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THE MARCONI HIGH VACUUM CATHODE RAY OSCILLOGRAPH

In the following article the advantage of the high vacuum type of oscillograph over the gas focussed oscillograph are discussed and a description of the latest type of commercial high vacuum oscillograph developed by the Marconi Company is given.

THE high vacuum oscillograph has been developed for use in circumstances where the gas focussed counterpart is ineffective. Two major defects are present in the latter type of oscillograph, origin distortion and a frequency limit* set by the defocussing of the electron beam; both of these limitations have been substantially removed in the high vacuum oscillograph. Origin distortion is entirely absent while the frequency limit is set not by considerations of focus but by the finite time of transit of the electrons from one deflecting system to the other. If this transit time is long compared with the periodic time of the observed phenomena then a spurious phase shift is observed in the resultant trace.† Further, the modulation characteristics of the vacuum oscillograph are considerably better than those of the gas focussed oscillograph; the Wehnelt cylinder of which cannot be used for purposes of modulation without causing a loss of focus of the beam.

The disadvantages of the high vacuum oscillograph when compared with a gas focussed oscillograph are :—

(1) A higher anode voltage is necessary in order to obtain a good focus.

(2) More care must be exercised in the deflecting circuit design in order to maintain a good focus over the screen of the oscillograph.

(3) The resultant trace is not so well defined.

Since the disadvantages and advantages possessed by each type of oscillograph are not common to both, the selection of a suitable cathode ray oscillograph for some particular purpose should be made with reference to the individual merits of both types.

The normal operating voltage for the oscillograph is between the limits of 1,000 to 2,500 volts, but it is not possible to state the exact photographic recording speed since the modulation control may be adjusted within wide limits. This restriction does not apply in the case of gas focussed oscillographs since only one

* Ref. MARCONI REVIEW No. 53, p. 20.
† H. E. Holmann. "Wireless Engineer," Vol. 10, p. 484.

value of Wehnelt cylinder voltage is possible for a focussed spot corresponding to a fixed anode voltage and filament current.

The trace on a vacuum oscillograph becomes more clearly defined as the beam current is decreased, i.e., as the modulation control becomes more negative. This

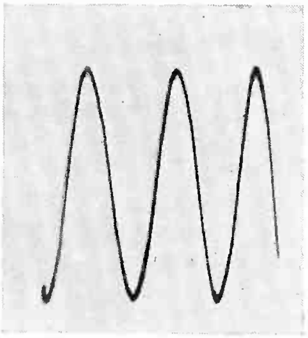

FIG. 1.

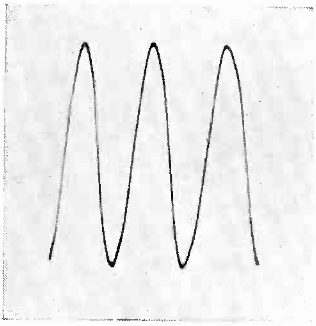

FIG. 2.

effect is shown in Figs. 1 and 2, for two values of modulation voltage. Provided that the deflectional sensitivity of the oscillograph is not important, the most satisfactory pattern is obtained by using a high anode voltage and restricted beam current, but in many cases some compromise will be found necessary.

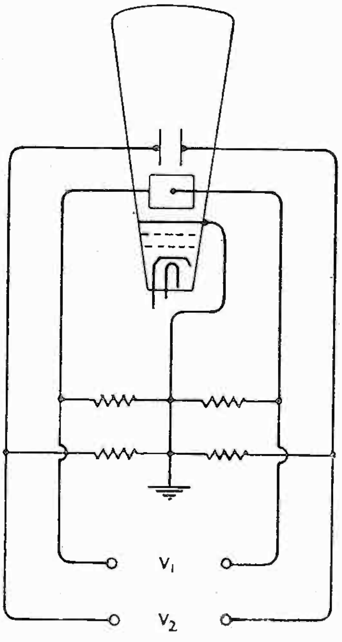

FIG. 3.

The vacuum oscillograph may be deflected either magnetically or electrostatically without loss of focus provided that suitable precautions are taken. For purposes of general laboratory measurement it is found preferable to use electrostatic deflection, since magnetic deflection becomes impracticable for frequencies in excess of about 10,000 ∿. When electrostatic deflection is used it is preferable to arrange the deflecting circuits so that the instantaneous mean potential of both pairs of deflecting plates is zero with respect to the anode. The photographs shown in Figs. 1 and 2 were taken under these conditions. This condition may be met by connecting the deflecting plates in push-pull as shown in Fig. 3, in which V_1 and V_2 are the deflecting voltages. Under certain circumstances it may be found difficult in practice to provide a push-pull connection to one pair of plates. It is possible to obtain a moderately focussed trace if one pair of plates is connected in the normal manner (i.e., one plate connected to anode and the other to the voltage to be examined and the other pair of plates being connected in push-pull). Fig. 4 shows the definition obtainable under these circumstances for which a low beam current

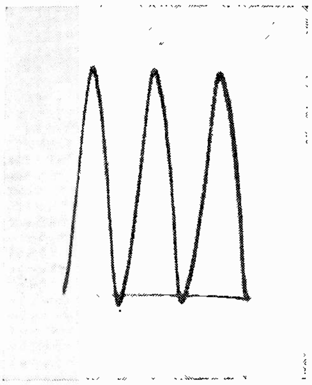

FIG. 4.

was used. If a vacuum oscillograph is used with the standard design of time base and rack mounted equipment* then the oscillograph would be used in this manner. For special purposes, however, push-pull time bases are available.

The deflectional sensitivity varies slightly according to the method of deflection. If three of the four deflecting plates are connected to the anode and the remaining plate connected to a variable D.C. supply, a series of deflection/deflecting voltage curves are obtained as shown in Fig. 5. It will be observed that the deflectional sensitivity is different when the deflecting plate is at positive potential to the anode than

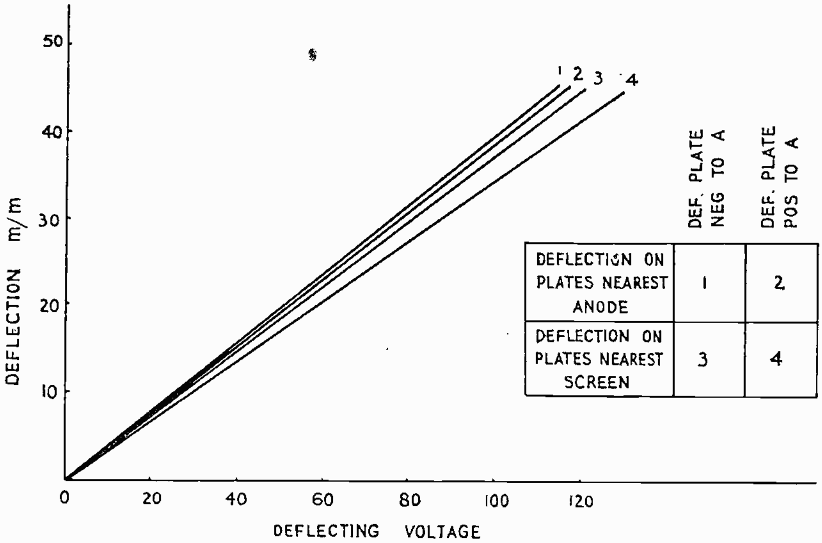

FIG. 5.

when it is negative and further that the effect is greater for the deflector plates nearest to the screen. This difference of sensitivity causes a distortion of the trace, which for the want of a better name has been called trapezium distortion. If two time bases are connected to the cathode ray oscillograph to give a television scan, the effect of this trapezium distortion may be shown (Fig. 6). It will be observed that instead of the scan having a perfectly rectangular shape it is slightly deformed. This distortion is generally less than 2 per cent. for double push-pull deflection. If a push-pull time base is used in conjunction with a single phase

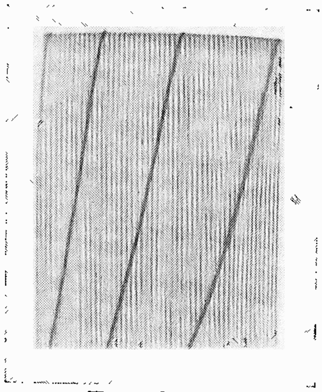

FIG. 6.

* Ref. MARCONI REVIEW, No. 53, p. 19

time base, then a scan approximating to the figure of a trapezium is obtained. The actual figure obtained may be determined by consideration of the sensitivity curves shown in Fig. 5. Correcting devices* for trapezium distortion are known, but their use is not general since the distortion is usually small.

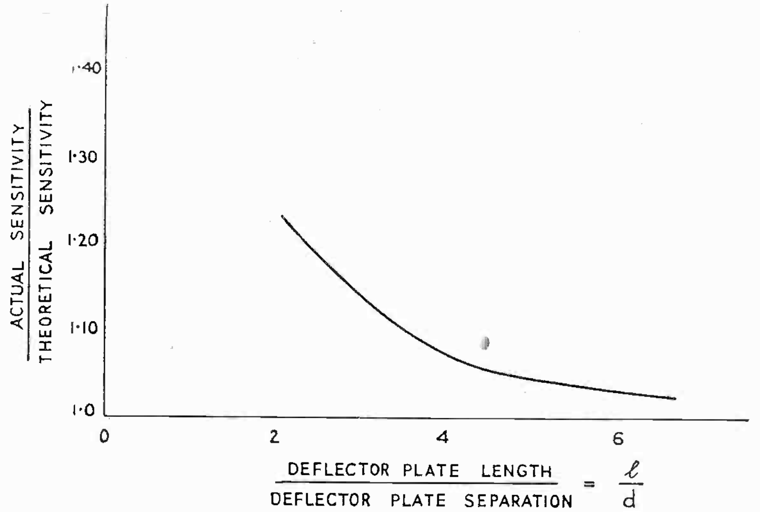

FIG. 7.

The trapezium distortion is caused by the fringing field at the edges of the deflector plates. In order to determine the magnitude of this effect measurements were made on the actual sensitivity of the oscillograph compared with the value

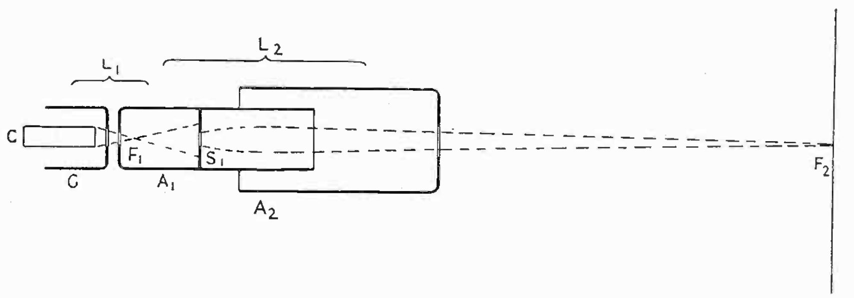

FIG. 8.

calculated from simple theory. If the fringing field at the edges of the deflector plates is neglected, then the following formula for the sensitivity may be used :—

$$S = \frac{Ll}{2d\ V}$$

where S is the sensitivity in mm/V.
L is the effective electron beam length.
l is the deflector plate length.
d is the separation between the parallel plates.
V is the anode voltage.

* Ref. Patent No. 422,708.

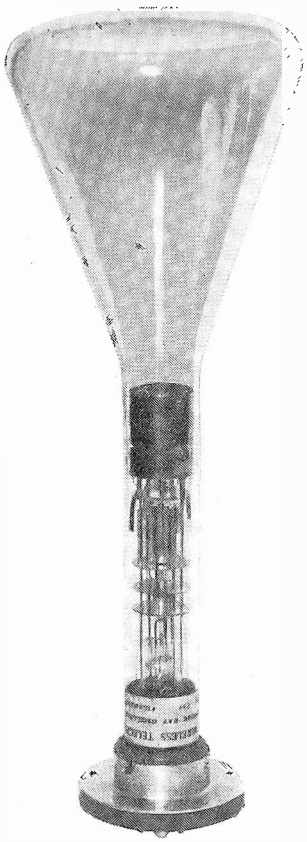

FIG. 9.

FIG. 10.

In practice it is found that due to the fringing field the sensitivity is greater than the value given by this formula. The dfference between the actual and theoretical sensitivity therefore gives a measure of the fringing field. Fig. 7 shows the relation between the ratio of actual sensitivity to theoretical sensitivity plotted as a function of the deflector plate length divided by the separation. This curve, however, only applies to the type of construction in use, as the influence of charged electrodes near the deflecting field will change the fringing field.

A further form of distortion experienced with cathode ray oscillographs is the modulation of one pair of plates by the other. The effect, however, is generally quite small.

A photograph of the completed oscillograph is shown in Fig. 9. The main external dimensions except the length are the same as the gas focussed oscillograph, both are provided with 10 point bayonet caps and sockets which are interchangeable. The focussing of the high vacuum oscillograph is performed by means of two electron lens combinations as shown in Fig. 8. The electron beam is brought to an effective focus at F_1 by means of the electron lens combination L_1, and is then allowed to diverge. The paraxial rays are selected by means of the stop S_1 and the electron beam is then brought to a focus on the fluorescent screen at F_2 by means of the electron lens combination L_2. The electron beam is then deflected by means of two pairs of deflector plates placed at right angles to one another, the sensitivity of which is approximately 0.38 and 0.35 mm/V. for the two pairs of plates at an anode voltage of 1,000.

If the cathode ray beam is not deflected it may be used to demonstrate the properties of an electron microscope. For this purpose the first anode voltage is adjusted not to give the smallest image on the fluorescent screen but an image of the cathode. The range of control provided on the standard rack equipment is usually sufficient for this purpose. An irregular image of the cathode will then be observed on the fluorescent screen similar to that shown in Fig. 10.

The electrode G serves to modulate the intensity of the beam and the anode A_1 serves as a focussing control since it changes the effective focal lengths of both L_1 and L_2.

The mechanical construction of the oscillograph has been improved with the object of providing more uniform characteristics and also ability to withstand the stresses imposed by normal handling in transit. The method adopted is to interlock the electrodes on suitable mica insulators, the whole assembly forming a rigid mount.

A. J. YOUNG.

ELEMENTARY PRINCIPLES OF AERIAL DESIGN

The following article forms the subject of an introductory lecture on aerials given at the Marconi College. It covers the more general considerations underlying the design of vertical aerials for short, medium, and long waves, and takes some account of the special requirements for broadcasting.

A SUITABLE starting point for a paper dealing with aerials is found in Kelvin's classical formula for the periodic time of oscillation of a closed oscillatory circuit, expressed in the form :

$$t = 2\pi\sqrt{L.C.}$$

where L and C are in Henrys and Farads.

The complementary case is that of the open oscillator, commonly called an aerial, which differs from the closed oscillator in that the two properties of inductance and capacity are distributed along an open conductor. But the open conductor also implies another property, namely, that of radiation into free space, a property analogous to a load coupling and hence one whose effect is equivalent to a series resistance in the aerial circuit. The open and closed circuits are both amenable to the same rule for determining the period, provided that in the former case the quantities for inductance and capacity are modified to suit the effectiveness of their distributed nature, a provision which can best be appreciated by considering a simple case.

The simple open oscillator is a wire of finite length, that is with an open end in the case of an earthed wire, or two open ends if the wire is in free space. The wave travelling along the wire is reflected at the open end, and the result of forward and backward waves is a standing wave with sinusoidal current and voltage distribution as seen in Fig. 1. Let us assume a plain straight wire of length l in free space with a uniform distribution of inductance per centimetre and of capacity per centimetre, say L_o and C_o respectively, so that the total quantities become $l.\ L_o$ and $l.\ C_o$. It can be deduced from the figure that the effectiveness of the inductance will be greatest at the centre, where there is most current ; similarly the effectiveness of the capacity will be greatest at the extremities where voltage is highest ; in fact it is pretty clear that the effectiveness of each centimetre of distributed inductance or capacity will vary from point to point along the wire as a sine function.

The current at the centre of the aerial, or at the base of the quarter wave aerial, is a maximum or loop value, hence the average current in either type of aerial is $\frac{2}{\pi}$ times the loop current. Taking one ampere as loop current value it is clear that the effectiveness of the total aerial inductance, that is the effectiveness of its reaction, is $\frac{2}{\pi}$ times the reaction due to one ampere passing through a similar value of concentrated inductance. The same reasoning applies to the capacity reactance, so that altogether we may say that the effectiveness of the aerial inductance and capacity is $\frac{2}{\pi}$ times in each case the effectiveness of similar but concentrated quantities.

There is one other point relative to the capacity that calls for explanation: alongside the aerial in Fig. 1 there is a sketch of an equivalent concentrated circuit, and it will be appreciated, firstly, that one half of the aerial is charging or discharging with respect to the other half, hence we are dealing with half values; secondly, that the two half capacities are in series, hence the circuit capacity is one quarter of the total capacity. Substituting these quantities in the original equation—

$$t = 2\pi\sqrt{\frac{2}{\pi}\,l \cdot Lo \cdot \frac{2}{\pi}\,l \cdot \frac{Co}{4}} = 2\,l\,\sqrt{LoCo}$$

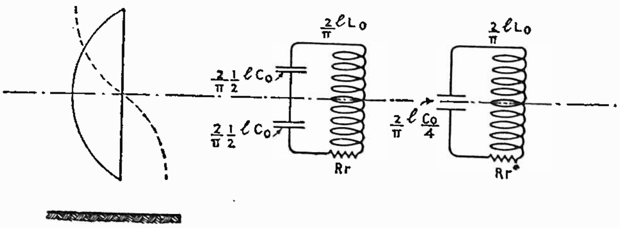

FIG. 1.

Thus for a conductor oscillating in free space

$$t = 2\,l\,\sqrt{LoCo}$$

In the case of the earthed aerial, the entire capacity is charging or discharging with respect to earth, hence the 1/4 capacity factor does not apply and the formula is

$$t = 4\,l\,\sqrt{LoCo}$$

NOTE.—If c.g.s. units are employed

$$t = \frac{4l}{v}\sqrt{Lcms \,.\, Ccms}$$

where L*cms* and C*cms* are now in Centimetres of inductance or capacity, and where v is the velocity of light. But $vt = \lambda$, also $\lambda = 2l$, or $4l$ as the case may be, hence for a plain straight wire $\sqrt{Lcms \,.\, Ccms} =$ unity.

Aerial Length.

The length employed in the above formula is the electrical length. Owing to "end effect" and retardation of velocity along wires, the physical length of the actual aerial is never less than given by the factor 0.95, and may be even 0.8, times the electrical length, a matter of great importance when designing aerials; but it is equally important to appreciate that for the purpose of characteristic calculations the electrical length is the most appropriate.

Having discussed the natural period of an aerial, let us next examine its efficiency, that is the performance in relation to height and wavelength.

Radiation Efficiency and Metre Amperes.

This is the problem of obtaining maximum signal strength at a distant receiver for a given power input to the Transmitter Aerial. Although transmission is specified, conditions are nearly reciprocal and the conclusions arrived at for the case of transmission will cover the requirements of reception. There is, however, an exception in the case of short waves, for while it is advantageous to concentrate radiation around a low angle in the vertical plane of a transmitting aerial, it is inexpedient to do so at the receiving end because there is a well recognised condition of fading allied with a shifting angle of incidence: in order to deal with this practical aspect of the problem it is necessary to design a S.W. receiving aerial with somewhat less concentration in the vertical plane than for the corresponding transmitter aerial.*

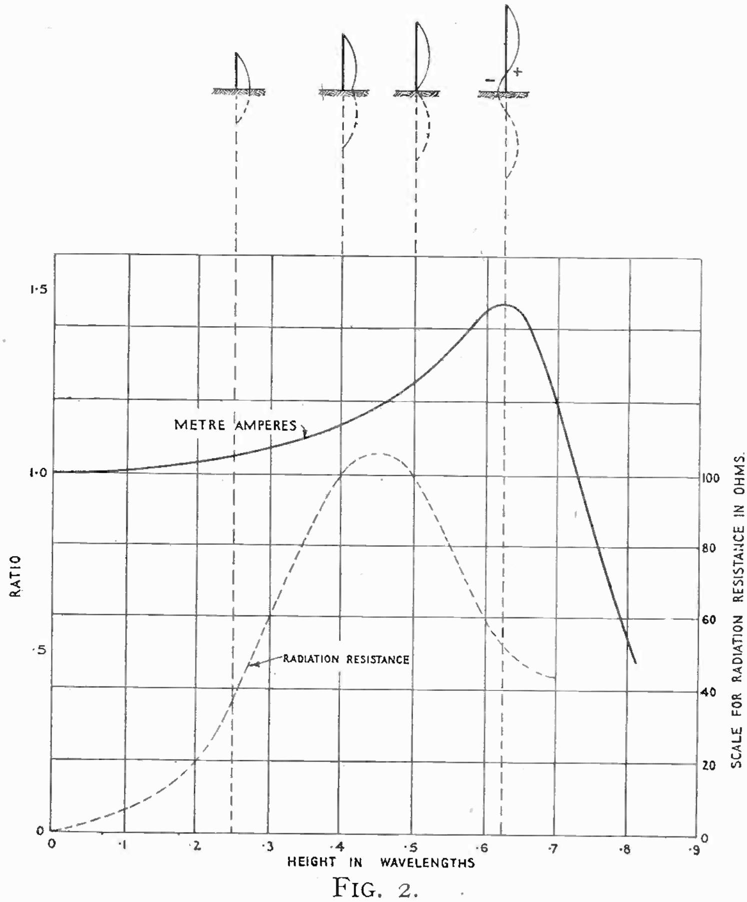

FIG. 2.

Reverting to the subject of radiation efficiency, it can be shown from first principles that, for any point on the horizon some distance from an aerial system, the field strength of the signal is proportional to the vertical height of the aerial and to the average current along the aerial, provided that current sign is taken into the reckoning. The two quantities height and current may be multiplied together and the product supplies a method for comparing the probable performance of various aerials on the basis of signal strength at a given distance. This product is termed the " Metre Amperes " and, as far as a single number goes, is a remarkably useful guide, although we now know that it does not provide a completely adequate

* The writer has digressed somewhat here because frequent misunderstanding exists as to the implications of a reciprocal path. There can be no reasonable doubt as to general reciprocity in the medium between any two widely separated points, but whereas this implies identical transmitting aerials at each end of a radio circuit, or identical receiving aerials, it does not necessarily imply that the receiving aerial in its characteristics should be a replica of the transmitting aerial.

picture of the aerial's properties. A curve of Metre-Ampere values is given in Fig. 2 and will be discussed in the course of the paper.

In order to possess full information of an aerial's properties we must have knowledge of both the relative signal strength at a distance and the actual form of the polar curve of energy distribution in the vertical plane, known as the vertical polar characteristic. The precise delineation of the polar curve is outside the scope of this paper, nevertheless it will be time usefully spent if we consider in greater detail the overall efficiency of an aerial and, in particular, the bearing of each component of Metre-Amperes on the results. This brings us back to "Height," which—

Determines the Radiation Resistance, and thus the "Amperes."
Determines the "Metres."
Determines the Vertical Polar Characteristic.

Radiation Resistance.

The term Radiation Resistance is an indication of the radiating property af an aerial: it might be regarded as a measure of the degree of coupling between Aerial and Ether, inasmuch as such coupling determines the load thrown on to the aerial.

If R symbolises radiation resistance, P the rate at which energy is transferred to the Ether, and I the current at any point along an aerial, then for a perfectly conducting earth and non-ohmic (filamentary) aerial

$$P = RI^2$$

Obviously, therefore, the value of R depends upon where I is measured, and by general consent the point has been defined as at maximum oscillatory current; strictly speaking, where there is a current loop and no reaction. This will be at the centre of a simple half wave aerial or at the base of a simple earthed quarter wave aerial.

The calculation of Radiation Resistance for various heights of straight aerial is a fairly elaborate matter; it has been undertaken by Pierce, Cutting, Ballantine and many subsequent authorities, the agreement between the various results being consistent within expected limits, so that the published curves of radiation resistance, such as Fig. 3 herewith, may be accepted. Important values are 36.6 ohms for a quarter wave aerial, 73.2 ohms for a half wave aerial well above earth, and approximately 100 ohms for a half wave aerial close to earth: these two latter figures will be referred to again.

Raditation Resistance is of little value as a means of direct comparisons between aerials, but it is of basic importance in calculations relative to aerials; thus knowing R_r we can calculate loop current and hence average current for a given height and type of aerial.

Radiation Resistance: Long Waves.

All long wave aerials are low compared to the wavelength radiated, and for such aerials it can be shown that R_r varies as the square of the height. This will be obvious if we consider the vertical polar curves for a number of straight conductors, differing in length but all much shorter than some common radiated wavelength: since they are all short the vertical polar curves will all practically coincide with the simple cosine curve, that is, they will coincide with each other. Again, for constant power the areas will be similar, hence for a given power radiated the area and shape of the vertical polar curve will be constant whatever the height of aerial, that is, for low aerials the field strengths will be similar and the Metre-Amperes will be constant. If we put this into figures and remember that the ratio of the average currents, say i_1 or i_2, is the ratio of the loop currents, say I_1 and I_2, we have :—

$$i_1 \cdot h_1 = i_2 \cdot h_2, \text{ but } I^2_1 \cdot R_1 = I^2_2 \cdot R_2 \text{ hence } R_1 : R_2 = h^2_2 : h^2_1.$$

It follows that in the imaginary circumstances of a perfectly conducting earth, the Metre-Amperes would be constant, that is, signals would be equal whatever the aerial height below, say, $\frac{1}{4}\lambda$. It will be seen from the curve of Metre-Amperes that up to $\frac{1}{4}\lambda$ heights the value is pretty constant.

Actually, of course, this is not the case, because the earth is only a partial conductor and introduces losses, also there is another factor in the insulators which cannot stand unlimited voltages. It will be convenient to discuss these two factors separately :—

(A) *Efficiency.* Earth resistance and stay losses are practically constant over the long wave spectrum, absorbing by far the greater proportion of H.F. energy, hence it is expedient to increase R*r*, that is to push up the height to the economical limit and thus increase the efficiency ratio.

Note that even the maximum height economically possible still yields quite a low R_r value on long waves and resort is made to the Earth Screen, an artifice by which the earth losses are reduced. It may be regarded as an artificial earth or, and possibly more correctly, as the lower half of a dipole aerial of which the vertical aerial member and top screen form the upper half.

(B) *Insulation Limitations.* The practical dimensions and nature of insulators limit the voltage that can be applied to an aerial, so that a low current value is desirable : this implies a high aerial, that is an aerial of high R value. But even with the highest R value reasonably attainable the voltage would be still too high for any appreciable power input and it is necessary to make use of the "Capacity Top," by which artifice it is possible to have a comparatively heavy current in the vertical aerial member without undue rise of voltage at the aerial extremity.

Radiation Resistance : Medium Wave Aerials.

The European medium wave broadcasting band lies between 200 and 545 metres, and within such limits it is often economically possible to erect aerials $\frac{1}{4}\lambda$ high, while the single mast type of aerial is being erected for heights up to approximately 0.6λ at a number of the more important broadcasting centres.

The quarter wave aerial corresponds to a R*r* of 36.6 ohms, at which figure the power radiated bears a favourable relation to the power wasted in the earth resistance, so that the erection of an earth screen is scarcely justified.

As the height increases beyond the quarter wave the rate of increase of R*r* slows down and almost follows a straight line law until the height reaches about 0.4λ. At this point a coupling effect between the aerial and its image begins to have appreciable effect and will be considered shortly ; for the present it suffices to point out that the R*r* curve bends round to a maximum of approximately 105 ohms at 0.45λ height and drops to 100 ohms at 0.5λ height, thereafter dropping rapidly to a minimum of 44 ohms at 0.7λ, where we may leave it, as outside the scope of this paper, with the remark that the value rises and falls with increasing height, tending to the limiting and constant value of R*o*; that is, in the limit Radiation Resistance and Surge Impedance coincide.

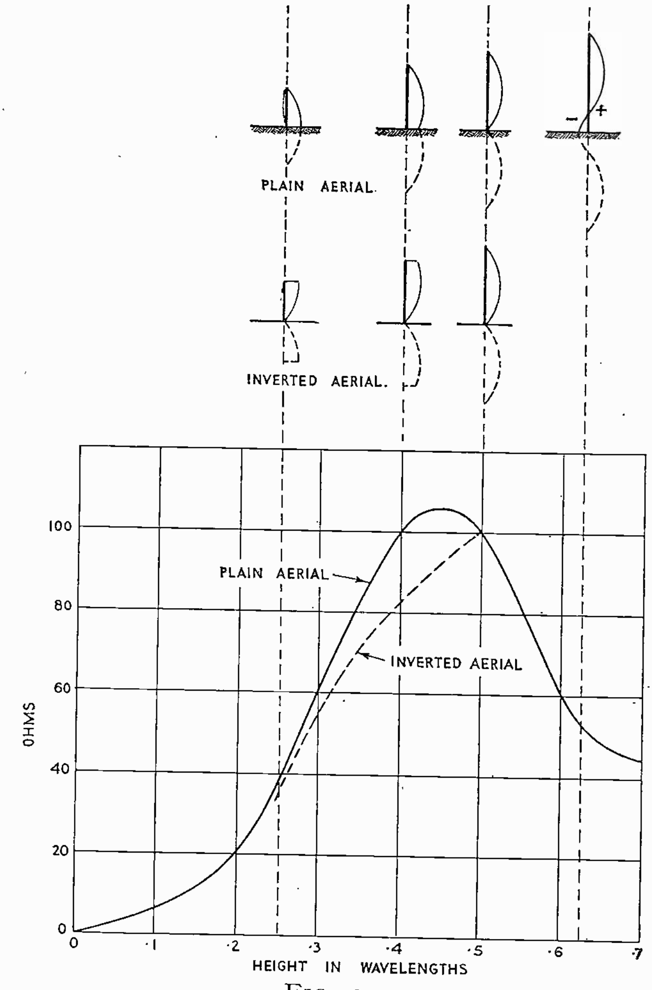

FIG. 3.

Fig. 3 gives an idea of the variation of R*r* with height of aerial, under the wholly imaginary conditions of a perfectly conducting earth. Note that the rapid drop in R*r* between 0.5λ and 0.65λ is mainly due to the decoupling effect of current reversal in accordance with sinusoidal distribution: as height increases beyond 0.70λ the increasing separation between the sections of the aerial, on which current is of opposite sign, introduces a phasing effect which alternately restores and diminishes R*r*.

An important addition to Fig. 3 relates to the radiation resistance of inverted aerials, presently to be mentioned. Note that between the limits involved, viz., 0.25λ and 0.5λ, there is no optimum coupling effect.

Note on Coupling Between Aerial and Image.

Calculation indicates that the radiation resistance of a simple half wave aerial in free space is 73.2 ohms : in effect this aerial is an oscillatory circuit and if a second

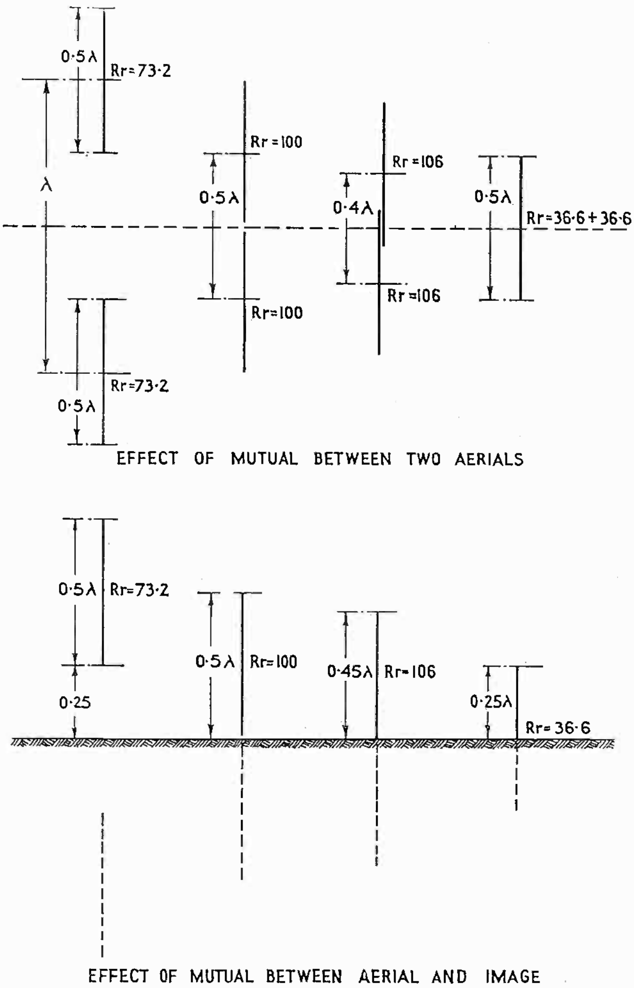

FIG. 4.

and separately excited aerial, of coincident current phase, is brought end-on into line with the first the condition is clearly that of two coupled circuits. There is little mutual effect until the separation between aerial centres decreases to one wavelength, but below this the mutual increases appreciably, that is, there is an increase in the R*r* value of each aerial ; this mutual effect continues until the separation between centres is reduced to 0.4λ when the mutual reaches a maximum. Thereafter the R*r* of each aerial diminishes with diminishing separation until the two aerials merge into one and the mutual vanishes completely. Now apply the idea to a half wave aerial whose centre is a half wave above earth ; this is equivalent to a centre to centre separation of one wavelength, as between the aerial and its image, and at such a separation the mutual is only just being felt and therefore the R*r* value will not differ appreciably from 73.2 ohms. If, however, the aerial is brought down to the level of the earth, equivalent to a centre to centre separation of 0.50λ between the aerial and its image, the mutual between aerial and image is sufficient to increase the R*r* value to some 100 ohms. The next stage is to reduce the height of the aerial; when height is reduced to 0.45λ, equivalent to a centre to centre separation of 0.40λ, the mutual has reached an optimum, R*r* reaching a peak value of some 106 ohms despite the lesser height. As the height is further reduced the aerial and image mutual decreases rapidly and vanishes. When the height has decreased to that of a $\frac{1}{4}$λ aerial R*r* has dropped to 36.6 ohms, just half the value of a half wave aerial in free space.

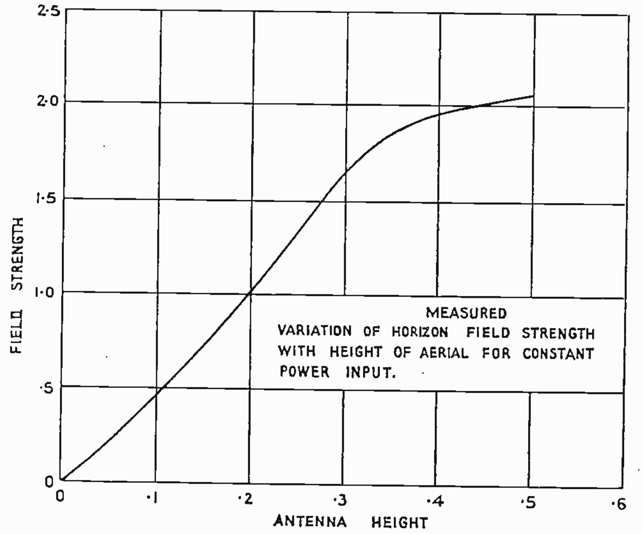

FIG. 5.

Reversing the above process, for plain aerials between the 0.25λ and 0.50λ aerial heights it becomes apparent that the R*r* value rises to a maximum and drops slightly before the half wave height is attained.

Fig. 4 illustrates the sequence outlined above.

Actual Effect of Height.

The preceding curves, Figs. 3 and 4, are calculated for imaginary conditions of a perfectly conducting earth: unfortunately there is little published data of actual measured Metre-Amperes against various heights of aerial and Fig. 5, due to Messrs. Nickle, Dome and Brown, may not be typical, although it is an accurate representation of a particular set of measurements.

Radiation Resistance: Short Waves.

We next come to short waves, where the variations in R*r* are pretty much as for medium waves. On the other hand ground absorption losses become of considerable magnitude, although to counterbalance this the wavelength dimensions are such that an aerial may be erected at an appreciable height away from earth.

This matter of the value of the radiation resistance for a half wave aerial raised above earth becomes quite a practical issue for short wave communications ; it is also an important one because of earth propagation losses, which increase practically in the ratio of the square root of frequency and are very marked at high frequencies. These propagation losses decrease rapidly as the aerial is raised above ground level.

It must be accepted as a fact that for short wave communication the useful radiation is, very roughly speaking indeed, that emitted around an inclination of 10 degrees to the horizontal, so that higher angle radiation and horizontal radiation is lost energy.

As will be seen from an examination of the relative polar curves shown in Fig. 6, the decrease of mutual coupling between aerial and image following the raising of an aerial above earth alters the shape of the vertical polar curve, cutting off high angle radiation and concentrating radiation more towards the horizontal, thereby to some extent benefiting the concentration around 10 degrees. The effect of mutual

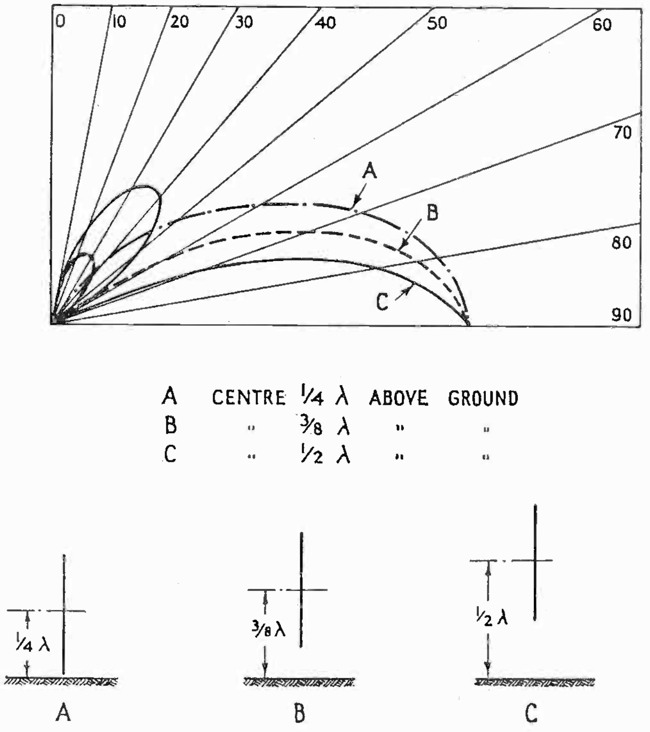

Fig. 6.

practically ceases at a separation of one wavelength ; on the other hand the earth propagation losses, which diminish rapidly at first, continue to diminish for heights varying from one to three wavelengths, according to the nature of the ground, hence the main improvement following the raising of a S.W. aerial above earth is the decrease in earth propagation losses.

It has been remarked that horizontal propagation is of no value for S.W. communication, in direct opposition to medium wave technique, therefore the quantity

"Metre Amperes" begins to lose its significance at the higher frequencies. Since Metre-Amperes is no longer a direct index of aerial efficiency for short waves, some other quantity must be sought, such as the ratio of power usefully radiated around 10 degrees to that radiated in all other directions. The ratio depends upon ground absorption and has been calculated* by T. L. Eckersley, who finds that in the case of a half wave vertical aerial close to earth the resistance equivalent of the aerial radiation in the wanted direction is 31 ohms for a 22 metre wave. Thus in the ideal case of a perfectly conducting earth the power ratio is 31 : 100 ohms, say 30 per cent. Actual tests near Chelmsford indicated that ground losses increased the total radiation resistance to 165 ohms, so that the efficiency figure drops to 18.8 per cent. Other workers in other countries, i.e., where ground conditions may diverge widely from Chelmsford, find a much lower value for the total R value; it is, however, abundantly obvious that the efficiency of a short wave aerial close to earth is very low.

The improvement in distant S.W. signals effected by raising the aerial is striking; thus on the England-Australia route Eckersley and Tremellen have found a gain of 10 times in field strength, with 15 metre waves, by raising a half wave vertical aerial from close to the ground up to a height some five wavelengths above ground. Experience, as well as calculation, indicates that the greater proportion of gain occurs as the aerial is raised through the initial wavelength, and in practice half a wavelength between lower tip and earth is often ample clearance.

NOTE (A).—The practical method of gauging the efficiency of various heights and types of short wave transmitting aerials is by measuring the level of received power, the datum being a vertical half wave aerial close to earth.

NOTE (B).—In Fig. 3 the curve of Rr shows a bend about the half wave height, where current changes sign, but in the case of short wave aerials it is possible to extend height and, by means of phasing coils or folding and inter-folding the conductors, to obtain the effect of constant current sign. In this way a curve for the radiation resistance appropriate to S.W. aerials would continue to rise for some wavelengths, tending towards a steady maximum value equal to the surge impedance of the conductor.

Earth Resistance and Inverted Aerials.

As mentioned, at medium wave frequencies the direct earth resistance loss is not sufficient to justify an earth screen, nevertheless such loss is appreciable and at the higher frequencies associated with short waves may become quite serious: the obvious method of reducing this loss is to reduce the earth current to a minimum.

In the case of vertical half wave aerials close to earth, if a tank circuit is interposed between earth and aerial terminal it is clear that no oscillatory current enters the earth and that the only earth current is the H.F. feed current which maintains the aerial oscillations and whose magnitude is equal to "Watts/Terminal Impedance": this is the minimum possible earth current. In the case of aerials between 0.25λ and 0.5λ high it is definitely advantageous to design them with a T top, or similar device, in order that they may oscillate as half wave aerials and be fitted with terminating circuits which reduce earth current to the minimum. An aerial so designed is known as an "inverted" aerial, and will be referred to again later.

* MARCONI REVIEW, No. 23, 1930.

Metres.

The foregoing paragraph concludes our consideration of Radiation Resistance in its relation to the Ampere component of the quantity "Metre Amperes." The direct effect of height, as determining the metre component, is obvious, although mention must be made of the fact that many writers refer to the "average height" of an aerial, regarding current as fixed at maximum value. Whether the height is "averaged" or whether current is averaged makes no difference to the final figure of Metre-Amperes, but the Author prefers to regard height as the actual height and current as the quantity to be modified by averaging it, that is, by applying the form factor.

Height and the Vertical Curve.

Following its influence on radiation coupling the height of an aerial determines the form of energy distribution in the vertical plane.

It has been mentioned that low aerials, that is very short aerials, give a cosine distribution in the vertical plane; this is because the intensity of polarised radiation is proportional to the angle of elevation. For aerials whose height is commensurate with wavelength, the simple cosine rule no longer applies and we may sketch the effects very briefly as follows:—

(A) Provided current is in one sense, the higher the aerial the greater the phase difference between, say, its extreme elemental portions for radiation inclined to the horizontal: this phase difference increases the ratio between inclined and horizontal radiation intensity, that is, it tends to sharpen the vertical polar curve.

(B) Again, if we conceive an aerial of height h and power input P to be made up of a number of elemental aerials, we may reasonably assume that each element has a proportional input p and that the field strength in the horizontal is proportional to $\sqrt{p}$; in fact we may say that field strength equals $K\sqrt{p}$. Now extend the aerial to a height $4\,h$: there will be four times as many elements, each with one quarter of the original input, so that the field strength now equals $4K\sqrt{\frac{p}{4}} = 2K\sqrt{p} =$ twice the original strength.

Taking these two facts (A) and (B) together it is clear that, provided current is in one sense, the higher the aerial the more concentrated the energy in the horizontal plane and the sharper the vertical polar curve, two most important properties for medium wave transmission.

The actual distribution of energy at various angles is calculable, and, in its more fundamental aspects, is a fairly simple problem but cannot be dealt with here:* the important point, and one we must take for granted, is that the calculated polar curves show increasing horizontal field strength between, say, $1/4\lambda$ and 0.625λ height of aerial; in other words, there is a rise of Metre-Amperes between these limits.

In the case of aerials greater than 0.5λ in height, the current sign will change as the half wave height is passed, so that the lower section of the aerial tends to cancel out the horizontal radiation from the upper section, thus there is a definite

* E. Green, "Experimental Wireless," Oct., 1927.
N. Wells, "Electrical Review," 25/5/28 and 1/6/28.
A. W. Ladner, MARCONI REVIEW, No. 33, 1931.
E. A. Laport, "Electronics," Feb., 1935.

limitation to the useful height for which a medium wave aerial can be designed. The actual limit is not reached at the half wave height, where current changes sign, because, as we have seen, there is a rapid drop in the value of R_r which tends to keep up the average value of the current until the height reaches 0.625 wavelength. Thus, for a given input the maximum value of Metre-Amperes occurs when the aerial is 0.625 wavelenth high.

All this is merely an explanation of effects which can only be dealt with adequately either by mathematical or graphical methods.

Incidentally, and reverting to short wave technique, the Marconi-Franklin Uniform Aerial is a somewhat unique type of vertical aerial in which the current is of constant sign throughout and of approximately uniform, or uniformly tapering magnitude. Thus the height may be and actually is extended to two or even three wavelengths.

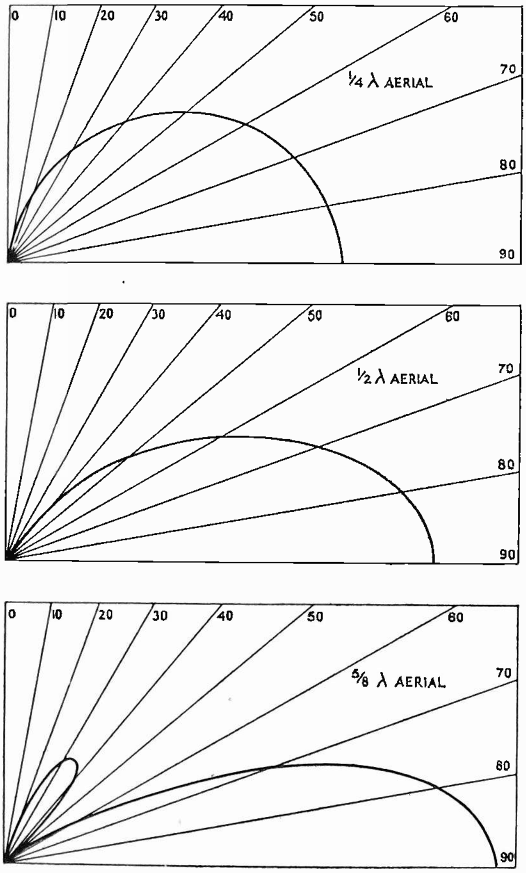

FIG. 7.

Medium Wave Anti-Fading Aerials.

An examination of the polar curves of Fig. 7 for Quarter Wave, Half Wave and 0.625 Wave Aerials reveals the fact that in the latter type there is a gain of some 45 per cent. in field strength over the Quarter Wave type, but, and this is more important, there is also an absence of radiation between 40 degrees and 60 degrees to the vertical. Broadly speaking, radiation around 50 degrees is reflected at such a distance and at such intensity as to interfere with the direct ray throughout a zone at some distance from the aerial, and therefore this height of aerial would be less prone to distant fading—on the other hand, there is a secondary loop between 30 degrees and 40 degrees which indicates a liability to interference effects in a zone fairly close to the aerial. A compromise between 0.50 height and 0.62 height has been found most effective and probably a height of 0.55 is a good basis for design. As precise calculations are not possible, it is usual to give some latitude in height by means of an adjustable extension.

Aerials of this type are known as "Anti-Fading Aerials" and are constructed as a single mast which also forms the conductor. Their appearance has become familiar through illustrations in the technical journals. It should be noted that some of those already installed suffer a serious disadvantage from a varying cross section, tending towards a concentration of capacity at the centre of the mast, where it is least desirable. The effect of this is to distort the sine form of current distribution, and because of the combined effect of current distortion and ground absorption, the actual vertical polar curve departs appreciably from the theoretical curve of a filamentary aerial above a perfectly conducting earth; nevertheless the self-supporting high aerial is a substantial advance in the technique of broadcasting. It is probable that increasing experience will confirm the desirability, if not the necessity, of building such aerials with electrically uniform cross-section.

Artificial Height.

In connection with long waves, it was mentioned that a capacity top is employed to increase the amperes, of the Metre-Amperes, without unduly raising end potentials: in effect this practice amounts to an artificial extension of the aerial height, because, in the case of long waves, the effect of the top end of a quarter wave aerial is almost wholly that of a simple capacity. A somewhat similar idea is applied to medium wave technique, but in order to stimulate the effect of additional height upon an aerial already one quarter wavelength, or more, in actual height it is necessary to

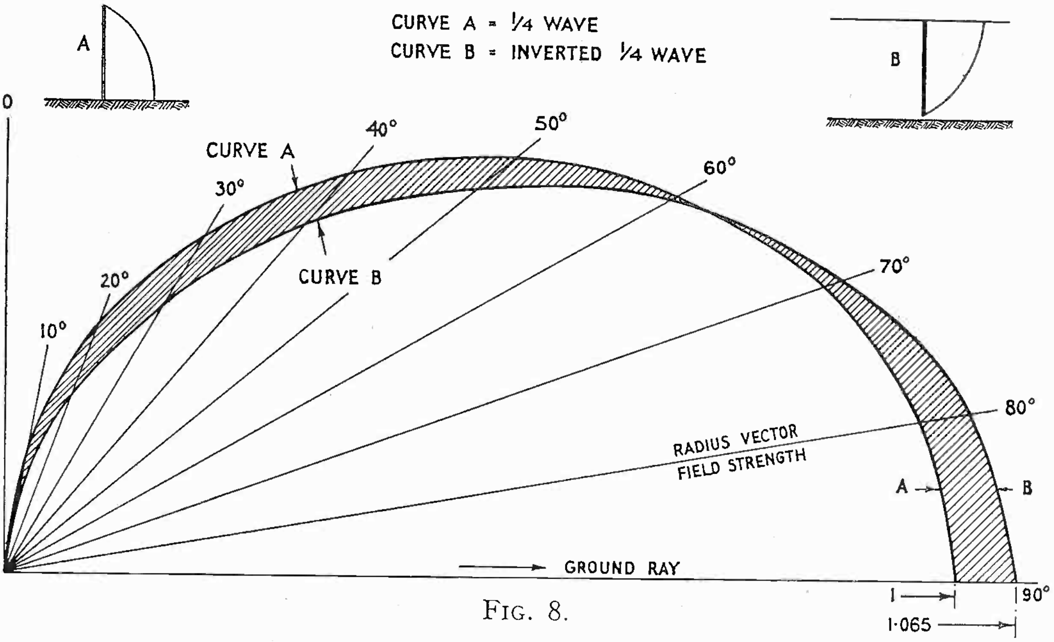

FIG. 8.

employ both inductance and capacity: generally speaking this can best be done by employing two lengths of wire running horizontally away in opposite directions from the upper end of the aerial, in fact the so-called half wave Tee aerial. For all practical purposes the two horizontal lengths, in which current is equal and opposite, cancel each other as regards radiation, provided each horizontal limb is appreciably less than 0.25λ. Of course it would be possible to stimulate a given length of wire by a combination of a capacity top and an inductive coil, and this has been done, but it is doubtful if much can be gained by departing from the simpler and more direct method of folding the top when the dimensions are such that it would, otherwise, radiate.

One particularly interesting case is the Inverted Quarter Wave Aerial, seen in Fig. 8, in which the presence of the horizontal limb gives to the vertical limb the form of current distribution appropriate to the lower half of a half wave aerial. This is a complete inversion of the distribution along a plain quarter wave aerial, and, since it increases the centre to centre separation between aerial and image, the effect is to sharpen the vertical polar curve, with the result that there is less angular radiation. The actual reduction is of the order of 12 per cent. to 20 per cent. between the angles of 40 degrees and 20 degrees. In the aerial as depicted, and as hitherto generally erected, we now suspect some radiation from the horizontal limbs.

For heights between $1/4\lambda$ and $1/2\lambda$ the inverted arrangement is definitely preferable because it permits an aerial termination with earth current at a minimum and because the field strength is increased, with a corresponding diminution of the unwanted high angle radiation.

Summary.

For Long Waves and Medium Waves the quantity Metre-Amperes is an excellent indication of the relative performance of various aerials on a common frequency. It is also some index of relative anti-fading properties, since higher values correspond to sharper polar curves.

Aerial Resistance is an important quantity for calculations but is of little value as an index of efficiency. Moreover, it is difficult to measure accurately the aerial resistance at loop current values on any but complete quarter wave aerials.

LONG WAVE AERIALS should be as high as consistent with economical considerations. They may be equipped with capacity tops to prevent undue rise of voltage, and they may be equipped with earth screens to reduce the earth resistance losses.

MEDIUM WAVE AERIALS fall into three main types, depending upon the actual frequency and also upon the importance of the service :—

(A) The simple type, generally below one quarter wave in height.
(B) The inverted type, applicable to heights below half wavelength, with a useful lower limit of one quarter wavelength.
(C) Vertical half wave aerials, with a limiting height of about 0.55 wavelength.

Both types (B) and (C) give a gain in field strength and a reduction of high angle rays when compared with type (A), the highest aerial showing the greatest improvement. The termination appropriate to the two latter types permits a reduction of the H.F. earth resistance losses to a minimum, also earth propagation losses are less with these two types than with directly earthed aerials of the quarter wave type.

SHORT WAVE AERIALS. Short wave aerials, if of the Uniform type, may be extended in height to two or three wavelengths with consistent gain of concentration in the vertical field, also with consistent diminution of ground absorption losses. Alternatively, a simple half wave aerial may be raised above earth with corresponding diminution of ground absorption losses.

It might be added also that short wave aerial systems are built up of half wave units to form so much active "surface" with directive properties, Beam Aerials; but whatever the system or aerial the efficiency is generally measured by comparing the gain in field strength with the field strength due to a simple vertical half wave aerial close to earth. For example, on 16.13 metres at a distance of 3,700 miles a "Uniform" transmitting aerial, having an active height of 2.5 wavelengths, gave an average gain of 4.75 dB. when compared with a half wave vertical aerial close to earth.

N. WELLS.

SCATTERING, POLARISATION ERRORS, AND ACCURACY OF SHORT WAVE DIRECTION FINDING

The theory of the spaced frame direction indicator has been discussed in a previous article. It was shown that if properly set up so that there is no transfer coupling between the cables or outer sheath and the frames, the polarisation errors should be eliminated.*

In the present article experiments will be described to indicate how far this result has been achieved ; measurements will be given of the degree of scattering error to be expected, and a comparison made with the performance of an improved Adcock in a selected site.

THE spaced frame system used has undergone a certain amount of evolution since the experiments began in January this year.

As originally set up, the aerial system consisted of two frames, 6 feet by 6 feet, connected by two 100 feet lengths of flexible, paper-insulated, lead-covered D.F. cable to a central hut, where a phase changer and output circuit (to a receiver with a cathode ray indicator) were housed. With this arrangement any convenient aerial spacing up to about 60 m could be obtained.

For short distances the cable was stretched out to its full length and then returned on itself to the selected position of the aerial.

In the final arrangement two frames, 8 feet 4 inches by 8 feet 4 inches, were rigidly set up 20 m. apart along a North and South line. They were carefully arranged with their planes perpendicular to the line joining them. The cables joining them to the central hut consisted of two Franklin feeder pipes, diameter = 2.5 inches, with a central pair of wires passed through spacing insulators every 2 feet, the wire spacing being 0.75 inches. The aerials were untuned and connected straight on to the cable wires as shown in the figure.

The hut housing the phase changer and receivers was not quite central, but tests have shown that this lack of symmetry is not important.

The general layout is shown in Figure 1. The cables from the two aerials are brought to the phase balancer, the resultant output of which is led to the receiver and cathode ray indicator.

Behaviour of Aerial Systems—Elimination of Polarisation Error.

With such an arrangement the polarisation error (as indicated in the previous article) should be eliminated.

Local tests of the transfer coupling of the sheath of the cable to the frame aerials were made.

A horizontal aerial was set up 40 feet from one of the frames, with its centre in the plane of the aerial, and raised 5 feet from the ground.

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* MARCONI REVIEW, March-April, 1935.

The frame aerial was connected to a local shielded receiver of small bulk (signal measuring set) and the horizontal aerial oriented till the received signal was a minimum. The frame was then connected to the cable in the normal manner, and the signal was indicated on the receiver in the hut. It was found that the horizontal aerial had to be moved about half a degree for a minimum. It was therefore concluded that the transfer E.M.F. from cable to frame was more than 40 dB. down on the direct E.M.F. in the frame (equal vertical and horizontal fields) for the case represented, i.e., angle of incidence about 82 degrees (elevation 8 degrees). The angle of incidence was not small enough to represent a very severe case.

More conclusive evidence was obtained from tests from relatively close pulse transmitters, giving rays with small angles of incidence.

These included vertical pulse transmissions on $\lambda=60$ m., and a 53 m. transmission from an experimental station at Orfordness, set up by the Radio Research Board. Perhaps the latter is the more convincing.

On the morning of June 11th, this transmission was received on a shielded "U" type of Adcock aerial set up at Writtle on a more or less perfect receiving site. The bearings exhibited the most violent form of night effect, errors of 40 degrees and over being often observed.

The spaced frame receiver with cathode ray indicator showed a ground signal (rather weak) and a strong E layer reflection. From the displacement of the E echo the angle of incidence could be calculated. It was 20.5° (elevation angle 69.5°).

The phase difference of the arrival of the high angle signals on the frames was determined by the position of phase balance.

This gives $\sin\theta \sin\phi$, where θ is the azimuthal angle from the E.W. direction, ϕ = angle of incidence. Knowing ϕ, θ could be determined. It was $26.3° \pm 1.45°$ N. of E. The true bearing as nearly as it could be measured from a map was 26 degrees N. of E. The probable error 1.45 degrees was determined from the mean square deviation from the mean of the individual settings of the phase balance. The results imply that the polarisation error for this rather extreme case with an angle of incidence of only 20.5 degrees was less than 1.5 degrees, whereas on the Adcock it was of the order of 20 degrees or 30 degrees.

In this connection it must be remembered that the Adcock system is at a disadvantage compared with the spaced frame system in respect of D.F. accuracy on high angle rays.

Thus on the Adcock aerial the desired vertical pick-up for high angle signals varies as $\sin^2\phi$, where ϕ is the angle of incidence, because, firstly, the pick-up of each vertical aerial varies as $\sin\phi$, and secondly, the differential pick-up of a pair of vertical aerials again varies as $\sin\phi$.

The horizontal pick-up of the cables, on the other hand, does not vary appreciably with θ when θ is small. Thus as ϕ decreases there must come a point where the horizontal pick-up swamps the vertical, and polarisation error will appear. From results on the Writtle Adcock this angle is of the order of 30 degrees.

The wanted pick-up of the frames of the spaced aerial system, on the other hand, does not decrease with decreasing angle of incidence. It follows that the ratio of the spurious horizontal pick-up on the cable to the required pick-up also does not decrease with the angle of incidence, and the system is nearly as free from polarisation error at small angles of incidence as at large.

The vertical incidence pulse transmission supplies additional evidence of the freedom of the spaced aerial system from polarisation errors. A vertically propagated wave should produce equal and equi-phased signals on the two frames.

Any deviation from this state will indicate either a deviation from the vertical in the direction of the ray, or a pick-up of the horizontal E.M.F. by the cable sheath transferred to the frames.

Perhaps the best way of discriminating between these two possibilities is to determine the difference in balance for a right and left hand polarised ray. A little consideration will show that the spurious E.M.F. due to horizontal cable pick-up is reversed relative to the frame pick-up when the direction of polarisation is reversed. It is sufficient then to show that there are cases where the left and right hand rays give the same balance.

In these circumstances cases where a difference in balance is observed can be attributed to true lateral deviation. Taking the observations so far obtained, it appears that the deviations from equi-phase conditions are small, corresponding to 0.5 degrees to 1.5 degrees deviation from the vertical in normal cases, and that the differences between right and left are of the order of 0.5 degrees in some cases, so that it would appear that the spurious pick-up was some 35 to 40 dB. below the wanted.

An analysis of these results shows that the polarisation error to be expected at 45 degrees incidence is less than $\pm$ 0.5 degrees. This is an upper limit. Actually no variations which can be definitely attributed to polarisation error have been found.

In the interpretation of the other experiments a rather rigid specification of the limit of the polarisation error is required, since the total residual errors are rather small, and it would not be possible to separate the parts played by scattering error and polarisation error unless the latter could be limited to an amplitude small compared with the former. The point is of some practical as well as theoretical importance, because according as the residual error is a polarisation or scattering error, this error may or may not be still further reduced.

Experimental Observations.

The main experiments were carried out on pulse transmissions from DOD on a 41.45 m. transmitter at Nauen ($d = 900$ km.). Other results were obtained on pulse transmissions from Montreal, $\lambda = 32$ m.

Pulse transmissions are more convenient and more accurate than C.W. transmissions. Where the true direction of the station investigated is not exactly perpendicular to the line joining the aerials, the phase difference which is proportional to $\sin\theta \sin\phi$ (θ azimuth, ϕ angle of incidence) is not the same for all the rays, for though θ is the same, ϕ is not.

The balance for the different rays is different, as has been observed. Where C.W. is used, only a blurred mean balance can be obtained.

The measure of the scattering angle which depends on the degree of balance obtainable will then include a spurious effect due to the non-coincidence of the various points of balance. The main results therefore are obtained on pulse transmissions. There were considerable modifications and technical improvements made during the course of the experiments, and the later ones are more definite and exact than the earlier.

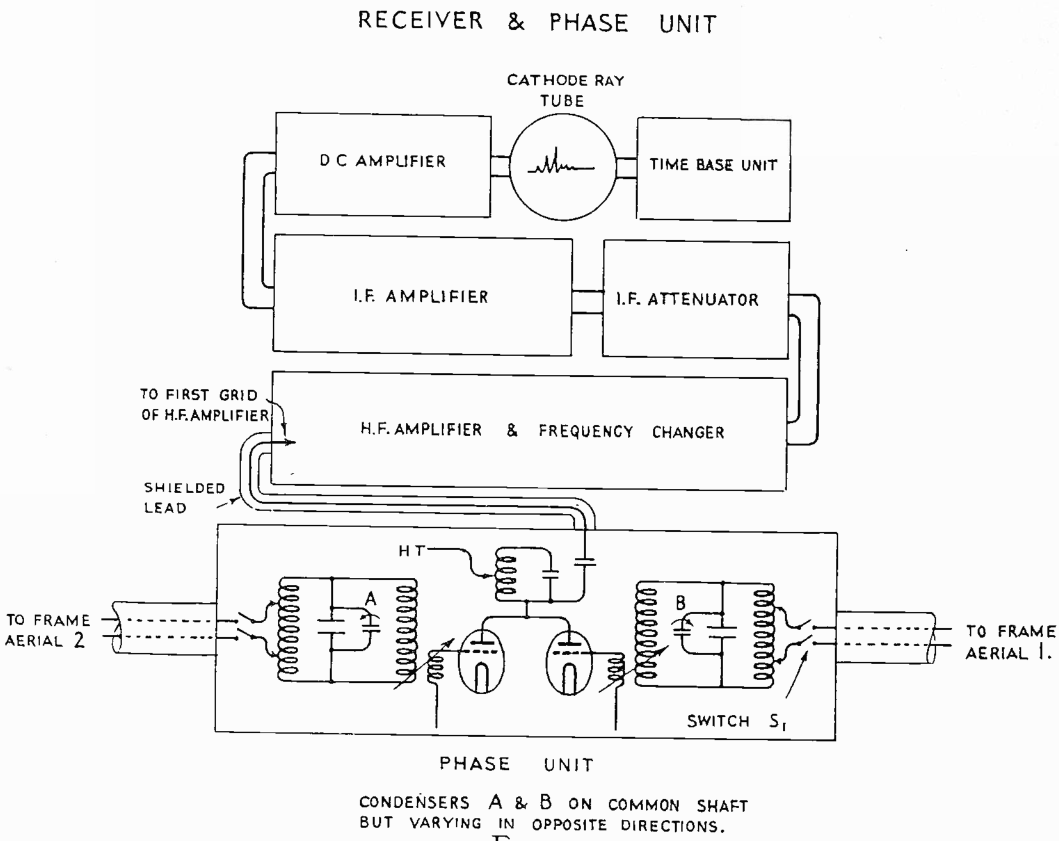


FIG. 1.

Some difficulty was originally experienced in specifying the zero point (equal phase) of the phase changer. The method adopted was to set up a local transmitter on the line A B passing through the central point between the aerials, and perpendicular to the line joining them.

Signals from such a transmitter should then be in phase on the two aerials. The setting of the phase changer for balance in these conditions should give the zero phase difference position. Alternatively the zero position could be found by tuning to maximum output each of the input circuits A and B (Fig. 1) (since the phase changing depends on mistuning).

These two alternative methods did not always agree, although the difference was small on the 40 m. wavelength. The trouble was finally traced to the distortion of the local field by a long wire fence, which was finally removed. Good agreement between the two methods was then obtained.

Spacing Experiments.

In the earlier experiments, in which the flexible D.F. cable was used to connect the aerials with the central hut, observations with different aerial spacings were made.

The experimental procedure was as follows :—

Pulses were received from DOD, λ 41.45 m. on the double frame and phase unit, and the pulse pattern was given as a nearly stationary picture on the cathode ray oscillograph.

The relative amplitude and phase controls were then manipulated to suppress the main pulse. (The balance depended a little on what part of the rather complex pulse was chosen.) This balance position varied slightly from time to time, but after a little while a mean position could be found. The phase unit was then left at this setting, and the ratio of the balanced signal to the signal from one of the aerials alone was observed by opening the switch S_1 in the input of one of the cables. This ratio could be reasonably well determined with the help of the attenuating stage A.

Thus, when the switch was opened, the signal increased by an amount which was measured by the number of decibels introduced in the attenuator to keep the output level.

The results obtained at different spacings are shown in the following table :—

Date.	Spacing M.	Balance dB. Average.	Diff.	Ratio u/v.	Probable scatter spread $0.466\phi_0$
1935.					Degrees.
Feb. 25 ..	15	22	6	1/25.2	0.96
	30	16 (10-20)		1/12.6	0.96
Mar. 4 ..	60	10	6	1/6.32	0.96

In the table, the second column gives the aerial spacing in metres, the third gives the degree of balance, and the sixth the equivalent angular spread deduced from the relation :—

$$\phi_0 = \sqrt{2} \frac{\lambda}{2\pi d} \rho \text{ given in the first paper.}$$

This contains a rather useful confirmation of the theory, in that it implies that when the spacing is doubled the balance is reduced by 6 dB. A study of the third column of the table shows that this is actually the case. Put in another way, the experiments at various spacings lead to the same degree of angular spread.

It should be noted that the figures given for degree of balance in dB. are not very precise, for in the first place, the attenuator only varied in steps of 2 dB., and in the second place, the intensities were so variable that it was impossible to get an exact measure of the balance.

Although these results are in accord with the scatter theory, it does not necessarily rule out the possibility that the variability was due to a residual polarisation error, which would also be likely to increase in amount as the spacing of the aerials is increased.

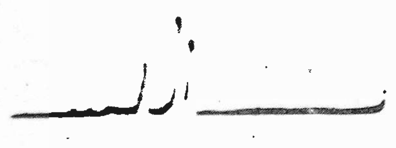
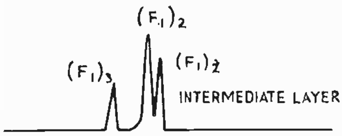
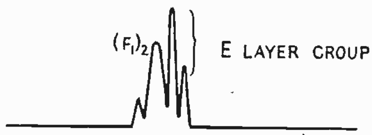


FIG. 2.

FIG. 3.



A. WINTER
FIG. 2A.



B SUMMER
FIG. 3A.

It was stated in the previous article that there are two alternative methods of obtaining the probable error ϕ_0. One is the method just described, and the other is by determining the deviation from the mean of a number of individual settings. A comparison of the two methods is shown in the following table :—

Date.	Spacing.	Balance dBs.	Ratio.	Probable scatter spread $0.466\,\phi_0$.	Probable scatter spread from individual readings.
1935.				Degrees.	Degrees.
Mar. 25 ..	20	20—25	$\frac{1}{20}$ — $\frac{1}{35.2}$	0.49 — 1.02, 0.75	0.75 0.65
Apr. 1 ..	20	10	$\frac{1}{6.32}$	3.16	2.3

It is seen that there is fair agreement between the alternative methods of calculation.

This is not the place to discuss in detail the complex echo patterns observed in the DOD pulse transmissions, except in so far as they affect the argument on D.F. accuracy. It must be observed, however, that if the direction of the station required differs appreciably from the direction of the median line perpendicular to the aerials, it is necessary to know the angle of incidence to determine the bearing exactly.

Thus in the actual case examined, i.e., the signals from DOD, the true azimuth was 12 degrees north of east. The apparent direction, without correcting for the angle of incidence, will vary from 12 degrees for glancing incidence to 8.4 degrees for angles of incidence of the order of 45 degrees such as have been recorded. This is not serious, however, if the arrangement is used as a course indicator, where the azimuthal angle θ is small, for rays of different angles of incidence lie between θ and 0.7θ, and when θ is of the order of 1 degree or 2 degrees the maximum error is of the order of half a degree to 1 degree.

Measured angles of incidence on the experimental transmissions from DOD vary from 75 degrees or so for an E_1 reflection to 34°—30° for F_3 reflections.

The pulse pattern, of which examples are shown in Figs. 2 and 2A and 3 and 3A, indicate very considerable seasonal variations.

In the winter and equinoxial conditions the normal type of transmission in the early afternoon consists of a second and third order F_1 layer reflection, the second order F reflection having an angle of incidence about 45 degrees and the third order F reflection about 36 degrees. Generally there were distant irregular scattered signals beyond $(F_1)_3$, the origin of which was obscure. These were less and less obvious as the season advanced, and in summer were generally below noise level.

$(F_1)_2$* was invariably associated with a weaker pulse which preceded it.

This can probably be attributed to an intermediate layer between E and F_1; the angle of incidence of this lies between 53 degrees and 47 degrees (elevation 37° to 43°).

The first order F_1 ray is never present. It is almost certainly intercepted by the E layer and probably absorbed.

In the summer, a group of E layer reflections is almost invariably present. The first, second and third order reflections can generally be distinguished with angles varying from 77 degrees to about 54 degrees. These are followed by a second and generally third order F_1 reflections. The diffuse second order intermediate layer is obscured and is probably intercepted by the E layer, though there is evidence of it on one or two occasions.

In the winter and equinox period, then, even the first pulses are high angle 40—45 degrees elevation.

The uncertainty of the zero of the phase calibration, due to the presence of the wire fence, makes the absolute azimuth unreliable, and the values, uncorrected for angle of incidence, lie between 8.2° and 12.3°

The following table gives the scatter angles (angles of uncertainty) measured during this period.

---

* Nomenclature of pulses is as follows :—

Pulses reflected from E layer are labelled E_1.

,, ,, ,, Intermediate layer are labelled $F_1 1$.

,, ,, ,, F_1 layer are labelled F_1.

The suffix outside the bracket represents the ray order, i.e., $(F_1)_2$ represents the second order reflection from the F_1 layer.

There is no need to distinguish between ordinary and extraordinary rays as these were in general not resolved.

TABLE II.

	dB. Balance.			$0.466\phi_0$.			
Date.	$(F_1{}^1)_2$ Intermediate.	$(F_1)_2$	$(F_1)_3$	Inter. $(F_1{}^1)_2$	$(F_1)_2$	$(F_1)_3$	Remarks
1935 Apr. 1	2-3	10	10	16.4-13.7	4.7	4.7	Magnetic storm.
,, 15		10, 20 M. 16		—	2.14		
,, 29	12	16, 18		3.6	2.14, 1.67		
May 13	10, 12	18, 20	10	4.14, 3.6	1.67, 1.31	4.14	
,, 15	10	10		4.7			
,, 15	10	20		4.7	1.31		
,, 20	14	25	12	2.75	0.75	3.6	
Average	10dB.	17.3dB.	11.0dB				

The results tabulated here give a measure of the residual error to be expected (on an individual reading). They also throw light on the origin of this residual error.

Two alternatives exist. Firstly, it may be residual polarisation error, and secondly, it may be true scattering error. In the author's opinion the evidence points clearly to the latter.

In the first place the residual errors are rather larger than the 0.5 degree to be expected as a maximum for the residual polarisation error at 45 degrees incidence.

In the second place a large difference in residual angle of the intermediate layer reflection $(F_1{}^1)_2$ and $(F_1)_2$ the second order F_1 layer reflection was almost invariably observed. Thus the character of the balance on $(F_1{}^1)_2$ was, in every case, observed quite definitely to be different from that on $(F_1)_2$. It was more difficult to get a balance on $(F_1{}^1)_2$ and the ray appeared to be more diffuse. This appears in the records of the dB. balance, which on the average is 7.3 dB. worse on $(F_1{}^1)$ than on (F_1) and in the residual error which is as much as 6.7 on the former as compared with 2 on the latter. This difference can hardly be attributed to polarisation error, for the angles of incidence differ only slightly, and if anything $(F_1{}^1)_2$ is generally more nearly plane polarised than $(F_1)_2$.

The difference must be attributable to scattering error. This suggests the presence of a diffuse scattering layer intermediate between E and F_1 and is probably the region where the main scattering (observed in Ongar experiments) originates.

This is in agreement with Pausey's experiments on longer waves.

Absolute Azimuth.

As stated previously in the summer months after about the middle of May, E layer reflections appear. The angle of incidence is so large that practically no correction on the measured azimuth is required.

The wire fence was removed on May 20th and subsequent results were freed from the uncertainty of the phase balance zero.

The azimuth angles as measured on the E group of reflections are tabulated below :—

Date.	Bearing N. of E.
20/5/35	12.0
27/5/35	12.4
3/6/35	12.05*
17/6/35	11.15 12.40*
24/6/35	13.6 12.2
1/7/35	12.20
	12.25 $\pm$ 0.31

* Slight uncertainty in phase zero.

The true bearing of Nauen is 78 degrees 29 minutes W. of N. and the difference from the mean is 0.75 degrees.

The agreement is satisfactory considering that the aerials were set up by magnetic compass and that the deviation at Broomfield is not accurately known.

A few observations have been made on pulse transmission from Montreal λ 32.15 and on vertical pulse transmission on 60 and 80 m. wavelength.

The Montreal results are tabulated below :—

Date.	dB. Balance.	$0.466\phi_0$.
31/3/35	10 15	2.97 1.67
28/4/35	12	2.37
5/5/35	10	2.97
12/5/35	10	2.97
	$<$ 10	$>$ 2.97
		average 2.6 deg.

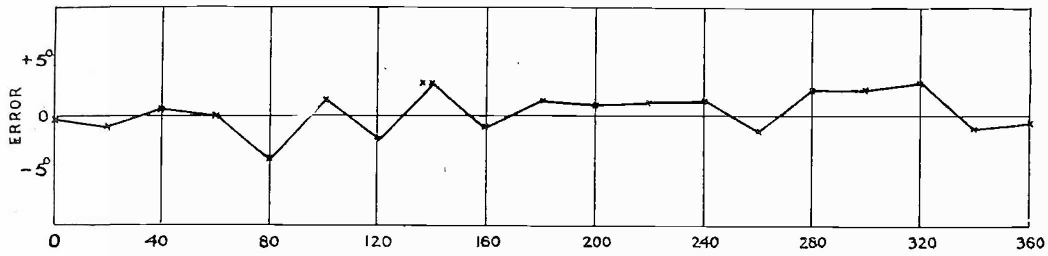
The scatter spread is of the same order as that for the 41 m. wave.

It is thought that the scatter spread increases with the distance of the transmission path, but not enough measurements have been made as yet to confirm this.

The balance on C.W. transmissions differs in a rather marked way from that on pulses. On the latter, some sort of balance can be obtained on the individual pulses at any moment.

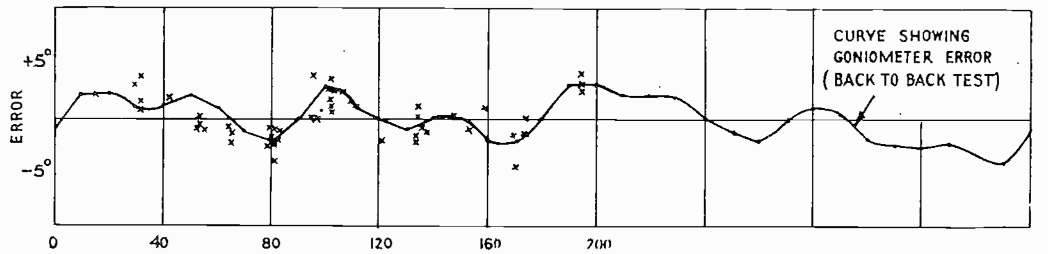
On the former, however, considerable periods occur when the signal is weak, i.e., 15 or 20 dB. below average, when there is absolutely no difference in the intensity in the balanced and unbalanced positions. It is suggested (and has been before suggested) that there is a main ray of more or less definite direction which will show a good balance, together with a scattered residue which is so spread that it shows no signs of balance. When receiving C.W. it is possible for the main rays to balance by phase opposition for appreciable periods during which the phase indicator shows no balance. On the other hand, with pulses this phase cancellation is less probable, and the relatively good balance for main ray and scattered is obtained.

On the other hand the C.W. balance may be worse because such signals are made up of a number of rays with different balance positions.



LOCAL CALIBRATION ON 40 M
.BOUT 200 M RADIUS (MAY 1935)

FIG. 4.



x ERRORS OF DISTANT STATIONS (λ 24–45 M) (MAY 1935)
DISTANCE OF STATIONS > 250 KM.

FIG. 5.

Performance of Adcock D.F.

The experiments just described give a fairly clear idea of the limiting accuracy obtainable on the range of wavelength, say between 30 and 50 m., when the polarisation error has been eliminated, or at least reduced to small dimensions.

It is interesting to compare this with the performance of an Adcock aerial recently set up in what appeared to be a practically ideal site as far as obstructions are concerned. The aerial was erected in a flat site near Writtle, and the nearest obvious obstructions were more than 400 m. away. The aerial differed from the original one set up at Broomfield, the alterations including (1) an increase of height up to 30 feet and (2) decrease of spacing between. The aerial feeders were buried 6 feet in the ground and care was taken to make all four identical in electrical characteristics.

A small hut was provided and the dimensions of the receiver and its auxiliaries were reduced to a minimum. The purpose of this was to avoid the transfer to the aerials of energy picked up by the receiver casing, etc., from the horizontal field of the wave. Some evidence of such an effect had been observed at Broomfield.

Local tests on 40 m. showed that the aerial arrangement was, on the whole, very free from local site errors (Fig. 4).

Fig. 5 shows the errors obtained on a large number of stations on wavelengths between 30 and 50 m. The stations were mostly European, but some long distance ones were included. The distances of the stations were in all cases greater than 280 km.

It will be observed that the errors are small, generally not exceeding 2 degrees.

It would appear that for such distances the performance of the Adcock on these waves approaches the limiting accuracy obtainable, as measured by the spaced frame system. A few measurements have been made on relatively close stations.

A set of measurements made on the s.s. *Normandie* at Havre shows a slightly wandering bearing due to polarisation error.

At a distance of 86 km. on a 53 m. wave, violent polarisation errors were observed.

It would appear that the Adcock aerial fails to eliminate polarisation errors for angles of incidence less than about 30 degrees. There is therefore a region beyond the range of the direct ray up to about 300 km. where the Adcock fails to function properly on account of polarisation error, even when the wavelength is so chosen that the receiver is beyond the skip zone. This gap can probably be bridged by the help of the spaced frame receivers, for in the particular case of the Orfordness transmission, the direct ray was still available for D.F. (on pulse) when the angle of incidence (20 degrees in this case) of the first reflection was great enough to provide D.F. accuracy within $\pm$ 1.5 degrees on the first reflected ray.

Conclusions.

In the conditions so far examined the final accuracy of direction finding appears to be limited by the scattering spread which is of the order of 1 degree—2 degrees. For distances beyond about 300 km. the performance of the Adcock appears to approach this limiting accuracy. At shorter distances the Adcock aerial is subject to polarisation errors which increase as the range is reduced until such ranges are reached that the direct ray swamps the reflected one.

In this region, i.e., $<$ 300 km., it would appear probable that the spaced frame aerial would give accurate bearings at all distances and that when the incident angle of the reflected ray becomes too small the transmitter will be close enough to obtain bearings on the direct ray. The D.F. operations are greatly facilitated by using the transmission of impulses.

It is assumed throughout that a wavelength is chosen for which the receiver lies outside the skip zone. With unsuitable wavelengths where this condition is not fulfilled it is impossible to obtain accurate D.F., for the scattered signal is, in general, not directive.

In any organised D.F. service the operator should know definitely from the character of the signals received whether the transmitter is in the skip zone or not, for in the former case no bearing is obtainable except from a beam transmitter which would not be used in such an organisation.

T. L. Eckersley.

BROADCASTING IN INDIA

NEW MARCONI STATIONS FOR HYDERABAD.

THE Government of His Exalted Highness the Nizam of Hyderabad—one of the largest and most progressive of the Indian States—has decided to organise an up-to-date broadcasting service for the State with transmitters situated in four of the most important centres.

It is intended to inaugurate this service early next year with the opening of two of these broadcasting stations. These are being manufactured by the Marconi Company and will therefore assure a broadcasting service for Hyderabad of the same high quality which distinguishes services carried out with Marconi installations in many countries throughout the world.

One of the first two stations will have a power of 3-5 kilowatts, capable of being increased to 6-10 kilowatts, and this will be installed at Hyderabad. The second, a station of 500 watts, will be installed at Aurangabad. High-precision drives and all the latest refinements of modern broadcasting technique are being incorporated in these transmitters. Complete studio equipment and all the necessary apparatus for outside broadcasting are also being supplied by the Marconi Company for use in connection with these stations.

Village Reception.

The scheme will include a widespread development of broadcasting to the villages in the Hyderabad State upon lines suggested by Colonel Hardinge, a member of the Executive Committee of the Indian Village Welfare Association, during his visit to Hyderabad in November last year.

The importance of this scheme is indicated by the fact that the Hyderabad State covers an area of 82,000 square miles, with a population of over 15 millions of people.

Broadcasting in an experimental form has already been carried out in Hyderabad, a small station owned by Mr. Syed Mahboob Ali—who is now Director of Wireless of the State of Hyderabad—having given transmissions since 1933.

It was obvious, however, that in order to appeal to a larger section of the population of Hyderabad it would be necessary to broadcast in several languages, and this it is intended to do when the new scheme comes into operation.

The principal station, in the capital city, will transmit in Urdu, the official language of the State of Hyderabad, as well as in English. The second station at Aurangabad will broadcast in Marathi, while the third and fourth stations which have been planned for Gulbarga and Warangal, will use the Kanarese and Telugu languages respectively. In this manner the indigenous population will be served in their own vernacular.

The masts for these stations, as well as the broadcasting equipment, are being supplied by the Marconi Company, who will erect at Hyderabad two 300 feet insulated steel lattice masts which will be brilliantly illuminated during the hours of darkness as a safeguard to the aeroplanes using the Indian air route.

The Broadcasting Programmes.

The new broadcasting services will be of the greatest value in improving the cultural outlook of the population and the programmes will be specially devised to cater for urban as well as rural interests. Talks on hygiene, agriculture, and other subjects of educational value will find a special place in these programmes, and the fact that transmissions will take place in four languages will ensure that they reach the largest possible numbers of people

Community Receivers.

About 2,000 villages will be provided with special community receivers installed in schools and public squares, where the population will gather to listen collectively to the broadcast transmissions.

Allowance has been made for the absence of skilled supervision over these receivers in the villages, the instruments having been specially designed to operate for long periods without inspection. The receivers have fixed tuning and are operated from batteries. Freshly charged batteries will be delivered regularly from a central charging station to ensure an uninterrupted service.

On the technical side, the Hyderabad scheme will have behind it the advantage of the accumulated experience of the many years of broadcasting activity of the Marconi Company, so that the general performance of the stations will be of the highest order and in all respects up to the stringent requirements of the regulations laid down from time to time by the International Broadcasting Conventions.