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WIDEBAND SQUINTLESS LINEAR ARRAYS

By A. ROGERS, C.Eng., M.I.E.R.E.

Marconi Radar Systems Limited will be pleased to talk to those interested in either wideband squintless feed assemblies with low sidelobe characteristics as part of complete new installations or linear feed assemblies, as described in this article, for application to existing radars.

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WIDEBAND SQUINTLESS LINEAR ARRAYS

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A new form of wideband high power linear array is described having a frequency independent beam pointing direction. The basic technique has been developed in waveguide for radar applications in the S- and L-bands.

Initial studies were carried out using an X-band waveguide model which established the potential performance of such an array. This work was followed by prototype full scale aerials for S- and L-bands.

The significant details are given of performance obtained to date, in connection with 18 ft S- and L-Band arrays feeding cylindrical reflectors in transportable form, and 45 ft S- and L-Band static surveillance aerials.

In these types of arrays a fundamental requirement is that the transmission line path length to all radiators must be electrically equal and remain so over a frequency band. The waveguide geometry used to achieve this requirement in an elegant and compact layout is presented, together with a description of the method by which a controlled distribution of power across the array is catered for. Mention is made of the dependence on numerical controlled machining as a method of producing the developed waveguide units to the required tolerances to ensure repeatability of performance.

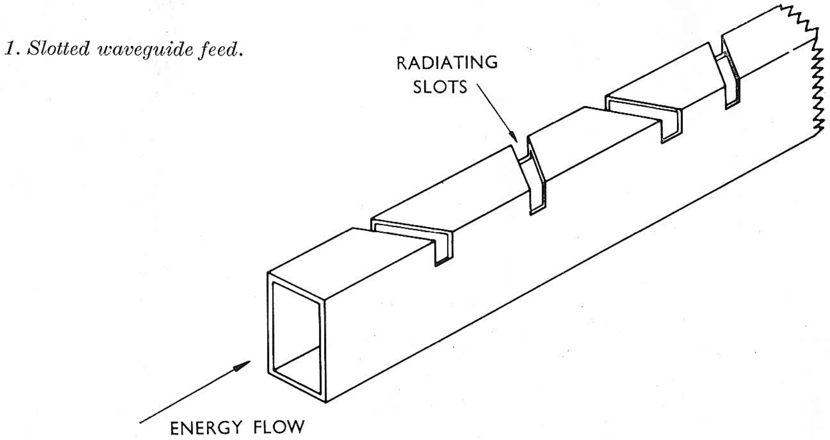
The problems associated with this type of array becomes more pronounced as the length of the array (for a given frequency) increases. The worst problems are indicated, and the methods by which they have been overcome, particularly in the larger arrays.

Introduction

Many aerials developed for radar purposes during the last 30 years or so have been for use in frequency bands lying between about 1,000 MHz and 10,000 MHz.

A fair proportion of these aerials have been linear arrays where, in order to keep the attenuation of the signal as low as possible, waveguide has been used for the dual purpose of providing radiating sources and feeding energy to them. For reasons of economy, many of these arrays have consisted of a single piece of rectangular waveguide having radiating slots cut in either the narrow or broad face and fed with r.f. energy from one end only. In other words, a series fed array. (See Fig. 1).

Fig. 1. Slotted waveguide feed.



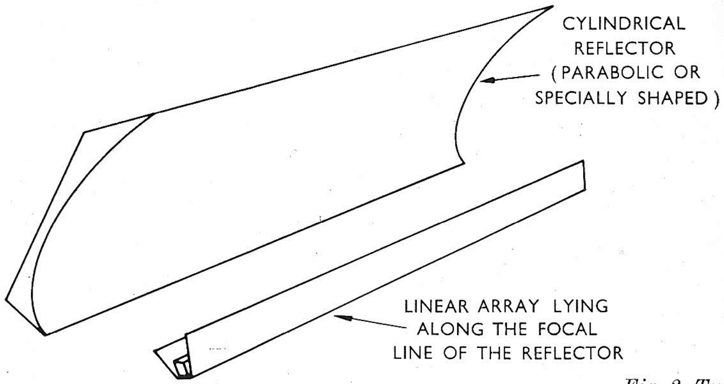


Fig. 2. Typical radar aerial.

A feature of the series fed array, which is for many purposes undesirable, is that the direction of the main beam relative to the true broadside of the array changes with the frequency, since the electrical path length between radiators cannot be maintained constant for all frequencies. For example, a typical S-Band array operating in No. 10 waveguide over a 200 MHz frequency band around 3,000 MHz squints its main beam by from 1° to 6° in the plane of the array (with respect to the true broadside direction) at different frequencies within the operating band.

Two disadvantages arising out of a frequency sensitive beam squint are:—

(i) Angular recalibration is necessary when the frequency of operation is changed, thus it is not possible to use such an aerial for time sharing frequency diversity.

(ii) Under wideband jamming conditions, since the beam direction with respect to the array is different at each jamming frequency, interference enters the system over a much greater angle than the single frequency beamwidth. Thus a much greater search angle can be rendered unusable than in the case of a non squinting aerial array.

Squintless Arrays

The basic aerial design now to be described arises mainly out of the requirement for high power frequency diversity operation in the S- and L-Bands, using linear arrays feeding parabolic or shaped cylindrical reflectors as shown in Fig. 2. The necessity is that several transmitters operating simultaneously at different frequencies in each band, should be able to feed into a common aerial system and have a common beam pointing direction.

In a linear array the radiation is ideally required to be in phase at all radiators. This is arranged approximately in the series fed array by making the spacing between adjacent radiators electrically equivalent to about one complete wavelength. The resultant main beam is nearly broadside to the line of the array, but changes direction with frequency. Typically a 5% bandwidth array will squint by $+1^\circ$ to $+6^\circ$ over its frequency band.

The prime requirement for an array to be both squintless and non-sensitive to changes in frequency is that the r.f. energy from the transmitter must arrive at all radiators in the same phase and must maintain this condition for all operating frequencies. This implies that all feeder paths from transmitter to radiators must be of equal length and be in transmission lines having common dispersion characteristics.

The term "squintless" in the title is used as both a name and a description, but the property is by no means a unique feature, since many other aerial types are also squintless. For example, an aerial having a single horn feed obviously fulfils the condition of the previous paragraph.

Fig. 3 shows schematically an established method of parallel feeding an array in waveguide, whereby a single input is successively divided until the required number of radiators has been catered for. A particular amplitude distribution can be achieved by using the appropriate inequality of power split at each junction. The disadvantage of this method is that it becomes bulky when applied to an array having a large number of radiators.

A modified form of the Fig. 3 arrangement has been developed for waveguide use which preserves the essential quality of equal path lengths, but which is far more compact and lends itself well to modern production methods. The geometry of the scheme is shown in Fig. 4 where it is seen that

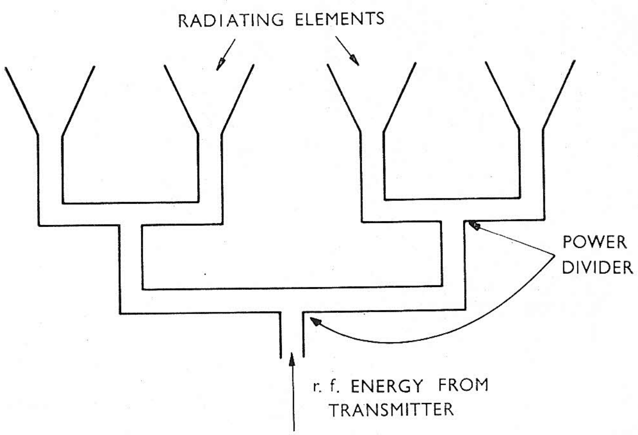


Fig. 3. Parallel feed system.

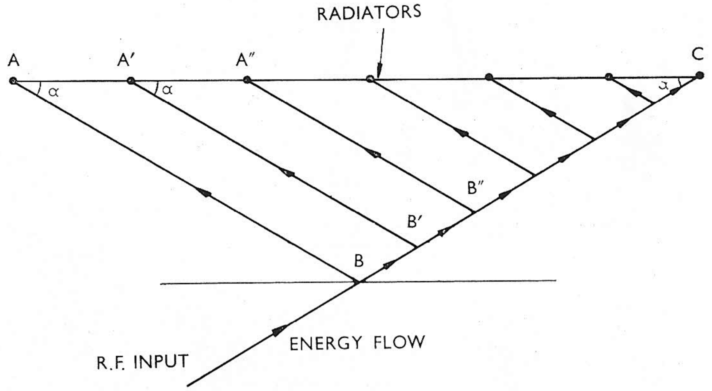


Fig. 4. Schematic geometry of squintless feed.

the basic figure is the isosceles triangle. In the figure we have the following relationships:

Angle BAC = angle BCA,
and angle BAC = angle B′A′C = angle B″A″C etc.,
Thus length BA = length BC,
and length B′A′ = length B′C,

and so on. From this it can be seen that any path from point B to a radiator is the same length as the path to any other radiator and the basic requirement is fulfilled.

X-Band Model

Feasibility studies were carried out using an X-Band waveguide model incorporating the geometry of Fig. 4. An approximation to the model is shown in Fig. 5, where it is seen that r.f. energy is fed into a waveguide

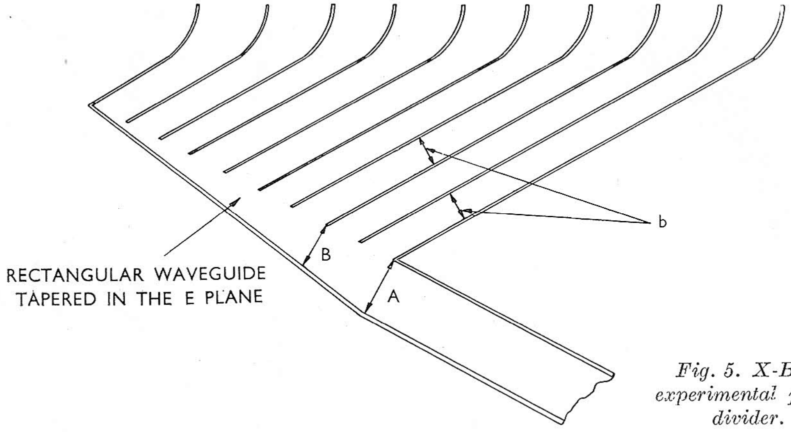


Fig. 5. X-Band experimental power divider.

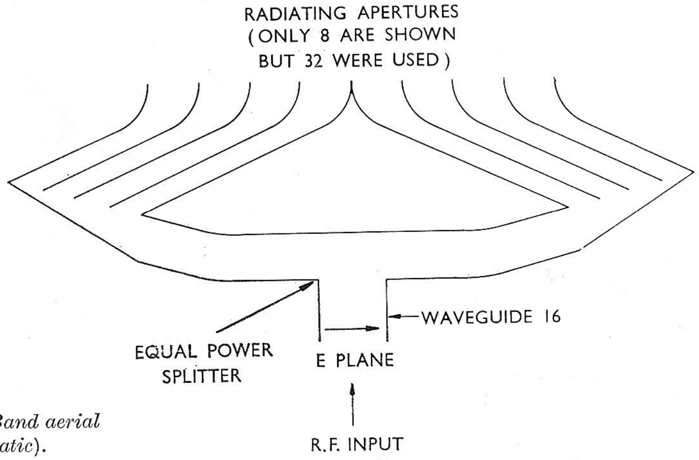


Fig. 6. X-Band aerial (schematic).

which is tapered in the E-plane. Narrow channels along the tapered section form a series of E-plane dividers. At each junction a fraction of the incident energy is extracted approximately according to the ratio b/B, where b is the E-plane height of the narrow channel (constant for all channels) and B is the E-plane height of the tapered guide at that junction. The H-plane of the structure is into the paper and is of constant dimension for all channels.

The model was fabricated using channels cut from waveguide No. 16, soldered together to form the narrow waveguide assembly, the curved

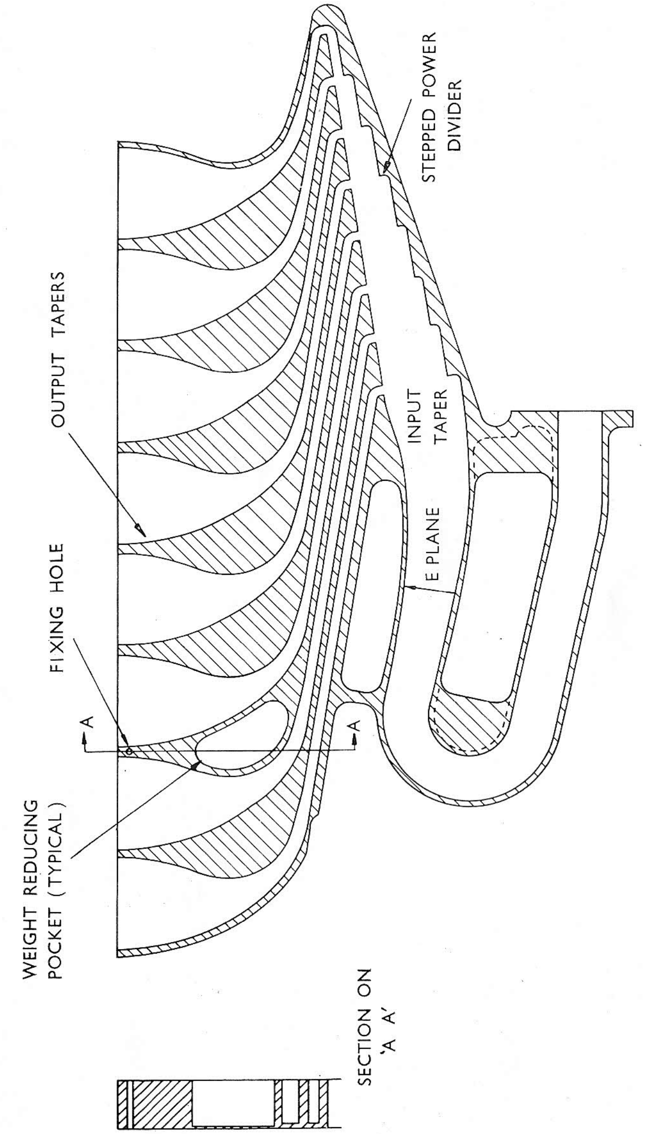


Fig. 7. S-Band 8-output module.

radiating horns and input tapered waveguide being added as separate assemblies.

Two such assemblies were produced, which were fed from a T-junction E-plane power splitter as shown in Fig. 6, to give a symmetrical power distribution having an edge taper of approximately −14 dB.

Radiation pattern measurements in the plane of the array showed that the model performed well over almost the whole of the band covered by waveguide No. 16, i.e. from about 8,000 MHz to 11,000 MHz, wherein sidelobes of no worse than −30 dB were obtained. The input impedance of the model was not a particularly good match at all frequencies, but this was partly due to the type of radiating horn used.

S-Band 18 ft. Array

Success with the X-Band model encouraged development of an S-Band (3,000 MHz) prototype linear array, with a view to feeding parabolic and shaped cylindrical reflectors to be used in a transportable radar system.

Although making a single X-Band model by the fabrication technique described was reasonable, the method was not considered acceptable for the larger waveguide sizes either for prototype or production. Fortunately a manufacturing method became available which has since proved to be ideally suited to the task, namely, numerically controlled milling. In this method the machine is made to cut the shape required, from a solid billet of material, in accordance with a control routine contained on magnetic tape.

The first full sized prototype attempted was an S-Band linear array 18 feet in length having a total of 64 radiators spaced at about 3/4 wavelength intervals. Detailed consideration of the design showed that it would not be possible to use only two units, or modules, fed from a centre splitter as in the X-Band model. This is mainly because of two opposing dimensional limitations.

(i) A lower limit to the width of narrow channel (b in Fig. 5) that can be cut to a given depth, and

(ii) An upper limit to the width (A in Fig. 5) of input waveguide, to avoid creating a resonant cavity for higher order waveguide modes.

Due to these limits there is a limit to the lowest value of the ratio b/A which can be used. This automatically sets a limit to the power division ratio (which is approximately equal to the numerical values of b/A), at the first narrow channel being fed from the input waveguide. Thus for a given amount of power required at the first radiating outlet of a module, there is an upper limit to the total power into the module, and a limit therefore to the number of channels that can be fed from a single input waveguide.

Bench tests carried out on abbreviated models operating in S-Band resulted in a complete module being built for electrical assessment using the modified geometry shown in Fig. 7. The basic isosceles triangle is still apparent, but bends have been added to enable the narrow channels to enter the main waveguide at right angles, thus reducing the size of the discontinuity to a minimum. The radiating outlets consist of a combined E-plane taper and bend, designed to improve the match into a flare.

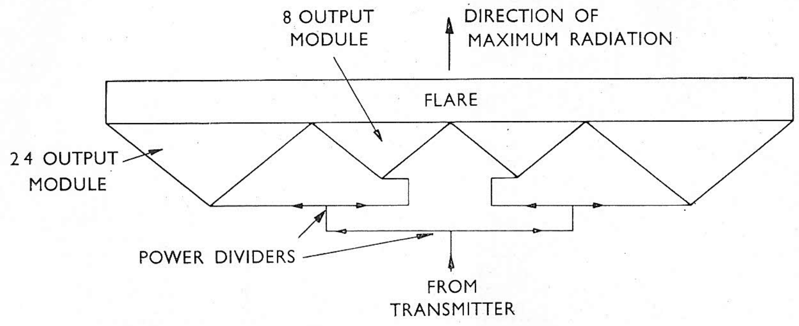


Fig. 8. S-Band 18 ft. feed (schematic).

The tapered bend was developed from a low v.s.w.r. wide band taper in which the waveguide impedance varies with distance according to the following:

$$Z_0(S) = (Z_1 \, . \, Z_2)^{\frac{1}{2}} \exp[-\tfrac{1}{2}(\ln \, . \, Z_2/Z_1) \cos(\pi S/L)]$$

where S = distance along waveguide axis

$Z_0(S)$ = characteristic impedance of the taper section at point S

Z_1 = characteristic impedance of input waveguide

Z_2 = characteristic impedance of output waveguide

L = total length of tapered section.

In the case of a rectangular waveguide having a taper only in the E-plane the function reduced to:

$$b(S) = b_1(b_2/b_1)^{[S/L-(1/2\pi)\sin(2\pi S/L)]}$$

where $b(S)$ = tapered waveguide height at point S

b_1 = height of input waveguide

b_2 = height of output waveguide.

The straight taper formula was used as the basis for a tapered bend designed on the principle that the rate of bending should vary continuously, and be lowest at each end of the tapered section.

The solution was obtained as a set of simultaneous equations, and co-ordinates for tapers conforming to given boundary values were calculated with the aid of a computer program. The input tapered bend is derived from the same formula.

The main divider waveguide is a series of E-plane steps rather than a smooth taper since in practice this method gave better control of the power division at each junction, with less phase dispersion than a smooth taper.

Except for the power divider stepped taper, for which no better substitute has yet been found, all shapes have been smoothly curved to make for easier milling. It is seen that even the stepped taper has radiussed inside corners. The maximum depth of channel milled is 1·42 inches, being half that of the H-plane dimension of waveguide No. 10. Two pieces are cut out in mirror image form so that when joined to form a complete module the overall waveguide depth is 2·84 inches, having a split line half way across where it has negligible electrical effect.

Following successful closed circuit tests on this module an 18 ft S-band prototype array was designed and built. Fig. 8 shows a schematic of the module formation, where it is seen that there are two unequal sizes of module in each half array. Due to the limitations mentioned above, the modules nearest to the mid-point of the array are only able to provide 8 radiators each, as opposed to the 24 fed by each of the outer modules. Interconnection of the modules is by waveguides and three power splitters resulting in a single input point to be fed from an r.f. source. A flare is used to match the radiating outlets to an 18 ft × 6 ft parabolic cylinder reflector.

Radiation pattern measurements on the prototype indicated that this design has achieved better than −29 dB sidelobes over a 500 MHz frequency band centered on 2,900 MHz. It is known that there is a linear phase error from centre to edges of the array which could be reduced by a small change to the geometry of each type of module. The estimated achievable sidelobe performance for the design is −34 dB which compares well with the theoretical performance of −40 dB. The measured sidelobe performance quoted was for the linearly polarized array; the subsequent fitting of a quarter wave plate circular polarizer over the radiating apertures caused a little deterioration in that performance. High power testing of the more critical parts of this array indicates that it will handle 5 megawatts peak power, and 12 kilowatts mean power with a reasonable safety margin. It has not been found necessary to pressurise the modules and flare of the array.

L-Band 18 ft. Array

Attention more recently turned to the problem of designing a similar high power 18 ft array for a band of frequencies centered on 1,310 MHz. At these frequencies waveguide is not an automatic choice since the introduction of triplate transmission line some years ago. However, the high power requirement and the basic simplicity of the present waveguide

approach decided the issue, with the result that an extremely successful 18 ft transportable aerial is now available for L-band.

The design is very similar to the original X-Band model in that the complete array consists of only two power dividing modules. This is possible within the limitations pointed out above, since only 14 radiators are necessary in each half of the array.

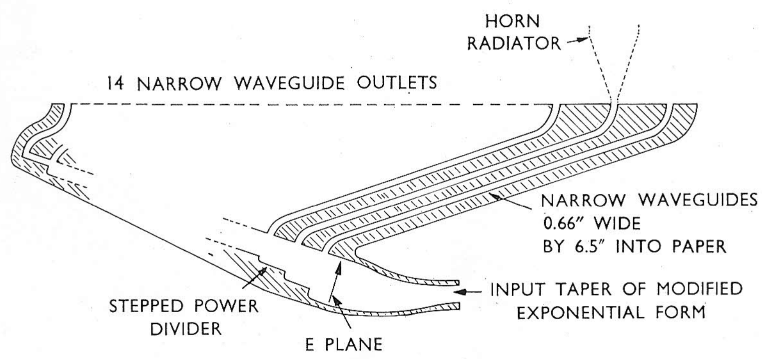


Fig. 9. L-Band 14-output module.

The module geometry is shown in Fig. 9 where it is seen that the only new feature compared to Fig. 7 is the absence of exponential tapers at the radiating apertures. The narrow (0·66 in. × 6·5 in.) apertures feed into horn radiators which make a flare unnecessary and replace the original machined outlet tapers used at S-Band. These economies have kept the size and weight of the finished array to a minimum and considerably reduced the amount of material and machining required. The overall H-plane depth of channel used in the module is as for waveguide No. 6, that is, 6·5 inches, and as in the S-Band case is produced by assembling two mirror image halves each cut to a depth of 3·25 inches.

The two modules, with horns, become a complete array by joining them to a centrally located power splitter fed from a single input waveguide. Fig. 10 shows the general appearance and proportions of a complete feed fitted to an 18 ft by 6 ft vertical aperture cylindrical reflector, designed to give cosecant squared coverage in the vertical plane. This aerial is required to achieve a sidelobe performance in the plane of the array not less than 28 dB below the main beam level, and has been designed against a theoretical amplitude distribution capable of −40 dB sidelobes for a perfect case.

Closed circuit measurement carried out on the individual modules of the prototype indicated a close approximation to the theoretical amplitude distribution

$$A_n = 0{\cdot}1 + 0{\cdot}9 \cos^2 \frac{\pi x}{a}$$

where n is the radiator number and x is its distance measured from the centre line of the total aperture a. The measured phase error at the module

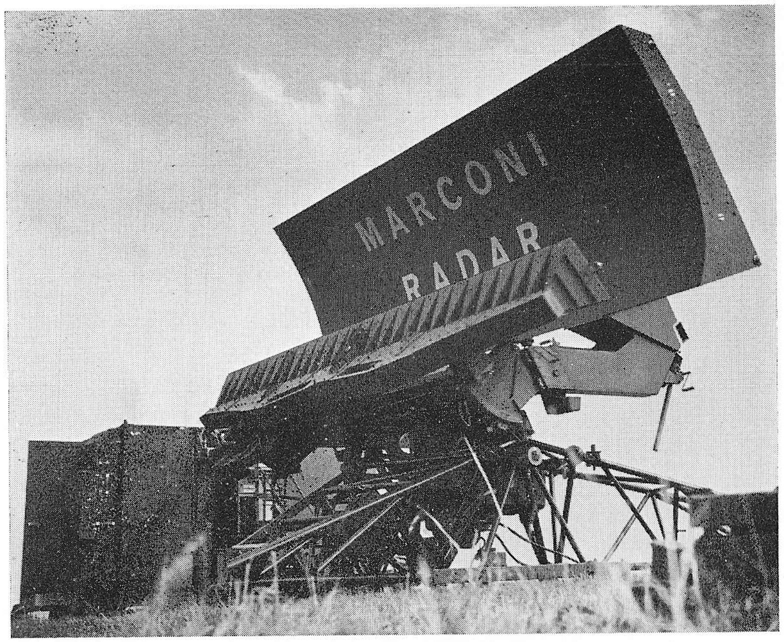


Fig. 10. L-Band 18 ft. radar aerial.

outlets was such that the phase front of the radiation would have a linear error reaching as much as 40 degrees (electrical) at the ends of the array.

Radiation pattern measurements on the full prototype aerial confirmed a sidelobe performance of no worse than -30 dB over the frequency range 1,150 MHz to 1,480 MHz, although the specified design band was only 1,250 MHz to 1,370 MHz.

A small correction has since been made to the basic isosceles triangle geometry with a view to improving the phase error on the production aerials. Closed circuit measurements on individual modules show that in the improved version the phase error has been considerably reduced, to not worse than 12 degrees in the design frequency band. The good

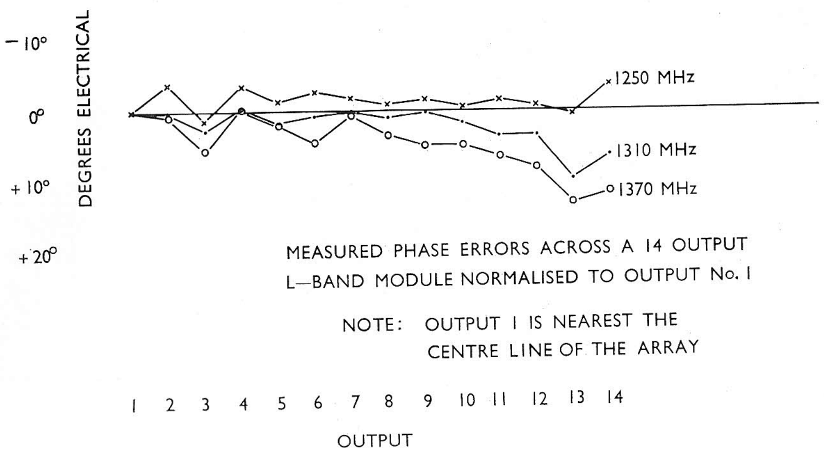


Fig. 11. Phase errors of L-band module.

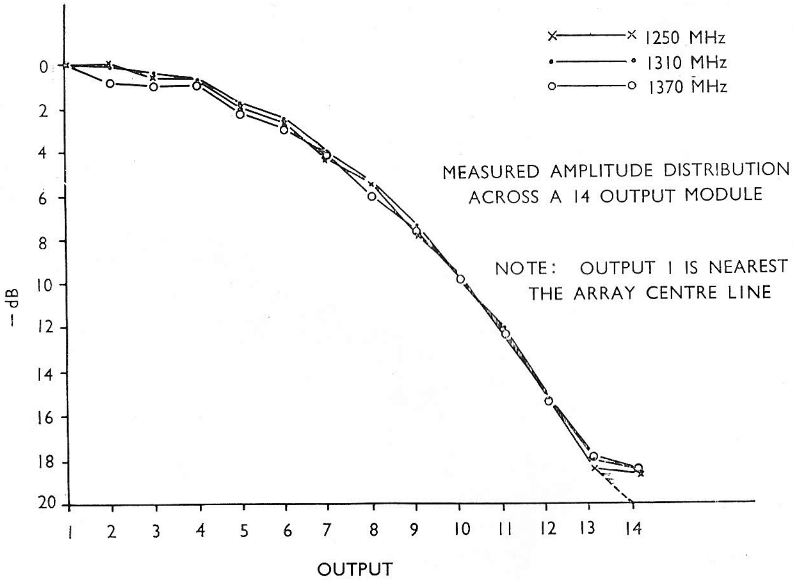


Fig. 12. Amplitude distribution of L-band module.

amplitude distribution obtained on the prototype has been preserved. Graphs of the results are shown in Figs. 11 and 12.

Radiation pattern measurements carried out on a complete aerial incorporating the improved version of the modules, show that in the plane of the array the sidelobes are now better than -34 dB over the band,

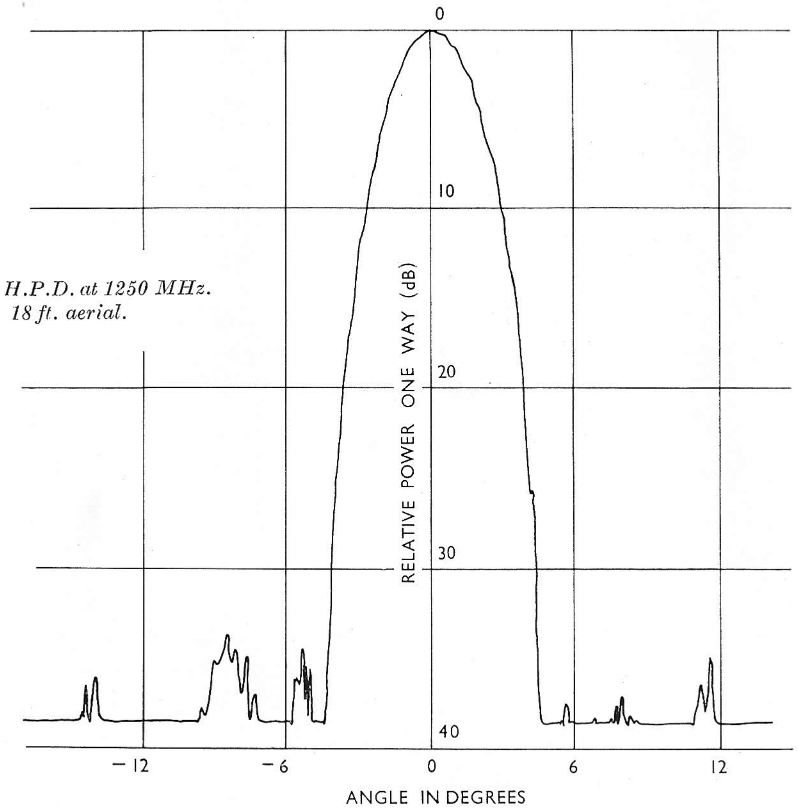


Fig. 13. H.P.D. at 1250 MHz. 18 ft. aerial.

from 1,250 MHz to 1,370 MHz. A typical pattern taken at 1,250 MHz is shown (Fig. 13).

Pattern measurements have also been carried out for a production aerial outside the specified band, and the performance is good (better than -29 dB sidelobes) over a 400 MHz band centred on 1,300 MHz.

Measurement carried out to establish that the basic requirement of a non-squinting beam had been achieved, proved that the main beam direction did not vary by more than 4 minutes of arc over the specified frequency band. It is felt that this deviation is largely the experimental error incurred in performing the measurement.

Arrays with 45 ft. Apertures

Following the successful 18 ft arrays, attention turned to the design of 45 ft long high-power squintless arrays, for use in the S- and L-Bands, required to feed offset cylindrical reflectors of 45 ft (horizontal) by 15 ft (vertical) aperture.

The problems associated with applying the module technique increase rapidly with an increase in the total number of radiators required in the array.

Experience has shown that, ideally, all arrays using the module geometry described above should consist of only two modules if the best approximation to the theoretical amplitude and phase distribution is to be held over the widest operating band. This ideal might well be applied to large arrays if it were possible to machine waveguide channels to the same depth and very much narrower in the E-plane than at present. Since this is not economically possible with present tools and materials then, for the reasons mentioned briefly above in connection with the 18 ft S Band array, more and more modules are required as the number of radiators increases.

Increasing the number of modules used requires that the waveguide system interconnecting them becomes longer and more complex. In addition since the electrical path length to any radiator is dependent upon the wavelength in the waveguide, which in its turn is dependent upon the height of the cross section, the production tolerances become highly significant as the total path length increases. This can be established fairly easily by expressing the incremental change in guide wavelength as a function of a small change in the H-plane dimension. A typical numerical example shows that an average error of 0·001 in. in this dimension through a 120 in. length of waveguide number 10 (S-Band) causes a phase discrepancy in the emergent wave of 3° compared to the nominal case.

Since the best control of cutting depth guarantees only a $\pm 0{\cdot}002$ in. tolerance on each machined half cross section there is a total possible H-plane error of $\pm 0{\cdot}004$ in. The result of using many modules is a tendency towards a stepped phase and amplitude distribution, caused by the inevitable dispersion associated with these components over a wide frequency band, so that in the final analysis a large multimodule array requires considerably more care to achieve the high standard of performance associated with the small, less complex arrays. However, on balance this constructional method is superior to any other waveguide layout in terms of compactness and repeatability, and offers a consistently good wideband performance.

The arrays which were designed for 45 ft S- and L-Band aerials will now be described in a little more detail.

S-Band 45 ft. Array

This was designed against similar requirements to those described above for the smaller aerial. Namely, sidelobes lower than 28 dB below the main beam peak, and wideband capability (of the order 15%) in S-Band coupled with the ability to handle r.f. powers up to 5 megawatts, and a total mean power of 20 kilowatts in the event of four transmitters operating in diversity.

The pitch of the radiating apertures was chosen to be 3·2 inches, which gives nearly optimum spacing at 3,000 megacycles, requiring 168 apertures in all to make up the 45 ft length.

Detailed consideration of the module geometry limitations against an amplitude distribution conforming to the law

$$0{\cdot}1 + 0{\cdot}9 \cos^2 \frac{\pi x}{a}$$

showed that a module at the centre of the array could only supply power to 7 radiators without its input guide E-plane dimension becoming large enough to support the orthogonal and higher order modes. The centre modules are the most critical in this respect since there is an almost uniform amplitude distribution over the limited aperture that can be served by a single module in that region. On the other hand, a module further out in the array can supply at least three times as many outputs without running into moding problems.

This line of reasoning automatically leads to the possibility that one might use the largest size of module permissible in each particular section of the array; an approach which was adopted in the 18 ft S-band case above. However, although the solution has its good points, it suffers from the disadvantage that a certain amount of asymmetry within each half array results, tending towards an additional sacrifice in performance. This is due to the inevitable mismatches, which although individually insignificant can become important in their summation, and hence give rise to unbalanced impedances at junctions, when asymmetries are present.

The approach finally used was to make all modules the same size, each feeding 7 radiating apertures. In its basic form, therefore, the array would consist of 24 modules each catering for a particular part of the total amplitude distribution, these modules themselves being fed from a power dividing network.

In order to reduce the physical complexity of feeding 24 separate modules a new approach was adopted whereby 12 double modules were used. Each module block contained 14 radiating outlets divided into 2 sections each of 7. The 2 sets of 7 outlets were fed from a common input waveguide divided, by means of a septum placed parallel to the H-plane, into 2 separate waveguides each feeding its own stepped power divider in accordance with the basic module principle described earlier.

A typical module of this type is shown in Fig. 14 where it is seen that apart from the double module idea the basic geometry is similar to that described for the 18 ft S-band array. The 12 modules now comprising the array had to be connected together by means of a waveguide network with a total of 11 two way power dividers. So as to reduce the number of separate waveguides to a minimum, the majority of these dividers were incorporated in 2 machined waveguide labyrinths (which have been named manifolds), each one feeding 5 of the modules in each half array.

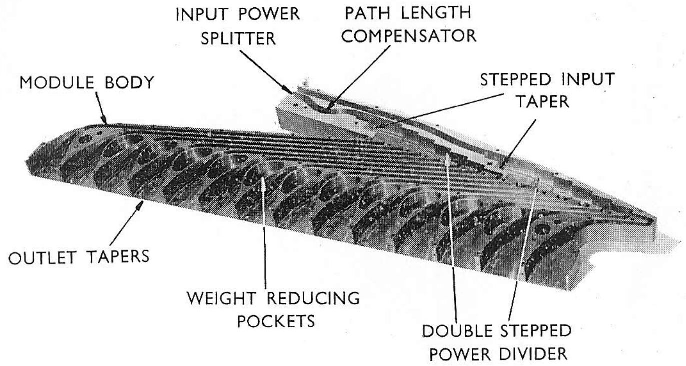


Fig. 14. Module for 45 ft. S-band feed.

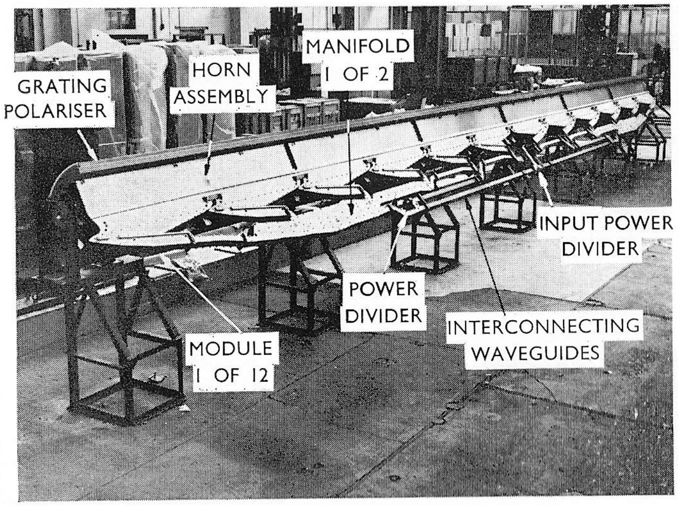


Fig. 15. Complete 45 ft. S-band feed.

The first module to each side of the array centre-line was fed from a separate power splitter which had its input connected direct to the central equal power splitter carrying the total input power for the array. The photograph contained in Fig. 15 shows a complete S-band feed assembled, and it will be seen that the outside shape of the manifold (labelled) is suggestive of the waveguide layout contained therein.

In order to provide a degree of control over the spread of mechanical tolerances, the waveguide layout was arranged to allow the insertion of shims in the waveguides leading to the first two modules on either side of the feed centreline. Thus the phase error distribution across the three modules to each side of centre (carrying the bulk of the power) could be significantly levelled. Further adjustment to level the phase across the complete feed was made by shimming the central, equal power splitter, so as to move it bodily to left or right of the centreline.

All of those power dividing components requiring shaping in the E-plane (excluding the flare and some straight waveguide) have been milled by a numerically controlled machine as previously described. In order to provide a degree of freedom during development the modules were divided into 2 main sub-sections. This division is indicated in Fig. 14, which shows the form of an assembled half module. It is seen that one sub-section comprises all the narrow waveguide channels and the associated outlet tapers; the second sub-section contains the stepped power divider which has, for reference purposes, been called a backstep taper. By using this subdivision it was possible to standardise the body part containing the narrow channels which was common to all modules; thus during development this section was retained to assess several different designs of the stepped power divider sub-section, this being a relatively small part of the overall module production programme required for the numerical controlled machining.

In order to arrive at the correct geometry for the module body containing the narrow channels, use was made of one of the early S-band modules used in the 18 ft array described earlier. This module was provided with the detachable double stepped power-divider just described, and the corrections to the basic geometery to give the required electrical path lengths, as opposed to the apparent physical path lengths, were obtained from electrical measurements using the module. During development most of the measurements were made using closed circuit techniques, and when sufficient of the design had been completed the results obtained in this way were used in a computer program to predict the horizontal polar diagram of the array.

The S-band development programme ended with the construction of a full 45 ft array which was eventually field tested in conjunction with a cylindrical parabolic profile reflector having a 45 ft horizontal aperture

by 15 ft vertical aperture. Reflectors of this type have to date utilized an off-set array of the series fed slotted waveguide type.

Assembling the array to a 45 ft reflector proved to be a major mechanical exercise. It was necessary to complete the assembly and accurate alignment of the feed components at ground level using special jigs.

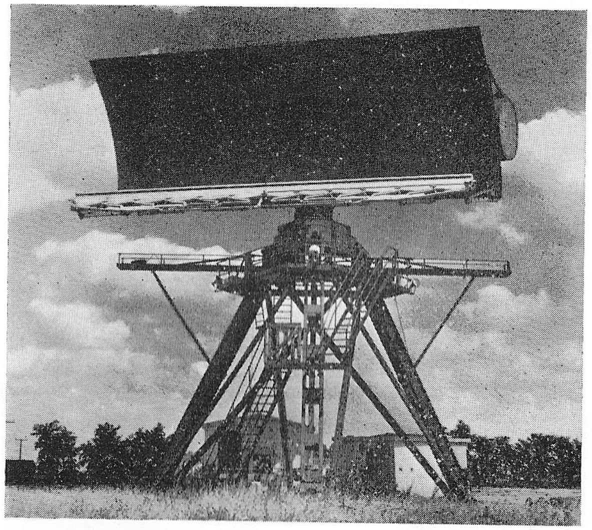


Fig. 16. S-band 45 ft. surveillance aerial.

The jigs themselves had to be accurately established in order to ensure that the phase centre defined at the flare aperture lay well within a straightness cylinder of no greater than 0·05 in. diameter. The set of 12 modules were assembled to a 45 ft long support beam (flanged at the middle), which acted as a backbone for the structure, and were accurately aligned before adding the remaining components.

The complete assembly was then split at the centre line and lifted onto the support arms of the reflector in 2, $22\frac{1}{2}$ft long, sections. To reduce the work of aligning the feed to the reflector the mounting brackets on the supports were pre-aligned using weight representing the distributed load of the feed. The alignment accuracy finally achieved was such that the nominal phase centre of the feed was straight to within 0·025 in. in any direction and lay within one eighth of an inch of the true focal line of the reflector. Fig. 16 shows the complete S-band antenna.

Horizontal polar diagram measurements showed the feed had achieved the specified performance of -28 dB sidelobes. The accompanying table of results indicates the essential features of the measured patterns over the frequency band from 2,700 MHz to 3,100 MHz, but these frequencies do not by any means represent the limits of good performance. Rather better results than those shown has been predicted, but unfortunately the only suitable reflector available was an old one which no longer conformed to the required profile accuracy. Measurement of the constancy of the main beam direction in the horizontal plane was achieved by superimposing recorder patterns at differing frequencies whilst maintaining synchronization between the recorder chart and the aerial turning gear. With care, the stability of modern pattern recording equipment renders almost obsolete the tedious theodolite sightings that would otherwise be necessary. The beam shift across the frequency band was shown to be not greater than 2 minutes of arc. The sidelobe performance deteriorated a little with the subsequent fitting of a quarter-wave plate, circular polarizer over the radiating apertures. A special waveguide circularizer had been developed which proved itself on performance but added considerably to the cost, weight and overall size of the array. Although a quarter-wave plate circular polarizer does not readily lend itself to the wideband performance demanded of this feed, it was used to reduce weight and cost.

45 ft S-Band results

Frequency MHz.	Highest Sidelobes dB	Angle at which Sidelobes fall below −40 dB	−3 dB Beamwidth (Degrees)
2,700	−29	6°	0·58
2,800	−28·5	6°	0·57
2,900	−29·5	6°	0·54
3,000	−30·5	6°	0·54
3,100	−28	10°	0·50

Only a relatively small section of the interconnecting waveguide of this array is pressurized for high power working. Power tests were carried out during development on typical module assemblies which indicated that it would be unnecessary to pressurize these particular components. The complete set of modules and manifolds comprising an array are therefore held at atmospheric pressure and are merely supplied through controlled bleeds with dry air obtained from the pressurized part of the waveguide run. The feed in its final form is considered capable of handling peak r.f. powers up to 5 megawatts and mean r.f. powers up to 20 kilowatts.

L-Band 45 ft. Array

As explained in connection with the 18 ft L-band squintless feed, waveguide is not an automatic choice for an array of this type at these

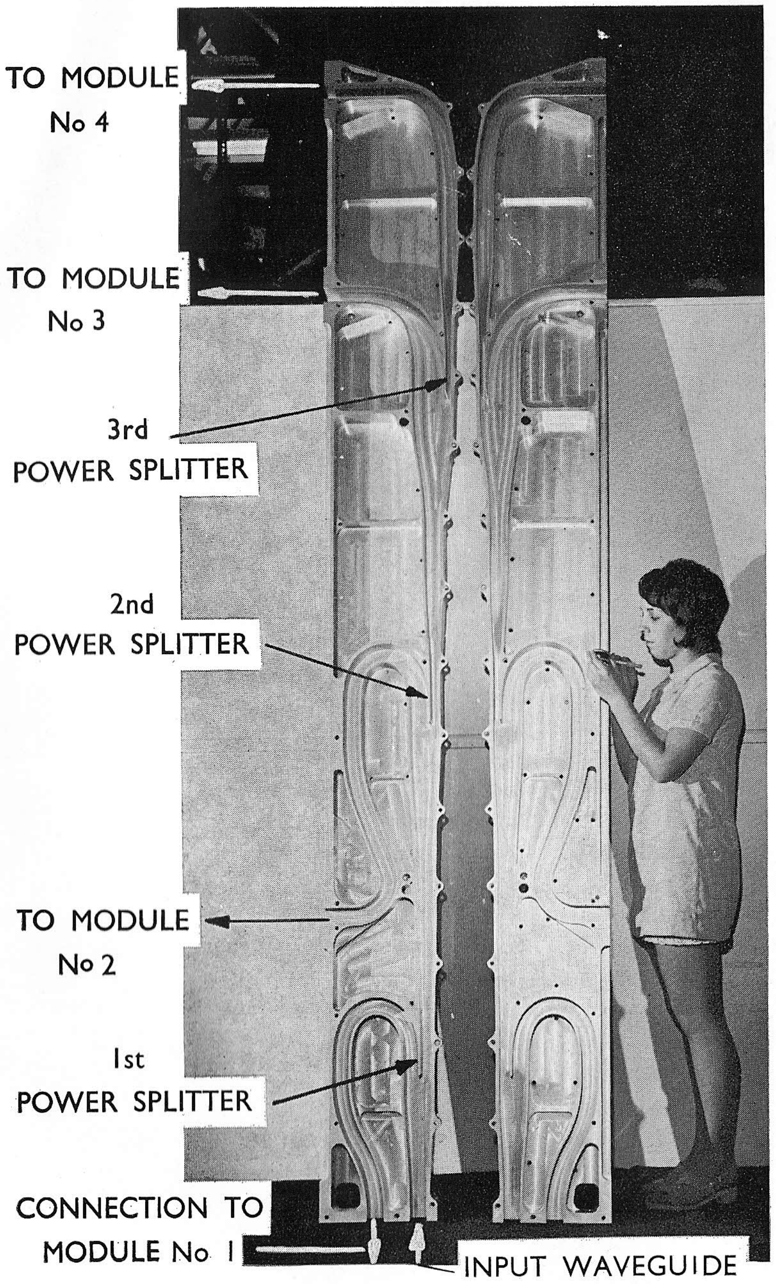


Fig. 17. L-band manifold. 45 ft. feed.

frequencies, but the machined waveguide solution which had proved to be so successful in the case of the 18 ft aerial was an attractive proposition since the basic development problems had already been solved, and there were no doubts about its high power capability.

The main performance aims for the 45 ft array were the same as for the smaller version, that is, close in sidelobes lower than −28 dB and a working bandwidth of 120 MHz minimum centred on 1,310 MHz.

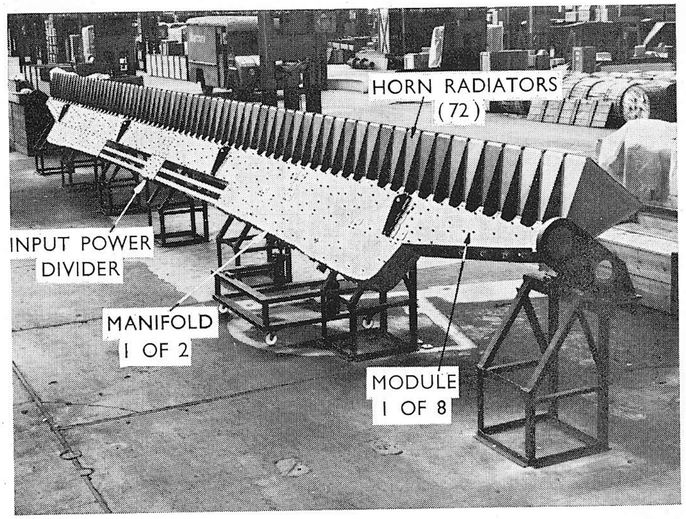


Fig. 18. Complete 45 ft. L-band feed.

Using a radiating aperture pitch of 7·5 inches the array required 72 radiators. Consideration of the physical and electrical limitations of module design previously described showed that it would be possible to achieve the array with 8 modules, each of which would supply energy to 9 radiators. In this case, it was not necessary to adopt the doubled module technique used in the large S-band feed, since a significantly smaller number of radiators was involved.

The broad dimension of the module waveguide channels was chosen to be 6·5 in., the same as for standard L-band waveguide No. 6.

Thus the final form of the array was 8 module power dividers each having an internal geometry similar to those of the 18 ft L-band array, feeding energy to 72 horn radiators. The 4 modules in each half array were interconnected by a machined waveguide manifold containing 3 two-way power dividers, and the 2 halves were joined to the single input waveguide through an equal-power splitter (also machined). The layout of the waveguide contained in the manifold is shown at Fig. 17; the 3 splitters can be clearly seen.

Each module supplied power in accordance with a specific part of the amplitude distribution law

$$0{\cdot}1+0{\cdot}9\cos^2\frac{\pi x}{a}$$

by virtue of its internal geometry.

The 8 modules were to be supported at the focus of the cylindrical reflector by 7 boom arms. Thus it was considered feasible to construct the feed in such a way that it would form a fairly rigid beam capable of supporting itself across the 7 booms. With this in mind each module was designed with flat end faces capable of bolting directly to adjacent modules. Fig. 18 shows a complete L-band feed and the major components are indicated. It is seen that unlike the previous designs described, the modules and interconnecting waveguide manifolds have external shaping which is not indicative of the internal geometry.

By drawing upon the experience gained with the smaller arrays it proved possible to achieve module designs giving acceptable electrical performance at the first attempt. However, some correction to the path lengths in the manifold had to be made to produce the correct phase across the outlets of the modules, and this item had to be programmed a second time.

Unlike the large S-band array the L-band waveguide system is not so sensitive to the ±0·002 in. accepted magnitude of manufacturing tolerances and a sufficiently close reproduction of the performance was obtainable without the need for any form of tuning.

The assembly and alignment of the L-band array followed much the same pattern described for the S-band array, except that wider tolerances were permissible in respect of straightness. The prototype was tested in conjunction with a shaped cylindrical reflector having a horizontal aperture of 45 ft, and a vertical aperture of 15 ft designed to give cosecant squared coverage over a wide angle in the vertical plane.

The table below lists the salient features of the horizontal polar diagrams. It is seen that the required minimum performance was obtained over most of the design band, unfortunately as in the S-band case the reflector used in the trial was well below specification. Also listed are the results of some additional measurements made at frequencies well outside the design band, showing a consistently good performance from 1,100 MHz to 1,425 MHz. These limits are mostly dependent upon the proximity of waveguide cut-off at the lower end, and the behaviour of the oversize waveguide in some of the modules at the upper end of the range. Additional measurements showed that the main beam did not change direction by more than 2 minutes as the frequency was changed across the design band.

The array is not pressurized above normal atmospheric pressure, but is supplied with a flow of dry air obtained from the pressurized waveguide connecting it to the transmitters. There are no doubts concerning its ability to handle at least 5 megawatts peak r.f. power and a mean power of 20 kilowatts.

L-Band 45 ft Results

Frequency MHz	Highest Sidelobes dB	Angle at which Sidelobes fall below −40 dB	−3 dB Beamwidth (Degrees)
1,100	−29·4	20°	1·50
1,150	−29·6	20°	1·48
1,230	−29·8	24°	1·35
1,250	−30	20°	1·30
1,270	−31	20°	1·29
1,290	−28·2	20°	1·29
1,300	−27·5	20°	1·29
1,310	−28·5	20°	1·29
1,330	−28·5	24°	1·28
1,350	−28·5	20°	1·23
1,370	−30·8	20°	1·20
1,380	−29·4	22°	1·20
1,400	−29·8	24°	1·20
1,425	−26·8	25°	1·20

Large Squintless Arrays

The 45 ft S-band array is already very complex, and the present machining limitations do not encourage a further increase in aperture in this band, since a greater number of modules would be necessary resulting in increased complexity and dispersion. To allow a larger total aperture without a greater number of modules, it will be obvious from the arguments already presented that a fundamental requirement is for a new manufacturing technique which will provide channels, within a module, which are much narrower than is possible at present.

The L-band array still has something in hand and could probably be extended to a 60 ft aperture without exceeding the complexity already apparent at S-band.