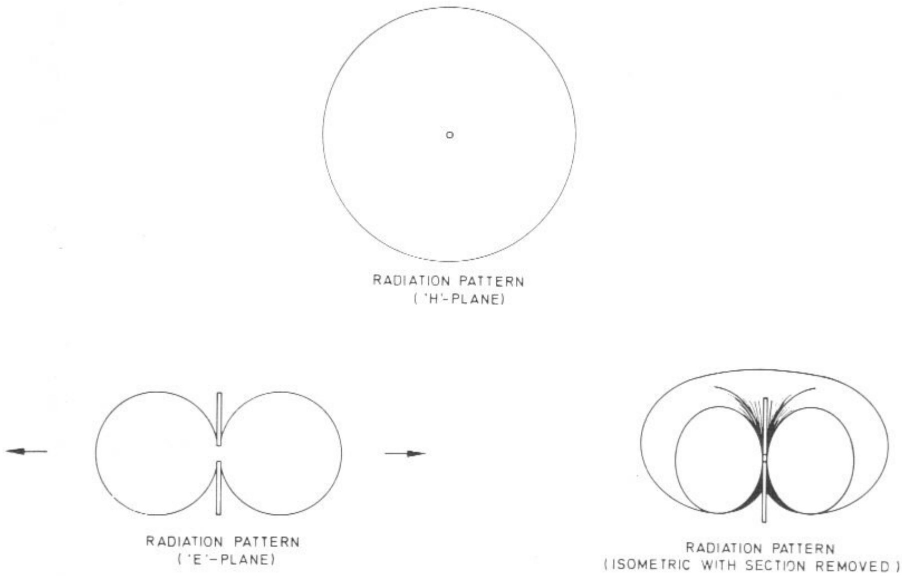


Fig. 1 Dipole Antenna Radiation Pattern

The half-wave dipole is normally used as a reference for gain in VHF and UHF antennas. The dipole has an effective gain of approximately 2.2 db over an isotropic radiator, which is a theoretical source of radiation having a spherical pattern with equal gain in all directions. The isotropic radiator is normally used as a standard reference at microwave frequencies.

2.2 Gain Antennas (transmitting and receiving)

This type of antenna uses phased driven elements and/or passive reflecting elements arranged to concentrate the radiation pattern into one or more defined directions.

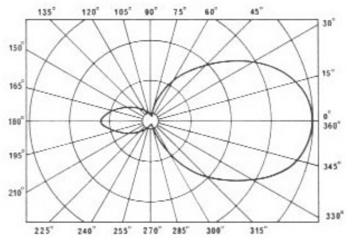
The total combinations possible are too numerous to outline in these notes. It can be seen however, from the various examples in Figs. 2 and 3 that the effect of concentrating the pattern in a particular direction is to produce an effective gain in that direction. This increase in gain cannot be achieved without a reduction in gain in other directions and it is this effect which improves the performance of a directional antenna by limiting unwanted radiation in other than the desired direction(s).

The best analogy illustrating the overall principle of obtaining gain by modification to the radiation pattern is that of a spherical balloon filled with a non-compressible liquid such as water. In its normal state it shows the pattern of an isotropic antenna with equal radiation in all directions. By compressing the balloon at opposite ends of a diameter, the shape becomes that of a 'doughnut' and the diameter at right angles to the line of compression extends to give the effective dipole gain of 2.2 db over an isotropic source.

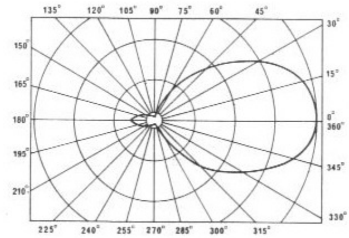
By applying pressure at other points, the shape of the balloon can be altered to produce radiation patterns similar to those of directional antennas. It can be seen that, although the shape can be adjusted so that the distribution of liquid indicates the relative radiation in any direction, the overall volume of liquid and hence the **total** radiation, remains the same.

E-PLANE DIAGRAMS FOR VARIOUS GAIN ARRAYS

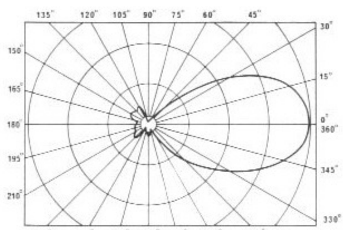
NOTE: POLAR DIAGRAMS HAVE BEEN NORMALISED TO SHOW IDENTICAL SIZES OF THE MAIN LOBE.



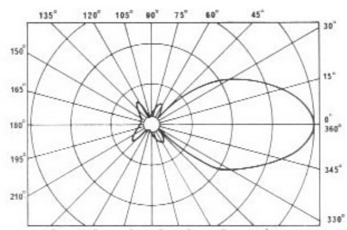
2-element Yagi
(gain approx. 5 db)



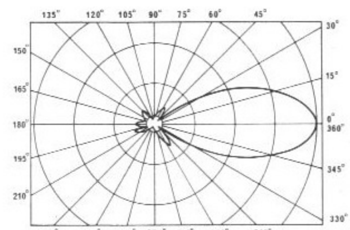
3-element Yagi
(gain approx. 7 db)



4-element Yagi
(gain approx. 8.5 db)



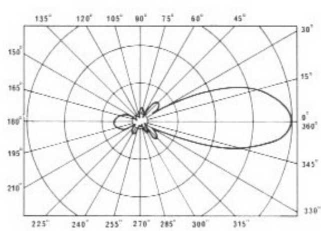
6-element Yagi
(gain approx. 10 db)



8-element Yagi
(gain approx. 11.5 db)

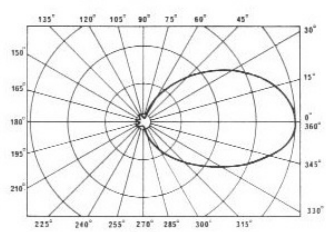
Fig. 2 VHF Yagi antennas — Typical radiation patterns

12-element Yagi
(gain approx. 12 db)



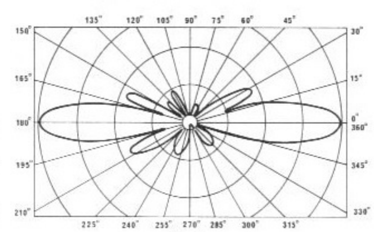
E-plane

Corner reflector
(gain approx. 10 db)

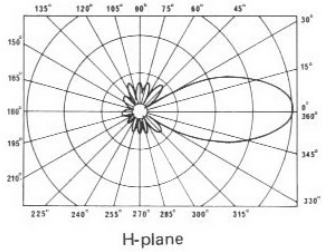


E-plane

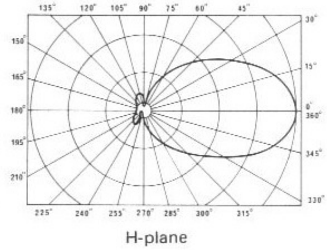
High gain omni-directional
(gain approx. 5 db)



E-plane



H-plane



H-plane

NOTE: POLAR DIAGRAMS HAVE BEEN NORMALISED TO SHOW IDENTICAL SIZES OF THE MAIN LOBE.

3. Antennas at Less than Free Space Conditions

If a half-wave dipole antenna is located near to a reflecting object, then any energy received by this object will obviously be reflected and will modify the effective shape of the radiation pattern of the dipole when measured at the far field. Further, if this reflecting object is adjusted in length to be resonant at the frequency in question, then the reflected energy will be at its maximum. Adjusting the position of the object so that it is in the same plane as the dipole at a spacing where the reflected energy is in the correct phase, will reinforce the main radiation in a given direction. This is the first step in the development of an antenna with gain in one direction.

From this it can be seen that if a dipole is supported by a metallic structure and this structure is in sufficiently close proximity to the dipole, then its effect on the overall radiation pattern can be similar to that given above.

4. Effect of Mast Supporting Structure on a Half-Wave Dipole

4.1 Effect on Antenna Impedance

Before considering the effect of a nearby or supporting structure on the radiation pattern of an antenna, it is important to observe the effect of spacing on the impedance and the ultimate standing wave ratio obtainable.

Assume that a half-wave dipole in free space has its normal impedance of approximately 70 ohms. If this antenna is now placed in close proximity to a metallic structure with surface dimensions at least one wavelength in any direction, then the effective impedance of the antenna will change as the spacing between the antenna and the surface of the structure varies.

The approximate impedance resulting from the variations in spacing will be as follows:

Table A

Spacing from Structure	Impedance
0.5 Wavelength ($\lambda/2$)	70 ohms
0.33 Wavelength ($\lambda/3$)	100 ohms
0.25 Wavelength ($\lambda/4$)	83 ohms
0.16 Wavelength ($\lambda/6$)	50 ohms
0.1 Wavelength ($\lambda/10$)	20 ohms

Converting Table A to effective VSWR, assuming a cable of 70 ohms characteristic impedance, we have:

Table B

Spacing from Structure	VSWR
0.5 Wavelength ($\lambda/2$)	1 : 1
0.33 Wavelength ($\lambda/3$)	1.4 : 1
0.25 Wavelength ($\lambda/4$)	1.2 : 1
0.16 Wavelength ($\lambda/6$)	1.4 : 1
0.1 Wavelength ($\lambda/10$)	3.5 : 1

Note:

$$\text{VSWR} = \frac{Z1}{Z2}$$

Assuming the use of feeder cable having an impedance of 50 ohms — this value of characteristic impedance is now generally accepted throughout the world — then the VSWR values will now become:

Table C

Spacing from Structure	VSWR
0.5 Wavelength ($\lambda/2$)	1.4 : 1
0.33 Wavelength ($\lambda/3$)	2 : 1
0.25 Wavelength ($\lambda/4$)	1.66: 1
0.16 Wavelength ($\lambda/6$)	1 : 1
0.1 Wavelength ($\lambda/10$)	2.5 : 1

To assist in appreciating the dimensions involved, the following Table (D) shows the various fractions of a wavelength relative to different frequencies.

Table D

Frequency	$\lambda/10$	$\lambda/6$	$\lambda/4$	$\lambda/3$	$\lambda/2$	λ
450 MHz	6.7 cm	11.1 cm	16.7 cm	22.3 cm	33.5 cm	67 cm
150 MHz	20 cm	33.4 cm	50 cm	66.6 cm	100 cm	200 cm
75 MHz	40 cm	66.8 cm	100 cm	133.3 cm	200 cm	400 cm
40 MHz	75 cm	125 cm	187.5 cm	250 cm	375 cm	750 cm

Other dimensions (in centimetres) can be calculated from the simple formula

$$\frac{30{,}000}{\text{MHz}} = \lambda\,(\text{cm})$$

4.2 General Effect on Radiation Pattern

Reference should be made to Fig. 4 which shows typical mast cross-sections and associated antenna configurations. It can be seen that the supporting structure can vary from a single small diameter pole through various mast sizes up to a solid structure having dimensions extending for many wavelengths.

Obviously, the larger the mass behind the dipole the greater the tendency to limit the radiation pattern in the rearward direction. This particularly applies where the metallic structure is solid or with wire meshing where the mesh diagonal measurement is considerably less than a quarter wavelength. In the forward direction, the presence of a larger screen behind the antenna tends to reduce the width of the lobes produced, particularly those in the same plane as the structure.

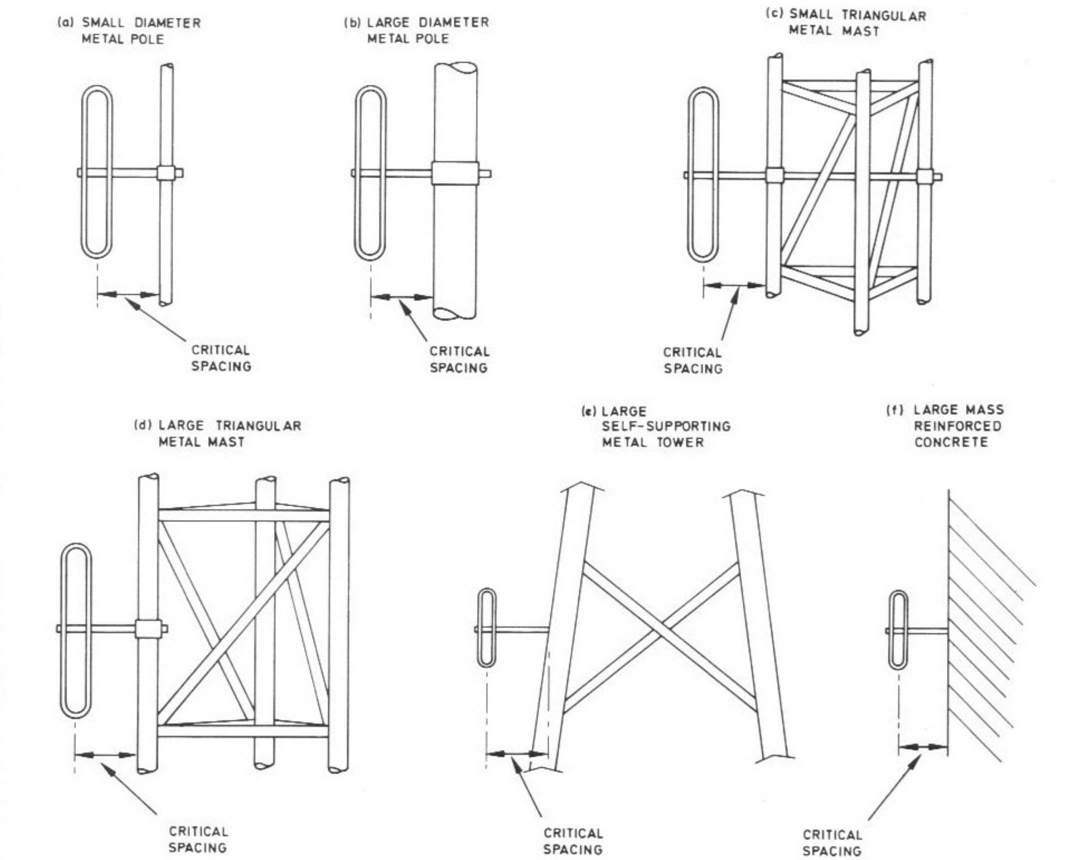


Fig. 4 Mast/Antenna configurations

4.3 Effects on Radiation Pattern as a Function of Spacing from Structure

The most important effect on a half-wave dipole is the change of its radiation pattern as the distance between the dipole and the structure varies.

If one considers the structure as a reflecting surface then (referring back to Section 3 above) it can be seen that the spacing will affect the phase difference between the originating source in the dipole and the signal arriving back at the same point in the dipole after reflection.

The reinforcement pattern of the radiation will, therefore, vary and cause changes in the lobe pattern.

Examination of the first line of diagrams in Fig. 5 shows the changes in radiation pattern as the spacing between a dipole and its supporting structure of $\lambda/8$ diameter varies. Subsequent lines indicate the modification to these patterns made by increasing effective structure diameter.

Further increases in the size of a solid structure reduce the radiation in the rearward direction still more, and ultimately a structure size is reached where the radiation will not extend appreciably behind the structure.

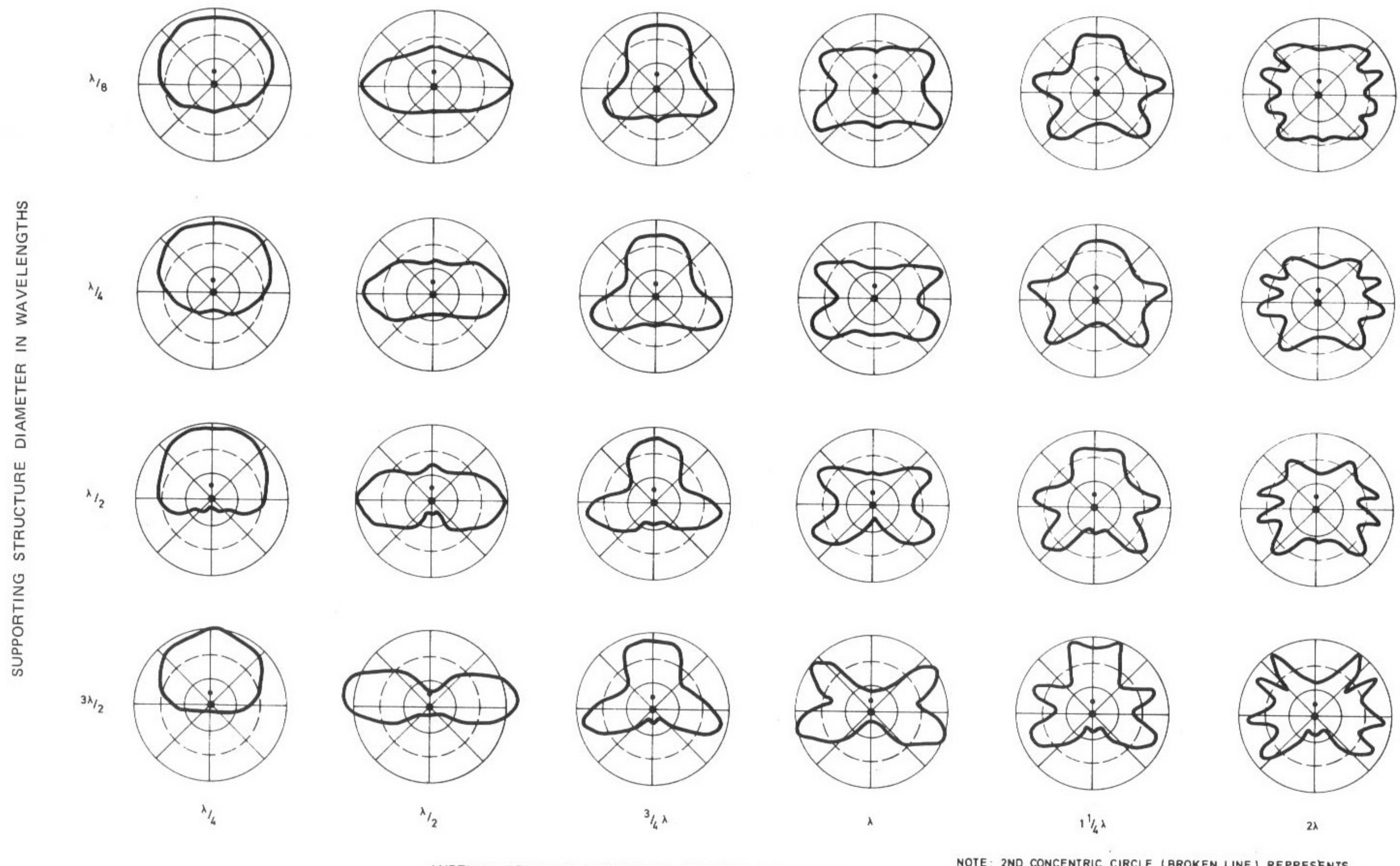


Fig. 5 Effect of spacing on radiation pattern

With open structures, such as lattice masts and towers, the cut-off of the rearward radiation is defined but tends to show multiple lobes of narrow beamwidth and considerable depth. Fig. 6 indicates typical horizontal patterns of omni-directional antennas mounted on large cross-section towers: (a), (b) and (c) show the effect of side mounting at various spacings, (d) the result of corner mounting and (e), (f) the effect of mounting antennas on opposite sides of the tower and feeding them in phase.

4.4 Number of Lobes Produced

Examination of the patterns obtained (Fig. 5) highlights certain details. At each odd quarter wavelength spacing a forward lobe is produced, whilst for each even quarter wavelength two additional lobes – one in each direction in the same general plane as the structure – appear. Further analysis based on the above shows, therefore, that the resulting number of lobes is exactly equal to the number of quarter wavelength spacing intervals between the antenna and its support structure.

Where the number of vertical tower members extend over a considerable area behind the antenna, the number of lobes cannot be easily predicted and the pattern shown in Fig. 6 illustrates such an effect.

4.5 Construction of Supporting Structure

The variation of the radiation pattern as a function of the structure details is of some importance. With an open form of construction there will be multiple reflections and, consequently, differing phase arrival times between the various reflections. This effect will tend to produce subsidiary lobes within the main pattern. Typical examples are shown in Fig. 6.

Further variations can be caused by a 'lossy' structure and the mounting of an antenna on, say, the wall of a non-reinforced building could well show considerable differences in radiation pattern under differing climatic conditions. Fortunately, the type of antenna normally mounted in this manner usually falls into the directional category and, therefore, a degree of protection exists at the rear of such an antenna – by virtue of the rear reflecting element in the case of a Yagi or the screen assembly in the case of a corner reflector type. With such antennas, therefore, the variation with differing mounting structures can be less marked, although possibly still objectionable under some circumstances. Where the effect is unacceptable, then the inclusion of a mesh screen mounted on the face of the structure behind the antenna is to be recommended. Such a screen should not be less than a wavelength square.

The provisioning of a screen is often considered advantageous behind single or stacked/bayed Yagi antennas where the back radiation is required to be minimal, and where isolation between antennas on opposite faces of a mast is required to be as high as possible (see Fig. 7). The use of such a screen behind stacked and/or bayed antennas also serves as a more consistent form of construction with electrical constants less likely to cause variations in the overall pattern. It minimizes effects caused by nearby antennas and metalwork etc. Again, the size of such a screen should not be less than a wavelength square **per antenna** in the array.

This type of construction tends to explain some of the more consistent results obtainable with corner reflector antennas.

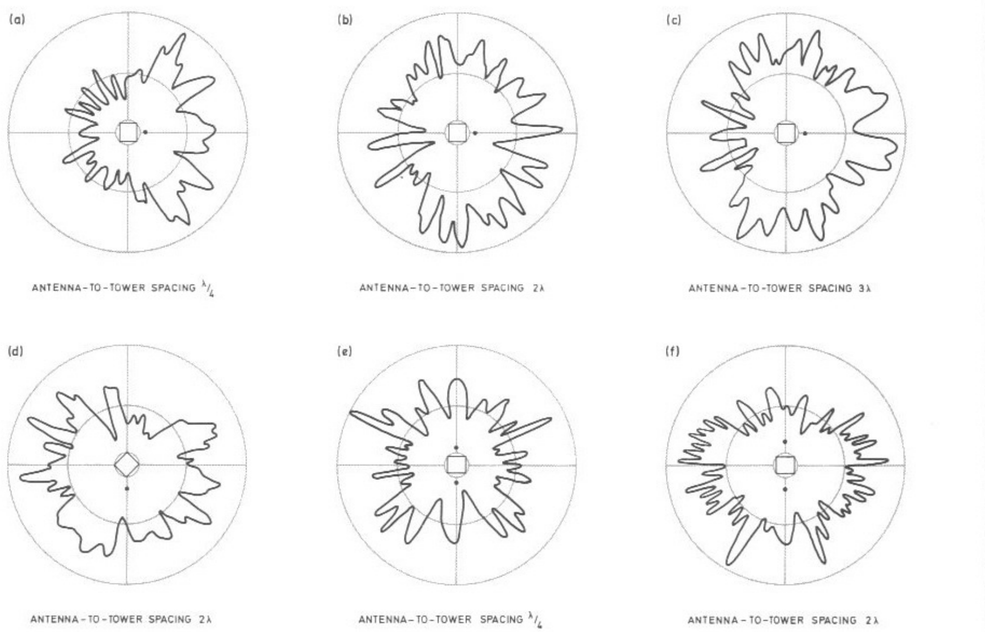


Fig. 6 Typical 'H'-Plane patterns of omni-directional antennas mounted on metal towers of large cross-section (in excess of 5λ square)

These polar diagrams are based on information published by the Phelps Dodge Communications Company, U.S.A. and are reproduced with their kind permission.

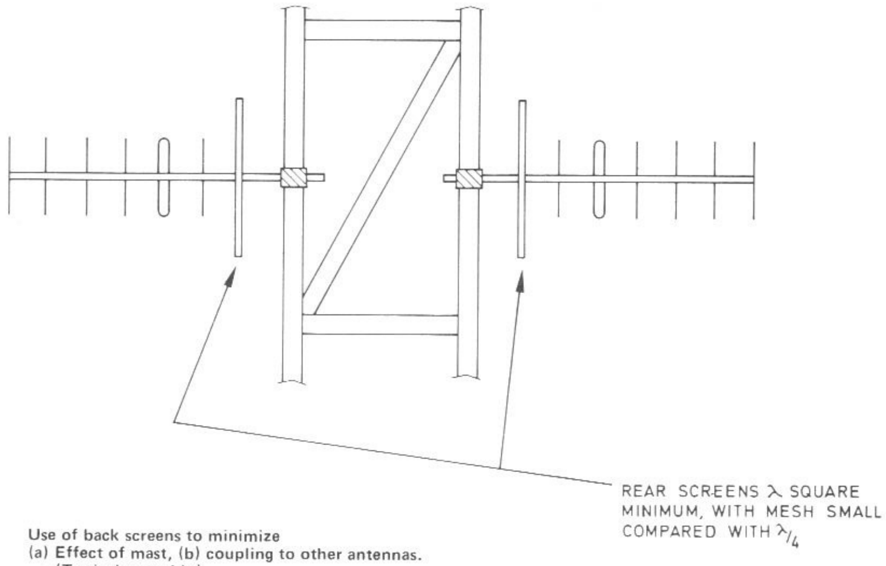


Fig. 7 Use of back screens to minimize
(a) Effect of mast, (b) coupling to other antennas.
(Typical assembly)

5. Use of Supporting Structure as a Means to Obtaining Desired Radiation Pattern

As can be seen from analysis of Fig. 5 the desired patterns around a swing of not less than 180° can, theoretically, be obtained by suitably mounting the antenna concerned at an optimum distance from the structure. However, it can be seen from Fig. 6 that structures having large open areas of lattice construction cannot be relied upon to produce 'clean' radiation patterns with smooth outlines.

Some care must be exercised, therefore, when considering the use of the mast as a passive element.

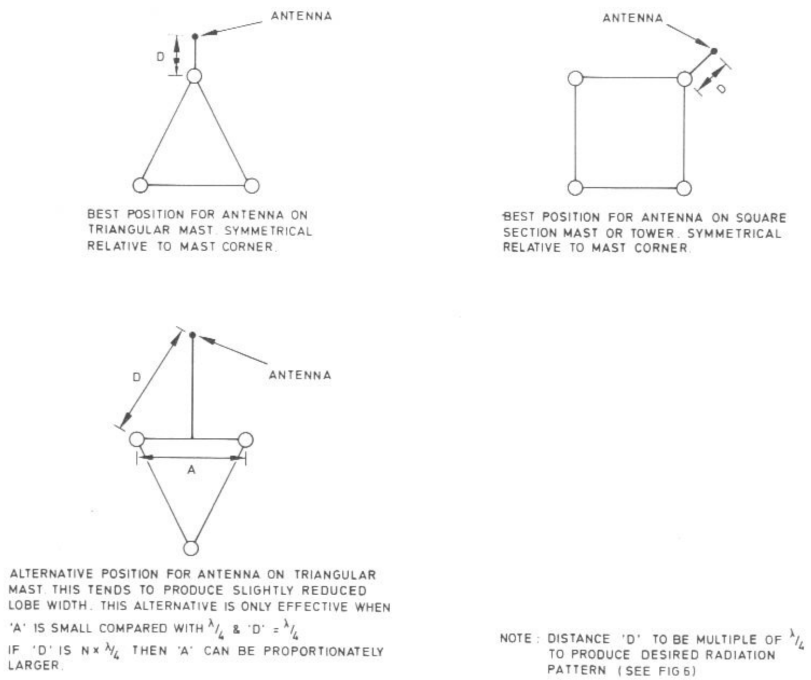


Fig. 8 Minimizing unwanted effects caused by structure layout

The standard circular pole type of support tends to exhibit similar pattern modifying effects to that of a conventional reflector element in a directional antenna and, therefore, no difficulty should be experienced in providing the desired pattern.

With lattice masts, even those of small size, care should be taken when positioning the antenna concerned. Where possible, there should be one structure element governing the position and other parts of the mast should be located symmetrically behind the predominant structure element and screened by the main element as much as possible. This infers that the mounting of an antenna on the corner support will give the best results. Fig. 8 refers.

If possible, the inclusion of a mast joint within half wavelength of the antenna centre should be avoided. The reason for this is clear if the general principle of non-linear rectifying action is considered in its relation to the production of spurious signals and intermodulation. Obviously, the placing of a 'rectifying joint' in a radiation system can only lead to problems of mutual interference on the site and in its vicinity.

Where joints cannot be avoided and indeed even if they fall some distance outside the main field, the use of copper straps by-passing them should be considered during installation.

6. Omnidirectional Coverage from Side Mounted Antennas on Large Metallic Structures

Occasions may arise when there is a need for omnidirectional coverage using side mounted antennas on large objects, such as water towers etc. Owing to the large area of screening present, there will obviously be a lack of signal at the rear of a single antenna. The solution, therefore, is to fill in such poor areas to provide as near an omnidirectional radiation pattern as possible.

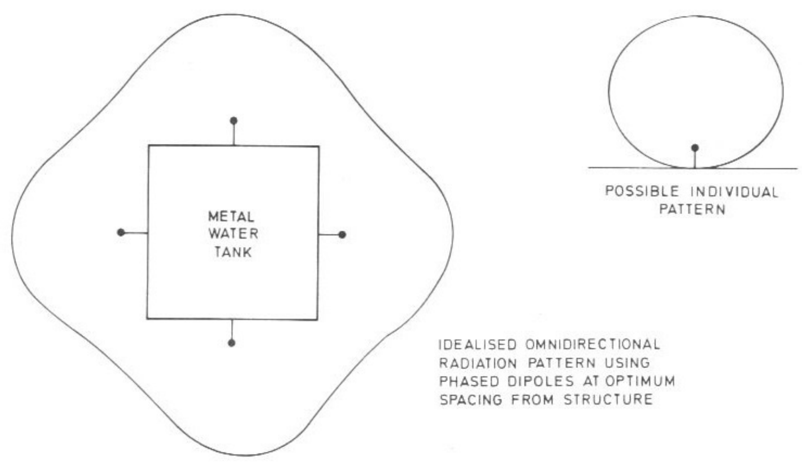


Fig. 9 **Antennas on large structure giving omni-directional coverage**

To achieve this will require additional radiating antennas located at strategic points on the sides of the water tower. Referring to Fig. 9, it can be seen that each individual antenna mounted at, say, a quarter wavelength from the structure would, if fed separately, provide substantially the pattern shown. To enable four such patterns to be additive and provide an all-round pattern, the feeding of the antennas must be such as to ensure correct phase relationships and for this reason the antenna array for a particular structure is usually designed for that sole purpose. The factors affecting such a design are relatively complex and are not, therefore, included in these notes. Furthermore, it would normally be necessary to perform a comprehensive field pattern test on the completed assembly to confirm its actual performance.

7. Conclusions

Whilst the foregoing notes indicate the general effect of a structure upon a given antenna, the patterns and ultimate performance resulting for multiple antenna assemblies on the larger type of structure are often more complex. The radiation patterns shown in these notes are, in general, those obtainable with the smaller type of structure; the larger open structures (as shown in Fig. 6) tend to break up the patterns into lobes having much deeper nulls. Larger solid structures show a reduction in the number of lobes but generally at the expense of rearward radiation.

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