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THE FISCHER LARGE-SCREEN PROJECTION SYSTEM*

by

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SUMMARY

The paper describes the Fischer system of large screen television projection which makes use of an "eidophor" liquid. Consideration is given to the brightness requirements, and the principles of the schlieren optical system are discussed together with the manner in which the Eidophor functions. The technical problems involved are dealt with and the results obtained with the third prototype examined.

1. Introduction

There are many possibilities for the solution of the difficult problem of large screen projection of television pictures, and it would almost be foolish to consider one or the other method as absolutely best. The system which is to be discussed here has been influenced from its beginnings by a clear and definite aim: the television picture should, in every respect, be of the same quality as the modern motion picture, i.e., of equal brightness, size, definition and gradation. I realize of course that this is a very ambitious aim and I would by no means maintain that it has already been reached at present. On the other hand, I should like to make it clear that all our work has always been done with this aim in view. And as the development proceeds, the fundamental difficulties that might hinder the final success grow smaller and smaller.

You will allow me a short summing up of how the system has been developed so far. Professor Dr. F. Fischer applied for a patent for his basic ideas in November, 1939, and started their practical development in the AFIF (Department of Applied Physics of the Swiss Federal Institute of Technology, Section of Industrial Research). With his almost unlimited courage he tackled the underlying problems that had never been treated before. He constructed the first prototype of the projector which was first operated in the year 1944. The results of this construction, however, were by no means encouraging and did not by far fulfil the hopes that were put in it. The difficulties, it is true, were not of such nature as to render any further pursuit of the idea absolutely hopeless, but it seemed clear that the success could only be reached at a much greater expense of research and development than was originally thought. But Prof. Fischer did not allow himself to be troubled and courageously started to design a second prototype. Already the outward appearance of the second projector made it clear that his bold original plans had been revised. Still the equipment was very large and complicated and there could hardly be any serious hope of its practical adoption in that shape. But the first target that had to be reached was the proof that the system could work at all. When Prof. Fischer's untimely death in the year 1947 brought his tireless activity to an end, the second projector was not yet in operation and the main problems were by no means solved. We do not lessen Prof. Fischer's lasting merits as a pioneer, if we say that only the development made after his death gave the system a basis for its practical adoption. The success is in the first

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place due to the optimism and untiring energy of his former collaborators, Dr. H. Thiemann, F. Mast, K. Hetzel, Dr. F. Held and Dr. R. Petermann.

On the occasion of the International Television Convention in the summer of 1948, the operation of the second prototype could be demonstrated. The quality of the pictures which was reached then gave proof of considerable progress, and helped to strengthen very widely the hope of final success. Those responsible were convinced that the new experiences and discoveries would furnish the essential data for a third prototype which, considerably simpler and smaller than the second, should come much nearer to a solution that could be practically adopted. This third prototype which was first operated in December, 1950, fulfilled our hopes in every essential point.

Since in this stage the stress lay on the problems of practical adaptation, it was time to secure the help of a competent industrial producer and to leave to him the responsibility for this difficult task. This was done in the spring of this year and the rights for the utilization of our system now lie with the firm Dr. E. Gretener A.G., in Zurich. As a university department we have retained the possibility to further the development in close collaboration with the firm.

2. Theoretical Requirements of the System

It will be known that the Eidophor system makes use of a light source for the production of the screen picture. The brightness, therefore, as in cinema projection, depends largely on the power of this light source. This fact and the relatively great efficiency of the system enable us to produce very powerful light fluxes which are sufficient even for the screens of the largest theatres. A further advantage lies in the possibility of adapting the optical layout of the system to the architectural necessities of the various theatres and to install the projector in the existing booth, as it is commonly done with ordinary cinema equipments.

The brightness B_s of the screen required in good cinema projection amounts to about 10 ft-lambert. For a given screen area A' the required light flux can be computed as follows

$$\Phi_s = \frac{\pi}{0{\cdot}8} A' B_s \qquad (1)$$

The factor 0·8 is the coefficient of remission of the screen, as for an ordinary medium quality cinema screen with diffuse reflexion.

Table 1 states the screen areas used in some well-known cinemas on the Continent. The light flux necessary for these screens according to formula (1) is given as well. The table shows

Table 1

Screen Areas and Light Fluxes in some Cinemas on the Continent

Cinema	Seats	Screen Size (Picture Width) in ft.	Screen-Area (m^2)	Projection Distance (m)	Projection Angle (degree)	Light Flux (ASA) lm
Kapitol in Bern	720	19	4·2×5·6=23·5	34	17	3161
Urban in Zürich	1150	22	5×6·7=33·5	31·5	12	4506
Rex in Paris	3200	33	7·5×10=75	45	21	10087
Marignan in Paris	1800	40	9×12=108	33·5	23	14526
Le Régent in Neuilly-sur-Seine	1400	19	4·2×5·6=23·5	26	15	3161
Cinéac des Ternes in Paris	600	19	4·2×5·6=23·5	22	18	3161
Cinéac in Strasbourg	500	16	3·5×4·7=16·5	21	23	2219
Royal in Rabat	1500	20	4·5×6=27	39	20	3631
Palazzo del Cinema in Venice	1400	33	7·5×10=75	34	12	10087
Palladium in Copenhagen	1400	27	6×8=48	35	5	6466
Asta at The Hague	1200	22	5×6·7=33·5	27	3	4506
Capitol at The Hague	1000	20	4·5×6=27	23·5	17	3631

that $\Phi_s = 10{,}000$ lumen are necessary for the largest theatres. This means an enormous light-flux in television, and we have now to consider how it can be produced.

We shall assume, without going into details now, that the projection of our picture follows exactly the same principles as cinematographic projection. Only we have the Eidophor surface instead of the film and we shall therefore speak of the Eidophor picture. In Fig. 1 the Eidophor picture of the area A lies in the plane S, the projection screen of the area A′ in the plane S′.

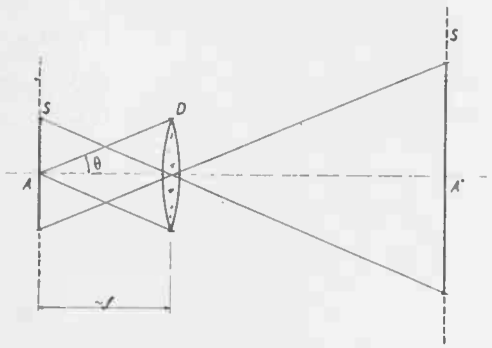


Fig. 1.—Principle of projection. The projection lens of diameter D is at a distance from S of about f = focal length (for lateral magnifications of $m = \sqrt{A'/A} \gg 1$).

The total light-flux that falls on the screen is equal to the light-flux passing the lens. From every point of the Eidophor picture a light-pencil of half the opening angle 2θ hits the lens; thus the light-flux can be computed to be

$$\Phi_s = \pi . B . A . \sin^2 \theta \quad \ldots\ldots (2)$$

B being the brightness of the Eidophor picture, and $\sin\theta$ being $\sim D/2f$, therefore,

$$\Phi_s = \frac{\pi}{4} BA \left(\frac{D}{f}\right)^2 \quad \ldots\ldots (3)$$

$(D/f)^{-1}$ is called the f-number of the lens.

If we put the expression from (1) for Φ_s, and using $m = \sqrt{A'/A}$ we get:

$$B = \frac{m^2}{0{\cdot}2}\left(\frac{f}{D}\right)^2 . B_s \quad \ldots\ldots (4)$$

From (4) we can compute the necessary brightness B of the Eidophor picture, if we know the brightness of the screen. If the screen area $A' = 75\ m^2 = 7{\cdot}5 \times 10\ m^2$ and the Eidophor picture area $A = 7{\cdot}5 \times 10\ cm^2 = 75\ cm^2$, we get $m = 100$. In cinema projection the area A has a fixed value and is much smaller, namely $3{\cdot}5\ cm^2$, which makes $m = 463$. Table 2 presents the values of B for some values of D/f for both cinema and television.

Table 2

D/f	$m = 100$ B	$m = 462$ B
1 : 1	175	3,740
1 : 2	700	15,000
1 : 5·5	5,250	114,000

B in candles/cm².

It follows that the area A plays a decisive part, and if we compare with cinema projection we see that in television we have the advantage of having this area 20 to 30 times larger. In consequence, we can use apertures (of about 1 : 5·5) which do not present great optical difficulties even in more complicated systems, and which allow quite reasonable lens diameters. However, the projection cannot be effected without losses, as we have assumed so far. The losses that we have to take into account are very considerable and may reach the factor of 10 (and more) against about three for the cinema. The brightness of the Eidophor picture actually required for the production of 10,000 lumen is, therefore, in our example for an f-number of 5·5 about 50,000 to 70,000 candles per cm².

But modern arc lamps, such as the Ventarc lamp developed by the firm Dr. E. Gretener, A.G., can produce average brilliancies in the crater up to and above 120,000 candles per cm², so that the conditions in this respect are fairly favourable.

I should like to point out that the figures mentioned here refer to one single example. But according to the given practical requirements, all sorts of variations can be made. The only purpose of the figures given above is to show that the production of light fluxes as required in the largest theatres can be effected by existing means.

3. Description of the Optical System

The basis of our projection system is a kind of light valve and we shall presently see the elegant principles that govern the light control. The

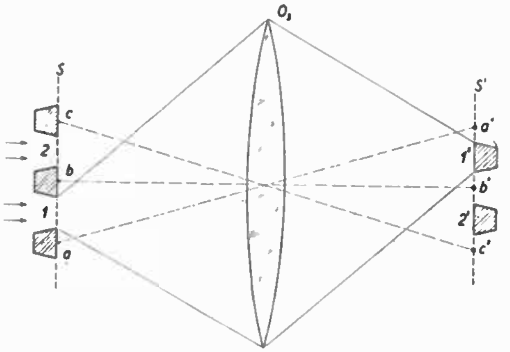


Fig. 2.—Principle of a schlieren optical system.

most important element is the so-called schlieren-optical system. Fig. 2 shows the diagram of such a system. The image of a system of bars and slits lying in the plane S and illuminated from the left, is projected by the schlieren-optical system O_s on to an analogous system of bars and slits lying in S′. As shown in our diagram, the images of the slits 1 and 2 fall on the bars 1′ and 2′, and the images of the bars a, b, c on the slits a′, b′, c′. Under these circumstances no light is allowed to pass into the space to the right of S′.

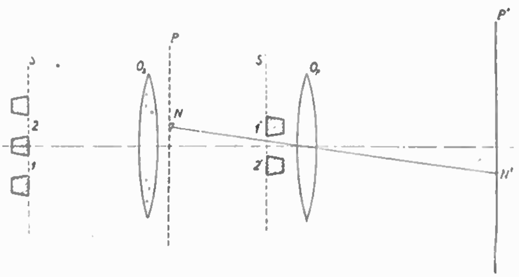


Fig. 3.—Development of schlieren optical system.

We now expand the system by joining a new lens O_p immediately behind S′ (Fig. 3) and choose its focal length so as to project the image of a plane P near the schlieren lens O_s, on to the screen P′.

A small glass prism N is now placed on a point of the plane P. Consequently the light pencil passing N is deflected from its original direction according to the deflection angle of N. The rays of this pencil can therefore partly pass the bars 1′ and 2′ and are focused by the lens O_p on the screen in N′, where they appear as a luminous point. The brightness of the point N′ depends on how much of the light pencil is allowed to pass bars 1′, 2′, and this varies according to the deflection angle of the prism. We now imagine the whole plane P to be covered with as many adjustable prisms as there are picture points on the picture to be projected. We can now control the brightness of any image point on the screen P′ by suitably adjusting the deflection angles of the prisms. Our pictures are thus produced on a raster basis, i.e., they are composed of individual discrete picture points.

It was Prof. Fischer's ingenious idea to produce the prisms by depositing a rastered electric charge on a thin oil film. Under the influence of the electrostatic forces the surface of the oil is deformed and in this way the required raster elements are formed. The exact geometrical shape of these elements is important only in so far as it influences the light efficiency

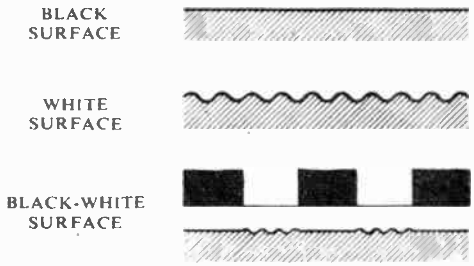


Fig. 4.—Deformation of the Eidophor liquid.

to a certain extent. The charge is applied point by point by means of a cathode beam, and we can thus employ the methods used in the technique of cathode ray tubes. In order to produce a television picture, deformations in the form of sine-shaped wave-traces are engraved along the lines of the picture. The amplitude of the wave controls the brightness of the corresponding part of the screen picture. In Fig. 4 the system is shown schematically.

An ideal reproduction equipment should be able to store the picture information for the duration of one picture period. This means that the deformations on the oil should remain for the duration of one picture period, but decay as quickly as possible after the period is over. This decay, however, is only possible if the electric charge that produces the mechanical forces decays as well. For this purpose, the oil, the

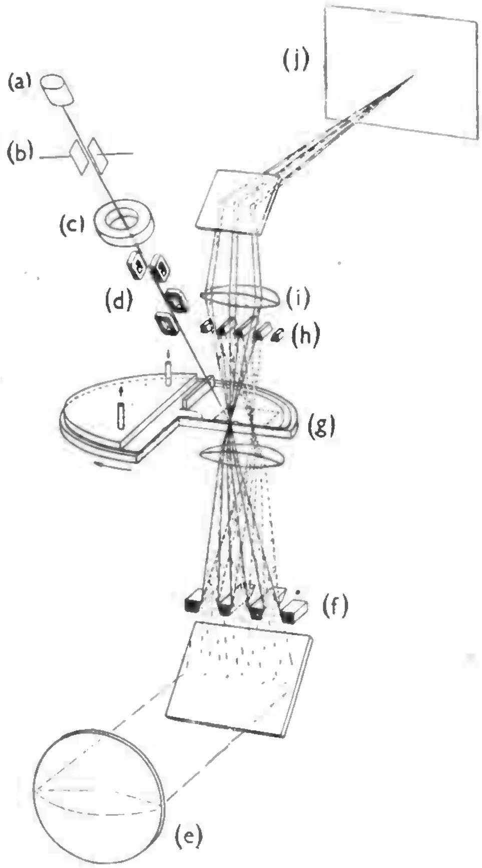


Fig. 5.—Diagrammatic arrangement of the "Eidophor" projector.
(Based on the second prototype.)

- (*a*) Electron gun
- (*b*) Modulation grid
- (*c*) Focusing coil
- (*d*) Scanning coils
- (*e*) Arc lamp
- (*f*) Lower grating
- (*g*) Eidophor
- (*h*) Upper grating
- (*i*) Objective lens
- (*j*) Screen

Eidophor as Prof. Fischer has called it, has been made conductive. The deposited charges, therefore, decay according to a time law corresponding to an exponential function. The electric conductivity governs the time constant. The mechanical processes of the formation and the decay of the deformation are subject to a certain inertia. The decisive forces for this are the surface tension which tends to level out the surface of the liquid, and the viscosity which takes the function of damping. If we watch one given image point we observe the following process: At the beginning of the image period, the cathode ray passing the image point deposits an electrical charge within a very short time $< 10^{-7}$ sec. The electrostatic forces become effective at once and the deformation of the surface begins according to an exponential law (cf. Fig. 6). The time constant is proportional to the quotient of the surface tension and the viscosity. For a non-conductive Eidophor the deformation would tend to reach a definite final value (Fig. 6a). As, however, the charge diminishes according to an

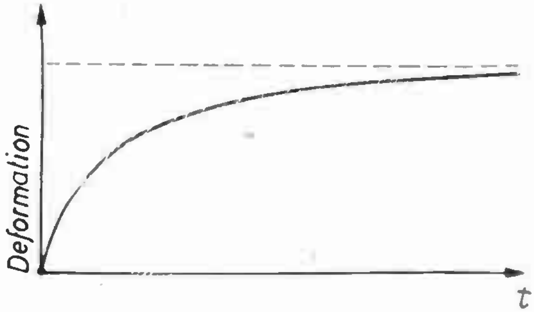
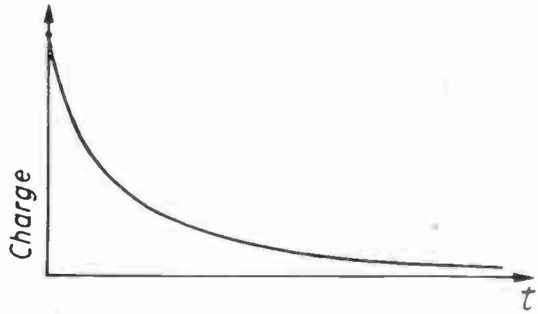
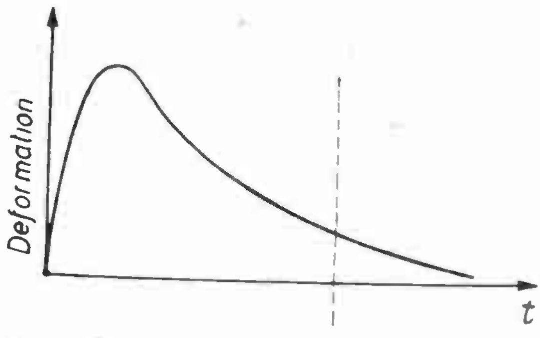


Fig. 6.—(a) Build-up of the deformation for a non-conductive liquid.



(b) Decay of the charge in a conductive liquid.



(c) Development of the deformation in a conductive liquid.

exponential function, the forces causing the deformation are diminished as well (Fig. 6b), so that both causes result in a development of the deformation as illustrated in Fig. 6c. For a whole series of successive image periods, a development as illustrated in Fig. 7 results. For all practical purposes, a remainder of 10 per

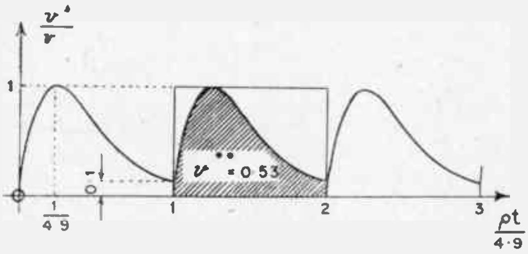


Fig. 7.—Development of the deformation of the medium with time.

cent. of the deformation, at the end of the image period, is tolerable. This time law of the deformation allows an effective light-storage of about 70 per cent.

As is easily seen, the Eidophor image constantly carries a certain average negative charge which exercises a constant average mechanical pressure on the oil surface. If the oil film were left to itself it would be pushed out of the image field in the course of time. To prevent this, the Eidophor-carrier is slowly being turned so that the oil film in the image-field is constantly renewed. Since the rotation is very slow, its influence on the image is practically nil.

The maximum amplitude of the deformation is only a few thousandths of a millimetre. Consequently, the oil surface must be of the highest quality as even the smallest deficiencies result in an undesirable brightening-up of the screen. Fortunately this trouble can be removed to a certain extent in a comparatively easy way. If the relationship between the dimension of the raster elements and the other dimensions of the schlieren-optical system is appropriately chosen, the deflection of the light is accompanied by diffraction, which allows for a schlieren system of lower imaging quality to be used successfully.

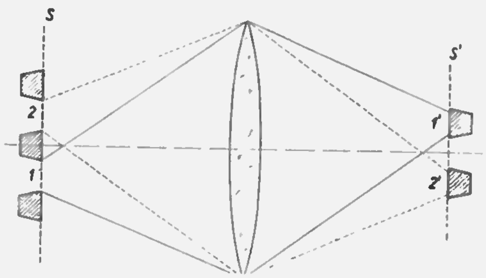


Fig. 8.—Schlieren system using diffraction.

We can now make the second bar system 1′, 2′ (Fig. 8) somewhat wider than the optical image of the slits 1, 2. The result is an elimination of the brightening-up effect of certain deformations, deformations exceeding a certain area now remaining without effect.

This new layout of the schlieren-optical system has made it possible to design a new simplified projector which is also reduced in size. Its diagram is shown in Fig. 9. The schlieren lens was replaced by a spherical mirror. Instead of two separate bar systems we now use a single one which comes twice in action. It consists of a number of mirror strips which are fixed at twice the focal distance, at an angle of 45 deg. with respect to the optical axis of the mirror. Thus the bar system carries its own image that is reflected by the mirror. The Eidophor picture itself is

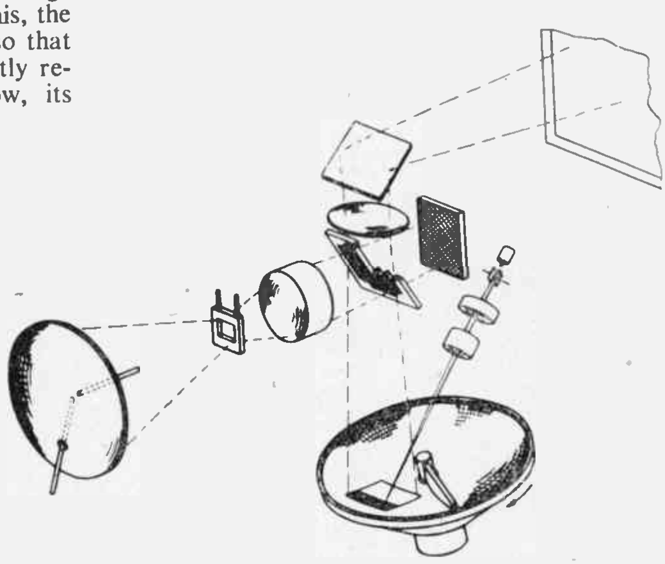


Fig. 9.—Diagram of the Eidophor projector (third prototype).

placed on the spherical mirror and again consists of a thin oil film. The mirror is now caused to rotate slowly and a straight radial ruler allows the passage of a quantity of oil necessary for the production of the picture-carrier.

Optically the system works as follows: The mirror strips are illuminated by an arc lamp, the light-pencil of which is at a right angle to the axis of the spherical mirror. By an illuminating lens an image of the arc crater is formed on the Eidophor. The relative position of the bar system and the spherical mirror is so as to cause all the light to fall back on the arc, owing to the focusing power of the spherical mirror, as long as the Eidophor surface is absolutely smooth. But as soon as the Eidophor surface is deformed, the light is accordingly allowed to pass through the slits of the bar system and to enter the projection lens. It then reaches the screen by a deflecting mirror. Of course, full use is made of the diffraction optic and the edges of the mirror strips are, therefore, blackened and non-reflecting. The deposition of the charge on the oil film has been taken over from the old system without any change.

The principal advantages of the new system as compared with the old one are

Fig. 10 (above).—View of third prototype projector. The "electron gun" structure can be clearly seen, also the Eidophor container.

(Right) View of the projector from the rear. The arc lamp projector is prominent, and the high-vacuum equipment can be seen below it.

the following. Owing to the use of a reflecting optic, the light path through the schlieren system is now only half its original length. The diffraction optic also allows us to make use of a large image angle in the schlieren system and a consequent small focal length of the mirror. This leads to a much more convenient optical layout and to a considerable reduction of the outward size of the projector. Even now it does not take up more space than an ordinary cinema projector. This reduction in size is clearly illustrated by the fact that the distance of the two bar systems of the schlieren-optical system was about 3 metres in the old projector whereas the distance between the reflecting bars and the mirror is only 75 cm in the new system. Also the cooling of the Eidophor liquid has been made easier, as the Eidophor picture itself can now be cooled. This, in turn, allows a reduction of the rotating speed of the mirror so that the production of interlaced pictures is possible without difficulties.

4. The Definition of the System

Having seen the underlying principles of the operation of this system we shall now discuss some of the most important details. A problem of the first importance is, of course, the question of definition. Contrary to certain other systems, the definition of the picture is totally independent of the light-capacity, which, of course, is a great advantage. We know that the pictures are rastered. The attainable limit of the resolving power is dependent on the number of the raster elements and this might be the cause of a certain limitation. But this is, in practice, by no means the case as it is possible to produce more than 1,000 raster elements per line, a number which meets all requirements for the time being. The same can be said about the number of lines. We did not limit ourselves to any fixed number, and our system has been working at 392, 625 and 729 lines. The situation may be most clearly illustrated by saying that the system allows frequency band widths of 10 Mc/s and more to have their entire picture information on the screen.

5. Production of Picture Raster

Contrary to the functioning of the ordinary cathode ray tubes we do not use amplitude modulation but a kind of velocity modulation of the cathode ray. To produce the picture raster we have to deposit a periodic distribution of the charge along every line of the Eidophor picture, the magnitude of this charge being proportional to the brightness of every picture point.

The cathode ray which is of constant intensity shows a rectangular cross-section on the oil surface. The height of this rectangle is the same as the width of one picture line, its width being about 10 to 20 per cent. of the height. As long as the cathode ray travels along the line with constant velocity, it will deposit per unit of length a constant charge on the surface, the density of this charge being proportional to the writing speed for a constant intensity of the beam. We can thus influence the density of the charge by varying the writing speed. If the speed is great, a small charge is deposited; if it is small the charge becomes proportionately greater. In order to produce the modulation, an alternating voltage of constant frequency is superimposed on the line sweep voltage. The frequency of this additional voltage controls the dimension of the raster elements, the amplitude controlling the density of the charge deposited (cf. Fig. 11).

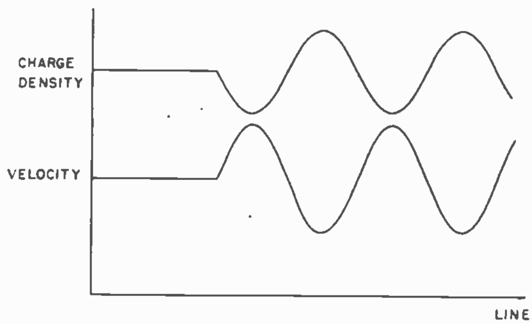


Fig. 11.—Velocity modulation of the cathode ray.

For the practical application of this modulating system it is useful to introduce the additional modulation velocity through separate plates. For the full control of the picture modulation potentials of about 1 V are sufficient.

It can be seen from the way the raster is produced that it is very important that the size and shape of the cathode ray spot remains unchanged over the whole picture area. Great care must therefore be given to an accurate focusing of the beam. Any widening of the spot causes the picture to grow darker, but the definition of the picture is hardly influenced by this. In order to obtain a constant rectangular shape of the spot, a mechanical tungsten diaphragm is placed in the cathode ray optic in the crossover of the electrons in front of the cathode; the rectangular opening of the diaphragm is $0{\cdot}1 \times 0{\cdot}015$ mm (= $0{\cdot}004$ in. $\times$ $0{\cdot}0006$ in.). A magnetic lens projects the image of this opening electronically on the Eidophor surface at the scale 1 : 1. The considerable inclination of the cathode ray with respect to the picture plane demands, of course, adequate correcting potentials, which must be varied with great precision so as to assure good focusing. Moreover the ordinary difficulties that arise in any electron-optical system have to be overcome, and the

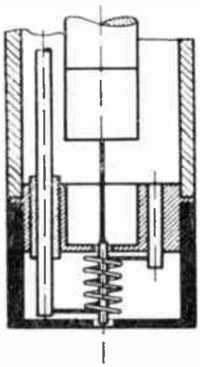


Fig. 12.—Cross-section of the cathode of the electron-gun.

actual limitation of the imaging quality of the crossover diaphragm lies in the aperture defects of the magnetic lens.

A valuable help in the solution of the whole problem is of course the constant beam current. In order to obtain the necessary density in the cathode beam, a special cathode was developed. Unfortunately the use of oxide-coated cathodes is impossible. The hydrocarbon vapours produced by the Eidophor would soon render such a cathode ineffective. For the time being pure tungsten is used as material for the cathode. Fig. 12 shows a diagram of the cathode now used. The carrier of the emission is a tungsten bar which tapers at its back end to avoid a great loss of heat. This bolt is surrounded by a helix made of tungsten wire which serves to heat up the bar. The transmission of heat through the radiation of the heated helix does not suffice to bring the bolt to the high temperature required. We therefore apply to the helix a potential of adequate magnitude, negative with respect to the bolt. The bolt is thus submitted to an intense bombardment of electrons, which results in an additional heating up. By means of this device, for the size of the spot as given above, the beam current can reach about 20 μA, an intensity which is sufficient for the full control of the television picture for line-numbers and picture frequencies as they are used to-day. The picture and line deflections are effected magnetically. The dimensioning of the deflection elements was given special care, not only in connection with the problem of focusing, but also in order to reduce the distortion of the picture to a minimum.

6. The Eidophor Liquid

The technological problems that had to be solved in the development of the whole system were numerous and also very difficult in parts. The Eidophor liquid and the cathode beam are placed in a vacuum. In order to keep the pressure at about 10^{-5} to 10^{-4} mm Hg, a continuously operating oil diffusion pump is mounted on the projector. Vacuum technique is so easily handled to-day that such a pump no longer presents any serious difficulties for the practical application of the projector.

A problem of fundamental importance was the production of a suitable Eidophor liquid because it had to meet requirements in many respects. In the beginning of the development it was a disputable point whether or not the oil would bear the intense bombardment of electrons of a velocity of about 20 kV without being destroyed. Indeed, some initial difficulties in this respect had to be overcome, but we are now sure that the Eidophor liquid can have a quite considerable life. If the oil was suitably chosen, no perceptible destruction was observed. Further qualities of the Eidophor liquid should be: very small vapour pressure (less than 10^{-5} mm Hg), optimal surface tension, dielectric constant, viscosity and electric conductivity. Of course the Eidophor should be as transparent as possible to prevent any influence on the colour of the screen picture. It is thus easily seen that the production of a suitable Eidophor liquid is a science of its own. Although many improvements are still to be desired, the results reached so far are quite satisfactory, especially if we consider the complicated nature of the problem.

It was mentioned before that the decay of the Eidophor deformation depends on the viscosity of the oil. As the viscosity, in turn, is largely dependent on the temperature, it is necessary to keep the temperature of the Eidophor constant during the period of its operation. This constancy however need not be very accurate, and an ordinary refrigerating machine, such as is commonly used in household refrigerators, can be used for this purpose.

The whole process of the production of these images is a very sensitive method to show very small optical inhomogeneities. Unfortunately there are not only the voluntarily produced inhomogeneities which serve for the production of the picture, the oil surface sometimes also shows undesired ones that appear as defects of the screen picture. Our worst enemy in this respect is any kind of dust that may enter whilst the system is put together and which may then be deposited on the optically sensitive parts. One of the most critical points is the spherical mirror which is at the same time the carrier of the Eidophor. The polish of its glass surface must be of an excellent quality and the metallizing (done by evaporation) can hardly be carried out carefully enough.

7. Conclusions

The results that have so far been reached with the third prototype can be described as follows: The laboratory equipment is capable of projecting 4,000 to 4,500 lumen on the screen. The contrast ratio between "black screen" and "white screen" is 1 : 200 to 1 : 400. The producible contrast in a picture is naturally largely influenced by the projection room, since the quantity of ambient light brightening up the dark parts of the picture depends on the nature of this room. The subjective impression that is given by the picture can quite well be compared with that of an ordinary motion picture. Gradation and definition will of course vary according to the quality of the picture source. Experience has shown that the observer has a tendency to judge the gradation of large pictures much more severely than the one of an ordinary home set. A very careful electrical correction is therefore necessary. With respect to definition no final verdict can yet be given, but interlaced pictures of 625 lines have yielded quite encouraging results. It is certain that any limits of the quality of the picture lie for the time being in the picture source and not in the projector. If there have been any troubles that could not be eliminated so far they have been due mostly to dust particles that could not be removed in time. But the continual progress observed justifies an optimistic outlook.

Our system will have to stand the practical test outside the laboratory before long. We know very well that the final practical success is still far away and we are far from underestimating the difficulties. But we also have every reason for looking ahead optimistically, hoping to have that bit of luck which is indispensable for any kind of undertaking.

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A SYSTEMATIC METHOD OF LINEAR SMALL-SIGNAL V.H.F. ANALYSIS FOR VALVE CIRCUITS*

by

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SUMMARY

While equivalent circuits of the valve with properties simulating electron inertia effects are known, the increased use of the V.H.F. band and the use of valve connections other than the once customary cathode-separation type has brought about the need for a simpler and more direct system of valve circuit analysis which ensures that electron inertia effects are inherent in the results.

This paper outlines such a system of small-signal analysis. A basic functional circuit system of the triode is developed, in which the valve is regarded as a passive circuit element described by a set of linear equations expressing the mesh current associated with each adjacent pair of electrodes in terms of external small-signal voltages applied between a common point and each electrode. The general method of applying this basic system to any specific problem is to substitute an impedance (or a short-circuit) for one or more of the ideal external generators, in accordance with the substitution theorem of network analysis.

The system is particularly applicable to the calculation of the noise factor of V.H.F. valve circuits Typical examples which illustrate the method of application are given.

1.0. Historical Introduction

1.1. It has long been recognized that the rapid early advance in the technique of valve amplifier design resulted partially from the advent of the small-signal equivalent circuit of the triode, as originally proposed by Nichols[1] in 1919 and developed by others (Fig. 1). This equivalent circuit interpreted the essential characteristics of the valve in a way which enabled the existing tools of linear circuit analysis to be applied directly to valve circuits.

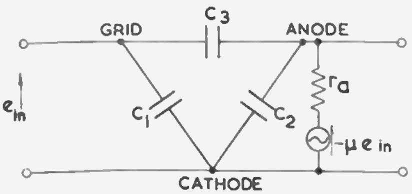

Fig. 1.—Nichols' equivalent network for the triode.

With the development of tetrode and pentode valves, the capacitance between the control-grid and anode was, for most purposes, reduced to a negligible magnitude. Apart from the practical advantages in enabling high gain, stable R.F. amplifiers to be built, this also enabled considerable simplification of the valve equivalent circuit to be made. Thus, the input and output valve capacitances were included in the external circuits and the control-grid to anode direct capacitance was disregarded (Fig. 2). The equivalent circuit was thereby reduced to an ideal alternating voltage generator in series with a resistor (the anode a.c. resistance) or an ideal current generator in shunt with the same value of resistance. In this form the equivalent circuit of the valve as an amplifier at low, or moderately high, radio frequencies is in common use to-day.

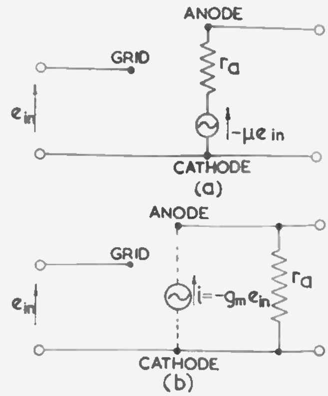

Fig. 2.—Two alternative equivalent circuits for the valve, in current use.

1.2. The effect of electron inertia on valve characteristics was initially investigated by Benham[2] in 1928, who showed that, among other things, the resulting phase lag of the alternating

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component of current behind the corresponding electrode voltages modified the inter-electrode capacitances. In 1936, North and Ferris[3] showed that, at the higher radio frequencies, the input damping resulting from electron inertia was of sufficient importance to become a limiting factor in amplifier design. This electronic input damping was subsequently accounted for in the equivalent circuit by shunting an appropriate resistor across the input terminals of the modified Nichols circuit for the pentode.

1.3. Two years later, Strutt and van der Ziel[4] published the results of an investigation into the effects of the connecting wires between the electrodes and the base pins. The most important result was that the self-inductance in the cathode lead common to input and output circuits produced input damping similar in its effect to that produced by electron inertia. With valves then in current use, this lead inductance effect was the greater of the two. As with electronic damping, lead inductance damping has, in subsequent literature, been accounted for by an appropriate value of shunt resistance across the input terminals. The other effect of cathode lead inductance, namely, the reduction in the magnitude of the mutual conductance by the usual feedback effect, appears to have been given no emphasis. Very recently, Zepler[5] has emphasized the importance of the self-inductance and mutual inductance associated with the leads to all three electrodes of a triode, in their effect on the input damping of a conventional cathode separation circuit.

1.4. The importance of noise arising from the shot effect in the first valve of a R.F. amplifier has long been recognized. More recently, noise effects at very high frequencies allied with the electronic input damping have been investigated, usually under the name induced grid noise.[6] Such effects have often been calculated in terms of the usual equivalent circuit by ascribing to the electronic input damping equivalent resistance a Johnson noise, as if this resistance were at five times the absolute standard room temperature.

2.0. The Need for a New Approach

2.1. It is apparent from the preceding section that electron inertia effects, important in the V.H.F. range, have in the main been represented by *ad hoc* modifications to the L.F. equivalent circuit for the cathode separation valve amplifier. While these modifications are undoubtedly correct within their intended domain, their scope is limited to the type of valve circuit for which they were originally devised. Uncritical application to other types of circuit, or to different forms of circuit adjustment, can lead to erroneous results, examples of which are to be found in existing literature. Furthermore, such special artifices lead to no basic concept or general method.

There is need, therefore, for a fundamentally new circuit concept of the radio valve, which is of general application and deals inherently with electron inertia effects. This need has been brought about, not only by the importance of electron inertia effects in the increasingly used V.H.F. band, but also by the increased use of circuit arrangements other than the cathode separation arrangement.

2.2. Since amplifiers in communication networks usually consist of several stages in cascade, and since the theory of four-terminal networks in cascade has been highly developed, it is natural to seek an equivalent four-terminal network for any single valve stage. The Nichols circuit is one of this class of network, and for L.F. application it can also be adapted to grid separation or anode separation arrangements.

For V.H.F. application, a general equivalent circuit of the valve, composed of standard active and passive circuit elements, was devised by Llewellyn.[7] A different type of equivalent circuit, of the same class, but which fits in with the nodal method of network analysis, has also been devised by Llewellyn and Peterson.[8] Very recently, yet another circuit representation in which the active circuit elements have been replaced by negative resistance elements, has been developed by Keen,[9] although it does not appear to have been extended to V.H.F. application.

All these representations have this in common: they are descriptions in terms of the familiar active and passive circuit elements of electrical engineering, descriptions which are artificial and are liable to conceal the true interaction between valve and circuit. As a result, they sometimes become cumbersome when applied to V.H.F. problems.

A different approach to the circuit concept of the valve has been made by Campbell, Francis and James,[10] who consider the valve as a multi-terminal passive network. The essence of this method is that, while no artificial model composed of standard active and passive elements is used, the valve is treated as a circuit element in its own right, described by a set of linear simultaneous equations between the electrode voltages and currents. Such a network is readily reduced to a four-terminal form, once the method of valve connection is defined.

2.3. The present work describes in detail what is, in effect, a development from this last-mentioned approach in which the valve is regarded as a passive linear circuit element, but differently arranged so as to enable it to deal inherently with electron inertia effects. This is largely achieved by approaching the problem as much from the standpoint of the internal action of electrode systems as from the standpoint of circuit analysis. The result is a systematic method of analysis which, apart from utilitarian considerations, has an heuristic value in that it enables one to understand, in a direct intuitive way, the "effects" of electron inertia and, therefore, to appreciate the limitations of such concepts. The basic mathematical treatment of electron inertia is long and tedious with little in it to enable the circuit engineer to form a clear picture of the whole situation. An adequate functional circuit model of the valve, on the other hand, should enable one to form a coherent mental picture of its operation, using only the elementary concepts of circuit analysis.

3.0. On the Interaction Between Valve and Circuit

3.1. As a starting point in introducing the new scheme of circuit analysis, some familiar properties of the valve are re-stated in a form which leads directly to the concepts underlying the proposed functional model of the valve as a circuit element. Here, as in the remainder of this work, illustrations are confined to the triode system. Since triodes are now often used in the early stages of V.H.F. amplifiers, this does not seriously limit the range of immediate application.

Consider the steady-state or static circuit shown in Fig. 3. Direct e.m.f's V_g (negative) and V_a (positive) are applied by ideal zero-impedance generators. Under this condition, the cathode-grid space (space I) acts as a space-charge control diode, the control voltage V_c being given in terms of the actual electrode potentials (relative to the cathode) by:

$$V_c = \sigma(V_g + V_a/\mu) \quad \ldots\ldots\ldots\ldots (1)$$

where σ is a geometrical constant, slightly less than unity in practice, μ is the triode amplification factor, and contact potentials and like effects are included in V_g.

The finite ratio of charge to mass of an electron, as well as being responsible for the space-charge limitation of current, results in a finite time of transit in each space, expressed by:

$$\text{(space I)}\ \tau_1 = \frac{5 \times 10^{-8} d_1}{V_c^{1/2}}\ \text{(sec)} \quad \ldots\ldots\ldots (2)$$

$$\text{(space II)}\ \tau_2 = \frac{3{\cdot}3 \times 10^{-8} d_2}{V_c^{1/2} + V_a^{1/2}}\ \text{(sec)} \quad \ldots\ldots\ldots (3)$$

Here, d_1 and d_2 are the spaces traversed (cm), τ_1 is the transit time in space I and τ_2 is the transit time in space II.

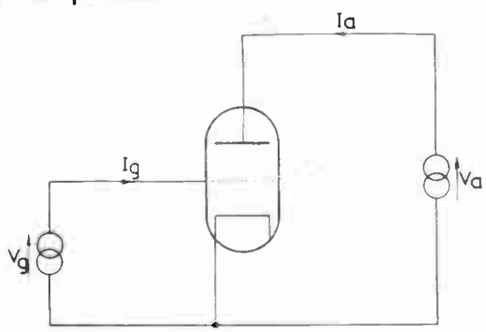

Fig. 3.—The conventional static circuit of the triode.

3.2. If, now, small alternating voltage components are superimposed on V_g and V_a, the space currents will have corresponding alternating components. In the customary manner, it is assumed that the response to all such small alternating components is linear, so that the superposition theorem of linear circuit analysis is valid.

In the theory of the static state of the valve, it is usual to consider the rate of arrival of electrons at an electrode and the resulting *branch* current in the connection to the electrode.

For an adequate theory of the small signal dynamic state of valve operation, however, it has long been considered necessary to take account of the fact that electrons in motion across an inter-electrode space continuously *induce* a current between the bounding electrodes. Therefore, it is natural to consider the induced electronic alternating component of current and the resulting *mesh* current in the external circuit associated with the bounding electrodes. This

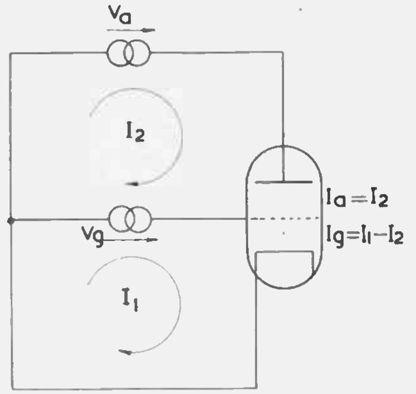

Fig. 4.—Illustrating the induced currents in the inter-electrode spaces by mesh currents in the external associated circuits. The network is the same physically as that of Fig. 3.

is the essence of the approach of the present work. (Fig. 4.) In the static (or quasi-static) case the difference between the two approaches is trivial, since with negative grid potential (Fig. 3), $I_1 = I_2$ and the branch current to the grid, $I_1 - I_2$, is zero, the current flowing, in effect, direct from cathode to anode.

3.3. The alternating voltages will produce a displacement current across each space by virtue of the ordinary "cold" inter-electrode capacitances, as well as producing a purely electronic induced current. When the cathode is cold, the triode can be regarded as a multiple capacitor, the direct (partial) capacitances c_1 and c_2 associated with spaces I and II respectively being most important. The direct capacitance c_3 between cathode and anode through the grid mesh is usually relatively small, especially when μ is large, and is often negligible. When, as is sometimes the case, c_3 includes inter lead-in wire and such like capacitances as well as the smaller capacitance through the active part of the grid, it is no longer negligible. The superimposed cold capacitances of the electrode spaces are shown in Fig. 6.

4.0. The Proposed Passive Linear Circuit System

4.1. The small-signal circuit system is developed from Fig. 4 of the preceding section. Instead of placing an ideal external generator across each space, one is placed in each of the three electrode branch connections, and the current arising from purely electronic effects is considered in the mesh associated with each of the two spaces. A simple application of the superposition theorem[11] in conjunction with the considerations of section 3 readily yields the linear equations connecting the mesh currents i_1 and i_2 with the branch e.m.f.'s e_1, e_2 and e_3, as is demonstrated below with the help of Fig. 5.

1. Let $e_2 = e_3 = 0$; then if y_1 is the electronic admittance of space I and if y_2 is the electronic transadmittance of the current in space II with respect to the total e.m.f. across space I, we have:—

$$i_1 = y_1\left(1 + \frac{1}{\mu}\right) e_1 \text{ and}$$

$$i_2 = y_2\left(1 + \frac{1}{\mu}\right) e_1 \quad \ldots\ldots\ldots\ldots\ (4)$$

2. If $e_1 = e_3 = 0$, then:

$$i_1 = y_1 e_2 \text{ and } i_2 = y_2 e_2 \quad \ldots\ldots\ldots\ (5)$$

3. If $e_1 = e_2 = 0$, then:

$$i_1 = \left(\frac{y_1}{\mu}\right) e_3 \text{ and } i_2 = \left(\frac{y_2}{\mu}\right) e_3 \ldots (6)$$

Superimposing (4), (5) and (6) yields:

$$\left.\begin{aligned} i_1 &= y_1\left(1 + \frac{1}{\mu}\right)e_1 + y_1 e_2 + \frac{y_1}{\mu} e_3 \\ i_2 &= y_2\left(1 + \frac{1}{\mu}\right)e_1 + y_2 e_2 + \frac{y_2}{\mu} e_3 \end{aligned}\right\} \ldots (7)$$

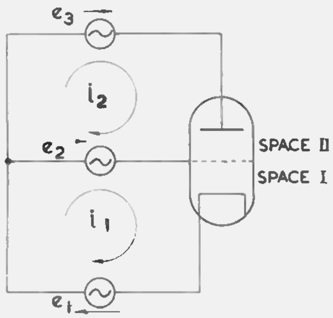

Fig. 5.—Illustrating the system of small-signal mesh currents i_1 and i_2 associated with the two inter-electrode spaces, and the applied small-signal e.m.f. in each branch.

Currents induced directly in space II by electrons moving in space I, and vice versa, are neglected on the assumption that the grid mesh is relatively fine and exercises appreciable screening. Only currents in space II resulting from the passage of electrons from space I between the grid wires are considered.

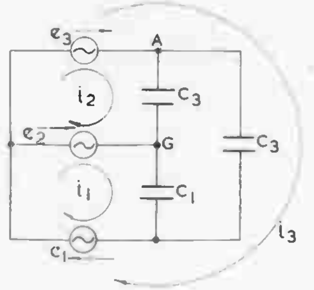

Fig. 6.—Illustrating the superimposed "cold" capacitance meshes, with the additional mesh i_3 to include C3.

4.2. In equations (7), the cold inter-electrode capacitances have been disregarded, and their effect must now be considered. The appropriate capacitance network is illustrated in Fig. 6, in which a third mesh current i_3 is included to take account of the effect of $C3$. The equations connecting the mesh currents with the branch e.m.f.'s are obtained as follows:—

1. Let $e_2 = e_3 = 0$. Then if we write η_1 for $j\omega c_1$, and similarly for $C2$ and $C3$.

$$i_1 = \eta_1 e_1,\ i_2 = 0,\ i_3 = \eta_3 e_1 \quad \ldots\ldots (8)$$

2. Let $e_1 = e_3 = 0$, then

$$i_1 = \eta_1 e_2,\ i_2 = -\eta_2 e_2,\ i_3 = 0 \quad \ldots\ldots (9)$$

3. Let $e_1 = e_2 = 0$, then

$$i_1 = 0,\ i_2 = \eta_2 e_3,\ i_3 = \eta_3 e_3 \quad \ldots\ldots (10)$$

Superimposing (8), (9) and (10) yields:

$$\left.\begin{aligned} i_1 &\doteq \eta_1 e_1 + \eta_1 e_2 \\ i_2 &= -\eta_2 e_2 + \eta_2 e_3 \\ i_3 &= \eta_3 e_1 + \eta_3 e_3 \end{aligned}\right\} \quad \ldots\ldots (11)$$

4.3. The proposed set of linear equations which define the triode system as a passive circuit element are obtained by superimposing equations (7) and (11), and are expressed:—

$$\left.\begin{aligned} i_1 &= \left[y_1\left(1 + \frac{1}{\mu}\right) + \eta_1\right] e_1 + (y_1 + \eta_1) e_2 + \frac{y_1}{\mu} e_3 \\ i_2 &= y_2\left(1 + \frac{1}{\mu}\right) e_1 + (y_2 - \eta_2) e_2 + \left(\frac{y_2}{\mu} + \eta_2\right) e_3 \\ i_3 &= \eta_3 e_1 + \eta_3 e_3 \end{aligned}\right\} \quad (12)$$

The system is illustrated by the schematic diagram of Fig. 7, in which e_1, e_2 and e_3 are the values of three zero-impedance, alternating-voltage generators associated with the external circuits. The properties of the valve are defined by the set of simultaneous linear equations (12) between the mesh current associated with each pair of electrodes and the applied e.m.f. in the branch of the external network associated with each electrode.

4.4. Spontaneous random fluctuations associated with the shot effect are taken into account by including the induced noise current components associated with an infinitesimal frequency range of response (such as f to $f + df$), in spaces I and II. A component δi_1 originates in space I and the component δi_2 in space II results from the electron stream from I passing into II between the grid wires. In so far as all electrons contributing to δi_1 pass through the grid into space II, δi_1 and δi_2 are completely correlated and a relationship exists between them. The mesh currents arising from the shot effect, and which are to be superimposed on the circuit of Fig. 7, are shown in Fig. 8. The set of equations applicable to the calculation of valve noise in the V.H.F. range of response are expressed:—

$$\left.\begin{aligned} i_1 &= \left[y_1\left(1 + \frac{1}{\mu}\right) + \eta_1\right] e_1 + (y_1 + \eta_1) e_2 + \frac{y_2}{\mu} e_3 + \delta i_1 \\ i_2 &= y_2\left(1 + \frac{1}{\mu}\right) e_1 + (y_2 - \eta_2) e_2 + \left(\frac{y_2}{\mu} + \eta_2\right) e_3 + \delta i_2 \\ i_3 &= \eta_3 e_1 + \eta_3 e_3 \end{aligned}\right\} \quad (12a)$$

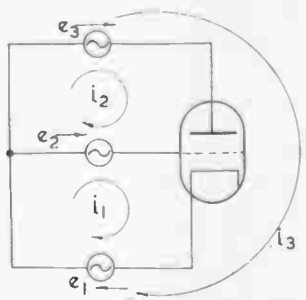

Fig. 7.—The proposed basic triode system with three mesh currents, i_1, i_2 and i_3, and three applied e.m.f.'s, e_1, e_2 and e_3. This system is formed by the superposition of the systems of Figs. 5 and 6.

It should be noted that any noise currents induced in space I not correlated with space II noise currents, or any external noise sources, must be dealt with by separate calculations. The resultant noise current in the required part of the external network is determined by the sum of the squares of the moduli of the several parts.

4.5. The system is readily extended to multi-electrode valves. If the coefficients of the e's were written in the general form γ_{kl}, the general set of equations for an n- electrode valve would be written

$$i_k = \sum_{1}^{n} {}_l\gamma_{kl} e_l \; (k = 1 \text{ to } n - 1) \quad \ldots\ldots\ldots(13)$$

where the e's are applied between each electrode and a common external point. This system of equations does not include the effect of direct capacitances through one or more grids: their inclusion would require additional relations, corresponding to the third equation in (12) for the triode.

5.0. The Values of the Electronic Admittances

5.1. A set of equations has been given to define the triode system and although much analysis can be carried out with these equations as they stand, until the electronic admittances y_1 and y_2 are evaluated in terms of known parameters, they remain, as it were, a blank form.

No complete expressions for these electronic admittances are known, but by making a number of inevitable approximations, the Benham-Llewellyn theory may be applied to the problem. The resulting expressions are quite well known. The assumptions are that the initial electron velocity at the cathode is negligible in its effect, that the grid mesh is fine enough to preclude direct induction from space I to space II, and that the electrode system is uniform for all electrons.

If α_1 is written for $j\omega\tau_1$, where τ_1 is the mean transit time in space I, then when the transit time τ_2 in space II is neglected, these well-known results are:

$$y_1 = g_m \left\{ \frac{\alpha_1^4}{12\left[\frac{1}{6}\alpha_1^3 - \alpha_1 + 2 - (2+\alpha_1)\varepsilon^{-\alpha_1}\right]} - \frac{\alpha_1}{2} \right\} \quad \ldots\ldots\ldots\ldots(14)$$

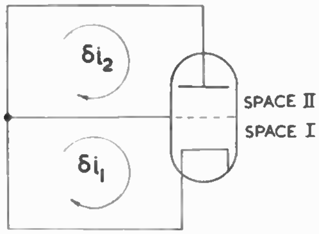

Fig. 8.—The mesh currents δi_1 and δi_2 arising from the shot-effect and associated with the frequency response range f to $f + df$.

$$y_2 = g_m \left\{ \frac{\alpha_1^2\left[1 - (1+\alpha_1)\varepsilon^{-\alpha_1}\right]}{6\left[\frac{1}{6}\alpha_1^3 - \alpha_1 + 2 - (2+\alpha_1)\varepsilon^{-\alpha_1}\right]} \right\} \quad (15)$$

When the transit time in space II is brought into account, equation (15) for y_2 must be multiplied by the factor

$$\frac{2}{1+\kappa}\left\{\frac{\kappa-1}{\alpha_2^2}\left[1 - (1+\alpha_2)\varepsilon^{-\alpha_2}\right] + \frac{1}{\alpha_2}\left(1 - \varepsilon^{-\alpha_2}\right)\right\} \quad \ldots\ldots\ldots\ldots(16)$$

in which $\alpha_2 = j\omega\tau_2$ and $\kappa = (V_a/V_c)^{1/2}$. If, as is usually the case in practice, $\kappa \gg 1$, then this factor (16) is very nearly equal to

$$\frac{2}{\alpha_2^2}\left[1 - (1+\alpha_2)\varepsilon^{-\alpha_2}\right] \quad \ldots\ldots\ldots\ldots(17)$$

5.2. Expressions (14) and (15) with (17) are too cumbersome for ready application to circuit problems, but when $\omega\tau < 1$, as is often the case, the expressions may be written as power series in α. Thus

$$y_1 = g_m\left(1 - \frac{1}{5}\alpha_1 + \frac{7}{300}\alpha_1^2 - \ldots\right) \quad \ldots(18)$$

$$y_2 = g_m\left(1 - \frac{11}{30}\alpha_1 + \frac{11}{150}\alpha_1^2 - \ldots\right) \times \left(1 - \frac{2}{3}\alpha_2 + \frac{1}{4}\alpha_2^2 - \ldots\right) \ldots(19)$$

These are immediately reducible to the convenient form $g - jb$ which can be applied directly to circuit problems with a minimum of algebra. In detail,

$$y_1 = g_1 - jb_1 \quad \ldots\ldots\ldots\ldots(20)$$

$$\text{where } g_1 = g_m\left(1 - \frac{7}{300}\omega^2\tau_1^2\right) \quad \ldots\ldots(21)$$

$$b_1 = \frac{1}{5} g_m \omega\tau_1 \quad \text{.................}(22)$$

and $y_2 = g_2 - jb_2$ ....(23)

where $g_2 =$

$$g_m\left(1 - \frac{11}{150}\omega^2\tau_1^2 - \frac{11}{45}\omega^2\tau_1\tau_2 - \frac{1}{4}\omega^2\tau_2^2\right) \quad \text{....................}(24)$$

$$b_2 = g_m\left(\frac{11}{30}\omega\tau_1 + \frac{2}{3}\omega\tau_2\right) \quad \text{......}(25)$$

retaining only terms up to the second power in $\omega\tau$. Formulae (20) to (25) are adopted provisionally, in this work, for V.H.F. analysis.

5.3. A further simplification may be made by retaining only the first power in $\omega\tau$, and writing in the polar form $y = |y|\varepsilon^{j\phi}$. In detail,

$$y_1 = g_m\varepsilon^{j\phi_1} \quad \text{.....................}(26)$$

$$y_2 = g_m\varepsilon^{j\phi_2} \quad \text{.....................}(27)$$

where $\varphi_1 = \frac{1}{5}\omega\tau_1$ ....(28)

$$\varphi_2 = \frac{11}{30}\omega\tau_1 + \frac{2}{3}\omega\tau_2 \quad \text{...........}(29)$$

are the phase angles of y_1 and y_2 respectively. These expressions for the admittances in the form of magnitude and phase angle are especially helpful in promoting an intuitive understanding of some electron inertia effects.

5.4. Finally, in the range of frequencies low enough to permit the phase angles to be disregarded,

$$y_1 = y_2 = g_m \quad \text{...................}(30)$$

This condition can often be applied to circuits operating at frequencies up to several megacycles per second without serious error, and, in fact, has been so applied uncritically to much higher frequency ranges. Under such conditions, though, the results are more qualitative than quantitative, a fact that has seldom been appreciated.

All the expressions for y_1 and y_2 given in this section are well known to a greater or lesser extent. They are collected together here in a form which displays the various orders of accuracy and the range of applicability of each order.

5.5. For the calculation of noise currents it is necessary also to evaluate the valve noise current components δi_1 and δi_2 appearing in the system of equations (12a). As with the electronic admittances, no complete expressions are known, but for most V.H.F. problems in which $\omega\tau < 1$, a simple relation between δi_1 and δi_2 is adequate.[12] It is:

$\delta i_2 =$

$$\delta i_1\left(1 - \frac{1}{3}\alpha_1 - \frac{1}{12}\alpha_1^2\right)\left(1 - \frac{2}{3}\alpha_2 + \frac{1}{4}\alpha_2^2\right) \quad \text{..............}(31)$$

To an accuracy including the first power in α,

$$\delta i_2 = \delta i_1\left(1 - \frac{1}{3}j\omega\tau_1 - \frac{2}{3}j\omega\tau_2\right) \quad \text{.....}(32)$$

The value of δi_1 is given by the well-known expression of Rack:

$$|\delta i_1|^2 = 4k\,(0{\cdot}644\,\theta_c)\,g_m\,.\,df$$

where k is Boltzmann's constant and θ_c is the absolute cathode temperature. In many problems, however, it is more convenient to define an equivalent noise resistance R_n of the triode in terms of δi_2 by the relation:

$$|\delta i_2|^2 = 4k\theta_0 R_n |y_2|^2\,.\,df \quad \text{...............}(33)$$

where θ_0 is the absolute room temperature, as was first used by van der Ziel and Versnel.[13]

6.0. The General Method of Application

6.1. The functional system illustrated in Fig. 7 and described by the set of equations (12) is a general system on which all circuit problems of the triode can be based. The method of applying this basic system to any specific problem is to substitute impedances (or short-circuits) for one or more of the external voltage generators, as required by the problem in question, and solve the set of equations (12) for the values of the mesh currents. This substitution is governed by an application of the converse of the well-known substitution theorem of network analysis. According to this, any zero impedance voltage generator which forms only part of a network may be replaced by an impedance such that the potential difference across it, derived from the current through it, is equal to the generator voltage reversed in sign. Thus, if e is the generator voltage and i is the current through the impedance Z which is to replace the generator, then

$$e = -iZ \quad \text{........................}(34)$$

When the impedance is a short-circuit, then clearly $e = 0$ since i is always finite.

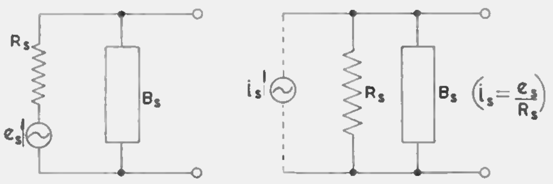

Fig. 9.—Equivalent voltage-generator and current-generator sources with the susceptance external to the valve input terminals.

6.2. In paragraph 4.2 it was stated that η is written for $j\omega C$ where C is the cold capacitance between the electrodes. With some problems, however, there may also be an external admittance connected directly between two adjacent electrodes, and in such cases η will include this admittance. An example is to be found in the method of neutralization in which the unwanted grid-anode capacitance is made part of a parallel resonant circuit. The impedance of the connecting wires to the electrodes is neglected when making this short-cut; otherwise, a more complicated method must be used.

6.3. The basic system characterized by equations (12*a*) may readily be applied to the calculation of the noise factor of a single stage. This is accomplished with great simplicity if the output terminals of the stage in question are short-circuited, and the noise factor is defined by the relation:

$$N = 1 + \frac{\overline{i_o{}^2}_v}{\overline{i_o{}^2}_s} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (35)$$

where $\overline{i_o{}^2}_v$ is the mean square current in the output due to the noise originating in the valve stage alone, and $\overline{i_o{}^2}_s$ is the mean square current in the output due to the source noise alone. The shot noise and any transit time noise effects correlated with it are taken care of by the system of equations (12*a*). Noise from other sources in the stage not correlated with the main shot noise has to be treated separately, the mean square currents in the output then being summed to form the resultant value of $\overline{i_o{}^2}_v$.

The noise factor of a whole receiver is of greater practical interest than that of a single stage. As is well known, when the gain of the first two stages is sufficient, and the bandwidth of the main amplifier is less than that of these stages, this overall noise factor is given by

$$N = N_1 + \frac{(N_2 - 1)}{M_1} \quad \ldots\ldots\ldots\ldots (36)$$

in which N_1 and N_2 are the noise factors of stages 1 and 2 respectively, and M_1 is the available power gain of stage 1 in the same state as when N_1 is calculated. The noise factor N_2 is calculated with a source admittance equal to the output admittance of stage 1, modified by any transforming network which may be interposed. It follows from equation (36) that the available gain M_1 of the first stage is of interest as well as the stage noise factor, and if M_1 is not large, the noise factor of the second stage is of interest also.

6.4. The calculation of the available gain, using the system of equations (12) can be simplified by adopting the following procedure.

Firstly, calculate the current in the short-circuited output of the stage. In doing this it is expedient to consider the source to be applied to the input of the stage in the form shown in Fig. 9, in which the usual source voltage e_s and resistance R_s are replaced by an equivalent current generator i_s in shunt with the source admittance Y_s $(= 1/R_s + jB_s)$. The source can then be regarded as having a mesh current i_s $(= e_s/R_s)$ which is coupled to the valve input mesh by the admittance Y_s, as is shown in Fig. 10, and direct application of equations (12) can then be made.

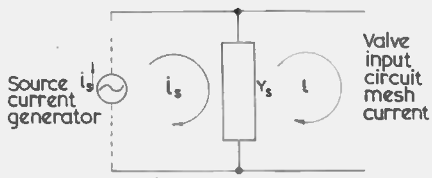

Fig. 10.—Mesh currents in the source and input coupling network. The source resistance R_s is included in the admittance Y_s.

Secondly, calculate the output admittance of the stage with the source admittance Y_s in position. This is carried out in the usual way by placing a voltage generator e in the output short-circuit and calculating the resulting current i in this short-circuit. Then $Y_{out} = i/e$.

Thirdly, the available gain is then calculated as follows, with reference to Fig. 11. In accordance with the maximum power transfer theorem of network analysis, the output load admittance Y_L $(= G_L + jB_L)$ must be the conjugate of the

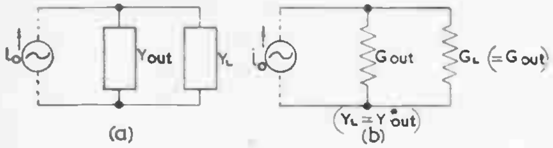

Fig. 11.—The valve output circuit. To obtain the available gain, the load admittance Y_L is made equal to the conjugate of the output admittance Y_{out}, which results in the equivalent circuit (b).

stage output admittance Y_{out} ($= G_{out} + jB_{out}$) in order to obtain the available output power in G_L. Thus we make $G_L = G_{out}$ and $B_L = -B_{cut}$ the first of these being the "matching" and the second being the "tuning" of the load.

If i_o is the current in the short-circuited output of the stage, then with matching and tuning of the load, it is seen from Fig. 11 (*b*) that the current in G_L is $i_o/2$. The available power output is then

$$P_{cut} = \frac{|i_o|^2}{4\, G_{out}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (37)$$

With reference to Fig. 10, it is seen that the available source power is given by

$$P_{in} = \frac{|i_s|^2}{4\, G_s} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (38)$$

where $G_s = \frac{1}{R_s}$.

The available gain is the ratio of equations (37) and (38) and is

$$M = \left|\frac{i_o}{i_s}\right|^2 \frac{G_s}{G_{cut}} \quad \ldots\ldots\ldots\ldots\ldots (39)$$

The ratio i_o/i_s has been calculated in the first step, and G_{out} is obtained from Y_{out}, calculated in the second step.

6.5. These calculations are equally well applied to cathode, grid or anode separation amplifier connections. Self and mutual lead inductances can, if necessary, be included, although such inclusion complicates the problems, and much useful information can be obtained without.

Other parameters, such as input admittance and the conditions for the complete stability of a stage are readily evaluated by the method.

Some examples of its application are given in an appendix. An example of application to the calculation of noise factor has been given elsewhere.[14]

7.0. Acknowledgment

Acknowledgment is made to the Ministry of Supply for permission to publish this paper. The opinions expressed do not necessarily represent the views of the Department.

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APPENDIX

Specific Applications

The input and output admittances of a cathode-separation triode amplifier stage are calculated, providing two specific examples to illustrate the general method of application. When, in these examples, specific expressions for the electronic valve admittances and the cold valve susceptances are substituted for the general symbols, two cases arise according to whether the grid-anode capacitance c_2 is neutralized by parallel resonance or not. The resulting expressions for the output conductance are then used to calculate the available gain of such a stage, in each case.

For the calculation of input admittance, e_2 in Fig. 7 is the input e.m.f.; $e_1 = 0$ if the lead inductance common to input and output circuits is neglected; and $e_3 = -i_2/Y_L$ where Y_L is the output load admittance. The direct cathode to anode capacitance c_3 and the associated mesh current i_3 are disregarded, since such a capacitance can be regarded as being included in Y_L.

The input admittance is basically defined as:

$$Y_{in} = \frac{(i_1 - i_2)}{e_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (40)$$

Under the above-mentioned conditions, equations (12) become:

$$\left.\begin{aligned} i_1 &= (y_1 + \eta_1)e_2 - \left(\frac{y_1}{\mu}\right) Y_{L}^{-1} i_2 \\ i_2 &= (y_2 - \eta_2)e_2 - \left(\frac{y_2}{\mu} + \eta_2\right) Y_L^{-1} i_2 \end{aligned}\right\} \ldots (41)$$

or, after transposing to form a set of equations for i_1 and i_2:

$$\left.\begin{aligned} i_1 + \left(\frac{y_1}{\mu}\right) Y_L^{-1} i_2 &= (y_1 + \eta_1)e_2 \\ \left[Y_L + \frac{y_2}{\mu} + \eta_2\right] Y_L^{-1} i_2 &= (y_2 - \eta_2)e_2 \end{aligned}\right\} \ldots (41a)$$

i_2 follows immediately from the second equation, and substitution for i_2 in the first gives i_1. The resulting value of $i_1 - i_2$ leads to

$$Y_{in} = (y_1 - y_2) + (\eta_1 + \eta_2) + \frac{\left[\eta_2 - \frac{(y_1 - y_2)}{\mu}\right](y_2 - \eta_2)}{Y_L + \frac{y_2}{\mu} + \eta_2} \ldots (42)$$

The first two main terms of this expression represent the input admittance with a short-circuited output (Y_L infinite). The real part of $y_1 - y_2$ is the electronic input damping, and the imaginary part is the electronic increase in input susceptance. The term $\eta_1 + \eta_2 = j\omega(c_1 + c_2)$ is the cold input susceptance under short-circuited output conditions. The third main term in equation (42) represents the change in input admittance occasioned by the presence of Y_L. Through η_2 ($= j\omega c_2$), this term also accounts for the well-known Miller effect.

In most triodes used in V.H.F. input stages, μ is between 40 and 100, with the result that both real and imaginary parts of $(y_1 - y_2)/\mu$ are negligible compared with other terms present in equation (42). Accordingly, (42) may be expressed in the approximate form:

$$Y_{in} = y_1 - y_2 + \eta_1 + \eta_2 + \frac{\eta_2 (y_2 - \eta_2)}{Y_L + y_2/\mu + \eta_2} \ldots (43)$$

In order to resolve this into a conductance and a susceptance, it is necessary to assign real and imaginary parts to the various symbols as follows:

$$y_1 = g_1 - jb_1 \,;\, y_2 = g_2 - jb_2 \,;\, Y_L = G_L + jB_L.$$

The electronic input conductance and susceptance are then expressed:

$$g_t = g_1 - g_2 \text{ and } \omega c_t = b_2 - b_1.$$

It is also convenient to define a capacitance $c_0 = c_1 + c_2 + c_t$.

On substituting these values in (43) and carrying out the usual operation of rationalizing, neglecting the term b_2/μ in comparison with other terms present, the following results are obtained:

$$G_{in} = g_t + \omega c_2 \frac{(G_L + g_2/\mu)(\omega c_2 + b_2) + g_2(B_L + \omega c_2)}{(G_L + g_2/\mu)^2 + (B_L + \omega c_2)^2} \ldots\ldots\ldots\ldots (44)$$

$$B_{in} = \omega c_0 + \omega c_2 \frac{g_2(G_L + g_2/)\mu - (\omega c_2 + b_2)(B_L + \omega c_2)}{(G_L + g_2/\mu)^2 + (B_L + \omega c_2)^2} \ldots\ldots\ldots\ldots (45)$$

These expressions are derived on the assumption that the valve stage is stable in the presence of c_3, such as would be attained if the load conductance G_L were sufficiently large.

For the calculation of output admittance, e_3 in Fig. 7 is the e.m.f. applied to the output terminals, $e_2 = -(i_1 - i_2)/Y_s$ where Y_s is the source admittance, and $e_1 = 0$ as before. As before, also, the mesh current i_3 is temporarily disregarded. The output admittance is basically defined as

$Y_{out} = i_2/e_3$ . . . .(46)

Under these conditions, equations (12) become:

$$\begin{aligned} i_1 &= -(y_1+\eta_1)Y_s^{-1}(i_1-i_2)+(y_1/\mu)e_3 \\ i_2 &= -(y_2-\eta_2)Y_s^{-1}(i_1-i_2)+(y_2/\mu+\eta_2)e_3 \end{aligned} \quad (47)$$

or, after transposing,

$$\begin{aligned} (Y_s+y_1+\eta_1)\, i_1-(y_1+\eta_1)i_2 &= (y_1/\mu)Y_s\, e_3 \\ (y_2-\eta_2)i_1+(Y_s-y_2+\eta_2)i_2 &= (y_2/\mu+\eta_2)\, Y_s e_3 \end{aligned} \quad \text{. . . . .(47a)}$$

On solving for i_2, transposing and using equation 46, there results:

$$Y_{out} = \frac{y_2}{\mu} + \eta_2 + \frac{\eta_2[y_2-\eta_2+(y_1-y_2)/\mu]-y_2(y_1-y_2)/\mu}{Y_s+y_1-y_2+\eta_1+\eta_2} \quad \text{. . . . .(48)}$$

Again, $(y_1-y_2)/\mu$ is usually negligible, so that an approximate expression is:

$$Y_{out} = \frac{y_2}{\mu} + \eta_2 + \frac{\eta_2(y_2-\eta_2)}{Y_s+y_1-y_2+\eta_1+\eta_2} \quad (49)$$

To this should be added the term η_3 to account for the cathode-anode capacitance which was disregarded in the above calculation.

As was done with the input admittance, this can be resolved into conductive and susceptive components, using the same notation, with $Y_s = G_s + jB_s$.

When $\eta_2 = j\omega c_2$, and the triode is not neutralized, the results are:

$$G_{out} = \frac{g_2}{\mu} + \omega c_2 \frac{g_2(B_s+\omega c_o)+(\omega c_2+b_2)(G_s+g_t)}{(G_s+g_t)^2+(B_s+\omega c_o)^2} \quad \text{. . . . .(50)}$$

$$B_{out} = \omega(c_2+c_3) + \omega c_2 \frac{g_2(G_s+g_t)-(\omega c_2+b_2)(B_s+\omega c_o)}{(G_s+g_t)^2+(B_s+\omega c_o)^2} \quad \text{. . . . .(51)}$$

in which b_2/μ has been disregarded.

If the triode is neutralized by parallel tuning of c_2, so that only a residual small conductance remains between anode and grid, $\eta_2 = G_2$ and the output conductance and susceptance are expressed:

$$G_{out} = \frac{g_2}{\mu} + G_2 + G_2 \frac{(g_2-G_2)(G_s+g_t+G_2)-b_2[B_s+\omega(c_1+c_t)]}{(G_s+g_t+G_2)^2+[B_s+\omega(c_1+c_t)]^2} \quad \text{. . . . .(52)}$$

$$B_{out} = \omega c_3 - G_2 \frac{b_2(G_s+g_t+G_2)+[B_s+\omega(c_1+c_t)](g_2-G_2)}{(G_s+g_t+G_2)^2+[B_s+\omega(c_1+c_t)]^2} \quad \text{. . . . .(53)}$$

For the calculation of the available gain the factor $|i_o/i_s|^2$ of equation (39) must be evaluated, where i_o is the current in the short-circuited output resulting from an input current generator i_s acting across a source admittance Y_s (refer to Fig. 10).

In Fig. 7, e_1 and e_2 vanish, while $e_2 = -(i_1 - i_2 - i_s)/Y_s$. Again, i_3 vanishes.

The solution of the pair of resulting equations in i_1 and i_2 for i_2 gives:

$$i_2 = \frac{i_s(y_2-\eta_2)}{Y_s+y_1-y_2+\eta_1+\eta_2} \quad \text{. . . . .(54)}$$

and this is the value of i_o in equation (39) for the present example. Then:

$$\left|\frac{i_o}{i_s}\right|^2 = \frac{|y_2-\eta_2|^2}{|Y_s+y_1-y_2+\eta_1+\eta_2|^2} = \frac{g_2^2+(\omega c_2+b_2)^2}{(G_s+g_t)^2+(B_s+\omega c_o)^2} \quad \text{. . . . .(55)}$$

Using formula (50) for G_{out}, neglecting the term g_2/μ on account of its relative smallness, and substituting for the various symbols in equation (39), leads to the result:

$$M = \frac{G_s[g_2^2+(\omega c_2+b_2)^2]}{\omega c_2[g_2(B_s+\omega c_o)+(\omega c_2+b_2)(G_s+g_t)]} \quad \text{. . . . .(56)}$$

This is the available gain of a non-neutralized triode stage. G_s and B_s are usually chosen to give a minimum noise factor (see ref. 14), and with the values thus conditioned, the available gain is determined.

In the neutralized triode stage, we have

$$\left|\frac{i_o}{i_s}\right|^2 = \frac{(g_2-G_2)^2+b_2^2}{(G_s+g_t+G_2)^2+[B_s+\omega(c_1+c_t)]^2}$$

and equation (52) gives the output conductance of the stage. In this case, however, g_2/μ is no longer negligible.

NOTICES

Scottish Television Conference and Exhibition

The Scottish Section of the Institution is to hold a Conference and Exhibition at the Engineering Centre, Sauchiehall Street, Glasgow, on March 14th and 15th to mark the opening of the Kirk o'Shotts Television Transmitter for the Scottish Area.

A number of papers on various aspects of television are to be presented at the Conference, and many manufacturers in the Radio Industry are co-operating in the Exhibition by the display of television equipment.

A registration fee of 7s. 6d. will be payable by all taking part in the Conference. Full details can be obtained from the Local Honorary Secretary.

Kirk o'Shotts Television Transmitting Station

In order to bring television to Scotland by the earliest possible date the B.B.C. proposes to bring into service the low-power transmitter at the new television station at Kirk o'Shotts on Friday, March 14th, on an experimental basis.

The General Post Office is installing a radio link to bring the television programmes to Scotland which will also be on an experimental basis for the first few weeks. Interruptions to the service may therefore be necessary from time to time for adjustments to the radio link and to the equipment at Kirk o'Shotts.

The Kirk o'Shotts station will carry the same programme as the existing stations at Alexandra Palace, Sutton Coldfield and Holme Moss, except that between 10 a.m. and 12 noon on weekdays during the first few weeks a still pattern will be broadcast instead of the usual morning film.

It is expected that the low-power transmitter will provide satisfactory service over a considerable area of Central Scotland, including Edinburgh and Glasgow, but reception will be more liable to interference, particularly in fringe areas, than it will be when the high-power transmitter comes into service.

Information in Industry

Much of the success of the drive for industrial productivity depends on the speedy provision of accurate information in scientific and industrial fields. Recognizing this fact, the Department of Scientific and Industrial Research has recently made available to Aslib a special grant to establish a consultant service in the special library and information field.

This service, drawing upon the existing resources of Aslib, and backed by new research into information techniques, is now available to advise those who are considering the establishment of special libraries and information services in industry and research establishments, and to assist the development of existing services. Details regarding this service and other facilities provided by Aslib can be obtained from the Director, Aslib, 4 Palace Gate, London, W.8.

Dr. Hilary Moss

Dr. Hilary Moss (Member) has recently left this country to take up the appointment of Chief Engineer of the Electronic Tube Corporation, of Philadelphia.

Dr. Moss, who for the past five years has been Chief Engineer of Electronic Tubes, Ltd., will be well known to members for his papers on Cathode Ray Tube design in the *Journal* and elsewhere. He has also been prominent in Institution affairs, having served both on the General Council and on the Programme and Papers Committee. He was Chairman of the Committee from 1947 to 1949.

May 1952 Graduateship Examination

The next examination will be held on Wednesday, Thursday and Friday, May 14th, 15th and 16th, 1952. Entries for this examination from *home* candidates must be lodged with the Institution not later than April 1st, 1952.

The closing date for *oversea* candidates for the November 1952 Graduateship Examination is May 1st, 1952.

Year Book and List of Members

Members are reminded that the Fifth (1951) Edition of the Year Book and List of Members is now available from the Institution, price 2s. 6d., post free.

In addition to listing the complete membership of the Institution at October 31st last, the personnel of Institution Standing and Local Section Committees are detailed. The Year Book also gives details of papers presented at the 1951 Convention and before Local Sections between 1948 and 1951.

WIRELESS BROADCASTING AND REDIFFUSION SYSTEMS FOR COLONIAL TERRITORIES*

by

A. Cross (*Member*)† and F. R. Yardley (*Associate Member*)‡

A Paper presented at the Third Session of the 1951 *Radio Convention on July 25th at University College, Southampton*

SUMMARY

This paper, although based primarily on the development of the broadcasting system now installed in the Colony of Trinidad, B.W.I., describes a combination of services which could equally well be provided in any other area in the British Commonwealth. A similar system has, in fact, already been partly installed in Jamaica and plans are now complete for the commencement of operations in British Guiana.

The system here described consists of:— (*a*) A medium-wave broadcasting service for primary coverage of areas of densest population, (*b*) A short-wave broadcasting service for island-wide coverage of those areas not reached by the medium-wave transmissions, (*c*) A dual-programme Rediffusion service installed in city and urban areas, (*d*) An experimental single-programme Rediffusion service installed in two rural villages, and (*e*) Experimental community receivers installed in small villages.

Each of these services is briefly described in this paper, together with reasons for their use. Problems which arose during planning and installation are discussed, together with the methods employed to overcome them.

Reference is made to studio construction as well as equipment used in the control of programmes originated in the studios, particular attention being paid to economy both in construction and operation. The use of V.H.F. links for programme input purposes to the Rediffusion systems is described in detail, as this application of V.H.F. communication to a broadcasting service is believed to be the first of its kind ever used in a British Colony.

Means of reception of the B.B.C. and U.S.A. Overseas Broadcasting Services are also discussed in detail, as certain programmes in these services play a major part in the life of the Colony, and consequently have to be relayed regularly to the listeners. It is essential, therefore, to maintain good reception with as little interference and fading as possible.

It may not always be possible to provide a combination of Rediffusion and wireless services, but any one or more parts of the scheme could easily be adapted to the economical and physical features of the areas it is proposed to develop. Since the last world war, several Rediffusion services have been installed in the Far East and in the near future developments will take place in other parts of the world, thus bringing education and entertainment to many peoples.

1. Topographical Features, Geographical Features and Details of Population

The island of Trinidad is situated on the North-East coast of Venezuela, approximately 20 miles from the South American continent, and since it is within 10 deg. of the Equator the climate is tropical. The normal ambient temperature is from 88 deg. to 90 deg. F in the shade and in the sun 120 deg. or more can be experienced. There are two seasons only, the dry season from December to May and the wet season from June to November. During the wet season, humidity frequently approaches 100 per cent. and it is not unusual to have 1 in. of rainfall in five minutes without warning.

These conditions impose peculiar difficulties and render particularly stringent the conditions

* Manuscript received 1st April, 1951.

† Formerly Overseas Rediffusion, Ltd., now with Rediffusion (Yorkshire), Ltd.

‡ Broadcast Relay Service (Overseas), Ltd.

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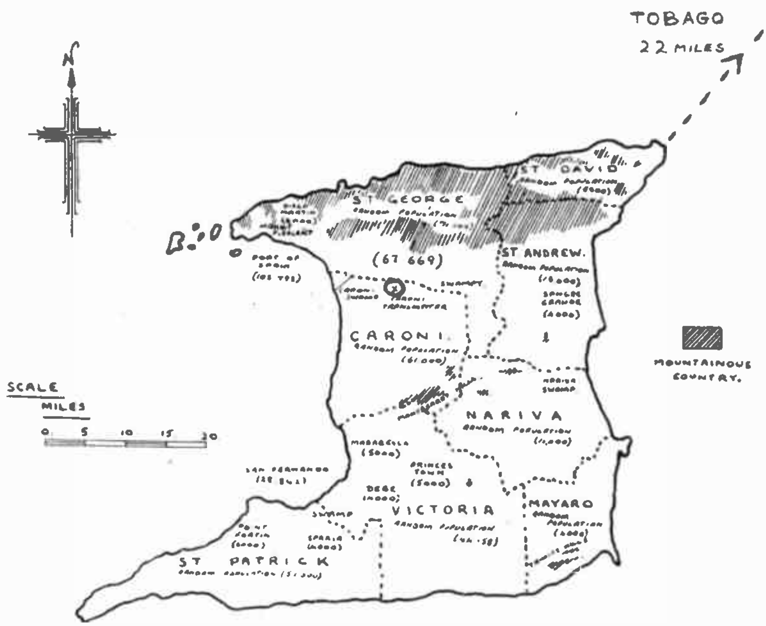

Fig. 1.—Population densities, Trinidad.

under which communication equipment is required to carry out its normal functions. Some of the resultant problems are dealt with in this paper.

Figure 1 shows the distribution of population in the Colony as well as the topography. It will be seen that, of a total population of some 500,000 people, roughly 106,000 are located in the capital, Port of Spain, and 29,000 in the oil-field centre of San Fernando, while 67,000 live in the dormitory area by the foothills of the northern range of mountains. The remaining population has a random distribution and is concerned mainly with agriculture.

One-third of the population, which is mainly coloured, is almost totally illiterate, but although the people are very cosmopolitan, particularly in the capital, English is the only language that need be spoken in the broadcasting service.

Figure 2 shows the ground conductivity and it will be seen that this, in conjunction with the previous Figure, poses a difficult problem for the radio engineer to ensure adequate coverage over the main centres of population, and a reasonable service to such of the indigenous population as can afford receiving equipment or could foregather at a communal centre to be served by a single receiver. It should be noted that the Colony of Trinidad also includes the Island of Tobago, some 22 miles from the North-East corner of the main island, and here the broadcasting service has to provide for approximately 5,000 people.

Conditions in the Colony, but outside the main population centres, are extremely primitive. There are no electric supply mains other than those available in Port of Spain, San Fernando and the dormitory area previously referred to.

2. Local Broadcasting Facilities Previously Available

Prior to the installation of the facilities described in this paper, the number of receiving sets in the Colony totalled approximately 6,000, most of these being suitable for short-wave and medium-wave reception. The Colony did not possess its own broadcasting service, but a low-powered, medium-wave transmitter operated by the American military base on the island, and such Venezuelan and South American medium-wave stations as could override the prevailing noise levels provided mediocre reception. Short-wave reception of the overseas programme from the B.B.C. and certain American stations made up the balance of broadcast programmes available.

Of the 6,000 receivers in the Colony, at least one-third were battery operated, and, due to lack of adequate maintenance facilities, many of these were out of action for long periods.

In 1935 a single-programme relay service was started in Port of Spain and by 1946 approximately 3,500 houses in the city were served by this system.

In August, 1946, plans were laid down for the expansion of broadcasting in the Colony and the various aspects of the work involved are described in this paper.

3. Methods of Broadcasting Adopted

Having regard to the type and availability of

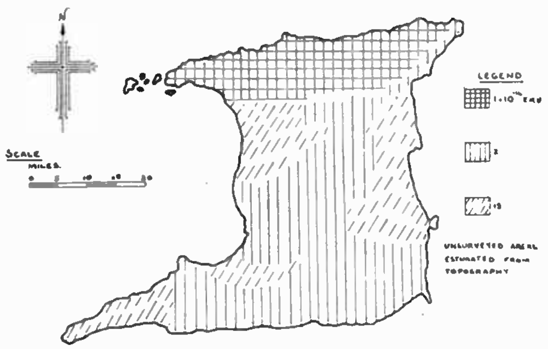

Fig. 2.—Ground conductivity, Trinidad.

existing receiving sets, the distribution of population, the ground conductivity, the mountainous nature of the terrain, and taking into consideration economic and other factors, it was decided that the broadcasting needs of the Colony could best be served in a number of separate and distinct ways, i.e.—

(*a*) By the provision of a vertical incidence short-wave transmission service,

(*b*) By the provision of a low-powered medium-wave transmission service on conventional lines,

(*c*) By the expansion and development of the existing Rediffusion service to the maximum possible extent,

(*d*) By the provision of community receivers.

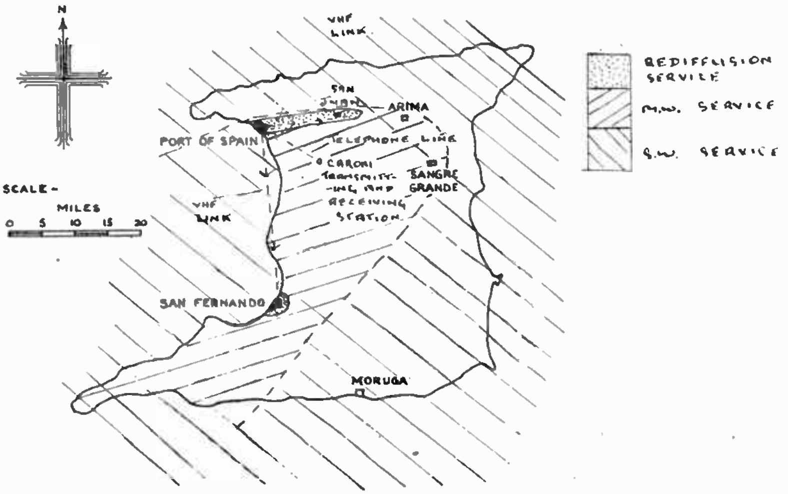

Fig. 3.—Area served by each of three different methods of broadcasting.

Figure 3 shows the coverage which is at present obtained by these methods.

3.1. *Short-distance High-frequency Broadcasting Service*

The decision to use this method of broadcasting was made in order to ensure adequate coverage over those parts of the Colony not reached by the medium-wave transmissions. As the soil conductivity is very poor in the northern part of the island, many villages along the north coast could not be economically covered by the medium-wave transmissions, but, by using vertical incidence short-wave transmissions, these shadow areas could be reached by radiating the signal in a vertical direction and obtaining almost vertical reflection from the F2 layer. The technical considerations affecting vertical incidence transmission have been dealt with elsewhere.[1]

To operate a system using high-angle radiation throughout the normal hours of broadcasting, at least two frequencies are required and must be selected so that they are lower than the critical frequency for the sun spot number prevailing in the season of operation. They must, however, be as near the maximum usable frequency as the conditions of international agreement permit, the object being to obtain maximum reflection of energy with as little loss as possible due to absorption in the ionosphere, and if a frequency too far below the M.U.F. is adopted, losses due to attenuation in the ionosphere will be proportionately greater.

In discussing the results obtained from this particular method of broadcasting, it must be pointed out that the experiments were carried out prior to the International High Frequency Broadcasting Conference at Mexico City, and the frequency allocations used were, of necessity, provisional allotments. Sufficient experience has been gained, however, to say that the system of vertical incidence broadcasting is entirely satisfactory for use in locations of a mountainous nature when clear channels in suitable frequency bands can be secured.

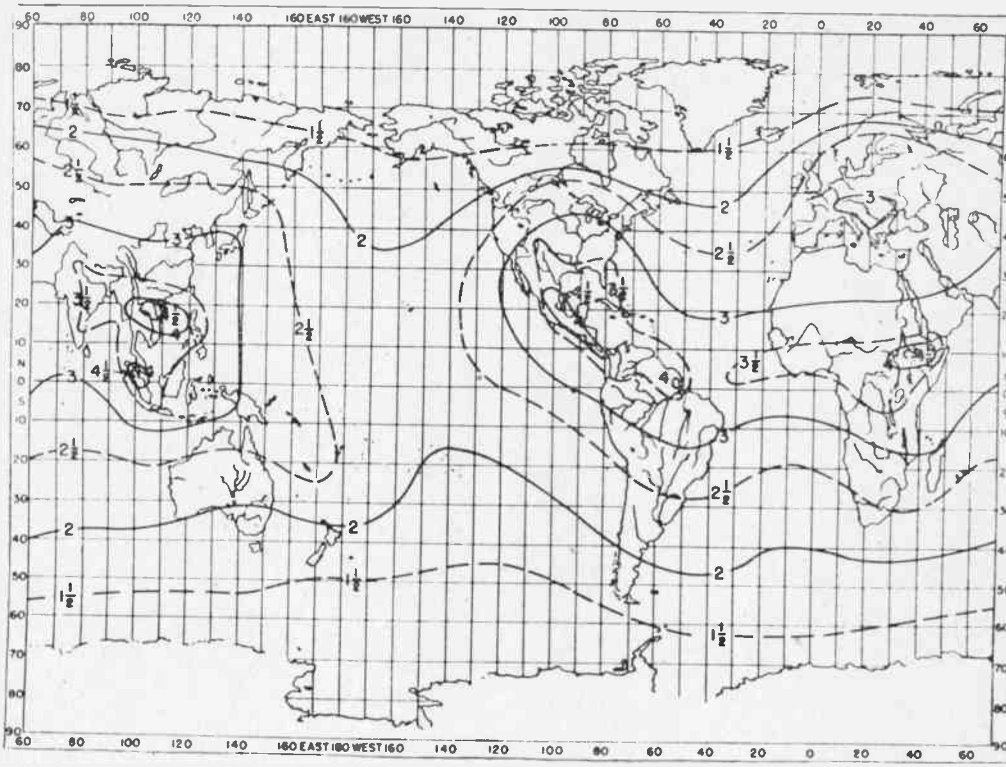

Fig. 4.—Typical noise curves for months of June-July-August.

3.2. *Medium-wave Broadcasting Service*

In planning this service, the choice of a suitable transmitting site was limited to an area some six-seven miles from the centre of Port of Spain, the capital of the Colony, and it was considered that a minimum ground wave field intensity of at least 10 mV per metre was necessary to render good primary coverage over the city itself, although a minimum of 0·5 mV per metre was considered sufficient for the remainder of the island. In deciding on these levels, due reference was made to the available frequencies, and particularly to atmospheric and man-made noise levels. For this purpose, noise-grade maps prepared by D. K. Bailey of the U.S.A. and noise curves prepared by the United States Army Signal Corps (Fig. 4) were used. Whilst it was desirable to maintain a 38-db signal/noise ratio over the service area, a value of 20 db was regarded as an absolute minimum. In practice, a 38-db ratio is maintained during the day up to the 0·5-mV/m ground wave field intensity contour, reducing to 20 db at the same distance after 20.00 hours local time. To maintain the higher signal/noise ratio at this field intensity over the broadcasting day of 17 hours was considered uneconomical.

Ground conductivity over the island was found to be poor except for the transmitting site itself, which is in the centre of a sugar cane plantation on the marshes. To the north of the island, mountainous country reduces the ground conductivity to the poor value of 1×10^{-14} E.M.U.s. The actual transmitting site has a conductivity of 15×10^{-14} E.M.U.s which enabled an efficient earth system to be installed.

The choice of frequency depended largely upon available channels and assignments to nearby South American stations. Stations in the North American area, situated north of line 18 deg. N, are controlled by a North American Regional Broadcasting Agreement, but Trinidad, being so far south, experiences little interference from this direction. A frequency of 1,295 kc/s was allocated initially, as it was thought noise levels on this channel in the standard broadcasting band would be lower than on the longer wavelengths. Furthermore, the transmitting site being adjacent to an airport, the use of high aerial towers, which would have been necessary had a low frequency been used, was prohibited. Only recently, however, a frequency of 790 kc/s has been allocated to Trinidad and, with a view to improving the primary service area, negotiations are proceeding with the Department of Civil Aviation for permission to erect a 300-ft. tower, this height being approximately one quarter wavelength of 790 kc/s.

During the planning of the service, limitations were placed on the power of the station, owing to long delivery dates and shortages of suitable transmitting equipment, but a 2-kW transmitter was eventually obtained which just provides sufficient power to the aerial to cover Port of Spain with a field intensity of not less than 10 mV per metre on a frequency of 1,295 kc/s.

The radiating system consists of an inverted T aerial 110 ft. high and 120 ft. across the top, erected on a buried radial earth at least a quarter wavelength of 1,295 kc/s in radius. The efficiency of this system is such that the unattenuated field strength at 1 mile per kW radiated is 190 mV per metre and these results are considered satisfactory. If permission is obtained to erect a 300-ft. tower, the frequency will be reduced to 790 kc/s, and it has been calculated that the distance of the 0·5 mV per metre contour will be increased by 8-10 miles through this change.

Should it not be possible to erect the new tower it is still proposed to improve the coverage by installing a 5-kW transmitter, although the increase in power will only give similar results to those which a lower frequency and higher aerial will provide. The capital costs of these respective changes differ so much that the former possibility is undoubtedly the most economical.

The following table shows the comparative improvements which will be obtained over the existing service by decreasing frequency, increasing aerial height and increasing power. The aerial efficiencies of 150 and 200 mV per metre unattenuated at 1 mile for 1 kW radiated are those obtainable with the existing aerial and proposed aerial respectively, on the frequency of 790 kc/s.

Figure 5 shows actual field strength contours and Fig. 6 the improved service area by increase of aerial height, decrease of frequency, and increase of power.

3.3. *Methods Adopted for the Reception of Short-wave Services from the U.K. and U.S.A. for Subsequent Rebroadcast*

The design of a receiving station and suitable aerial system, for the purpose of receiving overseas programmes, for subsequent rebroadcast to the Colony, was based primarily on the need to receive the B.B.C. short-wave service directed to the West Indies, and certain overseas transmissions from the U.S.A.

Simultaneous reception from both these countries was necessary, and accordingly high-gain aerial arrays covering a frequency band of 10-20 Mc/s, with a mid-frequency of 15 Mc/s, were erected and directed on New York and London.

Estimated Field Strength Contour for Ground Conductivity

1 to 2 × 10^{-14} E.M.U.s and Signal/Noise Ratio of 20-38 db.

Transmitter Power	Frequency	Aerial Efficiency mV/m-1 mile-1 kW	Field Strength Contours in Miles		
			10 mV/m	2 mV/m	0·5 mV/m
2 kW	1,295 kc/s	190	3·9–5	8·5–11·0	17–21
2 kW	790 kc/s	150	5·1–7	11·5–16·0	22–30
2 kW	790 kc/s	200	6·0–8·4	13·5–18·5	25–32
5 kW	790 kc/s	150	6·5–9·2	14·5–20·0	28–36
5 kW	790 kc/s	200	7·6–10·5	16·5–22·0	31–41

NOTE.—Curvature of the earth will limit distances over 32 miles.

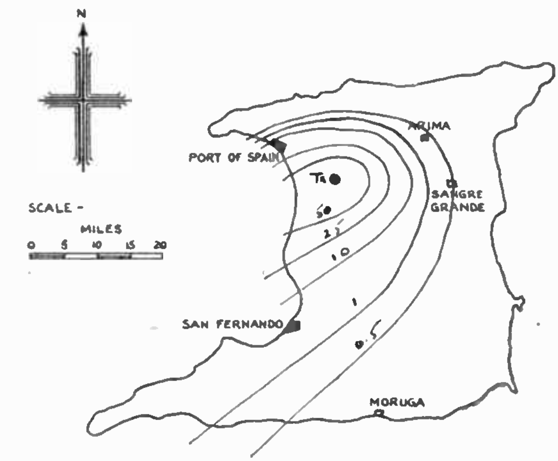

Fig. 5.—VP4 RD Trinidad. Field strength contours in millivolts per metre.

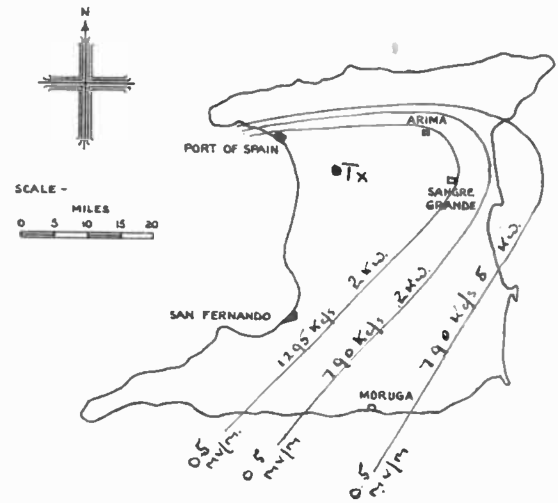

Fig. 6.—Comparisons of ground wave field strength contours for decrease in frequency and increase in power.

To avoid the need for individual arrays on the London and New York paths, an antenna system to permit simultaneous reception from two directions was designed in the laboratories of Central Rediffusion Services, Limited, by T. S. Popham.[2]

The radiation pattern of this antenna is characterized by two major lobes, the angle between each of their planes of elevation being, within certain limits, adjustable at will. The antenna is of the non-resonant type and hence is to a certain extent aperiodic.

The antenna consists of two horizontal parallel wires fed at one end and terminated by a resistance so that they carry a progressive wave with no reflection at the far end.

If the lengths of the wires are reduced the angle between the two lobes increases and the lobes themselves become broader, the radiation pattern tending to a figure-of-eight. Thus for reasonable directional properties and gain, the angle between the two lobes must not exceed 90 deg. If the lengths of the wires are increased, the angle between the two lobes is reduced and the lobes become longer and narrower. Hence the only limitation to the smallness of the angle between the lobes is that of the physical size of antenna that can be tolerated, while the performance of the antenna steadily improves as the length is increased. A theoretical treatment is given in the Appendix.

The particular merit of this aerial system is that it is possible to receive from two directions using one array, whereas with the use of rhombics having similar gain, two arrays would be required.

Two of these arrays were erected in Trinidad to give spaced diversity facilities and they were fed to the receiving station through co-axial feeders.

The station equipment itself was designed for general short-wave reception and twin diversity reception in the form of an electronic diversity switch and two high-quality communication receivers. A control desk was provided to facilitate the setting of levels, monitoring, metering and switching. The design of the electronic switch has been discussed elsewhere,[3] but a brief reference to the principle of operation may be interesting. The apparatus is intended for use with a dual diversity reception system, where it is assumed that two similar receivers are available. The audio frequency output of the receiver with the larger radio frequency input is always selected and applied to the output amplifier of the unit, the switch being controlled by the A.V.C. lines of the two receivers. Switching is effected at high speed and without interference, rendering a change-over virtually inaudible. Rapid fading up to a maximum frequency of approximately 10 c/s is adequately smoothed out, though where the mean level of both signals varies, a change-over of output level is unavoidable.

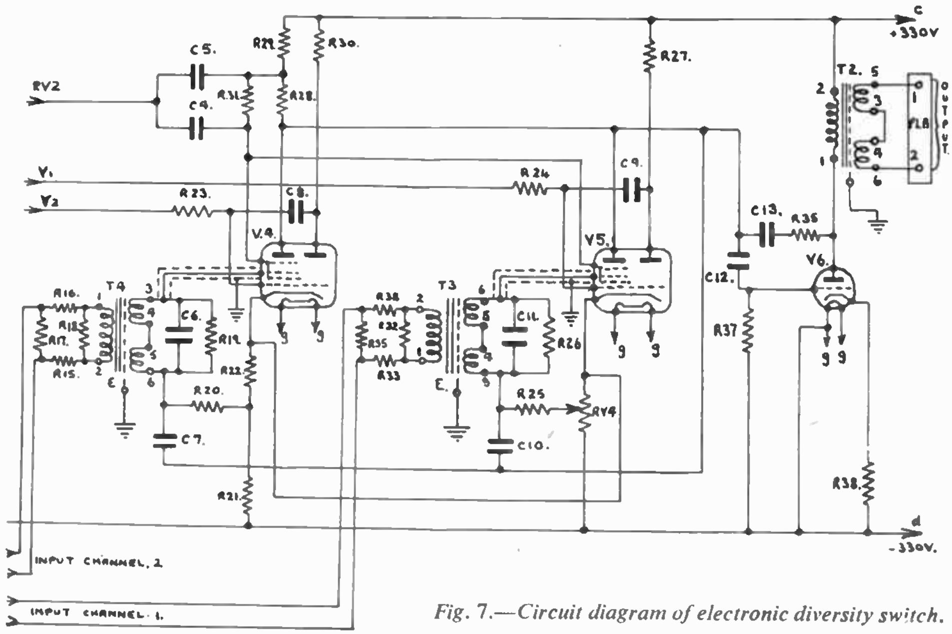

Fig. 7.—Circuit diagram of electronic diversity switch.

Figure 7 shows the electronic switch circuit and it may be separated into two distinct sections:—

(*a*) the switching circuit,
(*b*) the audio frequency amplifier.

The switch, a square-wave single-stroke "flip flop" employing two valves, is initiated by the difference in potential between the two receiver A.V.C. lines; a third valve in series with the "flip flop" operating under constant current conditions ensures that there is no switching due to both A.V.C. lines changing potential together, with respect to chassis. Two neon lamps, connected one to each anode circuit, provide indication of switching sequence.

The voltage developed across the switch valve anode circuits, applied through a resistive/capacitive network to the triode grids of two triode hexodes, is sufficient to bias a hexode audio frequency amplifier well beyond cut-off, so that only the channel fed through the receiver with the larger A.V.C. voltage, i.e., the larger input signal, remains operative.

Figure 8 shows the receiving station equipment and Fig. 9 the aerial layout.

Fig. 8.—Receiving station equipment.

3.4. *Dual-programme Wired Broadcasting Service*

Until 1946 only a single-programme Rediffusion system was in operation in Trinidad, and this was confined to Port of Spain, the capital. Large-scale developments have since taken place and a dual-programme system now serves Port of Spain, San Fernando and San Juan, this latter point being centrally situated in the dormitory area by the foothills. The service was designed to cover 15,000 subscribers and to date approximately two-thirds of this number are receiving two programmes.

Programme inputs to each of these centres are originated in the broadcasting studios in Port of Spain, and fed by telephone lines to San Juan, but as no land lines exist between Port of Spain and San Fernando, two V.H.F. links are used for programme relay purposes between these two points. A more detailed description of these links is included elsewhere in this paper.

The general principles of audio frequency wire broadcasting methods have already been fully described by P. Adorian[4] and the present paper deals mainly with problems arising from the operation of such a system under colonial and tropical conditions.

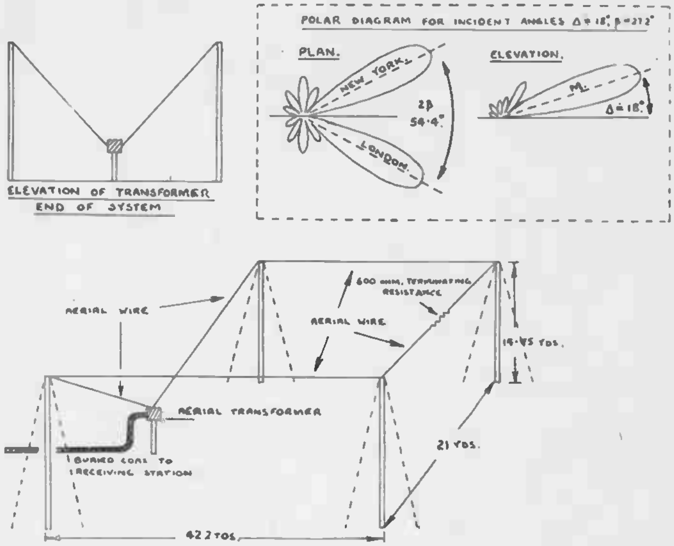

Fig. 9.—Bidirectional aerial layout, Trinidad.

In order to avoid erection of poles solely for the Rediffusion service, a system of joint construction with the power and telephone companies was agreed upon, and the main feeders of these three services are supported on common poles. Cross-talk is avoided by transposing not only each individual programme pair, but by transposing both programme pairs at regular intervals. Furthermore, correctly balanced twin wire is used on the main feeders, consisting of 16 and 18 S.W.G. twin-polythene insulated dumbell cable. Branch feeds or drop wires to individual subscribers utilize the maypole system of distribution, in conjunction with single pothead insulators fixed under the eaves of the property, 22 S.W.G. polythene-insulated star quad cable being used for drop-in purposes.

To guard against static build-up on the system, each individual feeder is earthed at the source and two lightning discharge tubes are suitably connected between each line of each feeder and earthed.

The use of polythene-insulated cables in Rediffusion systems has only been introduced since the war, and experience gained during the war led manufacturers to believe that polythene as an insulant would be entirely satisfactory for use under tropical conditions. Experience gained in Trinidad since 1948, however, has resulted in two interesting discoveries which have been of great assistance to cable manufacturers in this country in helping them to improve the life of their products under severe tropical conditions.

When polythene is exposed to sunlight, changes occur in appearance and in electrical and mechanical properties. The rate at which these changes take place depends upon such factors as the ambient temperature, the amount of sunlight which reaches the polythene, and the penetration of ultra-violet light. The last factor is dependent upon the geographical location, the aspect, the atmospheric conditions and the cleanliness of the material.

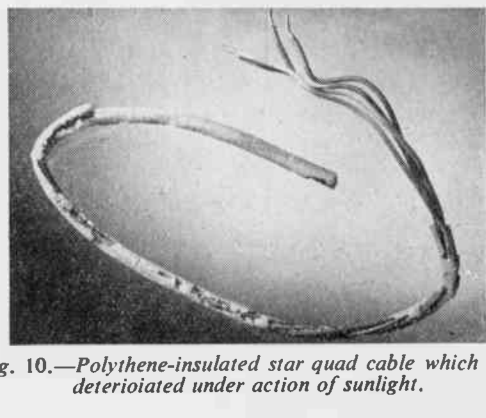

Fig. 10.—Polythene-insulated star quad cable which has deterioiated under action of sunlight.

In Trinidad it was noticed that some cables were beginning to deteriorate after having been erected for only a few months, and the practical outcome of this deterioration was the appearance of cracks (mainly transverse) which penetrated the polythene, in many cases to the conductor (Fig. 10). It was soon proved that this deterioration was due to intense ultra-violet light such as is experienced under conditions of tropical sunshine, and a means had to be found whereby the polythene cable could be protected from the action of sunlight. The cheapest and most convenient method was the incorporation of 2 per cent. of channel black or carbon black in the polythene, during manufacture, and the manufacturers now claim that polythene-insulated cables, insulated with at least 25 mils of 2 per cent. carbon black polythene, will give a useful life of from 15-20 years in bright sunshine in temperate climates. It is confidently expected that the life of this cable will also be of the same order in tropical conditions.

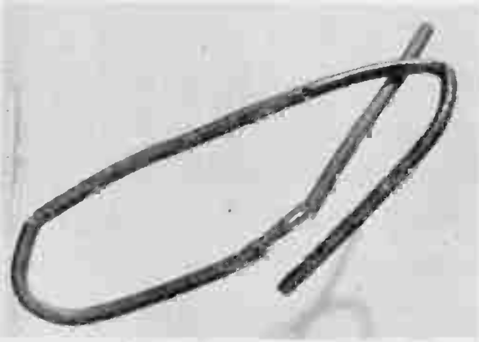

Fig. 11.—Polythene-insulated star quad cable which has been attacked by ants.

A further discovery was made, shortly after several thousand yards of cable had been erected, which indicated that polythene is quite palatable to a species of ant known as the Monomorium Destructor, in spite of the fact that polythene is supposed to be quite immune and impervious to animal life. This insect would enter the cable at the make-off, or sometimes through the sheath, consume the interior polythene leaving only the four conductors in a hollow shell, (Fig. 11). The problem was overcome by impregnating the polythene with a percentage of lead naphthenate during manufacture, which chemical gives off an odour repellant to the ant. Local applications of a solution consisting of mercuric chloride dissolved in shellac were also effective and were widely used until such time as the supplies of cable containing lead naphthenate became available.

Fig. 12.—Tilandsia, or Old Man's Beard, growing on overhead cables in the West Indies.

Not only can exposed wiring in the West Indies suffer from attacks of insects, but it can also be attacked by a parasitic growth known as Tilandsia, or Old Man's Beard (Fig. 12). This is a purely vegetable parasite and is actually a form of grass, the seeds of which are thought to be carried by the wind. To date no such growths have occurred on polythene-insulated cables.

Maintenance of the whole system is systematically and regularly carried out by a special staff, but the number employed is kept to a minimum, as the network, plant and equipment have been designed to ensure a minimum of work consistent with a reliable service.

3.5. *Single-programme Rediffusion Services for Use in Isolated Village Communities*

When consideration is given to the provision of a service to isolated village communities, certain factors raise many complications, foremost amongst which are the absence of any form of power supply and lack of communication lines by means of which the programme input can be carried. The size of the communities, the isolation one from another, and very often their economic standard, have entirely precluded any consideration of power supply link or input line construction and the design of equipment for the provision of a wired service in such conditions must be made on the basis of absolute self-sufficiency. In broad terms the distribution point must have its own means of generating a power supply, the programme input must be provided by radio reception and the whole station must be so reliable that it will function with the minimum of attention. Such a combination has been developed and a full-scale experiment recently completed in two villages in Trinidad. The installation was so designed as to require no attention other than for normal maintenance and battery recharging. From the engineering aspect these experiments have already provided information on reliability of equipment operating under stringent tropical conditions and a check on the ageing of the simplest network and subscribers' equipment.

The station equipment consists of a pre-tuned V.H.F., H.F. or M.F. high-quality broadcast radio receiver and high-fidelity audio frequency amplifier with an overall sensitivity better than 0·1 V input to give either 10 or 20 W output as required, at less than 3 per cent. distortion for 75 per cent. modulation at a frequency of 1,000 c/s.

The output stage of the amplifier consists of two or four pentode valves giving 55 V r.m.s. into an impedance of 300 or 150Ω for two or four valves respectively, depending upon the number of subscribers. Provision for the addition of further amplifiers is also incorporated, so that the output power can be increased within the limits of the available power supply.

The overall frequency response of the receiver and amplifier is claimed to be ±5 db from 50 to 12,000 c/s and the signal/noise ratio better than 65 db.

The power unit supplies 300 V, 200 mA H.T., and 12 V L.T. from a 12-V accumulator of 450 Ah capacity, using a rotary transformer for generation of H.T. A clockwork time switch with a 35-day movement is incorporated in the power pack for automatic on/off switching of the equipment at predetermined times.

The receiver, amplifier and power equipment is all housed in a weatherproof kiosk and a second kiosk, the interior of which is treated with acid-proof paint, houses the accumulators. Ventilation is obtained in the battery kiosk by a small cowl fitted on the roof and suitably protected against access of insects and dust (Fig. 13).

The accumulators can be charged from petrol-driven generating sets, local water-driven generators or wind-driven generators where wind velocities are high enough. In Trinidad petrol-driven generating sets are used, but serious consideration is being given to the use of wind power for float charging purposes.

As the two kiosks are normally intended for outdoor use, it is desirable to install them at the foot of a distribution pole from which the wired circuits can be distributed to the area it is intended to feed. The receiving aerial is mounted on top of this pole and in the case of V.H.F. reception, a uni-directional aerial is used, but for medium-wave or short-wave reception a rod aerial is adequate.

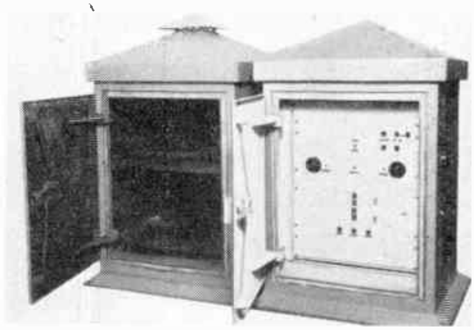

Fig. 13.—Unattended, single-programme, Rediffusion equipment housed in weatherproof kiosks.

Numerous types of cable have been examined in order to determine which is most suitable for schemes such as the Trinidad experiment, and twin 7/·0148 S.W.G. polythene-insulated dumbbell cable, each composite conductor containing a steel strand, has been found to be ideal. Apart from its strength, it is quite flexible and can be attached to trees, houses or other means of support and, furthermore, can be wired directly on to a loudspeaker from the junction box on the main feeder. It can also be used for main distribution work, the only limit being its loop resistance, but a heavier type can be obtained and used in those parts of the network where load-carrying capacities need to be higher.

In these village schemes economy is a most important factor and the cable must as far as possible be supported on whatever means are already available, such as trees, houses and poles. There are numerous efficient means of attaching the cable to these supports, but polythene-insulated thimbles, which can be hooked on to beam hooks, are relatively simple and economical to use. In certain instances pothead insulators must be used, particularly where junctions have to be made in the main feeder. When a subscriber is connected, a self-tapping connector is merely screwed on to the feeder and connection

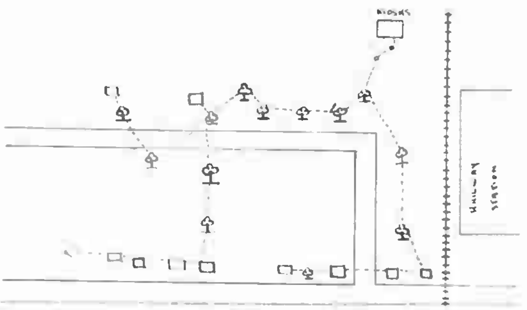

Fig. 14.—Plan showing part of Carapichaima, and illustrating how maximum use is made of natural supports for the network.

is made by two sharp needle points, the drop wire being connected in a similar manner.

Permanent magnet 5-in. diameter loudspeakers having flux densities of the order of 10,000 gauss are fitted on 15 in. × 15 in. baffle boards containing volume controls, to give full, three-quarter, half, quarter and zero volume levels. These installations are merely hung in the corner of the subscriber's living-room and the drop wire from the feeder is taken directly to a terminal panel on the back of the baffle board.

A typical plan of Carapichaima, one of the Trinidad villages referred to previously, shows the practical scheme (Fig. 14).

There is no doubt at all that properly devised and rendered under a sympathetic and understanding control these rural Rediffusion systems will play a very important part in the amelioration of the conditions of life in native villages, whilst as a concrete example of what can be done, the Trinidad experiment may be regarded as a model for other developments.

3.6. *Community Receivers*

A great deal of thought has been given to the provision of broadcast entertainment to colonial peoples living in rural areas where public power supplies are not available. Quite apart from the difficulties in providing a programme, the main difficulty is providing means for reception of that programme were it available. The larger majority of these people have not the means to purchase a receiver, nor the means and facilities for maintaining it in operating condition. It follows, therefore, that such receivers must be provided and maintained by the administration of the territory concerned. Quite obviously, receivers cannot be installed in every home at the expense of the authority, but a solution to this obstacle has been the use of a community receiver whereby a gathering of people can listen to their nearest or their local broadcasting station.

Experiments conducted in India, Burma and Malaya have shown that the general design of community receivers must be such that reliability under tropical conditions is of major importance, coupled with a reliable means of power supply. The quantities involved to date have not been large and in consequence the choice of receiver has been limited to standard models which are generally available to the public. These receivers have been supplied by the manufacturers with no change in basic design apart from the means of housing, which has usually taken the form of a robust metal or wooden box suitably ventilated. In certain instances preset tuning facilities are desirable, particularly when the local station transmits on the standard medium-wave broadcast band. In the case of short-wave reception, it is preferable to provide a limited range of tuning by locking the tuning mechanism so that the main tuning condenser can only be varied slightly about the frequency it is desired to receive.

Economy of operation is a most important factor, and the only practical method of providing power supply has been the use of secondary cells of the standard 6-V type. Such accumulators can be purchased in large numbers, and are readily available on the open market.

Primary battery operation has been tried but, quite apart from high cost, it is not recommended owing to the limit such batteries place on the output of the receiver. On the other hand, the use of primary cells has quite successfully been accomplished in receivers designed for individual use, where audio power output need only be low but, again, availability of replacements must be given prior thought before any large numbers of receivers are sold to the public.

In order to conserve energy, valves must where possible be of the directly- rather than the indirectly-heated type, and, furthermore, indirectly-heated valves do tend to show a greater frequency drift during the warming-up period.

High-tension supply is derived by means of a vibrator unit, but whilst rotary convertors might well be used in place of vibrators, the latter are easier to replace and are less costly.

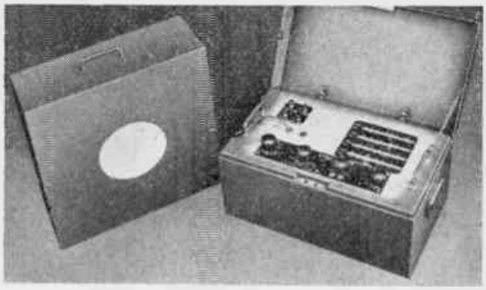

Fig. 15.—Community receiver for use in rural villages.

Higher outputs than 3 W to the loudspeaker are not normally necessary, as audiences do not exceed more than 100 people in average instances, but in order to obtain such an output level, at least 25 W power supply input will be required. This will constitute a drain on a 6-V accumulator of approximately 4 A, and re-charging will be necessary every few days, depending on the size of battery and number of hours the receiver is in use every day. By using a mechanical time switch, incorporated in the receiver, it is possible to limit listening periods to predetermined times and thus conserve power. However, receiver power outputs need not necessarily be as high as indicated previously, i.e. 3 W, and if this level were reduced to 1 W, which power should be adequate for small audiences, battery life can be extended.

Discharged batteries must be replaced by charged batteries and a central means of charging is a necessity. For this purpose mains power supply or small petrol-driven generating sets are necessary. The use of manual-powered generators is not satisfactory as the effort required to charge batteries is enormous, but consideration has been given to the use of wind power and there is no reason to doubt that a wind-operated charging plant would be quite satisfactory in those areas where wind velocities are high enough.

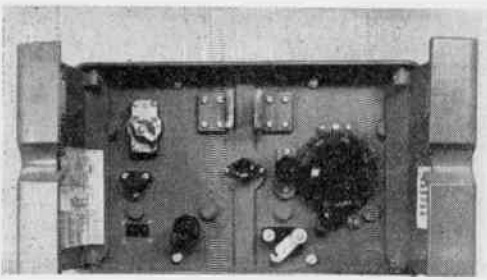

Fig. 16.—Village community receiver with doors open.

Figures 15, 16 and 17 illustrate the different types of receivers which have been considered and used for community listening purposes.

4. Construction of Broadcasting Studios

Economical considerations play a most important part in constructions of this nature, particularly in those Colonies where operations will only be on a small scale owing to financial circumstances, and whilst it would be desirable to follow closely along the standards set by the B.B.C., financial limits have to be considered.

Acoustical design of broadcasting studios is a subject about which there is a great deal published, but unfortunately the opinions of the various authors differ as to the requirements and so far personal opinion and judgment play a major part in deciding whether or not a studio has good acoustical properties.

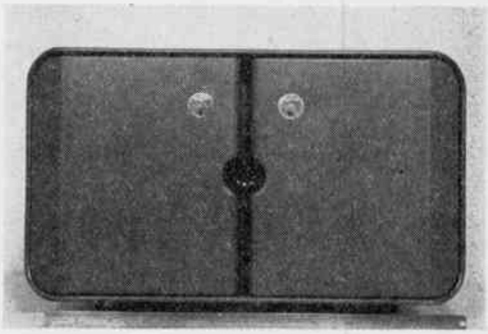

Fig. 17.—Village community receiver with doors closed.

The following constructional details, based on information obtained from the B.B.C. and from other technical sources, have been used with success in the Far East. As far as possible, local material was used throughout, this being very much cheaper than importing material from other countries, and the methods of construction used for the building were considered with a view to economy, without a major reduction in standards.

The subject generally has to be divided into two parts; firstly, the sound-proofing or insulation and, secondly, sound treatment or correction.

4.1. *Soundproofing*

A 4½-in. brick wall, suitably plastered on both sides, will, in conjunction with a sound-insulated partition, provide a very high degree of sound insulation, this combination having been used by the B.B.C. The sound-insulated partition consists of a 2 in. × 2 in. stud partition covered on both sides with ½-in. building board and then with ½-in. plaster board. The whole framework is mounted on a pad of resilient material, such as sponge rubber, and similar material is placed between the head of the partition and the structural or true ceiling. No wall ties whatever must be used to support this partition and the only contact it has with the main structure is via the resilient material.

A false ceiling constructed of lath and plaster on joists rests upon the top of the sound-insulated partition and again no rigid ties must be used to support this ceiling to the main structure. The former, however, must be as rigid as possible and it is suggested that the joists be 4 in. × 2 in. timber. These can be tied to the main ceiling by means of hangers suitably insulated with rubber.

The floor of the studio may be of sound-insulating material if this is really necessary, but for the sake of economy can be made of boarding nailed to battens, fixed to the true floor and isolated from the sound partitions by resilient material, or it could be of a floating pattern type, making contact with the main structure via a resilient material. The latter construction is advised, as it is quite certain that a floating floor is a most important point in the prevention of sound transmission. The true floor must be of massive and rigid construction, but there is no need to go to the expense of making it of concrete.

A door to resist the transmission of sound may be constructed of layers of laminated wood and sheet lead. Doors have been built successfully on this principle with three layers of white pine and two layers of 4-lb sheet lead alternately, making a total thickness of 3 in. They can then be veneered or otherwise finished in the usual way. Special care must be taken with the sides, top and bottom to ensure that the door closes tightly, thus preventing sound passing through the cracks around the edges. If the edges of the door are wedge-shaped and lined with sorbo rubber about 1 in. thick, this type of seal will last a long time and give reasonable results. It is important to have a suitable lever-type handle for firmly closing the door and making it as air-tight as possible. Generally the shape is similar to that of a refrigerator door. Other types of doors have been used, such as those made of well-seasoned solid oak at least 2 in. in thickness or solid mahogany also of the same thickness.

Windows should be kept as small as possible and double plate glass, set in sorbo rubber or soft felt, will give adequate insulation. If each pane of plate glass is of different thickness, even better results can be obtained. Plate glass suitably set will give an average sound reduction of up to 35 db.

It is absolutely essential to keep all false walls, ceilings and floors suitably insulated from the true structures, as if there is any rigid mechanical connection, sound can be easily transmitted via this path from an outside source.

The theory of the construction explained above is that the sound passes through the materials of different densities and the greater and more frequent the change, the greater will be the attenuation of the sound waves.

4.2. *Sound Treatment or Correction*

A sound wave originating in a studio is absorbed to a certain degree by the material of which the studio walls, ceiling and floor are constructed. The amount of absorption also depends upon the frequency of the sound and various materials can be used to control this absorption. In general, they are of the porous type, such as felt, mineral wool and the like, but these materials do not absorb sufficiently well frequencies below 500 c/s. The sound-absorbing characteristics of most materials are not constant over the A.F. range, consequently a careful selection of materials is necessary to secure the required reverberation effect when designing a studio. Carpets and drapings absorb higher frequencies to a greater extent than lower frequencies, whilst other materials react in the reverse manner. Hair felt of 1-in. thickness possesses a high degree of absorption at high frequencies, whilst wood panelling of a fairly light type absorbs mainly low-frequency sound energy. Wallpapers of a certain type will increase the absorption of lower frequencies considerably, whilst reducing absorption of higher frequencies.

Reduction in absorption at the lower frequencies is due mainly to the wide difference in

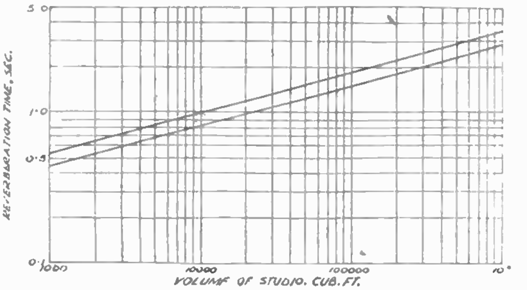

Fig. 18.—F. R. Watson's curves showing comparisons of studio sizes for various lengths of reverberation time.

wavelengths of frequencies between 50 and 10,000 c/s, i.e., 22 ft. as against $1\frac{1}{4}$ in. A wavelength of 22 ft. is very little effected by absorption materials of thicknesses of 1 or 2 in., but a comparatively small wavelength of $1\frac{1}{4}$ in. is to a certain degree.

Absorption of lower frequencies occurs when light wooden panels are struck by a sound wave. The panelling vibrates, the period of vibration depending upon the amount of damping applied to the panels, and sound is thus converted into energy, which is dissipated in the form of vibration, friction, etc. This is known as absorption by resonance.

A certain degree of reverberation is desirable in a studio, depending upon the size of the room, otherwise it would seem dead and unnatural, but the reverberation time must be kept down to certain limits in the interests of intelligibility. Fig. 18 will give an indication of the optimum reverberation time for studios having volumes between 1,000 and 1,000,000 cu. ft. This curve is based on information due to F. R. Watson and it is still employed as a basis in the design of studios.

It is not practicable to define exactly the quantities of porous and resonant material required for a studio, to obtain a desired effect, but as a guide it has been suggested that the wall surface should consist of four-fifths resonant material and one-fifth absorbent material.

One school of thought believes it is undesirable to have parallel walls in a studio, but it has been found that for most types of programmes, normal rectangular studios are preferable and definitely more economical to construct.

4.3. *Practical Results*

A studio has already been constructed and thoroughly insulated in the manner described above. The leakage was negligible, the studio itself being practically 100 per cent. *soundproof.*

The sound *treatment* used (Fig. 19) consisted of $\frac{3}{4}$-in. flat plywood panels, 6 ft. in length, mounted vertically on wooden battens at alternate centres of 16 in. and 24 in. This studio is only 13 ft. high, 24 ft. long and 20 ft. wide. One of the 20-ft. walls was treated with soft plaster on a material known as Newtonite for 5 ft. above the plywood panels and finished off with a 2-ft. frieze of absorbent tiles. The opposite wall was fitted with absorbent tiles as far as the ceiling, from the top of the plywood panels. The two longer walls were treated with absorbent tiles and soft plaster on Newtonite to a height of 5 ft. above the plywood panels, with a 2-ft. frieze of tiles to the ceiling—thus a studio was obtained with a live and dead end.

Fig. 19.—Corner of studio showing use of resonant panels.

Absorbent tiles may be difficult to obtain, but limpet asbestos, which can be arranged to have similar absorbent characteristics, will be quite suitable instead. In the studio under discussion, limpet asbestos was used instead of tiles, when supplies of the latter were used up. If Newtonite is not available, any form of proprietary lathing with a soft plaster is quite suitable. To obtain a better finish, it can be covered by a mural rexine, but as the plaster portions of the wall are above a height of 6 ft., there is little likelihood of them being damaged by contact and the rexine would not be a necessity.

5. Brief Details of Studio Control and A.F. Equipment

As in the construction of studios, economy in cost of equipment has to be seriously considered when small-scale operations are to be developed.

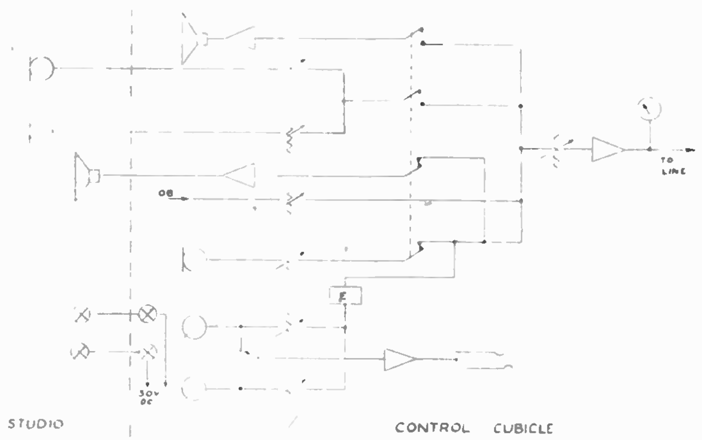

Fig. 20.—General layout of studio control circuits.

Simplification of control systems is, therefore, of paramount importance and can be accomplished without any degradation in the fidelity of the system.

This summary describes the A.F. control circuits for a typical small local station operation, utilizing one control room and one or two studios. The general layout of circuits is shown, and whilst it is not the authors' intention to furnish detailed instructions covering the installation of such a system, it is intended to provide ideas which experienced engineers might find helpful in designing their own studio circuit arrangements.

Figure 20 shows a general layout which has been found satisfactory and which can be combined with further studios if more facilities are needed. The studio contains only two microphones, talk-back loudspeaker and cueing facilities. The control cubicle contains a mixing system consisting of at least seven faders, two or preferably three transcription turntables, one microphone for announcements or talk to studio purposes, and cueing control keys. As tape recorders are indispensable, room must be provided for two such units, but since they are usually complete with record and playback amplifiers as well as gain controls, all operational control can take place where the units are mounted.

The mixer unit is made up of two sections, each containing three and four faders respectively (Fig. 21). The former is used for fading and/or mixing the outputs of two transcription reproducers and one microphone. The reproducer heads are fed direct into unbalanced 25-Ω faders, the outputs of which are paralleled and fed into a switched equalizer, which provides varying degrees of bass lift or top cut depending upon the recording characteristic of the transcriptions which are used. The microphone is fed via a 300-Ω balanced to 600-Ω unbalanced transformer into a 600-Ω fader, and this fader output is paralleled to the output of the mixer, which in turn is fed via a 600-Ω unbalanced to a 300-Ω balanced transformer. The output level of this unit is −80 db below 1 mW, which means that an average recording will give an output of −73 V.U. peak programme level. Using a good moving-coil microphone fitted with a 300-Ω transformer, the output level is approximately −60 db on 1 mW.

Pre-fade listening facilities, in the form of a two-valve amplifier connected via a double-throw switch across the output of the reproducer heads, prove invaluable for the simple operation of the transcription turntables.

Fig. 21.—Typical studio control desk showing mixer panel.

The second section of the seven-way mixer unit contains two microphone faders of 300-Ω input impedance for control of the studio microphones, one fader for input control from a remote line (e.g., outside broadcast) and a fourth input is provided for the output of the three-way mixer section just described, which is fed in parallel with the outputs of the microphone faders to a master fader. The output from this point is taken to an amplifier with a gain producing an output level of 3 V across 45 Ω, for an input level of −69 db on 1 mW. A programme meter is connected across the output of this amplifier for level control.

Cueing signals are originated, from the control panel on the mixer unit, in the form of green and red lights, the former acting as a warning signal and the latter indicating that the studio is "on the air." This facility is accomplished simply by applying d.c. to the cueing circuits by means of a double-throw switch.

By suitable and simple safeguards the studio loudspeaker will only receive an input from the control cubicle when the "speak to studio" key is operated, but the circuit will only be complete when the red cue light is off.

Pre-fade, loudspeaker, and line amplifiers can all be housed in the control cubicle, with other associated equipment, or alternatively in a special equipment room.

6. Use of V.H.F. Links for Relaying Programmes

In common with other services in the Colony the telephone service was restricted in its development during the war years and it was not possible to obtain telephone lines to provide an input to the wired broadcasting system in San Fernando, from the control centre in Port of Spain. Accordingly, permission was sought and obtained for the erection of two "one-way" V.H.F. links between Port of Spain and San Fernando to carry programmes for the Rediffusion system in the latter place. The distance involved is approximately 25 miles and it is believed that the first link, which was placed in operation during 1948, is the first of its kind ever used for relaying programmes in a British colony.

The first channel was established on a carrier frequency of 73·02 Mc/s using a crystal-controlled transmitter designed to give an output power of 50 W unmodulated carrier, and a crystal-controlled superheterodyne receiver to give an A.F. output of 1 V r.m.s. across 600 Ω for an R.F. input of 5 mV modulated 30 per cent. at 400 c/s (Fig. 22). The A.F. response of this equipment is level to within ±2 db from 50-8,000 c/s for a distortion of less than 5 per cent. at 95 per cent. modulation, this standard of performance being of special importance.

The transmitter employs a push-pull crystal oscillator which also functions as a frequency trebler and is followed by two further push-pull trebler stages, giving an overall frequency multiplication of 27. The output stage employs a double tetrode specially designed for operation

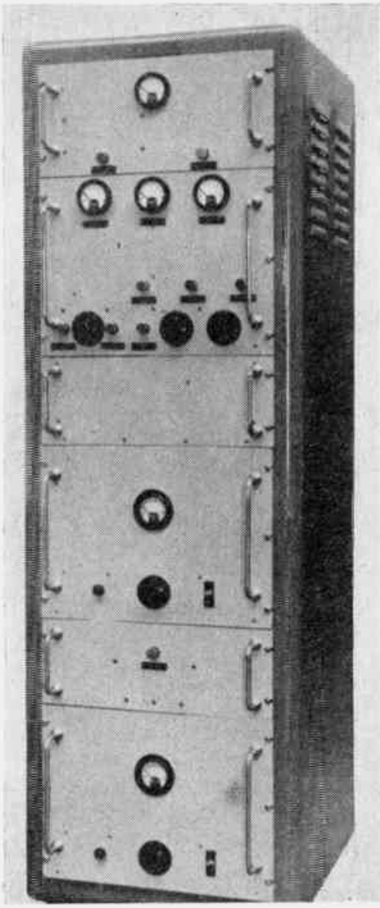

Fig. 22.—V.H.F. link equipment used in Trinidad for programme relay purposes.

at very high frequencies, and will match into a 70-Ω coaxial feeder. The modulator is designed for anode modulation and the unit comprises a pentode input stage followed by a triode driving a push-pull tetrode modulator operating in Class AB. A voice-operated gain control is incorporated so that the modulation depth remains substantially constant for large changes in input level, but only commences operating at 60 per cent. modulation depth. The A.F. input can be increased by 20 db for an increase in modulation depth to 90 per cent.

A superheterodyne circuit is used in the receiver design with a crystal-controlled oscillator. Two double triode valves are used in the oscillator circuit, a frequency doubler and two stages of frequency trebling, giving an overall multiplication factor of 18. There are three stages of I.F. amplification at a frequency of 4·85 Mc/s and the circuits are designed to give a response curve having a flat top with steep sides. The I.F. chain is followed by signal and A.V.C. rectifiers and a tetrode output stage gives an audio output of 2 V into 600 Ω. During periods of no signal a further circuit mutes the receiver, thus preventing unwanted noise being introduced into the output.

The second link was established over the same route using equipment illustrated in Fig. 23. The transmitter is capable of producing 10-15 W R.F. output on a frequency of 72 Mc/s and A.M. is employed, the modulator frequency response being level within ±2 db from 400-10,000 c/s, falling to ±3 db at 100 c/s.

The receiver is crystal controlled and 1 μV R.F. input modulated 30 per cent. at 400 c/s produces an A.F. output of 50 mW. The frequency response is claimed to be level within ±2 db from 200-10,000 c/s. A carrier-operated muting device is incorporated which disconnects the output in the absence of an incoming signal. The circuit is also noise compensated so that it will only be operated by an incoming carrier and will be unaffected by the presence of noise.

The aerial arrays at both transmitting and receiving sites are similar and are mounted on convenient high points or buildings (Fig. 24). They have been designed to give unidirectional characteristics along the transmission path and consist of one driven element, two directors and

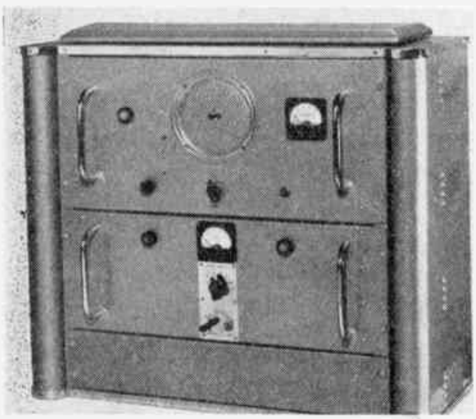

Fig. 23.—V.H.F. link equipment used for programme relay purposes in Trinidad.

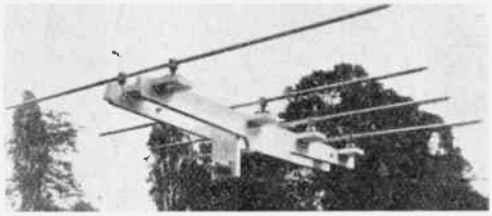

Fig. 24.—V.H.F. aerial array used in Trinidad.

one reflector. This arrangement is matched through a Y network and balance to unbalanced stub, and is connected to the transmitter or receiver by coaxial feeder. When correctly adjusted, this type of antenna will give a gain of 8 db over a half-wave aerial and a front to back field-strength ratio in excess of 3 : 1.

This method of providing radio inputs to remote points has proved entirely practicable under conditions of continuous operation and ensured programme quality superior to that which could have been obtained with telephone lines had they been available.

7. Conclusion

The future expansion of broadcasting in certain colonial territories is largely dependent upon economic conditions, and it is hoped that the foregoing remarks will provide a basis for future technical planning, particularly for small-scale operations in areas which up to the present time have been precluded from enjoying broadcasting amenities, owing to financial and geographical limitations.

8. Acknowledgments

The authors wish to record their appreciation to the Boards of Central Rediffusion Services, Ltd., and Overseas Rediffusion, Ltd., for permission to publish this paper.

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10.0. Appendix

A Bidirectional Antenna

Theory of the Antenna

The antenna consists of two horizontal parallel wires fed at one end and terminated by a resistance so that they carry a progressive wave with no reflection at the far end (Fig. 25).

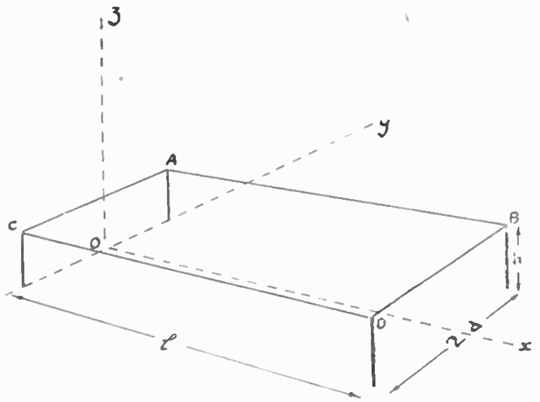

Fig. 25.—Dimensions of bidirectional aerial.

Let h = height of wires above earth
$2d$ = distance between wires
l = length of each wire
λ = wavelength

and let (r, θ, ϕ), the co-ordinates of a distant point, be defined as in Fig. 26.

If β and δ give the direction and elevation of OP we have

$$\left.\begin{aligned} \sin\theta\cos\phi &= \sin\delta \\ \sin\theta\sin\phi &= \cos\delta\sin\beta \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots (1)$$

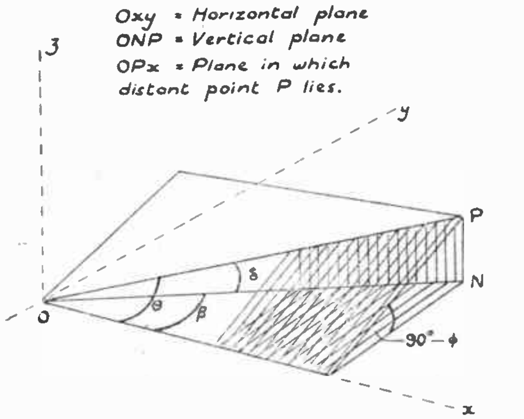

Fig. 26.—Diagram showing relation between electric field and angles of elevation and deviation.

On the assumption of a perfectly conducting earth the antenna can be represented by four wires, as shown in Fig. 27.

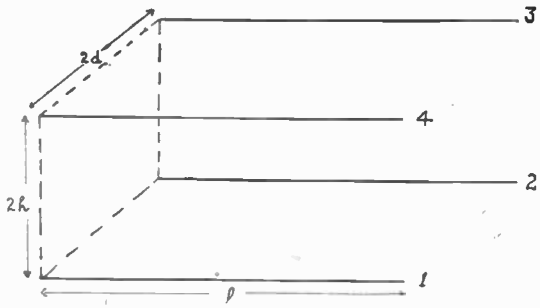

Fig. 27. Theoretical representation of antenna.

Neglecting the attenuation in the wires the currents at distances ξ along each wire are

$$\left.\begin{aligned} I_1 &= I_0 \exp j(k\xi - \omega t) \\ I_2 &= -I_0 \exp j(k\xi - \omega t) \\ I_3 &= I_0 \exp j(k\xi - \omega t) \\ I_4 &= -I_0 \exp j(k\xi - \omega t) \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots (2)$$

where $k = \dfrac{2\pi}{\lambda}$, ω = angular frequency.

The radiation field at a distant point (r, θ, ϕ) due to wire 1 is

$$\{E_\theta\}_1 = \sqrt{\frac{\mu_0}{\epsilon_0}}\{H_\phi\}_1 = -\frac{j\omega\mu_0}{4\pi}\frac{\sin\theta}{r}$$

$$\exp j(kR - \omega t) I_0 \int_0^l \exp jk\xi(1 - \cos\theta)\, d\xi \quad \ldots (3)$$

where the units are rationalized M.K.S. units. (See Stratton, Electromagnetic Theory, p. 440.)

Evaluation of the integral gives

$$\{E_\theta\}_1 = j60I_0 \frac{1}{r} \frac{\sin\theta}{1-\cos\theta} \sin\left[\frac{kl}{2}(1-\cos\theta)\right] \exp j\left\{kr-\omega t+\frac{kl}{2}(1-\cos\theta)\right\} \quad \ldots .(4)$$

The fields due to the other wires differ only in phase from that due to the first. The appropriate phase factors are

$$\left.\begin{aligned} f_1 &= 1 \\ f_2 &= -\exp(-j2kd\sin\theta\sin\phi) \\ f_3 &= \exp(-j2kd\sin\theta\sin\phi \\ &\qquad - jk2h\sin\theta\cos\phi) \\ f_4 &= -\exp(-j2kh\sin\theta\cos\phi) \end{aligned}\right\} \quad \ldots .(5)$$

Finally, the total field is

$$\begin{aligned} E_\theta &= \sqrt{\frac{\mu_0}{\epsilon_0}}\, H_\phi = \{E_\phi\}_1[f_1+f_2+f_3+f_4] \\ &= \{E_\theta\}_1(-4)\sin[kh\sin\theta\cos\phi] \\ &\quad \sin[kd\sin\theta\sin\phi] \\ &\quad \exp j\{-kh\sin\theta\cos\phi - kd\sin\theta\sin\phi\} \\ &= j240I_0\frac{1}{r}\cot\frac{\theta}{2}\sin\left[\frac{kl}{2}(1-\cos\theta)\right] \\ &\quad \sin[kh\sin\theta\cos\phi]\sin[kd\sin\theta\sin\phi] \\ &\quad \exp(-j\omega t + j\alpha) \ldots\ldots\ldots\ldots\ldots\ldots(6) \end{aligned}$$

where α is a phase angle.

The radiation pattern is given by

$$F(\theta,\phi) = \cot\frac{\theta}{2}\sin\left[\frac{kl}{2}(1-\cos\theta)\right] \sin[kh\sin\theta\cos\phi]\sin[kd\sin\theta\sin\phi] \quad \ldots\ldots\ldots\ldots(7)$$

The radiant energy flow is determined by the function

$$S^* = \frac{1}{2}E_\theta H_\phi = \frac{480I_0^2}{2\pi}\cdot\frac{1}{r^2}[F(\theta,\phi)]^2 \quad (8)$$

and the power dissipated in radiation is

$$W = \frac{480I_0^2}{2\pi}\int_0^\pi\int_{-\pi/2}^{\pi/2}\{F(\theta,\phi)\}^2\sin\theta\, d\theta d\phi \quad (9)$$

The radiation resistance is

$$\mathscr{R} = \frac{960}{2\pi}\int_0^\pi\int_{-\pi/2}^{\pi/2}\{F(\theta,\phi)\}^2 d\theta\, d\phi \quad \ldots\ldots(10)$$

since $W = \frac{1}{2}\mathscr{R}I_0^2$, I_0 being the peak current.

Design Procedure

In the practical design of the antenna, the following procedure is adopted: Values of θ and ϕ are given for which maximum radiation is required, say Θ, Φ. The least values of h and d are then chosen to make

$$\left.\begin{aligned} \sin[kh\sin\Theta\cos\Phi] &= 1 \\ \sin[kd\sin\Theta\sin\Phi] &= 1 \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots(11)$$

these being the greatest values the functions can attain. l is then chosen to make

$$g(\theta) = \cot\frac{\theta}{2}\sin\left[\frac{kl}{2}(1-\cos\theta)\right] \text{ a maximum}$$

Thus

$$\frac{dg}{d\theta} = \frac{kl}{2}\sin\theta\cot\frac{\theta}{2}\cos\left[\frac{kl}{2}(1-\cos\theta)\right] - \frac{1}{2}\operatorname{cosec}^2\frac{\theta}{2}\sin\left[\frac{kl}{2}(1-\cos\theta)\right] (12)$$

and $g(\theta)$ has a maximum when

$$2\,.\,\frac{kl}{2}\sin\theta\cot\frac{\theta}{2}\sin^2\frac{\theta}{2} = \tan\left[\frac{kl}{2}(1-\cos\theta)\right] \ldots\ldots\ldots(13)$$

Thus, l is determined so as to satisfy

$$\frac{kl}{2}\sin^2\Theta = \tan\left[\frac{kl}{2}(1-\cos\Theta)\right] \ldots(14)$$

If a is the radius of the wires, the terminating resistance is given by:—

$$Zo = 276\log_{10}\left[\frac{2d}{a}\cdot\frac{1}{\sqrt{[1+(d/h)^2]}}\right] \quad \ldots .(15)$$

Example:

An antenna is required to transmit or receive radiation in two directions an angle 45 deg. apart at an elevation 18 deg. The wavelength is:—

$$\lambda = 16{\cdot}7 \text{ metres}$$

thus:

$$\beta = 22{\cdot}5^\circ$$
$$\delta = 18^\circ$$

and equations (1) give $\theta = 28^\circ\ 30'$

$\phi = 49^\circ\ 43'$

Equation (11) now gives $h = 13{\cdot}5$ metres

$d = 11{\cdot}5$ metres

$l = 50$ metres

CONTRIBUTION:

A NOTE ON IONOSPHERIC CONDITIONS WHICH MAY AFFECT TROPICAL BROADCASTING SERVICES AFTER SUNSET*

by

B. W. Osborne, M.Sc. (*Associate*)†

Ionospheric reflection at nearly vertical incidence is often convenient for the propagation of local high frequency broadcast transmissions,[1,2] but while reliable reception between sunset and midnight is of considerable programme value, there are certain ionospheric phenomena, peculiar to the neighbourhood of the magnetic equator, which can cause intolerable fading at these hours over short paths involving reflection at the F2 layer. The occurrence of these effects may at times be sufficiently frequent to decrease materially the quality of the service.

At low latitudes, the height of the F2 layer generally increases rapidly after terrestrial sunset up to the time of sunset on the ionosphere, and this height increase may be followed by the appearance of clouds within the F2 region. The electron density of these clouds, as observed at Huancayo in Peru in 1938, has been discussed by Booker and Wells.[3] The critical penetration frequency of the layer often shows erratic changes from hour to hour, associated with the height variations and with the occurrence of scatter. The F2 layer may disintegrate entirely at the approximate time of ionospheric sunset,[4] giving a diffuse scattered echo-pattern, at vertical incidence, over wide ranges of virtual height and transmitted frequency. Under these conditions reflected signals show rapid and intense fading.

This scatter at Singapore is most frequent at the equinoxes, between the hours of 1900 and 2100 local time, and may occur on as many as half the days of the month. There is some reason to believe that the frequency of occurrence of this equatorial scatter is greatest at the maximum of the 11-year sunspot cycle. Propagation conditions are better at the solstices, at these hours, when the layer often remains intact throughout the evening.

This scatter occurrence prohibits the determination of the maximum usable frequency for a given range, as when the layer itself has no stable existence, neither the critical frequency nor the layer height exist as measurable entities, and in practice reflected signals from the F2 region are not always intelligible, even though the signal strength may be high.

The boundaries of the area within which these equatorial scatter phenomena exist have not yet been determined, but unless there are pronounced longitude discontinuities along the magnetic equator, it seems possible that the sunset effects may be present on some days during equinoctial periods at all places within the "equatorial trough" of low daytime critical frequency, where the magnetic dip does not exceed about 25 deg.

Acknowledgment

The work referred to above was carried out as part of the programme of the Radio Research Board, and this note is published by permission of the Director of Radio Research of the Department of Scientific and Industrial Research.

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* A contribution made at the Third Session of the 1951 Convention following the reading of the paper by P. Adorian and A. H. Dickinson.[1]

† Radio Research Station, Slough.

U.D.C. 621.396.812.4.

HIGH FREQUENCY BROADCAST TRANSMISSION WITH VERTICAL RADIATION*

by

P. Adorian (*Member*)† and A. H. Dickinson (*Associate Member*)‡

A Paper presented at the Third Session of the 1951 *Radio Convention on July* 24*th at University College, Southampton*

SUMMARY

The economic and physical difficulties of medium and long wave broadcasting which are met, particularly in undeveloped areas, are dealt with. The point is brought out that correct siting for getting reasonable coverage for an area usually means high capital cost in connection with the establishment of the station and also high maintenance costs. The idea is developed that if broadcasting were directed in a vertical direction, exact siting of the station would not be very important provided there is reasonable soil conductivity.

Reference will be made to the usable wavelengths in different parts of the world both as regards maximum and minimum and their effect on the cost of the aerial system. Three types of aerial for vertical radiation are described, and graphs illustrating polar diagrams are included.

1. Broadcasting in Difficult Areas

The majority of radio engineers live in areas where industry and public services are well developed and where broadcasting, whether as a public service or a commercial operation, is carried out on conventional lines. When additional broadcasting facilities are to be introduced in such countries, either to improve reception or to provide additional programme matter, it is usual for engineers to recommend conventional medium wave, or long wave, transmission.

In recent years it has become necessary in some areas, particularly in America, to introduce V.H.F. transmission for local broadcasting owing to the non-availability of wavelengths in the medium wave band.

When, however, considering the introduction of broadcasting services in areas where, except in the main centres of population, public services such as power, water supply and roads are not generally available, and where the average income of the population is low, neither medium wave nor V.H.F. broadcasting is particularly suitable.

These remarks apply to certain colonial areas where if medium wave broadcasting were employed to cover the whole of the area, the transmitter might have to be located at a site where the cost of the services such as roads and power supply might be prohibitive. The same remarks apply to the transmitting aerial and in such cases the staffing of the transmitter may become unduly difficult and expensive.

The position is very similar in the case of V.H.F. broadcasting as in that case it might be necessary to place the transmitter on top of an isolated mountain in order to obtain reasonable range. With V.H.F. broadcasting the further difficulty has to be faced that, owing to its limited use at present for sound-only broadcasting, V.H.F. receivers are not made in large quantities and are, therefore, beyond the means of the population.

H.F. broadcasting is being used to a considerable extent for long-distance broadcasting but in the past has not been considered suitable for local broadcasting due to the fact that normally this type of broadcasting has been used in a manner where even a few miles away from the transmitter the signal strength has become heavily attenuated, while at long distance, say, 1,000 miles away, reasonably good reception can be obtained by receiving reflected rays only.

This paper describes a system of broadcasting that employs high frequencies but in conjunction with aerial systems which concentrate the maximum amount of energy in a vertical direction from the transmitter and then depend on reflection from the F2 layer, which is about 200 miles above ground.

It will be seen from the following that by the use of suitable frequencies in the H.F. bands it is

* Manuscript received April 29th, 1951.
† Central Rediffusion Services, Ltd.
‡ Jamaica Broadcasting Co., Ltd.
U.D.C. No. 621.396.677.2.

possible to obtain vertically directional aerial patterns that provide a reasonably efficient broadcasting service over an area of 150-200 miles radius without producing undue interference at distances greater than these.

The advantages of the system are that relatively inexpensive aerial systems utilizing masts one-quarter to three-quarters wavelength high can be used; the actual location of the transmitter is not critical and that commercially manufactured receivers with H.F. bands (so called short-wave bands) can be obtained by listeners at reasonable cost.

It is realized that reception with this type of broadcasting is not quite as good as would be obtained with a suitably located high-power medium wave transmitter, but it is considered as a reasonable commercial compromise.

At the time when this paper is presented there are two such transmitting systems in operation in the West Indies, and in general their operation can be considered satisfactory except that interference from transmitters located long distances away is experienced on some frequencies after sunset. It is hoped, however, that when the advantages of the system receive world-wide recognition, international agreement may be reached for setting aside certain channels in the H.F. band to be used for vertical transmission only and these channels can be used many times over in different parts of the world in this particular manner.

An interesting point that should be mentioned in connection with this H.F. method of local broadcasting is that, particularly in tropical areas, static interference may be quite considerable on medium wave bands while not so serious on H.F. bands.

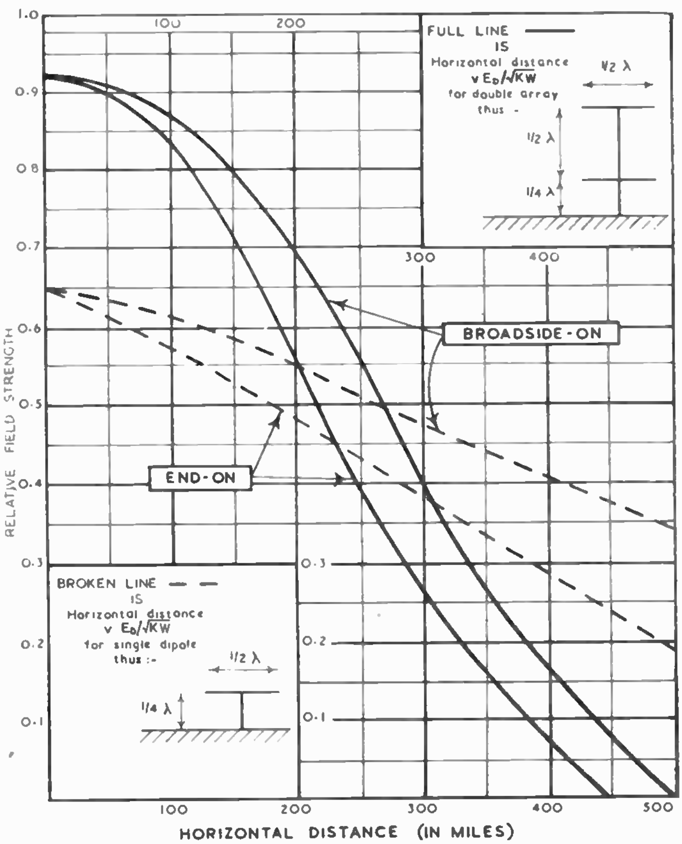

Fig. 1.—Horizontal distance v $E_D\sqrt{KW}$ for single and double horizontal ½ λ dipole array

On the other hand, it must be said that the variation of ionospheric conditions from year to year, month to month, day to day and hour to hour may necessitate long-term or short-term changes in frequency. This is a disadvantage as more than one channel may have to be allocated to a station and it is not convenient for listeners to have to change the setting of their receivers during different parts of the year or day. From experience gained so far, however, it would appear that good reception can be maintained at latitudes between 20°N and 10°N with only two wavelengths, the shorter of the two being used mainly during the day and the longer at night time.

2. Aerials for Vertical Broadcasting

In the following, three types of aerials used for vertical broadcasting will be discussed, as follows:

(1) The Trinidad Aerial: This consists of two half-wave dipoles in the same vertical plane, the lower of which is quarter-wavelength from the ground and the higher three-quarters-wavelength above ground. Both dipoles are fed with current of the same phase and magnitude. It is known as the Trinidad aerial because it has been operating in Trinidad since 1948.

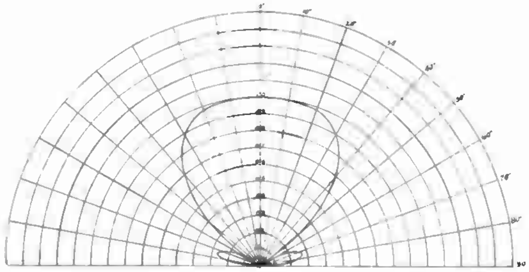

Fig. 2.—Calculated V.P.D. of Trinidad aerial in plane perpendicular to plane of array

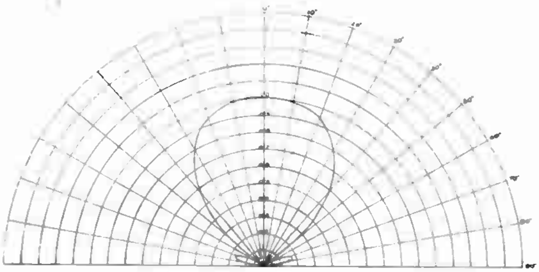

Fig. 3.—Calculated V.P.D. of Trinidad array in a plane at 45 deg. to the plane of the array

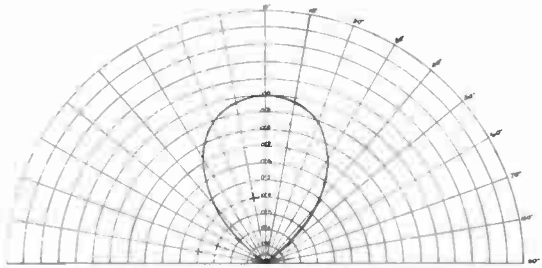

Fig. 4.—Calculated V.P.D. of Trinidad short-wave aerial in plane containing array

(2) The Jamaica Aerial: This aerial consists of four half-wave end-fed aerials (or two full-wave dipoles) in the same horizontal plane. The two "full-wave dipoles" are half-wavelength apart and both are quarter-wavelength above the ground. The aerials are fed with current of the same phase and magnitude. This aerial has been in operation in Jamaica since mid-1950.

(3) The 16-Element Array: This aerial is not yet in operation but has been designed theoretically by one of the authors (A. H. Dickinson). It consists of 16 half-wave dipoles all in the same horizontal plane; each group of four is in line and spaced half-wavelength from the next group. All aerials are quarter-wavelength above earth and are fed in phase.

It will be noted that in all these three aerials the earth is used as a reflector and it is, therefore, essential for the correct operation of these aerials to have a good earth. In practice this is done by burying a number of wires just below the ground under the aerial system.

No attempt is made in this paper to deal with the mathematics involved in the calculation of the polar diagrams, but a list of references is included at the end of the paper giving sources for calculating polar diagrams for aerials such as described here.

2.1. *Trinidad Aerial*

Figure 1 shows in solid line the relative field strength of the Trinidad aerial plotted against horizontal distance from the transmitter for single hop F2 transmission. As a comparison the relative field strength for a single half-wave dipole, quarter-wave above ground is also shown. In each case both the broadside-on and end-on values are given and for intermediate angles values between those shown on the graph would apply.

It should be realized that the values are for average conditions only as, owing to the varying conditions in the F2 layer, the field strengths are subject to short-term and long-term variations.

It will be seen from Fig. 1 that, using an aerial such as the Trinidad aerial, greater field strength is obtainable near the transmitter and a lower value of field strength further away.

The actual polar diagrams of the Trinidad aerial in three horizontal directions from the aerial is shown in Figs. 2, 3 and 4. For the sake of clear illustration, a three-dimensional polar diagram has been constructed, Fig. 5. It will be seen from Figs. 2 to 5 inclusive that this aerial has a small lobe at a relatively low angle and, therefore, not only is wasteful of power but can cause a small amount of interference at long range.

2.2. *Jamaica Aerial*

The vertical polar diagrams for this aerial are shown on Figs. 6 and 7. It will be seen that this aerial is a great improvement on the Trinidad aerial.

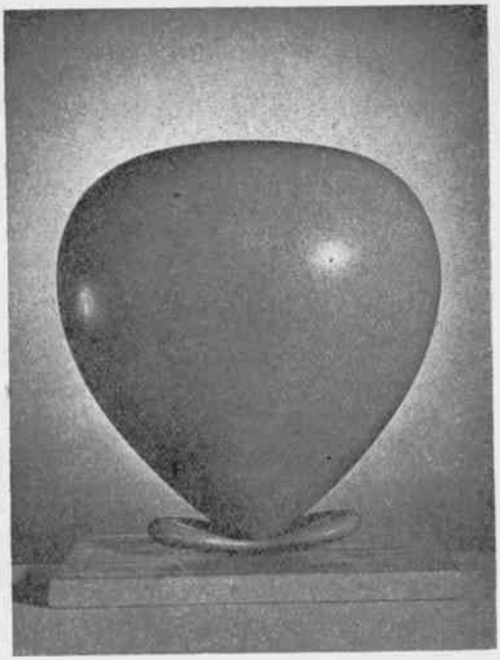

Fig. 5.—*Trinidad aerial: three-dimensional polar diagram*

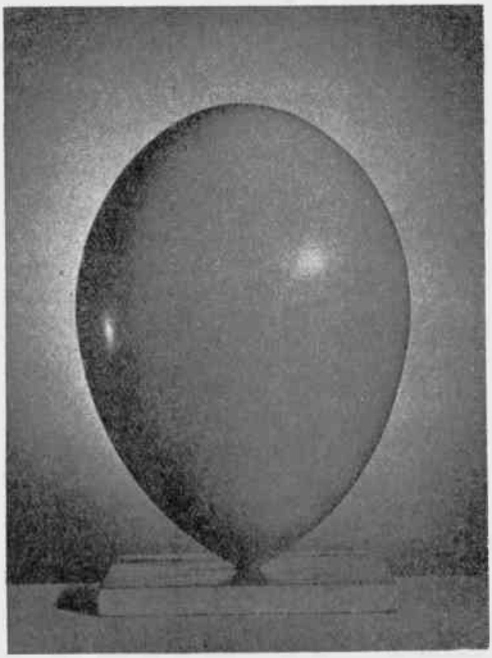

Fig. 8.—*Jamaica aerial: three-dimensional polar diagram*

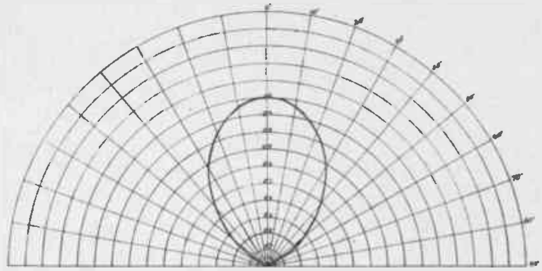

Fig. 6.—*Calculated V.P.D. of Jamaica aerial in plane perpendicular to elements*

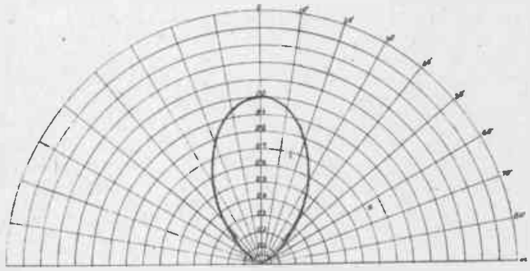

Fig. 7.—*Calculated V.P.D. of Jamaica aerial in plane containing elements*

This is clearly illustrated with the help of a three-dimensional polar diagram which has been constructed and photographed (Fig. 8).

2.3. 16-*Element Array*

For the sake of clarity Fig. 9 shows the general plan view of this aerial together with transmission lines but without matching devices which may be necessary between the dipoles and lines.

The calculated polar diagrams for this 16-element array are shown in Figs. 10 and 11.

3. Variation of Field Strength

It is beyond the scope of this paper to deal with the conditions determining the choice of suitable frequencies to be used by vertically radiating broadcasting stations in different parts of the world and different times of the sun cycles. These are matters which have been dealt with at length in various standard reference works and considerable technical assistance is given by British and other Government organizations in the forecasting of these conditions.

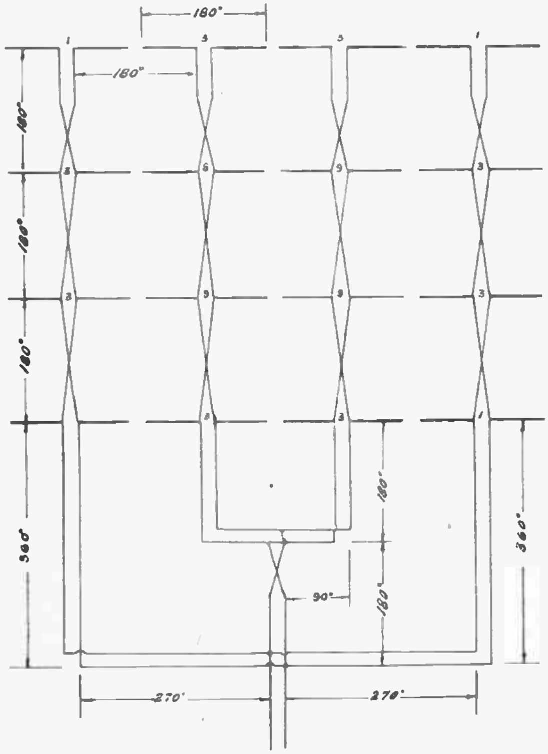

Fig. 9.—*Plan view of* 16-*element array*

Note.—Figures at dipole feed points indicate the amplitude of the current fed into the dipole. No matching devices shown

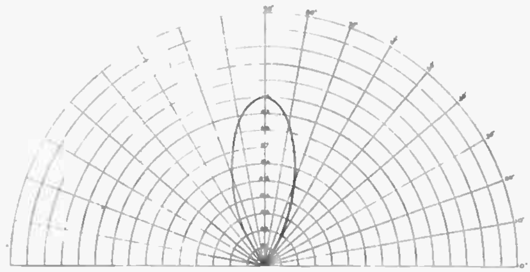

Fig. 10.—16-*element binomial array in plane parallel to elements*

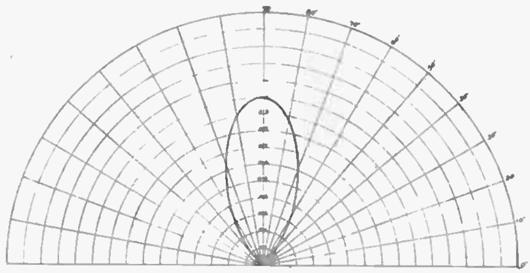

Fig. 11.—16-*element binomial array in plane bisecting elements calculated V.P.D.*

The field strength which can be expected with vertical radiation can be estimated fairly accurately by a method which, although empirical, does agree fairly well with the theory of wave propagation in an ionized medium.

Briefly, the field strength is calculated for a single hop transmission under conditions of perfect reflection, allowance being made for non-deviative absorption losses.

Let E_o = field strength at 1 km,

then $\frac{E_o}{d}$ = F_o = unabsorbed field strength at ground distance D

where $d = 2\sqrt{\left\{ h_e^2 + \frac{D^2}{4} \right\}}$

and h_e = virtual height of the reflecting layer

Let F = the homogeneous field strength at ground distance D,

and let α = non-deviative absorption loss in decibels;

then $F = F_o - \alpha$

The non-deviative absorption loss is made up of several factors, depending upon the diurnal, seasonal, monthly and eleven-year solar activity variation of the sun.

The diurnal variation factor represents absorption over a 24-hour day and is fairly well described by the formula:

$$K = 0{\cdot}142 + 0{\cdot}858 \cos \chi$$

where χ is the sun's zenith angle.

Charts are available from which values of K can be determined for different times of the day and various seasons of the year. (United States Department of Commerce, National Bureau of Standards Circular 462, 1948.)

A residual seasonal variation of absorption, beyond that represented by the diurnal variation factor, varying in value between unity and 1·3, also occurs and must be taken into consideration. It is denoted by the symbol J.

The activity of the sun follows a 27-day and 11-year variation coincidental with its rotation and sun spot number. Absorption due to this activity is represented by the symbol Q and increases almost linearly between sun spot zero and maximum, thus:

$Q = 1 + 0{\cdot}005\ R$, where R is the predicted sun spot number.

The diurnal, seasonal, 27-day and 11-year solar activity variations, JQK, can be combined to give an expression for non-deviative absorption, which, however, is still dependent on the frequency of transmission. A table is given below showing the degree of absorption in db for various frequencies above 1 Mc/s at vertical incidence and to obtain the total non-deviative absorption for a frequency of, say, 5 Mc/s, the absorption factor at 5 Mc/s, i.e. 7 db, must be multiplied by the combined factor JQK.

Absorption Factors for Various Frequencies at Vertical Incidence

Frequency—Mc/s	Absorption Factor—db
2	26
3	17
4	10·5
5	7
6	5
7	4
8	3
9	2·5
10	2

4. Practical Results and Conclusions

The system of broadcasting described here has not been operating long enough to give complete and absolute evidence as to its performance. During its operation in Trinidad and Jamaica, however, it has been established that within the limits of the available frequencies, reasonably good broadcast reception is possible in the area of the operation without undue interference at greater distance.

As an example, it may be stated that the signal strength from the Jamaica aerial was measured at a distance of about 1,000 miles and it was found that, when the signal strength about 30 miles from the aerial was 1 millivolt/metre, at 1,000 miles away it was 20 microvolts/metre. The practical performance of these aerials is being examined now in more detail and it is hoped at a later date to present an analysis of these results.

In the meantime, the conclusion that can be drawn from the observations already made is that if a number of channels were set aside for this vertical method of broadcasting in difficult areas, then these channels could be used over and over again without objectionable interference between stations sharing the channels.

At the time of writing this paper there is no effective international agreement on this matter and, therefore, particularly at night time, interference is experienced in the service areas of the vertically radiating stations from other H.F. stations radiating at high power and at low angle.

Until international agreement is reached on this matter full utilization of the technical advantages of vertical H.F. broadcasting cannot be achieved.

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THE DESIGN AND DEVELOPMENT OF THE DECCA FLIGHT LOG*

by

G. E. Roberts†

A Paper presented at the Fourth Session of the 1951 *Radio Convention on July 26th at University College, Southampton*

SUMMARY

The paper first outlines some of the problems involved in the presentation of navigational data. The choice of co-ordinates is discussed and examples are given which seem to merit human judgment in preference to fully automatic computation. Convenient compromises requiring less complex computers are described, with details of the Decca Mark 01 Flight Log. The servo mechanisms involve a d.c. sign-changing circuit, a d.c. amplifier with a slope of 10 amperes per volt and backlash neutralizers. Mechanical and electronic frequency changers are compared.

1. Introduction

The Decca Flight Log is one of the many possible methods of translating the information offered by the Decca Navigator receiver into a form more convenient than that of the usual Decometer display. It is therefore desirable to describe very briefly the basic data it receives from the Decca receiver.

This information relates to the phase pattern of four ground transmitters, and it is normally displayed on three meters individually labelled "Red," "Green" and "Purple." The pattern takes the form of three families of hyperbolae (Fig. 1) and the meters are used in conjunction with a chart of the terrain which has these hyperbolae overprinted. Each hyperbola in the Red family is numbered, the numbers rising as one proceeds outwards from the central master transmitter, and the figure displayed at any instant on the Red Decometer corresponds to the number of some unique red hyperbola which runs through the position of the receiver. Likewise, Green and Purple. The interval between two adjacent hyperbolae is referred to as a "lane" and it will be noticed that all Red lanes are of equal width on the base line (shown dotted) between the two foci, but that elsewhere lanes of large number or of small number are wider than those of intermediate numbers.

Only two Decometers need be used in fixing one's position, ignoring the one which offers the widest lanes and, therefore, the lesser accuracy in that locality.

* Manuscript received July 18th, 1951.
† The Decca Navigator Co., Ltd.
U.D.C. No. 621.396.932.

2. An Outline of the Problem

Although it is possible to determine position with remarkable precision by referring two Decometer readings to a chart, this procedure is inconvenient for a solo air pilot, and not the most useful to a navigator. There is a dereliction of accuracy due to the difficulty of reading two moving instruments at the same instant. The information is slightly late by the time it is plotted, and information regarding course corrections to maintain a required track can only be obtained from a plurality of fixes spaced less frequently than might be desired. The problem originally set which led to the development of the

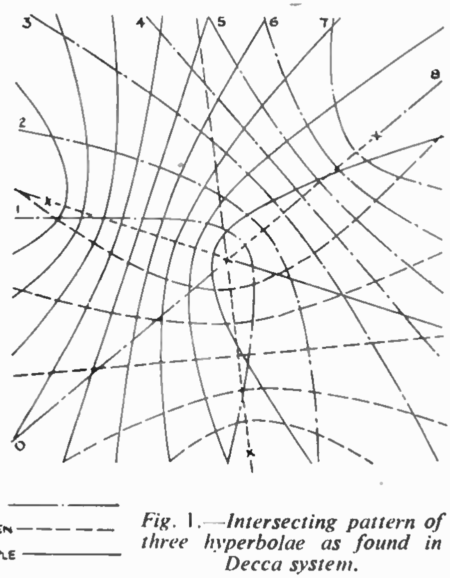

Fig. 1.—Intersecting pattern of three hyperbolae as found in Decca system.

Flight Log was that of producing an instrument which would display the "intelligence" concealed in the Decometer readings, in a readily assimilable form without recourse to calculation or significant mental effort, and without manipulation.

3. Some Essentials of the Problem

Now the identification of a ground position (i.e., identifying a point in a two-dimensional surface) requires two elements of information, no matter what form they take, e.g., latitude and longitude, two grid references or cartesian co-ordinates, range and bearing from an agreed datum as in polar co-ordinates, etc. Without recourse to a chart, none of these is of great use unless one has a clear picture in one's mind of that particular co-ordinate system in relation to the terrain. Given two figures for latitude and longitude, few people could name the locality so identified. The comparative incomprehensibility of Decca information is due to its being cast in a completely unfamiliar hyperbolic co-ordinate system. The two systems which readily suggest themselves as useful are:—

(1) Range versus bearing from destination;

(2) Progress along the scheduled track versus perpendicular distance off track.

4. A First Attempt

The first attempt was an approximation to the latter. This amounts to using a system of cartesian co-ordinates with the destination as origin and the required track as the zero ordinate. Two instruments are used, one to display a figure for "miles to go" and the other "miles off track." It is desirable at this stage to ignore practical details and consider only the functions required of the computor which furnishes this information to the meters. To this end one may well consider the simplest way of arriving at such information manually. Suppose one prepared a table of figures showing the Red and Green readings corresponding to a series of points along the track, perhaps one mile apart. Then one column of figures alone will serve as the milometer, i.e., as the Red Decometer arrives at the readings listed, the "miles to go" figure is quoted. "On track" verification is obtained just as simply. As each listed Red reading is obtained, the Green reading must be the one listed also, or else one is off track by an amount which can be deduced from the discrepancy plus further tabulated information about lane widths and other factors. The necessary corrections for curvature of the hyperbolic lattice, curvature of the track, changing lane widths and changing angles of cut become tedious in the extreme, and the increase of stored information needed is formidable.

This line of development was then slightly modified with some success for not too complex a track. If it is required to define holding patterns for aircraft, or intricately curved tracks for coastal shipping, etc., further difficulties arise. These difficulties are inherent in the choice of co-ordinates and may be considered without reference to the apparatus at all. When aircraft are required to delay their arrival, some suitable orbit or other holding pattern must be adopted, and consequently tracks such as (*a*) or (*b*) in Fig. 2 are used.

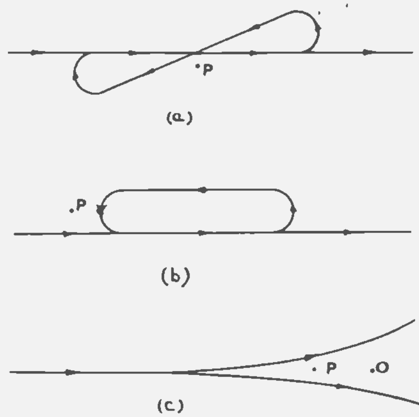

Fig. 2.

If an aircraft is at P in (*a*) or (*b*), it is not possible to say whether it is off track to the left or right unless one knows which way it is heading and something of the past history of the track. For any automatic computor to cope with such a situation, it must be made much more complex. It must be endowed with memory and information from the compass. Furthermore, the final answer it must give is in some measure dependent on the reasons why such a track was stipulated and what likelihood of calamity attaches to deviation one way or the other. If the original choice of track was rather arbitrary, the decision may well be arbitrary too, but if a ship is at P in (*c*), and has been given a choice of two safe channels round an obstacle O, the choice involves additional knowledge of tides and currents, and the limits of manœuvrability of the craft. It is now beginning to look much more like a case for intelligent human judgment than one for automatic computation.

It is apparent that the method of approach chosen has succeeded in making a very simple matter look very complicated. It is well worth recalling the old adage: "If it's difficult, it's wrong."

Any one of the cases depicted in Fig. 2 could be dealt with by a pilot if he could be given the information in Fig. 2, plus the past history of the track. But Fig. 2 does not confuse his mind with any apparent co-ordinates at all. It gives a pictorial presentation. It argues that two figures on instruments will usually convey less information than a fix on a map showing that one is now passing over Southampton. A recorded trace showing that one has arrived from the west completes the information. This line of development gives the added advantage of complete flexibility against restriction to a predetermined track.

5. Map Presentation

It was thus agreed that it would be better to move an indicator appropriately over a map than to use two dials. The c.r. tube presents itself as a familiar and readily movable indicator. However, it is not convenient to get it to leave a recorded trace, and it might well involve some complexity of associated apparatus. Something like the usual pen-and-paper roll recording instrument is more suitable and offers a very permanent record of the flight for filing purposes, as shown in Fig. 3. If the paper is driven in accordance with the north-south movement of the aircraft and the pen is driven in accordance with the east-west movement of the aircraft, the desired results can be obtained. Now, this certainly can be done, but the computor required to extract these two components from Decca readings in hyperbolic co-ordinates without losing the very high accuracy of Decca is neither simple nor of light weight, though it may well become so one day.

Consequently, a compromise is sought, and, therefore, one should examine the reasons why this computation is needed and discover whether any part of it is not strictly necessary.

We start with two movements on two Decometers and we have to end up with two

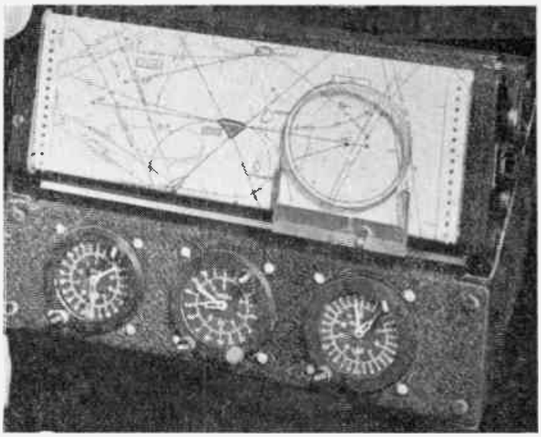

Fig. 3.—The Display Head, showing chart, inking device and Decometers.

movements, one being the movement of the paper and the other the movement of the pen. Since the paper is to roll off a spool and on to another it is difficult to imagine how we can do otherwise than be content with motion in a straight line. The pen may be driven along a cross slide by a lead screw very conveniently and again produce motion in a straight line. Ideally, therefore, we require the aircraft movement resolved into two components at right-angles.

5.1. *The Simplest Case*

Now there are three small localities in the Decca coverage which are very special cases. In these places the required results would be obtained without any computor at all. Since the hyperbolae have so little curvature in these areas that they may be regarded as straight without introducing detectable errors, and the angle of cut happens to be 90 deg., we could use one Decometer via a torque amplifier to drive the paper, and the other to drive the cross slide. We merely choose a suitable scale, maybe one Green lane to 1 in. of paper movement, and one Purple lane to so much movement of lead screw. These movements will not be equal in general because one Purple lane will not usually be worth the same amount of terrain as a Green lane. Now, something like this has actually been done, but with a Flight Log originally made for other purposes, so that the movement produced by one Purple lane was disproportionately small. This defect was rendered comparatively innocuous by the very simple expedient of distorting the chart slightly, making the scale in the east-west direction dissimilar from that in the north-south direction. This method is quite acceptable provided one does not press it too far. We are all quite used to distorted maps whether of the Mercator or poly-conical projections and where inverse Decca does not look too bizarre it is perfectly usable.

One of the special localities includes London Airport and a test was conducted as follows: A road vehicle was driven over all the London runways except the duty one. Both edges of the runways were used, and in some cases a good deal of circling and figures-of-eight took place within the runway width. The recorded trace was then examined for lack of agreement with the printed chart. The result is shown in Fig. 4. (The trace does not appear as a smooth line, its staircase appearance being due to the use in this particular apparatus of step-by-step servo systems.) Subsequently, "blind" instrument driving was successfully attempted.

5.2. *The General Case*

Let us now see what is involved in extending this method from such very special cases to the general case. We might start by extending the area represented on the London Airport map. Not much extension is possible without including Purple lanes which are noticeably wider, and so we have to introduce non-linear distortion of the map. It also quickly becomes evident that the first and last lanes are not parallel, and a new kind of treatment is required in which the amount of distortion of the Green scale depends on the instantaneous Red reading. Straight lines on the terrain have become curves on the map. The most distressing distortion of all is associated with a change in angle of cut from the original 90 deg. Examples are given in Figs. 5 and 6.

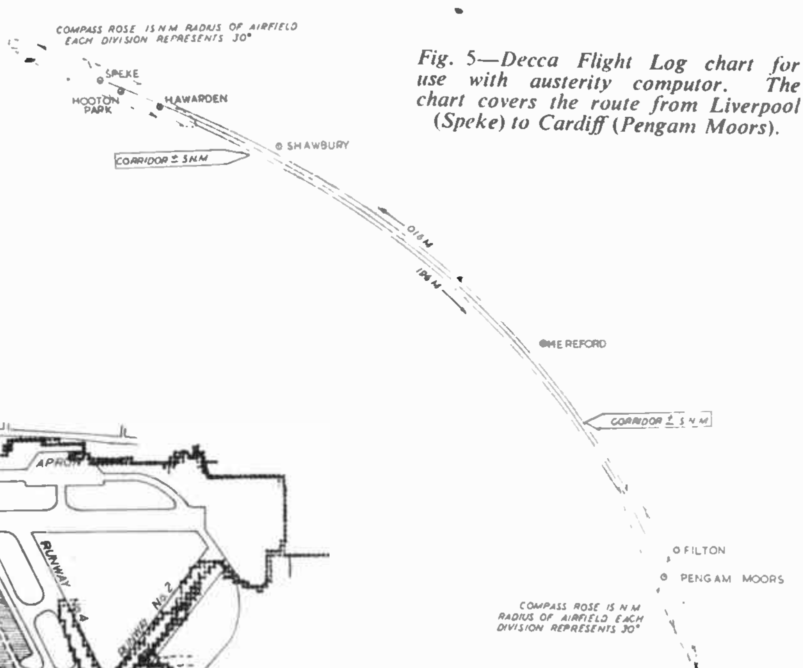

Fig. 5—Decca Flight Log chart for use with austerity computor. The chart covers the route from Liverpool (Speke) to Cardiff (Pengam Moors).

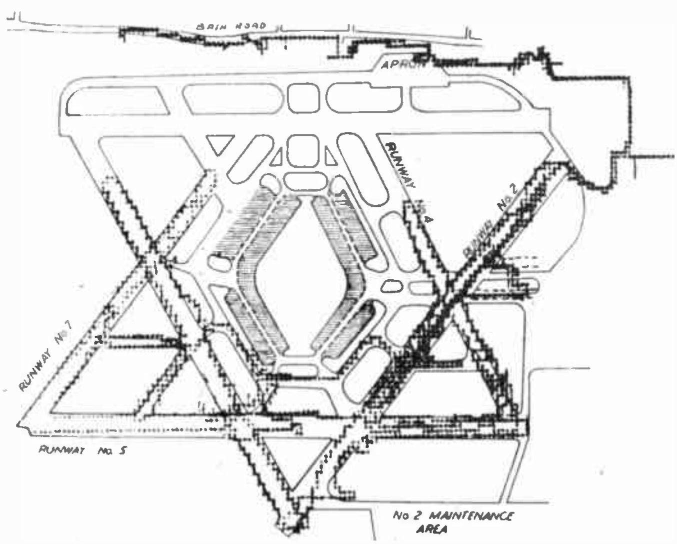

Fig. 4 (left).—Track of a vehicle equipped with the Decca Flight Log, following the runways and taxi tracks of London Airport. This is a facsimile of the actual chart used.

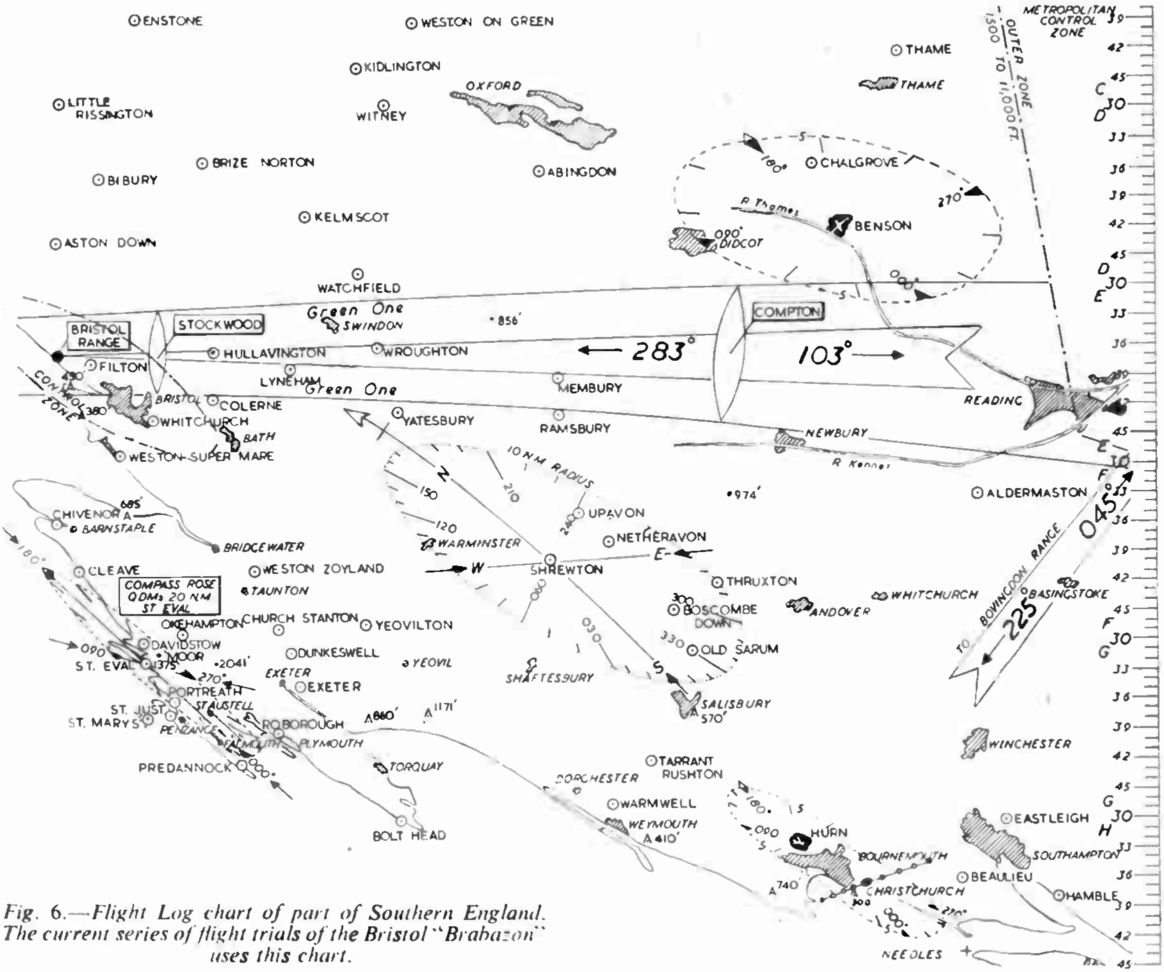

Fig. 6.—*Flight Log chart of part of Southern England. The current series of flight trials of the Bristol "Brabazon" uses this chart.*

5.3. *Partial Computation*

Any attempt to get rid of this distortion completely will inevitably lead to all the difficulties of a full-scale hyperbolic computor. However, if part of the distortion could be got rid of, the remnant might be acceptable. We need to find some easily executed mathematical operation which would change the hyperbolic pattern into one which looked to the eye more nearly like a cartesian system. Three aspects of this problem are important.

The first arises out of the compromise nature of the requirement. It will not be mathematically immaculate and may look crude or clumsy. In such circumstances there are likely to be several quite separate answers for different localities in the Decca cover. If each locality is large so that frequent changing from one system to another is not required on a long flight, this might be acceptable.

The second is a consideration of the mathematical operations which can be performed without overtaxing a lightweight computor.

The third may well be peculiar to Decca, and presumably would not arise in connection with other navigational systems.

The Decca receiver supplies to each of three meters voltages proportional to the sine and cosine of the angle to be displayed. One complete revolution corresponds to one lane, and consequently at intervals of one lane the receiver outputs have returned to identical values. Consequently an error in the receiver output voltages of n per cent. produces an error of reading of no more than n per cent. of one lane. If the reading is of the order of 1 lane, the error is of the order of n per cent. If the reading is of the order of 50, the error in total reading approximates to $n/50$ per cent. Thus, at the cost of introducing multiple ambiguities which are resolved by other means, an overall accuracy is attained which is large compared with that of the apparatus used.

The case is analogous to that of a butcher's weighing machine in which weights are used, the weights always being integers of pounds, and the ounces are displayed on a scale. Provided the zero has been properly set, no defect in the machine can produce errors of more than 1 lb. Thus, when weighing out, say, 5½ lb., the weighing is about five times as accurate as the machine. If we now pass this figure of 5½ into a computor which has an error of n per cent. also, we immediately lose the added accuracy. Some of the Decca patterns include over 300 lanes, and, if the computor is to avoid adding disproportionately large errors on top of the 1 per cent. attainable in the receiver, it needs to have an overall error of no more than 1 in 30,000. This intolerable situation can only be avoided at the cost of quite severe limitations on the functions attempted in the computor. Additional errors introduced by a computor may conveniently be thought of as a "handling charge." Now the weighing machine did not handle the 5 lb. Consequently the handling charge was for the ½ lb. only. Similarly the Decca receiver handles the decimal figures only. It never handles the 300 lanes.

5.4. *Possible Computations*

The computor must thus be fed with the decimals only, as the lane numbers are obviously too large to handle. When it is first set in operation, the whole numbers must be reset manually, and from then on the computor merely adds-in the extra ones accumulated as it goes, but never uses these in any of its mathematical functions. The latter must thus be limited to those operations which can be performed whilst remaining in ignorance of the whole number. In fact, one is only allowed to see the changes in the growing or decreasing number, but never the number. Therefore, all operations must be performed on the differential of the variable and not on the variable itself. If, then, the operation is to change R into function R where R is the Red lane number, that function must be such that its differential contains no terms in R, since we are not allowed to handle the latter. Then from R and G, where G is the Green lane number, we cannot obtain RG or R^2 or $1/R$. Thus, we cannot undertake any vector calculations. We can obtain purely 1st-order terms like kR and kG if k is not excessive so that it magnifies the errors greatly. We can also obtain $R + G$ and $R - G$, and $k(R + G)$ or $k(R - G)$.

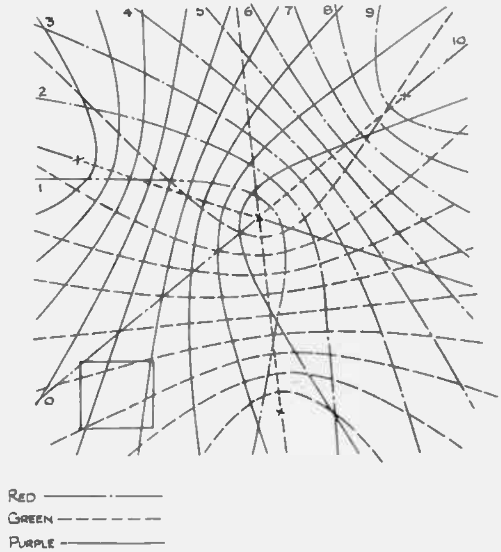

Fig. 7 (a).

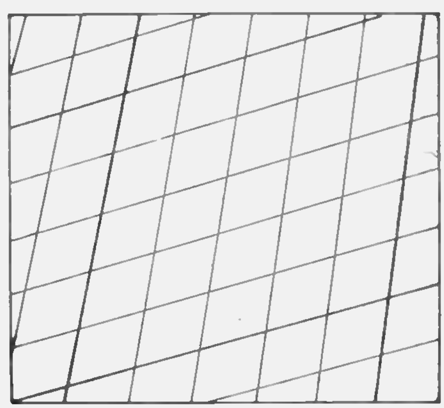

Fig. 7 (b)

The final result is that any computing we do to reduce the distortion of the map must be of the simplest. It is quite rigidly limited to combining the three given variables in any way that involves only adding and subtracting, and adding constants, or multiplying by constants not immoderately large.

5.5. *Preliminary Manipulation*

This extremely meagre repertoire will certainly leave some distortion in areas such as Fig. 5, even after suitable treatment. The best that can be done with it is easily arrived at graphically. Looking at Fig. 1 again, it will be noticed that the Green pattern is comparatively coarse and the Purple comparatively fine. For our purposes this is arbitrary and misleading, and by multiplying Green, Red and Purple by 3/3, 3/4 and 3/5 respectively, we obtain symmetry in this respect.

5.5.1. The Long-range Case

Dealing with the worst areas first, we examine the locality outlined in Fig. 7a, which is shown enlarged in Fig. 7b. If we use this as it stands we shall get the result we saw in Figs. 5 and 6, and it is apparent that, if Fig. 7b were printed on thin rubber sheeting and then pulled out of shape until the lattice became cartesian, we would obtain Fig. 5. We must derive some new lattice more nearly cartesian so that much

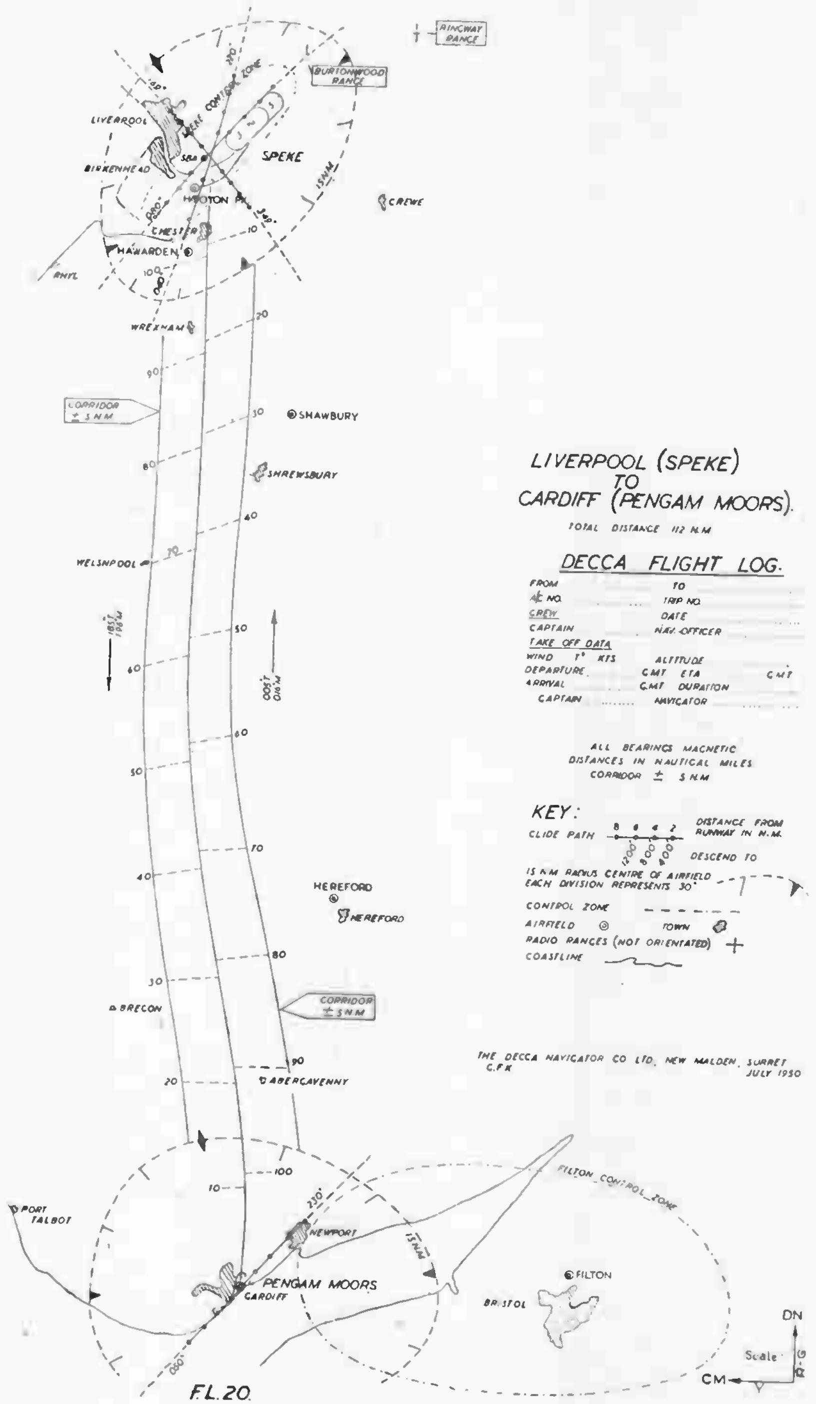

Fig. 8.—*Improved version of Fig. 6.*

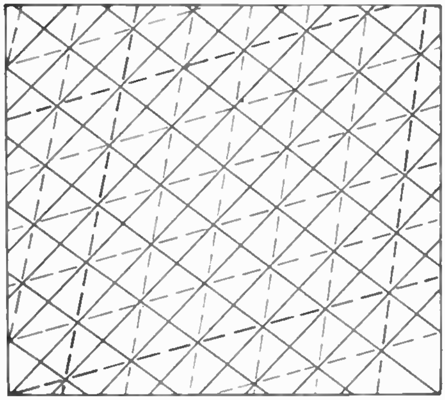

Fig. 9.

less pulling out of shape has to be done.

The diagonals of Fig. 7b would be quite acceptable, as shown in Fig. 9, and, of course, one set of diagonals represents the sum of Green and Purple, and the other set of diagonals represents the difference. It is a most fortunate coincidence that this is one of the computations we are allowed to make. We therefore drive the pen and the paper not on Green and Purple respectively, but on k_1 (Green + 3/5 Purple) and k_2 (Green − 3/5 Purple), k_1 and k_2 being chosen to give the scale of map we desire and to convert squares into the quasi-rectangles of Fig. 9 as nearly as possible. Compare the result in Fig. 8 with Fig. 5.

5.5.2. Other Patterns

Space does not permit of more than a list of other co-ordinates used without considering how they were obtained.

Figure 10 illustrates a difference pattern $R - G$, it being remembered that Purple and Red are never used in any circumstances without first being brought to the scale of Green, as previously mentioned. These difference patterns must, of course, be new hyperbolae on the line between two slave transmitters as base line.

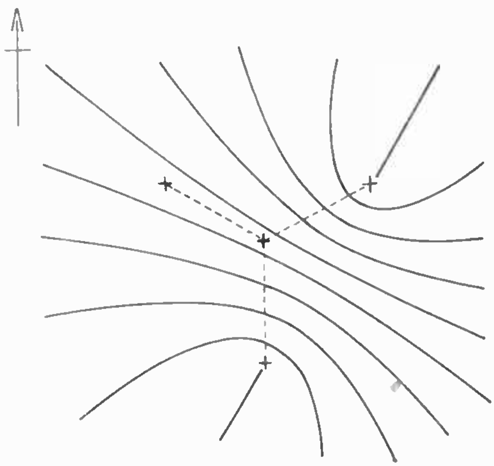

Fig. 10.—Red − Green pattern.

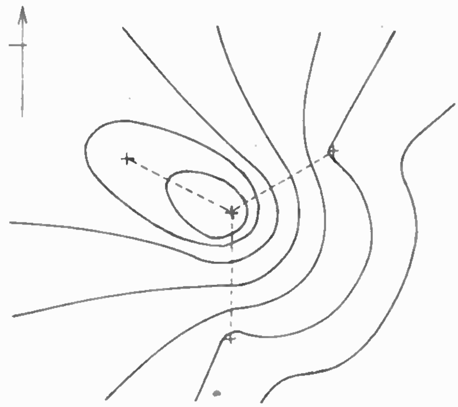

Fig. 11.—Red + Green pattern.

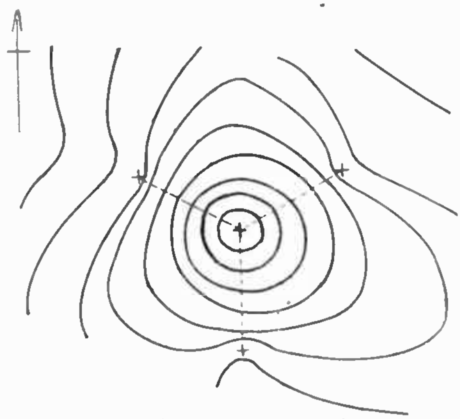

Fig. 12.—Red + Green + Purple pattern.

Figure 11 illustrates $R + G$ and Fig. 12 illustrates $R + G + P$.

Figure 13 shows the way in which the Decca coverage is divided into seven localities and the solutions used for each. Very considerable overlap of these localities may be tolerated where convenient.

5.5.3. The Short-range Case

Three solutions are possible in the centre area

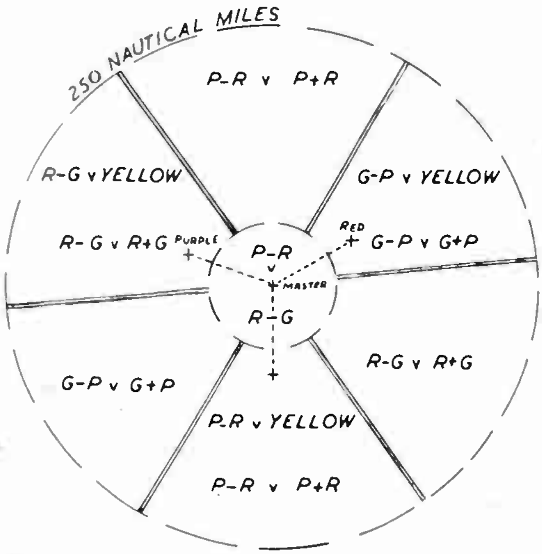

Fig. 13.—*Typical distribution of combinations of co-ordinates.*

and each of these is arranged to cancel out the signal from the master entirely. Consequently the curvature (the worst in the cover) around this area is swept away.

5.6. *Economy by Permutation*

A list of the functions which will be required of the computor, but only two at a time, is as follows:—

1. R	*6. −P*	*11. R−G*	*16. R−P*
2. G	*7. R+G*	*12. G−P*	*17. −R−G*
3. P	*8. G+P*	*13. P−R*	*18. −G−P*
4. −R	*9. P+R*	*14. G−R*	*19. −P−R*
5. −G	*10. R+G+P*	*15. P−G*	*20. −R−G−P*

A pair can be selected from these in 360 different ways, but of these only 96 are worth having. These can be divided into two equal groups, such that each pair in the second corresponds to some pair in the first with the pair interchanged. By arranging to interchange the connections to the Display Head servos, it is thus possible to reduce the 96 to 48.

Similarly this 48 can be arranged in two groups, such that each is the negative of the other. If this reversal is made possible independently on each of the output servos, the number reduces to the following twelve:—

1. R versus G	*7. R+G+P versus R−G*	
2. G versus P	*8. R+G+P versus G−P*	
3. P versus G	*9. R+G+P versus P−R*	
4. R+G versus R−G	*10. R−G versus G−P*	
5. G+P versus G−P	*11. G−P versus P−R*	
6. P+R versus P−R	*12. P−R versus R−G*	

This list can be further shortened without loss of possible functions by taking it in two stages.

In stage one *R*, *G* and *P* are fed into a device which has three output channels A, B and C. It merely connects *R*, *G* and *P* to A, B and C respectively or else it commutates them round into one of the other two possible arrangements. The three functions it performs are:—

1. A = R	*B = G*	*C = P*
2. A = G	*B = P*	*C = R*
3. A = P	*B = R*	*C = G*

This having been done, the list reduces to:—

1. A+B versus A−B	*3. A+B+C versus A−B*
2. A−C versus A−B	*4. C versus B*

Thus, with two devices in the computor, one merely performing a three-way switching function, and the other performing any two of four possible functions, plus a couple of subsequent sign reversals and an interchange switch, we can obtain all the 96 functions required.

In addition, we shall require to be able to alter independently the scale of the two movements which are ultimately to be produced in the display head. The routing of the whole of the essential functions may now be fixed, and it is shown in Fig. 14.

6. Electronic versus Mechanical Methods

We are now in a position to consider some of the practical details involved and may as well start at the Red unit. The data received is in the form of two voltages proportional to the sine and cosine of an angle α which represents the required data. Since the signal strength may vary despite very good A.G.C., either of the voltages considered alone is without meaning. We have to deal with α and it is to be fed into a 3/4-times frequency multiplier. It will have to handle frequencies throughout the range of half a cycle per second to zero to half a cycle per second in the negative direction. Thus, it must at all times use two-phase quadrature signals and be devoid of any tuned circuits. Alternatively, the information could be taken from an earlier stage in the Decca receiver where it is available as a phase comparison between two signals of 340 kc/s. The appropriate frequency multipliers and dividers to 255 kc/s would suffice to effect the required conversion to the scale of Green. But the Purple channel would require similar

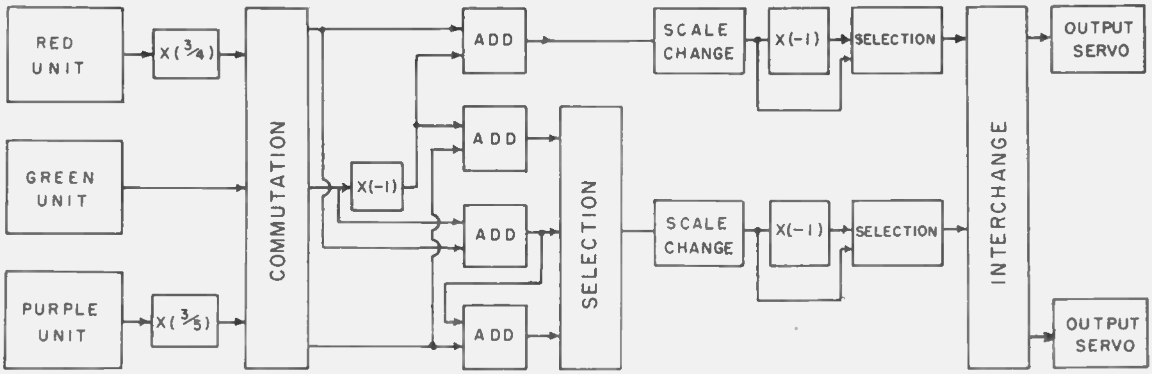

Fig. 14.—Block diagram of the Flight Log Computor.

treatment and then all three channels would be at a common frequency and adequate freedom from mutual interference would in practice be difficult, especially in the commutation unit which has to follow. If we convert the signal into a mechanical rotation, the frequency changing reduces to no more than a pair of gear pinions, but switching rotating shafts around in the commutation unit is not as convenient as electrical switching. Despite a very firm belief that electronic methods are, in general, to be greatly preferred to mechanical methods, the mechanical method was chosen in this case. But the final outputs will clearly have to be in electrical form for convenient transmission to a remote display head. We may, therefore, seek an opportunity to convert the information back into electrical form as quickly as possible.

If we attempt this immediately after the frequency multipliers we shall facilitate the commutation greatly. We should next require four sets of beat frequency stages, all handling inconveniently low and "negative" frequencies. All signals would require to be handled in two phase, and always treated as a rotating field.

Although this is not impossible, it is more liable to complications than a unit consisting of four differential gears. If the scale-changing units can conveniently be electronic, it is clearly desirable to make the transition before going into the selector unit.

It was decided that the range of scale changes required was such that the 10-in. width of map could be equivalent to between 20 lanes and somewhat over 300 lanes and that this should be done in logarithmic steps of not more than 20 per cent. The contribution to distortion, due to scale errors, would then be slight. This requires 16 steps, each of 6/5. If we use an electronic frequency changer, we shall have, in addition to all the difficulties previously mentioned, the inconvenient multiplication factors involved, such as $(6/5)^{15} = 19{\cdot}392$. The mechanical equivalent is a 16-speed gear box and is undoubtedly easier. The remaining functions consist of reversals and switching, and are obviously more easily done electrically.

7. Demarcation of Electrical and Mechanical Domains

For our purposes, it appears that, where information is in vector form, operations on the length of the vector are more easily done electrically.

The Decca receiver defines the angle of the vector in electrical terms. The following operations are more easily carried out electrically:—

(1) Memorizing the value of the angle for periods up to a minute.

(2) Obtaining a negative copy of the angle.

(3) Switching, marshalling and generally re-routing into multiple channels.

(4) Obtaining functions of the rate of change of the angle (i.e., frequency), particularly for large values.

Most other operations are done mechanically.

8. The Input Servo

We may now return to the Red unit. The receiver output supplies voltages proportional to sine and cosine respectively, and having a peak value of 20 V, except when the signal falls below the A.G.C. level. Since an aircraft may fly along a lane for long periods, these voltages may or may not vary, and must be handled as D.C. at all times.

Firstly, they each go into a reversal circuit, the essentials for which are outlined in Fig. 15. It will be seen that the first valve grid is supplied with the mean between the given potential and the required negative copy, and this should always be zero.

Any errors appears reversed and magnified some 100 times at the anode, with an added constant for the H.T. This latter is removed by the following potential divider connected to the negative rail at the expense of a 2/3 reduction in magnification. A cathode follower supplies a copy with adequate power and feeds this back to the initial potential divider. Thus, an error of about one in seventy is sufficient to maintain the output potential. The high degree of feedback (about 50 per cent.) makes the whole circuit very stable and insensitive to supply voltage and valve deteriorations. The error of one in seventy referred to may be further reduced by making B about 3 per cent. larger than A.

In addition to sine and cosine, − sine and − cosine are now available, and these four are fed into a ring resistor to which two movable sliders connect at points 180 deg. apart, as in Fig. 16.

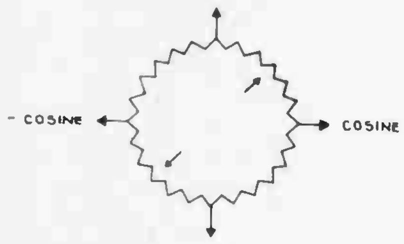

Fig. 16.—The servo potentiometer.

The rotating potential diagram thus formed contains two null points. In order to obtain a linear relationship between null movement and signal movement, the ring resistor must be non-linear, and the required law is easily obtained by stamping the appropriate shape of ring out of a sheet of carbonized paper. If the two wipers are not on the nulls, they will collect a voltage which is a function of their positional error, and by feeding this error voltage via an amplifier to a

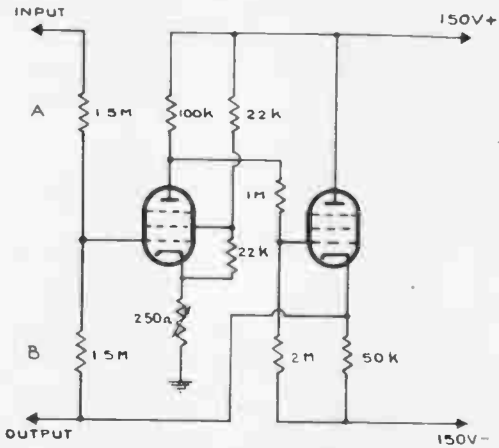

Fig. 15.—The d.c. reversal circuit.

motor, the motor may be geared to drive the wipers towards the nulls. The input signal has thus been converted into a mechanical rotation from which abundant power can be drawn. To obtain the required accuracy, the amplifier needs a slope of 10 A/V. Each wiper goes to the grid of a pentode of nominal slope of 8 mA/V (EF91). These are biased near cut-off for zero grid signal, and each has in its anode a relay. Operation of one relay runs the motor one way and the other runs reversed. Each grid also carries a small capacitor which feeds it with a saw-toothed voltage of some 70 cycles. The essentials of the circuit are shown in Fig. 17.

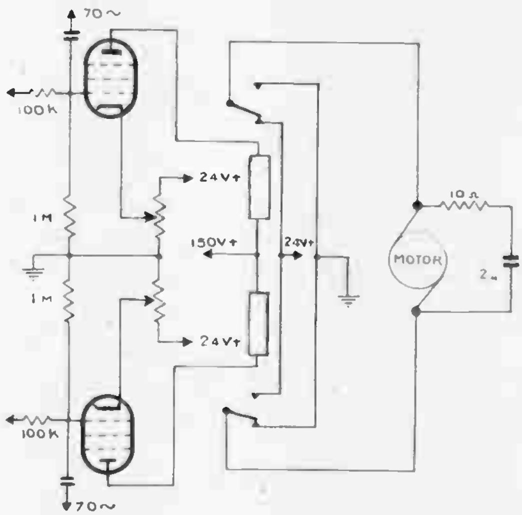

Fig. 17.—Push-pull d.c. amplifier of 10 amperes per volt.

The bias setting is such that for zero error voltage the positive peak of the saw-tooth just fails to operate the relay. A small error voltage will then cause the relay to chatter, and it will be in the operated position for a brief moment only, whilst the saw-tooth is close to its peak. A larger error voltage will cause this moment to be of longer duration followed by an interval which is shorter. Meanwhile, the motor is being fed with pulses of current of increasing duration, and the mean D.C. value of these pulses is proportional to the "mark-space" ratio. Reasonable linearity of the amplifier calls for a good saw-tooth shape, but in this application the linearity is not critical. Neither is it necessary to smooth out the motor current into D.C. In fact, if adequate suppression is included, it is an advantage not to smooth it, as the starting threshold for the motor when under load is thereby slightly improved.

Throughout the whole computor there are 14 valves requiring saw-tooth voltages, and a cathode follower is therefore used after the miniature neon tube.

This apparatus is repeated for Green and Purple, only the output gear ratios being different, and each unit includes five refinements worth mentioning.

1. On those rare occasions when loss of signal prevails long enough for the aircraft to have traversed more than one lane and less than two, the motor will run to the new null position when the signal returns, having lost exactly one complete lane. The correct reading then has to be reset manually, and, to avoid troubling with the decimals, a control is provided which will advance the unit exactly one complete rotation without losing count of coincidental aircraft movement. This is done by swamping the error voltage with added D.C. of appropriate sign, and the unit runs in the required direction continuously. If the control is held long enough to displace it by any value between ½ and 1½ lanes, upon releasing it will lock in to the proper place.

2. It could happen that a lane had been lost in the manner described at a time when the flight log was not being observed. Therefore, an indicator lamp is provided which lights if the signal falls to a dangerously low value for a significant length of time. This lamp remains lit until manually cancelled. The required performance cannot be obtained directly from the sine and cosine voltages supplied. These periodically fall to zero when functioning properly. It is necessary to detect that the length of the vector which they jointly define has fallen to a low value, a function previously listed as being better done electrically. Now, on the ring resistor shown in Fig. 16, there were two nulls, and the maximum voltages on the ring are found 90 deg. from these. They indicate the vector length. By putting a third wiper on the ring 90 deg. from the null wipers, this voltage is picked off. The three units feed these voltages to a common valve grid, via metal rectifiers to isolate them from one another, and the appropriate RC networks to give the necessary time constants. The valve has in its anode a relay which has a contact used either to make it self-holding or to feed a pulse back to the valve grid to keep the light permanently flashing as may be desired. This method of obtaining the vector lengths is simple at the expense of incurring an error of anything from 0 to 30 per cent. Such an approximation is quite adequate for the purpose.

3. Without affecting the maximum speed at which the unit will follow the signal, it is possible to limit the maximum acceleration. By setting the limit to a value similar to the maximum attainable by an aircraft, the much higher values produced by small random errors are cut off. For example, if the signal fails, the unit takes five seconds to stop and thus avoids losing a lane on a high proportion of occasions when it otherwise might. This type of function has been listed in the electrical domain, and is achieved by placing the appropriate value of capacitor across the null wipers. Too large a value will, of course, lead to hunting unless feedback proportional to velocity is used. In practice, feedback gives too small an improvement to justify the extra weight.

4. A considerable amount of mechanical gearing is to follow this unit, and the total backlash after a series of some 20 to 30 gear meshes may be serious. In practice, as much as 50 deg. of rotation may be lost. The cost and production problems involved in reducing and maintaining this value at a level of about 1 deg. are unthinkable. A correction device is therefore used. This is an operation requiring an indefinitely long memory of the sense of the last movement and of the value of the backlash angle, and on both counts falls in the mechanical domain. Some device is needed which will function only on those occasions on which the rotation reverses.

When it functions it needs to cause the unit to perform an excessive rotation; in fact, in excess of the signal by an amount equal to the backlash. This will then neutralize the backlash. The simplest method yet devised consists of no more than mounting the null-seeking wipers very loosely on their shafts so that they, too, have backlash, the latter being adjusted to the desired amount by an adjusting screw. When the signal reverses its direction of motion, the wipers are no longer on the nulls and the motor is consequently ordered to move. It now has to move some way before the wipers start to move, and it therefore makes an excursion which is longer than that made by the signal, by an amount equal to the backlash. This extra movement being just the amount which will be lost by the backlash in the gearing, the final output will have effectively no backlash. All that remains is a small time delay of little consequence. If further motion in the same direction occurs, since the mechanical play in the wipers has now been fully taken up, the process is not repeated.

5. At times, it will be necessary to change the map in flight, and the new map may call for changes of scale, etc. This process involves sliding gears in and out of mesh, and difficulties may arise if the gears do not happen to be rotating. Consequently, it is arranged that, throughout the duration of this process, a contact is made which energizes a circuit whose function is to cause all three primary drive units to hunt. All the gearing in the whole computor is, therefore, gently rocking to and fro at a frequency of about 1 cycle per second, and gear meshing is greatly facilitated.

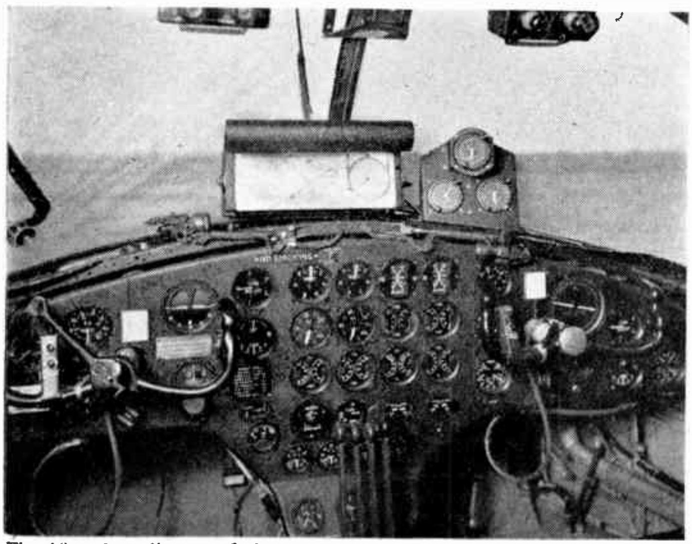

Fig. 18.—Installation of the Decca Flight Log Mark 01 in the Ministry of Civil Aviation's Handley-Page "Marathon." The display head and Decometer panel are seen centrally mounted. (The control box is mounted above the windscreen.)

9. The Mechanical Section

Referring again to Fig. 14, the next four operations are taken in one unit. The commutation and selection are achieved in the well-known manner generally used in multi-ratio gear boxes, which involves providing means of sliding gear pinions axially.

The multiplication by -1 is achieved with a reverse idler pinion, and the four additions are each done by a differential gear. Similarly, the 16-speed scale changing units follow fairly conventional lines.

10. The Output Servo

The two mechanical outputs have to be converted into electrical form for ultimate transmission to the display head. This is done by using the rotation to drive two wipers round another ring resistor. A direct voltage of 35 is applied between the wipers, and sine and cosine functions are obtained from the four static connections. These are used in the display head to control an identical servo circuit.

11. The Remaining Functions

The operation of multiplying by -1 is done by a relay which carries contacts arranged to interchange only the cosine and $-$cosine connections, and the selection is achieved by either operating or not operating the relay. Similarly, the interchange operation is performed by a relay carrying eight sets of changeover contacts, and it simply takes the group of four leads from one ring resistor and switches the whole group to the other head servo, meanwhile doing likewise for the remaining group of four leads.

12. The Display Head

The display head measures 4 in. × 4 in. × 12 in. approximately (see Figs. 3 and 18) and contains 20 ft. of paper on spools, and this roll accommodates a large number of separate and independent maps. When a new one is rolled into position it is necessary to move the paper and the lead screw manually until the pen occupies the appropriate place on the map. This position is found with the aid of the Decometers and the Decca lattice on the map in the usual manner. The mechanical motion required for this setting up is derived from two additional motors, and the movement is added to the servos by differential gears.

13. Resetting

To facilitate speedy resetting, the two reset motors should have a common control so that both motors can be run simultaneously at different speeds in such a way that the combined motion will run the pen over the map at any desired angle and speed. This is clearly easier to use than the equivalent of separate x and y shifts. To this end, on the control box a control knob of unconventional design is provided. The knob protrudes through a rubber mounting and is at rest when perpendicular to the panel. It can be tilted manually in any direction. Its operation is not unlike that of the control sticks of some aircraft. The pen will run in the direction in which the knob is displaced, and at a speed proportional to the displacement. The operator is not required to give any thought to the matter, merely doing to the knob what he would do to the pen if he were moving it by hand directly. The circuit is very simple, the essentials being given in Fig. 19.

Displacement of the knob displaces the contact shoe E so that it connects to one or to two of the 100k resistors and further displacement short circuits increasing amounts of the 100kΩ. Positive voltages appear at one or more of the points A, B, C and D. A and C are connected to a push-pull D.C. amplifier of 10 A/V, and its output drives the reset motor responsible for vertical movement. B and D similarly control horizontal movement.

14. Other Controls

The controls to the selection and commutation and scale-changing operations are all of the preselector type. Thus, the switches can be set to the requirements of the next map it is intended to use without disturbing the present functioning. At the moment it is required that the preselection

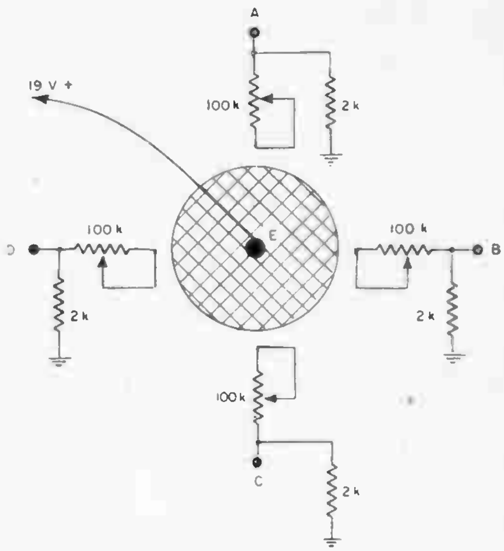

Fig. 19.—Circuit of the resetting control.

shall take effect, a button is pressed. This button closes a self-holding relay which turns on the current to the control circuits. The small motors which move the gear selectors run to their appointed places, and the last one to finish clears down the relay and leaves the control box available to accept orders for the next preselection. It is all a matter of very straightforward relay circuitry, not requiring detailed description.

15. Time Recording

The Decca receiver is also capable of providing pulses which succeed each other at the rate of three per minute.

The computor contains a ratchet relay which rotates once for 18 pulses. Every third position is wired to a control switch contact, and one other position is also wired to a separate contact on the same control switch. If the switch is turned to select one of these positions, a pulse once per minute or once per 6 minutes, as the case may be, is passed on to a relay. When this relay operates it causes the pen to make a small excursion in the vertical direction by adding some 10 V D.C. to the null-seeking wipers. After about one second it closes again, and operates a second relay which causes an excursion to the left. This occurs whilst the vertical error is recovering and thus results in a slant line. One second later, this relay clears down and the pen returns to its correct position without losing count of coincidental aircraft movement. It thereby offers the added facility of having a small triangular mark made on the track at selected time intervals.

There is thus a permanent record of the ground speed of the aircraft as well as its track. These time marks are also used in flight for quoting the estimated time of arrival, etc., and another position on the switch offers marks every one minute, with every sixth done twice to distinguish it from the rest and to facilitate counting up the total in units of 1/10th of an hour.

16. Conclusion

It is to be regretted that space does not permit of a description of the more interesting of the mechanical details, nor of the very remarkable inking system.

It should perhaps be said that the development of the Flight Log has opened a great many doors. Since it is imprudent to count chickens which may not hatch, it is not advisable to do more than mention that it may at some time lead to a method of converting mathematical information in two independent variables from one co-ordinate system to almost any other unambiguous co-ordinate system. It should also prove possible to provide computed information to hold aircraft or shipping to intricate courses automatically, and it can certainly provide the means of bringing in aircraft to a destination point to within plus or minus 10 seconds of an estimated time of arrival quoted half an hour before.

17. Acknowledgments

Acknowledgments are due to the author's colleagues and particularly to the late Mr. J. P. Copping, who advocated the system of map presentation with foresight and tenacity, to Mr. J. Vickers for the design of the reversal circuit, and to Mr. A. T. Holden and Mr. G. L. Wallis who devised the inking system (not described in the paper).

Thanks are also due to Mr. H. F. Schwarz for his help and encouragement and to the Decca Navigator Co., Ltd., for permission to publish this paper.

18. References

1. O'Brien, W. J. "Radio Navigational Aids." 1947 Radio Convention Paper. *J.Brit.I.R.E.*, **7**, No. 6, October 1947, pp. 215-246. (This Paper includes a detailed description of the Decca Navigator system.)
2. "The Decca Navigator." *Wireless World*, **52**, March 1946, pp. 93-95.
3. "The Decca Navigator." *Electronic Engng*, **18**, June 1946, pp. 166-171.

DISCUSSION ON

"SOME FUTURE DEVELOPMENTS IN AERADIO"*

C. B. Bovill (*Member*): I am glad to learn that the authors regard the use of H.F.-R.T. as a future trend for long-distance air communications. Results obtained already indicate how well it can work. Nevertheless I consider that there is room for much improvement.

I should like to feel that the frequencies used were more rigidly protected against interference from transmitters not concerned with aeronautical communications. At present one of the wavelengths used is often swamped by a broadcast transmitter. On another an auto-Morse transmission drifts from time to time right across the aero wavelength. No other communication compares in importance with one concerned with the safety of life and everything possible should be done to keep the aero channel clear of jamming.

From the point of view of static interference, such as precipitation static, an examination of the aerials of long-range aircraft at London airport reveals that there are still airlines which do not take very vigorous steps to reduce this form of interference. In the illustration of the "Comet" aircraft (Fig. 3) the H.F. fin aerial seems to have no protection against rain static and there seem to be no wick dischargers on the wing tips. At the speed of the "Comet" the interference should theoretically be higher than with other aircraft. Has the author any information on this subject?

At present aircraft on transoceanic routes are navigated by various means such as pressure pattern flying, Loran and Consol and astro-navigation. At fixed intervals the pilot reports his estimated position to shore-based stations by H.F. R.T. In the event of an aircraft being forced down, the air-sea rescue search is centred upon the estimated position. Because events happen quickly in the air, at the moment of an emergency, the pilot may only have time to give his callsign before he is called upon to give all of his attention to the flying controls. One therefore feels that the H.F. R.T. system could be beneficially supplemented by a D.F. service. So far H.F. D.F. has only met with limited success on long-range aircraft signals. On the other hand, the Navy used it very successfully for locating U-boats during the war. One wonders if the aeronautical authorities have studied the Navy's methods. My own experience leads me to think that the lack of success of long-range H.F.-D.F. in the air is due to the fact that Adcock D.F. was used. The aircraft aerial on H.F. radiates a predominance of horizontally polarized waves and this may be why results were so indifferent. Certain arrangements of Spaced Loop D.F. can give good results on such polarization and I should be interested to know of any tests which have been made.

L. W. D. Sharp: The present tendency in aircraft radio equipment is towards ever-increasing complexity which results in severe weight penalties and wastage of cargo space in the larger transport aircraft, and in the impossibility of fitting many of the radio aids in smaller aircraft. Attention should be paid to reducing the weight and size of the equipment in aircraft by simplification, rather than by exaggerated miniaturization which is accompanied by increased maintenance and cooling difficulties.

With this end in view, I would like to suggest that transmitter diversity be considered for long-range H.F. R.T. communication. This would permit the advantages of diversity reception with the use of a single aerial and a single receiver in the aircraft. In cases where adequate power is available it might even be possible to use a common ground transmitter driving two spaced aerials which would minimize the increased cost of the installation. In any event, the cost of providing diversity facilities would be confined to the smaller number of ground-station installations rather than a larger number of airborne installations.

The weight and space difficulties referred to above would appear to make the provision of public telephone facilities in civil aircraft highly uneconomic, particularly when viewed in relation to the short period of time during which such facilities could be employed in any single aircraft

* 1951 Convention Paper by G. R. Scott-Farnie and and M. I. Forsyth-Grant, *J.Brit.I.R.E.*, 11, No. 12, December 1951, pp. 595-606.

during a typical flight, and the likelihood of congestion on the available frequency channels in areas of high traffic density.

The authors' comments would be appreciated on the lack of any standardization of channel spacing on the H.F. band.

AUTHORS' REPLY

G. R. Scott-Farnie (*Associate Member*) and **M. I. Forsyth-Grant** (*in reply*): We agree with Mr. C. B. Bovill that there is room for improvement in the long-range H.F. R.T. It must be remembered that so far there has not been much chance of practice in this service, but it is growing and we can but hope that "practice will make perfect." Another help in this direction will come with the new "channellized" transmitters now in the early stages of production with some manufacturers in this country.

Interference from other transmitters is indeed a problem, and improved frequency generating elements in these will at least ease the problem. Nevertheless, this trouble remains as a serious matter which can only be solved by rigid adherence to international agreements. It is true that some older types of aircraft did not take adequate steps to reduce precipitation static, but we would assure Mr. Bovill that the "Comet" is fitted with wick dischargers to wing tips, tail-plane and fin. Experience with this aircraft has shown that interference of this nature is unusually low.

Direction-finding on H.F. to supplement the H.F. R.T. service would no doubt prove useful on occasions, but in our opinion so rarely as to fail to justify such a service on economic grounds. We cannot fully agree with the statement that H.F. D.F. on aircraft is generally indifferent. As far as civil aviation is concerned it is just not an ICAO requirement. We regret that we are not familiar with any test recently carried out to ascertain the merits of different aircraft aerial arrangements.

Mr. L. W. D. Sharp points out what is only too true as regards modern aircraft equipment becoming alarmingly complex, but we doubt if this can be much avoided. Simplification may be achieved to some extent by the avoidance of "many common user" units, but only at the expense of putting more than one egg in the basket! We would agree that simplicity and acceptability in design are indeed achievements to be aimed at.

The suggestion of using diversity in H.F. R.T. by having two ground transmitters or alternatively one transmitter with two spaced aerials is interesting. We doubt whether it would be justified either on technical or economic grounds for this purpose, especially when to some extent the speed of modern aircraft already gives their radio reception a space diversity effect. We might just point out that, generally speaking, radio reception in aircraft is very much superior to that obtained on the ground.

We would like to mention that attempts to use transmitter diversity on the ground point-to-point services, particularly for broadcasting meteorological information by radio-teleprinter, are showing considerable promise. Mr. Sharp is certainly correct in saying that diversity equipment should only be installed at the fewest possible number of stations.

There are indeed problems ahead for designers if all the passengers in a large and fast aircraft want to telephone in the short time available for the purpose. Of course, over large land masses controlled by one national authority, such as U.S.A., Canada or Russia, the matter would be much easier and multi-channel micro-wave equipment would probably be used in the future for this purpose.

We also deplore the present lack of standardization on channel spacing on the H.F. band. This applies equally to ground communications as well. Its fulfilment would enable the design of "omni-channel" equipment to be relatively easy using "crystal saver" and reference crystal-controlled receivers and transmitters, both on the ground and in the air.

Let us hope the day is not so far off when this will be accomplished.

GRADUATESHIP EXAMINATION NOVEMBER 1951

FIRST PASS LIST

This list contains the results of all candidates in the British Isles and those of the few oversea candidates available on January 25th, 1952.

Eligible for Transfer or Election to Graduateship or Higher Grade of Membership

The following candidates have passed the entire examination, or having previously been exempt from part of the examination have now passed the remaining subjects.

BESWICK, George Robert. *Birmingham.*
CRYER, Frank Stanworth. (S) *Liverpool.*
DENBY, Peter. *London, W.4.*
GAULDER, Clifford Francis. (S) *Feltham, Middlesex.*
GHOSH, Jyotirmay. (S) *Benares, India.*
LAJOIE, Marc Jean-Baptiste. *Mauritius.*
MCILWRAITH, John Wallace. (S) *Portsmouth.*
PALMER, Donald Ridgeway. (S) *Bexley, Kent.*
REID, John Michael. (S) *London, N.21.*
RICHES, William Henry. (S) *Selsdon, Surrey.*
RODMELL, Edward Cripps. (S) *Didcot, Berks.*
SHORT, Harry. (S) *Belfast.*
SKINNER, Peter. (S) *Surbiton, Surrey.*
WALSH, Michael William. (S) *Tralee, Eire.*
WHITE, Colin James. (S) *London, S.E.12.*
WHITEMORE, Gerald. (S) *Hayes, Middlesex.*
WYNN, Peter. (S) *Weston-super-Mare.*

The Following Candidates Passed Part I Only

AYIVORH, Samuel Clifford. (S) *London, W.2.*
BEAGLES, Ralph Edward. (S) *Manchester.*
BLASS, Peter Otto. (S) *Cuffley, Herts.*
EDGAR, Ronald Ian. *Romford, Essex.*
EDMONTON, John Ormonde. (S) *Tunbridge Wells, Kent.*
HALE, Leslie Norman. (S) *London, N.6.*
HEAD, Reginald Edward. (S) *Wolverhampton.*
JESSOP, Neville Henry. (S) *Seaford, Sussex.*
LINCOLN, Peter Arthur. (S) *London, W.3.*
MACKIE, Robert Pedie. *Glasgow.*
MCCONNELL, Brian. (S) *London, W.5.*
NIGHTINGALE, Daniel Edgar. (S) *London, S.W.12.*
RANGANATHA, Rama. (S) *London, W.2.*
ROSEN, Solomon. (S) *London, W.11.*
SCOULDING, William George. *Romford.*
SHEILS, Raymond. (S) *Liverpool.*
STOTT, Donald Geoffrey. (S) *Ashford, Middlesex.*
TAYLOR, Frank Howard. (S) *Southall, Middlesex.*
TRIBBLE, Kenneth Alan. (S) *Waihi, New Zealand.*
TURNWALD, Thomas Francis. (S) *Auckland, New Zealand.*
WOODFORD, Paul Ivor Keith. (S) *Trieste Force.*

The Following Candidates Passed Part II Only

BUNTING, Arthur. (S) *Colwyn Bay, North Wales.*
CHOLMONDELEY-SMITH, Douglas R. (S) *Auckland, New Zealand.*
CORLETT, William Edward. *Southampton.*
DUNNE, Michael Joseph. (S) *Ruislip, Middlesex.*
FINLAYSON, Andrew. (S) *Carlisle.*
LODDER, Albert Stanley. (S) *Carshalton, Surrey.*
MARTIN, Arthur William. (S) *London, N.4.*

The Following Candidates Passed Part IIIa Only

BETTERIDGE, John E. (S) *Ewell, Surrey.*
BROOKS, William Gilbert. (S) *Chichester, Sussex.*
KRUYSHAAR, Willem. (S) *Pretoria, S. Africa.*
LONGMAN, Charles Robert. (S) *London, N.8.*
MACNAMARA, Patrick Colman. (S) *Dromcollogher, Co. Limerick.*
MARTYN, Bernard Arthur. (S) *Craigie, Perth.*
MCDONNELL, Patrick Joseph. (S) *Nenagh, Co. Tipperary.*
MCSHANE, James Aloysius. (S) *Barrhead, Renfrewshire.*
PANDYA, Labhshanker Revashanker. (S) *Heston, Middlesex.*
RANADE, Maheshwar Trivikram. (S) *London, W.2.*
ROBINSON, Kenneth Robert. (S) *Weymouth, Dorset.*
SKINNER, Leonard Malcolm. (S) *London, E.10.*

The Following Candidates Passed Part IIIb Only

HAMMOND, Harold. (S) *Hove, Sussex.*
PADMANABHAN, K. P. (S) *London, W.4.*
RAJKUMAR, Gnanapragasam Manuel Pillai. (S) *Colombo.*

The Following Candidate Passed Part IV Only

STANBROOK, Donald. (S) *Calne, Wiltshire.*

The Following Candidates Passed Parts I and II Only

GEORGE, Cecil Barrie. (S) *Auckland, New Zealand.*
HAUGHEY, Peter. (S) *Belfast.*
SHEPHERD, Robert Morgan. (S) *Great Bookham, Surrey.*

The Following Candidates Passed Parts I and IIIa Only

BLIGHT, Ronald Ernest. (S) *London, W.14.*
BOURNE, Michael Sydney. (S) *London, W.14.*
COLLINS, Leslie George Herbert. (S) *London, S.W.16.*
PIERCEY, Alfred William Stockwell. (S) *Cheltenham.*

The Following Candidate Passed Parts II and IIIa Only

MAGUIRE, Brian. (S) *Dublin.*

The Following Candidate Passed Parts I, II and IIIa Only

COLLINS, William Oliver. (S) *Balbriggan, Co. Dublin.*

The Following Candidate Passed Parts I, II and IIIb Only

JONES, John Morgan. (S) *London, N.3.*

The Following Candidate Passed Parts I, II, IIIa and IIIb Only

DAVEY, Norman Charles. (S) *Thornton Heath, Surrey.*

The Following Candidate Passed Parts IIIa, IIIb and IV Only

FINN, Edward James. *Southampton.*

(S) denotes a Registered Student.

APPLICANTS FOR MEMBERSHIP

The following new proposals were considered by the Membership Committee at a meeting held on January 2nd, 1952: 16 proposals for direct election to Graduateship or higher grade and 14 proposals for transfer to Graduateship or higher grade; also 41 applications for Studentship registration.

The following are the names of those who have been properly proposed and appear qualified. In accordance with a resolution of Council and in the absence of any objections being lodged, these elections will be confirmed 14 days from the date of the circulation of this list. Any objections received will be submitted to the next meeting of the Council, with whom the final decision rests.

Transfer from Associate Member to Full Member

THOMAS, William John, B.Sc., Ph.D. *London, S.E.27.*

Direct Election to Associate Member

BHAGAWAT, Sadashiv Ramachandra, B.Sc. *Bombay.*
GILL, Dennis Maxwell. *Colombo.*
MASTERS, George, B.Sc. *Torquay.*
MERCH-CHAMMON, Edwin, Sqd.Ldr. *London, S.E.12.*
MITCHELL, Wilfred William Webb, Major. *Leigh, Lancashire.*
NARASIMHAN, Krishnamachari, B.A. *Delhi.*
POTOK, Michael Henry Nachemia, B.Sc. *Glasgow.*
RAMSBOTTOM, Winston Albert Mellor. *London, S.W.1.*
SAMUELS, Jeffrey George Joseph, M.B.E., B.Sc. *Kuala Lumpur.*
WALKER, Frederick William, Capt. *Leeds.*

Transfer from Associate to Associate Member

BEAUCHAMP, Kenneth George. *Coventry.*
HUGGINS, Peter. *Maidenhead.*
SAGGAR, Prem Chand. *Bombay.*

Transfer from Graduate to Associate Member

GRIMM, Frank. *Cambridge.*
HODGKINSON, Cyril Duncan, Lt. (L). R.N. *Portchester, Hants.*

Transfer from Student to Associate Member

JORDAN, Charles, Sqd.Ldr. *Marlow, Bucks.*
PETERSEN, Ronald George. *Ruislip, Middlesex.*
PHILPOTT, Stanley William David. *Barkingside, Essex.*
RAMAGE, Frank Archibald. *London, E.11.*

Direct Election to Associate

BEAVEN, Ronald Percy. *Swindon, Wiltshire.*
CONNOLLY-BROOKS, Arthur, Lt.-Cdr. (L). R.N. *Warrington, Lancashire.*
GREEN, Charles George. *Hampton, Middlesex.*
HALL, William Cuthbert. *Wantage, Bucks.*
HARRISON, Henry Milburn. *Hanworth, Middlesex.*
HUMPHREYS, Humphrey Ioan. *Liverpool.*

Transfer from Student to Associate

CONESA, Raphael, M.A., Ph.D. *Bombay.*
MANECKJI, Maneck Jehangir. *Bombay.*

Transfer from Associate to Graduate

BENSON, Francis William, F/O. *Hull.*
HUTSON, Geoffrey Henry. *Birchington, Kent.*

Transfer from Student to Graduate

PATEL, Jayantilal Rhmubhai. *Bombay.*

Studentship Registrations

AGGARWAL, Narain Dev. *Hoshiarpur, India.*
ANANTHARAMAN, Kalpathi Subramaniam, B.Sc. *Tambaram, India.*

BHATNAGAR, Virendra Kumar, B.A. *Kanpur, India.*
BHATT, Rajanikant Jatashanker. *Bombay.*
BISWAS, Ganapati. *Burnpur, India.*
BRADING, Donald Hugh. *Sydney.*

CHHABRA, Keshav Chander, B.Sc. *Delhi.*
CHHABRA, Yog Raj, B.Sc.(Hons.). *New Delhi.*
CONNELL, Andrew Wallace, B.Sc.(Eng.). *Glasgow.*

DALAL, Arun Champaklal. *Bombay.*

FERNANDO, Frank William. *Singapore.*
FRASER, Brian Wadsworth. *Bramley, Leeds.*

GADGIL, Anant Janardan. *Bombay.*
GANDHI, Jagdish Mitra, B.A. *Gurgeon, India.*

HAILSONE, Frank. *Glasgow.*

JAHANBIN, Ahmad Ali. *Wembley, Middlesex.*
JAIN, Nirmal Kumar, B.Sc. *Ambala Cantt., India.*

KAIRA, Krishnamurthy Rajarao, B.Sc. *Bombay.*
KAUSHAL, Rajendra Singh, B.Sc. *Bombay.*
KHARAS, Jal Ardesher. *Bombay.*
KOILPILLAI, Mary, B.Sc.(Hons.). *Madhura, India.*
KUNDU, Sunil Kumar, M.Sc. *Calcutta.*

LARRY, Ronald. *London, S.E.17.*

MACQUEEN, Robert Alexander. *London, N.22.*
MARKS, Leslie Dryden. *Plymouth.*
MOTHERSOLE, Peter Leonard. *Calne, Wiltshire.*

NARAYANA, Prasad. *Bangalore.*

PHILLIPS, Derek Henry. *London, N.2.*
PITT-JONES, John Hubert. *Karachi.*

QAZI, Mohd Akram. *Lahore, Pakistan.*

RAI CHAND, Suraj Kumar, B.Sc. *Bombay.*
RAMARAO, Penukonda Narasingarao, B.Sc. *Bellary, India.*
RAMESAMURTI, Revur S., M.Sc. *Kavali, India.*

SAHNI, Balak Ram. *Ambala Cantt., India.*
SAXENA, Gyan Prakash. *Lucknow, India.*
SINGH, Raja Ram, Lt. *Calcutta.*
SINHA, Naresh Kumar, B.Sc.(Eng.). *Bihar, India.*
SUTARIA, Kishor Champaklal. *Bombay.*

VEDARAMA, Iyer R. *North Parur, India.*
VENKATESHIAH, Narasipur Venkatram, B.Sc. *Bangalore, India*
VERMA, Yogendra Kumar, B.Sc.(Hons.). *New Delhi.*

FORTHCOMING MEETINGS

WEST MIDLANDS

Feb. 26th Wolverhampton and Staffordshire Technical College, Wulfruna Street, 7 p.m.
"Valve Manufacture."
C. C. VODDEN, M.Sc.

NORTH EASTERN

Mar. 12th Neville Hall, Newcastle, 6 p.m.
"Television Wire Broadcasting."
E. A. H. BOWSHER (*Member*).

SCOTTISH

Mar. 13th Natural Philosophy Department, The University, Edinburgh, 7 p.m.
"Radar as an Aid to Navigation."
N. J. DONALD, B.Sc.

Mar. 14th Engineering Centre, Sauchiehall Street, Glasgow, 7 p.m.
"The Future of Broadcasting."
P. ADORIAN (*Member*).

Mar. 14th and Mar. 15th Engineering Centre, Glasgow. Television Conference and Exhibition. To mark the opening of the Scottish Television area. (See page 90.)
Details from the Local Honorary Secretary, R. H. Garner, 66 Buchanan Drive, Cambuslang, Lanarks.

SOUTH MIDLANDS

Mar. 19th Exhibition Gallery, Public Library, Rugby, 7.15 p.m.
"The Application of Magnetic Amplifiers to Industrial Measurement and Control."
H. M. GALE, B.Sc.

LONDON

Mar. 27th School of Hygiene and Tropical Medicine, Gower Street, W.C.1, 6.30 p.m.
"The Application of Magnetic Amplifiers to Industrial Measurement and Control."
H. M. GALE, B.Sc.

LONDON

April 3rd School of Hygiene and Tropical Medicine, Gower Street, W.C.1. 6.30 p.m.
A Discussion on
"V.H.F. and U.H.F. Broadcasting."

NORTH EASTERN

April 9th Neville Hall, Newcastle, 6 p.m.
"Relative Advantages of A.M. and F.M."
J. R. BRINKLEY (*Associate Member*).

SCOTTISH

April 10th Works of Metropolitan-Vickers Ltd., Motherwell, 7 p.m.
"X-ray Equipment and its Control Gear."
Author's name to be announced.
(Lecture to be followed by a tour of the works.)

LONDON

April 16th School of Hygiene and Tropical Medicine, Gower Street, W.C.1, 6.30 p.m.
"Current Radio Interference Problems."
E. M. LEE, B.Sc. (*Member*).

SOUTH MIDLANDS

April 16th and April 17th The Winter Gardens, Malvern, 7.15 p.m.
Exhibition Gallery, Public Library, Rugby, 7.15 p.m.
"Acoustics and the Radio Engineer."
E. G. RICHARDSON, B.A., Ph.D., D.Sc.

LONDON SECTION MEETING

Wednesday, March 27th.

"THE APPLICATION OF MAGNETIC AMPLIFIERS TO INDUSTRIAL MEASUREMENT AND CONTROL"

H. M. GALE, B.Sc.

After brief reference to previously published work on Magnetic Amplifiers, the basic principles upon which they operate are outlined. The balance between the d.c. ampere-turns in the control circuit and the a.c. ampere-turns in the controlled circuit is mentioned and illustrated with typical waveforms and characteristic curves. The use of a positive feedback circuit is described as typical of a number of methods whereby the gain can be increased a thousandfold or more.

The general characteristics of magnetic amplifiers are discussed at some length in comparison with other amplifiers, mainly the thermionic valve and it is emphasized that the magnetic amplifier is complementary to it rather than a direct replacement. The magnetic amplifier, being a current-operated device, works best in low-impedance circuits while the thermionic valve, being voltage operated, works best in high impedance circuits. The following characteristics are discussed: Reliability, heat dissipation and heating up time, isolation between input and output circuits, impedance range, response time, size and weight.

Figures of actual performance of practical magnetic amplifiers are given, although it is pointed out that many of them are interdependent and not necessarily obtainable simultaneously in the same amplifier.

The emphasis throughout will be on applications in the field of industrial control and instrumentation, and it is intended to demonstrate a number of these applications.