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MARCONI'S WIRELESS TELEGRAPH COMPANY LIMITED
*Head Office, Marconi House, Chelmsford* *Telephone, Chelmsford* 3221 *Telegraphic Address, Expanse, Chelmsford*

# THE MARCONI GROUP OF COMPANIES IN GREAT BRITAIN

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Registered Office: Marconi House,
Strand,
London, W.C.2.

Telephone: Covent Garden 1234.

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# THE MARCONI REVIEW

*No. 127* Vol. XX *4th Quarter, 1957*

Editor : L. E. Q. WALKER, A.R.C.S.



## WIDER BANDS

THE past decade has witnessed the exploitation of many microwave bands for the purpose of providing additional communication facilities. Radio relay equipment is now manufactured in most technically advanced countries, and systems many thousands of miles in length have been installed throughout the world, with more under construction or at the planning stage.

The channel capacities already installed vary between sixty and six hundred telephone channels per transmitter, or the equivalent, and one of the big firms in America is believed to be planning the installation of a system (TH system) capable of handling up to one thousand eight hundred telephone channels per transmitter.

The development of these wideband systems has been made possible by the advent of the travelling wave tube amplifier, which is capable of providing, reliably, the necessary gain and power output, over the required bandwidths.

It may well be queried at this stage whether a TH type system is the ultimate wideband system as regards cost, simplicity and capacity, or whether it will give way, in due course, to something different.

Clearly a great deal depends on the rate of increase in the demand for additional communication capacity. Forecasts are many and varied in their optimism. It is, however, generally agreed that the potential demand for more channels, as indeed of almost all other services, is several orders of magnitude greater than that existing at the present time. Barring the possibility of a universal catastrophe, or the discovery of a radically different mode of communication, it is quite safe to assume that this potential demand will translate itself into an actual demand at an increasing tempo. While it may be argued that the demand for more telephone channels must ultimately reach a saturation level—it is indeed difficult to imagine an ever-increasing babel of conversations, flowing from one end of the earth to the other—the transmission of other kinds of information will probably be predominant.

To meet this demand more channels must be found, either by making a more efficient use of the bandwidths already available or by finding additional bands.

The first alternative implies the use of more efficient coding or modulation systems. At present, wideband microwave communication systems make use, almost exclusively, of frequency modulation with the result that the spectrum utilisation efficiency is of the order of 10% or less. For example, a 400 Mc/s spectrum is used to convey an intelligence bandwidth of only about 40 Mc/s. Clearly some large savings in bandwidth are possible here. Single side band modulation techniques offer the possibility of greatly increased channel capacities, which may be obtained at the expense of a large increase in radiated power and probably greater complexity. For example, a 1,000-channel SSB system requires a transmitter having a saturation power of about 300 watts, in order to provide the same grade of service as an F.M. system with a transmitter power of 10 watts, always assuming both systems benefit from the same aerial gain.

The exploitation of more radio bands appears to be nearing an end, as frequencies much higher than about 10 KMc/s are not suitable for radio communication work, because of greatly increased fading and atmospheric absorption. No doubt some use may still be made of them in special cases.

Guided wave systems, i.e., propagation within hollow waveguides, making use of the low loss ($H_{01}$) mode and frequencies of the order of 50–100 KMc/s and higher, when generators become available, may provide unlimited space for expansion, at least as far as one can see at present.

There are, however, difficulties, not all of them of a technical nature.

In the first place, the hollow pipe is a rather imperfect communication medium. The internal diameter must be large in comparison to the wavelength, in order to offer a reasonably small loss to the microwave signal—about 1 to 2 db per mile—and thus allow repeaters to be spaced at intervals of about 20 to 30 miles. In these circumstances, the waveguide is able to support several other modes, each possessed of a different group velocity, with the result that small discontinuities give rise to mode conversion effects and consequently severe echo distortion.

To combat this interference it is essential to use a rugged system of modulation, such as Pulse Code Modulation (P.C.M.), where the detection of the presence or absence of a pulsed signal, at a predetermined time, is practically all that is required to ensure satisfactory communication.

For a system such as this to be economical in terms of cost per channel-mile, it is important to use common equipment for as many channels as possible. Calculations of the variation in the group delay of the $H_{01}$ mode, in a suitable size of guide, indicate that bandwidths of 500 Mc/s per system, i.e., per transmitter, could well be used, provided these could be handled satisfactorily.

Within each 500 Mc/s band it should be possible to accommodate about 10,000 one-way telephone channels, or eight 4 Mc/s one-way television channels, on a single carrier. Double this traffic could be handled by the adoption of a slightly more sophisticated modulation technique. With known radio frequency multiplexing techniques, a single pipe could be made to carry 10 or 20 carriers or the equivalent of 100,000 to 200,000 telephone channels.

Once again the travelling wave tube enters the picture, because of its ability to handle, quite easily, bandwidths of this order. In fact, it may be said that this type of tube is misused in the present type of radio relay system. Its bandwidth capabilities are far greater than may conveniently be used.

There are, of course, other technical difficulties which beset the development of P.C.M. systems of such gigantic bandwidths. Given, however, the application of the necessary engineering effort, the resolution of these difficulties does not appear impossible at present. The development of generators and amplifiers of the travelling wave tube type and of other devices suitable for use at millimetre wavelengths is also within reach. In fact, great progress has already been achieved in this field.

Granted then that the technical difficulties of this communication system are resolved, in due course there remains the question of compatibility with present telephone transmission practice.

An important feature of this consists in multiplexing the individual voice channels on a frequency division basis, i.e., the individual voice channels are each translated to a higher but different frequency, so as to constitute, in association with one another, a single signal with an almost continuous spectrum—the baseband signal—which may extend up to about 8 Mc/s or more.

Coaxial cables and radio relay systems are capable of accepting this baseband signal, so that their interconnection need not involve a demodulation to voice frequencies. This demodulation process adds a certain amount of degradation (noise) and necessitates expensive equipment.

A P.C.M. system, on the other hand, is most economical when operated on a time division basis, i.e., the individual voice channels are each sampled, coded and transmitted in turn.

It is clearly impracticable to change overnight from frequency division to time division, even if coaxial cables were capable of accepting a wideband P.C.M. signal, which they are not.

We may well see, therefore, the development of two radically different telephone transmission practices, each best adapted to the transmission medium, or the frequency division baseband may have to be adopted for guided wave systems, with the resulting penalty of extra cost and reduced effectiveness, always assuming that the additional technical difficulties are overcome.

It is interesting to note here that the radio relay system, as we now know it, stands as a half-way house between the two competing philosophies. It has, so far, been designed to accept a frequency division baseband, and it is doing its job creditably. The travelling wave tubes it uses are capable of far more than is demanded of them; in fact, they are capable of handling the 500 Mc/s P.C.M. signals which we anticipate in guided waves. Here then the advantages of a change-over are indeed great. Instead of using six sets of equipment to handle a maximum of 10,000 channels in all, a single set of equipment would suffice. Aerials, smaller and less sophisticated, waveguides, branching systems, filters, travelling wave tubes of much lower quality, and consequently less costly, could be used for the same performance quality.

Whichever philosophy prevails, and it is doubtful if a clear-cut case will ever be made for the complete elimination of the one or the other—they each have a part to play—the next decade may well see the belated appearance of P.C.M. as an established means of wideband communication.

S. FEDIDA.

# A REVIEW OF RECENT INVESTIGATIONS INTO SUN-SPOT CYCLES

By N. A. Huttly, M.Sc.

*The object of this paper is to present a review of some recent papers on sun-spot cycles and to give some objective comments upon their aims and achievements.*

*When this survey was undertaken it was found impossible to include all papers on this subject which have been published during the past few years so that a selection was made which typified the many different approaches to a means of forecasting sun-spot numbers. As well as the papers under review there is included a short list of other references whilst still more references can be found from the quoted papers themselves.*

*The pattern of this review is first to summarise the paper under question and then to comment upon it.*

*Finally a short note on the behaviour of the present sun-spot cycle is given.*

**C. N. Anderson. A Representation of the Sun-spot Cycle.** *Terrestrial Magnetism and Atmospheric Electricity.* Vol. 44, 1939. p.175

The basis of the method formulated in this paper to predict the sun-spot cycle is an empirical cycle-matching procedure using the relative sun-spot numbers defined as

$$R = K(10g + f)$$

where $g$, $f$ are the group and total spot numbers respectively and $K$ a constant depending upon the observatory where the observations took place.

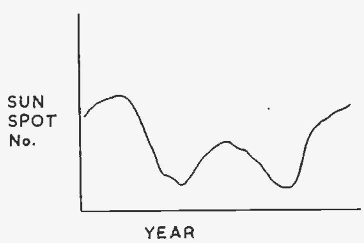


Fig. 1

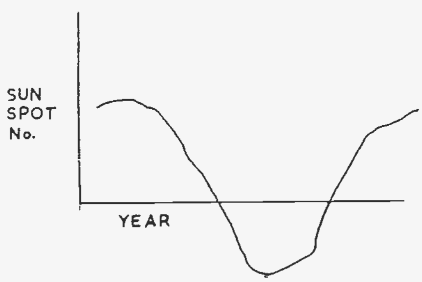


Fig. 2

After the numbers had been plotted in a conventional way, as in Fig. 1, the alternate cycles were reversed in sign, as in Fig. 2, thus giving a completely oscillatory effect with twenty-two year periods instead of the usual eleven year ones.

A periodogram analysis was carried out on the data in its modified form and its main component was found to be about twenty-two years. It was found, after several amendments, that the least residue was present when the main component was 22·25 years, and furthermore most of the components were harmonics of 312 years.

Fits of this harmonic series were made to the data and diagrams in the paper depict the results.

**Comments**

This paper employs a purely empirical approach (as far as can be judged) with no criterion, e.g. least squares, for fitting the periodogram. The periodogram analysis in itself, unless *a priori* periodicities are being investigated, is not an efficient method of attack and should be avoided. The final results of the paper, although agreeing well with results prior to 1939, are in poor agreement with observed results since then, as is shown below.

| *Year* | *Yearly average* *Expected* | *Observed* |
|---|---|---|
| 1939 | 93 | 88·8 |
| 1940 | 80 | 67·8 |
| 1941 | 72 | 47·5 |
| 1942 | 45 | 30·6 |
| 1943 | 38 | 16·3 |
| 1944 | 17 | 9·6 |
| 1945 | 1 | 33·2 |
| 1946 | 9 | 92·6 |
| 1947 | 20 | 151·6 |
| 1948 | 37 | 136·3 |
| 1949 | 59 | 134·7 |
| 1950 | 74 | 83·9 |
| 1951 | 78 | 69·4 |
| 1952 | 53 | 31·5 |
| 1953 | 42 | 13·9 |
| 1954 | 31 | 4·4 |
| 1955 | 20 | 30·8 |

*N.B.*—The expected values are read from a graph and errors in reading may mean that a slightly better agreement exists.

**W. Gleissberg. Predictions for the Coming Sun-spot Cycle.** *Terrestrial Magnetism and Atmospheric Electricity.* Vol. 48, 1943. p.243

This paper consists of a summary table of the probability of events in the coming sun-spot cycle (this cycle is actually the one which began in 1944) based on methods devised by the author in another paper. The author also quoted methods derived by other authors and gave references to them at the end of his paper.

The following is the table of probabilities as given in the paper.

| Time of rising 1/4 $R_m$ to $R_m$ | Prob^y. | Highest rel. Smoothed number | Prob^y. | Time of fall $R_m$ to 1/4 $R_m$ | Prob^y. |
|---|---|---|---|---|---|
| $t_r < 24$ mths. | 0·57 | $R_m > 100$ | 0·98 | $t_f > 60$ mths. | 0·97 |
| $t_r < 28$ ,, | 0·73 | $R_m > 120$ | 0·95 | $t_f > 70$ ,, | 0·91 |
| $t_r < 32$ ,, | 0·91 | $R_m > 140$ | 0·89 | $t_f > 80$ ,, | 0·73 |

$t_r$ = time of rise.
$t_f$ = time of fall.
$R_m$ = the highest smoothed relative number of the next cycle.

Since for all cycles average $R_m = 100$
average $t_r = 35$
average $t_f = 52$

the table shows that the coming cycle is interesting for its high maxima, steep climb and slow fall.

**Comments**

Without recourse to the other papers quoted it is difficult to assess the contents of this paper qualitatively. The observed results for the cycle investigated were:

| | |
|---|---|
| Maximum | 151·8; very high. |
| $t_r$ | 22 months; rapid. |
| $t_f$ | 60 months; slow. |

These results bore out the predictions of the paper, but how well is difficult to determine, in view of the lack of details given of the process involved and its accuracy.

**A. F. Cook. On the Mathematical Characteristics of Sun-spot Variations.** *Journal Geophysical Research.* Vol. 54, 1949. p.347

This paper is founded on papers by Stewart and Panofsky (Astroph. J.88, 1938. p.385), and Stewart and Eggleston (Astroph. J.91, 1940. p.72), in which a four parameter representation for the courses of sun-spot cycles is given. This formula determines the relative sun-spot number $R$ by

$$R = F(r - s)^{a} \quad e^{-b(r-s)} \tag{1}$$

where $r$ is the epoch in years and $s$ the epoch of the start of the cycle. $F$, $a$, $b$, $s$ are constant for any given cycle but vary from cycle to cycle.

Some of the results of Stewart *et al.* were in disagreement with observed results and this prompted the paper by Cook.

Cook's paper gives a two parameter representation based upon the smoothed relative sun-spot numbers

$$R = \frac{1}{12}\left\{(R_{-6} + R_{+6})/2 + \sum_{K=-5}^{5} R_K\right\}$$

where $R_0$ is the month in question.

From a table of

- $v$, epoch of the maximum (Zurich).
- $V$, height of the maximum (Zurich).
- $M_0$, area or zero moment under the cycle.
- $M$, first moment about an arbitrary time t.
- $W$, epoch of the centroid of the cycle.
- $v-s$, time of rise to maximum.
- $w-s$, time from start of cycle to centroid.

these empirical relations were found:

$$V = (0{\cdot}1993 \pm 0{\cdot}0040)\, M_0$$

$$\log (w-s) = (1{\cdot}3001 \pm 0{\cdot}0531) - (0{\cdot}2815 \pm 0{\cdot}0211) \log V$$

giving

$$\log (w-s) = 1{\cdot}4973 - 0{\cdot}2815 \log M_0.$$

From these values, for observed $w$ and $M_0$, and further formulae of Stewart *et al.* the values of $F$, $a$, $b$ and hence $R$ can be obtained.

The paper also included diagrams of the predicted and observed cycles from 1750 to 1948.

### Comments

The formulae quoted above are obtained by curves of best fit, and errors of estimation obtained, thus enabling one to appreciate the accuracy of Cook's predictions. In the event the observed and expected results for June 1948 and June 1949 were respectively 135·3, 143 and 136·0, 118.

**P. A. P. Moran. Some Experiments on the Prediction of Sun-spot Numbers.** C.C.I.R. VII Plenary Session, London 1953. Documents 355E and 357E.

In these papers attempts were made to fit autoregressive schemes of the type

$$x_t - m = a_1 (x_{t-1} - m) + \ldots\ldots a_k (x_{t-k-1} - m) + \varepsilon_t$$

to sun-spot data, where $\varepsilon_t$ is a random stochastic variable with zero mean and $m$ is the mean value of $x_t$ (for all $t$).

It was found that no improvement was obtained by using more than two terms in the autoregressive series and that the standard error of the prediction was about 16. The standard error increased as the prediction was carried further ahead, for example if the years 1950, 1951 were used to predict 1952, the standard error was 16, if they were used to predict 1953 the standard error had risen to 27.

The conclusion reached was that empirical methods would give as good a prediction as the linear autoregressive scheme used above but that improvement might be made if non-linear schemes were used.

A suggestion put forward was the investigation of the logarithm of the sun-spot numbers.

### Comments

From the investigations carried out in this paper it seems clear that linear regressive schemes will not give any better prediction than empirical methods. The limitation in usage of non-linear regression schemes is due to the inadequacy of the theory on this subject at the present time. A first estimate of the non-linear part of the sun-spot cycle might however be found empirically with a superimposed linear regressive scheme.

In this connection it is relevant to give a brief summary of a critique by Dr. E. R. Dalziel in Document 356E of the London session which dealt with the following three methods of prediction

(a) Harmonic Analysis.

(b) Cycle Matching.

(c) Auto-Regression.

The following observations regarding the limitations of the above methods were made:—

(a) Harmonic analysis only establishes the 11 year cycle.

(b) Most examples of this method predict for the decreasing part of the cycle and that is usually more well behaved and hence easier to predict.

(c) Autoregressive schemes use the whole data but smooth out some of the local " jumps " and knocks which seem to rejuvenate the damped oscillation present in the cycle.

The best prediction would seem to be a combination of methods (b) and (c).

**Secretariat of the C.C.I.R. Preliminary Report on Recommendations for the Prediction of the Solar Index.** VII Plenary Session, London, 1953. Document 258E.

This is a composite report dealing with different methods of predicting the Solar Index (defined as the smoothed average relative Zurich sun-spot number).

The report is introduced with a brief discussion of the nature of the problem including:

(a) The extrapolation of Time Series as defined by Wiener.
(b) The arbitrariness of the relative sun-spot number in respect of its definition and methods of measurement.
(c) The great variability of the phenomenon itself.

Two methods of attack were used on the problem.

(1) The use of auto-correlation on the finite series of sun-spot numbers.
(2) A more analytic approach using analytic functions which approximated to the auto-correlation function.

Both these methods had to satisfy the conditions of minimal quadratic error, and a linear relationship between the extrapolated value and its immediate predecessors.

**Method 1**

In order to avoid the large variations present in the sun-spot numbers smoothed relative numbers were used. With the correlation function $\phi(\tau)$, as defined below, for the finite series $f_t$

$$\phi(\tau) = \frac{1}{b-a-\tau} \sum_{t=a}^{b-\tau} f_t \, f_{t+\tau},$$

it was found that $a = 2$ years before a maximum of the solar cycle and $b = 3$ years before another maximum. After several comparisons of $\phi(\tau)$ based on different values of $a$ and $b$ had been made it was finally decided to take as the correlation function that $\phi(\tau)$ which had

$$a = 1749, \quad b = 1949$$

so that $b - a$ was 200 years.

It was noted also that the maximum value of $\phi(\tau)$ occurred when

$$\tau = 11{\cdot}10 \pm 0{\cdot}03 \text{ years}$$

i.e. for the solar cycle.

With this correlation function and using the method of least squares a linear estimate of $f_r$ of the form

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With this correlation function and using the method of least squares a linear estimate of $f_r$ of the form

$$f_r = \sum_{K=1}^{N} a_K\, f_{r-K}$$

was obtained. This gave a set of equations to solve for the $a_K$'s, viz:

$$\phi_r = \sum_{K=1}^{N} \phi_{K-r}\, a_K \qquad r = 1 \ldots\ldots N$$

from which the error of prediction could be calculated.

**Method 2**

In this method analytic approximations were made to the correlation function $\phi(\tau)$ and it was found that the best approximation was of the type

$$\phi(\tau) = \phi_1(\tau) + \phi_2(\tau) + \phi_3(\tau) + \phi_4(\tau)$$

where $\phi_1(\tau)$ = a constant.
$\phi_2(\tau)$ = a cosine function.
$\phi_3(\tau)$ = a mixed cosine and exponential function.
$\phi_4(\tau)$ = a linear function in $|\tau|$.

such that $\phi_1(\tau)$ corresponded to the mean of the observations, $\phi_2(\tau)$ corresponded to an oscillatory effect of the observations, $\phi_3(\tau)$ corresponded to an unknown function of the observations and $\phi_4(\tau)$ corresponded to slow variations in the mean of the observations. Inversion of the auto-correlations then gave the spectrum of the observations and hence the predictions.

Also in this report J. Karamata showed that the Levinson-Wiener method of extrapolation of time series had to be modified if only a single finite series of terms was available. With this modification he obtained a relation which could be used for prediction. He found that at least seven observations prior to the predicted one were needed to get a reasonable estimate. This optimum solution contained ten to eleven terms. With eleven terms he predicted the following sun-spot numbers.

| *Year* | *Predicted* | *Observed* |
|---|---|---|
| 1945 | 28·7 | 33·1 |
| 1946 | 65·8 | 92·5 |
| 1947 | 127·0 | 151·5 |
| 1948 | 162·9 | 136·2 |
| 1949 | 118·4 | 134·7 |
| 1950 | 99·0 | 83·9 |
| 1951 | 64·4 | 69·4 |
| 1952 | 35·1 | 30·9 |

It must be remembered however that in his calculations the method was only valid to predict the year 1951.

Finally the report also contained a note on the auto-correlation of smoothed functions.

**Comments**

From the results given in this report it seemed that the method of analytic functions was unsatisfactory and yielded no practical results. The linear estimater method yielded a standard error which decreased as the number of terms in the series increased, varying from 18·5 for two terms to 13·9 for twenty-two terms. Karamata's method gave a standard error of 10·4 which was better than the other method and also better than the method given by Moran. Probably if cycle-matching techniques were added to the above methods the error would be smaller still.

**C. N. Anderson. Notes on the Sun-spot Cycle.** *Journal Geophysical Research.* Vol. 59, 1954. p. 455

In this paper a demonstration is given that the pattern of sun-spot cycles repeats after a time lag of 169 years. A graph giving the yearly average of the unsmoothed relative Zurich sun-spot numbers for 1749-1917 was superimposed on that of 1917-1953 (the alternate cycles were reversed in sign c.f. Anderson Terr. Mag. and Atmos. Elec. Vol. 44, 1939. p.175) and quite a startling similarity resulted. The slight deviation from perfect agreement prompted the study of these 169 year periods and it was found that the variation in lengths of intervals of fifteen consecutive eleven year cycles, based on sun-spot minima and ending on the date plotted, followed an oscillatory curve with a steady trend commencing at 164 years and tending, at the present time, to 170 years. The oscillation about this trend appears, however, to be damped (see Fig. 3).

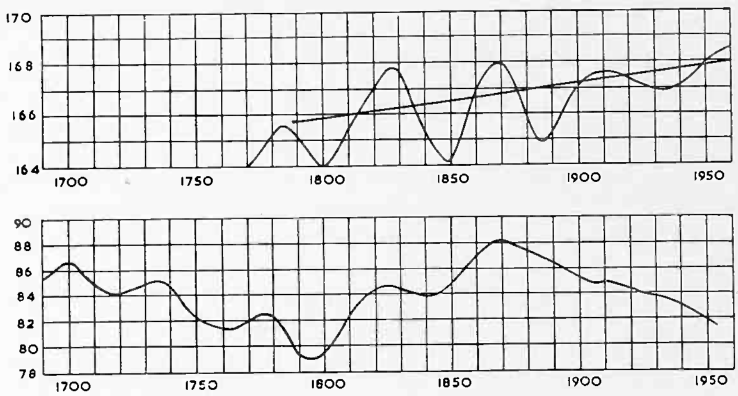


FIG. 3

The fifteen cycle periods were then split up into two $7\frac{1}{2}$ year periods and this showed that the 169 year period ending in 1953-4 was made up of an 81 year half (starting in 1873) and an immediately preceding 88 year half. Using this scheme as a basis the next sun-spot minimum was predicted to be between 168 and 169 years after 1798, or during 1966-7.

Using data going back to A.D. 301 it was found that the interval length of 15 cycles had an average of 166 years and followed a normal (Gaussian) distribution with 50% of the lengths falling between the mean $\pm$ two years. A periodogram analysis of the harmonics of a 388 year period showed that there was a main component of 22·5 years and a subsidiary one of 17·75 years. (The period was taken to be 388 years instead of 312 years as in the earlier paper because of the analysis above.)

**Comments**

There seems no limit to the ingenuity of such a subjective approach, but earlier remarks regarding periodogram analysis are still pertinent. The data at present is too inconclusive to show whether the above matching is realistic or not.

With this matching, the predicted sun-spot annual averages are:

| *Year* | *Predicted* | *Observed* |
|---|---|---|
| 1952 | 22·8 | 31·5 |
| 1953 | 10·2 | 13·9 |
| 1954 | 24·1 | 4·4 |
| 1955 | 82·9 | 30·8 |
| 1956 | 132·0 | 132·4* |
| 1957 | 130·9 | |

* provisional.

There is no doubt, the general trends agree but it is difficult to add all the empirical corrections necessary to improve the prediction.

**C. M. Minnis. A New Index of Solar Activity used on Ionospheric Measurements.** *Journal of Atmospheric and Terrestrial Physics.* Vol. 7, 1955. p. 310

This paper introduces a new index of solar activity based on the critical frequency $f$. The measurements use the $F_2$ layer since the E layer is less sensitive to solar changes and the $F_1$ layer cannot be easily distinguished from the $F_2$ layer during the winter at certain observatories.

If an exact functional relationship existed between the mean intensity of ionization and the mean sun-spot number and if in addition the ionosphere was not subject to irregular disturbances then it is reasonable to suppose that the monthly mean value of the $F_2$ layer critical frequency $f$ could be expressed exactly as a single-valued function of the monthly sun-spot numbers $R$. The measured quantities $f_m$ and $R_m$ do not have such a (1, 1) correspondence although the correlation between them is high.

The basic assumption of this paper is that $f_m$ and $R_m$ contain components $R_v$, $f_{vc}$ which do have such a relationship. Since the $F_2$ layer changes in a fairly consistent manner with changes in magnetic activity, $f_{vc}$ has to contain a term to allow for this, for this term the monthly mean $C$, of the international magnetic character is used. These assumptions can be expressed as follows

$$R_m = R_v + R_x \tag{1}$$

$$f_m = f_{vc} + f_x \tag{2}$$

$$f_{vc} = a + b\,R_v + kC \tag{3}$$

where $a$, $b$, $k$ are constants for a given month and time of day at a given observatory and

$$\Sigma R_x = \Sigma f_x = 0$$

Using (1), (2), (3)

$$f_m = (a + k\overline{C}) + bR_m - bR_x + k(C - \overline{C}) + f_x \tag{4}$$

where $\overline{C}$ is the mean of $C$ using the whole period of observation. Thus the graph of $(f_m, R_m)$ gives a scatter of points and a linear best fit can be obtained. If this line is

$$f_m = (a' + k\overline{C}) + b'\,R_m$$

then

$$R'_m = \frac{f_m - (a' + \overline{kC})}{b'} \tag{5}$$

Therefore for each month, from $f_m$, an estimate of $R_m$ is obtained by $R'_m$. Now from (3)

$$R_v = \frac{f_{vc} - (a + kC)}{b} \tag{6}$$

and this shows a close resemblance to (5). Therefore $R'_m$ could be taken as an estimate of $R_v$. In fact

$$R'_m = R_v + R_y + R_c$$

where

$$R_y = \frac{f_m - a'}{b'} - \frac{f_m - a}{b} + f_x/b$$

$$R_c = -k\left(\frac{\overline{C}}{b'} - \frac{C}{b}\right)$$

It was found that if $R'_m$ was measured at different observatories, the mean value of $R'_m$ was comparatively insensitive to changes in $C$. Therefore, if

$$\begin{aligned} I_{F2} = \overline{R'_m} &= R_v + \overline{R_x} + \overline{R_c} \\ &= R_v + R_z \end{aligned}$$

then $I_{F2}$ is the new solar index.

It was found from $R_m = R_v + R_x$

and $I_{F2} = R_v + R_z$

that $R_m$ is of a much greater variability than is $I_{F2}$ and this suggests that the variance of $R_x$ is greater than the variance of $R_z$. In fact, var $R_x \fallingdotseq 10$ var $R_z$, that is, $I_{F2}$ is a more stable estimate of $R_v$ than is $R_m$.

The paper concludes with criticisms of two other indices of solar activity.

(a) Twelve month running-mean sun-spot number.

(b) Relative critical frequency proposed by C. W. Allen.

Index (a) was rejected on the grounds of greater extrapolation errors due to the fact that the most recent value of it is six-months earlier than the month for which prediction is needed and also because it does not give a unique determination of the twelve monthly running mean of the critical frequency.

Index (b) was rejected on the grounds that it was not a pure index but depended on which observatories were selected to make the measurements.

### Comments

In view of the comments at the end of the paper, presented by the Secretariat of the C.C.I.R. at the Warsaw conference, regarding the difficulty of reducing the error in predicting sun-spot numbers to a negligible amount it seems that from the points of view of ionospheric forecasting the method outlined in the above paper has much to recommend it. It cannot, however, be used to predict the observed sun-spot numbers themselves, without knowledge of the variability of $R_x$. Notice must be taken, however, that the results of the above paper are confined to a short time scale as compared to sun-spot data and hence prediction of the $I_{F2}$ index may be more difficult than suggested.

**Czechoslovakia: Prediction of the Relative Sun-spot Numbers.** C.C.I.R. VIII Plenary Session, Warsaw 1956. Document 218E

The substance of this paper is a brief outline of a method to predict the relative sun-spot number $R$ and some conclusions obtained as to the behaviour of past sun-spot cycles.

The formula given for $R$ during an arbitrary cycle is

$$R = \frac{1}{2} R_m \left\{ 1 - \cos \frac{2\pi t}{a T + (1 - a) t} \right\} \tag{1}$$

where $a = T_1/(T - T_1)$ (2)

and $R_m$ is the theoretical maximum of the cycle, $T$ the duration of the cycle, $T_1$ the time from the beginning of the cycle to its maximum, $T - T_1$ the remainder of the cycle. For prediction $R_m$, $T$, $a$ and the time of the beginning of the cycle have to be determined.

The data was split up into odd and even cycles and the following conclusions deduced:

(1) The curve of odd cycles has maximum in a period of 80 years.
(2) That for even cycles is 66 years.
(3) When both curves in phase, high maximum and low minimum result.
(4) When in opposite phase the extrema compensate.
(5) Both curves coincide in phase once in 176 years.
(6) Odd cycles retain their character to a greater degree than even ones.

Using the prediction formula above the following results were given.

| Cycle | Time of theoretical beginning | $R_m$ | $T$ | $T_1/T$ | Time of Maximum |
|---|---|---|---|---|---|
| 19th | Beginning of 1956 . . . . . . | 100 | 13·0 | 1/3 | 1959 |
| 20th | End of 1969 . . . . . . | 30 | 14·5 | 0·4 | 1975 |

**Comments**

No method is given for the evaluation of $R_m$ so that the accuracy of this method is not calculable. The predictions concerning the present (19th cycle) do not seem very good as the observed figures for 1956 of $R_m$ are $>$ 100 already, and the maximum appears more likely to occur in 1957. Furthermore the beginning of the present cycle was in 1954.

**Secretariat of C.C.I.R. Prediction of the Solar Index.** C.C.I.R. VIII Plenary Session, Warsaw 1956. Document 254E

This report was divided into two parts, the first part contained a summary of papers collected by the Secretariat before the London assembly of 1953 and the second part dealt with further studies. Throughout this report the solar index referred to was the smoothed annual average of the Zurich relative sun-spot numbers (defined in previous papers).

The studies summarized in the first part of this report together with the accuracy of their predictions may be briefly set out as follows:—

(1) A study by Yule, based on a linear regression analysis yielding a standard error in the solar index of 15·41.

(2) A study by Moran, based on curvilinear regression giving a standard error of 13.

(3) A method by Gleissberg (see his paper summarized earlier) based on statistical laws linking the averages of four years maxima and minima, rise and decay times.

(4) A method outlined in the London Document 258 where a theoretical standard error of 8·29 was obtained; unfortunately in practice other adverse factors are present and this would make the standard error increase beyond 10.

(5) The C.R.P.L. method (MacNish and Lincoln); this was based on an auto-regressive scheme and yielded a standard error of 13·4.

(6) A method of prediction due to Waldmeier based on laws which link together certain characteristic parameters of the solar cycle. This method yielded a standard error of 9·49 but since the prediction was during the face of the cycle, where accurate results are more easily obtainable, it was felt that the standard error using the whole cycle would be greater than 10.

In the second part of this report dealing with further studies, it was found that a completely linear prediction was impracticable since the standard error of such a prediction was too large. Therefore recourse had to be made to a non-linear prediction. This took the form

Prediction (of solar index)

= First non-linear prediction (of solar index).

+ Linear prediction (of solar index—first approximation)

and it was with the non-linear prediction of the first approximation that the studies of the C.C.I.R. were concerned.

These fell into two parts

(a) An investigation into the main elements of the cycle defined in a non-continuous manner.

(b) A prediction of the first approximation defined continuously.

In method (a) the quantities used were, the magnitude of the maximum $M_n$, the time $T_n$ between the maxima $M_{n-1}$ and $M_n$ and the time $t_n$ between the minima $m_n$ and $m_{n-1}$. Using least squares fits, the following prediction formulae were obtained.

$$M_n = 274{\cdot}8 - 15{\cdot}06 \quad \delta_{n-1} - 10{\cdot}90\ \delta_{n-2}$$

$$T_n = 5{\cdot}6 + 0{\cdot}00168\ S(M,\ M/4)_{n-1} + 0{\cdot}000279\ S(M,\ M/4)_{n-2} + 0{\cdot}00269\ S(M,\ M/4)_{n-3}$$

$$t_n = 12{\cdot}21 + 0{\cdot}0420\ I(20)_{n-1} - 0{\cdot}4214\ I(20)_{n-2} + 0{\cdot}0541\ I(20)_{n-3}$$

where $\delta$ is the decay time, $S(M, M/4)$ the area between the maximum ordinate and that ordinate on the falling side of the maximum whose value is a quarter of the maximum and $I$ (20) the range of the minimum between the ordinate of value 20.

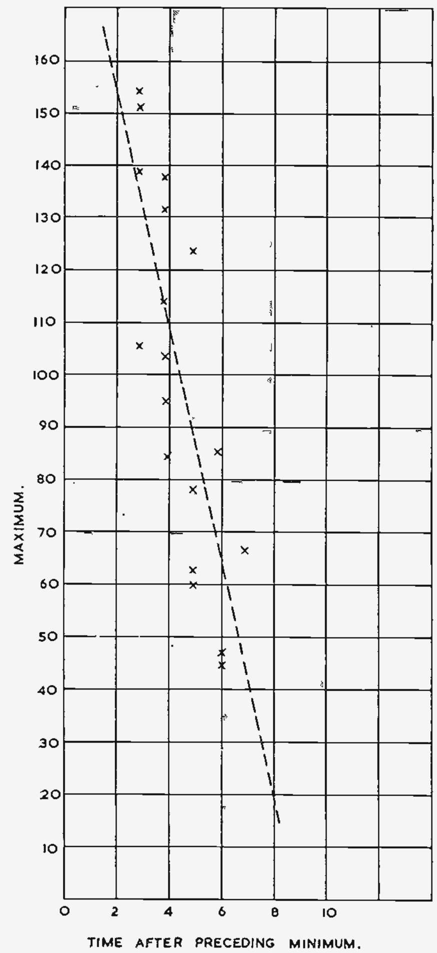


FIG. 5

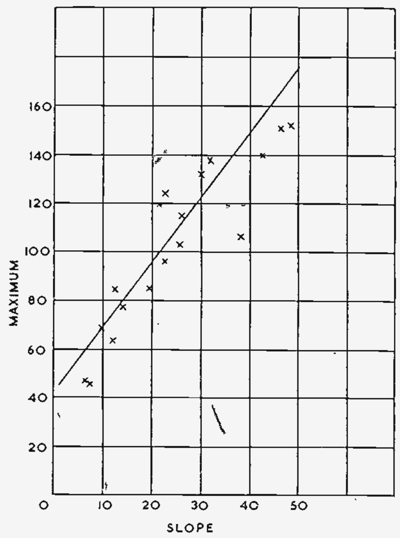


FIG. 4

In method (b) integrals of the form

$$I_2(t) = \int_{t-1}^{t+1} f(t)\, dt$$

$$I_5(t) = \int_{t-2.5}^{t+2.5} f(t)\, dt$$

were used, where $f(t)$ is the solar index at time $t$, and the following formulae obtained (again using least squares fitting).

$$f(t) = 0{\cdot}24\,[I_5(t - 3{\cdot}5) + I_5(t - 9) - 1{\cdot}19\, I_5(t - 5)]$$

$$f(t) = [I_5(t - 3{\cdot}5) + I_5(t - 9)]\left[0{\cdot}2864\,\frac{I_5(t - 11)}{I_5(t - 9{\cdot}5) + I_5(t - 15)} - 0{\cdot}048\right]$$

$$f(t) = A\, I_2(t - 11)\, k(t)$$

where $k(t)$ is a function of $I_2(t - 2)/I_2\,(t - 13)$, obtained empirically.

### Comment

The results of these investigations showed that no better predictions had been obtained than those achieved by earlier methods, and it would seem that a standard error of less than 10 is unlikely to be achieved especially in view of the somewhat arbitrary definition of the solar index. The methods outlined above however are to be preferred to some of the more subjective approaches of other authors in view of the fact that the error of estimation can be ascertained and therefore confidence limits on the prediction set up.

## Some Comments on the Behaviour of the Present Sun-spot Cycle

In Fig. 4 a plot of the maximum, $R_m$, of the relative sun-spot number is made against the slope of the increase of $R_m$, where the slope is defined as

$$\frac{\text{Maximum } R - \text{Minimum } R}{\text{Time of maximum} - \text{Time of minimum}}$$

This graph shows that the steeper the slope the higher the maximum. (N.B. The definition of slope above does not take into account the fluctuations of the rate of climb from minimum to maximum.)

A provisional estimate of the slope of the present cycle gives a value of 40 and from Fig. 4 this shows that the maximum should be about 140.

From Fig. 5, which is a plot of maximum against time from preceding minimum, it is seen that the maximum of the present cycle should occur three years after the preceding minimum, i.e., some time in 1957.

From predictions given in some of the preceding papers and the empirical judgments on the trend of the present sun-spot cycle it is possible to give other estimates of some of its characteristics.

Using Yule's prediction the sun-spot number for 1957 will be 171·4 with a standard deviation of 15 and for 1958 it will be 157·2 with a standard deviation of 15.

Using Moran's prediction the figure for 1957 will be 147·1 with a standard deviation of 13 and for 1958 the figure will be 108·3 with a standard deviation of 14.

From all the above it seems that the maximum of the present cycle is during 1957 and that its maximum is 140 — 150. From other papers it seems that the cycle will end about 1966.

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# THE MEASUREMENT OF WORLD-WIDE THUNDERSTORM ACTIVITY AT A SINGLE LOCALITY

By G. A. Isted

*Experiments have shown that it might be possible to record the world-wide thunderstorm activity from a single locality. Striking similarity is shown between the mean diurnal variations of thunderstorm activity at Great Baddow, Essex, for April,* 1954, *and at California for the same period.*

It is well known that, because of pollution in the atmosphere, the measurement of the potential gradient, from which the earth's vertical electric field can be deduced, is both difficult and unreliable anywhere but over the oceans. Mauchly([1]) has measured this potential gradient over the oceans in fair weather, and has found that the diurnal variation proceeds according to Universal Time. His curve is reproduced in Figure 1(*a*).

In a previous publication([2]) an attempt was made to show that V.H.F. propagation in some of its aspects was related to the earth's vertical electric field, and, following Wilson's([3]) theory that this electric field is maintained by the world-wide thunderstorm activity, experiments were described which suggested that this activity could be recorded at a single locality, and that the state of the earth's electric field could thus be assessed without the need for its direct measurement.

Apparatus was described for counting the electrical impulse disturbances which can be observed in the 0·3—12 kc/s band and which are presumed to have been caused by lightning. This apparatus consisted of a wide-band audio-frequency amplifier, an electronic counter arranged to be triggered by the received impulse, an integrating circuit and a pen recorder. The counter was designed to be independent of received impulse amplitude for all input values above the threshold value set at $100\mu V$; it was therefore not unduly influenced by local thunderstorm activity. The aerial normally used was a 60 ft. lattice steel mast insulated at its base, but a combination of loop and vertical aerials provided facilities for measuring the direction of arrival of the disturbances.

A curve representing the mean diurnal variation of thunderstorm disturbances, recorded at Great Baddow, Essex, during the experiment, was given for April, 1954, and is reproduced in Figure 1(*b*) plotted here on a logarithmic scale. Attention was drawn to the similarity of the diurnal variation of the potential gradient measured by Mauchly to that of the recorded thunderstorm disturbances. In particular it was pointed out that the two well-defined peaks of activity, one at 16 hr, the other at 21 hr U.T., corresponded to the peak thunderstorm activity in the African and American Continents successively.

Directional measurements indicated that the majority of disturbances did in fact arrive from the direction of those continents at the times specified. Directional measurements, furthermore, showed that thunderstorm centres were mainly westerly between 24 hr and 09 hr U.T. and easterly between 09 hr and 12 hr U.T.; this suggested that the broad minimum centred on 09 hr U.T. was caused by the reduction of thunderstorm activity during the sun's passage over the Pacific Ocean.

The claim was then made that the diurnal variation in the number of disturbances measured from a single locality represented a true assessment of the total world thunderstorm activity. This claim has since received strong support from Holzer and Deal(4) in California who describe a similar experiment in the 25—130 cycle/second band but, in their case, they record the integrated amplitude of the disturbances.

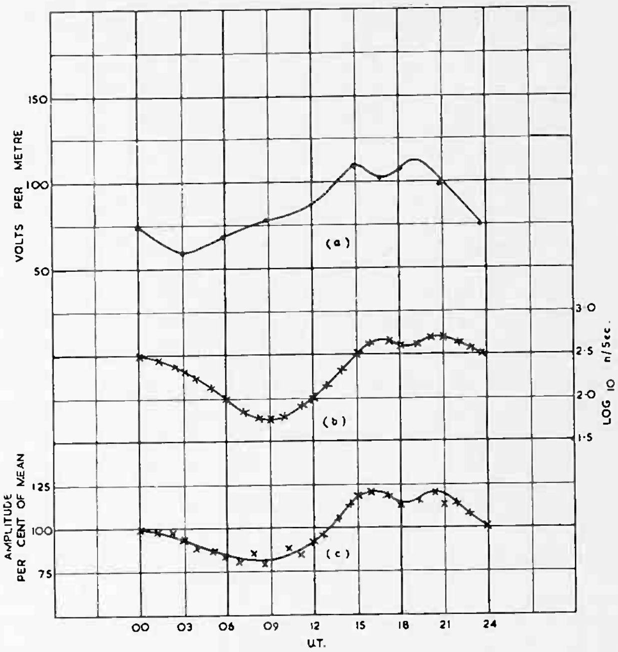


FIG. 1

*Mean diurnal variation af* (a) *the earth's potential gradient over the oceans, February to April, 1929,* (b) *the number of thunderstorm disturbances recorded in England, April, 1954, and* (c) *the integrated amplitude of thunderstorm disturbances recorded in California, March-April, 1954*

Most fortunately, in their communication, Holzer and Deal have given a curve, reproduced in Figure 1(*c*), representing the diurnal variation of thunderstorm activity, measured in California, for the same period of March-April, 1954. The two independent curves, although differing somewhat in proportionality, demonstrate quite clearly that they represent a phenomenon which is related to Universal Time and not to Local Time which differs by eight hours. Holzer and Deal associate the two maxima between 14 hr and 21 hr U.T. with the mid-afternoon thunderstorm activity in Central Africa and the Amazon Valley successively and they come to the conclusion that the low attentuation in the very low frequency band makes it possible for disturbances due to lightning to be recorded from all parts of the world. The results of the two independent investigations, considered in relation to Universal Time, would seem sufficient evidence to support the claims that the total world thunderstorm activity can be measured from one locality.

Both curves are in reasonable agreement with Mauchly's measurement of the potential gradient, particularly between 12 hr and 24 hr U.T. but whereas Mauchly has measured the minimum of the potential gradient to be at 03 hr U.T., the results of both independent thunderstorm recordings would imply that the minimum should occur between 08 and 09 hr U.T. This suggests that the earth's electric field may not be so closely related to the world thunderstorm activity as Wilson has suggested when the sun passes over the Pacific Ocean, at which time storm activity is greatly reduced.

The author is grateful to Mr. C. J. R. Pallemaerts for his valuable assistance in these experiments.

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## BOOK REVIEWS

*Noise*, by A. van der Ziel. Chapman and Hall, 1955. 60/-.

It would in no way have detracted from the value of this book if a less succinct title had been chosen to indicate more accurately the scope of the contents—Noise in Electronic Devices. The limitations set by noise in an intelligence-conveying system as they affect receiver performance or transmitter power have long been known and the nature and causes of noise itself are equally familiar. Professor van der Ziel's contribution is to assemble the data from a wide range of sources (unfortunately nothing later than 1953) and produce a very readable dissertation on spontaneous fluctuations in general, a feature being the frequent reference to measurements which are of immediate interest to both physicist and/or engineer, so that a well-balanced contribution of theory and practice results.

The author's claim that the book reduces solutions of most noise problems to an analysis of simple networks is in the main well founded, though it must be admitted that a large number remain which are not amenable to this simple treatment. The type of noise problem encountered in information theory has been deliberately excluded, those interested in this aspect of the subject being referred to one of the other volumes in the Prentice-Hall Electronic Engineering Series.

The use of footnotes to the text is sufficiently frequent to be irritating, whilst their use for the references makes location difficult; in other respects the illustrations and format are good; the index, however, is inadequate for a book that will be frequently referred to and deserves something better.

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*V.H.F. Radio Manual*, by P. R. Keller. George Newnes, Ltd. 30/-.

This book covers in just over 200 pages the equipment employed in the frequency band 30 Mc/s to 450 Mc/s and some of the services occupying this band. As a consequence a somewhat condensed style has had to be adopted together with the assumption that the reader has some familiarity with the fundamentals of the subject. This condensation may have been carried too far. It is surprising, for instance, not to find a chapter devoted to the generation of these frequencies although some of the information one would expect to find in such a chapter is covered elsewhere. Again the lack of detailed information on the concept of receiver noise factor or of the use of noise generators for the comparative, if not absolute measurement of receiver efficiency, is to be deprecated.

The practical engineer working in this field will, however, find in this book most of the circuit details, formulae and " tricks of the trade " he urgently needs but cannot quite remember. To him as well as to the keen amateur experimenter the book should be invaluable.

References are given at the end of each chapter but it is suggested that if they were even more numerous the value of the work would be increased. Nevertheless a first class attempt has been made to cover this wide field within the limits imposed and an excellent balance has been struck between the theoretical and practical approach to the subject.

*Hi-Fi Loudspeakers and Enclosures*, by A. B. Cohen. Chapman & Hall. 37/6.

In these days, when high fidelity reproduction of long playing gramophone records, magnetic tape recordings, and F.M. broadcasts, is becoming increasingly popular, it is opportune that a book dealing very fully with the moving coil loudspeaker assemblies used in Hi-Fi installations should make an appearance.

The book is well and interestingly written by the Engineering Manager of University Loudspeakers Inc., and explains from first principles, and in considerable detail, the design and construction of the dynamic, or moving coil, type of loudspeaker. The wide range single speaker, and multiple speaker systems, are fully dealt with, and the advantages of each type are fully illustrated. It is interesting to note that whereas British manufacturers specify speaker magnets in terms of flux density in the gap: the Americans specify the weight of the magnet and the material of which it is composed.

The importance of proper acoustic matching between the loudspeaker and the cabinet to form an integrated whole is clearly explained in the middle section of the book which deals very thoroughly with different types of enclosures, including baffles, bass reflex cabinets and folded horns. Listening room acoustics, and the position of the loudspeaker and the listener relative to the room boundaries are adequately covered in the last section of the book.

A survey of the basic types of loudspeakers and the principles involved, forms the subject of the opening chapters, but it is a pity that the latest type of constant charge push-pull electrostatic speaker is only referred to in a footnote, with no mention of its wide range performance. Presumably details are not yet available in America.

The text is liberally supported with numerous diagrams, graphs and tables, and the author is to be congratulated on his lucid explanations which are given without the aid of mathematics. A useful index is included and an appendix gives constructional details of a number of American commercial enclosures.

The book should prove very useful to all those who wish to construct or assemble their own loudspeaker equipment, and to those who require a better understanding of the loudspeaker systems used with modern high fidelity equipment.

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*Television Receiving Equipment*, by W. T. Cocking. Published for *Wireless World* (Iliffe and Sons, Ltd.). 30/-.

In the ten years or so which have passed since the reopening of a television service in this country, the television receiver has undergone an intensive process of development, in much the same way as did the sound receiver in the 'thirties. The results to date have been noticeably similar—a uniformity of outward appearance and performance, and a reduction in size and manufacturing cost, brought about by the successful application of component miniaturization and large-scale production techniques. No longer does the prospective buyer enquire into the technical niceties of the receiver of his choice; the depressing uniformity of the product makes this an unprofitable occupation.

*Television Receiving Equipment*, by W. T. Cocking, now in its Fourth Edition, deals, to quote the dust-jacket, " comprehensively with television receiving equipment, and gives many practical details and design data." No exception can be taken to this statement in its general sense, but the impression gained from a study of the book is that a disproportionate amount of space is devoted to certain selected topics. Can it be entirely a coincidence that these are subjects already dealt with at length by the author, in the technical press?

Thus, the subject of deflection occupies no less than seven chapters, comprising 121 pages, as well as two appendices; Band III Convertors, on the other hand, which one might expect to be of some interest to the purchaser, are dismissed in slightly more than three pages. Synchronizing has 46 pages, power supplies less than five; while three and a half are devoted to the admittedly obsolete thyratron oscillator.

Nor has the author considered it necessary to provide a bibliography to encourage wider reading; nine references to original sources (two of them his own), can hardly be adequate for the broad subject with which his book is concerned.

On the credit side it can be said that the book is likely to prove a valuable reference source to the experimenter. Not the least of its virtues is the practical viewpoint assumed by the author; typical component values are indicated wherever a circuit is discussed, and " know-how " of the kind which one normally accumulates by bitter experience is a notable feature.

The book is well printed, on good quality paper, with the clear illustrations that one has come to associate with the publishers of " Wireless World."

# AN EXPERIMENTAL WIDE BAND PARABOLIC AERIAL FOR THE 2,000 Mc/s BAND

By N. Ganapathy, B.E. (Hons.), Grad.Brit.I.R.E., and
P. E. G. T. Hopkins, M.I.I.S.

*The requirements of an aerial for use with 2,000 Mc/s band multi-channel links can be met by a horn-fed paraboloid which can combine the qualities of high gain and good impedance match over a very wide band. A 10 foot diameter parabolic dish aerial suitable for 30% bandwidth at 2,000 Mc/s is described and design considerations for the primary feed and the associated waveguide feeder are outlined. Typical figures for the performance of the experimental aerial with respect to impedance match, gain and radiation pattern are quoted.*

## Requirements

The essential requirements of an aerial for use with wide band multi-channel communication links are high gain, good impedance match over the operating band and low secondary side lobe levels. A parabolic reflector of sufficiently large aperture will give the required high gain and the design of the primary feed illuminating the dish will determine the impedance match and radiation pattern. A 10 foot diameter parabolic dish with the focus in the aperture plane, and with a theoretical maximum gain of 35·4 db at 2,000 Mc/s was chosen and it was proposed to illuminate the dish by a centrally placed waveguide flare. Since the primary feed would be situated in the aperture plane of the reflector an angle of illumination of $\pm$ 90° was required and although this would make the design of the flare more difficult, the anticipated advantages were reduced cross-talk between adjacent aerials and smaller back lobes. A waveguide feeder system was planned in order to overcome the difficulties of very wide band waveguide to coaxial transducers and also of unavoidable cable irregularities. The use of a narrow waveguide of dimensions 1 inch $\times$ 4·3 inch—which has since been accepted as an additional standard by some manufacturers—was envisaged so that the obstruction in front of the dish, caused by the narrow side of the waveguide feeder, could be reduced.

For multi-channel working, a very low-standing wave ratio in the transmission system is an important requirement and it was thought feasible to restrict the VSWR due to the aerial to not more than 1·06 (0·5 db). The aerial system, according to the preliminary design, consisted of the reflector with a matching vertex plate, the illuminating flare, one right angle H-plane bend and a short length of waveguide feeder leading down to the bottom of the dish and the sum of the reflections arising from all these components contributed to the estimated VSWR. The vertex plate matching technique was expected to reduce the reflection into the feed horn due to the dish, to an equivalent VSWR of about 1·01, and the bends and flanges making up the short feeder section were restricted to a VSWR of not more than 1·025 over the operating band. This implied that the reflections caused by the primary feed should yield a VSWR of not greater than 1·025 over the entire band.

The requirements as regards radiation pattern were that the primary feed should have a 10 db beamwidth of $\pm$ 90° to provide the optimum illumination for the paraboloid and that the secondary pattern of the aerial should be such that the first side lobe levels were —25 db and the back lobe —50 db with respect to the main lobe.

### The Waveguide Feed Horn

The design of a feed horn is determined largely by the reflector which it illuminates. The aperture dimensions for the horn are decided from considerations of a suitable primary pattern and the waveguide dimensions are tapered to give the chosen mouth dimensions. The result may be a pyramidal horn where both the E and H plane dimensions are flared, or a sectoral horn where only the E or H plane dimension is flared. The length of the flare may be chosen from considerations of impedance matching while bearing in mind that a short horn is to be preferred from the mechanical point of view. Having fixed initially the shape of the horn, the final

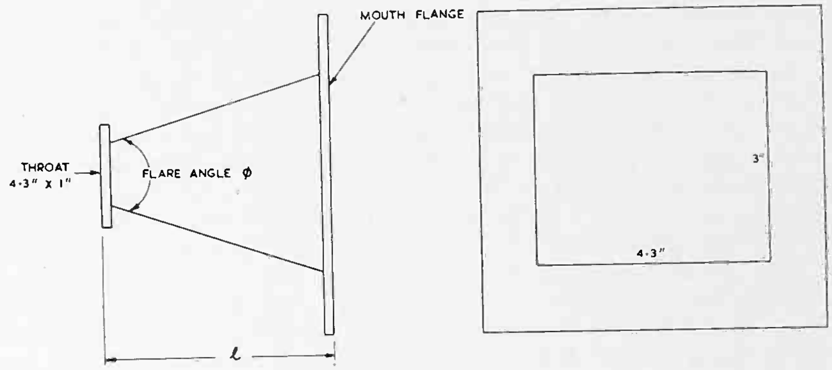



FIG. 1

dimensions are arrived at as a result of radiation pattern and impedance measurements made in conjunction with each other. In general, for the purpose of weatherproofing, the mouth of the horn may be required to be sealed with a suitable dielectric sheet in such a manner that the waveguide feeder system can be pressurized. In such cases the method of weatherproofing has to be decided first since it will modify the impedance characteristics and sometimes the pattern of the horn. A sheet of mica 0·003 inch thick, suitably fixed to the aperture and clamped by a cover plate, was planned for the feed horn.

### Primary Pattern

The illuminating horn should fulfil the following conditions as far as its radiation pattern is concerned.

(1) It should behave like a point source. If this is not achieved, the phase distribution across the reflector becomes non-uniform, resulting in reduced gain and increased side lobes.

(2) The illumination should taper down to the rim of the reflector to approximately —10 db with respect to the centre[1]. If the beam of the horn is wider, the increased gain of the reflector due to more uniform illumination may be partially offset by the reduced primary feed gain and may result in increased side lobe level.

(3) The illumination should preferably be circular (i.e., the levels should be equal in the E and H planes).

The aperture dimensions of the proposed horn to yield a 10 db beamwidth of $\pm 90°$ were obtained from empirical curves[2] and, for an operating frequency of 2,000 Mc/s, the dimensions were 3·25 inch × 2·78 inch. Considering that the waveguide dimensions were 4·3 inch × 1 inch, and also visualizing the use of beam-shaping flanges at the mouth of the horn, the aperture dimensions were chosen to be 4·3 inch × 3 inch with the result that the feed took the shape of an E plane sectoral horn (Fig. 1). The flare angle, which in turn determined the length of the horn to give the chosen aperture, would be responsible for the phase variations across the E plane of the horn, and should be kept small to minimize the phase variations. Sectoral horns of small flare angles ($<20°$) were made by flaring out the narrow dimension of the 4·3 inch × 1 inch waveguide to an aperture of 4·3 inch × 3 inch, and a concise account of radiation pattern tests conducted with these horns is given below.

A mouth flange of arbitrary size and thickness was fixed around the horn aperture and radiation patterns were taken for both the E and H planes. Despite the use of the mouth flange with varying widths for the E plane and the H plane, the best pattern obtained with a 4·3 inch × 3 inch aperture was still too sharp. In general the width of the E plane flange (along the wide side) had a noticeable influence on the E plane beam shape by widening it, but the H plane flange (along the narrow side) could not widen the H plane beam. Also, while the E plane beamwidth was affected only by the E plane dimension of the aperture, the H plane pattern was dependent on both dimensions of the aperture. In an attempt to improve the pattern in both planes, the aperture width in the E plane was progressively reduced by sawing off a short horn, and radiation patterns were taken with suitable mouth flanges. The finally accepted pattern had a fall at $\pm 90°$ of 12 db in the E plane and 13·5 db in the H plane at 2,000 Mc/s and was obtained with a 4·6 inch long horn, whose aperture was 4·3 inch × 2·5 inch and mouth flange 5·8 inch × 4·5 inch.

A study of the effect of the thickness of the mouth flange showed that the pattern was hardly affected, provided that the thickness was small compared to the wavelength, so that it did not simulate a choke flange. The inclusion of a thin sheet of mica at the aperture plane, according to weatherproofing requirements, did not change the pattern, but the use of an inductive window at the mouth (reducing the H plane dimension) for impedance-matching purposes, slightly improved the H pattern as might be expected. The patterns taken with the final form of the horn are shown in Fig. 2(*a*), (*b*) and (*c*) for 1,800, 2,000 and 2,200 Mc/s.

### Impedance Matching of Horn

The reflections occuring in a waveguide flare are at the throat and the mouth, and in an E plane flare these are both capacitive, the magnitude depending on the flare angle at the throat, and on the aperture dimension at the mouth. The weather-proofing mica seal at the mouth introduces a further capacitance at the mouth region and it is desirable to include the sealing arrangement at the very onset of the process of impedance matching of the horn so that the combined reflection at the mouth could be taken into account. The capacitive mismatch at the throat can be cancelled by introducing, at the junction of the taper to the straight waveguide (i.e., at the throat of the horn), an inductive iris. After reflection cancellation at the throat, the mouth admittances of the horn can be estimated by transposing, to the plane of the mouth along the slant length, the measured admittances at the throat. The mismatch at the mouth is appreciably reduced by the presence of a flange around the aperture, and the flange, while being necessary for purposes of beam shaping, also affords a convenient means of fixing the mica seal. The overall mismatch at the mouth

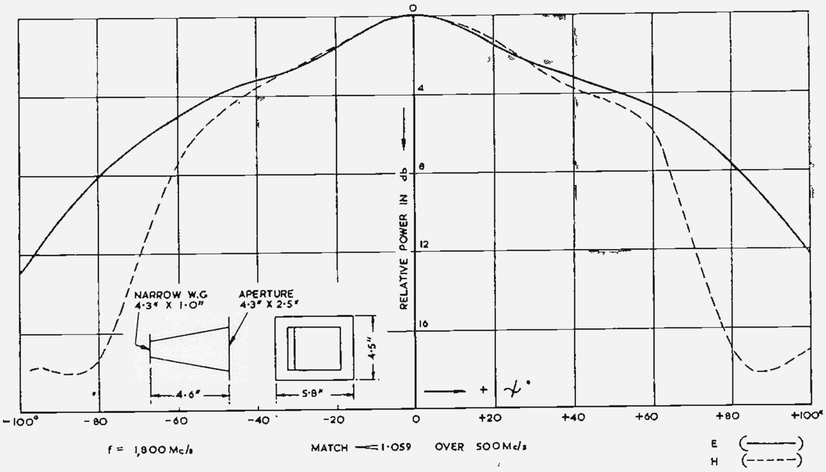



Fig. 2a

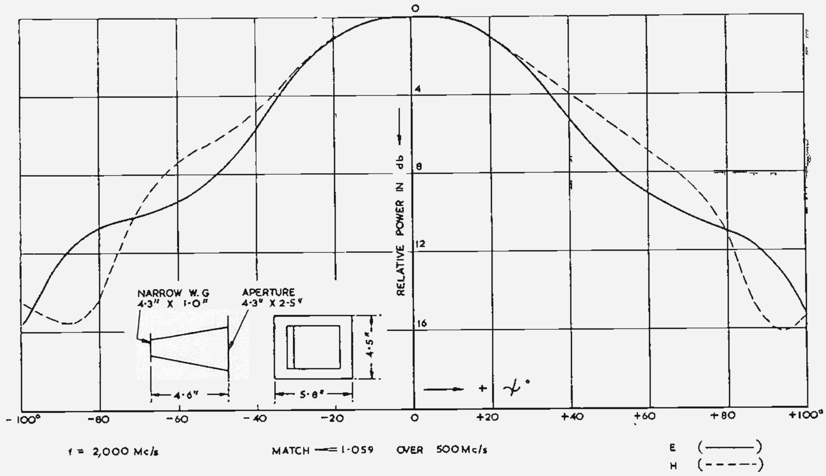



Fig. 2b

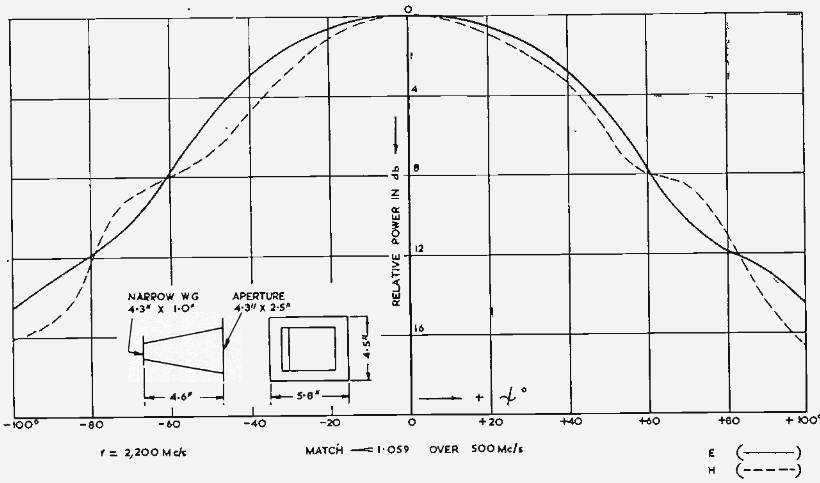



Fig. 2c

can be fully compensated for at a spot frequency by an inductive iris placed at the mouth region and the exact dimensions of the iris and its position are very much a question of trial and error owing to the fringing fields in the mouth region. The mouth iris may not provide compensation over a wide band, but the variations of mouth admittance over a very wide band (of the order of 30%) can be considerably reduced by the use of a resonant iris inside the horn placed between $\frac{\lambda_g}{8}$ and $\frac{\lambda_g}{4}$ from the mouth iris. The appropriate position, the $Q$, and the transparent frequency of the resonant iris are determined by the shape of the mouth admittance response.

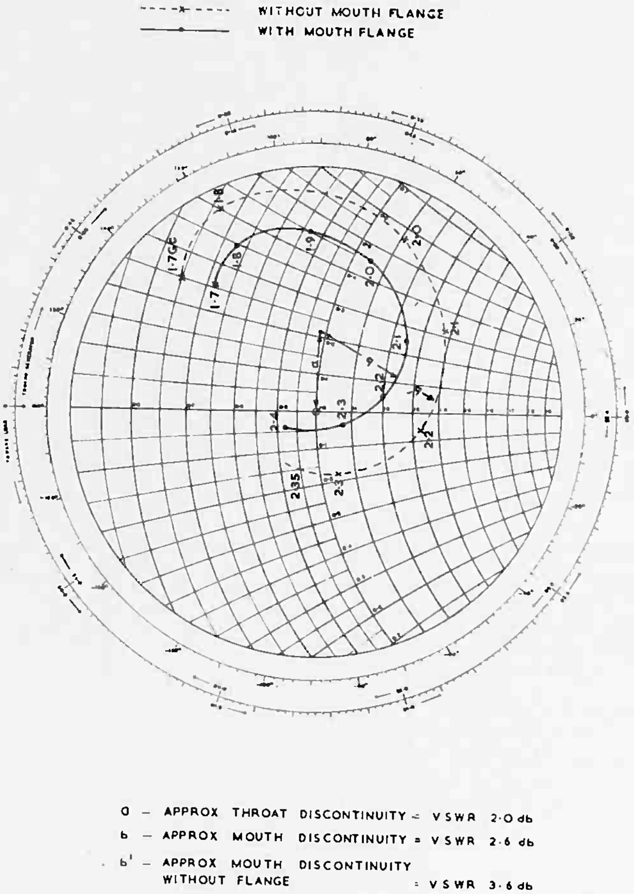



FIG. 3

An E plane flare, 4·6 inch long, was successfully matched using the above principles, and was used as the primary feed. An account of the experimental work is given below and this technique will apply to all E plane flares in general.

The horn admittance was measured with the flare radiating in "free space," the nearest obstruction being 15 feet away. The admittances at the throat of the horn over the band 1,700 Mc/s-2,400 Mc/s, with no flange at the mouth, and then with an $\frac{1}{8}$ inch thick flange, 5·8 inch × 4·5 inch o.d. soldered to the mouth, are shown in Fig. 3. The approximate throat and mouth discontinuities can be inferred from the offset distance of the centre of the loop on the Smith Chart, and its radius respectively.

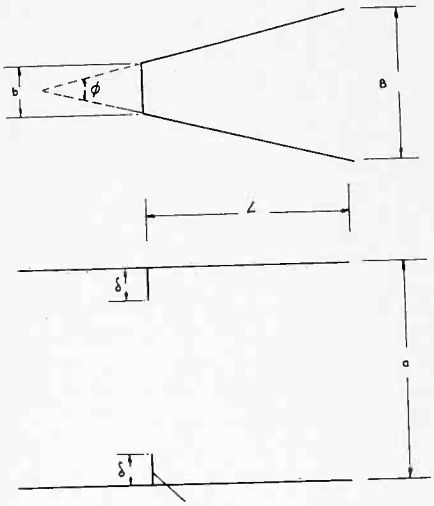
## Cancellation of Throat Reflections

It is shown by Lewin(3) that if a uniform waveguide of dimensions $a \times b$ is flared (in the electric plane only) to dimensions $a \times B$ over a length $L$ (Fig. 4) the reflection at the junction is equivalent to that produced by a normalized capacitive reactance $X_c$, given by

$$X_c = \frac{2\pi b}{\lambda_g} \cot \frac{2L}{B - b}$$

and that it can be matched out by a suitable inductive diaphragm at the throat. For moderate tapers, the symmetrical insertion of the inductive iris from each narrow side of the waveguide is given approximately by

$$\delta = \frac{a}{2\pi}\sqrt{\frac{a}{\pi}\cdot\frac{B-b}{bL}}$$




$\delta \simeq \frac{a}{2\pi}\sqrt{\frac{a}{\pi}\,\frac{B-b}{bL}}$

FIG. 4

Since this expression is independent of frequency, the compensation due to the iris is very broad-band (for moderate tapers, flare angle $<20°$).

It was also apparent from the admittance plot that a suitable inductive susceptance at the plane of the throat would cancel the throat reflections.

Inductive diaphragms, with different values of $\delta$, were inserted at the throat of the horn, and Smith Chart plots of the admittance at the throat were obtained over the specified frequency band. The appropriate iris was the one which centred the admittance response around the Smith Chart centre (Fig. 5).

### Cancellation of Reflection at Mouth

An approximate estimate of the mouth admittance could be obtained by transforming the admittance measured at the throat through the appropriate electrical length of the horn to the mouth plane, the length of the flare in terms of wavelength being calculated from the slant length of the flare. An inductive diaphragm with symmetrical penetration from each narrow side could cancel the capacitive susceptance at the mouth at one frequency, but it was a matter of trial and error to find the appropriate penetration of the iris owing to its complex behaviour at the aperture plane. Fig. 6 shows the Smith Chart plot of the mouth admittances (obtained by transforming the admittances measured at the throat) when an inductive iris of insertion $\delta=1$ cm placed at the aperture plane, cancelled the capacitive part of the mismatch at about 2,000 Mc/s. This curve could be shifted to either side of the conductance axis by altering the iris penetration $\delta$.

The conductance component of the mouth mismatch could be compensated at one frequency by placing the iris a short distance inside the horn, instead of at the aperture plane. It was found convenient, from the mechanical point of view to place both the iris and the mica sheet at the mouth of the horn, and to clamp them down by means of a cover plate, the thickness of which was equal to the required offset distance of the iris, and whose overall dimensions were the same as for the mouth flange (see Fig. 7). Changing the thickness of the cover plate corresponded to changing the distance of the mouth iris from the aperture plane, while the overall length of the horn was increased by the cover plate thickness, which was of the order of $\frac{1}{4}$ inch. The effect of increasing the offset $t$ of the iris was to move the mouth admittances response down the conductance axis, i.e., to increase the $G/Y_0$ components of the admittances (see Fig. 8). With the appropriate size of iris $\delta$, and offset distance

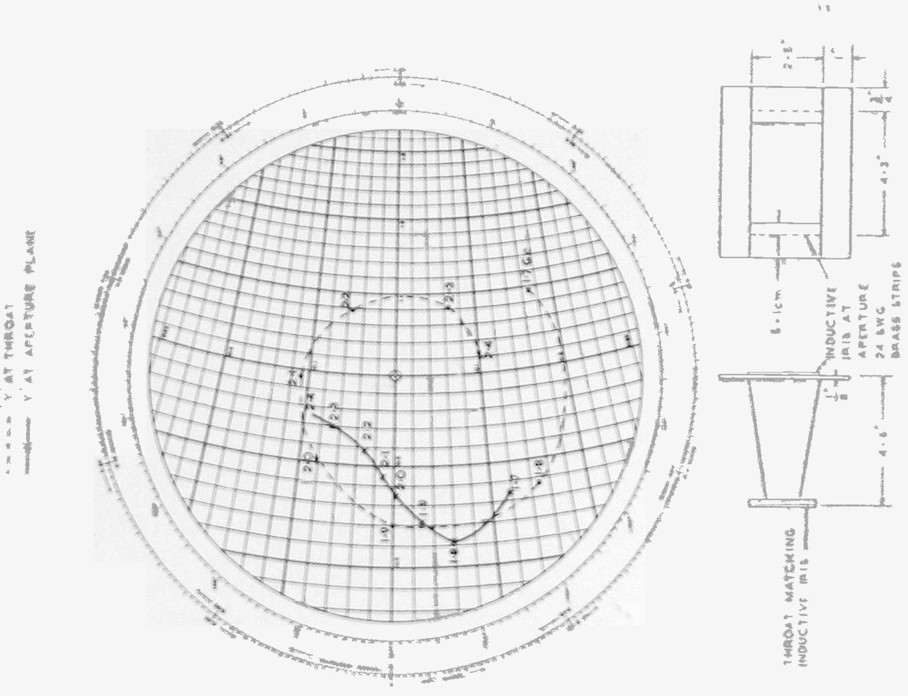

Y' AT THROAT
Y' AT APERTURE PLANE
INDUCTIVE IRIS AT APERTURE 24 SWG BRASS STRIPS
THROAT MATCHING INDUCTIVE IRIS

Fig. 6

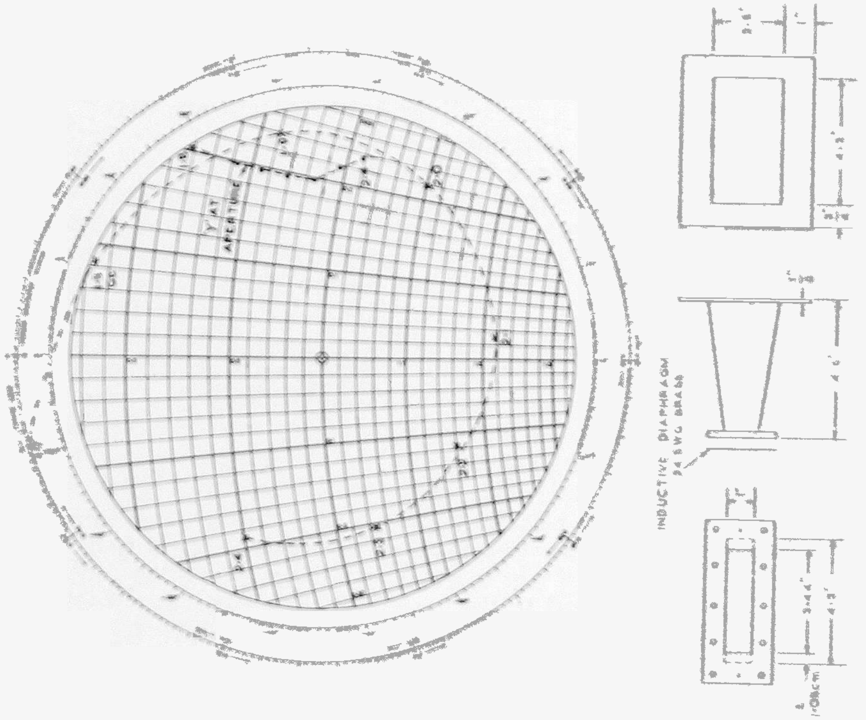
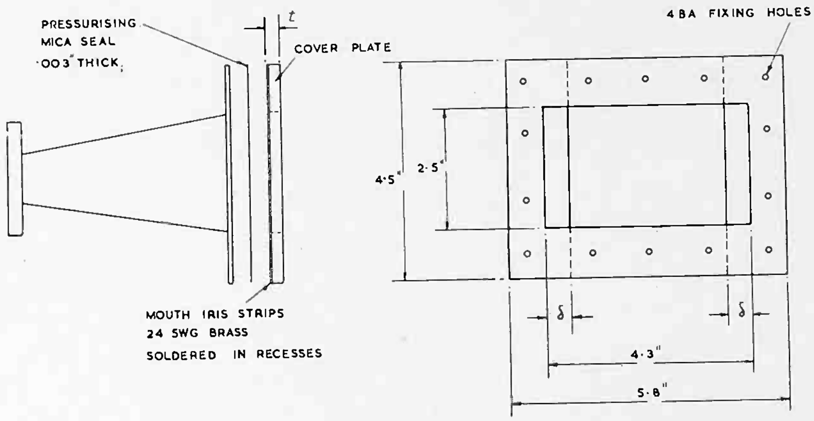

Y' AT APERTURE
INDUCTIVE DIAPHRAGM 24 SWG BRASS

Fig. 5

$t$ the horn could be completely matched at the centre frequency (2,000 Mc/s). The frequency response of the admittance at the mouth under these conditions lies at the centre of the Smith Chart (Fig. 9).




δ = SYMMETRICAL PENETRATION OF MOUTH IRIS
$t$ = OFF SET DISTANCE OF MOUTH IRIS

FIG. 7

## Compensating Resonant Window

The variation with frequency of the mouth admittance with the matching iris in position was of such a shape that suggested the use of a compensating resonant window placed inside the horn at a suitable distance from the mouth. The frequency response of the admittance of a resonant window plotted on the Smith Chart is a smooth curve passing through the centre of the chart, the susceptance changing from negative to positive when the frequency changes from below to above resonance. If the mouth response of the horn (shown in Fig. 9) were transferred to a plane RR removed from the mouth by a suitable distance towards the throat, the admittance response at such a plane would have positive susceptance for the low frequency end and negative susceptance for the high frequency end. If at such a plane RR a resonant window transparent at the centre frequency is placed, the combined admittance response would be a small loop curling round the Smith Chart centre. By choosing the correct $Q$ position and resonant frequency for the window, it was possible to match the horn over a band of 500 Mc/s to a VSWR of under 1·03.

A rectangular aperture resonant window was used and the dimensions of such a window were calculated from the relation

$$\frac{a}{b}\sqrt{1-\left(\frac{\lambda}{2a}\right)^2} = \frac{a'}{b'}\sqrt{1-\left(\frac{\lambda}{2a'}\right)^2}$$

where $a$, $b$ are the outside dimensions of the window, $a'$, $b'$ are the inside dimensions of the window and $\lambda$ is the free space wavelength at which the window is resonant.

Because of the tapering of the E plane dimensions of the horn, $b$ for the resonant window varied depending on the position of the window. For a chosen position and a chosen resonant frequency $f_c$, windows with different $Q$ were obtained by varying the

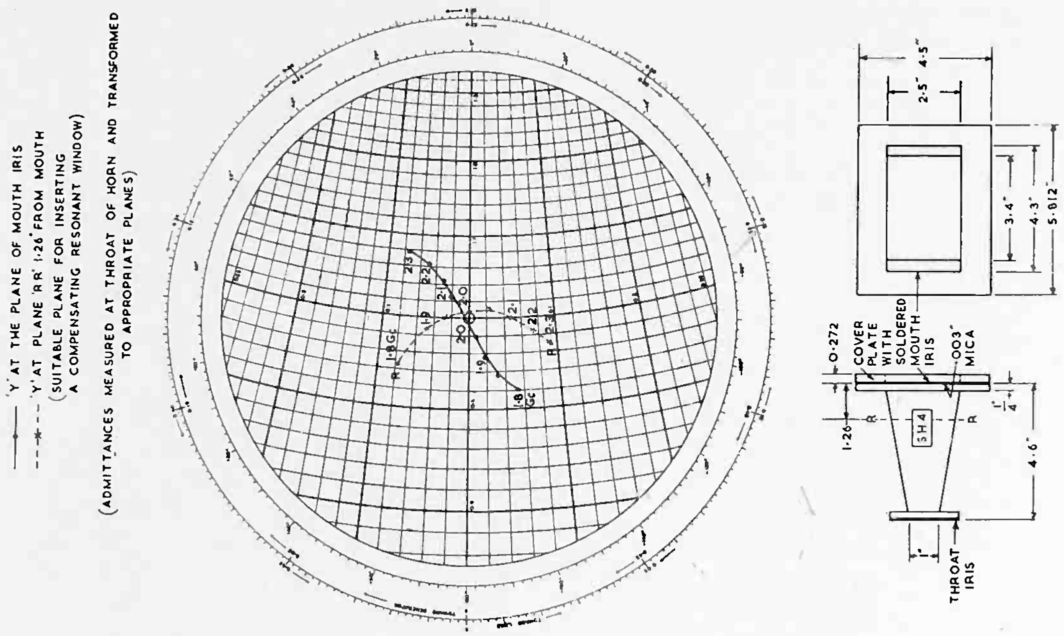

'Y' AT THE PLANE OF MOUTH IRIS
'Y' AT PLANE 'RR' 1·26" FROM MOUTH (SUITABLE PLANE FOR INSERTING A COMPENSATING RESONANT WINDOW)
(ADMITTANCES MEASURED AT THROAT OF HORN AND TRANSFORMED TO APPROPRIATE PLANES)
COVER PLATE WITH SOLDERED MOUTH IRIS
·003" MICA
THROAT IRIS
0·272
1·26
4·6"
3·4"
4·3"
5·812"
2·5"
4·5"
SH4

FIG. 9

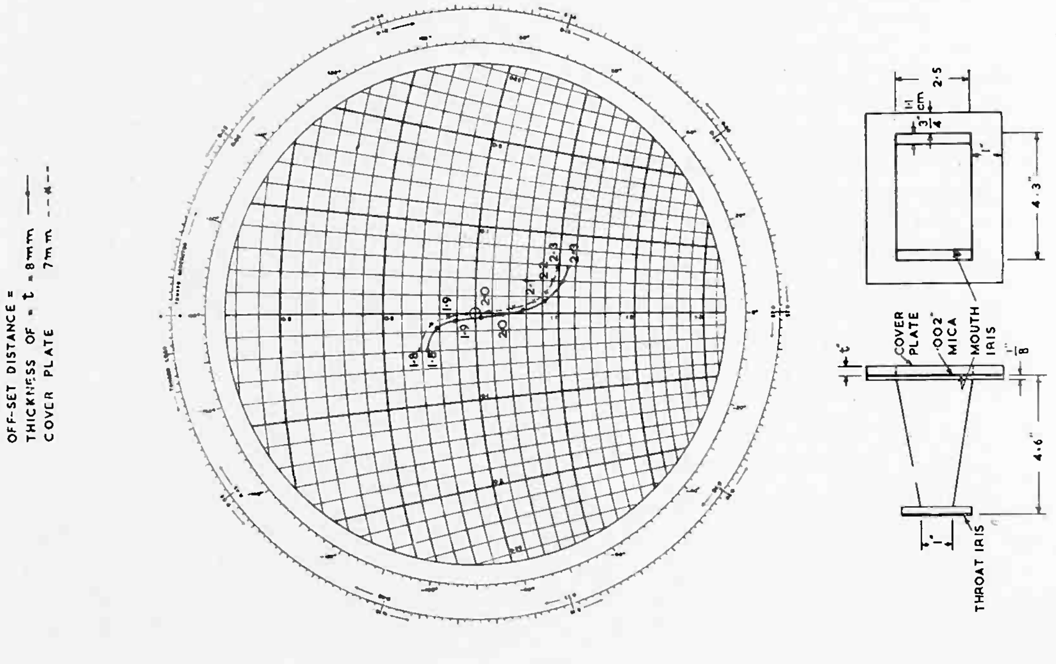

OFF-SET DISTANCE = THICKNESS OF COVER PLATE = t = 8mm
7mm
COVER PLATE
·002" MICA
MOUTH IRIS
THROAT IRIS
4·6"
4·3"
2·5
1·1 cm

FIG. 8

dimensions $a' \times b'$. The most suitable dimensions for the resonant window were obtained by trial and error and with such a window, the overall match of the horn was $<1{\cdot}03$ VSWR from 1,780 Mc/s-2,300 Mc/s as shown in Fig. 10.

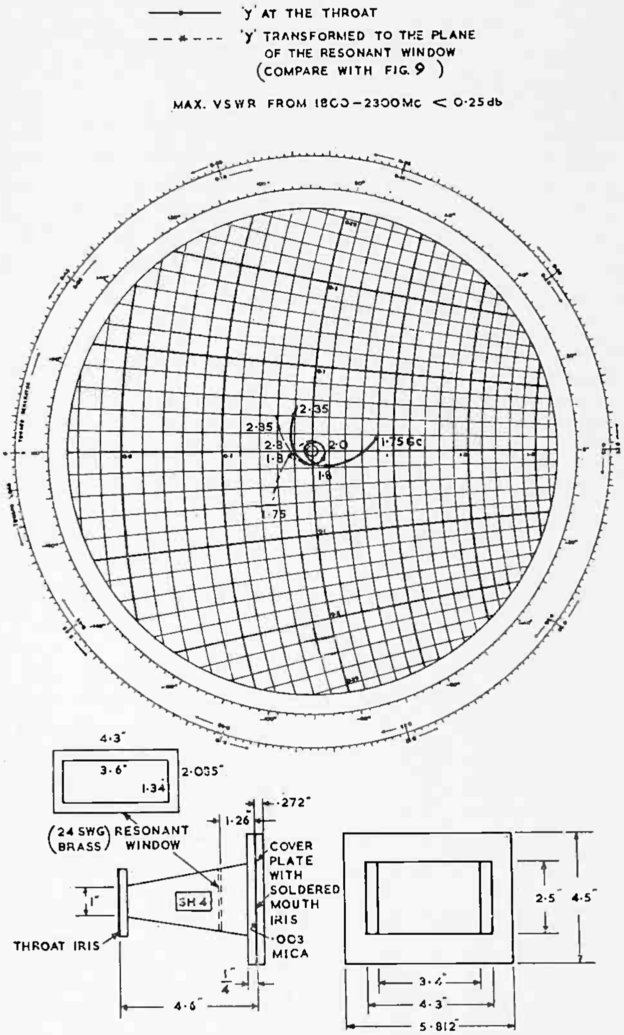



FIG. 10

## The Waveguide Feeder

The term feeder in what follows is used in rather a restricted sense and refers only to that section of waveguide running from the bottom of the reflector to the primary feed. For this feeder, it was decided to use a narrow waveguide of cross-section 4·3 inch × 1 inch (which has since been accepted as an additional standard for the 2,000 Mc/s band) in order to reduce the obstruction in front of the dish caused by the waveguide. Initial tests were carried out with horizontal polarization for the aerial, and the feeder ran vertically up with the narrow side facing the dish. The feed horn was connected to the feeder through a 90° H plane circular bend of 12 inch mean radius. A later improvement was to mount the feed horn in such a manner as to make the aerial polarization at an angle of 45° to the horizontal. By this arrangement it would be possible to have the polarization of two adjacent aerials mutually perpendicular, thus eliminating interference between the two while keeping the horn feeder assembly practically identical (see Fig. 11). The rotation of the polarization was achieved by the use of a 45° E plane bend between the feeder and the 90° H bend. The length of waveguide feeder was still vertical but was mounted parallel to the vertical diameter of the dish instead of along the diameter. The asymmetry produced across the aperture of the dish by this layout was not found to be serious and so the difficulty of providing a rigid mounting for an inclined waveguide feeder could be avoided.

### Waveguide Bends

The design of the feeder system required the use of one 90° H plane bend and one 45° E plane bend and it was hoped to design the bends to have a VSWR of not more than 1·015 each, over the operating band. Circular bends of 12 inch and 9 inch radius were fabricated and the results of the tests may be summed up as follows:—

(1) 90° H plane bends of 12 inch mean radius yielded a VSWR of about 1·015 between 1,700-2,400 Mc/s, while the 9 inch radius bend covered the band above 1,900 Mc/s for the same VSWR.

(2) 90° E plane bends of 12 inch mean radius were in general worse than corresponding H bends, possibly due to distortions produced in the curved broadside wall of the bends.

(3) 45° E bends of 12 inch mean radius were similar to 90° bends in VSWR, and when the mechanical tolerances were kept within very close limits, the 45° E bend produced a VSWR of not more than 1·02 over the entire band.

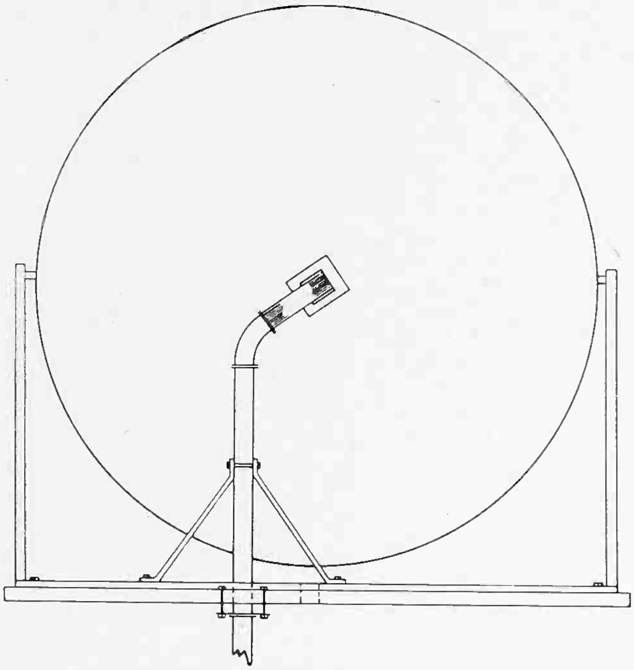


FIG. 11

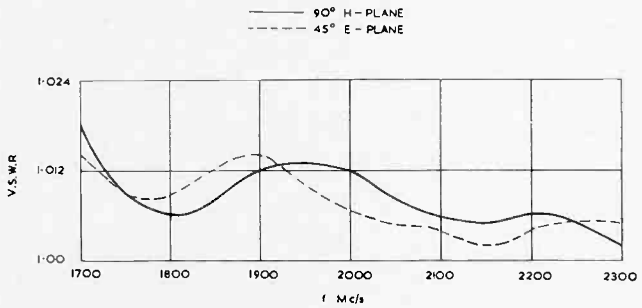



FIG. 12

A number of H and E bends were carefully tested and typical VSWR curves are given in Fig. 12.

Although the desired impedance characteristics could be achieved with 12 inch radius circular bends, they suffered from the disadvantage of being rather heavy and large. Double mitred bends and also a binomially stepped segmented E plane bend were tested, but finally the superior bandwidth characteristics of the circular bends outweighed other considerations.

### Flange Problems

One serious trouble which had to be tackled along with the design of the feeder system, especially when the aim was to get as low a VSWR as possible, was the problem of flanges. The difficulties encountered were contact trouble between flange faces and the problem of alignment of successive sections of waveguide to ensure repeatability of performance. The latter problem could be solved by enforcing very close tolerances in the cross-sectional dimensions of fabricated waveguide components and by using dowel pins and locating holes for all flanges. For long feeder runs " graded " waveguide was used, the different sections being assembled in the same order as they were drawn during manufacture so that aperture differences between successive waveguide lengths were minimized.

The solution of contact problems involved quite a number of systematic tests. To begin with the flanges were made ¾ inch thick to avoid buckling of the contact surfaces and the flange faces were machined to a high degree of flatness after soldering the flanges to the waveguide. Although this was acceptable in many cases, the presence of a groove in the flange face, housing a rubber ring for weatherproofing, tended to affect the contact around the waveguide periphery. The practice of using copper shims between flanges did not prove satisfactory owing to inconsistency of performance and also the need for having two rubber rings and one shim for each joint, which made it rather cumbersome for assembly on installation sites. The next step was to raise the flange surface immediately surrounding the waveguide aperture by about 0·001 inch in order to ensure good contact around the aperture. Copper plating, soft solder spraying and indium plating were tried and the most satisfactory results were obtained with indium. It was easy to apply a thin coating of indium over a small area surrounding the periphery of the aperture even on installation sites, and owing to the softness of the metal it produced almost a " cold weld " when the flanges were bolted together. The joint was rendered pressure-tight by inserting one moulded rubber ring between the pair of flanges, in a specially milled groove.

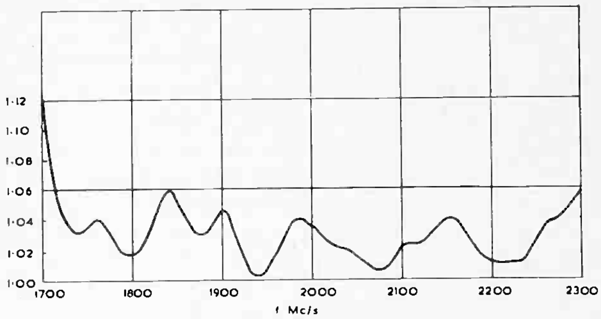


FIG. 13

Repeated measurements of the impedance match of the feeder assembly in its final form yielded a VSWR of less than 1·06 over 600 Mc/s when the horn was radiating in free space (Fig. 13).

As an experimental measure, the length of waveguide running from the feed horn to the fixture at the bottom of the aerial frame, comprising the 90° H bend and 45° E bend and a 6 foot length of straight waveguide, was " solid-formed " in one piece. This was achieved by bending a length of copper waveguide to the appropriate shape, thus avoiding the need for two pairs of flanges in this short length. However the problem of keeping the inside dimensions of the waveguide in bent sections was not easy to overcome, and two such solid-formed feeders were found to have a rather large discrepancy in dimensions, and poor impedance characteristics. The idea was abandoned because the VSWR obtained with these feeders were unacceptable.

## The Parabolic Reflector

The chosen reflector was a spun aluminium parabolic dish with an *f* number (focal length/diameter) of 0·25 and a nominal focal length of 70 cms. The theoretical maximum gain at 2,000 Mc/s for such a reflector, with the diameter of the physical aperture as 280 cms. (9 feet $2\frac{1}{4}$ inch) would be 35·4 db with respect to an isotropic source according to the relation

$$G_0 = \frac{4\pi.\text{Area}}{\lambda^2}$$

The choice of an $f$ number of 0·25, although it made the design of the feed horn to give a 10 db beamwidth of $\pm 90°$ rather difficult, had the advantage of reducing the cross talk between adjacent aerials and also the back lobe. Another favourable point was that the waveguide feeder would be close to the dish, thus simplifying the mechanical fixing of the feeder for the front-fed dish.

The spun aluminium dish was claimed to have a mechanical tolerance of $\pm \frac{1}{16}$ inch with respect to the true parabola and the ribs at the back of the dish offered convenient means of mounting the dish on to a framework without causing distortions to the profile. The aerial was mounted on a temporary frame and turntable about 25 feet above ground level to facilitate measurements of radiation pattern, gain and impedance characteristics.

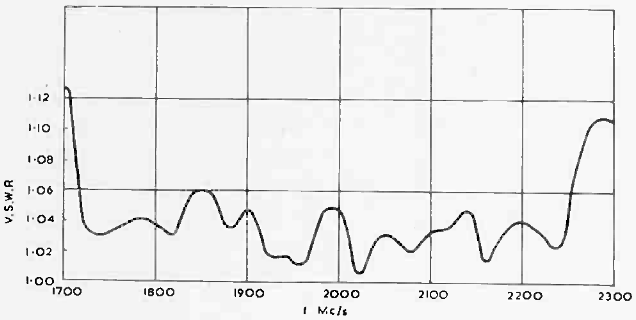



FIG. 14

## Reflection Cancellation

When a paraboloid is illuminated by a feed horn placed on its axis, the dish itself presents an obstacle to the radiation pattern of the horn and some of the radiated energy is reflected from the apex zone of the paraboloid back into the horn. This considerably modifies the impedance characteristics of the feed system to be different from free space conditions and the input impedance of the feed varies rapidly with frequency. It has been established(4) that this harmful effect can be overcome if it is possible to make the waves reflected back into the horn from the apex region of the paraboloid to be of opposite phase to those waves reflected from the surrounding regions so that they cancel each other at the horn. This can be accomplished by shifting a certain portion of the apex zone closer to the feed horn by a small distance, such that the net effect of all the waves reflected back into the horn is mutual cancellation. In practice, a vertex plate of suitable size and thickness is fixed to the apex region of the paraboloid and the dimensions of this plate, together with its distance from the reflector are varied to yield the optimum impedance characteristics for the aerial. In general, adjustment of the distance of the feed horn from the dish is also necessary.

While the vertex plate technique improves the impedance match of the aerial, it also results in increased side lobe levels in the secondary pattern, and a slight broadening of the main beam. However, the amount of deterioration of the secondary pattern will also be governed by the position and size of the vertex plate and a compromise can be reached between increased side lobe levels and poor mismatch of the aerial.

The size and shape of the vertex plate are still very much a matter of experimental study. For this experimental aerial, a metal plate of the same curvature as the apex of the parabolic reflector, but cut in the shape of a rectangle (side ratio similar to aperture of horn) was fixed over the apex region of the dish by means of adjustable screws. For various sizes of the plate, coupled with varied spacing from the main dish, the impedance match and the side lobe levels of the aerial were measured and the best compromise was chosen. It should be noted that the position of the feed horn had also to be adjusted to make the effective centre of feed lie on the effective focus of the paraboloid. Fig. 14 shows the VSWR for the complete aerial matched with the vertex plate.

The Appendix shows the influence of the vertex plate on impedance match, side lobe level and gain of the aerial.

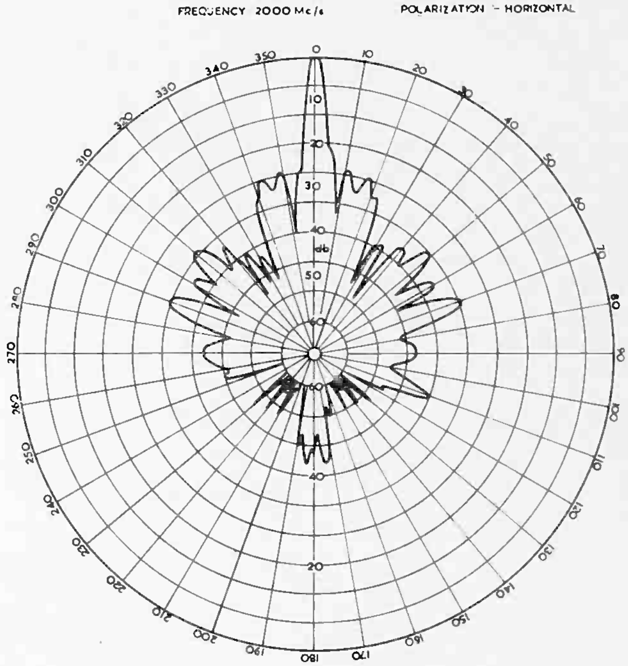



FIG. 15

**Radiation Pattern**

The secondary pattern of the complete aerial was measured by receiving a signal from a distant transmitter and comparing the relative received levels using a sensitive microwave superhetrodyne receiver with a calibrated attenuator chain in the I.F. stage. For polar diagram measurements the minimum distance between transmitter and receiver antennae is governed by the Fraunhofer region and a distance of about 400 feet between the two antennae was desirable. In order to overcome the difficulty of finding such a long range without obstruction, the path was effectively folded by the use of a passive reflector which was illuminated by the transmitter antenna and produced a beam along the axis of the paraboloid under investigation. The paraboloid was mounted on a turntable with its axis about 25 feet above ground level, special care being taken to ensure that the axis of the paraboloid was perpendicular to the axis of the turntable and that the beam received from the passive reflector was along the axis of the paraboloid.

A six foot length of waveguide feeder with the waveguide horn was fixed to the rim of the reflector and the receiver was connected to the aerial by means of flexible coaxial cable, so that the aerial could be rotated through $\pm$ 180° without trouble. Horizontal plane radiation pattern was obtained for various conditions, namely, (a) without and with vertex plate, (b) with the waveguide feeder placed along the diameter of the dish and (c) with the waveguide feeder offset parallel to the vertical diameter by the inclusion of a 45° E bend, for reasons discussed above. Typical radiation patterns obtained for cases (b) and (c) are shown in Figs. 15 and 16

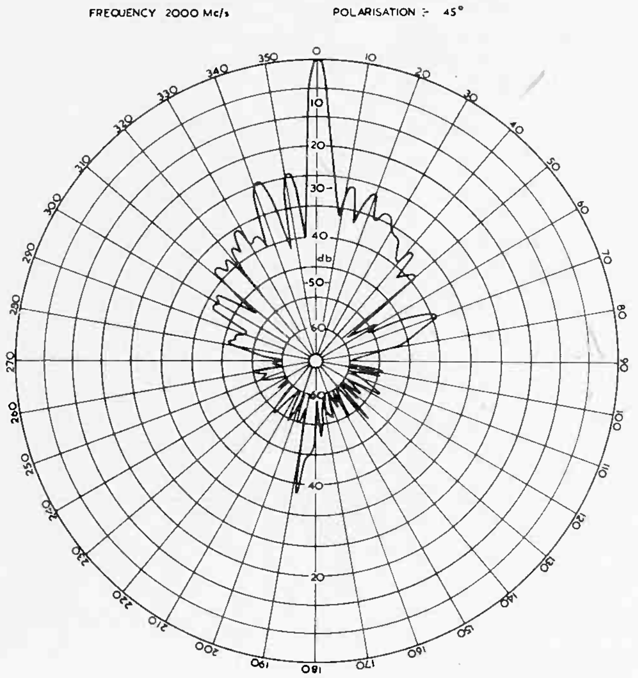



FIG. 16

and it can be seen that the first side lobe levels are 26 db below the main lobe, which has a 3 db beamwidth of 4°. The rather large back lobe is to be attributed to large metallic obstacles present in that direction.

## Gain

The gain of the 10 foot reflector was measured using the same transmitter as above and utilizing a standard horn of known gain as comparison. A pyramidal horn, with a calculated gain of 15·8 db was mounted alongside the paraboloid, with the two axes parallel to each other, along the transmitter beam. The received output of the horn and the aerial under test were connected alternately to the microwave receiver, using the same flexible coaxial feeder and the extra gain of the aerial over that of the horn was thus determined. Taking the mean of a number of readings at 2,000 Mc/s the gain of the parabolic aerial over an isotropic source was found to be 32·8 db, as compared to the maximum possible value of 35·4 db, showing an aperture efficiency of 55%.

## Mechanical Assembly

The aerial (Fig. 17) is normally mounted in an angle iron framework, which may be supported on a tower. The waveguide feeder is rigidly fixed to the bottom of this framework in such a way that the clamping arrangements present little obstruction in front of the reflector aperture. Particular care must be taken that the waveguide is not distorted by undue pressure on it from clamping bolts. Means are provided for adjusting, on site, the position of the feed horn with respect to the reflector according to design specifications. The final alignment of the aerial on its true bearing can be accomplished by means of two independent screw drives, one tilting the reflector through a small angle for elevation adjustments and the other swinging the framework for azimuth adjustments. It must be pointed out that the reflector is supported at its rim and that the pivots for vertical and horizontal tilting are in the plane of the aperture which also contains the focus of the paraboloid, with the result that tilting the dish through a small angle for final alignment still keeps the feed centred at the focus. The reflector is rigidly fixed after final alignment such that the adjustments are not disturbed by wind.

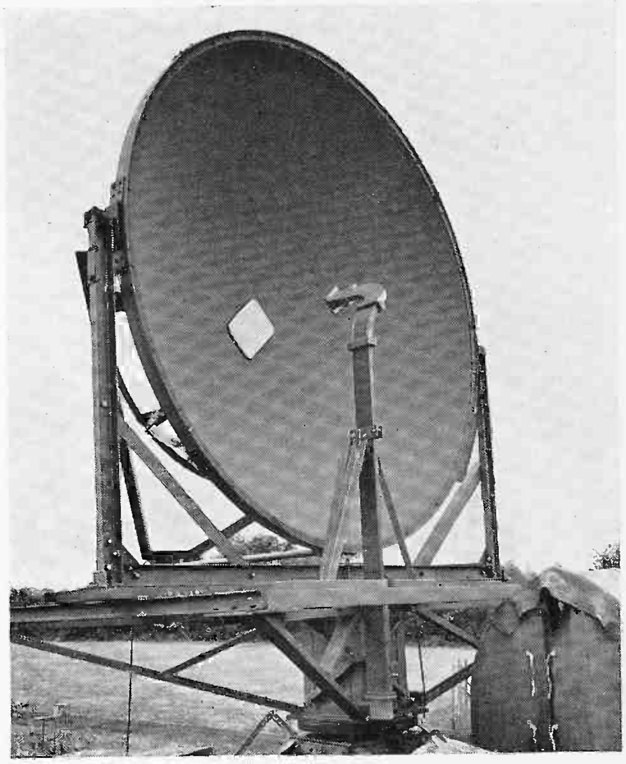


FIG. 17

The waveguide feeder system is pressurized with nitrogen for protection against moisture.

## Conclusion

The design and performance of the experimental aerial have been outlined above and 10 foot paraboloids of this design have been successfully used for an experimental microwave link in the 2,000 Mc/s band. The input VSWR for the paraboloid with the horn and associated waveguide feeder have been kept below 1·06 over a 550 Mc/s wide band, and below 1·1 over 600 Mc/s. A gain of 32·8 db (over an isotropic source) has been measured, showing an aperture efficiency of 55% and the side lobe levels have been kept to 26 db below the main lobe.

## Acknowledgments

Acknowledgments are due to those members of the Microwave Links Section of the Marconi Research & Development Groups who participated in the work described above.

## References

(1) Microwave Antenna theory and design. Silver, R.L. Series, Vol. 12, p. 347.
(2) Microwave Antenna theory and design. Silver, R.L. Series, Vol. 12, p. 364.
(3) L. Lewin, "Wireless Engineer," Vol. 26, 1949, p. 258.
(4) Microwave Antenna theory and design. Silver, R.L. Series, Vol. 12, p. 442.

## APPENDIX

### The Effect of a Vertex Plate

The effect of varying the size, shape and position of the vertex plate in respect to the reflector and feed horn on the Impedance Match, Side Lobe Levels of Radiation Pattern and Gain are shown in Figs. 18 to 25 which, taken with their captions, are self-explanatory.

Figs. 18 to 22 inclusive deal with the Impedance Match and show the effect on the VSWR with the inclusion of a vertex plate; varying the size and shape of a vertex plate; and finally varying the position of the vertex plate and the feed horn, relative to the reflector.

Figs. 23 and 24 show the result of including a vertex plate and the effect of varying the position of the feed horn relative to the reflector and vertex plate, on the first side lobe levels of the radiation pattern.

Finally Fig. 25 gives the gain curves, with and without a vertex plate, for various positions of the feed horn relative to the reflector.

### Impedance Match

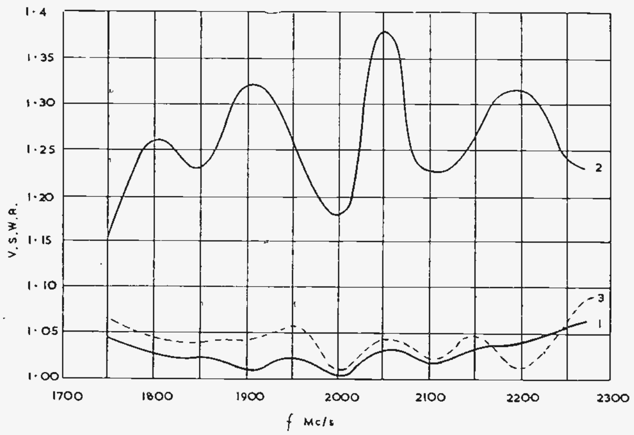



FIG. 18

*The VSWR of a typical feed system—*

1. *Measured when radiating into free space.*
2. *Measured when mounted in front of a paraboloid WITHOUT a vertex plate.*
3. *Measured when mounted in front of a paraboloid WITH a vertex plate.*

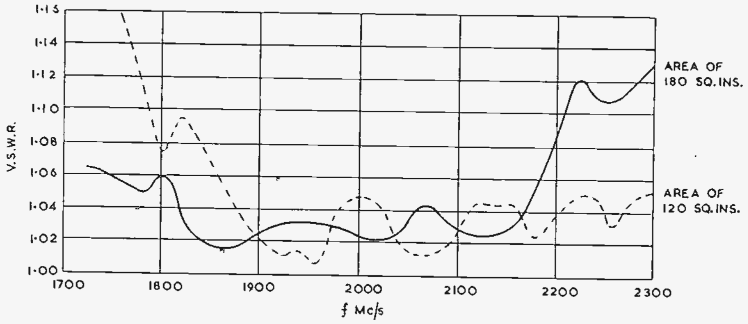



FIG. 19

*The effect of different sizes of vertex plate on the VSWR—bandwidth.*

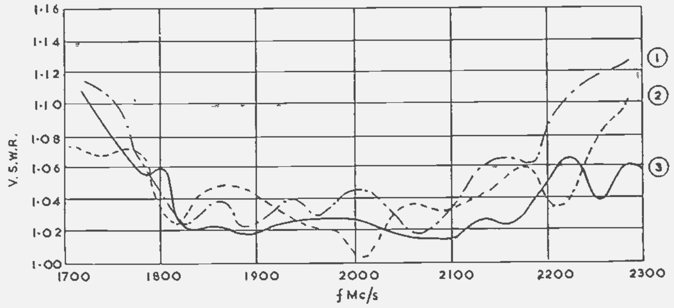
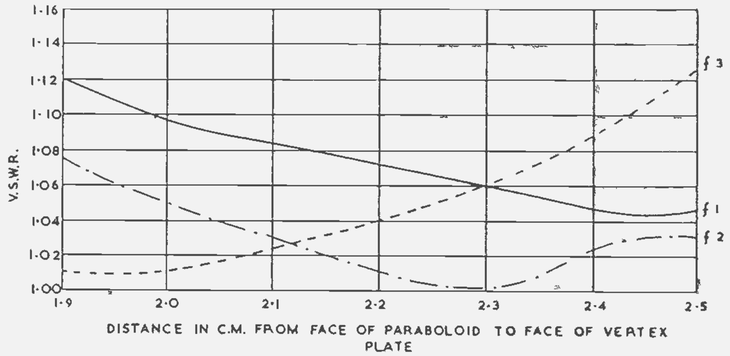



FIG. 20

*The effect on the VSWR—bandwidth with different shapes of vertex plates with approximately the same surface area.*

1. *Square vertex plate.*
2. *Round vertex plate.*
3. *Rectangular vertex plate.*



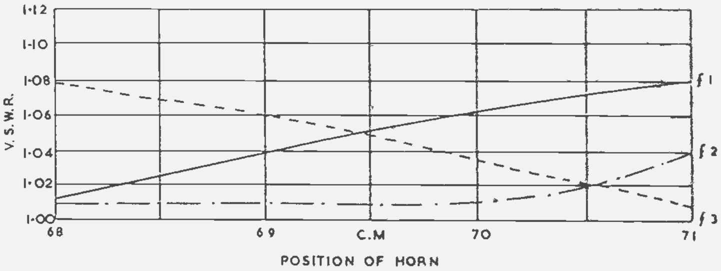

f1 = 1,800 Mc/s f2 = 2,000 Mc/s f3 = 2,240 Mc/s

FIG. 21

*The effect of the position of the vertex plate, at three fixed frequencies, for a fixed feed horn.*

FIG. 22

*The effect of the position of the feed horn in front of the paraboloid, at three fixed frequencies, with a fixed vertex plate.*




f1 = 1,780 Mc/s f2 = 2000 Mc/s f3 = 2,180 Mc/s

## Side Lobe Levels of Radiation Pattern

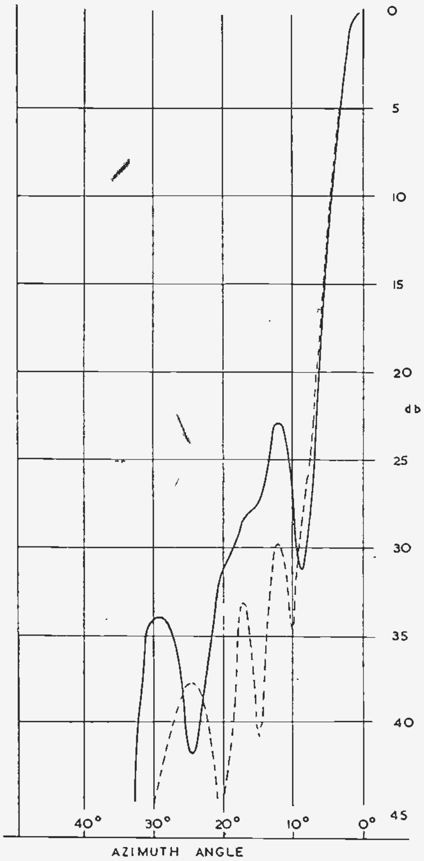



FIG. 23 *(right)*

*Typical effect of increased side lobe levels when a vertex plate is included.*

*Parabolic dish without a vertex plate. (Dotted line.)*

*With a vertex plate included. (Full line.)*

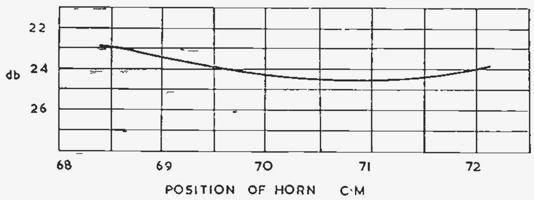



FIG. 24

*The effect on the side lobe levels of varying positions of the feed horn. The azimuth angle of the apex of the first side lobe remaining constant at 12°.*

## Gain

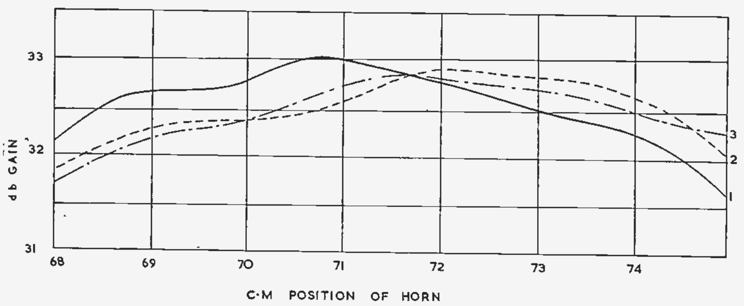



FIG. 25

*Typical gain curves of*

1. *Paraboloid without a vertex plate.*
2. *Paraboloid with a rectangular vertex plate.*
3. *Paraboloid with a round vertex plate showing the position of feed horn for maximum gain.*

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