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# THE DEVELOPMENT OF TRANSMITTING AERIALS FOR BANDS IV & V

## INTRODUCTION

THE FIRST ACTS of the European V.H.F/U.H.F Broadcasting Conference at Stockholm 1961 listed the allocation of television stations in the u.h.f band. It defined frequencies, radiated powers and radiation patterns for the whole of Europe.

More recently the BBC has started its planning of u.h.f stations and as a result aerial designers have had to clarify their ideas as to what form the design of u.h.f aerials should take. Apart from such requirements as horizontal and vertical radiated patterns (HRP and VRP) which can vary from site to site and the need for low order of reflection coefficient, the other important factors are that the bandwidth shall be wide enough for colour and that more than one programme shall be radiated from one mast; the British plan is that ultimately four-colour programmes will be radiated from each station.

The Stockholm Plan lists 4503 u.h.f transmitters for Europe, thus, even if the rate of growth is relatively low, industry has to decide on designs which can be produced in standardized form rather than have to produce a vast quantity of "one-off" specials.

## SURVEY OF POSSIBLE U.H.F AERIALS

It is worthwhile reviewing the two basic classes of aerials which can be used for u.h.f and to examine their advantages and disadvantages.

*1. Narrow Band or Single Channel Aerials*

These aerials operate on a single specific channel and cannot carry more than one programme.

Some of the various forms of narrow band aerials are as follows:

(a) helical aerial,
(b) slotted ring aerial,
(c) slotted coaxial line aerial,
(d) slotted waveguide aerial.

*2. Wide-band or Multi-Channel Aerials*

These aerials will cover several channels and can be used for the simultaneous transmission of more than one programme. Even used for a single channel they rationalize design and allow the use of standard piece parts.

The aerial consists of an assembly of panels (see Fig. 1) each mounting four twin dipoles stacked above each other and occupying a height of about two wavelengths, a width of one wavelength and a depth of half a wavelength. The use of such an arrangement allows the whole of Band IV and V to be covered in two editions of panels.

A second form of wide-band aerial is the "skewed-yagi" which has limited application and will not be discussed in this paper.

## MECHANICAL CONCEPT OF THE AERIAL

The wide-band panel type of aerial has been adopted as offering the best and most flexible arrangement. The

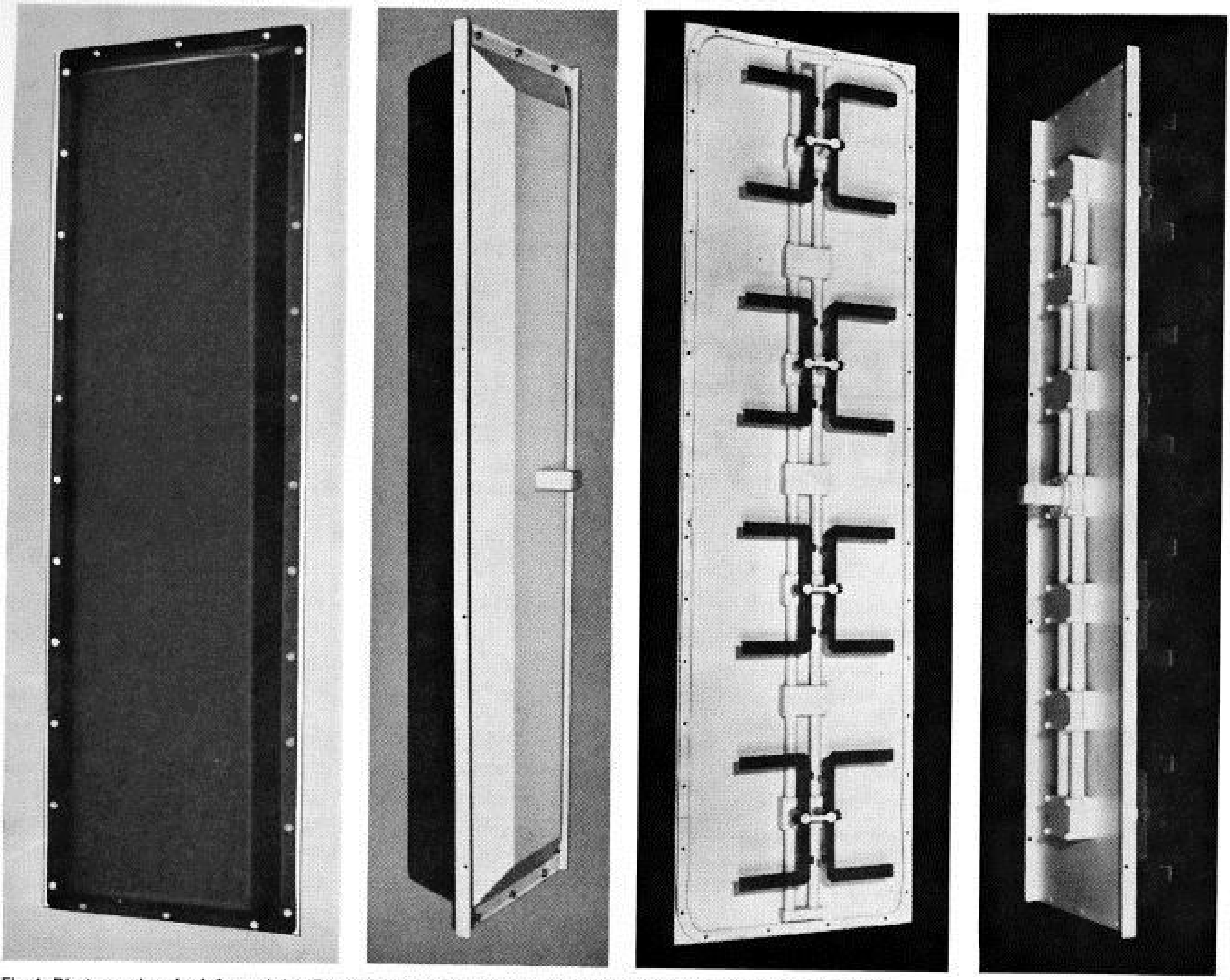

Fig. 1. Photographs of u.h.f panel. (a) Front view—with cover (Band V). (b) Side view—with cover (Band V). (c) Front view—without cover (Band IV). (d) Side view—without cover (Band IV).

aerial consists of a multiplicity of elements arranged in a square or pentagon or hexagon, depending on the diameter of the circle inscribed, in order to achieve the required horizontal radiation patterns, which in most cases is omnidirectional.

The smaller the inscribed circle the fewer elements required for a given uniformity of HRP, and hence the simpler and more reliable the aerial. However, this results in decrease of access space and consequently it has been decided that the structure of the aerial shall consist of a load-bearing cylinder of fibre glass of 5 ft in diameter with the square of four aerial panels mounted inside this cylinder and supported from it. This leaves the space inside the square free for distribution cables only and provides adequate climbing space for service access. Fig. 2 shows the arrangement of the panels inside the fibre-glass cylinder. The reason for off-setting the panels on the side of the square will be described later. Aerial gain is increased by vertical stacking of the panels.

## RADIATOR PANEL UNIT

The radiator panel consists of an array of eight dipoles mounted on a reflector screen. The dipole length is approximately $0{\cdot}8\lambda$ at the centre of the operating band. The dipoles are fed in pairs by a balanced line, which is made rigid enough to support the dipoles. A pair of dipole limbs and one conductor of the balanced feed line form one solid unit made from die-cast aluminium. The profile of the casting is chosen to be an angle in order to suit an economic manufacturing process. The balanced lines are supported by and fed via a balun which is also made of die-cast aluminium. The dipole pairs are fed in branch feed fashion whereby all elements of equal input impedance receive equal driving current. The power distribution system is made from

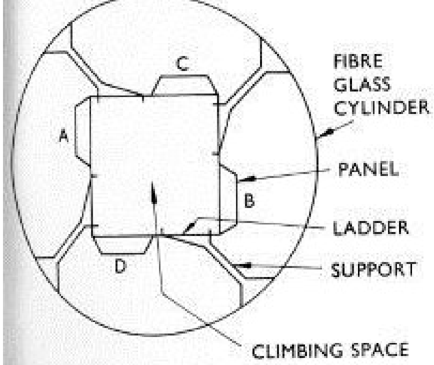


Fig 2. Arrangement of panels inside the fibre-glass cylinder.

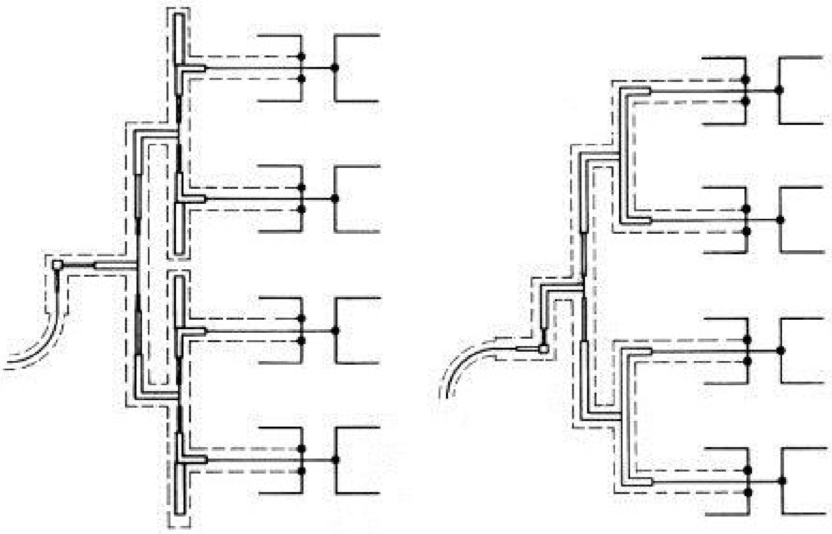

Fig. 3. (a) Band IV panel feed system. (b) Band V panel feed system.

a pair of coaxial feeders running side by side along the centre of the panel and which are clamped at the junction points to the screen by two halves of an aluminium block. The outer conductors of these feeders are made from 1 in. (2·5 cm) diameter aluminium tubes while the inners are silver-plated copper or brass rods. The dipoles are protected by a fibre-glass cover fixed to the screen and sealed airtight. The enclosed air space in the panel may be pressurized via the feed cable by dry air of 8 in. (20 cm) water gauge above atmospheric pressure. This facility is necessary in areas where the high degree of atmospheric pollution and moisture causes corrosion on metal surfaces.

Fig. 3 (a and b) shows the arrangement of the feeding system.

There are two principal electrical requirements:

(a) radiation pattern should remain constant in the band,

(b) input v.s.w.r should be below the specified maximum value.

Mechanically there are two problems:

(i) to produce a space saving design without sacrificing rigidity,

(ii) to produce an economic design without sacrificing the tolerances necessary in order that no electrical adjustment is required after assembly.

The developed radiator unit is essentially a compromise between achieving mechanical simplicity and meeting the performance of the aerial system.

After deciding the minimum climbing space, the least number of radiating panels which could be mounted round this passage could be determined. This stage of the work is important since the production cost of the aerial is proportional to the number of panels. Due to the large number of variables, the use of a computer is desirable. Anticipating the horizontal radiation patterns (omnidirectional or directional) most likely to be required by prospective customers, a large number of polar diagrams were calculated with different feeding arrangement of the panels and with assumed radiation patterns. From these results an arrangement which gave the greatest flexibility in horizontal radiation patterns with the least number of radiators provided the basis for the aerial design. At the first attempt it was found that five panels in Band IV and V would be the optimum number. Later on with some mechanical modification space saving was possible and only four panels round the climbing area were proved to be feasible. That defined the desirable horizontal radiation pattern of one panel to be cos $l^2\theta$. With further theoretical investigation the optimum dipole length and distance from the reflector screen was determined for minimum beam width variation in the operating band. Similarly the spacing between dipoles for maximum vertical gain of one panel was calculated. Unfortunately, these factors also have a dominant effect on the dipole input impedance and the optimum dimensions for the two requirements do not coincide but are, however, not very different. A small deviation from the ideal polar diagrams and an impedance compensation network in the power distribution feeder system provides acceptable results. In practice several

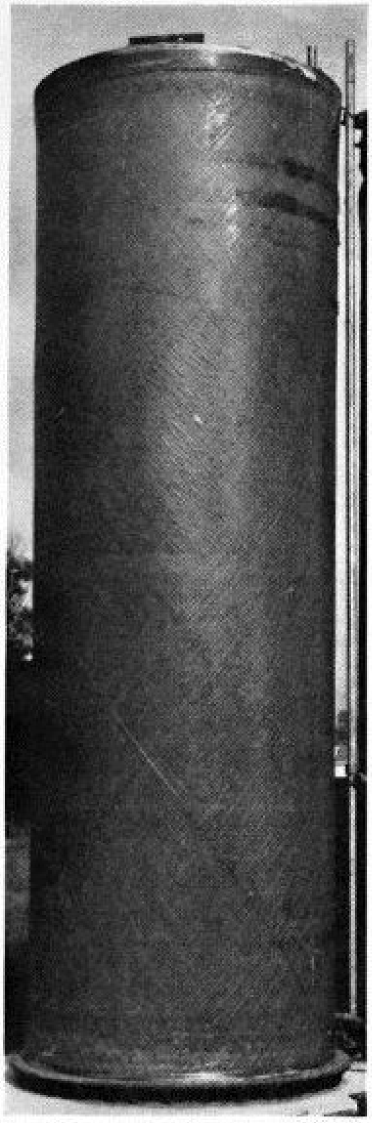

Fig. 4. Photograph of fibre-glass cylinder.

simultaneous experiments were necessary in order to find the optimum settings.

## THE DESIGN OF THE AERIAL

Gain of the aerial system can be determined from the specified mean effective radiated power and available transmitter power. The intrinsic gain of the aerial is given by the formula

$$G_I = G_s + L_F + L_D + L_s + L_N + L_B$$

where

$G_I$ is the intrinsic gain of the aerial, dB,
$G_s$ is the system gain, dB,
$L_F$ is the main feeder attenuation, dB,
$L_D$ is the distribution feeder attenuation, dB,
$L_s$ is the loss of all dielectrics in front of radiating unit, dB,
$L_N$ is the loss due to null filling, dB,
$L_B$ is the loss due to beam tilt, dB.

The aperture (A) of the aerial can be calculated from an approximate formula:

$$A = 0{\cdot}8\lambda\,\sqrt[10]{10^{G_I}}$$

or the number ($N_v$) of Band IV and V panels stacked vertically

$$N_v = 0{\cdot}2\,\sqrt[10]{10^{G_I}}$$

Two methods can be used for supporting the radiating panels

(a) 5 ft (1·5 m) diameter fibre-glass cylinder—this is the preferred arrangement.
(b) square mast up to 6 ft (1·8 m) sides.

*Method* (a)
The radiating units are mounted round a limited climbing space and individual panels are radiating radially apart from a small amount of skew. In this arrangement, the structural material in the radiation field is electrically transparent and the HRP is free from frequent ripples.

*Method* (b)
Radiating units mounted on the corners of the square mast and the individual panels radiate tangentially. Since the steelwork of the mast is in the radiation field and the panels "shadow" each other the HRP shows greater variation. In cases when the u.h.f aerial cannot be mounted inside the fibre-glass structural cylinder on top of a mast, this method provides a practical and economic solution with acceptable performance in the HRP.

The fibre-glass cylinders are made in lengths of up to 16 ft (4·9 m) and 5 ft (1·5 m) diameter. Flanges at the ends are turned inwards and clamped between steel rings so that cylinders may be bolted to each other. The material used for the cylinder is a specially woven glass fabric with fire resistant bonding resin. Four lightning protection wires are on the outside

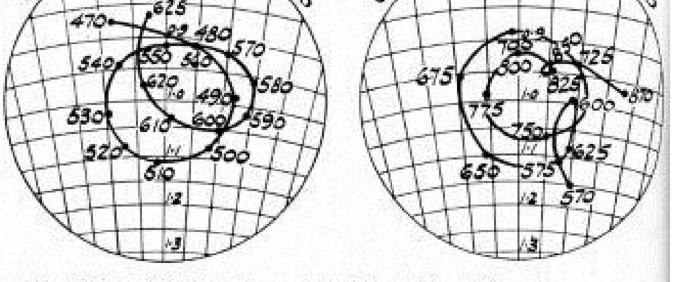


Fig. 5. (a) and (b), Impedance plots of Band IV and V panels.

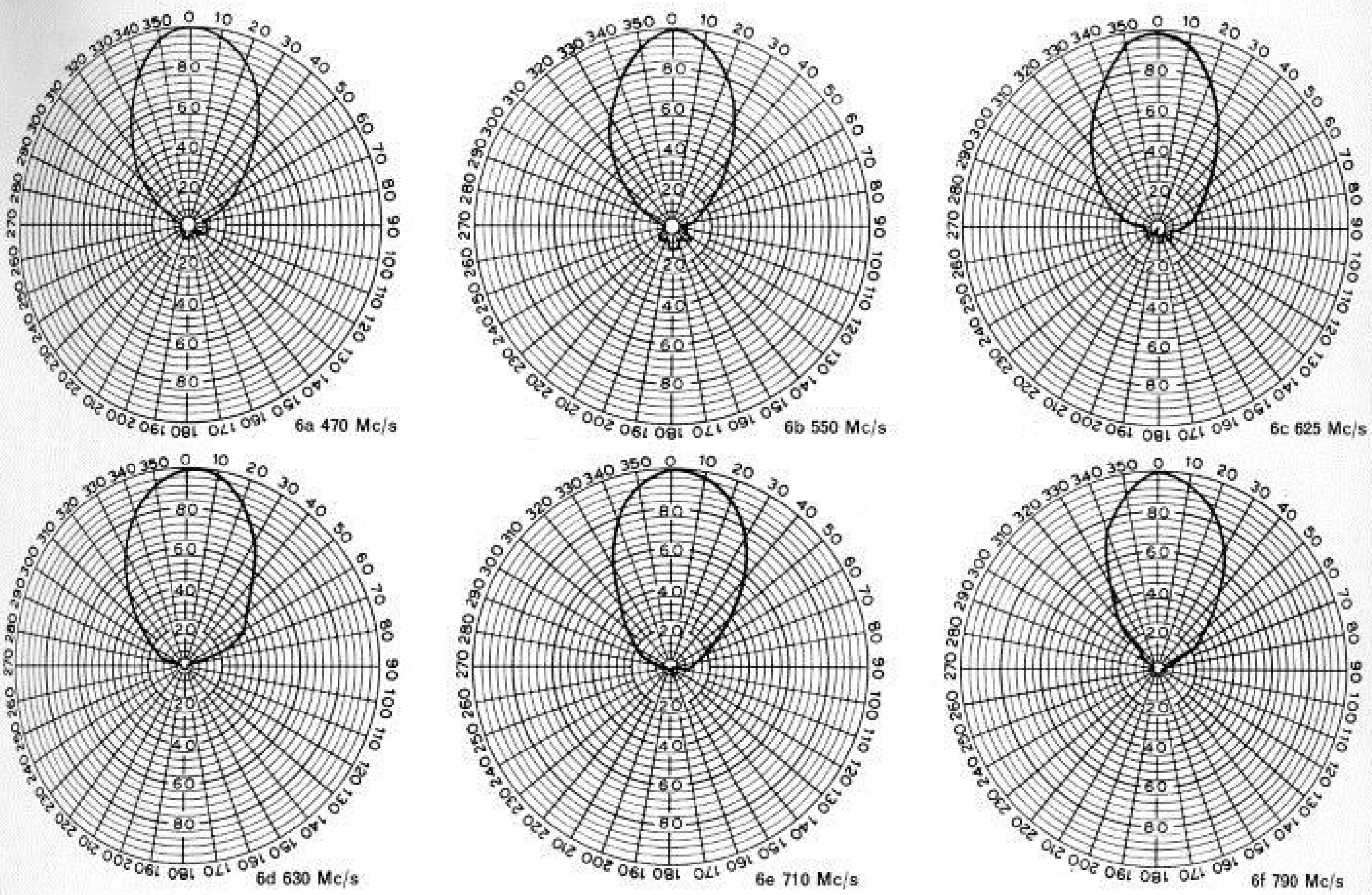


Fig. 6. Horizontal radiation patterns of Band IV and V panels.

surface at the neutral plane of the electric field so as not to interfere with the radiation pattern.

The radiator panels are fastened to vertical running steel ladders which are suspended from the cylinder flanges via rubber shock absorbers which damp the mechanical oscillation generated by gusty winds. Fig. 4 shows the cylinder with the panels inside.

## THE PERFORMANCE OF THE U.H.F PANELS

The frequency band 470 to 854 Mc/s is covered by two versions of 8 element u.h.f panel type aerials. The lower frequency radiating unit, the Band IV panel, has a bandwidth extending from 470 to 625 Mc/s, while the higher frequency unit, the Band V panel, covers the band 575 to 854 Mc/s.

### *Band IV Panel*

Within the band 470 to 625 Mc/s this aerial exhibits the impedance characteristic shown plotted on the Smith chart in Fig. 5a which shows a tightly coiled locus centred on 50 ohms and contained within the 1·17 v.s.w.r circle.

Horizontal radiation patterns are shown in Figs. 6a, b, c for the frequencies at the centre and edges of the band. The patterns show a tendency to become narrower as the frequency is increased which is a consequence of the dipoles approaching a wavelength in length. This effect is partly compensated for by the dipole-to-screen spacing becoming effectively greater, but owing to the difference in the rates of change of the two effects, compensation cannot be complete.

The measured vertical radiation pattern for the centre frequency is shown in Fig. 7a. Theoretically this pattern is given by the expression

$$E(\theta) = \frac{\sin\left\{\frac{\pi g N}{\lambda}\sin\theta\right\}}{N\sin\left\{\left(\frac{\pi g}{\lambda}\right)\sin\theta\right\}} \times \sin\left\{\frac{\pi d}{\lambda}\cos\theta\right\}$$

where

$g$ = interdipole spacing,
$N$ = number of elements,
$\lambda$ = wavelength,
$\theta$ = zenith angle measured from the normal to the panel,
$d$ = dipole screen spacing.

The theoretical pattern is also shown in Fig. 7a. It may be seen that the first null occurs at 14·5° away from the normal which is a fact of some importance in the problem of null filling which will be returned to later.

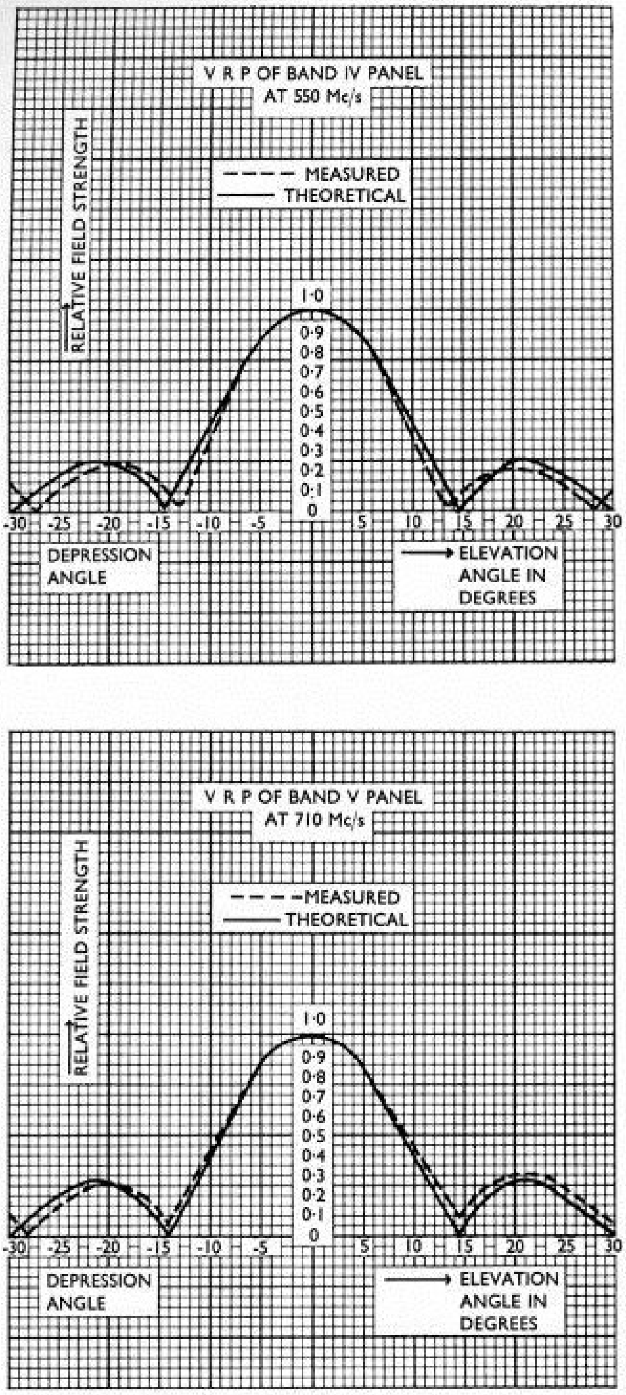


Fig. 7. Vertical radiation patterns of Band IV and V panels.

*Band V Panel*

The Band V panel has a similar performance to the Band IV, but over the band 575 to 850 Mc/s, its impedance characteristic is illustrated in Fig. 4b where it may be seen that the locus is centred on 50 ohms and contained within the 1·15 v.s.w.r circle.

Horizontal radiation patterns for the band edges and centre are shown in Figs. 6d, e, f. The vertical radiation pattern for the centre frequency is shown in Fig. 7b.

## BROADBANDING OF THE AERIAL SYSTEM

In a television aerial system it is essential that no appreciable reflected signal from the aerial should be allowed to travel back to the transmitter down the main feeder, otherwise this undesired signal will be reflected again from the transmitter and be transmitted as a 'ghost' signal delayed by the time required for two traversals of the main feeder.

A commonly used method of reducing reflections from the aerials to negligible proportions is to feed the elements through different lengths of cable which are chosen such that the reflections on arrival at the distribution point are phased so as to cancel out. For example, two similar aerials would be fed by cables differing in length by a quarter of a wavelength thus causing the two reflections to arrive back at the junction in antiphase by virtue of the one having travelled a half wavelength further than the other. The reflected power must be absorbed at the junction, however, or it will be re-reflected causing unequal power division between the two aerials. The principle is illustrated in Fig. 6.

This method is used in the aerial system described here but in this case there are four radiating units per stack which are to be fed with 0°, 90°, 180°, 270° phase progression which also gives the desired result.

If four unidirectional radiating units are placed symmetrically on a circle and energized in this phase progression, it has been found that the variation of the HRP of the assembly depends on the skew angle, i.e. the angle which a radius of the circle passing through the radiating unit makes with the direction of the

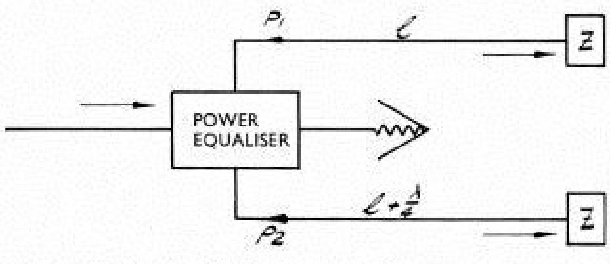


Fig. 8. Illustration of phase feeding principle.

maximum radiation of the unit. The minimum variation occurs when the skew angle is either near zero or 90°, the variation being least for the latter value. The small skew angle is used when the radius of the circle is small since the shadowing effect of one unit on its neighbour would be large if 90° skew angle, or tangential, mounting were employed.

For most u.h.f installations the supporting structure for the aerials will be designed to suit the layout required for producing omnidirectional patterns. In these cases there will be four panels per stack placed on the sides of a 26-in. square and directed radially. As the panels will be fed with the 0°, 90°, 180°, 270° phase rotation, it will be necessary to offset the panels about 3 in. from the centres of the sides of the square in order to provide the required skew. The resulting arrangement is shown in Fig. 3.

However, there will be installations where it will be necessary to mount aerials on the sides of existing aerial masts. The plan area of the mast would probably mean that many more than four panels per level would be needed in order to achieve the horizontal radiation pattern. Economy can be made by using four panels at 90° skew angle at the corners on a square section mast.

## PRINCIPLES OF POWER DISTRIBUTION

In order to produce the coverage required of a television broadcasting aerial, it is necessary to shape the beam both in the horizontal and vertical planes. In all cases it is necessary to have a narrow beamwidth in the vertical plane and also it is usually necessary to fill in nulls up to about 45° below the horizontal. In general the desired beam shaping in the vertical plane may be achieved by using a phase and amplitude distribution over the vertical aperture of the aerial or by an amplitude or a phase distribution alone. To be able to radiate the maximum possible power with a given array of identical aerials, a uniform amplitude distribution is necessary since each unit may be operated at

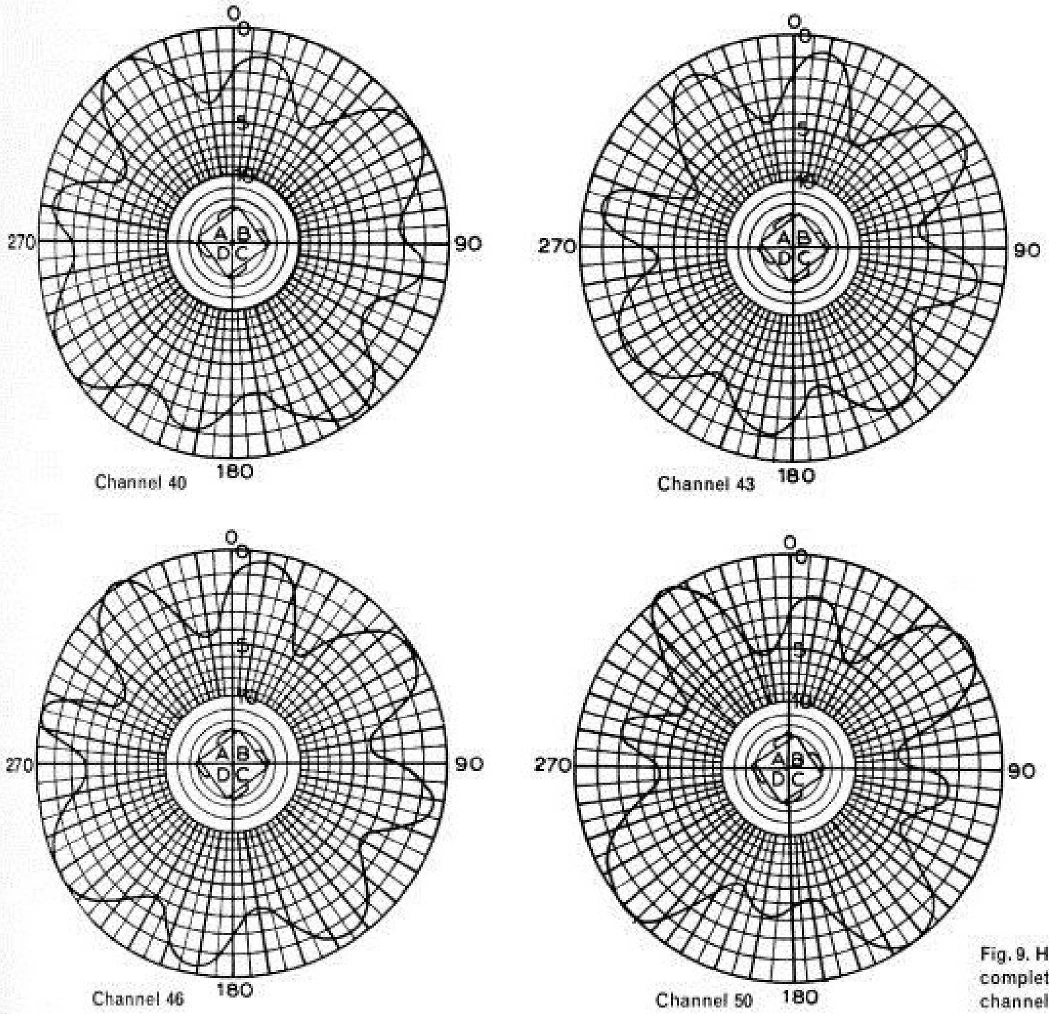


Fig. 9. Horizontal radiation patterns of a complete aerial system suitable for four channels, simultaneous transmission.

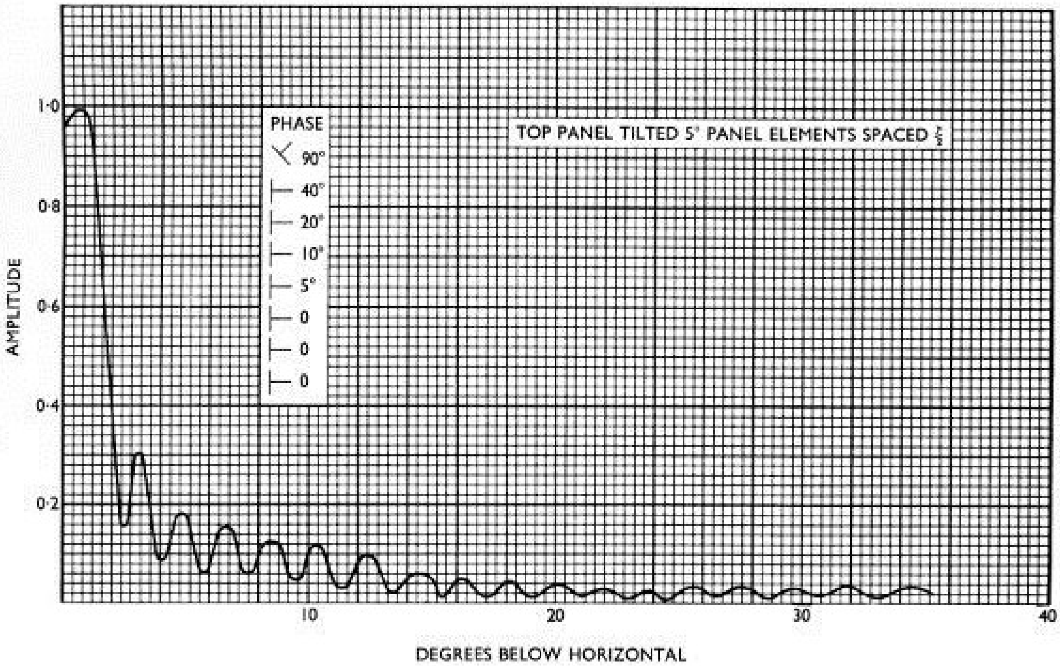


Fig. 10. Vertical radiation pattern of complete aerial.

its maximum power handling capacity. This consideration leads to the requirement that the beam shaping be achieved by a phase distribution only.

An omnidirectional horizontal radiation pattern is usually required and this may be produced by an appropriate configuration of uniformly fed units in the horizontal plane. If a directional HRP is required, it is usually not possible to achieve it by means of a phase distribution only so in this case one of two alternatives must be used. One is to have a non-uniform distribution of uniformly fed radiating units, and the other is to have a uniform distribution of non-uniformly fed units.

The HRPs of a complete aerial system are given in Fig. 9 where it may be seen that the variation of the pattern remains sensibly constant over a band of at least 80 Mc/s which includes four channels which can be used on the same site.

Directional patterns are produced when the radiating units are fed with unequal power and may be tailored to suit most requirements by an appropriate power division. A slight complication arises with the disposal of the reflected power since the reflections are no longer of equal amplitude, but this is easily dealt with by arranging that the feeder cable lengths are such that the vector sum of the reflections is zero.

## VERTICAL RADIATION PATTERNS

A vertical stack of panels fed with uniform amplitude and phase produces a vertical radiation pattern consisting of a horizontally directed main beam, and auxiliary beams and a number of nulls. In order to provide the best service area, however, the main beam must be depressed approximately 0·5° below the horizontal because the aerials will be mounted at heights of approximately 1000 ft (300 m) above the ground, and also the nulls in the pattern which occur at angles of depression between 0° and 45° must be filled in so that coverage is maintained right up to the transmitter.

For economic reasons it is better to feed the panels with equal power so null filling must be achieved by a phase distribution only. A requirement for null filling is that the signal shall not fall below the level given by

$$E(\theta) = \frac{E_0}{2\pi A} \operatorname{cosec}(\theta - \theta_1)$$

for $\theta$ between the half-amplitude angle of the main beam and 15° and by

$$E(\theta) = \frac{E_0}{4\pi A} \operatorname{cosec}(\theta - \theta_1) \quad \text{for} \quad 15° < \theta < 45°.$$

In the above expressions

$E$ is the amplitude at angle $\theta$,
$E_0$ is the amplitude of the main beam,
$A$ is vertical aperture in wavelengths,
$\theta$ is the angle of depression,
$\theta_1$ is the angle of beam tilt.

Mathematical analysis gives the following formula of phase distribution which satisfies the conditions. Starting with a theory strictly applicable to a continuously distributed source, a phase function was found which gave the desired pattern theoretically.

The function was of the form

$$\varphi(x) = -\frac{2\pi a}{\lambda(\operatorname{cosec}\theta_1 - \operatorname{cosec}\theta_2)} \times \log_e\left\{(\operatorname{cosec}\theta_1 - \operatorname{cosec}\theta_2)\frac{x}{a} + \operatorname{cosec}\theta_2\right\},$$

where

$\varphi$ = phase,
$x$ = height from base of the array,
$a$ = total height of the array,
$\lambda$ = wavelength,
$\theta_1, \theta_2$ = angles at the extremes of the range of interest.

The phase function $\varphi(x)$ was then sampled at discrete values of $x$ appropriate to the panel positions, and the VRP of a stack of panels fed with the phases so determined was then calculated on a DEUCE computer. It was found that the resulting pattern did not quite satisfy the conditions, so systematic incremental variations in the phases of each panel were applied by a method of dynamic programming which quickly led to a satisfactory solution.

Since the VRP of one panel alone gives a null at 14·5° below the horizontal it was impossible to eliminate this by a phase distribution only, so it was found necessary to tilt the top panel downwards physically by 5°.

The degree of null filling attainable is limited if the amplitude of the main beam must not fall more than 1 dB below the value it would have if the panels were uniformly phased. The method described above was pursued until this limit was reached. A typical vertical radiation pattern is shown in Fig. 10.

## DISTRIBUTION NETWORK

The components of the power distribution network consist of two power equalisers and four 4, 6 or 8 way splitter-transformers which together divide the power equally 16, 24 or 32 ways. Two $6\frac{1}{8}$ in. (15·6 cm) diameter coaxial feeders are used to bring the power from the transmitters to the base of the cylinder unit, each feeding into a power equaliser. One power equaliser feeds the upper half of the aerial and the other the lower half, thus providing a very reliable dual system. An advantage of the branched feeding system is that the pattern of the aerial at the beginning of a pulse is practically the same as that for a continuous wave.

The reflected power from the aerials is absorbed at the power equalisers by loads of the order of 1 kW power rating, and is prevented from passing down the main feeders by the provision of an extra quarter-wavelength of rigid line into one outlet of each power equaliser. The extra length of line causes the reflections to be in antiphase, thereby cancelling out.

The four outlets of the power equalisers are terminated in 4, 6 or 8 way splitters, which in turn feed into 16, 24 or 32 $\frac{7}{8}$ in. (22 mm) diameter cables of equal length. The phasing of the stacks required for beam tilting and null filling is produced by lengths of rigid line connected to the output ports of the panels. As all of the 16, 24 or 32 cables are of equal length and the panels which they feed are at different distances from the distribution point, it is necessary to dispose of the 'slack' cables by winding them round the inside wall of the cylindrical lower section housing the power equalisers and transformers.