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No. 58. *January-February, 1936.*

Editor: H. M. Dowsett, M.I.E.E., F.Inst.P.
Assistant Editor: L. E. Q. Walker, A.R.C.S.

RECENT DEVELOPMENTS IN MARCONI-ADCOCK DIRECTION FINDING

Since the introduction of the first medium wave commercial design of Marconi-Adcock direction finder in 1930, considerable advances in our knowledge of the problem have resulted. During the past few years development has continued and equipment of improved performance has resulted. It is the object of these notes to describe a few points of interest relating to medium wave Adcock direction finding.

THE principal services to which direction finders of the Marconi-Adcock type are used are:—

(1) Air navigational aids.

(2) Other services where adequate night precision of bearing is essential.

Present-day knowledge does show that the practical precision attainable with the Marconi-Adcock system is (except for a very small percentage of the time) adequate for all types of communications. The simplicity of the aerials, coupled with high sensitivity, makes the direction finder particularly useful in aiding aircraft during night flights.

Factors which still involve a lowering of the night precision are:—

(A) Poor site conductivity.

(B) Location of aerials near airport buildings, or other disturbing elements.

(C) The probable limiting accuracy in the direction of arrival of the wave.

(D) The standard wave error of the aerial system.

All of these factors require further study before an attempt at the precise forecasting of the probable night accuracy of any given installation can be assessed. By careful choice of site a considerable number of Marconi-Adcock stations have been successfully used and the percentage of failures is remarkably low. With continued research and development, aerials free from polarisation errors may result, but for the present the solution appears adequate until higher precisions are demanded.

Daytime Overland Field Intensity of an Aircraft.

One of the most difficult design problems associated with Adcock aerials is that of providing adequate sensitivity in order to ensure reliable reception of an aircraft at the required air-to-ground ranges. Fig. 1 illustrates the field intensity to be expected from a civil aircraft at various distances. Such an aircraft will have the following specification :—

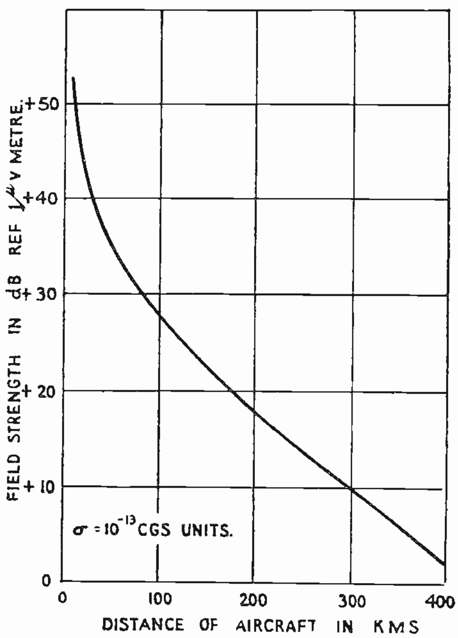

FIG. 1.

(1) Air speed 100-140 miles per hour.
(2) 200 ft. trailing aerial.
(3) Effective height aerial 6-7 metres.
(4) Transmitter power 100-160 watts.
(5) Flying overland for the purposes of Fig. 1, $\delta = 10^{-13}$C.G.S. units.

With the ever increasing speed of operation of modern aircraft one must expect a reduction in the effective height of the trailing aerial so that not only will the radiated power become lower and the ordinates of Fig. 1 need reducing, but the tendency will be to radiate horizontally polarised waves which will result in increased aeroplane effect and at night may tend to increase night effect. An inspection of the curve in Fig. 1 will clearly show that at ranges of 300 to 400 kilometres very low signal levels are the rule and Johnson or Schott noise may place a limit in range at which precise direction finding is possible. Poorly designed receivers will not allow adequate signal discrimination and radio noise may impair the quality of the service. Later in these notes we shall return to a discussion of the need for providing the highest sensitivity practicable, particularly at night time.

Sensitivity of Marconi-Adcock Direction Finders.

The 1930* design of Adcock direction finder sensitivity curve is shown in Fig. 2, curve A, while the 1935 model is indicated by curve B. Both curves relate to continuous wave telegraphy and it will be seen that the " effective pickup," as measured by sensitivity to obtain swing bearings of $\pm$ 5 degrees, has advanced by an average of 22 decibels. This improvement has been found necessary as a result of practical experience with the earlier equipments; these gains have been obtained in the following manner :—

(1) Improvements in aerial and feeder design.
(2) Improvements in radiogoniometer and input circuit design.
(3) The use of quiet valves in input circuits and improved selectivity.

Curve B of Fig. 2 allows a margin between receiver noise level and the signal at the maximum of the figure of eight of at least 20 decibels, while curve A provided a ratio of 14 decibels. In actual service radio noise will usually limit the effective ranges at which precise direction finding is possible.

* See MARCONI REVIEW, June, 1930.

Selectivity.

Recent specimen selectivity curves are illustrated in Fig. 3. The signal frequency selectivity (without the use of reaction) is shown as curve A, while the introduction of a low frequency filter improves the performance by an extent indicated by curve B.

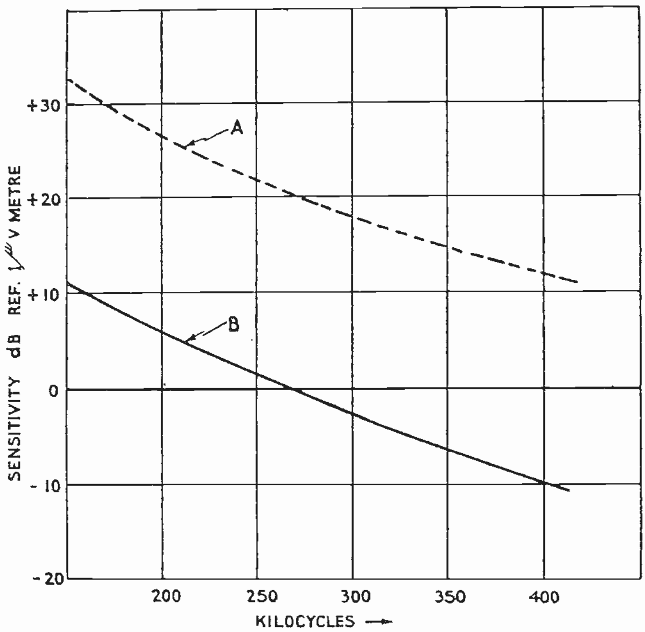

FIG. 2.

Both of these curves were taken by injecting signals of known intensity and frequency into an artificial non-receptive Adcock aerial.

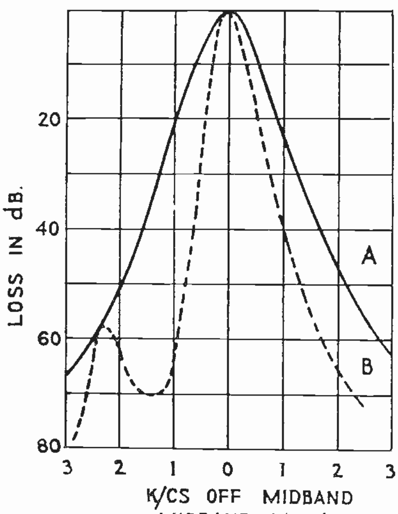

FIG. 3.

In cases where aircraft telephony is required curve A is employed and in this connection it is interesting to observe that many operators tune the carrier to a point approximately 8 decibels off mid-band frequency and a crude form of single side band and carrier reception results.

The Need for very Sensitive Receivers associated with Adcock Aerials.

From the preceding notes it has become apparent that very selective and quiet receivers are desirable for this type of direction finding. An ideal Adcock aerial should not be capable of receiving horizontally polarised waves and consequently at night time very exaggerated fading would be experienced. In fact a percentage of time would be recorded when no reception on an ideal aerial would be possible.

A loop aerial will efficiently receive horizontally polarised down-coming waves and although the observed bearing may be quite incorrect [in extreme cases indicate an error of $\pm$ 90°], it is possible with relatively simple receivers to maintain communication under conditions of intense "night effect." In other words, the loop aerial, from a polarisation point of view, can be regarded as a two-dimensional receiving system.

As a result of these facts it becomes apparent that the problem of obtaining the dual services of night time direction finding and communication in a single Adcock direction finder does place a greater need for a very high grade of equipment than is necessary with a loop.

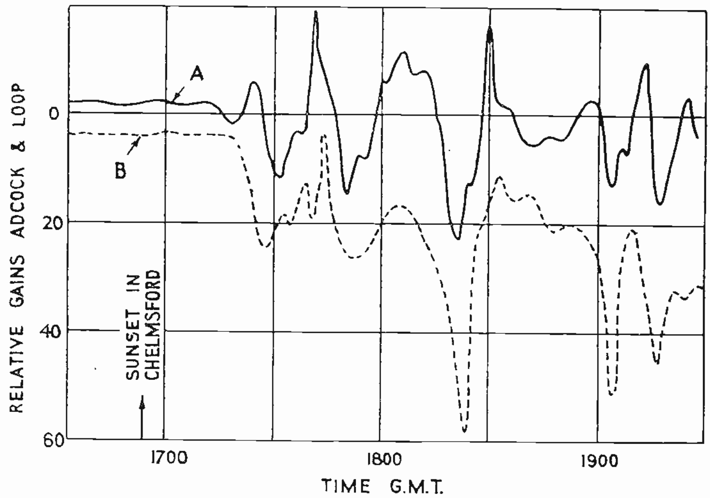

FIG. 4.

The curves illustrated in Fig. 4 show the relative gains between a Bellini Tosi aerial and a Marconi-Adcock aerial. During the daytime it will be seen that the loop has a steady gain of six decibels over the Adcock aerial. During night conditions slow fading on both the loop and Adcock aerials will be observed, but it should be noted that greater variations are recorded on the latter aerial. In Fig. 4 the loop measurements are shown by curve A, while simultaneous measurements taken on the Adcock aerial (on same site) are represented by curve B. One interesting point does emerge from these curves, namely that instead of the Adcock aerial being six decibels down as recorded during the daytime, periods of several minutes are experienced when the loop gain exceeds 34 decibels and short period values of 50 decibels have been recorded.

The curves given in Fig. 4 were taken at Writtle near Chelmsford and illustrate typical night observations. They clearly show why it is essential to provide high sensitivity in order that night direction finding and communication ranges may not be degraded due to the fact that under conditions of intense night effect the Adcock aerial is endeavouring to eliminate the reception of horizontally polarised waves.

The Marconi-Adcock Type DFG.10 Aerial System.

Fig. 5 illustrates the type of aerial system employed in recent 800-2,000 metre installations. Wherever possible an extension to the "shielded U" feeder system is employed ; this scheme assists in reducing charges at the ends of the feeders, and also shields necessary power, telephone and control cables and on poorly conducting sites assisting in raising the accuracy.*

Mast obstruction lighting is obtained by feeding the power to the top of the mast aerials by suitable cables and radio frequency chokes. The normal 50 cycle supply is used for energising the lamps ; in practice no loss in sensitivity due to mains noise has been recorded.

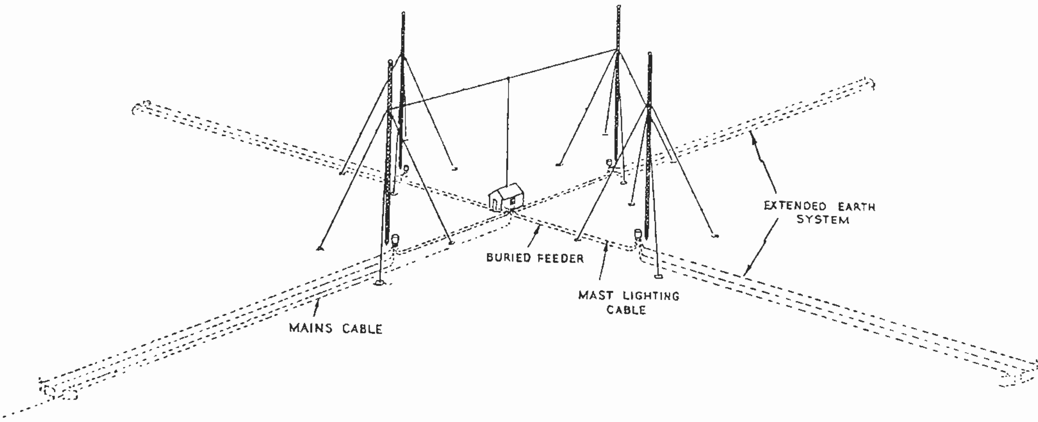

FIG. 5.

Night-time Accuracy.

In the MARCONI REVIEW of September, 1934, some statistical figures were given indicating the probable accuracy under typical night conditions. The comparative figures are as follows :—

Marconi-Adcock Standard Deviation ..	2.37 degrees
Loop Standard Deviation	12.35 degrees

Mr. R. H. Barfield† has made a considerable contribution to the scientific study of polarisation errors in various types of Adcock and loop aerials, but the writers have found that the statistical analysis does more truly indicate the night-time precision than the figures of standard wave error published in Mr. Barfield's paper.

Mr. R. A. Watson Watt has recently published a paper recording the results of further work on polarisation errors.‡

Comparative Statistical Accuracy of Short and Medium Wave Shielded "U" Aerials.

It is of interest to compare the probable night performance of Marconi-Adcock aerials when direction finding in the medium and short wave bands. Measurement has shown that the degree of balancing or shielding of the horizontal members of the aerial is inadequate when working on short waves at short distances. In general,

* See MARCONI REVIEW, July-August, 1931.

† R. H. Barfield, Proc. Wireless Sec., "I.E.E. Journal," Vol. 5, 1930.
R. H. Barfield, Proc. Wireless Sec., "I.E.E. Journal," Vol. 10, 1935.

‡ R. A. Watson Watt, "Wireless Engineer," Vol. 13, January, 1936, No. 148.

the ground ray of a transmitting station is not received by the direction finding aerial and consequently "night effect" is always present. It can therefore be said that (except in special cases) polarisation errors experienced at distances less than 250

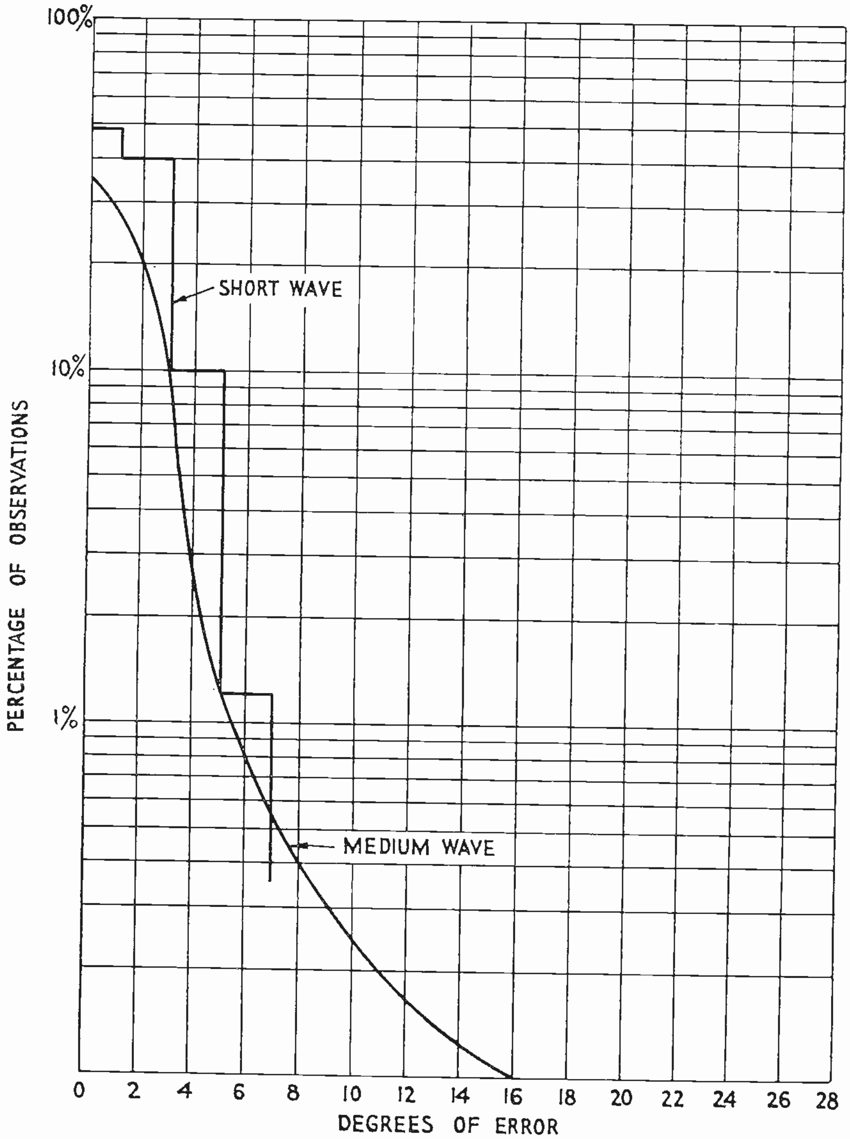

FIG. 6.

kilometres are excessive and the normal types of short wave Adcock aerial will not possess adequate precision to allow direction finding. For such distances aerials such as those described by T. L. Eckersley* are capable of carrying out this class of

* MARCONI REVIEW, Nos. 53 and 55, 1935.

service, but it is possible that the spaced loop method will suffer from inadequate pick-up when receiving weak signals at ranges where the short wave shielded "U" aerial will be efficient both from a reception and direction finding point of view.

In normal direction finding the medium wave Adcock aerial will always receive a ground ray and the presence of this ray does assist the aerial in attaining adequate night accuracy at distances where the short wave Adcock aerial is inaccurate. In making a comparison between the two direction finding wave bands, the medium wave curve given in Fig. 6 represents a typical aircraft communication requirement and applies to ranges of a few kilometres up to 800 kilometres. The short wave "U" Adcock curve indicates the probable accuracy attainable on waves between 25-45 metres (suitable for aircraft services) and at distances in excess of 300 kilometres. It will be seen that the two types of direction finder when operated at their appropriate ranges will provide a complete direction finding service.

The close agreement between the statistical analysis of many thousands of bearings clearly indicates the usefulness of the service attainable when the short and medium wave bands are used as complementary aids to navigation.

Limiting Accuracy due to Site Location.

Ideally, an Adcock direction finding station should be situated upon good conducting soil with conductivities ranging from that of sea water (10^{-11} C.G.S. units) to that of moist earth having a conductivity of 10^{-13} C.G.S. units. No deformation of the wave front should occur and apart from the aerials being upon the surface of the earth, the aerial should behave in a similar manner to a classical balanced Adcock aerial situated in free space.

In practice such ideals cannot be attained and as a result the most complex sites have to be considered. In some cases serious wave deformations exist due to the geographical location of the proposed direction finding station. Clearly such sites are not suitable for such services and it occasionally happens that testing may be necessary before these defects can be fully appreciated. In broken and mountainous country the daytime precision of a medium wave direction finder (of any type) may be quite inadequate for navigational purposes. The only solution to such cases seems to consist in erecting the aerials upon the highest ground available and discount bearings taken in directions known to be inaccurate. This procedure is analogous to the marine direction finding practice of classifying arcs of good bearing.

Assuming the country and site location to be of normal uniformity, both with regard to conductivity and contour, it is necessary that the ground in the immediate vicinity of the aerials be carefully chosen. It is clearly obvious that an Adcock aerial may receive horizontally polarised reflected rays upon reflection from the ground, particularly if the aerial elements are in effect supported at some angle other than the true vertical plane. The nature of the conductivity of the strata immediately underneath the top soil on the site may contribute to excessive night deviations. This aspect to the choice of sites is a difficult one to overcome and as a result each station becomes an experiment until extensive experience has been obtained in surveying sites.

So far no mention has been made of man-made obstructions and their effects upon accuracy. It sometimes happens that large metal masses such as hangars, masts, railways, overhead power lines, etc., are situated within several hundred yards of a loop aerial. Reasonably accurate daytime calibration curves are often obtained when working in a disturbed area and adequate precision is possible; in some of these cases an Adcock aerial would also be capable of a similar daytime precision. After nightfall re-radiation from the disturbing source due to the reception of reflected waves from the Ionisphere will occur; the secondary fields due to this reception of down-coming waves having varying polarisations can be efficiently received by the Adcock aerial. The chances of obtaining a reliable night calibration curve seem very remote and consequently such sites need individual study and treatment. The complexity of the problem of the effects of disturbing metal masses has not so far yielded to mathematical treatment, such as Mesny's ship studies; the variety of assumptions would in any case make such calculations of doubtful value when surveying a difficult site. Further study is necessary before precise rules will be available.

During the past two years site testing with a transportable Adcock equipment has resulted in establishing the potentialities of sites under consideration. These tests to be conclusive are very elaborate and a final conclusion cannot usually be obtained until the actual equipment with well established earth systems, control lines, hangars, etc., has been constructed.

So far no figures have been mentioned indicating the magnitude of errors due to the various site limitations. The following table, although open to criticism, may be helpful to the reader and has been compiled from actual experience.

TABLE II.

Disturbing Source.	D.F. System.	Magnitude of Errors.
DAYTIME 900 METRES—		
Hangars within 300 yards	Bellini Tosi	± 6 degrees
Hangars within 700 yards	Adcock	± 5 degrees
Geographically broken country . .	Loop and Adcock	± 25 degrees
Metal fences and telephone lines . .	Bellini Tosi	± 10 degrees
NIGHT TIME 900 METRES—		
Hangars	Marconi-Adcock	± 10 degrees
Large flat-topped transmitting aerial	Marconi-Adcock	± 7 degrees

In the case of daytime errors it is frequently possible to apply corrections, but in certain cases the magnitude of the deviation is variable and in general a degraded precision results. In Scotland, Cornwall, Switzerland and other parts of the world, serious daytime errors have been recorded; the magnitude of these geographical errors has ruled out the possibilities of using many otherwise desirable sites.

In broken country such as those mentioned above, it is necessary that the stations be erected upon mountain plateau and that bearings be taken upon machines flying at a great height, otherwise the limiting accuracy of the sites and intervening country is too low for carrying out the desired navigational services.

Quadrature Zero Clearing in Adcock Direction Finders.

For some years it has been found desirable artificially to clear the minima of a direction finder in order to allow crisp and well defined bearings. In this connection a very complete analysis of marine requirements has been published by C. E. Horton.*

* C. E. Horton, Proc. Wireless Sec., "I.E.E. Journal," Vol. 6, 1931.
Horton and Cramphorn, Proc. Wireless Sec., "I.E.C.," Vol. 8, 1933.

The problem of producing one sharp minimum in an Adcock direction finder is different from the marine case and in general consists in inducing quadrature E.M.F.s into the aerials in order to compensate for inequalities in effective heights of the four vertical aerials. The marine direction finder problem is more difficult due to the fact that the blurring of the minima is due to the metal masses of the ship, while in the Adcock aerial no such complex sources of secondary fields are permissible. In Fig. 7 an attempt has been made to illustrate the conditions met with in practical Adcock installations. If one carefully measures the effective heights of four physically similar mast aerials each located in the positions shown in Fig. 5, it will be found that discrepancies result and consequently the quality of the minima

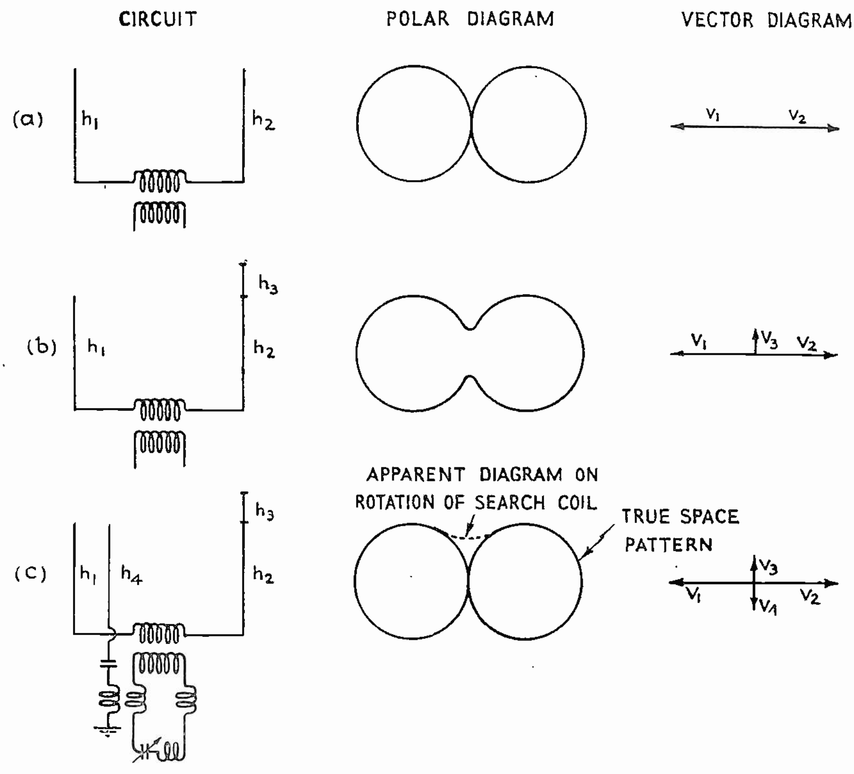

FIG. 7.

will be degraded and blurring will result. From the diagrams of Fig. 7 it will be seen that the radiation characteristics of each pair of spaced aerials can be resolved into a pair of tangent circles and, unless the effective heights are precisely equal, into another non-directive polar diagram.

In Fig. 7 (A) h_1 and h_2 represent the ideal case of two aerials of equal effective height and the polar and vector diagrams associated with this condition.

The vectors V_1 and V_2 represent the opposing E.M.F.s in the field coil when the signal is arriving at right angles to the plane of the aerials.

In Fig. 7 (B) the difference in effective height between a pair of aerials is represented by H_3. The vector V_3 shows the quadrature E.M.F. due to this inequality, and the polar diagram shows the blurred minima resulting.

As shown in Fig. 7 (C) it is possible by designing a circuit in a suitable manner to induce a counter quadrature E.M.F. and so sharpen the minima.

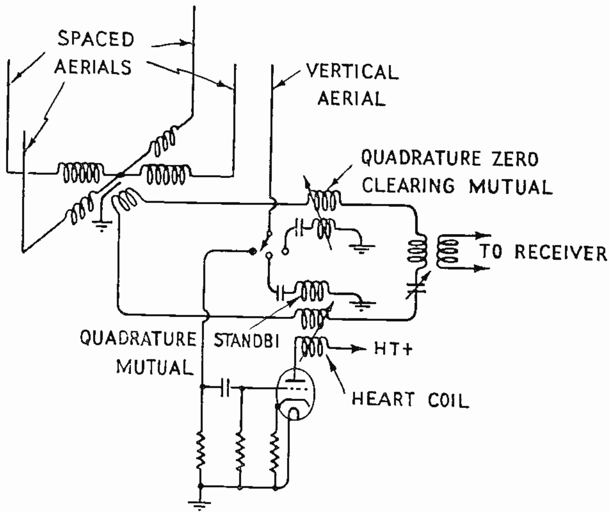

FIG. 8.

On rotating the search coil through 180° after the minimum on one side has been sharpened, there is an apparent increased blurring of the opposite minimum. This is due to the fact that the phase of one of the opposing quadrature E.M.F.s has passed through 180° and is now acting in the opposite sense.

Experiments have shown that by making the north and east aerials 70 ft. and the south and west aerials 60 ft. high, it has been found possible to clear the minima without in any way rotating the bearing of the desired signal. In the particular case mentioned the effective height of the tangent circle part of the aerial polar curve was about 5 metres and that due to the quadrature unbalance was 1.6 metres. A study of the vector and polar diagrams given in Fig. 7 makes it clear that no rotation of the bearing would be anticipated; this type of Adcock zero correction is therefore independent of the calibration of the station, which is not the case in most marine direction finders.

The quadrature compensating circuit is shown schematically in Fig. 8.

Quadrature Zero Clearing at Night Time.

For some years it has been observed that the strength* of the quadrature induced signal needed for zero clearing is a crude measure of the probability that the wave is circularly polarised, and in loop direction finding this indication is very useful in discounting bearings at night time. The same conditions apply equally well to the Adcock aerial, for a low percentage of the time when Adcock bearings should be averaged over several minutes the quadrature compensating mutual will act as a warning that all bearings should be treated as second class. So far a statistical analysis has not been made to determine how useful this device is in indicating very abnormal polarisation of the signal, but the percentage of cases in which the aid is useful is considered to be high.

Fineness of Minima.

The crispness of the quadrature compensated minima can be expressed in several ways, but the authors have not found it useful from an instrumental standpoint to

* See Keen, "Wireless Direction Finding and Directional Reception," Edition 2, page 103.

use a commonly accepted definition. This states that with a field of X microvolts per metre the total arc of silence should not exceed 2 degrees. A better alternative involving the rate of change in amplitude at small angles from the minima is as follows: for an angular displacement amounting to $\pm$ 1° off the true bearing, a continuous wave signal increment of at least 30 decibels is obtained. This measurement is subject to signal levels associated with normal direction finding and assumes linear input output conditions to exist in the amplifier.

This definition applies to the latest type of Marconi-Adcock DFG.10 installation. At night time this quality of compensation cannot be maintained for long periods without readjustment of the variable quadrature compensating mutual shown in Fig. 8.

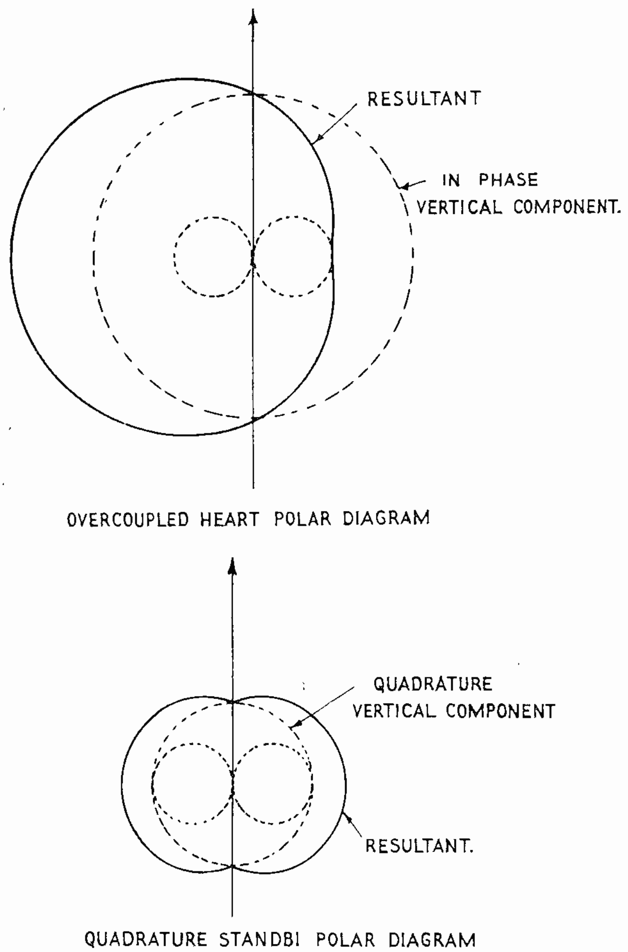

FIG. 9.

Quadrature Standbi Position.

In early models of Marconi-Adcock direction finders it has been usual to combine the vertical aerial and the spaced aerial E.M.F.s by means of a coupling valve. This scheme provides a cardioid polar curve and allows "sense" finding. This method is still retained, but even after using a linearity compensating circuit associated with this valve, intermodulation by strong local stations will occasionally make it impossible to observe the "sense" of direction adequately. Certain cases have been provided with tuned cardioid circuits in order that this occasional disability be eliminated. In general a valve-coupled cardioid or circle polar diagram will not possess a very low background noise level compared with diagrams produced by the aid of physical circuits. Recent work has resulted in the adoption of the quadrature combination of the vertical and Adcock electro-motive forces. The polar curves of the earlier mode of operation and the quadrature method are shown in Fig. 9, while the circuit of the latest method is shown in Fig. 8. From a consideration of the circuits it will be observed that by careless adjustment of the valve arrangement blind spots in the standbi position can be obtained, whereas the quadrature method can never result in this defect being produced. In certain American wireless beacons somewhat similar methods have been employed.

Remote Control of Adcock Aerials.

Flying limitations to the location of efficient Adcock aerials and the presence of wave distorting obstructions in the immediate vicinity of the aerials has resulted in a demand for a system of working in which the direction finder may be removed from the aerials by a considerable distance. Many cases may be solved by the use of suitable high frequency feeders covering a distance of 600 metres. This case involves designing suitable coupling transformers, balancing arrangements and feeder terminations.

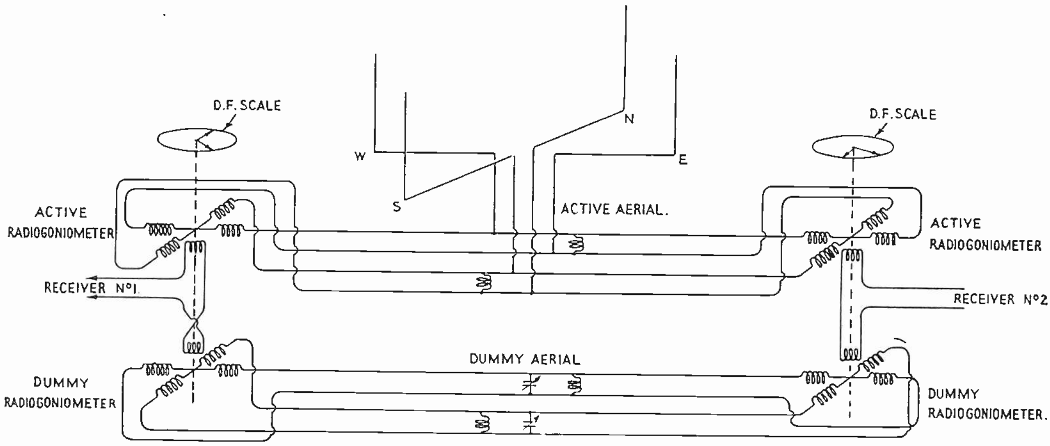

FIG. 10.

Recent work on the subject has shown that such distances can be spanned by high frequency feeders without a considerable loss in accuracy due to reflections in the cable, although the instrumental accuracy of the special types of radiogoniometer may be lower than is usual in such installations when the operator is located at the centre of the aerial system. These instrumental errors can be allowed for in the final calibration of the direction finder. By using remote aerials, a certain lowering of the sensitivity of the equipment must be expected, but measurement has shown that this loss, compared with the DFG.10 sensitivity curves of Fig. 2, curve B, does not make the equipment unattractive for carrying out the service when otherwise hopeless sites are encountered.

One difficult design problem associated with high frequency feeder cables is that of coupling the tight coupled radiogoniometer to the feeder without producing heavy reflections. It should be noted that quarter and half wave reflections are realities when using long feeders with mis-matched terminations. Using radiogoniometers having a coupling factor of 75 per cent. and a peak quadrantal error of 2 degrees, the leakage inductance is capable of producing heavy reflection errors due to cable and aerial inequalities.

Small phase changes in the feeders due to wrong terminations or inequalities in the cables themselves cause indistinct minima, which occur in the greatest magnitude at 45° to the lines of axis of the field coils.

Angular differences in the line length of the feeders of more than 3 or 4 degrees cannot be tolerated if the definition and accuracy of bearings is to be maintained over the required waveband.

Another more difficult case is that of locating the aerials several miles from the operating centre ; here the cable and termination losses are so serious that tele-control methods seem to be the only likely solutions of the problem. In such cases the direction finder and aerials are installed on a suitable site and the tele-control mechanisms replace the operator. The method has the virtue of high sensitivity, will allow twin-channel working and may solve the problem of installing direction finders on otherwise hopeless sites.

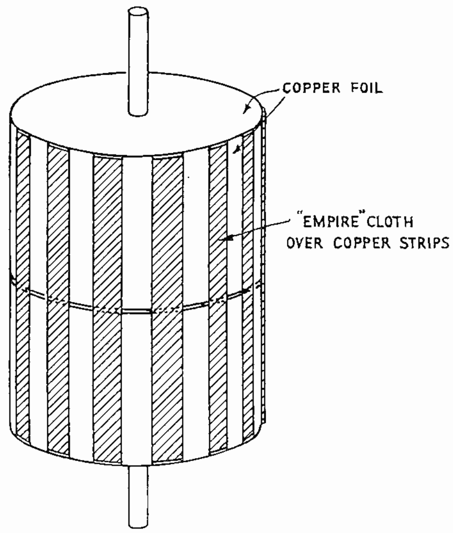

FIG. 11.

Work on the subject of producing commercially workable systems of both types is still proceeding and a successful solution to both problems is in sight. An experimental Adcock station using 450 yards of cable feeder has been in service for some months.

Twin-Channel Adcock Direction Finders.

In congested areas it sometimes happens that two services are required and only one aerial can be conveniently employed, also operation at a single centre is essential. A commercial twin-channel Marconi-Adcock system has been produced in the laboratory and final performance checks have demonstrated that the accuracy and sensitivity of each channel are almost identical with that obtained when using a single Adcock direction finder. One interesting test of the capabilities of this system is as follows : Two signals (C.W.) arriving in directions at right angles to each other :

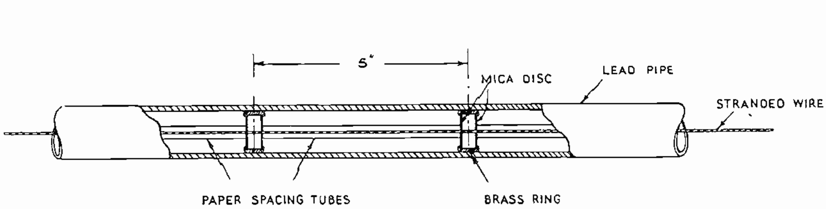

FIG. 12.

with a frequency separation of 15 kilocycles, one signal has a field strength of 2 millivolts per metre and the other 2 microvolts per metre. Under these stringent conditions first-class bearings on both channels without instrumental difficulties are possible. A reference to the field intensity curve shown in Fig. 1 will indicate the relative distances of the two aircraft. The circuit schematic of the arrangement used is shown in Fig. 10.

Interaction errors between the two channels in the various direction finding and searching positions are as follows :—

Direction finding	± 0.25	degrees
Standbi	± 1.0	,,
Cardioid	± 1.25	,,

In all cases the two channels were working under the most stringent conditions, namely, receiving the same station, one channel always observing the bearing and the other arranged for the three usual service requirements.

Shielded Radiogoniometers.

In order to eliminate as far as possible unbalances in the feeder system, recent radiogoniometers have been constructed with laminated electrostatic earth shields between the search coil and the field windings; also in order to reduce the probability of "night effect" during heavy fading, certain classes of Adcock direction finder use double shielding of the component coils preceding the first amplifier stage. The radiogoniometer search coil shielding design is shown schematically in Fig. 11.

It may not always be fully appreciated that during heavy fading it is necessary to ensure low direct pickup upon coils inside the receiver. In the latest Marconi-Adcock equipment the ratio of field strength necessary to produce equal outputs with the aerial connected to the receiver and disconnected at the mast bases is about 90 decibels and as a result the chances of night effect being recorded due to direct reception on coils is eliminated. Bearing in mind the loop to Adcock gains observed during heavy fading, it is of some importance to guard against this instrumental defect. The use of aerials possessing a high pickup factor assists in eliminating night effect due to coil reception in poorly shielded receivers.

Adcock Feeder Cables.

The concentric feeder cable designed in conjunction with Messrs. Henley has been found very efficient for this class of direction finding; the construction is shown in Fig. 12. The cable consists of a 1 in. diameter lead pipe with stranded inner conductor supported on mica disc insulators. These insulators are spaced by thin paper tubes every 5 in. and are clamped during the lead extrusion process at regular intervals. It has been found necessary to desiccate the cable in manufacture to prevent condensation and in practice the precise lengths of cable are supplied by the manufacturers ready for installation.

S. B. Smith.
G. F. Hatch.

ERRORS IN HEISING METHOD OF MEASURING DEPTH OF MODULATION

In this method the increase in output power is measured when modulation is applied, and from this the depth of modulation is calculated. The result is only accurate when there is no harmonic distortion, and it will be shown that a comparatively small amount of distortion can give rise to large errors in the measured depth of modulation. Four per cent. harmonic distortion may give rise to errors of as much as 10 *per cent. in the depth of modulation calculated on the Heising formula.*

Heising Formula.

In Fig. 1 let

I_o = value of carrier current in load R.
k = depth of modulation expressed as a fraction.
($k \times 100$ = percentage).
kI_o = amplitude of sinusoidal variation of carrier current at audio frequency
I_m = reading of load ammeter when modulation is on.

Then total power when carrier is modulated is $RI_o^2 + R(\frac{1}{2}kI_o)^2 = RI_o^2(1 + \frac{1}{2}k^2) = RI_m^2$

$$\therefore\ 1 + \tfrac{1}{2}k^2 = \frac{I_m^2}{I_o^2}$$

$$\text{or } k = 2\sqrt{\frac{I_m^2}{I_o^2} - 1}$$

I_m and I_o can be measured and hence k can be deduced.

Fig. 2 shows at

(A) Carrier wave with sinusoidal modulation of depth k. For this the Heising formula would give correct results.

(B) Carrier wave in which the modulation in the upward direction is reduced to $m.k.$, while it remains 'k' in the downward direction.

The total power represented in this is obviously less than would be obtained for a sinusoidal modulation of depth 'mk' since the swing in the downward direction is greater than this. Hence the Heising formula which depends on power measurement would give the depth of modulation as less than mk, whereas the true depth would be $\frac{1}{2}(m + 1)k$.

If $k = 1$ and $m = .8$ it can be shown by the method given in the appendix that the Heising formula would give the depth of modulation as .75 instead of .9.

(C) Carrier wave in which the modulation in the downward direction is reduced to 'mk' whilst remaining 'k' in the upward direction. The Heising formulae in this case will indicate a depth of modulation greater than k.

For $k = 1$, $m = .8$ calculation gives Heising figure as 1.03 instead of .9.

Cases (B) and (C) have been chosen as closely representing possible types of distortion, each representing equal modulation energy and equal harmonic distortion but for which in the example chosen the Heising formula would show a variation of 27 per cent. It will be shown in the appendix that the distortion in either case is under 5 per cent.

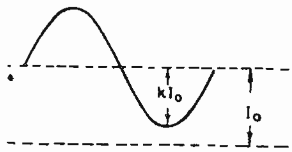

FIG. 1

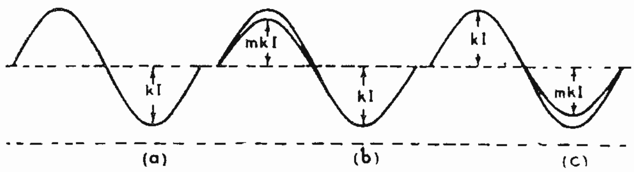

FIG. 2.

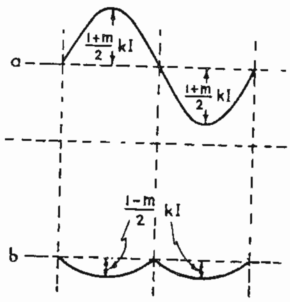

FIG. 3

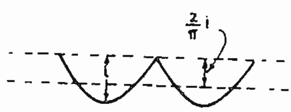

FIG. 4

When measuring modulation it is therefore essential to choose some method that takes account of both positive and negative swings. There are several such methods available.

(1) Measurement on the wave shape produced in an oscillograph.

(2) The percentage of modulation possessed by a wave can be determined by rectifying with a linear detector, which gives a current that varies with the carrier. The direct current component of the rectified wave being directly proportional to the carrier.

If this rectifier is now followed by a second one as illustrated in Fig. 5, the direct current read by the second meter will be a measure of the modulation as given by the following expression, where :—

I_c = direct current component of 1st rectifier.
I_m = „ „ „ „ 2nd „
K = A factor obtained by calibrating on A.C.

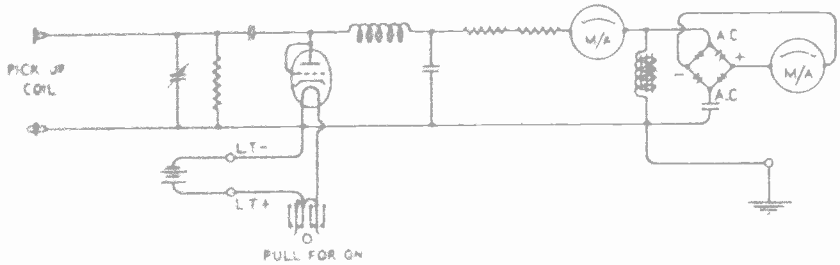

FIG. 5.

Then percentage modulation $= \dfrac{I_m \times K}{I_c} \times 100$

If the reading of the rectified unmodulated carrier current in the first rectifier is adjusted to be K times the full scale deflection of the instrument in the second rectifier then the latter instrument will read percentage modulation direct.

This is usually done and the instrument in question is calibrated direct in percentage modulation.

APPENDIX.

Heising Measurement with Distorted Wave Form.

In Fig. 2

Let I = Normal load current when unmodulated.
k = Depth of modulation.
m = Fraction by which upward swing is reduced.

Power in positive half cycle $= \int_0^{\pi} RI^2 (1 + mk \sin \theta)^2 \, d\theta$

$$= RI^2 \left\{ 1 + \int_0^{\pi} (m^2k^2 \sin^2\theta + 2\,mk \sin \theta)\, d\theta \right\}$$

$$= RI^2 \left\{ 1 + \tfrac{1}{2} m^2k^2 + \frac{4}{\pi} mk \right\}$$

Power in negative half cycle $= RI^2 \left\{ 1 + \tfrac{1}{2} k^2 - \dfrac{4}{\pi} k \right\}$

Average over cycle $= RI^2 \left\{ 1 + \tfrac{1}{4} (1 + m^2)\, k^2 - \dfrac{2}{\pi} (1 - m)\, k \right\}$

$$= RI^2 \left\{ 1 + \tfrac{1}{2} k^2 \right\} \quad \text{if } m = 1$$

$$= RI^2 \times 1.32 \qquad \text{if } k = .8$$

If $k = 1, \quad m = .8$

$$\text{Power} = \text{RI}^2 \left\{ 1 + .41\, k^2 - \frac{2 \times .2}{\pi} k \right\}$$
$$= \text{RI}^2 \; (1 + .41 - .127)$$
$$= \text{RI}^2 \; (1 + .283)$$

If k^1 = modulation figure given by Heising

$$\tfrac{1}{2}\, k^{1^2} = .283$$
$$k^1 = \sqrt{.566} = .75$$

representing 75 per cent. modulation.

The real value of modulation will be the mean of the upward and downward swings $\simeq$ 90 per cent.

In a similar way we can work out the effect of a reduced downward swing. In this case

$$\text{Average power} = \text{RI}^2 \left\{ 1 + \tfrac{1}{4}\,(1 + m^2)\; k^2\; \frac{2}{\pi}\; (1 - m)\; k \right\}$$

If $k = 1$, $m = .8$ as before.

$$\text{Average power} = \text{RI}^2 \left\{ 1 + .41 \quad .127 \right\}$$
$$= \text{RI}^2 \; (1 + .537)$$

If k'' = modulation figure given by Heising

$$\tfrac{1}{2}k''^2 = .537$$
$$k'' = \sqrt{1.074} = 1.035$$

whereas as before the real value of modulation is approximately 90 per cent.

We shall next investigate what percentage harmonic distortion such a wave form represents. By inspection of Fig. 2 (B) we see that it analyses into the two components shown in Fig. 3; (A) represents the fundamental component of amplitude $\frac{1 + m}{2}\, k\text{I}$, while (B) consists of a sine wave with one half reversed and of amplitude $\frac{1 - m}{2}\, k\text{I}$. This clearly contains no fundamental component, but only a DC component, 2nd and higher harmonics.

The DC component is equivalent to a change of carrier level, while the residue after this is removed is the true harmonic content.

Fig. 4 shows such a wave form enlarged; the peak amplitude is 'i' while the DC component is $\frac{2}{\pi}\, i$.

Total power in this wave form $= \tfrac{1}{2}\, \text{R}i^2 = .5\, \text{R}i^2$

$$\text{DC power} = \text{R} \left(\frac{2}{\pi}\right)^2 i^2 = .404\, \text{R}i^2$$

If we subtract the DC power from the total power we shall get the harmonic power.

$$\text{Harmonic power} = Ri^2 \left\{ \frac{1}{2} - \left(\frac{2}{\pi}\right)^2 \right\} = Ri^2 \times .096$$

$$\therefore \text{ RMS value of harmonics} = \sqrt{.096}\, i = \underline{.31\, i}$$

$$\text{The equivalent peak value} = .31 \times \sqrt{2}\, i = .439\, i$$

$$\text{In Fig. 3 (B) } i = \frac{1 - m}{2} kI$$

$$\therefore \text{ equivalent peak value of harmonics} = .439 \frac{1 - m}{2} kI$$

$$\text{The peak value of fundamental} = \frac{1 + m}{2} kI$$

$$\therefore \frac{\text{peak value of harmonics}}{\text{peak value of fundamental}} = .439 \frac{1 - m}{1 + m}$$

From this we can calculate the following table.

m	percentage harmonic distortion
.9	2.3
.85	3.55
.8	4.9

This shows that the Heising method can give results about 14 per cent. in error while the harmonic content remains under 5 per cent.

The more orthodox method of finding the harmonic power would be to analyse the wave form of Fig. 4 into its harmonic series.

This series is

$$\frac{2}{\pi} - \sum_{n=1}^{n=\infty} \frac{4}{\pi} \frac{\cos 2n\theta}{(2n+1)(2n-1)}$$

$$= \frac{2}{\pi} - \frac{4}{3\pi} \cos 2\theta - \frac{4}{15\pi} \cos 4\theta - \dots\dots$$

$$= .637 - .425 \cos 2\theta - .085 \cos 4\theta - \dots\dots$$

$$\text{Effective peak value of harmonics} = \sqrt{.425^2 + .085^2 + .0364^2 + \dots\dots}$$

$$= .436 + \text{a small quantity.}$$

This is in close agreement with the figure obtained directly.

E. GREEN.

If $k = 1, \quad m = .8$

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CONCENTRIC TUBE LINES

In the following article the concentric tube or parallel wire type of " resonant line " is discussed. The Q value of such a line is determined and results are given showing the effect of such lines on controlling the frequency of a test oscillator.

DURING recent years many attempts have been made to control the frequency of oscillators by means of parallel wires, or concentric tubes whose lengths are some multiple of a quarter wavelength of the oscillation. Such parallel wires, or concentric tubes, are commonly known as " resonant lines."

A very common type of such an oscillatory circuit is shown in Fig. 1.

The grid of the oscillating valve is connected to some point on the inner tube, and the position of this tap determines the sharpness of control as well as the amplitude of the oscillations. This shows a concentric tube line $\frac{1}{4}$ wavelength long with the two tubes joined at one end. Fig. 2 shows another method of connecting a concentric tube line to two valves in push-pull to form an oscillatory circuit. In this case the inner tube is half wavelength long and is free at both ends. The effectiveness of the control depends upon the selectivity of these " resonant lines." The conditions determining this selectivity can be readily deduced from the theory of the propagation of currents along wires.

The character of the line is given when the following quantities are known :—

- L the inductance per unit length.
- C the capacity per unit length.
- R the resistance per unit length.
- G the leakage conductance per unit length.

In the case of parallel wires and concentric tubes these characteristics refer to unit length go and return.

There are two important parameters of any transmission line, viz., the characteristic impedance Z_o and the propagation constant P. These are defined as follows :—

$$P = \sqrt{R + j\omega L} \cdot \sqrt{G + j\omega C}$$

and

$$Z_o = \frac{\sqrt{R + j\omega L}}{\sqrt{G + j\omega C}}$$

These are both complex quantities, but at high frequencies R and G are in practice usually very small in comparison with ωL and ωC, so that as a first approximation

$$Z_o = \sqrt{\frac{L}{C}} \qquad \text{(1)}$$

and $P = \frac{R}{2Z_o} + \frac{GZ_o}{2} + j\frac{2\pi}{\lambda}$ where λ = length corresponding to one wavelength (2)

This is usually written $P = \alpha + j\beta$ where α is called the attenuation constant of the line and β is called the wave velocity. If the leakage is negligible, as is usually the case in practice, then

$$\alpha = \frac{R}{2Z_o} \qquad \text{(3)}$$

At high frequencies the current is confined to a very thin layer on the outside of a wire, or to a very thin layer on the outside of the inner conductor and on the inside of the outer conductor of concentric tubes, so that the tubes comprising the line may be considered approximately of negligible thickness. In this case the formula $L = 2 \log_e \frac{b}{a}$ (e.m. units), given by Lord Rayleigh for the inductance of two concentric tubes each of infinitely small thickness, is applicable.

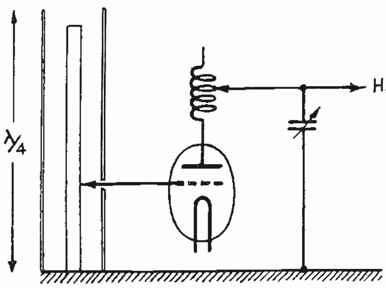

FIG. 1.

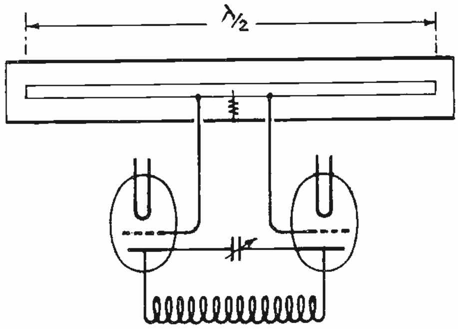

FIG. 2.

Here b and a are the diameters of the outer and inner tubes respectively. The capacity C is given by the formula

$$C = \frac{1}{2 \log_e \frac{b}{a}} \text{ (e.s.u.)} = \frac{1}{v^2} \cdot \frac{1}{2 \log_e \frac{b}{a}} \text{ (e.m.u.)}$$

where $v =$ the velocity of light $= 3 \times 10^{10}$ cms/sec.

$$\therefore\ Z_o = \sqrt{\frac{L}{C}} = 2 \log_e \frac{b}{a} \cdot v \text{ (e.m.u.)}$$

$$= 2 \log_e \frac{b}{a} \cdot v \cdot 10^{-9} \text{ ohms} = 60 \log_e \frac{b}{a} \text{ ohms}$$

$$= 138 \log_{10} \frac{b}{a} \text{ ohms} \qquad \text{(4)}$$

Assuming a ratio $\frac{b}{a} = 3.6$ then $Z_o = 77.6$ ohms. Calculation of resistance R at high frequencies is usually based on the fact that the skin effect is so great that R is equal to the resistance of a surface layer having a depth which for copper equals $\frac{6.62}{\sqrt{f}}$ cms. (where $f =$ frequency). Assuming the specific resistivity of copper to be 1,600 c.g.s. units then the H.F. resistance R for concentric tube feeder

$$= \frac{1.6 \times 10^{-6} \times \sqrt{f}}{6.62} \cdot \frac{1}{2\pi} \left(\frac{1}{a} + \frac{1}{b}\right) \text{ ohms}$$

$$= 38.5 \times 10^{-9} \cdot \sqrt{f} \cdot \left(\frac{1}{a} + \frac{1}{b}\right) \qquad \text{(5)}$$

The attenuation constant for this concentric tube

$$= \alpha = \frac{38.5 \times 10^{-9} \sqrt{f}\left(\frac{1}{a} + \frac{1}{b}\right)}{2 \times 60 \log_e \frac{b}{a}} \qquad \text{(6)}$$

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$$\text{and} \qquad Z_o = \frac{\sqrt{R + j\omega L}}{\sqrt{G + j\omega C}}$$

These are both complex quantities, but at high frequencies R and G are in practice usually very small in comparison with ωL and ωC, so that as a first approximation

$$Z_o = \sqrt{\frac{L}{C}} \qquad \qquad (1)$$

and $P = \dfrac{R}{2Z_o} + \dfrac{GZ_o}{2} + j\dfrac{2\pi}{\lambda}$ where λ = length corresponding to one wavelength (2)

This is usually written $P = \alpha + j\beta$ where α is called the attenuation constant of the line and β is called the wave velocity. If the leakage is negligible, as is usually the case in practice, then

$$\alpha = \frac{R}{2Z_o} \qquad \qquad (3)$$

At high frequencies the current is confined to a very thin layer on the outside of a wire, or to a very thin layer on the outside of the inner conductor and on the inside of the outer conductor of concentric tubes, so that the tubes comprising the line may be considered approximately of negligible thickness. In this case the formula $L = 2 \log_e \frac{b}{a}$ (e.m. units), given by Lord Rayleigh for the inductance of two concentric tubes each of infinitely small thickness, is applicable.

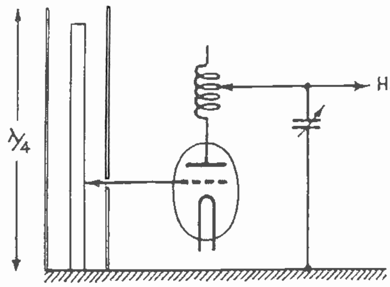
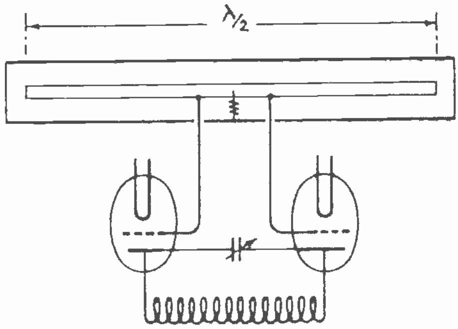


FIG. 1.



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where $v =$ the velocity of light $= 3 \times 10^{10}$ cms/sec.

$$\therefore Z_o = \sqrt{\frac{L}{C}} = 2 \log_e \frac{b}{a} \cdot v \text{ (e.m.u.)}$$

$$= 2 \log_e \frac{b}{a} \cdot v \cdot 10^{-9} \text{ ohms} = 60 \log_e \frac{b}{a} \text{ ohms}$$

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$$= 38.5 \times 10^{-9} \cdot \sqrt{f} \cdot \left(\frac{1}{a} + \frac{1}{b}\right) \quad \ldots \quad (5)$$

The attenuation constant for this concentric tube

$$= \alpha = \frac{38.5 \times 10^{-9} \sqrt{f} \left(\frac{1}{a} + \frac{1}{b}\right)}{2 \times 60 \log_e \frac{b}{a}} \quad \ldots \quad (6)$$

This expression is a minimum when $\dfrac{\frac{1}{a}+\frac{1}{b}}{\log_e \frac{b}{a}}$ is a minimum.

Consider b as a constant and write $x = \frac{b}{a}$ then the expression is a minimum when $\dfrac{x+1}{\log_e x}$ is a minimum. Differentiating and equating to zero

$$\frac{1}{\log_e x} - \frac{x+1}{x\,(\log_e x)^2} = 0, \text{ i.e., } x \log_e x = 1 + x \text{ or } x = 3.6.$$

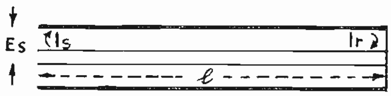


FIG. 3.

Therefore the attenuation is a minimum for the ratio of diameters equal to 3.6. Assuming this ratio then

$$\alpha = \frac{38.5}{120} \cdot 10^{-9} \sqrt{f} \cdot \frac{\left(\frac{1}{a}+\frac{1}{b}\right)}{\log_e \frac{b}{a}}$$

$$= \frac{38.5}{120} \cdot 10^{-9} \frac{\sqrt{f}}{b} \cdot \frac{4.6}{\log_e 3.6} = 1.15 \times 10^{-9} \cdot \frac{\sqrt{f}}{b} \quad \ldots \quad \ldots \quad (7)$$

$\therefore$ loss in dbs. per kilometre

$$= 20 \log_e \cdot \alpha \cdot 1000 \cdot 100 = 20 \log_{10} e \; 10^5 \cdot 1.15 \cdot 10^{-9} \cdot \frac{\sqrt{f}}{b}$$

$$= .00627 \frac{\sqrt{f}}{b} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (8)$$

Resonant feeders may be either open or short circuited at one end, but, for economy, the closed concentric tube feeder is usually employed.

If in Fig. 3 E_s = voltage at the open end of a feeder of length l cms.
I_s = current at the open end of a feeder of length l cms.
I_r = current at the short circuited end,

then theory shows that

$$E_s = I_r Z_o \sinh (\alpha + j\beta)\, l \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (9)$$

$$I_s = I_r \cosh (\alpha + j\beta)\, l \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (10)$$

Impedance into the feeder at the open end $= Z_s$ (say)

$$= \frac{E_s}{I_s} = Z_o \tanh (\alpha + j\beta)\, l \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (11)$$

In the case of resonance βl is an odd multiple of $\frac{\pi}{2}$ so that Z_s now becomes

$$= Z_o \tanh \left(\alpha\, l + jm \frac{\pi}{2}\right) \text{ where } m = \text{odd number.}$$

$$= \frac{Z_o}{\tanh \alpha\, l} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (12)$$

Now $\alpha\, l$ will always be small in all practical cases so that $\tanh \alpha\, l = \alpha\, l$

$\therefore Z_s = \dfrac{Z_o}{\alpha l}$ but since $l = \dfrac{n\lambda}{4}$ where n = number of quarter wavelengths in the line

$$Z_s = \frac{Z_o}{a} \cdot \frac{4}{n\lambda} = \frac{2Z_o^2}{R} \cdot \frac{4}{n\lambda} = \frac{8Z_o^2}{n\lambda R}$$

$$= \frac{8.60^2 \left(\log_e \frac{b}{a}\right)^2}{n.\lambda.\ 38.5 \cdot 10^{-9} \sqrt{f}\left(\frac{1}{a} + \frac{1}{b}\right)} = \frac{748}{n\lambda\sqrt{f}} \cdot 10^9 \frac{\left(\log_e \frac{b}{a}\right)^2}{\frac{1}{a} + \frac{1}{b}}$$

but $\lambda f = v$ (velocity of light)

$$\therefore Z_s = \frac{748}{n} \cdot \frac{10^9}{3.10^{10}} \cdot \sqrt{f} \cdot \frac{\left(\log_e \frac{b}{a}\right)^2}{1 + \frac{b}{a}} \cdot b$$

$$= 24.9 \sqrt{f} \cdot \frac{b}{n} \cdot \frac{\left(\log_e \frac{b}{a}\right)^2}{1 + \frac{b}{a}}$$

The maximum value of Z_s is given by the maximum value of $\frac{\left(\log_e \frac{b}{a}\right)^2}{1 + \frac{b}{a}}$ treating b as a constant. Putting $\frac{b}{a} = x$ and differentiating and equating to zero $\frac{2(1+x)}{x} = \log_e x$.

This gives $x = 9.2$.

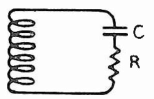


FIG. 4.

The condition for maximum impedance is given by the ratio of diameters equal to 9.2 and is not the same as for minimum attenuation down the feeder.

The selectivity of a circuit is generally considered as a measure of the variation of the impedance in the region around exact resonance. The "goodness" of the circuit shown in Fig. 4 $= Q = \frac{\omega L}{R}$. The impedance of this circuit $= R + Lj\omega + \frac{1}{Cj\omega}$.

Consider a small change of frequency δf so that

$2\pi\delta f = \delta\omega$ then impedance becomes $R + Lj\,(\omega + \delta\omega) + \frac{1}{Cj\,(\omega + \delta\omega)}$

$$= R + Lj\,(\omega + \delta\omega) + \frac{1}{Cj\omega}\left(1 - \frac{\delta\omega}{\omega}\right)$$

$$= R + Lj\omega + \frac{1}{Cj\omega} + Lj\delta\omega - \frac{1}{Cj\omega^2}\,\delta\omega$$

If $f = \frac{\omega}{2\pi}$ is the resonant frequency then for point δf off resonance the impedance becomes $R + Lj\delta\omega - \frac{1}{Cj\omega^2}\,\delta\omega = R + 2Lj\delta\omega$

If we choose $\delta\omega$ so that $2L\delta\omega = R$ or, in other words, the energy in the circuit is reduced to half its resonance value, then this value

$$\delta\omega = 2\pi\delta f = \frac{R}{2L} = \frac{\omega}{2Q} = \frac{2\pi f}{2Q}$$

or $$\frac{\delta f}{f} = \frac{1}{2Q}$$

To obtain a measure of Q for a concentric tube resonant feeder the same process can be applied.

The impedance of a concentric tube feeder closed at one end is given by equation (11), viz., $Z_s = Z_o \tanh (\alpha + j\beta)\, l$. Assume the frequency is off resonance by an amount δf then

$$j\beta l = j\frac{2\pi f}{v} l + j\frac{2\pi l}{v}\delta f = j\frac{n\pi}{2} + j\frac{2\pi l}{v}$$

$$Z_s = Z_o \tanh \left(\alpha l + j\frac{2\pi l}{v}\delta f + j\frac{n\pi}{2}\right) \quad (v = \text{velocity of light})$$

$$= \frac{Z_o}{\tanh\left(\alpha l + j\frac{2\pi l}{v}\delta f\right)} = \frac{Z_o}{\alpha l + j\frac{2\pi l}{v}\delta f}$$

At resonance the impedance $= \dfrac{Z_o}{\alpha l}$.

If δf is so chosen that the power in the circuit is halved, then αl must equal $\dfrac{2\pi l}{v}\delta f$.

$$Q \text{ (for resonant concentric tubes)} = \frac{f}{2\delta f} = f\frac{2\pi l}{2\alpha l v}$$

but $$\frac{1}{\alpha} = \frac{2Z_o}{R} \qquad \therefore \quad Q = \frac{2\pi Z_o f}{vR}$$

Q will be a maximum when $\dfrac{Z_o}{R}$ is a maximum and this is the same requirement making α a minimum. This occurs when $\dfrac{b}{a} = 3.6$. Since α for this ratio $= 1.15 \; 10^{-9} \dfrac{\sqrt{f}}{b}$

$$Q = \frac{2\pi}{2v} \cdot \frac{f}{\alpha} = \frac{\pi f}{v} \cdot \frac{b}{\sqrt{f}} \cdot \frac{10^9}{1.15} = b\sqrt{f} \cdot .091$$

The value of Q varies directly as the diameter of the outer tube and directly as the square root of the frequency. For very high frequencies it is possible to obtain very large values of Q. For example, consider a concentric tube, the diameter of the outer being 15 cms., length to give a wavelength of 6 metres, then $Q = 15\sqrt{5 \times 10^7} \times .091 \div 9000$.

A circuit with such a large Q value should be capable of stabilising the frequency of an oscillator.

To test this conclusion a concentric tube, 2.25 metres long of outside diameter 4.5 cms., was connected to the grids of two valves arranged in push-pull as shown in Fig. 5.

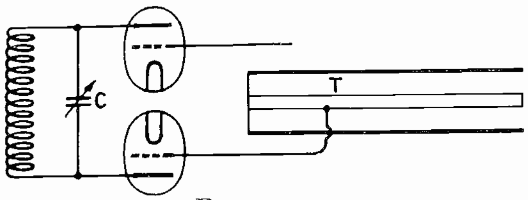


FIG. 5.

The position of the tap T on the inner tube could be varied and the wavelengths of the oscillations produced when the capacity C was varied were measured and the results are shown plotted in Fig. 6. The dotted curve gives the wavelength variation obtained when the concentric tube is replaced by an L.C. circuit tuned to 9 metres. It will be noticed that, as the tap T is moved nearer the closed end, the frequency of the oscillations becomes more nearly constant and is only maintained over a small variation of the capacity C. The energy in the oscillations decreases with the shorter tapped length. The Q of this concentric tube as calculated would be approximately 2000, but this would only be the case if the tap T was at the shorted end of the tubes. To obtain sufficient "grid" volts to maintain oscillations the

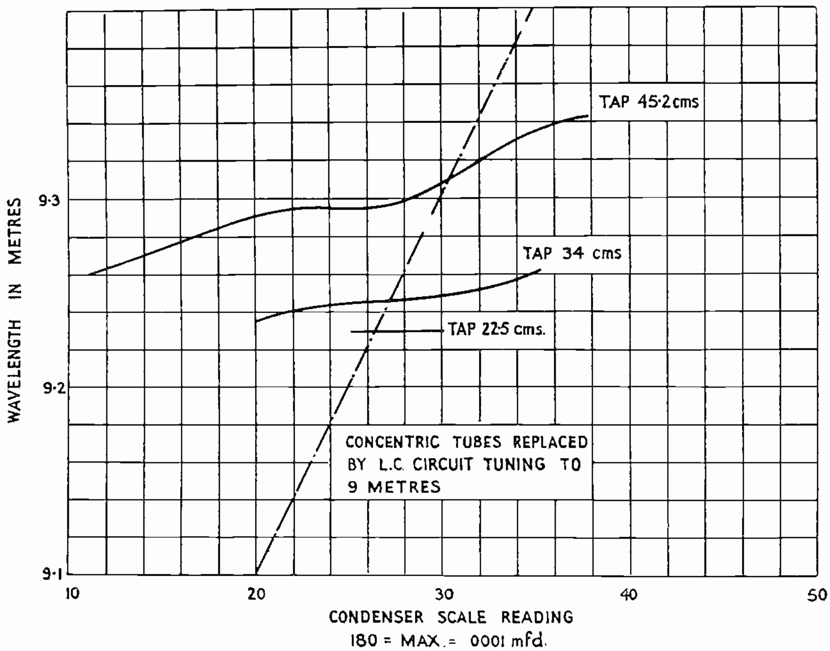


FIG. 6.

tap T with the circuit tested was found to be 20 cms. from the end, but it was necessary to increase this to 22.5 cms. to obtain a useful strength of oscillation. The load thus thrown on the feeder is equivalent to an increase in the value R, so that the Q of the practical circuit cannot approach the theoretical value.

By increasing the diameter of the tubes it should be possible to greatly improve on the performance shown above, and it has been found practicable to obtain very good frequency stability with such concentric tubes. B. J. WITT.

A NOTE ON A NEW DESIGN OF TRANSFORMER

The following article describes a new design of transformer providing a simple means of accomplishing coupling between a balanced circuit and an unbalanced circuit, at the same time providing a wide frequency band throughout which this coupling is uniformly efficient.

AS is well known in the communication art, it is in many cases highly desirable to use lines or cables in which two conductors are balanced to earth with respect to the energy they carry and their individual impedance to earth. Particular examples of such cases are connections between microphones and their associated amplifiers, long cable circuits and the interposition of amplifiers between parts of a line. For economy, however, it is desirable in many cases to use amplifiers in which each stage comprises a single valve. The input transformer of such an amplifier has therefore to couple a balanced circuit to the grid of a valve and bias or earth, i.e., to an unbalanced circuit. Hitherto this has been accomplished with either some appreciable effect on the line balance or by means of costly transformer constructions. It is the purpose of the present design to provide a simple means of accomplishing this coupling and at the same time a wide frequency band throughout which the coupling is uniformly efficient.

The design may be illustrated by reference to Figs. 1 and 2. In these figures, C indicates a transformer core built up of magnetic material by any of the methods familiar in the art, while A, B and D represent windings. Of these windings, D is composed of a convenient number of similar sections connected in series aiding and spaced by well known methods. The windings A are normally wound in layers, but the windings B are either wound in the reverse direction to those of A and D, or, alternatively, similarly wound to those of A but assembled in the reverse manner, i.e., revolved through 180° about a diameter before assembly. S_a, S_b, S_d represent screens of conducting material surrounding the windings A and B and on the inner radius of windings D respectively, but in all cases separated by layers of low dielectric insulating material from the windings and, in the case of S_d, from the remaining screens.

The method of connection is as follows. The winding D is connected in well known manner with the parts in series aiding, the start of the first section to bias or earth and the finish of the last section to the valve grid. This winding may, of course, have an additional impedance connected across its terminals or the valve grid may be replaced by a suitable load. The windings A and B may be connected in either of two ways—with the starts of the two windings commoned or the two finishes commoned, the remaining connections in either case forming the leads for connection to the line. In the form shown in Fig. 1, the screens S_a, S_b are commoned and earthed, while in the form shown in Fig. 2 the screen S_d is earthed, but the screens S_a, S_b are connected respectively to those terminals of the windings A and B which are connected to the balanced circuit.

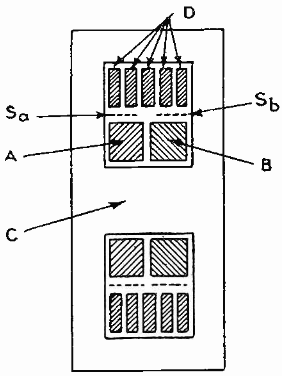


FIG. 1.

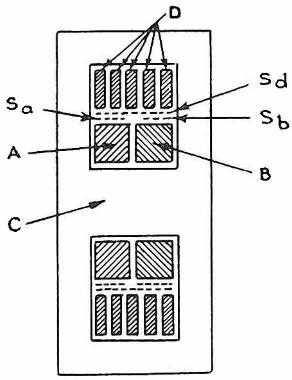


FIG. 2.

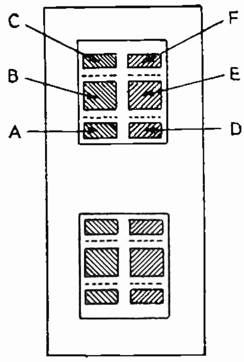


FIG. 3.

On examination of these arrangements it will be seen that the winding D enjoys all the known advantages of sectionalised windings permitting the resonance between

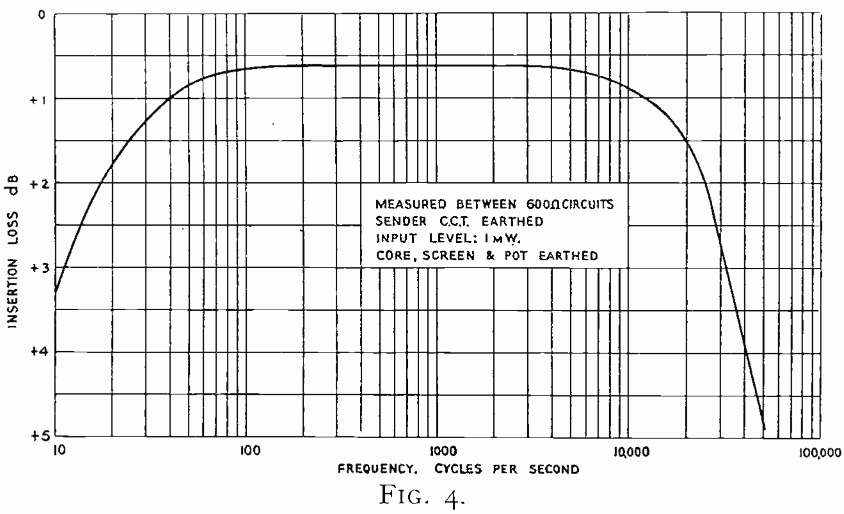


FIG. 4.

the transformer leakage reactance, the effective shunt inductance and the effective shunt capacity to be placed at a high frequency near the upper limit of the desired signal band. In this connection it will be noted that the capacity between the winding D and the screen S_d is much reduced by the small thickness of the sections forming the winding D.

On the other hand, the windings A and B are electrically similar both in the number of turns used and the disposition of these turns with respect to neighbouring parts. Thus the impedance between either terminal connected to the balanced load and earth will closely approach equality. In Fig. 1, however, there remains the difficulty that the screens S_a, S_b may not be of perfectly conducting material or the dielectric constants, etc., of the insulation between the winding A and the screen S_a and of that between B and S_b may differ. This effect is usually negligible at audio-frequencies, but where higher frequencies are desired the construction of Fig. 2 is preferred. In this case, the impedance to earth of each terminal of the balanced input is formed by that of the respective winding and screen to earth, of

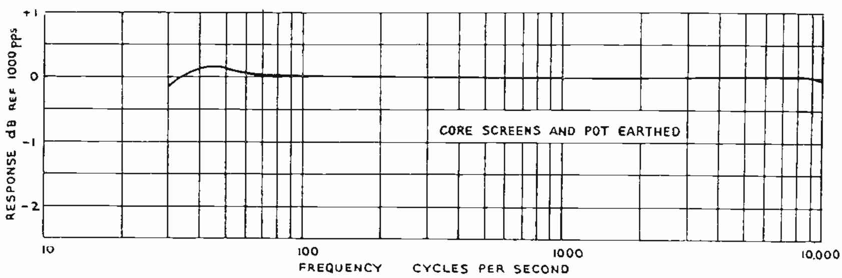


FIG. 5.

which that between S_a and S_d can easily be made to equal that between S_b and S_a within close tolerances. Moreover, these two capacities can be more definite and of higher power factor than is readily obtainable in the construction shown in Fig. 1.

A further modification of the design is required when the unbalanced impedance is of low value. An example of such a case is the connection between a microphone, which may not be sufficiently accurately balanced to earth, and the cable to its associated amplifier. In this case the capacity of the windings becomes of only secondary importance, increased coupling between the windings being the first consideration. The construction shown in Fig. 3, is therefore employed. The bobbins containing the windings A, B, C and D, E, F, are similarly wound, but assembled in the reverse manner. The windings B and E are connected with either the starts or the finishes commoned, the remaining leads being connected to the line. The outer leads of the windings A and D are also commoned and the inner leads of the windings C and F. The outer lead of C is connected to the inner lead of A, the remaining leads from D and F being connected to the microphone. Thus it will be seen that there is a high degree of symmetry in the disposition of the windings B and E with respect to neighbouring parts, and good electrical balance is therefore assured. Screens are fitted between the windings as shown in the figure, and connected to earth, when the transformer is designed for use at voice frequencies. For use at higher frequencies other screens may be fitted and connected to the ends of the windings B and E. The effect will then be somewhat similar to that obtained by the use of the construction of Fig. 2 for an input transformer.

Tests on balance with sample line transformers as in Fig. 3, show that the true centre point of the line windings departed from the design centre point by less than 0.2 ohms in 600 ohms for frequencies below 12 kilocycles per second. The reactance unbalance was corrected by a reactance greater than 100,000 ohms in shunt with one-half of the line windings. Earthing either side of the unbalanced windings had no apparent effect on the balance. An input transformer to Fig. 1 showed similar balance characteristics.

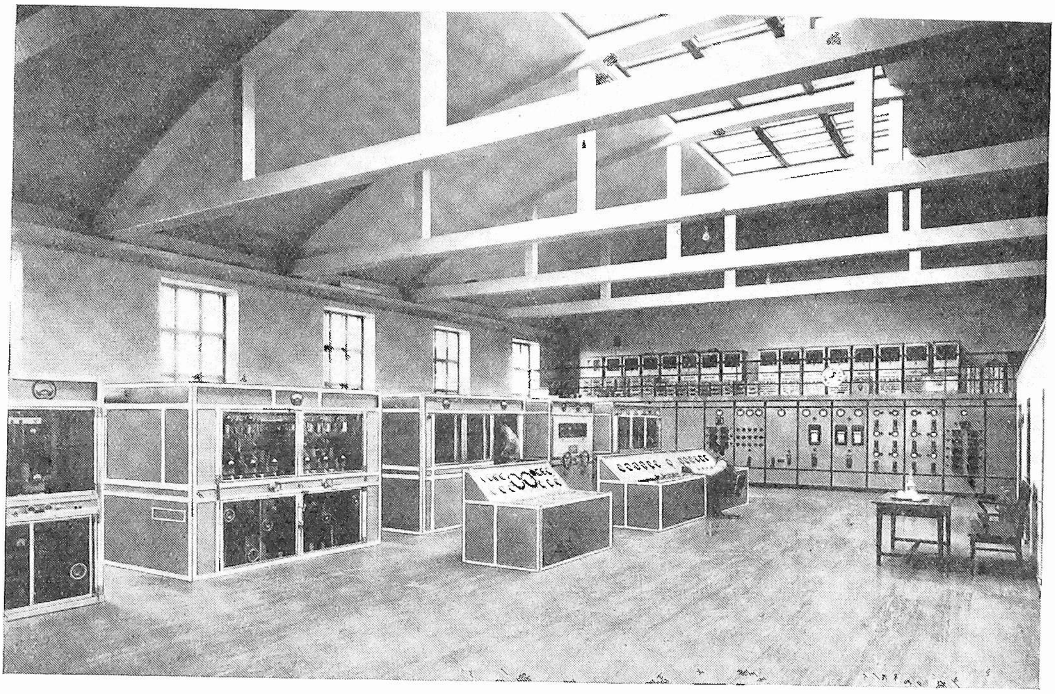
Fig. 4 shows the frequency characteristic of a line transformer. Inputs up to 200 milliwatts have been applied to this transformer without apparent distortion. Fig. 5 shows the frequency characteristic for an input transformer tested in a linear amplifier. Special transformers have also been made in which the primary inductance has been reduced to give a characteristic falling at low frequencies to equalise a given input.

Throughout these tests the standard type 325 laminic core has been used for the transformers, which have been mounted in cast iron pots measuring 4 inches by $2\frac{5}{8}$ inches by $2\frac{5}{8}$ inches overall.

F. M. G. Murphy.
C. D. Colchester.

MARCONI NEWS AND NOTES

NEW FINNISH HIGH-POWER BROADCASTING STATION.



150 *kw. Marconi Broadcasting Installation at Lahti, Finland.*

ON January 25th, in the presence of a distinguished gathering of Finnish notabilities, a new Marconi high-power broadcasting station was inaugurated at Lahti.

Finland covers a large area, and the Finnish broadcasting authorities felt that in order adequately to serve their listeners, particularly in the remote eastern and north-eastern districts of the country, a much higher-powered station than that used hitherto would be essential. An order was, therefore, given to the Marconi Company to supply a new 150-kilowatt station to supersede the existing 40-kilowatt station at Lahti.

The wireless transmitter for the new station was constructed at the Marconi Company's Works at Chelmsford, and incorporates the latest refinements in broadcast technique to ensure high fidelity of reproduction and great constancy of the carrier wave.

One of the features of the new station is the " series modulation " system which is also employed at Droitwich, at the new station at Lisburn in Northern Ireland, at Motala in Sweden, and other important stations.

The Lahti station operates with an unmodulated aerial carrier energy of 150 kilowatts, but it is so designed that it can also operate with a higher unmodulated carrier energy without any alteration to the equipment. The working wavelength is 1,807 metres, and the transmitter is capable of adjustment to any wavelength between the limits of 1,000 and 2,000 metres to allow for changing to another working wavelength should this be found desirable at any future date.

In view of the congestion of stations transmitting on the long broadcasting waveband exact adherence of the stations to their allotted wave is of the greatest importance, and the new Lahti station is stabilised by high-precision quartz crystal drive with thermostat control attaining a constancy of 5/1,000,000, a figure well within the exacting requirements specified by international radio conferences.

The transmitter consists of five aluminium units placed in line, a control desk, and a separate rack mounting the quartz crystal drive.

Marconi CAT.14 valves, operating at 18-20,000 volts to the anodes are used in the last stage of the transmitter.

The maximum modulation of the Lahti transmitter is 100 per cent. At modulation depths up to 90 per cent. the distortion does not exceed the tolerance of four per cent. permitted by the C.C.I.R. The frequency response of the transmitter is linear within one decibel between 30 and 10,000 cycles per second.

Short-Wave Broadcasting for Nanking.

THE Central Broadcasting Administration of Nanking have placed a contract with the Marconi Company for the supply and installation of a high-power short-wave broadcasting station rated at 35 kilowatts carrier power maximum.

The new installation is of an advanced type in which the principal features are simplicity and rapidity of wave-changing, great carrier constancy, and a performance in all respects equal to a medium-wave broadcasting station, so that music as well as speech can be broadcast without any deterioration in quality.

The transmitter is designed to cover a waverange of 14-100 metres and four spot waves are provided with a possibility of changing from one spot wave to another in approximately two minutes. Any other wavelength within the band of the transmitter may be selected by re-tuning and re-balancing the different circuits.

The transmitter, which is in many respects similar to the one installed by the Marconi Company in the League of Nations Station, near Geneva, will use four sets of directional aerials, mainly orientated to Europe and the United States. Two sets of aerials are for day communication and the two others for the night services. In addition, there are four omni-directional aerials for world-wide broadcasting.

Frequency response is of a high order, being within plus or minus two decibels over a frequency range of 50-10,000 cycles, and modulation is linear up to 80 per cent.

New High-Power Station for Esthonia.

THE Esthonian Broadcasting authorities have placed an order with the Marconi Company for a 50-kilowatt broadcasting station to be installed at Tallinn.

The new transmitter will be modulated at the final power stage by means of water-cooled modulator valves operating in a Class "B" circuit. Crystal control with a constancy of 5/1,000,000 will be incorporated. The distortion factor will fully meet the C.C.I.R. recommendations and at 90 per cent. modulation it will not exceed four per cent. Two Marconi CAT.12A transmitting valves will be used for the modulated amplifier stage.

The transmitting equipment will be adjustable to any wavelength within the limits of 300-545 metres and has been arranged for an increase in power to 100 kilowatts if desired at a future date.

The front of the transmitter will be in the shape of an enamelled metal panel switchboard, a type of construction greatly favoured by many broadcasting authorities.

An anti-fading aerial will be used with the transmitter.