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THE MARCONI REVIEW

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QUARTZ RESONATOR SERVO

A NEW FREQUENCY STANDARD

By Norman Lea, B.Sc., M.I.Mech.E., M.I.E.E.

A single-frequency amplitude-comparison servo associated with a Quartz Resonator is described.

It is shown that a single Quartz Resonator may be used both for initial stabilization by the balance of phases in a resonant loop and secondly for servo elimination of all major instabilities associated with the thermionic negative resistance.

Some preliminary experimental results show that applied frequency errors up to 10^{-7} *are reduced to about* 10^{-10} *by servo action.*

Introduction

IN the most common form of electro-magnetic oscillator, the frequency adjusts itself until a summation of the phase angles of all the components in a resonant circuit is zero.

As a consequence of this, the stability of frequency depends upon the phase stability of each component to an equal extent.

The circuit of such an oscillator falls naturally into two main parts, firstly the Resonator which consists effectively of L, C and R in series, and secondly an electronic system which behaves essentially as a negative resistance of magnitude R. Modern skill has enabled some resonators (particularly of the piezo-electric type) to be made extremely stable in phase, but, even with all known precautions, we are not able to construct electronic systems to give negative resistances of adequate phase stability.

In general, the reactance instability of a practical negative resistance is roughly proportional to its magnitude, which explains why an oscillator using a resonator of small R (that is high Q value) has good frequency stability. Even when the Q is high, for example 1 million, the demands on the phase-stability of the negative resistance are severe. For example, in order to take full advantage of the stability of a quartz resonator in a Frequency Standard, we would like the frequency instability due to the " negative resistance " alone to be no more than say 10^{-11}.

This would limit the phase-instability of the negative resistance to 2×10^{-5} radians, a figure which is unattainable when using existing thermionic valves or transistors.

The phase-instability of an electronic negative resistance depends mainly upon valve geometry, space-charge capacitances, complex cathode inter-face impedances, and transit-time delays. The prospect of reducing the total of these effects by a factor of 1,000 seems remote indeed, hence a new approach is essential if a notable advance is to be made in high-stability oscillator design.

The present article deals with frequency control by amplitude-sampling of signals in systems containing quartz resonators.

Amplitude Sampling Methods

In order to avoid the errors due to the phase-instabilities of thermionic systems, the principle of amplitude comparison can be used to indicate the relation between signals and resonator responses.

Such a method usually involves a system of detection capable of indicating departures from equal amplitude of response of a resonator to two frequencies, or of two resonators to a single frequency.

Two-frequency Methods

The use of two frequencies, one on either side of the centre of resonator response, is not ideal because it means that these must be of exactly equal amplitude before being impressed upon the resonator. Such a plan also is apt to involve violent transients in the resonator operating conditions.

The production of two accurately related frequencies by a modulation process is easy, but the heavy attenuation of the unwanted closely-spaced carrier and side-band is difficult, especially when high stability of level is needed for the wanted sideband. The use of two frequencies which are not co-existent (like those of an FSK signal) is not attractive, in spite of the elimination of the filtering problem, because we usually do not wish the controlled source to be frequency modulated.

An example of the two-frequency method was described by R. V. Pound in *Review of Scientific Instruments*, Vol. 17, November 1946. A number of variants of Pound's general scheme have been used since that date and it appears that they are not free from difficulties.

Two-resonator Methods

In the *Marconi Review*, No. 6, March 1929, a wavemeter due to C. S. Franklin was described. The frequency resolution of this instrument was made high by the use of (effectively) two resonators in association with a common amplitude detector. A single input frequency was used.

The objection to this plan for a single-frequency scheme is that it is more difficult to make two resonators of high stability than one. Franklin overcame this to a large extent by making the second resonator merely a minor modification of the first, that is to say reactance modulation was applied by the repeated manipulation of a switch. There is however a strong feeling that if we take a great deal of care to set up a resonator of the highest possible stability, it is wise to leave it undisturbed as much as possible.

Single-Frequency Single-Resonator Amplitude Sampling

Fig. 1 illustrates a method whereby the relation of a single frequency f to the characteristics of a single resonator LCR may be detected.

The figure involves a bridge arrangement which is operated (substantially at resistance balance by adjustment of R_1, R_2 and R_3 to suit R) at a condition alternately on either side of reactance balance by the inclusion of what may be called modulating reactances $\pm X$ and $\mp X$ in the right-hand arms. If the frequency f is accurately adjusted to resonance with LC, it is clear that values of $+X$ and $-X$ in the upper and lower bridge arms respectively will give an equal amplitude in the detector D to that given by $-X$ and $+X$ in the respective arms. It follows that a departure from equal amplitudes will indicate a departure from resonance and that simple servo arrangements may be set up to eliminate the departure.

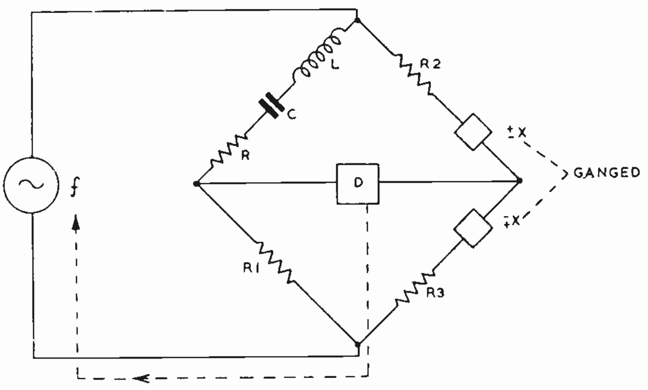


FIG. 1

The modulating reactances X may be produced in a number of ways, but it is preferable to make the change in the upper arm complementary to the change in the lower arm so that the total reactance in the right-hand branch is constant and near zero, for in this way departures from steady-state conditions in the resonator are avoided.

The reactance X may be a square-wave, sine-wave, or other convenient function of time. The detector D is arranged to be sensitive only to differences in amplitude at opposite phases of the modulation that is to say is made sensitive only to the modulation frequency itself. The output of the detector is arranged to provide a servo correction to the frequency f.

It is clear that no error can be introduced into the servo by changes in sensitivity or frequency response of the detector.

As there are no thermionic or other unstable devices in any bridge arm, the frequency of bridge-balance will depend to a high degree of accuracy on the LC product of the resonator LCR.

There is no special difficulty about the stability of the modulating reactance X, because X need be no larger than is required to give a reasonable servo signal. For example a value X corresponding to a frequency change of 10^{-8} is adequate for servo purposes even though the intrinsic instability of f is as much as 10^{-7}. In such a case a $0{\cdot}1\%$ instability of X will introduce a servo error no greater than 10^{-11}.

The source of frequency f in Fig. 1 may be a crystal oscillator with the usual amplifier, buffer, and AGC systems, but an interesting possibility of a simpler kind will now be discussed.

Frequency Stabilization by Simultaneous Phase-Balance and Amplitude-Sampling

It is clear that in the system of Fig. 1, the intrinsic frequency stability of the source *f* must be good enough to maintain a desired constancy during the time needed for the servo to eliminate the more slowly changing errors. If the servo correction is made more rapid, the source *f* need not be so stable.

For medium rates of correction, for example by two-phase motor, it is possible to obtain good performance by using merely an electronic negative resistance for the source.

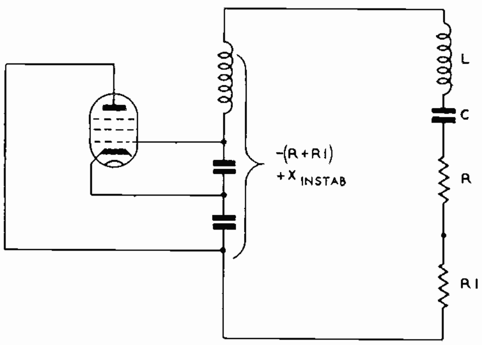


FIG. 2

If the right-hand arms of the bridge are made to have high impedances compared with the left-hand arms, the input impedance, of the bridge will be essentially that of a series resonator, so that good initial stabilization of frequency can be obtained even if the source *f* consists merely of a negative resistance.

A near approach to such an arrangement is shown in Fig. 2 where initial stabilization depends upon a Q-value of

$$\frac{\omega L}{R+R_1}.$$

If the bridge has equal resistance for the upper and lower arms, the initial stabilization is degraded only by a factor of 2 from that which would be obtained by using the high-Q resonator LCR.

Having achieved initial stabilization as in Fig. 2, servo correction by amplitude-sampling can be added in the manner of Fig. 3.

The impedances of the RH arms are made large compared with those of the LH arms, but not so large as to cause trouble with thermal noise in the detector D.

The servo-operated reactance X will clearly balance out all components of X_{instab}, subject to servo time delay and subject to the amplitude difference in the detector being not confused by noise.

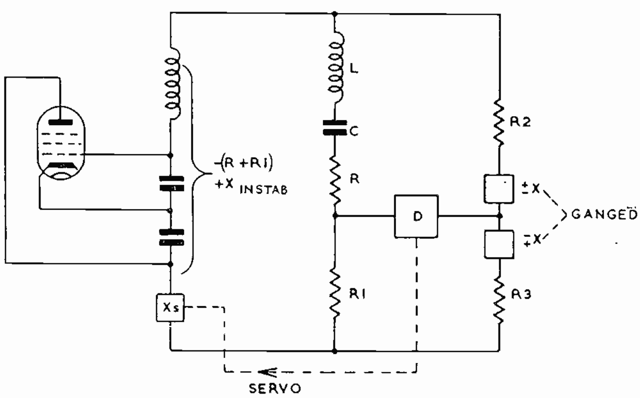


FIG. 3

If the supply voltages to the valves are well stabilized and reasonable precautions are taken against microphony and " hum " the components of X_{instab}, are essentially all within the correction rates obtainable by the servo.

The dual method of frequency stabilization illustrated by Fig. 3 is therefore of considerable interest and it has been explored in a preliminary way experimentally as now to be described.

Experimental Dual Stabilization

(5 *Mc/s Resonator with Sampling at* 75 *c/s*)

As the principle of Fig. 3 is likely to be useful in extending the accuracy obtainable from Marconi Precision Quartz Crystals of 5·0 Mc/s, it was decided to set-up a rough embodiment of Fig. 3 using a 5·0 Mc/s crystal.

After eliminating most of the difficulties which were to be expected in a roughly arranged bridge operating at 5 Mc/s, the experimental circuitry became as in Fig. 4.* This figure is largely self explanatory but attention may usefully be directed to certain points.

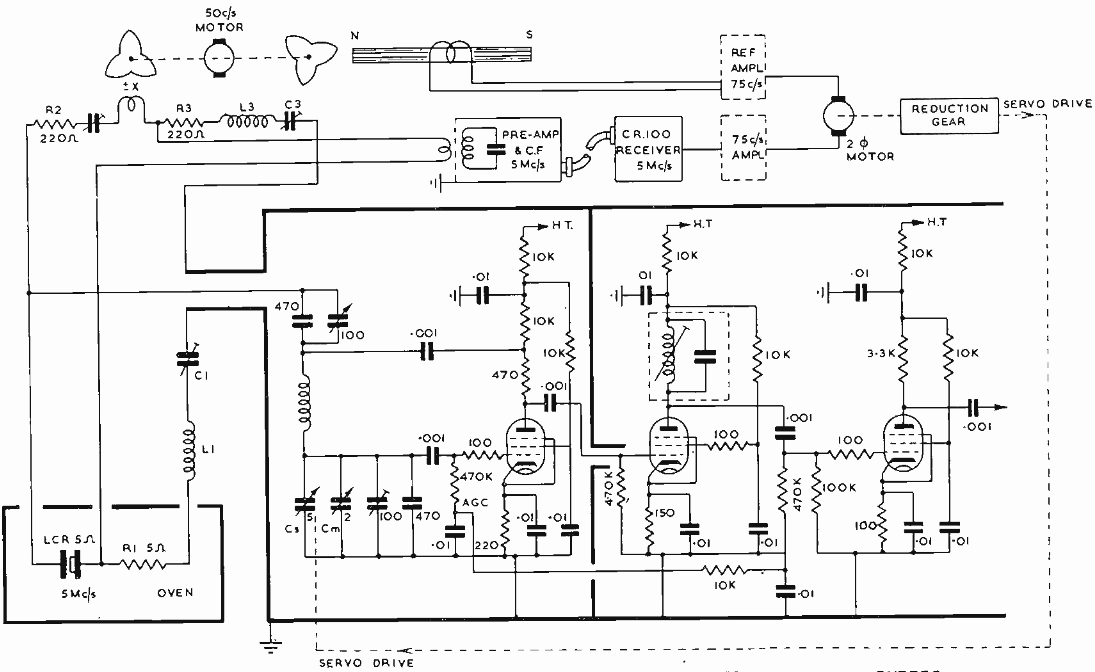


FIG. 4

With the low-impedance bridge arms used, the uncertainties due to earthing one side of the bridge input were not of serious consequence. This was fortunate because an "ideal" transformer capable of transferring the series-resonant characteristic of L, C, $(R+R_1)$ is not easy to devise.

For preliminary tests, it seemed quite satisfactory to disregard the thermal instabilities of R_2, R_3 and the modulated reactance X, so the only components of the whole system maintained at constant temperature were LCR and R_1.

In order to minimize difficulties due to unwanted 50-cycle modulation and 50-cycle hum the reactance modulation was carried out at 75c/s (sine wave).

Although some early tests were done with symmetrical complementary X modulation as indicated in Fig. 3, it was later thought simpler to apply symmetrical ($\pm$) modulation to one arm only as depicted in Fig. 4. A peak modulation of reactance corresponding to a frequency shift of 10^{-8} produced an actual frequency

*Note that for convenience the bridge has been drawn on its side as compared with fig. 3.

deviation of 10^{-10} and a 75-cycle sideband 107 dbs below carrier level, so these FM effects were of no serious consequence.

The use of L_1 C_1 and L_3 C_3 to give zero reactance in the bridge arms facilitated adjustments to known operating conditions. The capacitor C_2 was used to adjust the symmetry of modulation.

The sense of the servo correction was fixed by a two-phase motor, one winding of which was fed from a Reference Phase generator which was mounted on the same motor spindle as the modulating plate. The latter was made of copper and produced sinusoidal changes of inductance in a near-by coil.

The phase of the modulation was adjusted to allow for the phase shifts in the whole detecting system which latter consisted of RF preamplifier, cathode follower, Receiver type CR.100, selective 75 c/s amplifier and motor amplifier.

For the results now quoted, the AGC was set to give a level of about 0·1 volts RMS at the grid of the oscillator, which corresponds to a dissipation of about 12 μW in the crystal resonator. It is not yet known whether this is an optimum figure having regard to the extreme importance of stable quartz operation and the conflicting requirement of a good signal-noise ratio at the detector.

The level of signals at the anode of the amplifier was 6 volts RMS approximately, and at the anode of the buffer slightly more, so great precautions were needed to avoid leakage from these circuits into the RF bridge to an extent exceeding thermal noise.

Efforts in this direction were successful enough to obtain preliminary results, but it is evident that an investigation of the full accuracy of the servo system must await a fully screened and decoupled bridge and valve chain.

It was not thought worth while taking much notice of the long-time recordings of the arrangements of Fig. 4 against the best existing frequency standards, because the components L_1 C_1 and the whole of the right-hand bridge arms were outside the oven.

Experimental Results

Figs. 5, 6 and 7 indicate the effects on frequency resulting from manually applied changes of capacitance, HT, and LT voltages. The frequencies were measured against Oscillator 468 which probably had an instability of $\pm 1 \times 10^{-10}$ during the experiments. (Oscillator 468 is at present a prime component of the Marconi frequency standard installation).

Manual Change of Capacitance

Fig. 5 shows the frequency change with and without servo for a manual change of capacitor C_m of Fig. 4.

The change without servo is about 200×10^{-10}, whereas with servo it is less than 1×10^{-10}.

Change of H.T. (all R.F. valves)

Fig. 6 shows a frequency change of $+115 \times 10^{-10}$ for $+20\%$ H.T. without servo. This is in fair agreement with common experience for the type of crystal oscillator involved, using commercial valves.

With servo, the change is reduced to less than 1×10^{-10}.

Change of L.T. (all RF valves)

Fig. 7 indicates a non-servo frequency change -130×10^{-10} for an LT change from 5·0 to 6·0 volts. When the servo is made operative, the frequency change is less than 1×10^{-10} for the same LT change.

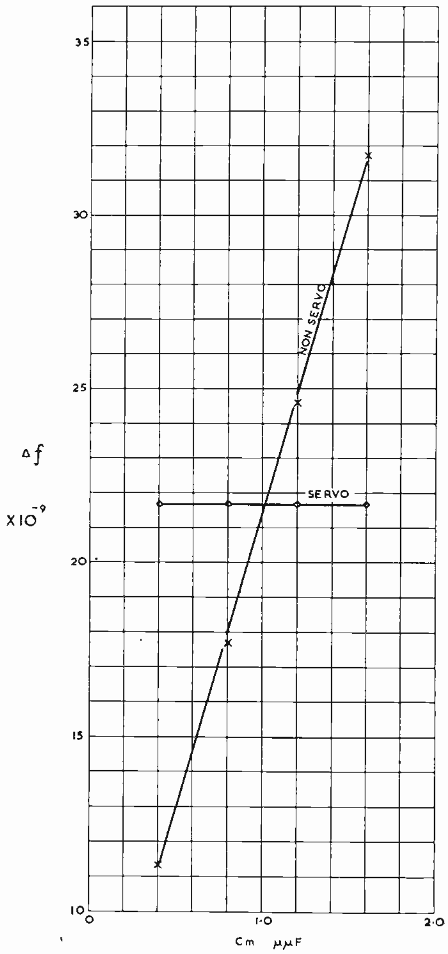


FIG. 5

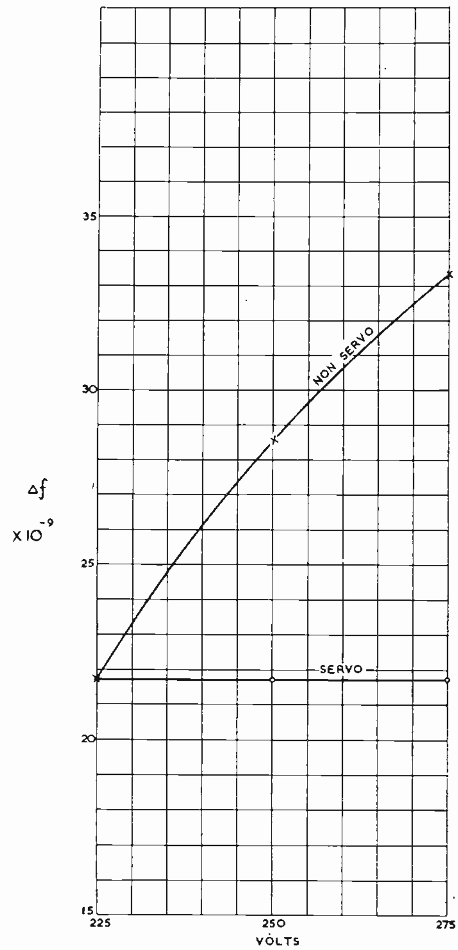


FIG. 6

Change of Oscillator valve

A total of seventeen valves all of CV.138 classification but of different makes and greatly differing histories were fitted in turn to the oscillator position of Fig. 4.

The resulting frequencies with and without servo are shown in Fig. 8. The valves are indicated by reference numbers at the foot of the Figure. Valve No. 1 was a comparatively new valve which happened to have been used in obtaining data for Figs. 5, 6 and 7.

Valves 2 to 15 inclusive were all old specimens which had been in continuous operation as oscillators or amplifiers for many thousands of hours. Some of them were rejects on account of serious cathode-interface impedance trouble.

Valves 20 and 21 were new as drawn from stores.

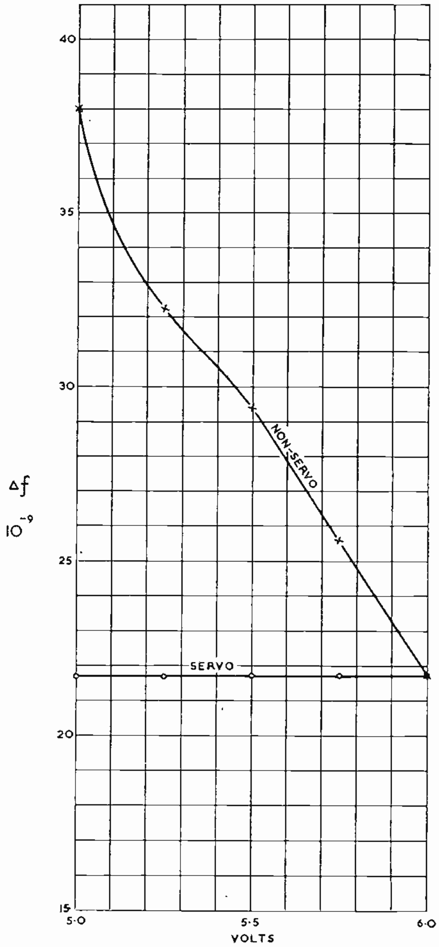


FIG. 7

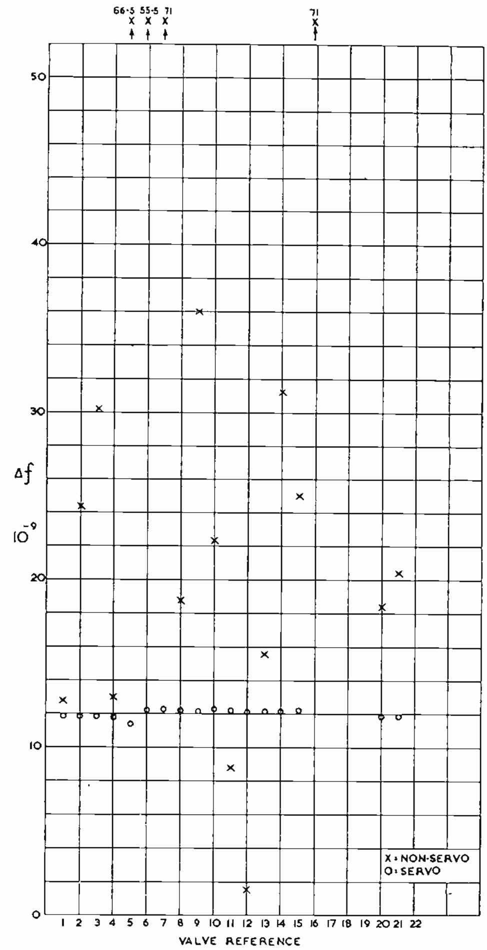


FIG. 8

It will be seen that the frequency range, without servo for all these valves is about 700×10^{-10}, whereas with servo the range is reduced to about 5×10^{-10}.

The reasons for incomplete servo correction are thought to be—

(1) Variations in the Standard of Reference (Oscillator 468) during the time of about $1\frac{1}{2}$ hours needed to carry out the tests. Variations of $\pm 2 \times 10^{-10}$ are possible.

(2) Residual unwanted coupling between RF bridge and the high level amplifier and buffer stages.
Some support for this is given by the figure for Valve No. 5 as this valve operated with an abnormal feed and AGC condition.

Change of Amplifier Valve

The miscellaneous collection of valves already used in the Oscillator position, were, with the exception of No. 1 valve, fitted in turn to the amplifier position.

Frequency checks with servo gave a total spread of 5×10^{-10}, which can be regarded as satisfactory in view of the fact that the amplifier results are subject to the same qualifications as are the oscillator results.

Conclusions

(1) The system of amplitude-sampling described has good prospects of eliminating more than 99% of the frequency instabilities due to valves and circuit components outside the bridge.

(2) The system of dual stabilization (same crystal resonator for both initial and servo control) appears to be entirely practicable.

(3) When using a 5 MC crystal and a sampling frequency of 75 c/s, the unintended frequency modulation is negligible for all immediate applications.
A rate of frequency correction of 10^{-9} per second is easily achieved.

(4) The existence of high-level 5 Mc/s signals adjacent to circuits which must operate down to " noise " levels at the same frequency, means that a full appreciation of system performance must await the construction of a properly engineered equipment.

(5) As the frequency stability possible with the new system is so much better than that available in present frequency standards, it is necessary to build several Quartz Servo Equipments in order to assess their performance.

(6) The construction of Quartz Servo Equipments appears to be fully justified even if the ultimate standard of frequency becomes (in some years time) a molecular or nuclear resonance. It seem likely that the Quartz Servo Equipment will be simpler and more convenient as a working standard for some time to come.

Acknowledgment

The author is indebted to his colleagues C. R. S. Ince and S. Demczynski for their enthusiastic support in carrying out the work described.

SOME EXPERIMENTS ON THE REFLECTING PROPERTIES OF METAL-TUBE LENS MEDIUM

By E. M. Wells, B.Sc.

A fully constrained refracting medium can be formed by stacking square, thin-walled wave-guide tubing. Experiments are described which were designed to show qualitatively the variation with angle of incidence of the reflection coefficient of such a medium. It is shown that the reflection coefficient is a function of polarisation. If the E-vector is normal to the plane of incidence, the tube walls parallel to this plane have negligible effect and metal-plate theory applies. If, however, the E-vector is in the plane of incidence, the constraint not present in the corresponding metal-plate case introduces a new phenomenon which to the writer's knowledge has not so far been recorded. Under certain conditions the reflection coefficient can approach unity. The limitations which this imposes on metal-tube lenses designed for wide-angle scanning is discussed in conjunction with experimental results on a lensed reflector. A possible means of overcoming the difficulty is suggested.

Introduction

It has been a logical development of the earlier metal plate lenses, especially at the shorter wavelengths, to interlace two such lenses with metal plates mutually perpendicular. Such lenses are not polarisation sensitive and are mechanically rigid.

Two forms of construction are open. One employs the egg-box principle, and the other the stacking of square thin-walled wave-guide tubing to achieve the same result. Working in the 8–10 mm. waveband, the Marconi Company have used the latter method and have constructed lenses of square copper tubes soft soldered together.

One of the lines of investigation has been the design of lenses capable of being used at high angles of scan, that is to say, optically speaking, lenses which have a large focal field. When a lens is fed from a scanning, as distinct from an on-axis, position, the angle between the wave normal and the normal to the lens surface is increased. It is therefore necessary to investigate the transmission properties of metal-tube medium when illuminated obliquely.

Previous Metal-plate Investigations

The theory of the metal-plate medium has been very completely covered by several Authors (at least for the ideal case of infinitely thin walls). The early work of Carlson and Heins(1)(2) provided expressions for the transmission and reflection coefficients of such a medium when the plane of incidence is normal to the plates. Later work has extended the subject to include angles of incidence at which secondary reflections are possible(3)(5)(6). Experimental corroboration of the theory has been forthcoming, some of which shows the effect of finite wall thickness(4)(7)(8).

If the plane of incidence is parallel to the plates, the theoretical problem is either trivial or covered by classical dielectric theory. Fig. 1 gives the key to the relative orientations of plates, plane of incidence, and plane of polarisation, involved in the complete study. It will be noted that in case B, although the medium has an effective refractive index, due to the plane of polarization being parallel to the plates, these same plates impose no constraint on the direction of propagation of energy inside the medium. On the other hand, in case D, there is no refractive index but there is constraint. In the case of the metal-plate medium, constraint and refractive index only occur together when the polarization is normal to the plane of incidence, as shown in case A.

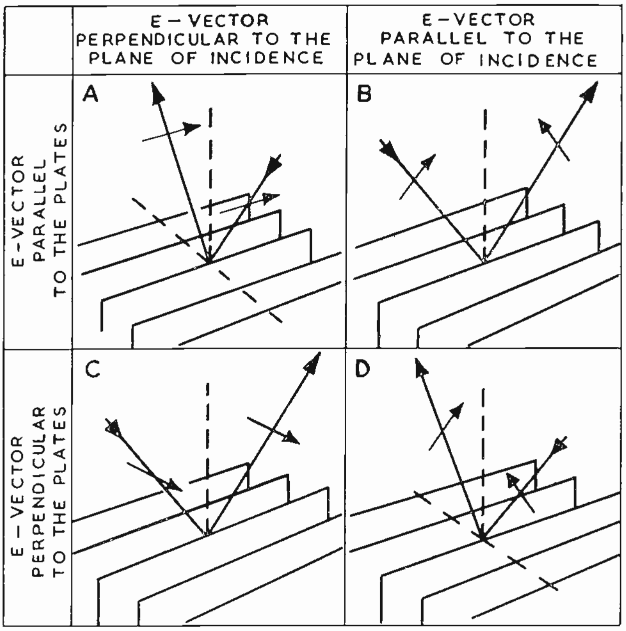


Fig. 1

Configurations involved in the study of metal-plate medium.

Substitution of metal-tube medium for metal-plate in Case A introduces no new factor. Metal-tube medium, however, also exhibits both refractive index and constraint when the E-vector is in the plane of incidence. It is therefore to be expected that classical dielectric theory no longer holds. In point of fact the greater part of the experimental work described in this article deals with the phenomena observed under these conditions.

Experimental Procedure

Before describing the experiments, it must be emphasized that the results obtained must be considered as qualitative only. Due to lack of available effort, no attempt was made to make the investigation exhaustive or quantitative, except in so far as was necessary to show the main features of observed phenomena. Where the ordinate of a curve has been labelled " Relative Power," it should be taken to mean " Relative Crystal Current." A rough microwave spectrometer was constructed as shown in the photograph, Fig. 2. The RF power from a millimetric oscillator was radiated by a small horn. This horn was at the focus of a six-inch diameter lens and is so dimensioned that substantially all the radiated power falls on the lens. The resultant beam illuminates the specimen of refractive medium under test. The distance between the transmitter and the specimen was four feet, and was chosen as being the shortest distance consistent with obtaining a substantially plane wave at the specimen, and also substantially all the power on it. The table for the latter was capable of rotation about a vertical axis. A small horn and receiving crystal were carried on the end of a four-foot arm which rotated about the same axis. Their purpose was to explore the angular positions and magnitudes of the beams reflected and/or transmitted by the specimen. The oscillator was modulated at 1,200 c/s, and the rectified output of the receiving crystal was amplified by a selective amplifier. The meter readings at the output of the second detector can be taken to be roughly proportional to received power.

The experimental procedure was to rotate the arm carrying the receiving feed horn until the latter was facing the transmitter. The radiated power and amplifier levels were adjusted to give a full-scale reading (100) on the meter. The specimen was then set on its table with its front face containing the axis of rotation, and with the angular scale reading zero when the front face was normal to the axis of the

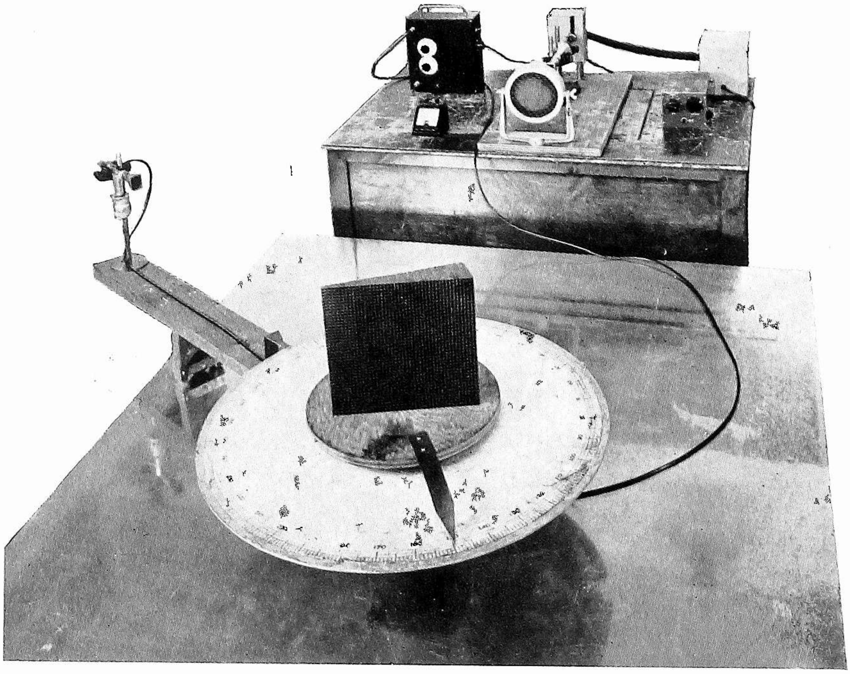


FIG. 2

Microwave Spectrometer.

transmitter. Geometrical tests assured proper alignment of transmitter, receiver, specimen and scale. Then with the specimen table set to give some particular angle of incidence, the receiver arm was rotated through the complete 360° to explore the magnitudes and angular positions of the beams reflected and/or transmitted by the specimen. If the specimen were a prism or wedge one would expect to see a beam transmitted through the prism, its angular position giving a measure of the refractive index; a beam reflected from the front face of the prism due to specular reflection; a beam reflected from the back face through the front face of the prism; and, if the grating spacing or angle of incidence or both were large enough, secondary maxima arising from all three of these causes.

Now at the range of four feet it may be considered to a first approximation that all the energy radiated by the transmitter is contained inside a hypothetical cylinder of six-inch diameter. If the edges of the specimen do not lie inside this cylinder, the angular distribution of energy in any of the above beams will owe nothing to the finite size of the specimen. Since the faces of the specimens in the results quoted were ten inches square, simple geometry shows that angles of incidence up to 50° may be used.

The meter reading at the peak of a specularly reflected beam may be taken as a measure of the power in that beam. For any other beam there is, strictly speaking, a correction due to projected areas, but no such correction has been applied. The quoted magnitudes merely refer to meter reading at the peak of the relevant beam.

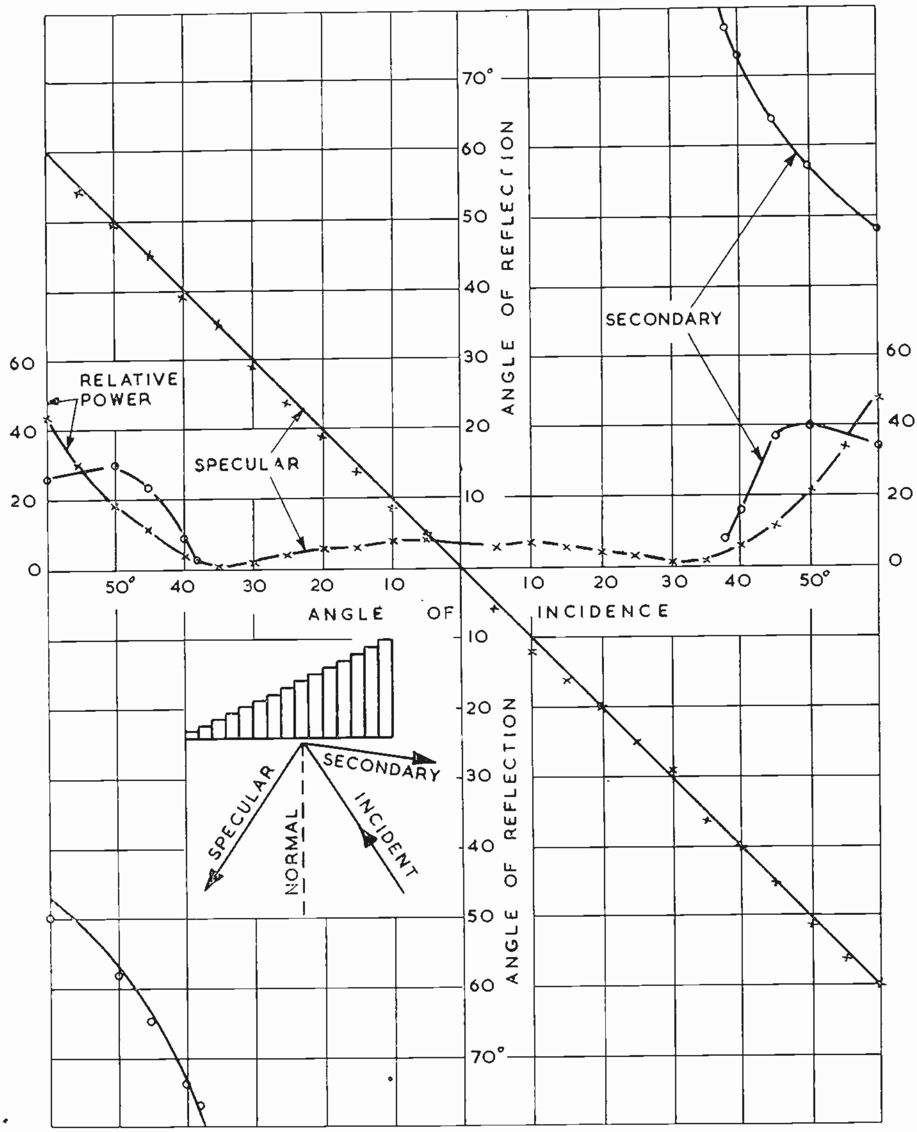


FIG. 3

Surface reflections from metal-tube medium. (E-vector normal to the plane of incidence).

Experimental Results

Using vertical polarisation, experiments may be performed which are very similar to previous work on metal-plate media(4).

Fig. 3 gives the results for a particular set of conditions. It will be noted that the power reflection coefficient of the metal-tube face shows the qualitative variation with angle of incidence that might be expected. The expected angular position of the secondary maxima was calculated from the distance between centres of adjacent tubes, and it will be seen that the observed angles are in close agreement. An analysis of this type of measurement is given by Cochrane.[4]

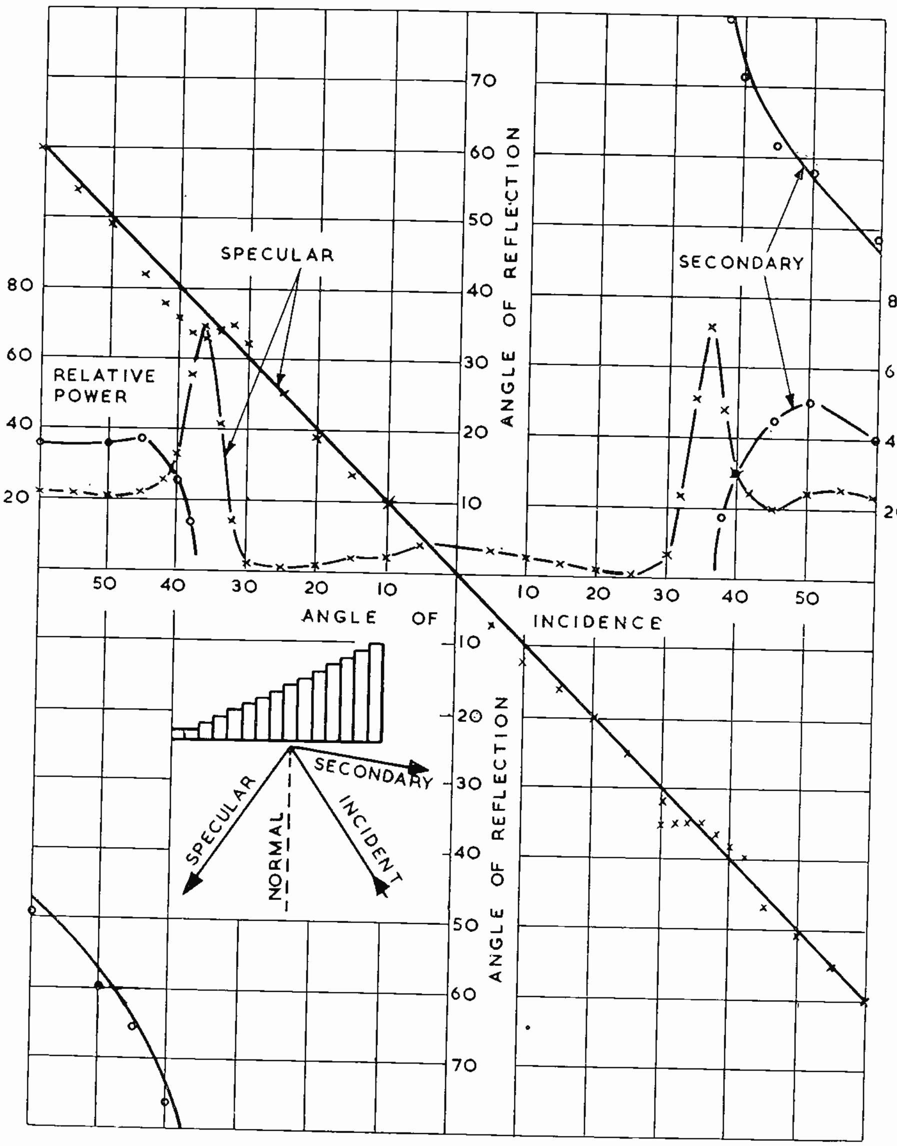


FIG. 4

Surface reflections from metal-tube medium. (E-vector parallel to the plane of incidence).

If the polarisation is rotated to lie in the plane of incidence, the curves show many points of resemblance (see Fig. 4), except in the neighbourhood of the angle of incidence for which secondary maxima are just beginning to emerge at grazing incidence. At this point there is a sharp increase in the total power reflected from the surface. This power appears as a beam in the neighbourhood of the specular reflection. There are, however, some points of non-resemblance with a specular reflection, if we define the latter as a reflection for which the angle of reflection equals the angle of incidence. In the first place the angle of reflection tends to

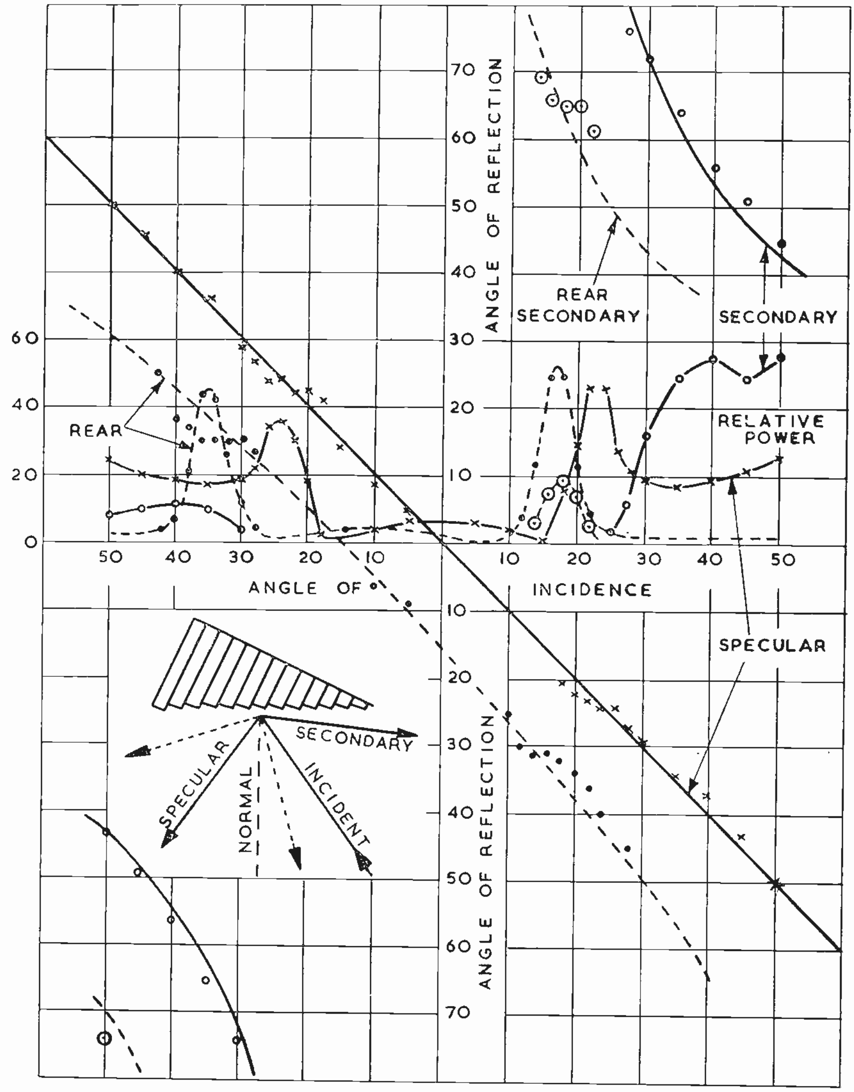


FIG. 5

Surface reflections from both faces of a prism. (E-vector parallel to the plane of incidence).

remain constant irrespective of the angle of incidence. Secondly there is evidence that the true specular reflection is masked by another of greater amplitude. In fact at those angles of incidence where this anomalous reflection has not attained its full amplitude there appear in some cases to be two separate beams. The one is specular having an angle of reflection equal to the angle of incidence, and the other having an angle of reflection equal to that angle of incidence for which this reflection has its greatest amplitude. From these points of difference we have called the anomalous reflection a " resonant " reflection.

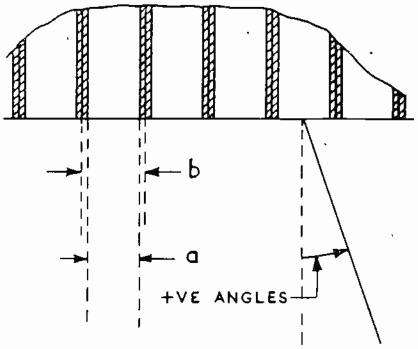


FIG. 6
Key to symbols.

The phenomenon may be observed on transmission out of, as well as into, the metal-tube medium. A particularly clear example of this was provided by illuminating the other face of the prism to that used in the previous two examples. In this case the front surface reflections show the same type of phenomenon, slightly assymetric with angle of incidence due to the obliquity of the tubes, and also with the resonant reflection of somewhat smaller amplitude. A set of specular, secondary and resonant reflections was now observed from the rear face of the prism as well. The pattern of these curves (shown dashed in Fig. 5) is displaced from the centre due to the double passage through the prism. Also the secondary maxima which owe their amplitudes to rear surface reflections, owe their angular position to the "grating spacing" for the front face.

The coincidence of the maximum of the resonant reflection with the angle of incidence for which a secondary maxima of the reflection is just grazing the surface was investigated further. In this later stage of the experiments the specimen was on occasion only six inches square. This did not appear to affect the angular position of the resonant reflection, nor, to a first order, its amplitude. The notation used is illustrated in Fig. 6, where it will be seen that *a* is the internal dimension of the square tubes and *b* is the centre-to-centre spacing of the walls. b/λ is thus the quantity previously referred to as the " grating spacing," and will be used as the abscissa for a graph of the theoretical angle of incidence for which a secondary maximum lies at grazing incidence (Fig. 7). Angles of incidence for maximum

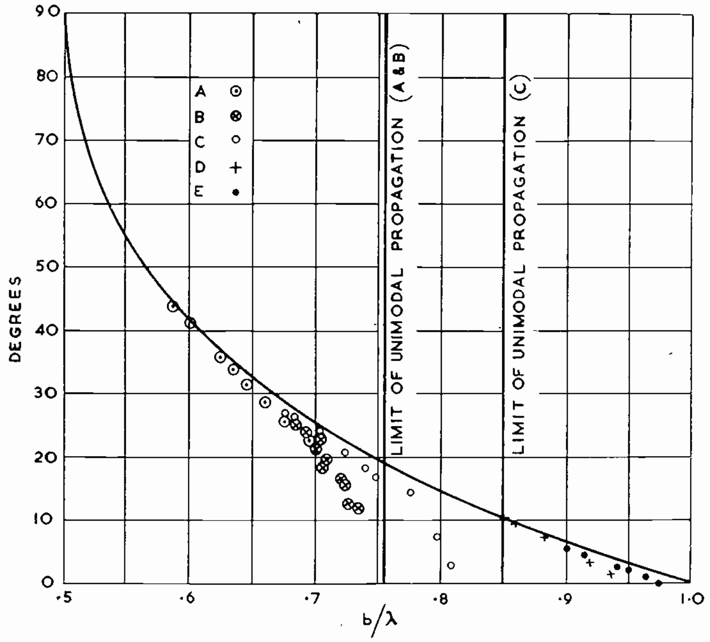


FIG. 7
Angular coincidence of " resonant " reflection and grazing secondary reflection.

resonant reflection are also plotted on this graph for several samples of metal-tube medium. In sample A, b/a=1·071 and in sample B,=b/a=1·068. It will be observed from Fig. 7 that the agreement between the plotted points and the curve becomes

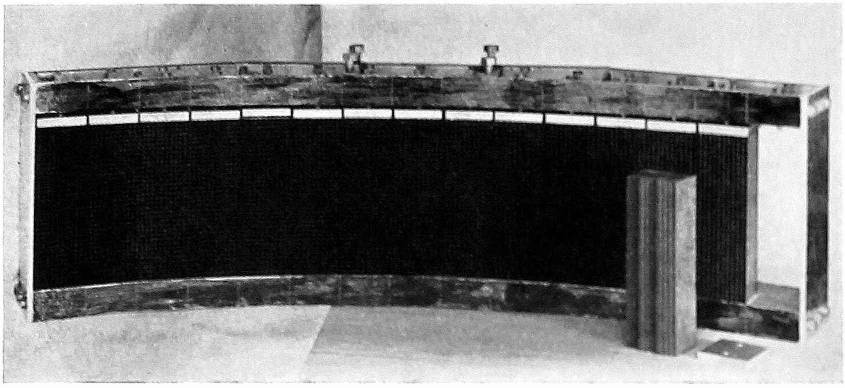


FIG. 8 (*a*)

Photograph of line-source reflector with one section removed and reversed to show stepped reflecting surface.

worse at shorter wavelengths. It was also noted that the amplitude of the resonant reflection became less, and in fact impossible to record at higher values of b λ than shown.

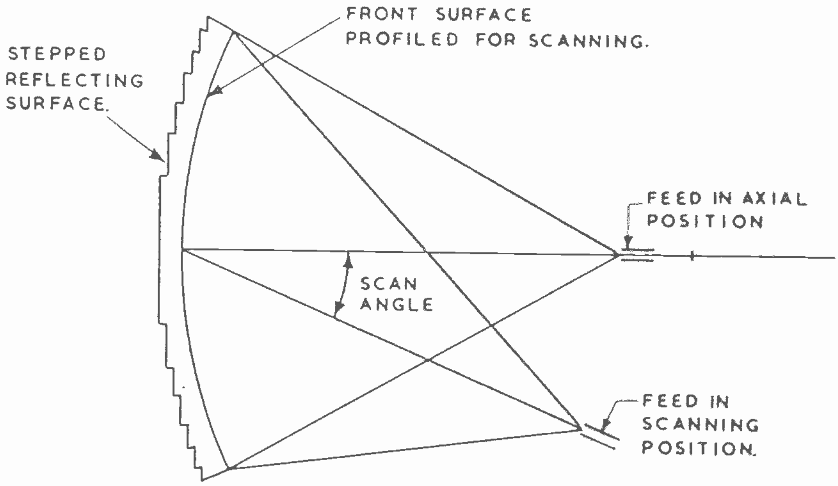


FIG. 8 (*b*)

Diagram showing method of feeding reflector.

Now for short wavelengths the square tubes are capable of sustaining more than one waveguide mode. The H_{11} and E_{11} become possible modes of propagation when a/λ is greater than ·707, that is to say for sample A when b/λ is greater than ·757, and for sample B when b/λ is greater than ·755. It is provocative to note that the

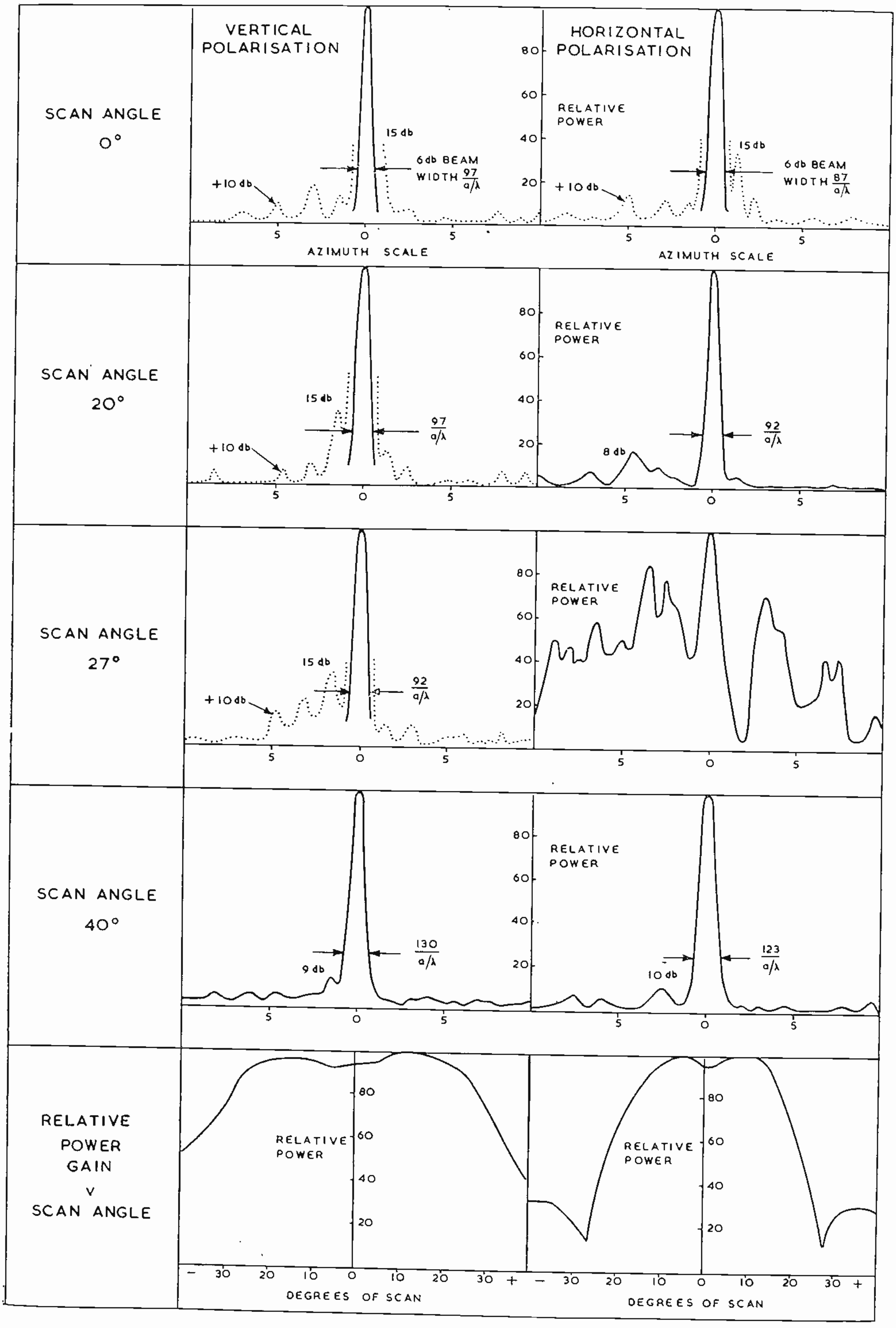


FIG. 9
Polar diagrams and gain curves for the reflector of Fig. 8.

points seem to follow a curve which is asymptotic to this value. To examine this coincidence further, media were constructed with other ratios of b/a. This was done by spacing the columns of square thin-walled tubes with brass strips, so increasing the wall thickness for the same value of a. Samples C, D, and E had b/a equal to 1·119, 1·664 and 1·960 respectively. The limiting values for unimodal propagation are therefore $b/\lambda = \cdot 848$, 1·176 and 1·386.

It will be noted that if the surface of the medium is illuminated obliquely with the polarisation in the plane of incidence, which is the situation in these last experiments, then there is a component of the E-vector normal to the face which

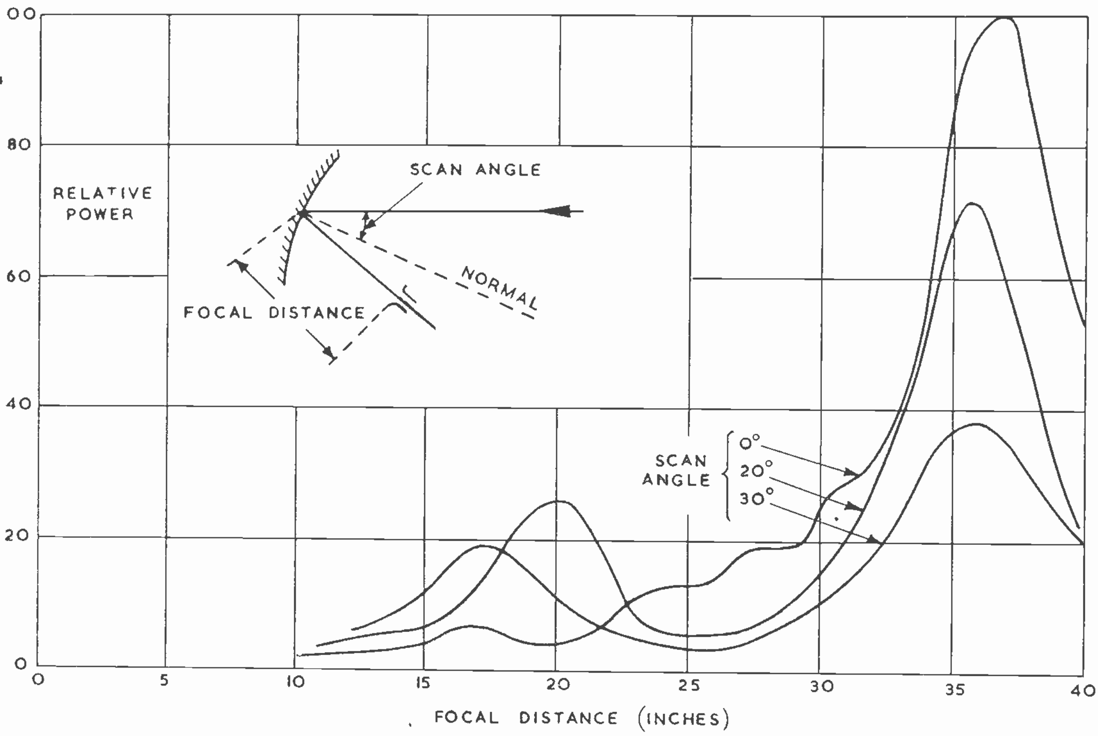


FIG. 10

Variation of gain with focal distance at various angles of scan of the reflector of Fig. 8.

will tend to excite the waveguide tubes in an E-mode. If the condition for a secondary maximum at grazing incidence is the same as the condition for maximum coupling into the E-mode, one would tentatively expect a greater fraction of the power to be reflected. A theoretical analysis of the fully constrained medium in terms of H_{11}, E_{11} and H_{01} modes should disclose the mechanism of the resonant reflection. Such an analysis still remains to be done.

Effect on Lens Design

It is important to consider what effect the above phenomenon would have on the use of the metal-tube medium in radio lenses. Now it is normal to employ a refractive index of about .6, that is to say b/λ will be about .67. Secondary reflection maxima, and therefore resonant reflection, will not occur unless the angle of incidence is greater than $29\frac{1}{2}°$ at some point on the lens surface. The phenomenon, therefore, always affects the performance of lenses with an F-number of unity or less, but assumes real importance in lenses especially profiled for high angles of scan. It is relevant to notice here that the metal-tube medium is especially attractive for lenses designed for wide angle linear scanning. Such a lens has surfaces which are not surfaces of revolution, and such surfaces can be built up piece-meal from metal-tubes where it would not be possible to, say, turn them from dielectric material.

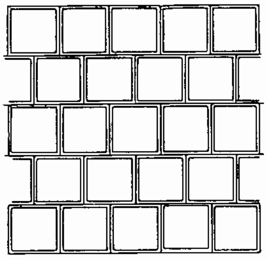


FIG. 11

"Staggered" packing of metal tubes.

In point of time the resonant reflection phenomenon was first observed in the behaviour of a metal-tube phase-corrected reflector designed for wide-angle scanning. The construction of this particular reflector was as shown in the photograph of Fig. 8. The front surface was cylindrical being profiled to scan an approximately 100λ aperture $\pm 30°$ with acceptable aberrations. The lens had a line focus and was fed by a line source. The tubes of the lens were normal to the front surface and were closed at their rear ends. These closed ends formed en masse a reflecting surface, which was stepped in standard fashion. Fig. 9 summarises the results obtained. The left-hand column shows that with the E-vector normal to the plane of scanning, the gain curve and the polar diagrams are of the form which could have been forecast from the expected scanning aberrations. If the plane of polarisation was parallel to the scanning plane, however, there was noticeable loss at angles greater than 15° and complete loss of gain around 27°, an angle which agreed with the resonant reflection data compiled later. At the time confirmation that the loss in gain was due to excessive front surface reflection was found by focal runs at various angles of scan as shown in Fig. 10. That is to say with the reflector aligned to receive signals at a certain angle of scan off axis, the distance from the line-source feed to the centre of the reflector was varied. At angles of scan around 27° it was found that most of the power was being focussed (rather imperfectly of course) to a point at roughly

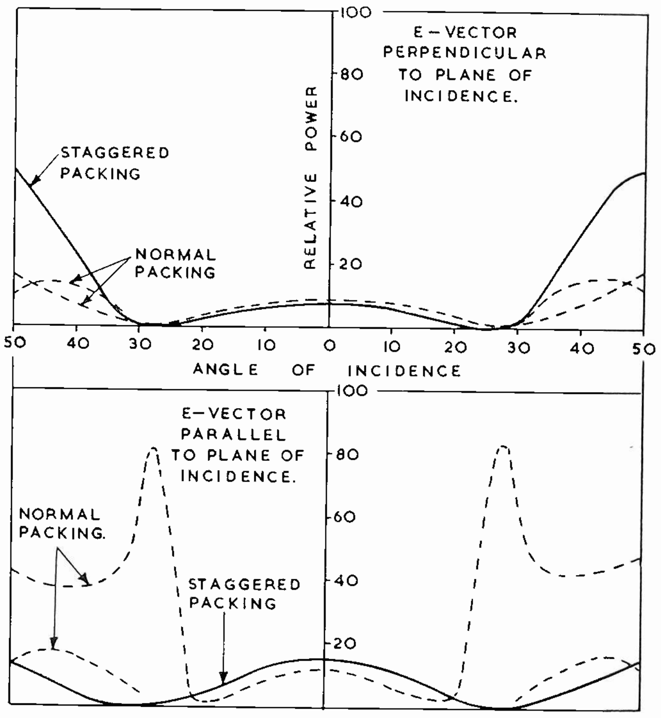


FIG. 12

Effect of "staggered" packing on surface reflections.

half the radius of curvature of the front face, i.e., the front face was acting as a first approximation to a reflecting parabolic cylinder.

Staggered Tubes

It has been suggested that a means of breaking up the formation of secondary maxima, which owe their origin of course to the repetitive structure of the medium, would be to stagger alternate rows of tubes as illustrated in Fig. 11. A sample of such a medium was constructed and reflection coefficient data obtained as before. The results are shown in Fig. 12, for the case $b/\lambda = \cdot 67$, refractive index $= \cdot 6$. Staggered packing is compared with normal packing for the two cases of E-vector parallel and perpendicular to the plane of incidence. It will be noted that when the E-vector is normal to the plane of incidence, the total power reflected from the surface is not, to a first order, affected by the method of packing, although secondary beams are now absent. On the other hand, the use of staggered packing for oblique incidence in the plane of the E-vector would seem to be distinctly advantageous. The elimination of the resonant reflection, which resulted from designing the medium to destroy the secondary maximum, is further evidence of their intimate relationship.

References

(1) J. F. Carlson and A. E. Heins, "The Reflection of an Electromagnetic Wave by an Infinite Set of Plates I." *Quart. App. Maths.* V.IV. No. 4, January, 1947.

(2) A. E. Heins and J. F. Carlson. "The Reflection of an Electromagnetic Wave by an Infinite Set of Plates, II." *Quart. App. Maths.* V.V., No. 4. April, 1947.

(3) Feodora Berz. "Reflection and Refraction of Microwaves at a set of Parallel Metallic Plates." *J.I.E.E.*, V.98, Part III, No. 51, January, 1951.

(4) C. A. Cochrane. "An Experimental Verification of the Theory of Parallel-Plate Media." *J.I.E.E.*, V.97, Part III, No. 46, March, 1950.

(5) E. A. N. Whitehead. "The Theory of Parallel Plate Media for Microwave Lenses." *J.I.E.E.*, V.98, Part III, No. 52, March, 1951.

(6) Bela A. Lengyel. "Reflection and Transmission at the Surface of Metal-Plate Media." *J. App. Phys.*, V.22, No. 3, March, 1951.

(7) J. Buze and M. Young. "Experimental Determination of the Reflection Coefficient of Metal-Plate Media." *J. App. Phys.*, V.22, No. 3, March, 1951.

(8) J. J. Brody, M. D. Pearson and S. R. Peoples. "Reflection of Microwaves from Metal-Plate Media." *J. App. Phys.*, V.23, No. 9, September, 1951.

(9) Brit. Pat. No. 629,108. N. M. Rust and M. Gregory. Improvements in or relating to Radio Mirrors.

A SHORT-SLOT HYBRID FOR 9 mm.

By E. M. Wells

The Short-Slot waveguide hybrid described by Riblet for a wavelength of 3 cm. (Proc. I.R.E., Feb., 1952) has been redesigned for use at a wavelength of 9 mm. In the form shown it has an easily reproducible performance which is adequate for many applications.

In the course of some development work at a wavelength of 9 mm. the need arose for a waveguide hybrid which could be cheaply reproduced in small numbers. The geometry of the magic-tee and rat-race were unsuitable for the problem in hand. In addition, a matched magic-tee tends to be an expensive component, while a rat-race was inadequate electrically, being essentially narrow band in directivity. A 3 db. directional coupler, which can assume a variety of forms, suited the geometrical

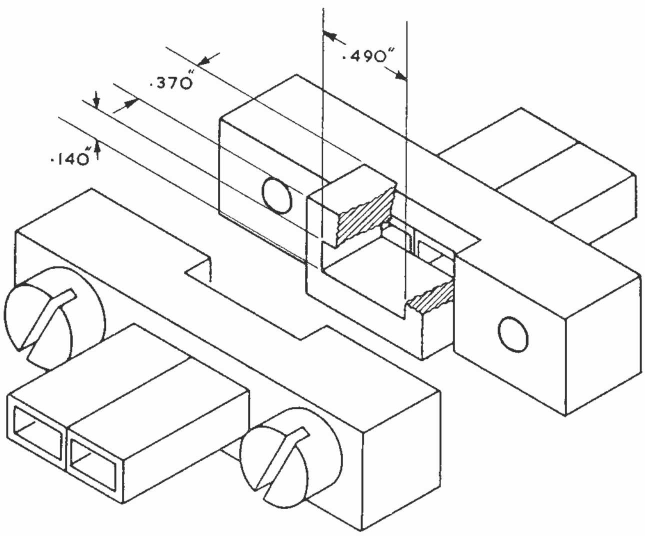


Fig. 1

Exploded view showing method of tuning cavity by sliding block in accurately fitting recess.

requirements. The short-slot hybrid appeared to offer the advantages of simplicity and adequate performance. This is in effect a 3 db. directional coupler in which the coupling is obtained through a single gap in the common narrow face between two parallel waveguides. For optimum performance the waveguide walls opposite the gap require shaping and a residual inductive shunt mismatch must be tuned out. 9 mm. waveguide is comparatively small (·280 in. × ·140 in. i.d. × ·040 in. wall), so that, in the interest of obtaining a rugged, reproducible component, the hybrid was designed to have three separate parts, namely, two pairs of waveguides feeding a rectangular open-ended cavity from opposite sides. The common wall between the parallel waveguides was made comparatively thick (·040 in.) and was finished square at the gap with no attempt to taper. No attempt was made to round off the step in the narrow face at the junction of guide and cavity.

The required capacitive tuning was obtained by offsetting the central cavity at right-angles to the common plane of the two opposing pairs of guides, thus forming E-plane steps at the junction. No loss was measured due to contact trouble at the mating surfaces which were ground off flat before assembly, and clamped tight after tuning for optimum directivity.

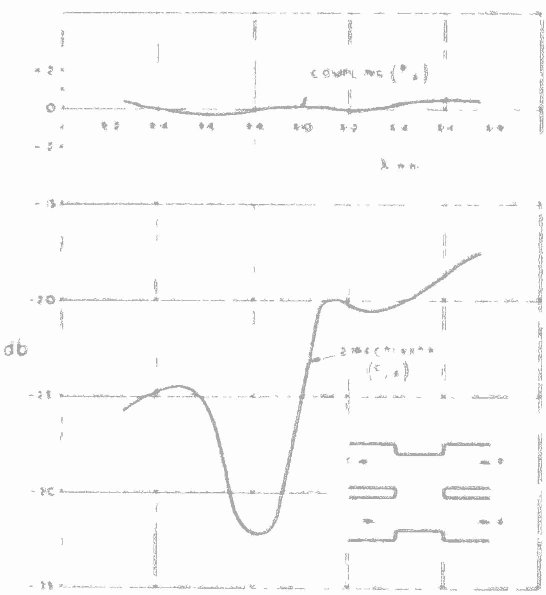


Fig. 2

Typical plot of coupling and directivity as a function of wavelength

The height of the cavity was made the same as that of the waveguide (·140 in.). Trial and error on a large number of specimens resulted in the dimensions shown for length and breadth (Fig. 1). The resultant directivity and coupling are shown in Fig. 2, the cavity in this case having been tuned for optimum directivity at 8.8 mm. (This last operation requires an offset of about $\frac{1}{32}$ in.) The match was better than ·95 VSWR over the useful range of the hybrid.

Although it is probable that improved performance might be obtained by relaxing the conditions on design imposed above, it was felt that these were justified in view of the fact that no appreciable deterioration of performance has been observed in the dozen or so specimens so far used.

VHF POWER TRANSMISSION EQUIPMENT FOR BAND III TELEVISION BROADCAST

BY B. M. SOSIN, B.Sc., A.M.I.E.E.

The following article describes apparatus for linking sound and vision television broadcast transmitters, working on Band III, to a common aerial. Details are given of the component parts, including a Vestigial Sideband Filter, a Frequency-discriminating Combining Filter, Test Load and Feeder monitoring components. The performance of the complete equipment is also discussed.

(1) Introduction

THE modern television broadcast station requires highly specialised equipment between the sound and vision transmitters and the aerial. In order to reduce the channel bandwidth, vestigial sideband vision transmission is now accepted as standard. The unwanted sideband can be suppressed at the transmitter, but there are disadvantages resulting from this which can be avoided by the use of a separate sideband filter. Furthermore, a common aerial system for both sound and vision shows such advantages over separate aerials[1] that this arrangement is now used almost universally. Some kind of combining unit, therefore, becomes necessary. Either a non-frequency discriminating or a frequency discriminating type can be used. The former behaves as a hybrid, but requires a turnstile type of aerial and two main feeders. The frequency discriminating combining unit is in effect a filter. With this only one main feeder is required and any aerial suitable for television can be used. The combining filter is more complicated and should be of the "constant resistance" type. Both methods of combining give good results and the choice is mainly that of economy in the particular installation and of the available equipment.

Although it is perhaps unnecessary to mention here the need for a test load capable of dissipating the full power of the transmitter, it must not be forgotten that only by means of a feeder changeover switch, can the load be connected.

Lastly, a feeder monitoring equipment capable of continuous indication of reflection coefficient and and power and possibly some trip device operating on an excessive reflection coefficient is highly desirable.

A description of the transmission equipment suitable for band III (174–216 Mc/s) television broadcast and performance details are given below.

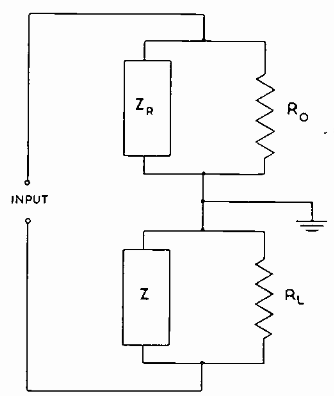


FIG. 1

V.S.B. Filter basic circuit.

(2) The Vestigial Sideband Filter

The Vestigial Sideband Filter is of the "constant resistance" type [2] [3] [4] which allows the filter to be inserted at any convenient point into the vision feeder without altering the response of the transmitter itself. It is based on the network shown on Fig. 1. R_0 is the characteristic impedance of the output feeder and R_L is the resistance of the absorber load, both equal to unity in normalized values. Now, Z and Z_R are two reactive elements which are reciprocal to each other, i.e., $Z = 1/Z_R$ (normalized values). In this case, the normalized input impedance is also unity for all values of Z. The reactive elements are T-connected stubs (5) (6) formed by lengths of coaxial transmission line. These are superior to simple tapped stubs because, for any required separation between resonant and anti-resonant frequencies, the mean impedance level can be controlled and hence the width of the rejection and transmission bands. The full equivalent circuit is given on Fig. 2. The difficulty of connecting the outer conductor of the input feeder to the live terminal (inner conductor) of the absorber load is overcome by taking the input feeder through the inside of the inner conductors of stubs Z_2 and Z_3. This connection is indicated on Fig. 2 by dotted line and the link A. Also it can be clearly seen on the pictorial sketch of the construction of the filter (Fig. 3). The stubs Z_1 and Z_{1R} are slightly less than a quarter wavelength long and are open and short circuited respectively at their far ends. The stubs Z_2 and Z_{2R} are very short indeed. The connections Z_3 and Z_{3R} are about 40 degrees (electrical) long and their normalized characteristic impedances are made lower and higher than unity respectively, for mechanical reasons.

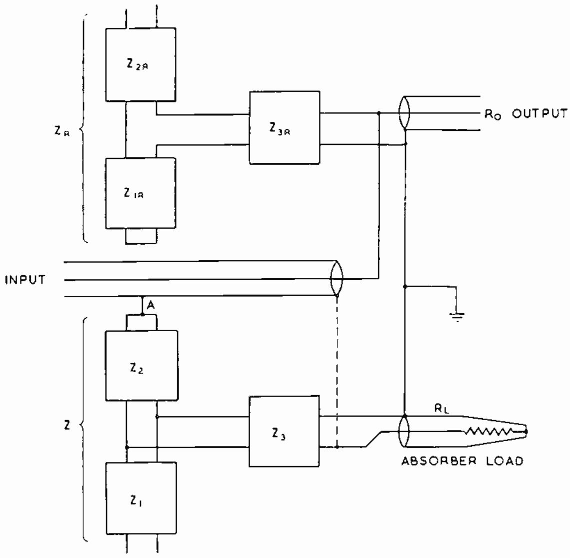


FIG. 2

V.S.B. Filter, full equivalent circuit.

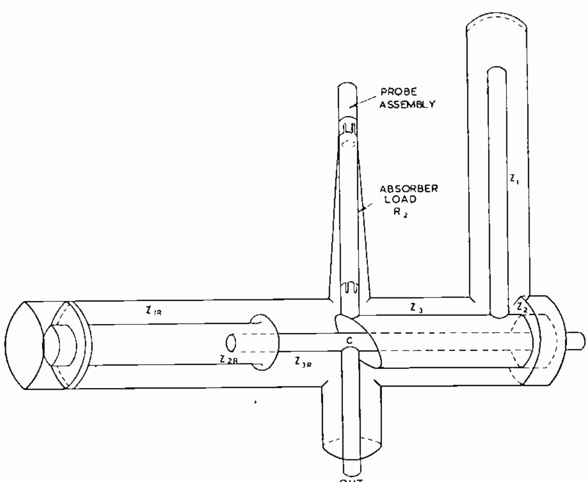


FIG. 3

V.S.B. Filter, coaxial construction.

Considering the terminal point of a circular conductor as the centre of the circle formed by the end of the conductor the " junction " of the network is brought to a single point C, thus minimising any spurious effects.

To meet the American or C.C.I.R. specifications for Vestigial Sideband trans-

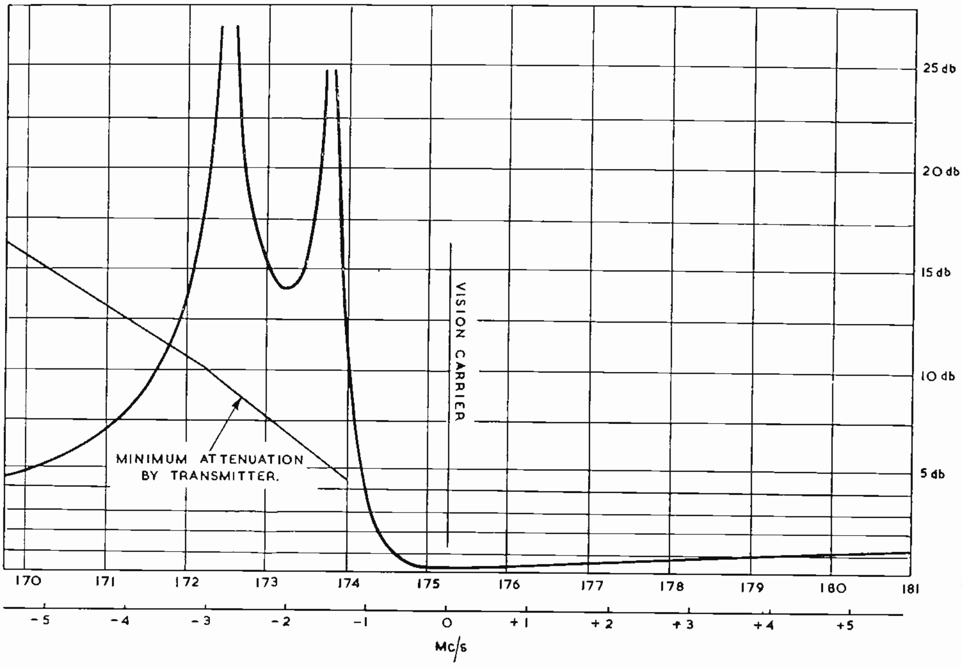


FIG. 4

Insertion loss of the V.S.B. Filter.

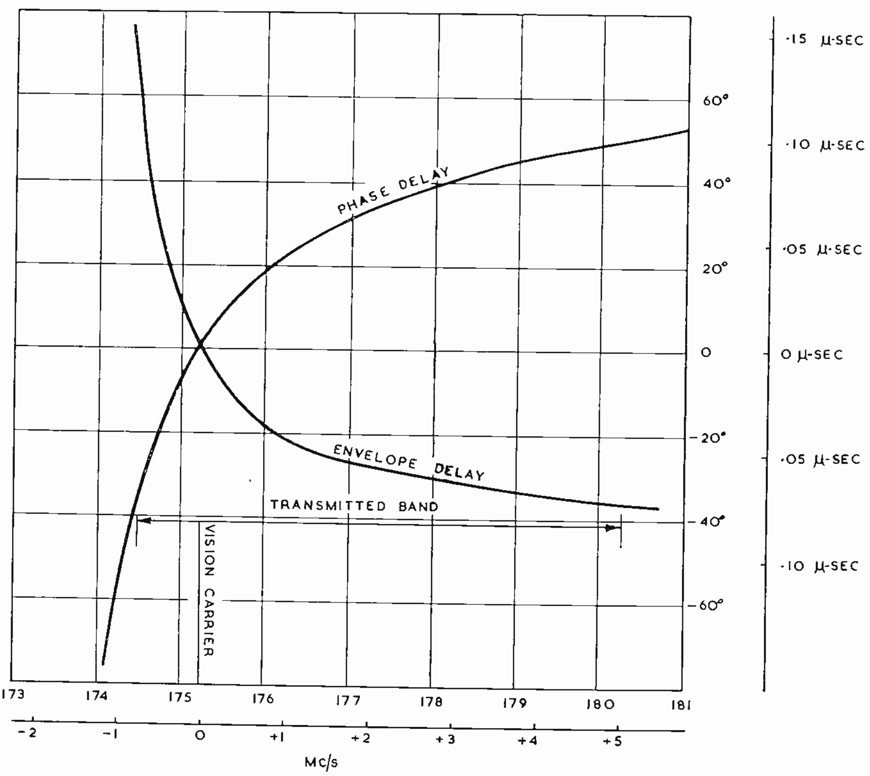


FIG. 5

Phase and envelope delay of the V.S.B. Filter.

mission the response of the output circuits of the transmitter is slightly off-centred and two filters as described above are connected in cascade. Off-centering of the transmitter output circuit not only helps to attenuate the unwanted sideband, but also improves the response to the wanted sideband. The two filters are tuned so that the minimum loss occurs at the vision carrier frequency in order to avoid a leak of carrier power to the absorber loads. In this way it is possible to use absorber loads of

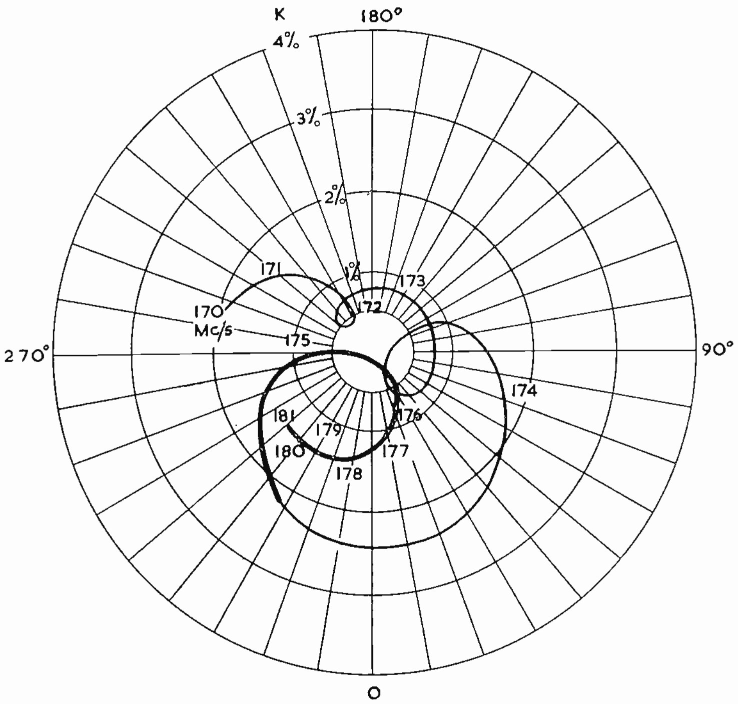


FIG. 6

Input reflection coefficient of the V.S.B. Filter. Frequencies are megacycles.

only 200 W dissipation for 10 KW transmitted power. The attenuation frequencies are staggered.

The measured insertion loss of the complete filter is given on Fig 4. The curve shown is true insertion loss (not merely a frequency response) and the accuracy of measurements is 0.05 db for loss not exceeding 1 db. The envelope delay is obtained graphically from the measured insertion phase delay angle (Fig. 5). The input reflection coefficient of the filter terminated by a matched load is plotted in polar co-ordinates (Fig. 6). The above measurements were taken with test gear specially developed for the purpose of setting up and measuring VHF filters, transmission lines, etc. The method is fully described in Ref. 7, but the apparatus has been considerably improved since that description was written.

(3) Combining Filter

A frequency-discriminating combining filter is used. It is based on a Maxwell bridge, which leads to a compact design with good performance.(6) (8) The advantages of this method are as follows:—

(*a*) Only two simple frequency-selective circuits are used.

(*b*) Vision and sound inputs are applied across the opposite diagonals of the bridge, which remains balanced over the entire frequency band. This considerably increases the insertion loss between the inputs without additional loss and complication of extra filtering sections.

(*c*) The filter is a constant-resistance network. This property dispenses with the problem of vision input impedance matching.

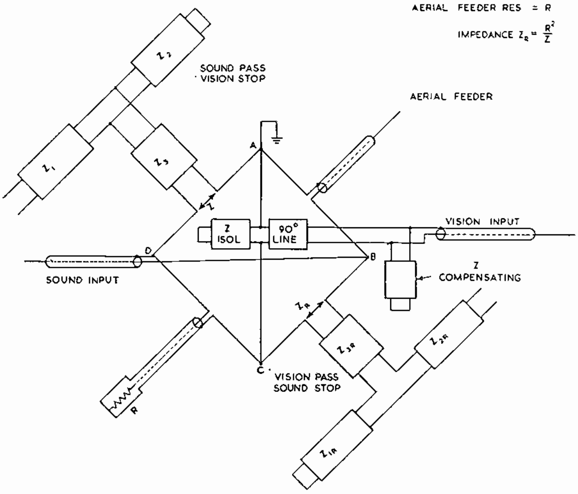


FIG. 7

Combining Filter, full equivalent circuit.

Fig. 7 gives the full equivalent circuit of the filter and a pictorial view of the physical arrangement is shown on Fig. 8. The frequency-selective circuits are again T-connected stubs. However, the lengths of Z_3 and Z_{3R} are now about 76 degrees (electrical). Because of a very small fractional separation between vision and sound frequencies Z_2 and Z_{2R} are very short indeed. In fact Z_2 is shorter than the radius of the inner tune of Z_3 making the connection difficult (connection is made by specially shaping the end plate), and the inner conductor of Z_{2R} hardly enters into the corona ring of the outer conductor. The stubs Z_1 and Z_{1R} are slightly shorter than a quarter wave-length and are made of large diameter tubes in order to reduce " sound " losses and to improve cooling. The sound input feeder is taken through the inside of the inner conductor of stubs Z_2 and Z_3, which overcomes the difficulty of the high potential on its outer conductor. The outer conductor of stub Z_{3R} is isolated from earth by means of a quarter wave-length isolating stub ($Z_{\text{izol.}}$). Unfortunately, this stub shunts the vision input, and has an appreciable reactance slope. This is compensated by a similar stub connected at a point a quarter wave-length towards the vision transmitter. The balancing load is "taken out" through the inside of the inner tube of the compensating stub. A two-slug variable transformer is provided in the feeder line to the balancing load. This enables the tuning out of the internal mis-balance of the bridge and so improves the insertion loss between inputs.

The filter is rated at 10 KW peak vision power, 5 KW sound power if frequency modulated or 2 KW sound power if amplitude modulated. The measured performance is given on Figs. 9, 10, 11 and 12, showing the vision and sound insertion losses, vision insertion phase delay angle, vision input reflection coefficient and the insertion loss between the inputs. The insertion loss between the inputs is, of course, dependent on the balance of the bridge. The measured curve, with the filter terminated by a matched load is in a way an indication of the internal mis-balance, however small it may be (the insertion loss would otherwise be infinite). The reflection from the output feeder and an aerial may either correct or more likely add to the mis-balance.

The minimum possible insertion loss between the inputs, assuming 2·5% reflection coefficient on the output feeder is also shown by the dotted line.

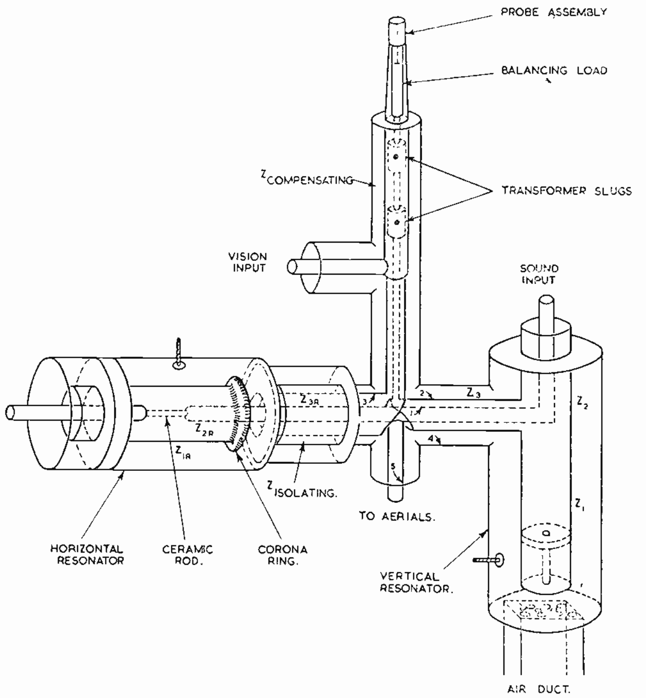


FIG. 8

Combining Filter, coaxial construction.

(4) Test Load

A test load is a lossy transmission line, obtained either by introducing a lossy dielectric in the space between the inner and outer conductor, or by using a resistor in place of the inner conductor. In the first case, the heat will be generated inside the dielectric and can only be removed effectively by changing the dielectric, i.e., using a liquid. Hard water is sufficiently lossy and a matched load can be constructed using it as the dielectric. Such a load is troublesome, because of the very high permittivity of water, which also varies with the temperature. In the second case the resistor should be of the thin film type in order to facilitate the removal of the heat generated. Also, it should not be affected by a cooling liquid or by a high current density. A " cracked carbon " resistor meets all the requirements, and has a very high power handling capacity.[9]

Out of a number of possible ways of construction, two types can be used for Band III television, which differ in the method of cooling the resistor. In the first load an intermediate coolant is used, namely, tetrachloroethylene. The load has a resistor for an inner conductor. The outer conductor narrows down exponentially towards the end of the resistor and is short circuited there. The space between is filled with the coolant, which is allowed to flow freely upward, then down through the heat exchanger, and back to the load; the outer conductor is perforated and everything is enclosed in a container. The heat is transferred to water in the heat exchanger. The complete load can be seen on the photograph (Fig. 14a). It will dissipate up to 5 KW. The resistor is $\frac{7}{8}$ inch in diameter and 11 inches long, excluding metallised ends. In the second type of load no intermediate coolant is used. Instead a thin film of water is used in direct contact with the surface of the resistor, while the main dielectric is polyethylene. Water flows in from the inlet, which is at the " earthy " end of the resistor, through the inside of the resistor and then back over its surface to the outlet. The load of this construction, using the same size resistor as the first type of load, dissipated easily 30 KW; the actual power limit is so far

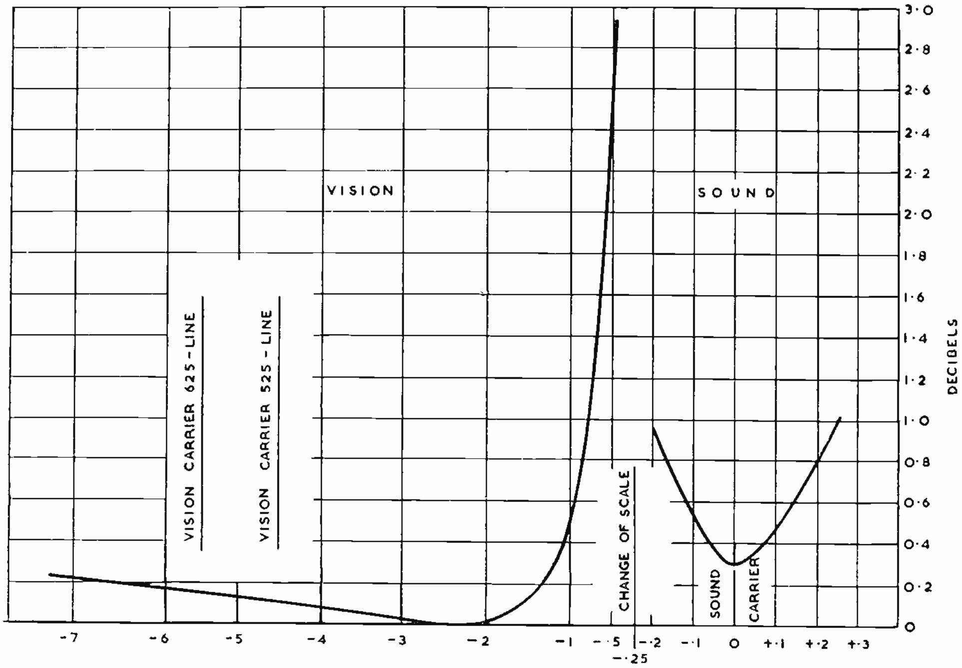


FIG. 9

Vision and sound insertion losses of the combining filter. Frequencies are megacycles from sound carrier.

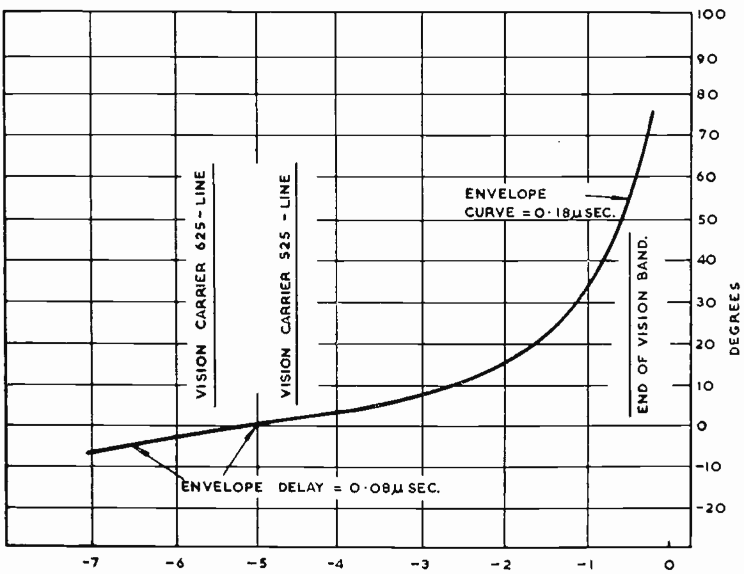


FIG. 10

Phase delay of the combining filter. Frequencies are megacycles from sound carrier.

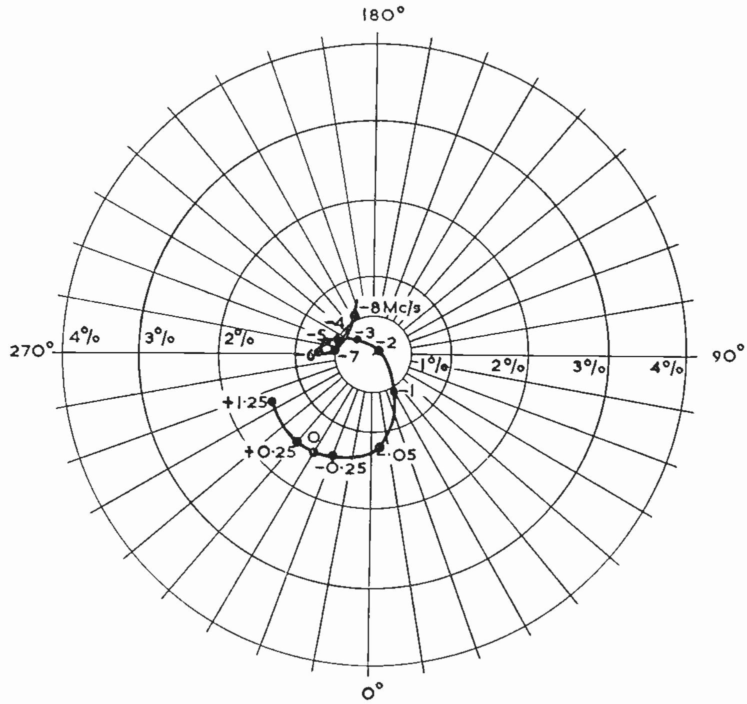


FIG. 11

Input reflection coefficient of the combining filter. Frequencies are megacycles from sound carrier.

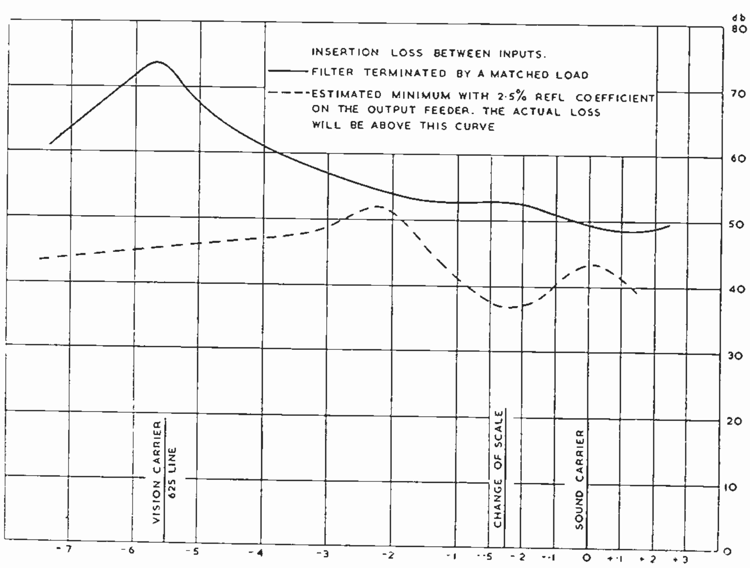


FIG. 12

A typical insertion loss between inputs of the combining filter. Frequencies are megacycles from sound carrier.

not known. Fig. 13 gives the input reflection coefficient which is very little affected by the water temperature.

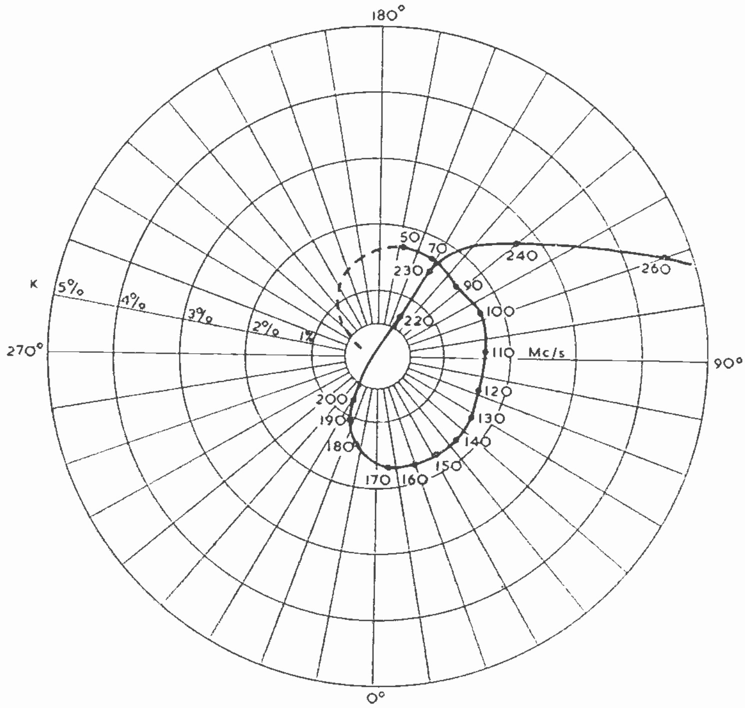


FIG. 13

Input reflection coefficient of the 30 kW. Frequencies are megacycles.

(5) Feeder Monitoring Equipment

The conditions existing on the feeder are monitored at three different points, that is on the output feeders of the vision and sound transmitters, and on the main feeder leading to the aerial. At these three points short lengths of transmission line, called " reflectometer lengths," are inserted in the feeder. These each contain two directional couplers, one being set to respond to the forward and the other to the backward wave. Now, the ratio of the backward wave to the forward wave is the reflection coefficient. Thus it remains to rectify the signals obtained from the backward and forward directional couplers and to display them on a suitable instrument, the ratiometer.

The ratiometer contains two separate moving coil movements on a common spindle. No controlling spring is used and the magnetic fields are non-uniform. When the current flows only through the " control " coil the needle indicates zero; the higher the current the larger will be the force pulling it to zero. The current in the second coil tends to deflect the needle, so that the deflection is a function of the ratio of the current in the deflection coil to the current in the control coil. When this ratio equals unity the needle is at full deflection. The meter is calibrated directly in reflection coefficient from 0 to 20%, enabling an easy reading of the low values of the reflection coefficient.

It is possible to cross-connect the signals from the directional couplers. By comparing the signal from the backward coupler on the vision feeder with that of the

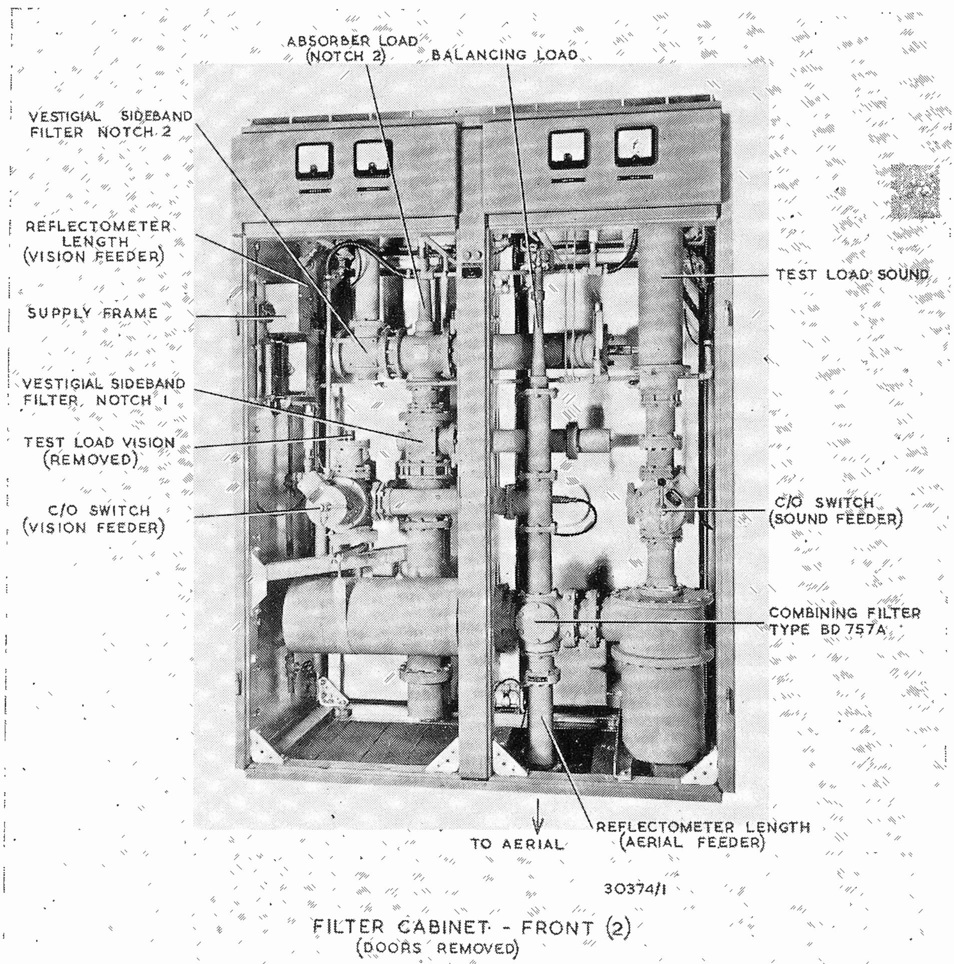
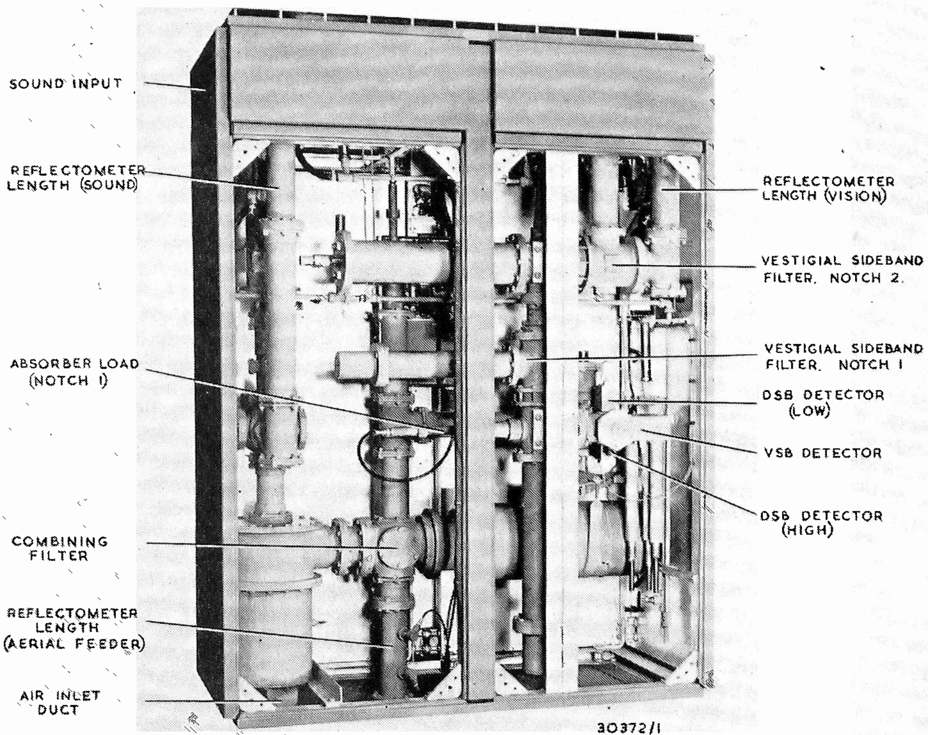


FIG. 14 (*a*)

forward coupler on the sound feeder, the sound transmitter only being switched on, an indication of the insertion loss between inputs at the sound frequency is obtained. This and the other similar cross connections are used for checking the Vestigial Sideband and Combining Filters. The signals from the forward directional couplers on the vision and sound feeders are also used to indicate vision and sound power.

Protection of the transmission equipment and aerial presents a more difficult problem than may at first appear. Neither overvoltage nor overcurrent can be used to actuate a trip because in the fault condition the feeder voltage or current may actually drop. The reflected wave, i.e., the signal from the backward wave directional coupler would again be unreliable because the transmitted power may be reduced. Excessive reflection coefficient is the only satisfactory criterion and is used in this equipment. If the signal from the backward wave coupler exceeds a predetermined



FILTER CABINET - REAR
(PANELS REMOVED)

FIG. 14 (*b*)

fraction of that from the forward wave coupler a magnetic-amplifier-relay trips the transmitter. The system is sensibly independent of the transmitted power.

(6) The Complete Equipment

The complete equipment is assembled into a double bay transmitter cabinet, which is approximately 2 feet 6 inches deep, 5 feet wide and 7 feet tall. The two photographs (Fig. 14a and Fig. 14b) were taken from the front of the cabinet with the doors removed and from the back with the panels removed. Also one of the loads

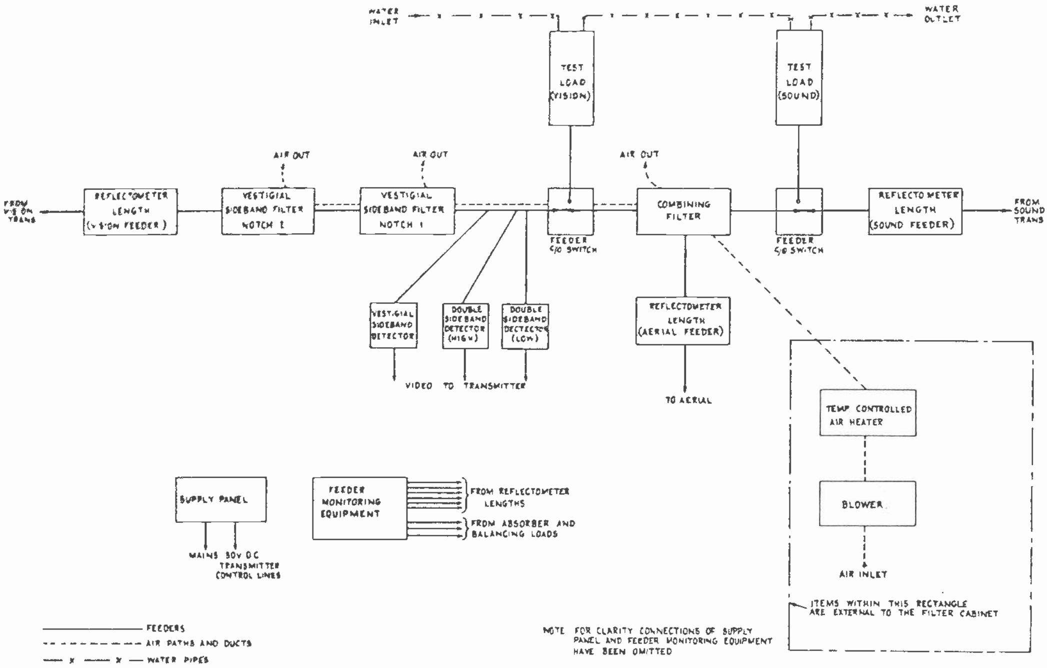


FIG. 15

The block diagram of the complete equipment.

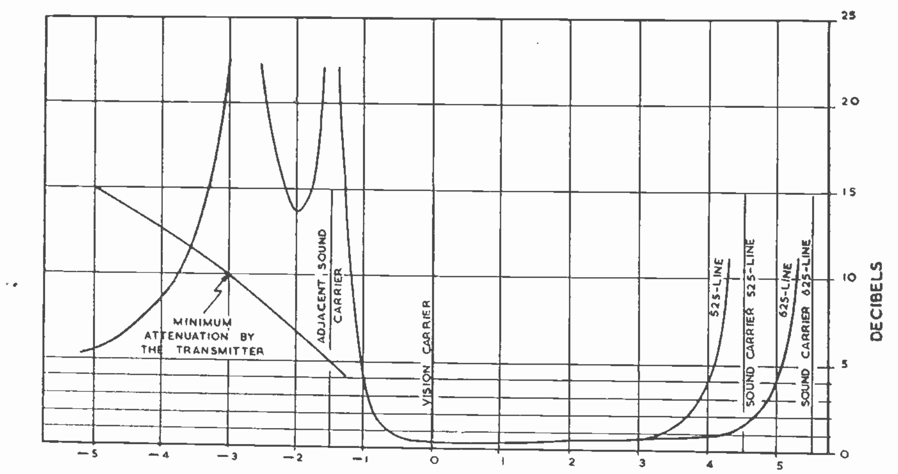


FIG. 16

Vision insertion loss of the complete equipment. Frequencies are megacycles from vision carrier.

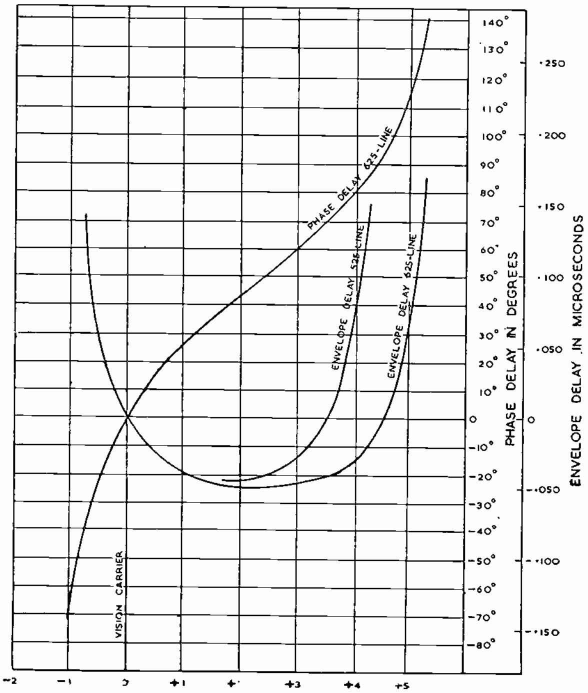


FIG. 17

Phase and envelope delay of the complete equipment. Frequencies are megacycles from vision carrier.

was taken out to show the side-band filter. The block diagram (Fig. 15) will make clear the connections of the equipment. Starting from vision input the transmission passes through the reflectometer length, then through the two parts of the Vestigial Sideband filter and so to the coaxial switch. From there it can be directed to the test load or via the combining filter and another reflectometer length to the aerial. The transmission performance of this path, that is the insertion loss and phase and envelope delays are shown on Fig. 16 and Fig. 17. It can be seen that the performance is entirely satisfactory for present television standards. From the sound input the transmission passes through a reflectometer length, and a coaxial switch, and from there either to the load or to the combining filter and aerial. The feeder monitoring equipment and some auxiliary equipment are also housed in the cabinet.

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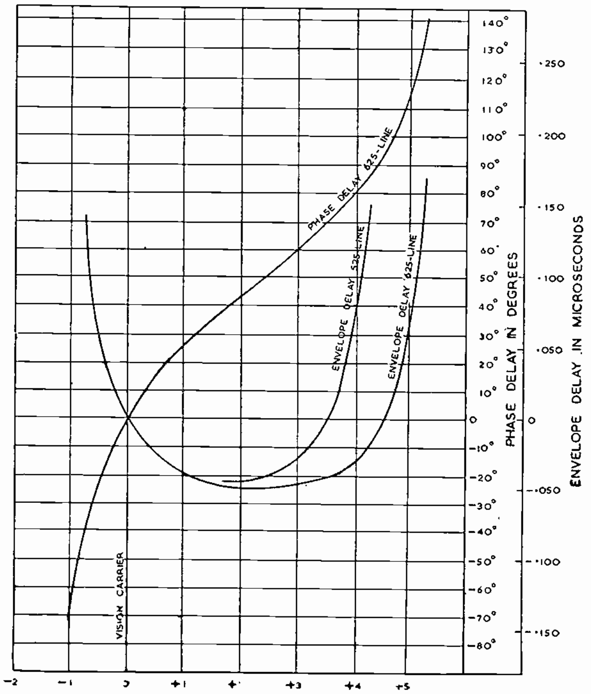

FIG. 17

Phase and envelope delay of the complete equipment. Frequencies are megacycles from vision carrier.

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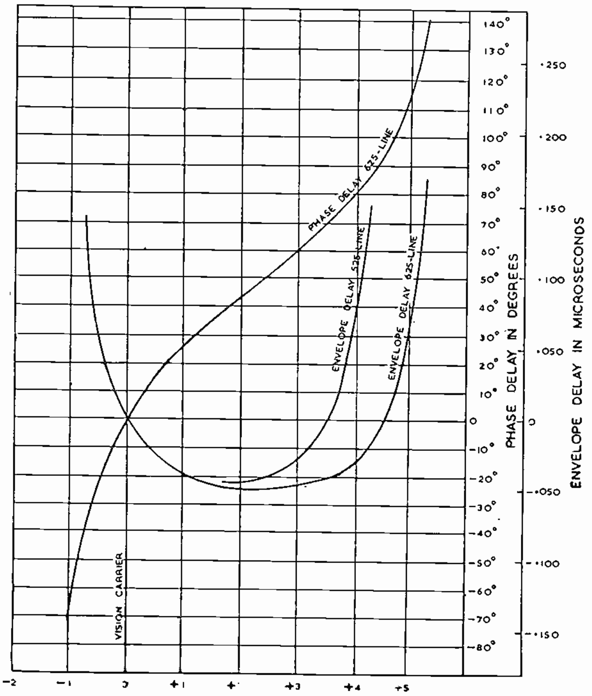

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