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AUSTRALIAN BROADCASTING CONTROL BOARD
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"TELEVISION TRANSMITTING AERIAL PERFORMANCE".

by

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TELEVISION TRANSMITTING AERIAL PERFORMANCE.

C O N T E N T S

TELEVISION TRANSMITTING AERIAL PERFORMANCE

Summary.

The paper outlines the choice of frequency, location, and required aerial pattern to meet the station requirements, then discusses co-siting and mast reflections, impedance requirements, typical aerial elements available for construction of aerials, and examples of their use at Australian stations. Phase-rotation of feeding elements and its effect on the HPD are discussed, then the stacking of elements to produce the required VPD, often determined by ghosting problems. Combinations of aerials on a single structure are considered, and methods of weather protection. The paper concludes with a study of aerial distortions and a review of the methods of verifying aerial performance once the station is in operation.

An attempt is made to cover the whole field in brief, and to this end a fairly large number of references is included. More detail is given of original or less familiar work.

Introduction - Basis of Planning.

1. The purpose of this paper is to discuss the performance of television transmitting aerials as a key factor in the satisfactory development of the Australian television services. The transmitting aerial is technically the most individual part of a television station - most other parts of the station can be standardised, but the transmitting aerial links the station to the surrounding country and its communities and generally must be individually engineered to meet the coverage requirements. (Ref. No. 1).

The planning of the Australian television service has proceeded on the basis that with the form of population distribution that exists, the most economical solution in terms of cost and usage of channels results in a main network of high-power stations of about 100 k.w. e.r.p. at spacings of the order of 80 miles. With this concept as a basis, it is possible to allocate service areas, and define the signals to be established at their boundaries. The detailed allocation of transmitting frequencies, selection of polarisation and frequency offsets can then be made to minimise interference between the several stations which must share each channel. It is then possible to examine suitable transmitting sites within the area, select the best compromise and determine the height of aerial and e.r.p. to give the required coverage. Fortunately, most of the Australian population lives in the vicinity of mountains high enough to be useful as television sites, and this considerably reduces the cost for a given area of coverage. However it is general experience that even though the site may be a mountain top, a mast of 400-500 feet is justifiable economically in most cases for the improvement in coverage that it produces.

Selection of Aerial Polar Diagram. Aerial Gain.

2. Given the aerial location in space, it is then possible to specify acceptable limits for horizontal and vertical polar diagrams.

The horizontal pattern is usually determined by the situation close to the limits of the service area - the balancing of power against that of co-channel stations to put the inevitable mush area into a region adequately served by station on another channel, the increase of signal strength in the directions of towns, or other areas receiving marginal signals, at the expense of those directions where reduced coverage radius is acceptable because of other stations, or the presence of unpopulated areas, such as mountain ranges, or seas.

The main lobe of the relatively sharp vertical pattern is directed usually to the horizon, but the control of the shape of the pattern below this is determined by the local coverage requirements within 10 miles of the station. In locations where considerable angles of depression are required, this can become the dominant factor in the design of the aerial.

Above the horizon, the lobe shape is usually of little importance - except that it represents wasted power - with the exception of Band 1 frequencies, where excessive power radiated upwards at angles of $4^{\circ} - 12^{\circ}$ can cause serious increases in co-channel interference by sporadic E propagation.

In most locations there is a wide range of vertical patterns acceptable for coverage purposes; over this range there may be considerable variations of aerial power gain, which gives the station engineer the opportunity to determine the most economical combination of aerial gain and transmitter power to give the required effective radiated power. (Provided that coverage is to be provided at all azimuths, the average effective radiated power is not affected by changes in the horizontal polar diagram.)

In those cases where the desired vertical aerial pattern is considerably sharper than that of convenient aerial elements, it becomes necessary to stack a considerable number of these vertically to achieve the desired gain. In this case the design depends primarily on the overall height of the aerial array, and only secondarily on the pattern or gain of the individual elements

A useful approximation is that the gain over a dipole is -

$$\doteq 1.2 \left\{ \frac{h}{\lambda} + 1 \right\} \text{ for horizontal polarisation}$$

$$\doteq 1.1 \left\{ \frac{h}{\lambda} + 1 \right\} \text{ for vertical polarisation.}$$

showing that the gain depends on the height in wavelengths. Increase of vertical gain requires a longer aerial system with a heavier mast to carry it and the cost of this must be balanced against the reduction in transmitter cost that results.

The lower gain with vertical polarisation is not fundamental, but results from the fact that the couplings between vertically polarised elements when vertically stacked are greater than for horizontally polarised elements. To obtain satisfactory bandwidth, the elements must be separated further than is desirable for optimum aerial gain.

The range of main aerial gains used in Australia is from 5 to 19 X that of a dipole.

Cositing. Mast Reflections.

3. Up to this point we have been considering only a single station. In planning the service, however, it is necessary to group stations serving the same area close together to simplify the viewers' aerials (Ref. No. 2), and match the coverage of the stations to avoid too large a ratio of field strengths at the receiver. This cositing of stations, usually within a mile, however gives rise to mast reflections (Refs. 3, 4, 5, 6), to minimise which necessitates very careful relative location, orientation, and choice of relative heights of masts. The best solution from this point of view is to co-mast the aerials, or use a common aerial. However, this is not always feasible, because of legal, economic or timing difficulties. Nevertheless it is already in use at Ballarat, and is likely to be used at future installations.

Even so, the method can only be used partially where four or five transmissions are required from one location. It is therefore, very desirable to lay out the mast positions and heights for the ultimate development of a transmitting area before the first mast is erected.

Measurements and observations have been made of the mast reflections occurring at a number of existing groups of aerial masts. These are mostly below the threshold of visibility, but can be studied by the use of sharply directional receiving aerials. As a result of this work, some rough general conclusions have been drawn for the typical Australian television transmitting aerial consisting of horizontal dipoles mounted in front of reflecting screens, fitted to the four faces of a square mast.

It is found that the reflections from the backing screens of the illuminated aerial give the strongest reflections, the lower portions of the mast or tower, and the aerial dipoles themselves seeming to have little effect. In the vertical plane, this reflection seems to be strongest in the direction of specular reflection of the incident energy from the centre of the illuminating aerial, and has a relatively sharp vertical polar diagram consistent with the whole height of the illuminated aerial operating as a single aperture at the frequency of the incident radiation.

In the horizontal plane, as might be expected, where a relatively high-frequency transmission illuminates relatively wide low-frequency screens, maximum reflection occurs in the direction of specular reflection. In the converse case, the effects are more complex, and sharp multi-lobed patterns may occur in cases of transverse resonance.

Control experiments have shown that reflection magnitudes are much greater when the aerial or mast face is square on to the incident radiation.

Visibility of mast reflections on the viewed picture depends not only on the reflection magnitude but on the time delay, short delays permitting larger amplitudes for the same disturbance (Ref. 5). It is not desirable to put masts closer than 200', because of mutual shadowing, impedance disturbance, and inter-modulation. Beyond 500' it is not usually possible to adjust the relative heights of masts to ensure that specular reflection from the backing screens is thrown either upwards or downwards at an angle greater than the maximum depression angle required for coverage, while retaining adequate height for all masts to give effective distant coverage.

If it is necessary to exceed 500' it is better to go to distances of about ½ mile or so, when the magnitude of the signal though of long delay, has fallen to an acceptable amount. "Square-on" orientations are avoided wherever possible. Relative mast locations are chosen to throw specular reflections into uninhabited areas.

In the case of aerials supported on relatively thin poles or tubes, such as the quadrant and side-fire helix, the magnitude of the reflections is much less and the mast location less critical.

Impedance Requirements

4. There is no need for very high accuracy of aerial impedance matching for the efficient transfer of power, - (a reflection coefficient of 20% would give only 0.2db increase in feeder loss) or to reduce the maximum voltage or current on the feeder (which is usually considerably larger than required to handle the power in order to reduce the attenuation to an economic value) - but there is a stringent requirement that on the main feeder the reflection coefficient shall be 2 - 4% only, near the vision carrier; reflection from the top of the main feeder travels downwards, is usually reflected quite efficiently at the transmitter terminals and travels upwards again to be radiated as a 'ghost' at a delay equal to the main feed length x 2.

The reflection over the whole vision band is of importance; the lower the reflection at vision carrier the greater the tolerable reflection at radio frequencies corresponding to the higher frequency picture components (Refs. 7, 8, 9). This requirement tends to dominate present aerial design, and leads to such arrangements as quadrature or phase-rotation feed of individual aerial elements. The combination of two nearly matched loads fed through branches differing by 90° in electrical length gives a very much better match than either load separately (Ref. No. 10). This is particularly important when the impedance of the individual aerial panels is disturbed by icing.

Recent developments (Ref. 11, 12, 13) indicate that in the near future the aerial impedance requirements may be relaxed by using techniques of feeding the aerial through a ring-bridge or equivalent system, which routes the reflection travelling down the main feeder not to the transmitter, but into a dummy load, where it is absorbed.

Where paralleled transmitters are used, the reflections from the two separate transmitters can be arranged to be in anti-phase on return to the main feeder. A more direct method of suppressing the reflection is employed in micro-wave systems in the form of an isolater, employing ferrites, which has a non-reciprocal transmission characteristic with small attenuation in the forward direction, and large attenuation in the reverse direction. This technique has recently been extended to high powers in the UHF band (Refs. 14 and 15) and may become available at VHF.

It will still be necessary to present an aerial match good enough to terminate properly the filters, diplexers, and other devices for combining transmitters over the whole of the television channel. Aerial mismatch can produce various not immediately obvious results e.g. mismatch of a sound diplexer can produce amplitude modulation of the FM from an impeccable sound transmitter.

Aerial Elements

5. Given the general requirements for the aerial system, a study can now be made of suitable forms of aerial, feeder and support structure to meet these requirements with reliability under local climatic conditions.

Whereas the vertical pattern depends primarily on the combination of aerial elements rather than their individual patterns, the horizontal pattern depends primarily on those of the aerial elements. The general requirement is for omnidirectional coverage with a tolerance of up to ± 2db (at the service limit of a 100kW erp VHF station the field strength varies with distance by at least 0.5db per mile. Hence ± 2db tolerance, corresponding to ± 4 miles in service range, is usually adequate). Therefore either elements with circular horizontal patterns, or a ring of directional elements must be used.

Elements based on Dipoles

5.1. For vertical polarisation the vertical dipole is the basic element (Refs. 16 and 17). In broad-band form this may take the shape of twin cones (Ref. No. 18) skeleton or solid, or a "discone" (Ref. No. 19). For horizontal polarisation the classical turnstile - two crossed half-wave dipoles with quadrature feed - is available, and also the quadrant (Ref. No. 20) (two horizontal half-wave dipoles at 90° forming two sides of a square with a single feed point between their adjacent ends). Both of these may use folded dipoles (Refs. 21 and 22) resulting in the super-turnstile (batwing) aerial (Ref. 23, 24, 25) or the folded quadrant (Ref. No. 26) respectively, to increase band width or modify impedance. Both require thin support poles so that it is difficult to achieve high gain by vertical stacking because of mechanical strength and windage problems; even so there is considerable disturbance of the horizontal pattern by the pole or mast. However, if this disturbance is properly related to the desired coverage, a very successful single channel aerial for Band III may be produced; such an aerial is in use at BTQ Channel 7 in Brisbane.

Elements based on Loops - Slotted Cylinders

5.2 A stack of separate resonant horizontal loops (Ref. No. 27) is not normally employed for television because of the support problem and the narrow band width. However, a somewhat similar aerial comprises a "side-fire" helix (Refs. 28 and 29) wound round and spaced from a central conducting tubular mast. If the circumference of each turn is a multiple of a wave length the radiation from each turn in any given azimuth at right angles to the mast, will be in phase, and the vertical pattern the same as that of a stack of loops. The vertically polarised radiation due to the inclination of the helix can be substantially eliminated by winding the aerial in two halves whose vertically polarised radiations are of opposite phase. Because of the travelling wave nature of the aerial, the bandwidth is adequate for television; the design requires only a small number of feed points and can give reasonably high gain. Such aerials are essentially omni-directional in the horizontal plane and are in use at TCN Sydney and ADS Adelaide. Another way to simulate a stack of resonant horizontal loops is to cut a narrow vertical slot in a cylinder of about one half-wavelength circumference (Refs. 30 and 31). If driven by a balanced feed across the centre of the slot, a mechanically simple and fairly wideband aerial results. Larger diameter cylinders may be used by increasing the number of vertical slots (Refs. 32, 33, 34, 35, 36). Such aerials have not up to the present been used in Australia for television transmission; owing to the need for a special design for each station the cost is fairly high.

Rings of Elements

5.3 Rings of elements (Refs. 37, 38, 39) are used where a large support mast is necessary to give high gain or to carry other aerials. One form (Refs. 40 and 41) comprises bent folded dipoles arranged at 120° round a tubular steel mast. In-phase or phase-rotation feed may be used and the pattern may be made directional by varying the location and power fed to individual dipoles. Calculation of such patterns based on measured phase and amplitude characteristics (Ref. No. 42) of the individual elements, is tedious but can be speeded up by the use of computers (Refs. 43, 44, 45, 46). This form of aerial is used at GLV Traralgon, Victoria, with a directional lobe of 300kW e.r.p. extending along the East Victorian coast, and at TNQ Townsville, Queensland, where a "three-bladed" pattern is employed to provide service up and down the coast and to Charters Towers inland. However the most usual arrangement (Refs. 23, 24, 47) is a "ring" on a square tower of four standard panels, each comprising two or four horizontal or vertical dipoles mounted at a critical distance in front of a reflecting screen, the dipole lengths, diameters and spacings being chosen to give a good impedance match over a wide band. The horizontal patterns of the individual directional panels cover approximately 90°, the signals from two adjacent panels combining opposite the corners of the tower to give an acceptable approximation to a circular horizontal pattern. As the width of the support tower (in wavelengths) increases, so does the effective diameter of the ring, and the greater becomes the departure from a circular horizontal pattern. Such aerials have been supplied to Australian stations by Marconi, R.C.A., Rohde and Schwarz, and Siemens. They are used for omnidirectional horizontal coverage at the National stations ABN Sydney, ABV Melbourne, ABQ Brisbane, ABS Adelaide, ABW Perth, ABT Hobart, and ABC Canberra, and by the commercial stations CTC Canberra, in N.S.W. at ATN Sydney, CWN Orange, NBN Newcastle, and RTN Lismore, in Victoria, at GTV and HSV Melbourne, in Queensland at QTQ Brisbane, in South Australia, at NWS Adelaide, and in Western Australia at TVW Perth.

<u>Aerials Directional in the Horizontal Phase</u>

6. By varying the relative power fed to panels and the number of panels on the different tower faces a convenient method is available for adjusting the horizontal pattern where required. Further adjustment may be made by twisting panels about a vertical axis. These are the methods used to obtain horizontal directivity at:-

WIN Wollongong, N.S.W.	(maxima along the coast, minima inland and out to sea).
BCV Bendigo, Victoria	(minimum towards Melbourne, maximum towards NW).
BTV Ballarat, Victoria	(minimum towards co-channel station at Shepparton).
GMV Shepparton, Victoria	(minimum towards co-channel station at Ballarat).
DDQ Darling Downs, Queensland	(maximum towards Toowoomba).
TNT Launceston, Tasmania	(maximum along N. coast).
TVT Hobart, Tasmania	(minimum to West).

It would appear that the majority of the high power stations yet to be installed in stages 3, and 4, will use similar arrangements of aerial panels. Other methods involve mechanical tilt of the aerial (Ref. No. 48). The maximum variation of e.r.p. with azimuth which has been employed is about 10 decibels (e.g. a variation from 25kW to 250kW); larger variations may result in ghosting in the deeper minima due to signals scattered horizontally from nearby more strongly illumentated areas.

In-phase and Quadrature Feeding. Physical Offsetting.

7. Quadrature feeding is necessary for turnstile or super-turnstile operation to provide a near-circular horizontal pattern. Rings of directional panels usually give satisfactory horizontal patterns with in-phase feeding. However, an alternative (Ref. No. 49) is to feed the panels in phase rotation, i.e. 120° for a triangular mast or ring of three, or 90° shift per face for square towers. As discussed above, this has important advantages in relaxing impedance requirements for the individual panels, as mismatch on the main feeder is the critical quantity. Unfortunately, this leads to degradation of the horizontal pattern. Considering for example a square tower, at any given azimuth there is appreciable contribution from panels on two faces. Referred to the centre of the tower, both phase and amplitude of the contribution from each panel vary symmetrically with departure in azimuth from the normal to the face. The contribution of the two panels effective at any azimuth may be added vectorially to give the complete horizontal pattern. With in-phase feeding, there are usually eight maxima, four opposite the faces and four opposite the corners of the tower, with eight equal minima at intermediate angles. If phase rotation of the panels is introduced, symmetry is disturbed, and four of the eight minima become much deeper, giving an unacceptable pattern. This may be overcome by twisting each individual panel about an vertical axis through its centre, when the amplitude pattern of the panel will twist, while the phase pattern remains stationary. By properly co-ordinating the directions of twist and phase rotation, the eight minima may be restored to equality, producing a horizontal pattern slightly better than with in-phase feeding. On a square tower, this results in four panels all twisted in the same direction, outwards from the tower faces. This is mechanically inconvenient, and it is better to twist the tower inside the aerial until the tower faces are again parallel with the panels. Twisting is then replaced by an offsetting of the panels from the centre of the tower faces, which also has the advantage of keeping the effective tower width at a minimum

Vertical Polar Diagram

8. This is primarily determined by the number and vertical spacing of elements (Ref. No. 50). For a given vertical aperture, the sharpest pattern is obtained by filling the aperture with a continuous distribution or current sheet uniform in amplitude and phase. In this case the vertical pattern is a sin x/x function and the gain a maximum. A fairly large number of vertically spaced elements driven with equal amplitude and in phase, approximates closely in gain and pattern to this ideal current sheet. The width of the main beam is then inversely proportional to the height hence the power gain is directly proportional to the height (Refs. 51 and 52). The main beam is bounded by sharp zeros, followed by smaller lobes half the width of the main lobe with successive amplitudes, 21%, 13%, 9%, of that of the main lobe. For aerials with a gain of 13 or 14 times (giving a net gain of 10, allowing for feeder losses) the first zero falls about 6° from the peak of the main lobe, the second zero about 16° etc. The peak of the main lobe may be tilted (usually downwards until centred on the horizon) by a small uniform phase-shift across the aperture. Where reception is necessary at angles of zero or null radiation, then "null-fill" may be provided. One method is to vary the relative power fed to the upper and lower halves of the aerial, e.g. 10% null-fill is obtained by feeding 60% of the power to the top half, 40% to the lower half, or vice versa. A second method is to de-phase the bottom quarter of the aerial by 60° for the same null-fill, with a gain loss of 0.1 to 0.2 db.

A third method of controlling null-fill, which is likely to be used more often in the future, now that the basic theory has been established, is to use unequal vertical spacing of aerial elements driven with the same amplitude and phase. (Refs. 53, 54, 55, 56, 57, 58, 59, 60). This method may find considerable use in the more general application of shaping the vertical pattern.

The general problem of the synthesis of an aerial system to provide a desired pattern (Refs. 61 and 62) is very difficult. In general the relative phase of signals in different directions is of no consequence. As the required current distribution in phase and amplitude across the aperture is the Fourier transform of the radiated pattern in phase and amplitude as a function of the sine of the angle of elevation (Refs. 63, 64, 65) there is no single rigorous solution, particularly as the tolerance in the vertical pattern can be quite wide. Normal design therefore, consists of postulating by various empirical methods (Ref. No. 66) a reasonable current distribution, and calculating the resultant pattern. The current distribution is then modified and the pattern recalculated; the process is then repeated until a practical solution is obtained. This can be done quite quickly with the aid of computers which are now becoming available.

In theory, it is possible to obtain a vertical pattern of great sharpness and therefore of high gain, from a small vertical aperture, by using the "superdirectivity" principle (Refs. 67, 68, 69, 70). Unfortunately this leads to very heavy currents in opposing phase flowing in closely adjacent elements. The resultant reductions in radiation resistance increases resistive losses in the aerial and reduce its bandwidth, so that television application at present seems unlikely.

"Ghosting" and Required Null-Fill

9. Determination of the required null-fill to provide good reception has not been easy to predict, and has required adjustment after installation. The required amount is not determined by signal strength, which is usually more than adequate at the close in locations involved, but by "ghost" or delayed images caused by reflections from neighbouring much more strongly illuminated areas. Little can be done to reduce these reflections, as the strong illumination is unavoidable to provide service elsewhere. It is therefore necessary to increase signal strength in the region of the minima until the reflections are swamped by the direct signal.

In Adelaide, surprisingly, reflections from the foothills of the Mt. Lofty range were found sufficiently strong to require the originally specified 10% null-fill to be increased to 25% to overcome ghosting in quite flat built-up areas. Further, it was found that the ratio of the field strengths of stations ADS Channel 7, and NWS Channel 9, each individually satisfactory, varied so much over the metropolitan area that breakthrough of each station occurred on many receivers, near the minimum in the vertical pattern of the other. Careful matching of the vertical patterns, was necessary to eliminate this.

In Hobart, reflections from certain vertical rock faces near the summit of Mt. Wellington, on which the stations are situated, gave such severe ghosting over one area between E and NE. that 30% null-fill was inadequate and it was necessary to revert on the Eastern face to a broader low gain vertical pattern, without any minima over the populated area of Hobart and suburbs (an effective null-fill of about 70%) to overcome the ghosting.

With large amounts of null-fill, gain is considerably reduced (1.6db for 30% null-fill) and there are other difficulties. It is then better to tackle the problem by a different method. If the vertical pattern is broadened by tapering power or reducing the number of panels, the latter as in Hobart, then loss of gain results. This is not always acceptable as it was in Hobart, with only 30 miles of land to the E. With a symmetrical main lobe, half of the power is wasted above the horizon, and it is possible to broaden the lobe below the horizon without loss of gain by producing a "flat-topped" unsymmetrical main lobe (Ref. No. 71). This approximates the "cosecant" aerial (Refs. 9 and 72) used in airborne radar, giving uniform signal strength and no minima over a wide range of horizontal distances from the station. This pattern is achieved by using a larger vertical aperture, with a symmetrical "bell-shaped" or Gaussian distribution of amplitude across the aperture, with a skew phase distribution. This method has been used on two faces of the tower at CTC Canberra, where severe ghosting from the mountains surrounding the Canberra "saucer" was expected. This was done at the cost of using 12 panels on these two faces against 9 on the other two conventionally driven faces. Maximum signal is still delivered horizontally, for the station has to serve the surrounding district also, but the radiated field falls by less than 6db at a depression angle of 10°. As a result of this "pelican's bill" vertical pattern and an increase in transmitter power to 12kW to compensate for the reduced aerial gain, very strong signals are established in Canberra, and in the majority of locations indoor aerials are satisfactory, outdoor individual or community aerials being used only in the minority of locations where ghosting is troublesome.

However large the aerial aperture, there is a limit to the gain available with the "cosecant" type of vertical pattern giving approximately constant field strength out to a certain distance. The theoretical maximum gain is of the order of 50 times that of a dipole, so that the problem does not arise with practical VHF aerials (the maximum gain so far used in Australia is about 20) but may be a limitation at UHF.

Feeder System

10. From the point of view of reliability of operation, the aerial and the main feeder to it are critical items of station equipment. On the one hand they have to stand a more severe environment (temperature changes, wind pressures, rain, and icing.) then the rest of the equipment - on the other hand the repair of breakdowns cannot be improvised quickly, and feeder or aerial faults could keep the station off the air for weeks. It is therefore universal practice in Australia to provide the main feeder in duplicate. If one feeder is used as a standby, this involves either manual or remote controlled switching near the top of the mast, both of which have their difficulties. General practice is therefore to use both feeders simultaneously, each driving approximately half of the aerial, the transmitter power being split between the two feeders at the transmitter

output. This avoids switching on the mast, and also permits operation of the station on one half of the aerial should the other half develop a fault. There are also further minor advantages in that the beam tilt may be adjusted from the ground after installation by varying the relative lengths of the feeders. (At TVT Hobart a handwheel operates a "trombone" or line stretcher for this purpose); in addition the null-fill may be adjusted if necessary by varying the proportion of power fed to the two feeders. The twin feeder arrangement does however impose a further design restriction in that the pattern of each half of the aerial separately must give satisfactory coverage, and this is not possible in some cases such as the complex aerial at CTC Canberra. Coupling between the aerial halves can also give "ghosting" in half-aerial operation.

Support Structure

11. To support a given aerial, masts are generally cheaper than towers (Ref. No. 73) but require considerably more ground area. There are complications with mast stability where the level changes of the mountain top are such that guys in one of the three or four directions are considerably longer than the others. Many television masts are constructed with "cantilever" top sections for the aerial to avoid any disturbing effect by guy wires. It is now considered (Ref. No. 74) that the disturbance of horizontally polarised aerials by guying the mast top above them is negligible; even with vertically polarised aerials the effect is small provided the guys do not approach the dipoles too closely.

The rigidity of the mast or tower when subjected to strong winds must be adequate to prevent appreciable variation in signal strength due to tilting of the vertical pattern. Half a degree movement is usually tolerable at VHF, but the requirement is more stringent at UHF. If the structure is used to support microwave relay parabolic dishes or flat reflectors very little movement at this level can be tolerated (Ref. No. 75). The deflection of towers under strong winds is often difficult to estimate, and in one case (Ref. No. 76) has been determined by simulating the wind thrust at the top of the tower by firing rockets lashed to the structure.

Tower or mast designs which give rise to sway or vibration (Ref. No. 77) under strong winds can cause serious faults, in aerial or feeder systems, sometimes by metal fatigue over a long period. Even where breakdown does not occur flexing of the aerial and feeder systems can give rise to annoying rapid fluctuations in signal strength.

Combinations of Aerials on One Mast or Tower

12. It is desirable in order to avoid mast reflections and often economic, to use only a single mast or tower at each transmitting site. Overseas (Refs. 78 and 79) there are many complex structures of this type carrying up to twelve aerials. Perhaps the most famous is the "Totem Pole" on top of the Empire State Building in New York (Refs. 80 and 81) carrying superturnstile and panel arrays, for ten VHF FM, and UHF TV transmissions.

Since aerial size is generally proportional to wavelength, from the structural point of view it is desirable to place the lowest frequency aerials at the bottom and the highest at the top. Unfortunately at some mountain sites this conflicts with the requirement of greater height for the lower frequencies to give first Fresnel clearance over the surrounding peaks. In cases where agreement cannot be reached between organisations as to who is to have the top position, it is possible to mount the aerials side by side on thin poles, supported from a large platform on top of the mast proper. This gives rise to the so-called "candelabra" structure (Refs. 36, 82, 83). There is some mutual disturbance of horizontal patterns, and coupling between the aerials giving rise to impedance changes and a danger of intermodulation. A heavy supporting structure is also necessary.

These techniques are in their infancy in Australia, where most stations use their own mast or tower. However the pairs of National and commercial stations at Ballarat, Victoria and Rockhampton, Queensland will in each case share a joint mast, carrying two separate aerials, and this practice is likely to be followed at many of the Stage 4 installations.

Where two transmitters at the same site operate in the same band, it may be convenient to use a common aerial of adequate bandwidth to radiate both their transmissions (Refs. 79 and 84). In this case the saving in cost of aerial and mast structure must be balanced against the cost of the high power filters (Refs. 85, 86, 87, 88, 89) to combine the two transmissions. This arrangement is used for the two National television transmissions from the Tokyo television tower.

Weather Protection

13. Apart from designing the mast to withstand the windage on the aerial and itself, the main problem is ice formation (Ref. No. 90) which upsets the aerial impedance, mechanically loads the dipoles and feeders, and increases the windage. Three main techniques are employed to minimise its effects. The simplest is to place fibreglass covers or "muffs" over the feed points or other critical parts of the dipole. This method has been used with reasonable success at the National and Commercial Hobart

stations ABT and TVT, on Mt. Wellington, where heavy icing is encountered.

Another technique is to build electrical heating elements into the dipoles or reflector bars, to maintain their temperature just above freezing point. The technique requires careful judgement in operation as it is not economic to supply sufficient heat to melt ice once formed - a much smaller amount of power will prevent icing if switched on before icing conditions develop. Even so powers of 30 or 40 kW are required. This method is used at the National station ABT Hobart, and also at CBN, Orange (On 5,000 feet Mt. Canobolas) in N.S.W.

The most satisfactory method, though of considerable initial cost, is to enclose the whole aerial structure in a fibreglass cylinder or "radome", built up in sections and supported by the mast. The slightly greasy surface and low thermal conductivity of the fibreglass prevent ice buildup. This technique is giving satisfactory results at the National and Commercial Stations ABNT and TNT on Mt. Barrow in Northern Tasmania, probably the most severe location for icing in the Commonwealth.

A logical development of this arrangement is to use the fibreglass cylinder as the support column for the aerial. European U.H.F. TV aerials have been built (Refs. 91, 92) using this principle; carrying it further, on locations where only a short mast is required, the whole structure can become a fibreglass cylinder of tapered thickness. A cylindrical tower 70 feet high of this type is in service in Norway; (Ref. 93) even the aircraft warning beacon is inside!

<u>Aerial Distortions</u>

14. If a sudden change in picture brightness is radiated simultaneously from all the elements of an aerial of considerable height there will be a difference in the time of arrival at locations at considerable angles of depression, which will blur or distort the transient response (Ref. 94, 95). For aerials not exceeding 100 feet in height the effect is small for 625 line systems, but it becomes appreciable for aerial heights about 250 feet. Apart from cost this is one reason why low frequency (Band 1) aerial gains are usually fairly low.

A more prevalent form of distortion can exist in those cases where two separate transmitters with a common RF drive feed the two separate halves of an aerial. At the minima in the vertical pattern, the contributions of the two halves of the aerial are out-of phase, and small differences in the phase shift or linearity of the two modulator characteristics are much magnified, giving a violent distortion of the grey scale and even a partially negative picture. This problem arose at the B.B.C. Crystal Palace transmitting station (Refs. 17, 96, 97), the solution being to parallel the two transmitter outputs, then split the power again to the feeders of the separate half aerials. By this means signals of identical characteristics are radiated from both halves of the aerial. However this involves considerable increase of feeder complexity, and the simpler arrangement has been used successfully at the National stations ABQ Brisbane, ADS Adelaide, and ABW Perth. In these cases, unlike the Crystal Palace, the first minimum in the pattern, reaching the ground less than a mile away, falls in uninhabited areas. However, the picture degradation in one of these areas has been confirmed by observation.

The opportunity arose to investigate the problem further during the initial testing of BTQ Channel 7 Brisbane, with twin transmitters, and a much higher gain aerial. The feeder system switching permitted the establishment of either separate or combined excitation of the two aerial halves. With the high gain aerial, the first minimum fell in inhabited country some three miles from the transmitter. With separate transmitters, severe picture distortion was observed in this area, which disappeared completely when the combined arrangement was used providing 10% null-fill in the area. In this case the receiver effects were aggravated by the fact that the minima of the sound and vision patterns fell some 200 yds. apart, so that in the absence of null-fill the sound to vision ratio varied wildly over a distance of nearly a mile. This is an example of another form of aerial distortion - inaccurate matching of patterns for vision and sound, which can cause considerable receiver difficulty.

Verification of Aerial Performance.

15.1 Impedance

Checking of the impedance presented by the aerial at the bottom of the main feeder, may be carried out in the classical manner with an R.F. bridge. This is slow, requires the provision of accurate tapered coaxial matching sections to connect the bridge to a suitable point on the feeder system, and is subject to interference pick-up from other stations working on the same channel (Ref. No. 98).

A simple method (Ref. 99) exploits the considerable length of the main feeder, by driving the test point from a sweeping oscillator through a fairly high resistance, so that the voltage at the feeder input fluctuates with the referred aerial impedance. A rectifier-oscilloscope combination is connected to the same point to display this voltage variation, the oscilloscope being synchronised with the frequency sweep. Calibration is effected by replacing the aerial at the top of the main feeder by a short circuit, thus obtaining a cycloidal frequency amplitude display corresponding to 100% reflection co-efficient. This method is an adequate verification of satisfactory performance, but is limited as a guide to action in rectifying poor performance. Elaboration of the method can however provide information on the location of faults. (Ref. No. 100).

A more elegant method and one closer to the final aerial usage, requires special radar-like (Ref. 101) equipment but no special arrangements for connection to the feeder system. The equipment comprises an oscillator on the television channel concerned, modulated by a 100 nanosecond sine-squared pulse, and a receiver with a calibrated attenuator input, and the receiver output connected to an oscilloscope with calibrated timebase. The large sending pulse is displayed, together with the individual reflected pulses from the various parts of the aerial and feeder system, which may be identified by the associated time delays. The ratio between each of these pulses and the sending pulse may be measured by using the attenuator to give the average reflection co-efficient over the television channel.

Aerial gain and pattern.

15.2 Checking of aerial patterns and gain, with the station operating is difficult (Ref. 102, 103, 104). Fortunately they do not need to be done independently, as the efficiency of aerial systems is high and capable of accurate estimation. The gain can then be calculated from the directivity or vice versa. In theory the vertical pattern can be checked by making a succession of field strength measurements on a radial run in a fixed direction; the horizontal pattern similarly by making a circular run at a fixed radius; unfortunately, except in very flat country, the variation in field between receiving sites is usually greater than the variations due to the pattern. A large number of points, and a statistical treatment, are necessary to achieve results of any value.

Nevertheless, fairly quick checks by this method can establish any large differences from the predicted pattern, such as a deep minimum in the horizontal pattern, or, the most likely installation error, the whole vertical pattern tilted up or down by an incorrect amount. Assuming the vertical pattern is the correct shape, the quickest method of checking tilt, is to explore the first minimum in the pattern underneath the main lobe. This usually falls in the area 2 to 5 miles from the transmitter, and in this area the radiated signal strength varies so rapidly with depression angle that the site-to-site variations are swamped. It is usually possible to establish the position of the minimum within ½ mile by two or three passes through the area, in those cases where the null-fill does not exceed 10%.

A check of absolute e.r.p. may be made in those cases where an elevated observation point sticks up into the centre of the main lobe within 20 miles of the station, with free space propagation between the points. Equipment accuracy then sets the limit.

However, the most satisfactory method of checking patterns, is to measure the ratio of signal strengths under two or more differing conditions of transmission at one receiving site. By this means the receiving site variations and most of the instrument errors are eliminated; only linearity of calibration over a range of a few decibals is required. The position of the maximum of the main lobe and of the minimum below it, may be checked by transmitting successively on the whole aerial and on each of two similar half aerials, and recording the three readings, at each location.

If in the centre of the main lobe, the fields from the two half aerials, corrected for the proportion of the power they normally radiate should add up to the field of the whole aerial, while at the minimum the field from the whole aerial should be the difference between those from the two halves. In order to locate these points it may be necessary to repeat the triads of measurements at several locations, calculating the phase shift between the two halves at each location, from the signal radios.

If a trombone type main-feeder phase-shifter is available, the vertical pattern may be swept or tilted past a fixed point, and a number of readings taken and plotted against phase shift to delineate the vertical pattern. Only a limited range of shifting is permissible before pattern distortion develops; it may be necessary to establish several points which give overlapping sections of the vertical pattern. A simple example of this technique is to measure the signal from the whole aerial at the horizon under the normal conditions, and with an additional 180° of feeder inserted in the feed to one half of the aerial. Even without a high power phase shifter the same technique may be employed where twin transmitters are used, by feeding the two halves of the aerial from separate transmitters. There is usually a phasing adjustment between the common RF drive and the two transmitter inputs; in any case short lengths of small diameter co-axial cable may be made up and connected in the drive to one transmitter to produce known phase shifts.

The most precise and general application of the ratio technique is to mount a reference aerial of known pattern or gain, at the top of the aerial under test, with a feeder of known loss running from the transmitter hall. It is then possible to switch power from a test oscillator (often an early stage of the vision transmitter itself) between the reference aerial and that under test. Measurement of the ratio at a considerable number of places in the field gives an accurate indication of the pattern and a good estimate of the gain.

As an alternative to ground measurement, aircraft, particularly helicopters, may be used. It is claimed (Ref. 106) that - with equipment suspended below the aircraft, to avoid disturbance of the measured field - a reasonably accurate check of the pattern may be made at lower cost and much more quickly than by elaborate systems of ground measurements. One of the difficulties is the accurate establishment of aircraft position.

This method is likely to find increasing use but it must be remembered that measurements need to be made not only to satisfy the station engineer that his aerial is working to specification but also to verify that coverage is satisfactory. If the coverage survey can at the same time verify that the aerial pattern is satisfactory, this appears the most economical solution, even though more costly than a pattern check alone by a different method.

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