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

RESISTANCE CONTROL OF MUTUAL INDUCTANCE COUPLING BETWEEN TWO TUNED CIRCUITS

An examination of methods for obtaining variable selectivity by changing the coupling between two tuned circuits indicates that the most satisfactory is by variation of mutual inductance. Any other form of coupling changes the frequency of one secondary current maximum when critical coupling is exceeded and this necessitates a change of carrier frequency if symmetrical frequency response is to be preserved.

Control of mutual inductance coupling by changing the spacing between primary and secondary coils gives satisfactory manual operation but cannot easily be adapted for automatic operation.

If the effective mutual inductance variation could be achieved by variation of, for example, resistance, automatic operation would be greatly facilitated. An attempt to control the mutual inductance between two tuned circuits by varying the resistance across a coil interposed between them is described below. A theoretical investigation is given and this is followed by the results of a confirmatory experiment on a typical tuned transformer.

Theory.

THE following assumptions will be made:—

1. The transformer primary is in the anode circuit of an H.F. pentode valve.
2. The valve has an infinite impedance and zero anode to grid capacity so that it may be considered as a constant current generator.
3. The resistance across the coil placed between primary and secondary may be replaced by an equivalent resistance across the mutual inductance coupling between the circuits. The equivalent resistance is to include the H.F. resistance of the coil itself.

The ratio of secondary circuit current to input current is obtained in preference to the ratio of secondary circuit output voltage to input current since the frequencies of maximum secondary current are more easily calculated.

The equivalent circuit will be that of Fig. 1A, which can be simplified to that of 1B.

$$\frac{I_2}{e_1} = \frac{1}{Z_4} \qquad \ldots \qquad (1)$$

$$\frac{e_1}{e} = \frac{Z_3 Z_4}{Z_2 (Z_3 + Z_4) + Z_3 Z_4} \qquad \ldots \qquad (2)$$

$$B = +\sqrt{k^2-n^2}\left(1-\frac{k^2n^2}{(1-\sqrt{(k^2-n^2)}\,[(k^2-n^2)]^{\frac{3}{2}}}\right) \quad .. \quad .. \quad (12)$$

$$\text{If } k >> n,\ B \div \sqrt{(k^2-n^2)}\left(1-\frac{n^2}{(1-k)k}\right) \quad .. \quad .. \quad .. \quad (12\text{A})$$

Since $n < k < 1$ the factor $\frac{n^2}{(1-k)k}$ may be neglected. A similar expression is obtained for the second root.

$$B \div -\sqrt{(k^2-n^2)}\left(1+\frac{n^2}{(1-k)\,k}\right) \quad .. \quad .. \quad .. \quad .. \quad (12\text{B})$$

Critical coupling occurs when $\sqrt{(k^2-n^2)} = 0$ or $k = n$.

It is interesting to note that the factor $(1 - B)$ in equation (10) tends to decrease the frequency of the low frequency secondary current maximum and increase the frequency of the high frequency maximum, though this effect is shown above to be small unless η becomes large. It will therefore be assumed that

$$B = \pm\sqrt{k^2-n^2} \text{ gives maximum } \left|\frac{I_2}{I}\right|.$$

It is now possible to examine the effect of the resistance R in parallel with the mutual inductance, M, when the coupling is greater than critical, i.e., $k > n$.

For the high frequency secondary current maximum, $B = \sqrt{(k^2-n^2)}$ and

$$\text{Max.}\left|\frac{I_2}{I}\right| = \frac{[1-\sqrt{(k^2-n^2)}]k.}{\sqrt{4k^2\eta^2 + \frac{k^2\phi\, 4n(2k(k-\sqrt{k^2-n^2})}{\sqrt{(1-\sqrt{(k^2-n^2)})}} + \frac{4k^4\phi^2\,(2k^2-n^2-2k\sqrt{(k^2-n^2)})}{(1-\sqrt{(k^2-n^2)})}}}$$

Replacing k by its approximate binomial expansion, $k - \frac{\eta^2}{2k} - \frac{\eta^4}{8k^3}$

$$\text{Max.}\left|\frac{I_2}{I}\right|_{f>f_0} = \frac{1-\sqrt{(k^2-n^2)}}{2\eta\sqrt{\frac{1+\phi n\left(1+\frac{n^2}{4k^2}\right)}{\sqrt{(1-\sqrt{(k^2-n^2)}}} + \frac{\phi^2n^2}{4(1-\sqrt{(k^2-n^2)})}}}$$

$$= \frac{\text{Max.}\left|\frac{I_2}{I}\right|\ \phi = 0.}{\sqrt{\frac{1+\phi n\left(1+\frac{n}{4k^2}\right)}{\sqrt{(1-\sqrt{(k^2-n^2)})}} + \frac{\phi^2n^2}{4(1-\sqrt{(k^2-n^2)})}}} \quad .. \quad .. \quad (13)$$

Since n is generally much less than 1, the amplitude $\left|\frac{I_2}{I}\right|$ will only be affected when ϕ becomes large, i.e., R becomes small.

For the low frequency secondary current maximum $(B = -\sqrt{(k^2-n^2)})$ a similar expression is obtained

$$\text{Max.} \left|\frac{I_2}{I}\right|_{f<f_0} = \frac{\text{Max.} \left|\frac{I_2}{I}\right| \phi = 0.}{\sqrt{1 + \phi \dfrac{\left(\dfrac{4k^2}{n} - n - \dfrac{n^3}{4k^2}\right)}{\sqrt{(1 + \sqrt{(k^2 - n^2)})}} + \dfrac{k^2\phi^2\left(4k^2 - 2n^2 - \dfrac{n^4}{4k^3}\right)}{n^2(1 + \sqrt{(k^2 - n^2)})}}} \quad \ldots \quad (14)$$

The factor multiplying ϕ has now become large and there will be considerable attenuation of the low frequency secondary current maximum even for high values of R.

Equation (9) above gives the secondary current amplitude ratio at any particular frequency, and since

$$\left|\frac{I_2}{I}\right|_{\phi=0} = \frac{(1 - B)k}{\sqrt{(\eta^2 + (B - k)^2)\ (\eta^2 + (B + k)^2)}}$$

the amplitude ratio for any value of ϕ may be expressed in terms of the ratio for $\phi = 0$, as follows :—

$$\left|\frac{I_2}{I}\right|_{\phi=\phi_1} = \frac{\left|\frac{I_2}{I}\right| \phi = 0}{\sqrt{1 + \phi_1 \dfrac{4nk^2}{(\eta^2 + (B + k)^2)\sqrt{(1 - B)}} + \phi_1{}^2 \dfrac{k^2(\eta^2 + (B - k)^2)}{(1 - B)\ (\eta^2 + (B + k)^2)}}} \quad \ldots \quad (15)$$

It is quite clear from expression (15) that change of ϕ will produce the most marked effect when B is negative, i.e., on the low frequency side, and to demonstrate the effect a series of curves are plotted in Fig. 2 for two identical coupled circuits having constants $k = 0.2$ and $\eta = 0.04$ for different values of ϕ. It is assumed that the value of n is independent of frequency over the range considered.

In order to allow comparison with experimental results the curves are plotted for secondary voltage output against frequency. The secondary voltage is obtained by multiplying expression (15) by $\frac{1}{j\omega C}$.

Small values of ϕ produce a considerable effect on the low frequency voltage maximum and for $\phi = .45$ the two voltage maxima are equal, whilst for values of $\phi > 2$ there is no low frequency maximum.

Experimental Results.

A Colvern variable spacing intermediate frequency transformer was used for the experimental verification.

The primary and secondary coils each had an inductance of 9,800 μhys. and they were tuned to 110 Kcs. by preset mica condensers.

A curve of coupling factor against spacing was first obtained by noting the resistive load reflected from the secondary circuit into the primary.

The Q of the primary circuit was measured with the secondary spaced as far as possible from it. The secondary coil was used as the source of injecting voltage and the resistance component of the primary circuit measured by adding known series resistances and noting the reduction in primary output voltage. The Q was measured as 25.

A spacing of $\frac{1}{8}$ in. between secondary and primary coils was chosen and this represented a coupling factor $k = 0.2$. A coil of 50 turns of 36SWG SC. copper wire was wound in the space between the two coils and various resistances were placed across its ends.

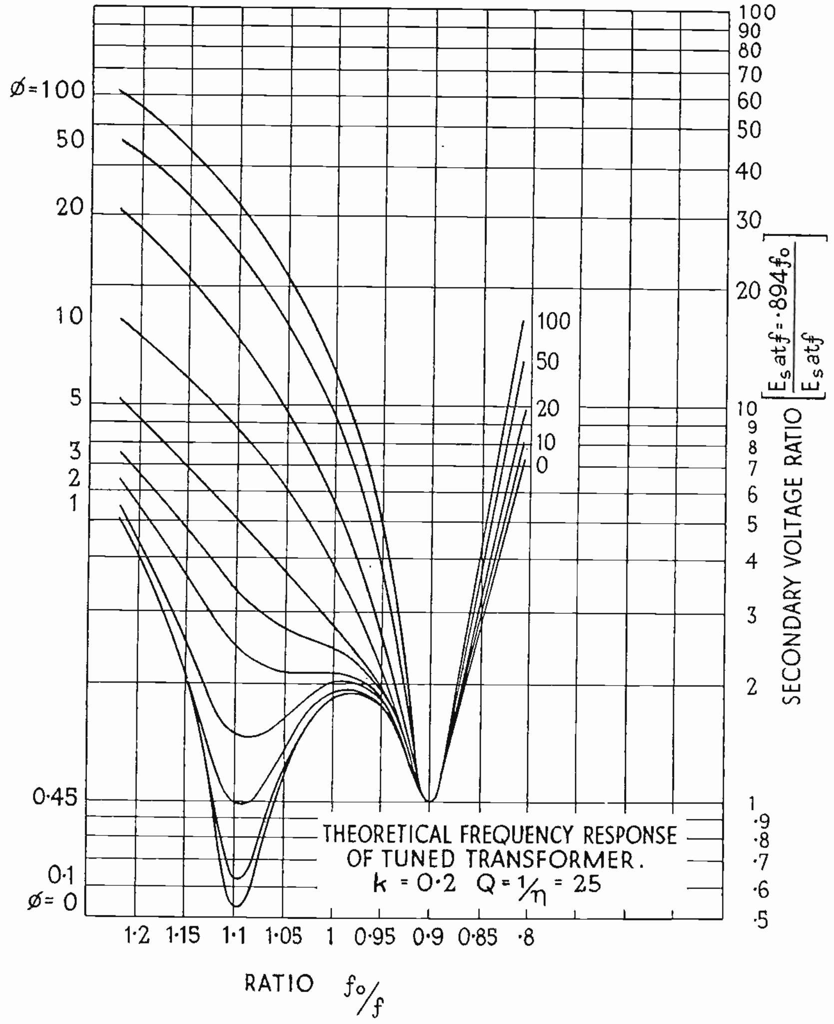

FIG. 2.

The primary circuit was connected in the anode of an H.F. pentode to the grid of which was connected a signal generator capable of covering the required frequency band and maintaining constant grid input voltage. The secondary output voltage was measured by a peak voltmeter.

Fig. 3 gives the secondary voltage curves over the frequency range with different values of shunting resistances across the central coil. The similarity between these and the theoretical curves of Fig. 2 is clearly seen.

The curves for R = ∞, i.e., $\phi = 0$ in Figs. 2 and 3, are not exactly identical; the measured low frequency maximum is less than the calculated. This may be due

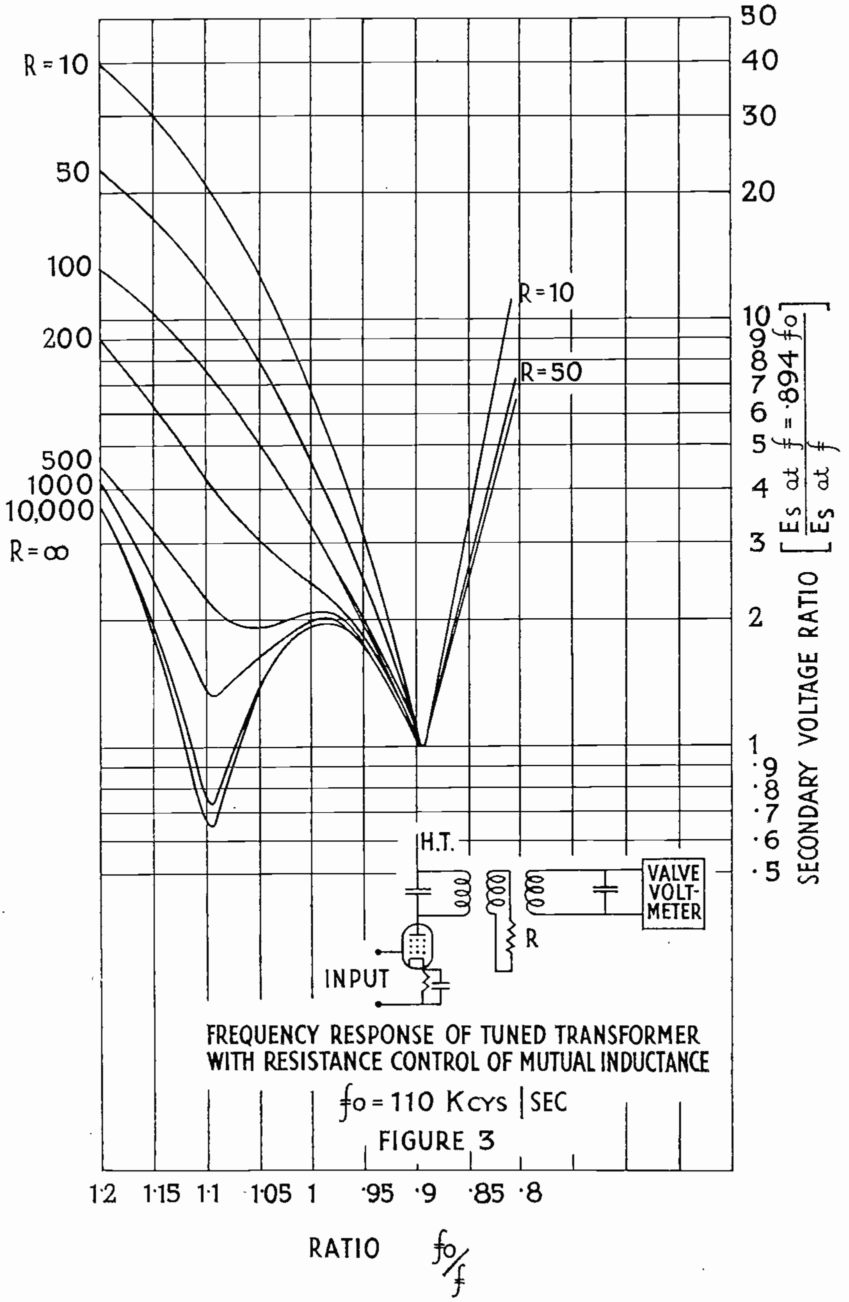

FIG. 3.

to capacitive coupling between the secondary and primary coils which will tend to discriminate in favour of the high frequencies, or it may be due to variation of n with frequency.

In Fig. 4 the ratio of high frequency voltage maximum at $\phi = 0$ to that for $\phi = \phi_1$ is plotted against ϕ, and it was found that by assuming $\phi = 1$ as equivalent to R = 1000, the measured and theoretical curves approximate quite closely. There is an unexpected rise in the experimental curve for low values of R. The internal resistance of the central coil which has not been included in R would tend to produce a measured curve lower than the calculated.

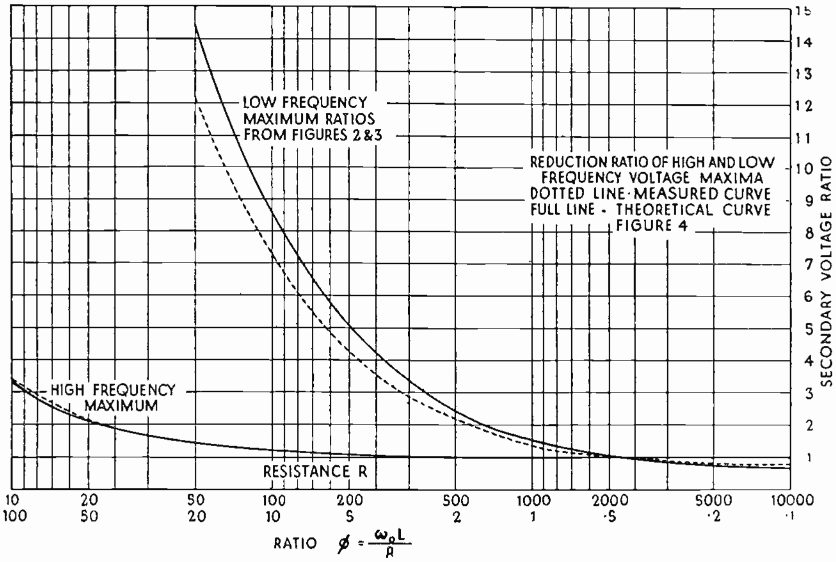

FIG. 4.

Fig. 4 also gives a calculated and measured curve for the secondary voltage reduction at a frequency corresponding to the low frequency voltage maximum when R is infinite. The voltage reduction is taken from Figs. 2 and 3 and therefore represents the attenuation ratio in terms of the voltage at the high frequency maximum. It was assumed again that R = 1000 was equivalent to $\phi = 1$.

Conclusion.

A resistance placed across a coil interposed between two tuned coupled circuits may be regarded as a resistance across the mutual inductance coupling.

Control of mutual inductance coupling by this method tends to suppress completely the low frequency secondary voltage maximum with little attenuation of the high frequency maximum.

This method of mutual inductance control does not provide a satisfactory control of selectivity for double side-band reception, though it has possibilities for single side-band reception.

Resistance control could be used to correct the asymmetricity of coupled circuit selectivity curves as shown by the curve for $\phi = .45$ in Fig. 2.

K. R. STURLEY
Marconi School of Wireless Communication.

AERODROME AND AIR ROUTE CONTROL

The subject of aerodrome and air route control is a very wide one, embracing very many branches of aeronautical science and it is proposed to treat it primarily as a problem, the solution of which depends, fundamentally, upon the provision of facilities for adequate communication between pilots of aircraft and the various control centres. It will be readily understood that before any measure of control can be exercised over the movements of aircraft flying on a busy air route a vast amount of information relating to weather conditions within a wide area, characteristics of the aircraft engaged on a particular route and the nature of the route itself must be instantly available to control officers, who must also be able to disseminate this information quickly and intelligently. Obviously, these considerations call for the employment of all forms of electrical communication, so organised that the different classes of information can be obtained and distributed with the least delay.

PROBABLY as a result of the success achieved with radio communication between aircraft and the ground during the war, 1914-1918, the nucleus of a control system already existed when civil aviation activities commenced in Great Britain in 1919. The Controllerate of Civil Aviation, as the department was then called, seems to have assumed that aerial transport would either supplant or complement the main railway services, since the air routes it then planned radiated from London in very much the same way as the trunk railway lines, i.e., to the north via Manchester, to the Continent via Folkestone, to the west via Southampton and Plymouth. Several existing radio stations were utilised and it was proposed to control the movements of aircraft by a system analogous to the block signalling employed by the railways.

Briefly, the procedure adopted consisted of signalling by radio telephony the departure of an aircraft to the intermediate and terminal airports. As the aircraft arrived at or passed over the intermediate airports, all other airports, including the terminus and the points of departure, were warned. Upon arrival at the terminal aerodrome, the news of the aircraft's landing was sent back to the intermediate stations and the point of original departure. Looking back, it is a little difficult to see what useful purpose the system served at the time, but it is perhaps of some interest to note that the elaborate precautions now taken to safeguard aircraft on civil air routes are based fundamentally upon the practice of an older form of transport.

The seeds of the present system were sown on the British stages of the London-Continental airway during the years 1920-1927. Three direction finding stations were provided during this period and with the comprehensive meteorological organisation already existing a comparatively large amount of bad weather flying on the Continental routes was made possible. Several cases can be cited of aircraft having flown either in or above the clouds to the vicinity of Croydon airport by means of positions obtained by direction finding ; the course for the last ten miles or so being checked by bearings received at the rate of two per minute. The late Captain F. L. Barnard, who flew Armstrong-Whitworth aircraft in one or two King's Cup races, was one of the first pilots to practice blind flying by the aid of radio direction finding and he never lost an opportunity of testing the possibilities of this form of navigation, with the result that he was always prepared in any but the worst of weather to trust implicitly in the ability of the radio personnel at Croydon to bring him over the aerodrome and to trust his own judgment in making the subsequent landing.

The complexity of the organisation required to ensure the rapid collection and dissemination of information vital to the control authorities and the crews of aircraft can be gauged if the various services which have to be provided at the present time are described.

First in importance is the aviation weather forecast service, which is organised on a truly international basis. So far as this country is concerned, radio weather messages are received daily by the Air Ministry at frequent intervals from :—

> Paris—which broadcasts by telegraphy collective messages containing reports from stations in Western and North-Western Europe, North Africa and the Eastern Atlantic ;
>
> Konigswusterhausen and Hamburg—which send out messages containing reports from stations in Northern, Central and Southern Europe ;
>
> Moscow—which broadcasts messages containing reports from stations in Russia and Siberia.
>
> Annapolis in America—which transmits American and Western Atlantic weather data.

All this information goes towards the making of the charts from which deductions as to the trend in the weather are drawn and circulated to pilots through the meteorological offices situated at the various civil airports.

Then there is a special weather organisation for each air route, which comprises the transmissions from selected stations of reports at half-hourly intervals. These reports are collected at some convenient centre, such as Croydon, and are broadcast to all other terminal aerodromes serving a given air route. The information so obtained is made instantly available for transmission to aircraft in flight, together with reports concerning sudden changes in visibility, cloud height and general conditions which, if considered to affect the regularity of air services, are sent additionally to the normal half-hourly reports.

So far we have dealt only with the collection and dissemination of weather information for aircraft engaged in regular transport services over given routes.

In order to make this information more generally available, the Air Ministry has erected a radiotelephony station at Borough Hill, near Daventry, which broadcasts radiotelephonic reports of weather conditions over Great Britain frequently throughout the day. This information is, of course, very valuable to special charter pilots and schools at which cross-country flying is carried out.

It is obviously necessary to provide a system for notifying the departure and arrival of aircraft engaged in international transport, together with details of the loads carried. This service was, in Western Europe and in this country, assured by means of medium wave radio-communication, but, owing to the increase in the amount of traffic and consequently the increase in the amount of signalling with its resultant delays, this type of information is now being transmitted by means of either short waves or special teleprinter circuits between airports.

Then there are what might be called the aircraft communication services, comprising stations for keeping touch with aircraft flying on the main stages of a route, stations used for local area communications, and, finally, navigational services, such as direction finding stations, navigational radio beacons and approach beacons using both medium and ultra high frequencies.

In Great Britain there are fifteen main radio stations, corresponding with aircraft flying on regular air routes. These stations are situated at Croydon, Pulham, Heston, Manchester, Portsmouth, Jersey, Bristol, Dublin, Belfast (Newtownards), Renfrew, Orkney, Shetland, Newcastle, Hull, Lympne. In addition, there are radio stations at Gatwick, Southampton, Doncaster, Isle of Man, Leeds-Bradford airport and Perth, which are used by aircraft approaching these airports for the purpose of obtaining navigational and weather information prior to landing.

All these two-way stations operate on medium wavelengths, and, with the exception of Lympne and Pulham, are equipped with Marconi-Bellini-Tosi direction finding apparatus.

The Bellini-Tosi system has been utilised so extensively because the majority of the stations mentioned are of a semi-permanent character and must necessarily remain so until such time as the recommendations of the Maybury Committee on the subject of air route control are implemented. During 1935 and 1936, when internal air transport commenced to grow, there was little or no regular night flying, and therefore a direction finding system prone to inaccuracy during the periods of darkness was not objectionable—in fact, the ease with which the aerial system may be erected and calibrated was an advantage at the time. The transmitting apparatus employed at most of the semi-permanent stations is housed in trailers and consists of the well-known Marconi D.M.1A. These trailers were arranged in such a way as to permit the complete stations to be operated from the vehicles, but, where convenient, the direction finding station was erected near the main buildings of the airport in order to facilitate liaison between the control authorities and the radio personnel; in these cases, of course, provision is made for the transmitter to be controlled remotely. As the direction finding stations are frequently used by pilots for the purpose of locating an airport in bad visibility, it is obviously desirable that they should be located close to the landing area and this need has been provided for at most airports.

At present, only the London-Continental airway is flown at night regularly, and in consequence this route is equipped with direction finding apparatus which allows accurate bearings to be taken during darkness. Most of the stations serving the British stage of this route are equipped with the latest Marconi-Adcock apparatus, which permits bearings to be taken simultaneously on two receivers, although only one aerial system is employed. Such a high degree of efficiency has been obtained with these receivers that it is possible to take simultaneous bearings on one station with almost 100 per cent. accuracy. This type of station was developed to meet the conditions met with on an air route where it is necessary to employ two frequencies for general communication purposes in order to avoid congestion.

In the past, the erection of the Marconi-Adcock system at an airport has presented difficulties on account of the facts that its aerials offered obstructions to aircraft; that it was necessary to instal the receiver in its hut in the middle of the aerial system and that, in order to prevent erroneous observations due to reflection of radio waves from metal buildings, wires or iron fences, it was important to place the station within an area free of all such obstructions. The latter consideration has been mainly responsible for the non-appearance of the Marconi-Adcock system at the airport of London, which is, of course, the terminus of a route flown by night. Now, however, it has been found possible to lead the energy received by the aerial system, by way of high frequency feeder lines, to a goniometer and receiver situated at some point remote from the aerials. At present, there is a limit to the distance from an Adcock aerial system at which a goniometer and receiver may be worked accurately, but the progress made during the last few years with the development of this form of direction finding makes one sanguine about the extension of this scheme in the near future. It is of interest to note that the new airport at Jersey is to be equipped with Marconi-Adcock apparatus, the aerial system of which will be 366 yards from the airport buildings, where the actual receiver and goniometer will be installed.

Before proceeding to describe how the various methods of airport and airway control are exercised by means of radio, it is desirable to outline the functions of the many types of radio beacon, which, in greater or lesser degrees, form part of a control system.

Radio beacons may be divided into the following classifications :—

(A) Medium wave beacons, for navigational and airport approach purposes.

(B) Ultra short wave beacons for airport approach purposes.

Medium wave beacons sub-divide into various classifications, such as omni-directional beacons, which are transmitters radiating from omni-directional aerials and transmitting a signal consisting of the station's call sign repeated several times and a long dash. This type of beacon is used largely in the mercantile marine service and its purpose is to enable ships to establish their positions by observing the bearings of a group of these stations by means of a direction finding receiver.

The omni-directional beacon has not in the past received very much attention from the aeronautical signals authorities because it entails the carriage of direction finding receivers in aircraft additional to the normal two-way communication apparatus. Owing to the fact that it is only within very recent times that the radio on board an aircraft has been operated by a separate member of the crew and that space in aircraft for other than essential radio apparatus has been restricted, it has not been possible to insist upon the carriage of special direction finding apparatus. Of course, directional receivers have been employed in aircraft for a very long time, but they have usually taken the form of attachments to the normal receiver. As the present tendency is to carry in all large aircraft a navigator—or at least somebody responsible for navigation—aircraft direction finding will become an important adjunct to the aircraft's instruments. The increase in signalling on the normal communication wavelengths is having the effect of slowing up the process of obtaining assistance from the ground direction finding organisation, therefore, the International Aeronautical Conference has planned groups of omni-directional beacons in various parts of Europe. Separate frequencies will be allotted to each group, and the stations of a group will transmit, one after the other, thus enabling several aircraft to plot positions simultaneously by means of their own direction finding apparatus. In addition, such an organisation permits aircraft to " home " on the airport of destination, since all the omni-directional beacons will be situated at important airports. It is not the intention to instal special stations for this beam system ; in the majority of cases, transmitters hitherto used for the point-to-point service and now freed by the introduction of short wave channels and teleprinter circuits, will be employed. As most of the transmitters will radiate between 150 and 250 watts, it will be possible for aircraft to obtain good bearings at almost any point within the areas served by these groups.

The medium wave beacon next in importance is perhaps that known as the " equi-signal " type. It is employed both for navigational and airport approach purposes. The " equi-signal " beacon comprises a directional aerial system capable of producing either two or four zones—usual equi-spaced—of equal signal strength. In the four course system, each component loop of the aerial system is energised alternately by a signal corresponding to an interlocking Morse symbol. For instance, the symbol " T " might be interlocked with the symbol " E." It will be seen that there are zones in which the Morse symbols combine to form a steady note upon receipt of which a pilot knows that he is " on course." A beacon of this type has been erected by the Marconi Company at the airport of London and will, it is understood, be used for demarcating approaches to the airport. The equi-signal beacon is used to a tremendous extent in the United States for navigational purposes, and is one of the two radio aids provided by the Federal Department of Commerce for air transport in that country.

The two-course medium wave beacon, which is almost entirely used in connection with airport approach work, consists of a transmitter energising two aerials—one of the frame type, the other having omni-directional characteristics. As is well known the characteristic radiation pattern of a frame aerial takes the form of a figure of eight. If, therefore, the phase relationship between the radiated current in the frame and the omni-directional aerials is reversed periodically, two heart shaped diagrams will be produced, owing to the addition and subtraction of the current in the omni-directional aerial and those in each half of the loop. If, in addition, the omni-directional aerial is keyed in such a way that alternate dashes and dots are radiated, means by which a pilot may determine the position relative to the equi-signal zone are provided. The equi-signal zones lie at 180 degrees to one another. A beacon of this type has recently been installed at the Liverpool airport by the Marconi Company and tests are now being carried out.

Now, in addition to providing means by which a pilot may be guided towards or away from an airport, it is obviously necessary to give him some idea of his distance from the boundary of the airport for which he is bound, or to warn him when he is approaching a point at which he must pick up a beacon signal on another wavelength. This is effected by small low powered transmitters known as " marker beacons " radiating either constant signals on the wavelength of the main beacon or a signal which traverses that received from the main beacon in such a way as to produce in the pilot's headphones a note rapidly varying in audible frequency. The latter type of marker is used mostly in conjunction with medium wave beacons of the approach type, having been chosen in preference to the alternative type on account of the fact that, as continuous waves are employed for this system, the marker signal would be indistinguishable from that of the main beacon were it not for the continuous variation in audible frequency. In an approach system, it is usual to provide two marker beacons ; one situated about three miles from the boundary of the airport, the other being placed on the boundary of the airport itself. In order that the pilot may distinguish the signals of the outer marker from those of the inner, or boundary marker, the variations in the note emitted by the former take place at the rate of one per second, whilst those from the latter vary at the rate of five per second. The urgent character of the signals from the boundary marker is unmistakable and no pilot, after practice, fails to remember the connection between the rapid variations of tone and the approach to the landing area. Marker beacons of this type have been incorporated in the beacon system prepared by the Marconi Company for the Liverpool airport.

The medium wave beacons which have been described can be used for either navigational or approach purposes. Owing to the fact that the number of medium frequencies available for the aeronautical radio beacon service is far too small to permit beacons of this type to be erected at every airport, it has been necessary to explore waves of high frequencies which, by reason of their rapid attenuation near the ground, appear to permit the establishment of a number of beacons at aerodromes within a relatively small area without mutual interference. The desirability of such a state of affairs will become evident when one considers, for instance, the number of airports, all within a small radius, needed to serve London.

The ultra high frequency radio beacon, working on a wavelength of 9 metres, was first developed in America. Serious attention was given to the system about three years ago by the German Air Ministry, which commissioned the Telefunken and Lorenz Companies to undertake further development.

The shape of the radiation curve obtained with the Lorenz and Telefunken beacon provides a theoretical " glide path," and during the past few years very much experimentation has been carried out with a view to devising instruments to enable a pilot to feel his way either down the underside of the curved beam, or through it, on to the landing ground. Actually, experience gained with the Marconi short-wave beam system for long distance communication some years ago showed that the shape of the underside of the beam varies according to the conductivity of the ground immediately in front of the array. For instance, an increase in the water content of the ground will result in a flattening of the path. This means that the mean angle of the glide path cannot be guaranteed.

In addition, the use of the " glide path " introduces serious complications in the control of the aircraft being flown down it, because of the necessity of maintaining constant air speed during a descent which, of course, does not occur at a constant angle relative to the surface of the ground. In actual practice, this disability does not detract from the value of a beacon system as an aid to pilots attempting to make a landing in bad visibility, for, since the distance between the outer and boundary markers is always known, it is a comparatively easy matter to adjust the angle of the glide in such a manner that, when the signal from the boundary marker is received, the aircraft is at such a height that the landing can be effected in a normal manner under all but the very worst conditions of visibility.

There remains one type of ultra high frequency beacon to be described. The Marconi Company has, for some time past, been conducting experiments with a system which, whilst retaining all the advantages of the other systems, does away with some of their disadvantages. The maximum radiation from this system takes place at 90 degrees from the equi-signal zones. This means that much power is wasted and in addition forms a source from which interference with beacons at other airports may arise. In this case, the radiation is sensibly concentrated in the desired directions ; namely, on the borders of the equi-signal zone. This enables a considerable saving to be made in the power required to operate the station, resulting in lower prime and maintenance costs. Actually, it is possible to obtain the ranges identical with those secured by the use of the German system by the employment of approximately one-third of their power. Only one equi-signal zone is normally provided. Another zone at an angular displacement of 180 degrees can be obtained by an alteration to the keying system ; no addition to the aerial system being required.

In Europe, control systems fall into two categories :—

Area control.

Airport zone control.

Area control consists of measures to ensure the safety of aircraft which have shaped courses for their destinations after completing the "take-off" and having reached the cruising height.

The departures of all aircraft engaged on international flights are signalled to the first stopping places, and to the terminal airports, thus enabling the control officers at those airports to estimate the times of arrival, and thus take any steps which may be necessary in advance to assist the approach of an aircraft.

The control officers at the airport of departure are responsible for advising an aircraft of weather conditions, and the movements of other aircraft, until it passes out of their zone, and, where possible, maintain a watch upon its progress subsequently for as long as its radio signals can be received. This precaution is necessary, for a pilot may be forced by weather, or other causes, to re-enter the control area and its presence may have the effect of modifying instructions given to other aircraft.

Upon quitting an airport, an aircraft must immediately advise the control by radio of its time of departure, its destination, its course, its height and whether it is climbing, descending or flying level. In addition, it must signal whether it is flying in cloud. This information is immediately transferred to a map of the area in which the aircraft is flying ; the aircraft itself being represented by a flag raised above the surface of the map to indicate its altitude. The control officer then considers the effect of the entry into his zone of this aircraft upon the flight plans of other aircraft in the zone and will advise changes of height and course if he considers it necessary.

It should be mentioned that control in Great Britain is, at present, purely advisory ; that is, the control officers, whether servants of the State or of the local airport authority, are not empowered to issue orders to pilots as to the height at which flight must be maintained, the speed of the flight, or the course to be steered. No pilot, however, would reject any reasonable advice received from a control, so that in practice, if not in theory, supervision is rigid. Most air lines would, of course, require explanations from any pilot who jeopardised his aircraft and its passengers and freight by disregarding the advice of a control officer.

The information contained in the radio message sent by a pilot immediately after his departure from an airport constitutes a " flight plan " and any changes thereto must be instantly notified for they may endanger other aircraft. For instance, if a pilot decides to fly in cloud at a certain height or to descend through a bank of cloud, risk of collision may arise which can be averted only by speeedy action on the part of the control.

The progress of an aircraft through an area is checked by means of position reports which are sent when either over or in the vicinity of certain landmarks which have been agreed upon internationally. When an aircraft is flying in or above cloud, its position can be determined only by radio direction finding.

As a result of long experience, the following forms of direction finding assistance have been found necessary on most air routes :—

(A) Positions in terms of direction and distance from a recognised landmark, which are obtained by the collaboration of two or more direction finding stations, the resultant bearings being plotted at the control.

(B) The bearings, usually obtained from the terminal airport.

(C) Magnetic reciprocal bearings, obtained from the terminal airport. A magnetic reciprocal bearing consists of the reciprocal of the true bearing to which allowance for magnetic variation has been made. Magnetic reciprocal bearings are often loosely called " courses," but the practice may easily give rise to serious consequences, since the information given by the direction finding station in response to a request for this form of assistance does not and cannot contain allowances for deviation and drift.

When an aircraft leaves one area and enters another, its pilot must notify the controls of each of the fact, and the " flight plan " must be signalled to the control of area just entered. If the terminal airport happens to be in this area, the pilot must also signal his estimated time of arrival in order that the control may make plans well in advance for the landing. The early receipt of this information is especially important when conditions of bad visibility exist at the terminal.

Airport zone control is concerned with the safety of aircraft within the vicinity of busy aerodromes. The size and shape of the area in which this form of control is exercised vary considerably, and there is no clearly defined policy as to what the ideal dimensions are, owing probably to the fact that methods of enabling aircraft to approach and alight at an airport in conditions of bad visibility are still largely experimental.

Full airport zone control is only instituted when weather conditions at the landing ground are bad. In normal circumstances, the control officers are concerned only with the observance of the usual rules regarding taking-off and alighting.

In order to give a clear idea of the workings of full airport zone control the procedure adopted at Croydon will be described.

It has already been explained that when entering a zone in which the terminal airport is situated the pilot of an aircraft advises the control of his estimated time of arrival. If zone control is in force, the pilot is accordingly informed and he is given a number which indicates his turn for landing. The controlled zone at Croydon has its boundary some 10 to 15 miles away from the airport. On approaching this boundary, a pilot is told whether he can enter it or not. Permission to enter the zone does not give the right to proceed to the airport and effect a landing. In general, it may be said that if the aircraft is in clear air above the bad weather it will be allowed to enter the zone and wait there until it receives permission to land. When that permission is granted, the aircraft is instructed to conduct its radio correspondence upon a specially allotted wavelength. From then onwards the pilot receives direction finding bearings and instructions until he lands. If, however, he is unable to effect a landing within a reasonable time and other aircraft are waiting, he may be told to proceed away from the zone on a course advised by the control, which will lead him away from any other aircraft in the zone.

The scheme outlined above will undergo modifications when the radio beacon organisation at Croydon has been perfected.

Inevitably there are many variations in application of zone control, each depending upon the facilities which exist for assisting aircraft to locate the airport.

In Germany, most of the main airports employ the ultra high frequency beacon system. In this case, an aircraft, after entering the zone and receiving permission to effect a landing, tunes into the radio beacon signals and flies towards the airport.

In Holland, a similar scheme is in operation except that medium wave beacons are employed.

Belgium has recently installed a medium wave beacon at the Brussels airport and the procedure for landing is similar to that employed in Holland.

France has had several systems under investigation at Le Bourget. Of these, the following may be mentioned :—

(A) The " ZZ " system, originally introduced in Germany. In this system, the pilot directs his course towards the airport by means of bearings received from the main direction finding station. After being informed that he is over the airport, he flies away in a pre-determined direction for a period of approximately ten minutes, and then executes a turn of 180 degrees. On the completion of this turn he commences to send out a series of signals on which bearings are taken by a special direction finding station situated at the edge of the airport. When he is on the correct approach path, the ground station informs him of the fact by radio. When he passes over the station the signal " ZZ " is transmitted. If the pilot has adjusted his height correctly after completing the 180 degrees turn, a normal glide should bring him to such a height at the moment of receiving the " ZZ " signal that a landing within the airport should be effected without difficulty.

(B) A medium wave beacon with markers.

(C) An ultra high frequency beacon with markers.

France appears to have adopted the same cautious policy as ourselves with regard to the employment of aids for landing and at present the tendency appears to be towards experimentation with a view to determining the relative merits of medium and ultra high frequency beacons.

Future Development in Air Route and Airport Control.

At the present time, complete air route and airport control exists in Great Britain only at Croydon airport, where it is exercised by officers appointed by the Air Ministry. Area control exists at Heston airport, where the staff is under the supervision of an Air Ministry officer. At other airports in the country, the duty is entrusted to officials appointed by the local airport authority and, owing to the fact that a large number of the municipal airports are without radio facilities, any control exercised must be restricted to the enforcement of the usual rules for conducting flight in the vicinity of an aerodrome.

It is obvious that any great expansion of commercial flying on the internal airways will call for a properly co-ordinated plan for the control of aircraft—in fact the need already exists, especially in the north-west of England.

Until the report of the Maybury Committee has been implemented, it is perhaps unwise to put forward any views on the type of organisation that is required.

There are, however, certain fundamental points which will have to be dealt with, whatever system of control is eventually recommended.

The most important one is the fact that commercial aircraft have not the monopoly of the air ; the rapidly expanding Royal Air Force will require more space for exercising, especially on account of the high-speed aircraft with which the service is being re-armed. Then the requirements of the private pilot have to be considered. Obviously, it is impossible to make the carriage of two-way radio equipment on every aircraft compulsory at this stage of development ; it would be equally impossible to accommodate the radio traffic resulting from any such compulsion on the limited number of frequencies available for civil aviation at present.

Therefore, although radio will increase in importance as an indispensable aid to the efficient control of traffic on organised airways, some other means of protecting the general safety of life in the air must be sought, and it seems that the American system of strata flight may become necessary. A recent regulation has been issued by the Bureau of Air Commerce requiring aircraft flying on courses between 360 degrees and 179 degrees to fly at odd thousands of feet, i.e., 1,000, 3,000, 5,000, 7,000 feet, while those flying on courses between 180 degrees and 359 degrees must maintain flight at the even thousands of feet, i.e., 2,000, 4,000, 6,000 and 8,000 feet. This regulation only applies in conditions of bad visibility to the airways recognised by the Federal authority.

The institution of any such arrangement—which, incidentally, would need some modification before being applied in this country, by reason of the requirements of service and private flying—would necessitate a somewhat different form of control from that employed at Croydon, where area and local zone control is exercised simultaneously by the same personnel.

It will be found that eventually the country will be divided into radio-communication areas, each with its own control office situated at its centre. Each office will be equipped with two-way radio-communication and direction finding station and the object of placing the office near the centre of the area served would be to make the most effective use of the radiation from the transmitting station and, at the same time, to restrict interference to the stations of control offices in adjacent areas. It would be necessary for each control office to be connected with the others and with the local meteorological office by landlines in order to facilitate the exchange of information regarding the movements of aircraft and weather conditions. In addition, the aerodromes and airports of an area would need to be connected to the area control office by landline.

To obtain flexibility with such a system, a centrally situated exchange is ideally necessary, but it is possible that such elaboration could be obviated by the provision of short wave radio channels, through which messages would be passed either by Morse or special teleprinters.

Important airports and aerodromes within an area would need to be equipped with low-powered two-way radio-communication apparatus, together with either direction finding and radio beacon facilities, or perhaps both.

The introduction of such a system as this would, without doubt, lead to the assumption of responsibility by the Air Ministry for area control, leaving local authorities free to exercise control over traffic in and out of airports under the supervision of the area control office.

A system similar to the one just outlined is being instituted in the United States and three area control offices are already in operation and another five are projected. Pilots of each aircraft must, before leaving on a scheduled flight, prepare a scheme showing altitude of flight, the estimated time of arrival over various points *en route* at which positions can be checked by radio, and the estimated time of arrival at the airport of destination. This scheme is then submitted to the area control office and unless it conflicts with the movements of other aircraft within the area the pilot is given clearance.

One of the difficulties connected with this scheme concerns the provision of controlled areas in the vicinity of airports and it is difficult to see how zones large enough are to be provided in the London area without overlap and the closing of through corridors below a certain height.

There can be little doubt that whatever system is introduced now, the rapid advance of technique will make early modifications necessary, especially in regard to local zone control, where television may eventually supersede some of the present methods of assisting landings.

In fact, the technique of air route control is just emerging from its infancy, and many branches of science will be called into play in the effort to further its efficacy, for aviation, both service and civil, can only be safeguarded by continual research and experimentation.

L. A. SWENY.

GENERAL EQUALISER THEORY, TWO TERMINAL AND CONSTANT RESISTANCE STRUCTURES

PART II.

The first part of this article appeared in the last number of THE MARCONI REVIEW, *and the article is completed in this part.*

Design Methods.

The data for design which must be available are the value of the terminating impedances between which the equaliser is to be inserted, the required attenuation-frequency characteristic of the equaliser and factors enabling a choice to be made of the type of equaliser to be used. These latter factors are chiefly concerned with impedance conditions, for the series and shunt insertion equalisers operate by virtue of changing the impedances facing both the generator and load, the constant resistance structures (A) and (B) face either the load or the generator with a characteristic impedance varying with frequency, while the remaining constant resistance types provide an invariant characteristic resistance. The particular use must decide which of these properties be preferred—for example, the need for proper valve loads may rule against the simplest forms. As type (E) of the constant resistance structures uses only two reactance arms, this type is commonly to be preferred to any other.

Examining these data, after a choice of type, in the light of the previous paragraphs it will be evident that much labour can be saved if the maximum attenuation required from the equaliser can be estimated. The saving of work will still be appreciable if the estimate has later to be modified and a recalculation undertaken.

In making this estimate, some features of all equalisers are usefully remembered. The dissipation occurring in all practicable components prevents zero attenuation being obtained and results in a " rounding " of the attenuation characteristic in this neighbourhood. The sharper the required decrease of attenuation in this neighbourhood, the higher the reactance values involved and the greater the minimum attenuation. Experience must decide the allowance to be made for this feature, dependent, as it is, on the components used. Alternatively, the equaliser can be designed on a dissipationless basis, the effective resistance of the reactance arms at minimum attenuation computed from the components' properties and the effective minimum attenuation resulting read from Fig. 5. This value can then be used for a revised maximum attenuation estimate and the design repeated—a process of successive approximation.

Presuming that the maximum attenuation has been estimated, it has been shown possible to translate the required attenuation-frequency characteristic into a required reactance-frequency characteristic, by the aid of Figs. 2—5. On this new curve points can be selected for the deduction of components' values. An inspection of Figs. 2 and 3 will show that the requisite reactance values increase very rapidly as the attenuation approaches the maximum. Hence if calculations are based on points in this region, small errors in data may lead to large errors in component values. A useful rule is therefore to base reactance design on data culled from regions away from both maximum and minimum attenuations.

To carry the design further, since equalisers are usually restricted to a small number of components for practical reasons, one of the eight reactance networks shown in Fig. 6 should be selected.

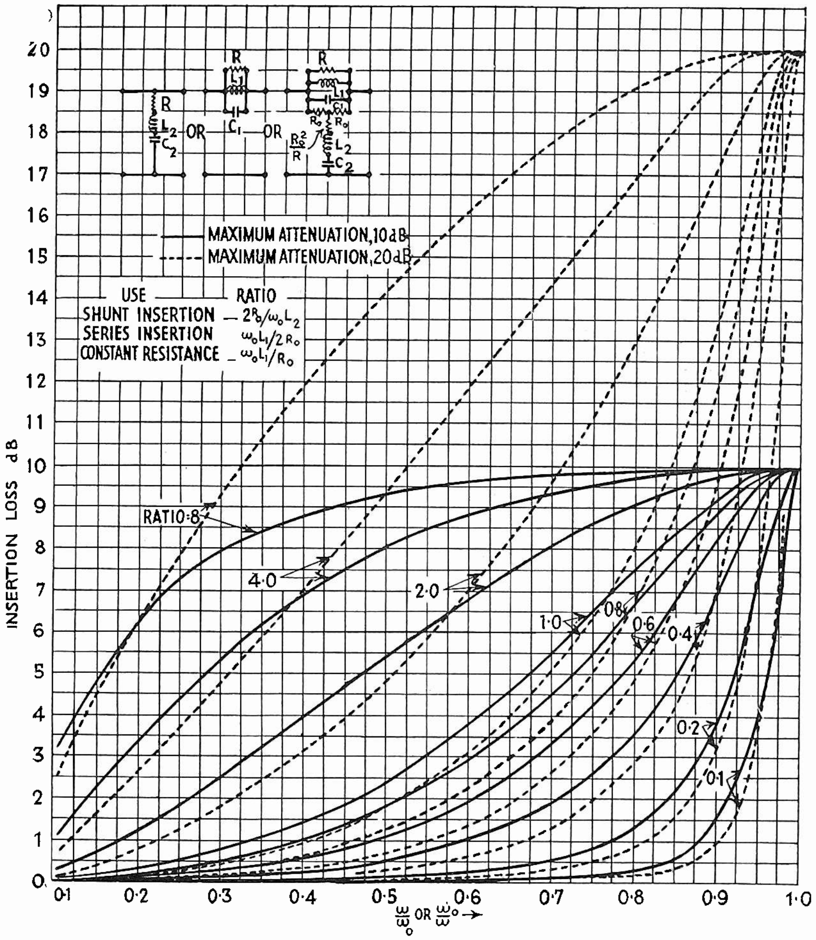

FIG. 9.

The formulæ for the more complicated networks are all based on a frequency of maximum or minimum impedance and the value of this frequency can usually be readily deduced from the data.

The next step is to form a number of simultaneous equations from the reactance-frequency requirements—two such equations if three components per arm are chosen and three such if four components are permitted. The solution of these equations, together with the frequency of maximum or minimum impedance chosen will determine the component values.

In the selection of a suitable network, a most useful simplification is that mentioned previously under "Reactance Characteristics." If a network of, say type A, provides a particular attenuation characteristic in series insertion, the same characteristic can be provided by the same number of components in a network of type B in shunt insertion. Again, the constant resistance structure of Fig. 1 (E) providing the same attenuation-frequency characteristic will use a series arm of the form for series insertion with a shunt arm of the form for shunt insertion. Thus it is only necessary to think of equaliser characteristics produced by the various network types when used as the series element in a constant resistance structure of type (E).

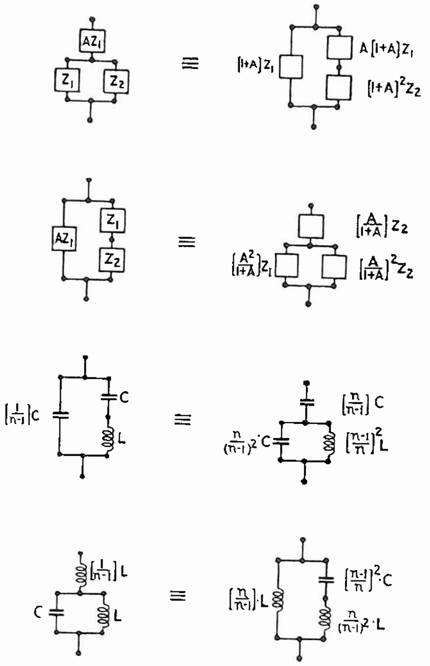

FIG. 10.

Using this assumption, the following broad guidance may be given :—Figs. 7, 8 and 9 show the behaviour of the simplest networks, but these may prove inadequate. This inadequacy occurs particularly if very rapid attenuation increments with frequency are required, e.g., for filter cut-off corrections, and is shown by impracticable component values. In such cases, three-element networks may be recommended, type A serving for a low-pass cut-off, type B for a high-pass cut-off. In the case of a band-pass correction, the four-element networks deserve consideration.

In general, an equaliser using more complicated networks provides a lower minimum attenuation than a number of equalisers used in tandem and is therefore preferable. It is not, however, always possible to provide the same characteristic by one complicated structure as may be available from two or more of simpler type.

Intervalve Correctors.

Corrector circuits used between the stages of an amplifier are commonly of three types, the correcting network being inserted in a cathode-earth connection, in series with the anode coupling to the succeeding grid or in shunt with that grid.

In cases where the valves' input admittances can be neglected, the first of these types can be translated into the form of an impedance added to that of the valve. The plate and grid coupling shunt impedances then form the effective load and the circuit is that of a valve generator with a series insertion corrector between it and a load. If a coupling condenser of appreciable impedance over the range considered is in use, this equivalent circuit must, of course, be modified.

For a corrector inserted in series between an anode and grid, the case is obviously that of the series insertion equaliser, with a load formed by the grid shunt impedance. The valve plate generator admittance and shunt coupling admittance are of course together equivalent to a generator of admittance equal to their sum.

When the corrector is in shunt with the succeeding grid, a separate shunt grid coupling element is not always used, e.g., the corrector has a finite impedance at zero frequency and so serves as a connection for the grid bias. In this case, if the coupling condenser has negligible impedance, the corrector can be considered as in shunt between a generator and load each equal to twice the impedance of the complete valve plate circuit. In other cases the corrector circuit may be more convenient in an equivalent form.

Caution must always be used in the design of such correctors, lest the effective plate load on valves be made undesirable.

Lemma—Inverse and Equivalent Networks.

In the constant resistance equalisers a network is specified to furnish a reactance equal to the square of the characteristic resistance divided by a designed reactance. Reactances of this type are said to be "inverse" and are discussed under this heading in the text books. For the present purpose, it will suffice to say that the inverse form to any of the networks shown in Fig. 6 as type A is that shown as type B and having the same number of elements. The converse is also true.

The component values are simply related as follows, using the subscripts A and B for the elements in networks of those types :—

$$\frac{L_B}{C_A} = R_o^2 = \frac{L_A}{C_B}$$

$$n_A = n_B \; ; \; m_A = m_B$$

In the same way the limiting resistances R_1 and R_2 used respectively in shunt with a series reactance and in series with a shunt reactance are related by :—

$$R_1 R_2 = R_o^2.$$

A number of element arrangements are shown in the text books to provide the same impedance behaviour if their component values are in proper proportion. Such networks are said to be "equivalent" and acquaintance with such alternatives frequently permits more convenient choice of component values for the same result. The usual procedure is to base design on, e.g., the networks shown in Fig. 6 and, when the component values have been determined, calculate such equivalents as seem promising. As examples which have been found useful the following cases may be mentioned : An intervalve shunt corrector comprising a resistance in series with a condenser shunted by a second resistance can be made equivalent to a resistance shunt and a second shunt consisting of a resistance and capacity in series —an equivalent allowing one component to be absorbed in generator or load impedances. Again, the network shown as Class 3A can be translated to a condenser in series with a parallel tuned circuit, while that shown as Class 3B can be rewritten as a series resonant circuit shunted by an inductance. Each of the networks of Class 4 can be shown equivalent to any one of three other arrangements.

Formulæ for the three element cases are shown in Fig. 10. For more complicated cases the text books should be consulted, notably K. S. Johnson's "Transmission Circuits for Telephone Communication," Appendices D and F.

Example.

As an example of the practice evolved from the preceding formulæ, the design basis for the results shown in Figs. 11 and 12 may be given. The first of these figures shows a filter frequency-response characteristic, for which the "rounding" in the neighbourhood of the lower cut-off required equalisation. The same figure shows the degree of success achieved by a filter plus equaliser characteristic. It may be remarked that detailed adjustment on test might have improved the result slightly, but not to any large extent. Fig. 12 shows the equaliser component values and connections as well as the frequency-response characteristic of the equaliser alone.

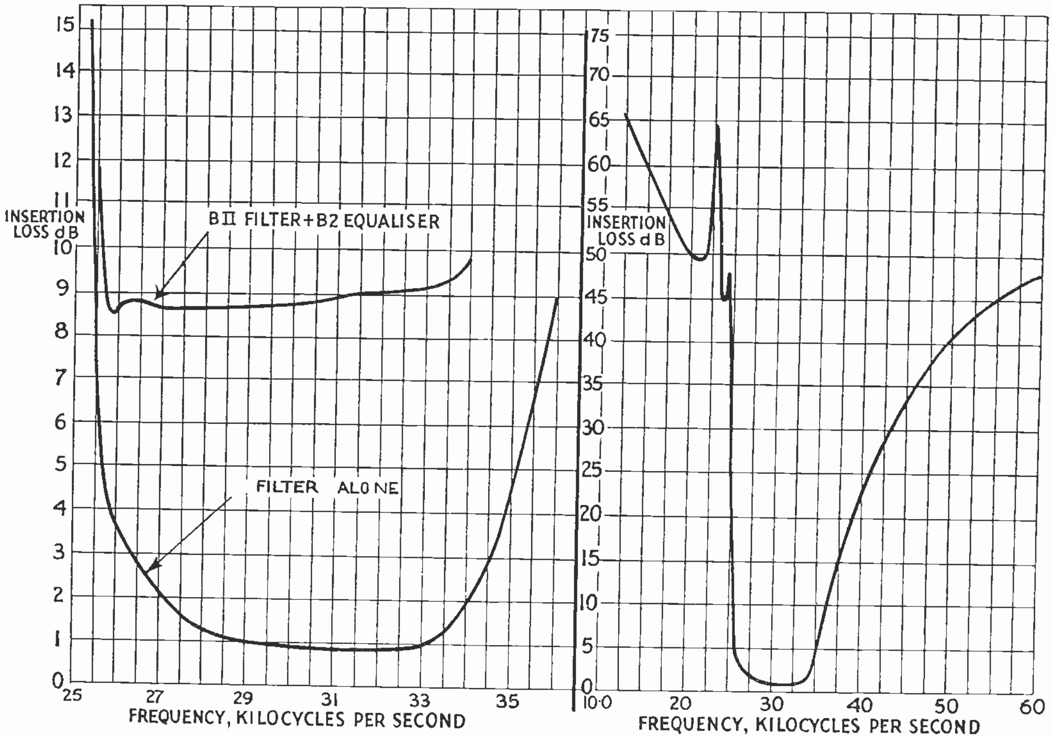

FIG. 11.

The data taken were :—

$R_o = 600$ ohms ; maximum attenuation 7.5 dB. ; minimum attenuation at 25.5 kcs.

Attenuation at 25.86 kcs., 3.2 dB.

Attenuation at 27.36 kcs., 6.0 dB.

The maximum attenuation and R_o values for a constant resistance structure yield $R_{11} = 822.8$ ohms and $R_{21} = \frac{600^2}{R_{11}} = 437.5$ ohms.

Calling 25.86 kcs. ν_1 and the reactance required there $\phi(\sigma_1)$, the formulæ or charts give $| \phi(\sigma_1) | = 459.8$.

Similarly if 27.36 kcs. be ν_2 and the reactance there $\phi(\sigma_2)$, then $| \phi(\sigma_2) |$ 1,108.2

As a next step, the network 3B of Fig. 6 was chosen to form the series arm of the constant resistance structure. For this choice,

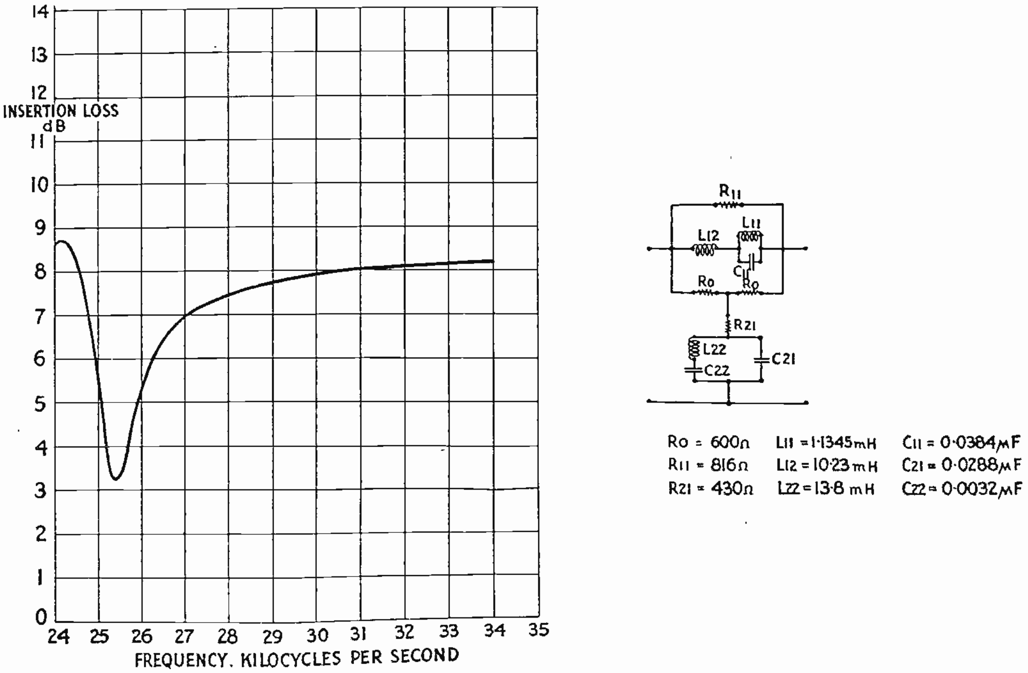

FIG. 12.

$$|X| = \frac{\omega_\infty L}{n-1} \cdot \frac{\omega}{\omega_\infty} \cdot \frac{\left[n - \dfrac{\omega^2}{\omega_\infty^2}\right]}{\left[1 - \dfrac{\omega^2}{\omega_\infty^2}\right]} \quad \text{and} \quad \frac{\omega_0^2}{\omega_\infty^2} = n$$

Hence $$\frac{\phi(\sigma_1)}{\phi(\sigma_2)} = \frac{\nu_1}{\nu_2} \cdot \frac{\nu_0^2 - \nu_1^2}{\nu_0^2 - \nu_2^2} \cdot \frac{\nu_\infty^2 - \nu_2^2}{\nu_\infty^2 - \nu_1^2}$$

Inserting figures, $\dfrac{\nu_\infty^2 - \nu_2^2}{\nu_\infty^2 - \nu_1^2} = 1.969.$

whence $\nu_\infty = 24.22$ kcs.

and $n = 1.109.$

Now to procure a value for L,

$$|\phi(\sigma_1)| = 459.8 = \frac{2\pi\nu_\infty L_{11}}{n-1} \cdot \frac{\nu_1}{\nu_\infty} \cdot \frac{\left[n - \dfrac{\nu_1^2}{\nu_\infty^2}\right]}{\left[1 - \dfrac{\nu_1^2}{\nu_\infty^2}\right]}$$

In this equation only L is unknown. Solving, the value obtained is $L_{11} = 1.134$ mH. The remaining components of the series arm follow from :—

$$C_{11} = \frac{1}{4\pi^2\nu_x{}^2L} \qquad \text{and } L_{12} = \frac{L_{11}}{n-1}$$

The shunt arm derives from the values so obtained.

$$L_{22} = C_{11} \times 600^2\,;\; C_{22} = L_{11} \times \frac{1}{600^2} \text{ and } C_{21} = L_{12} \times \frac{1}{600^2}$$

It will be noticed that all component values are normally in henries, farads and ohms.

On examining the filter curve, the data taken and the equaliser characteristic, discrepancies will be noted. These discrepancies are due to dissipation in components and the selection of data must largely be guided therefore by judgment. Alternatively, once the component values have been calculated, the dissipative case may be studied and the data revised.

Taking the simple case of minimum attenuation and writing Q for the coil reactance-resistance ratio, the calculated components will provide a series arm effective resistance of $16{,}950/Q$—which for $Q = 50$ is 339 ohms. This, in shunt with the permanent 822.8 ohms is equivalent to a total series resistance of 240 ohms, a value for which Fig. 5 shows an attenuation of 2.6 dB. For greater accuracy, the shunt arm effective resistance must, of course, be calculated.

F. M. G. MURPHY.

TUNED LINES AS REACTANCES

A recent paper on "Oscillators Stabilised by Resonant Lines" (MARCONI REVIEW, *Sept.-Oct.,* 1936, *No.* 62, *page* 14) *contained a brief reference to the selectivity characteristics of reactances consisting of lines whose length is suitably proportioned to the wavelength: and it was stated that whereas Terman showed that the rate of change with frequency of the reactance of such a line is greater than that of a single lumped reactance, a better comparison is with a circuit including both lumped inductance and lumped capacitance, which also has a greater rate of change of reactance with frequency than a single lumped reactance. The author is indebted to Dr. Zeppler and Dr. Böhm, of the Marconi Company, for pointing out that the proof there employed* (*equations* 10 *to* 13 *of that paper*) *is not satisfactory. Accordingly, the following is offered as a more complete treatment of this particular type of line.*

THE simplest lines which can be used as reactances are of length $(1/8)\lambda$ and $(3/8)\lambda$ (i.e. the optimum reactive lengths on either side of a $\lambda/4$ resonant line). Equation (8) of the previous paper, in agreement with Terman, gives the rate of change with frequency of the reactance of a line remote from resonance as

$$\frac{dX}{X} = \frac{4\pi l/\lambda}{\sin. 4\pi l/\lambda} \cdot \frac{df}{f} \qquad \ldots \qquad (1)$$

Substituting in this equation the values of 1/8 and 3/8 for l/λ will give $dX/X = (\pi/2)\, df/f$ and $dX/X = (-3\pi/2)\, df/f$ respectively. Now compare with the line a circuit comprising inductance L and capacitance C in series; at frequencies remote from resonance we may neglect the resistance, as was done with the reactive line, so that the net reactance of the circuit is

$$X = pL - 1/pC = pL\,(1 - p_0^2/p^2) \qquad \ldots \qquad (2)$$

where p is 2π times the frequency, and $p_0^2 = 1/LC$. Now let $p_0 = p$ for this circuit correspond to $l = \lambda/4$ for the line; then corresponding to $l = \lambda/8$ and $l = 3\lambda/8$ for the line, the conditions for the circuit with lumped reactances are $p_0 = 2p$ and $p_0 = (2/3)\,p$ respectively. On differentiating equation (2), it is found that

$$\frac{dX}{dp} = L\left\{1 + \frac{p_0^2}{p^2}\right\} \qquad \ldots \qquad (3)$$

$$\frac{dX}{X} = \left\{\frac{1 + p_0^2/p^2}{1 - p_0^2/p^2}\right\} \cdot \frac{dp}{p} \qquad \ldots \qquad (4)$$

Substituting in this equation the values $p_0 = 2p$ and $p_0 = (2/3)\,p$, the resulting values of dX/X are $(-5/3)\, dp/p$ and $(13/5)\, dp/p$, both greater than dp/p, and of the same order of magnitude as the values found above for the $\lambda/8$ and $3\lambda/8$ lines, namely $(\pi/2)\, df/f$ and $(-3\pi/2)\, df/f$. Performance comparable with that of longer lines (e.g. 5/8, 7/8 wavelength) could only be obtained by the use of a greater number of lumped reactances; the complexity of such a circuit is an obvious difficulty in practical application, but so is the bulk of a line which is longer than the minimum fraction of a wavelength that will give the desired type of impedance (inductive, resistive, or capacitive).

Since a resonant line (multiple of $\lambda/4$ in length) follows the same frequency law as a simple resonant L,C circuit, yet a tuned line which may be used as an inductance or capacitance (multiple of $\lambda/8$ in length) has greater selectivity than a lumped inductance or capacitance (corresponding in fact to a circuit built up of two or more lumped reactances), it would at first sight appear that benefit could be obtained from this greater selectivity by using a line such as $\lambda/8$ to replace one component of a tuned circuit, rather than using a resonant line such as $\lambda/4$ to replace the whole tuned circuit. But immediately a condition of resonance is established, the approximation of neglecting the resistance, which was employed in considering the line used as a reactance, ceases to be valid. For example, suppose a line of $\lambda/8$ (inductive reactance) to be joined to a condenser of correct capacitance to form a resonant circuit ; if the condenser is of very low loss, it may be that the resistance in the tuned line is an important factor in controlling both the amplitude of the current at resonance and the frequency characteristic of the system.

For such an arrangement we therefore revert to the full equation of the line,

$$Z = Z_0 \cdot \frac{\sinh. 2\,\alpha l + j. \sin. 2\,\beta l}{\cosh. 2\,\alpha l + \cos. 2\,\beta l} \quad \cdots \quad (5)$$

where $\beta = 2\pi/\lambda$ and $\alpha = R\ 2Z_0$. Since the attenuation constant α is small, we may approximate $\sinh. 2\,\alpha l \doteqdot 2\,\alpha l = Rl/Z_0$ and $\cosh 2\,\alpha l \doteqdot 1$. With these approximations equation (5) takes the form

$$Z = Z_0 \cdot \frac{(Rl/Z_0) + j.\sin. 4\pi l/\lambda}{1 + \cos. 4\pi l/\lambda} \quad \cdots \quad (6)$$

The reactive component is

$$Z_0 \cdot \frac{\sin. 4\pi l/\lambda}{1 + \cos. 4\pi l/\lambda} \quad \cdots \quad (7)$$

which for $l = \lambda/8$ reduces to $X = Z_0$. Series resonance could therefore be obtained with the aid of a condenser C such that $1/2\pi f_0 C = Z_0$, i.e. $C = 1/2\pi f_0 Z_0$, where f_0 is the desired frequency of resonance corresponding to $l = \lambda/8$. At any frequency f the net reactance is then

$$X = Z_0 \cdot \frac{\sin. 4\pi l f/c}{1 + \cos. 4\pi l f/c} - \frac{2\pi f_0 Z_0}{2\pi f} \quad \cdots \quad (8)$$

(In equation (8), l/λ has been replaced by f/c, the letter small c being used for the velocity of electro-magnetic waves.) Now let the actual frequency be $f = f_0 + \delta f$; as long as δf is reasonably small, i.e. the frequency is within the working part of the resonance curve of a highly selective circuit, we may neglect $\cos. 4\pi l(f_0 + \delta f)/c$ in comparison with unity, so that

$$X = Z_0 \cdot \sin. 4\pi\, l(f_0 + \delta f)/c - f_0 Z_0/(f_0 + \delta f) \quad \cdots \quad (9)$$

This can be expanded to

$$X = Z_0 \left\{ \sin. 4\pi l f_0/c \ \cos. 4\pi l \delta f/c + \cos. 4\pi l f_0/c. \ \sin. 4\pi l \delta f/c - f_0/(f_0 + \delta f) \right\} \quad \cdots \quad (10)$$

With the usual approximations for small values of δf, namely $\cos. 4\pi l \delta f/c \doteqdot 1$ and $\sin. 4\pi l \delta f/c \doteqdot 4\pi l \delta f/c$, and remembering that $4\pi l f_0/c = \pi/2$, equation (10) becomes

$$X = Z_0 \left\{ 1 - f_0/(f_0 + \delta f) \right\} = Z_0 \cdot \delta f/f_0 \quad \cdots \quad (11)$$

(taking only the first power of $\delta f/f_0$ in the binomial expansion of $f_0\,(f_0 + \delta f) = 1/(1 + \delta f/f_0)$.) From equation (6) the resistive component is

$$Z_0 \cdot \frac{Rl/Z_0}{1 + \cos.\ 4\pi l/\lambda}$$

which at $l/\lambda = 1/8$ reduces to Rl where R is the resistance per unit length of the line of length l. The ratio of the reactive and resistive components then gives the phase angle as

$$\delta = \text{arc tan} \left\{ \frac{Z_0}{Rl} \cdot \frac{\delta f}{f_0} \right\} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \ (12)$$

If in addition the condenser used to tune to resonance has a resistance r, equation (12) becomes

$$\delta = \text{arc tan} \left\{ \frac{Z_0}{Rl + r} \cdot \frac{\delta f}{f_0} \right\} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (12a)$$

This is the same type of law of change of phase angle with frequency as was shown to hold at resonance for both resonant line and parallel tuned circuit (equations (5) and (6) of the previous paper). The equivalent Q of the line used as a reactance is therefore $Z_0/2Rl$, or on writing $Rl = \rho$, as in the previous paper, $Z_0/2\rho$. Comparing with the result for the line at resonance, $Q = \pi Z_0/2\rho$ (top of page 18 of previous paper), it will be seen that the ratio

$$y = \frac{Q \text{ (line used as reactance)}}{Q \text{ (line used at resonance)}} = \frac{1}{\pi} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \ (13)$$

This is for the case of added capacitance of zero loss, and with the total resistance of reactive line the same as that of resonant line ; there are two other cases likely to occur in practice, still neglecting loss in the condenser. If the cross-section of the line is the same in each case, the reduction in length from $\lambda/4$ to $\lambda/8$ will halve the resistance, improving the ratio y to $2/\pi$. Alternatively, one might suppose the volume of the line to remain constant, for in many applications the maximum permissible bulk of the resonant or reactive line is the limiting factor in design. Halving the length only allows the diameter (to which the resistance is proportional at very high frequencies) to be increased in the ratio $\sqrt{2}:1$, bringing the ratio y up to $2\sqrt{2}/\pi$. This is still a value less than unity for y, so that even without making allowance for either condenser loss or the space which it occupies, a combination of line reactance and lumped reactance is less efficient than a single resonant line. Any real circuit must contain a certain amount of capacitance apart from the resonant line—e.g., stray capacitances associated with the valve—but clearly this should be kept small so as to make the line as nearly as possible the whole of the resonant system.

The characteristics of the system have been derived above for *series* rather than parallel resonance, because the resulting equations are more compact. With most resonant circuits there is a slight difference in frequency between series and parallel resonance, depending upon the magnitude of the resistance of the circuit ; but the shape of the resonance curve is similar for the two cases. In the present example, the value of capacity C′ for parallel resonance with a $\lambda/8$ line is given by

$$1/2\pi f_0 C' = Z_0 \left\{ 1 + (Rl/Z_0)^2 \right\} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \ (14)$$

in place of the simple relation $1/2\pi f_0 C = Z_0$ used above for series resonance. The additional term in (14) is of course only a small correction, being proportional to the square of the damping of the system.

There remains only the question of using *two* reactive lines together to form a resonant system ; but it is fairly obvious that this will always result in a single resonant line fed from a tapping at some point on its length. For example, reactive lines of $\lambda/8$ and $3\lambda/8$ joined in parallel immediately form a line of length $\lambda/2$ with voltage maximum at its centre and fed at a point one quarter of its length from one end.

In all cases there is a slight change in characteristic when the length of line is equal to a *large* number of wavelengths, owing to the displacement of the voltage and current maxima along the line with changing frequency ; but it was pointed out in the previous paper (under the heading " Long Lines for Anode-Grid Coupling ") that the magnitude of such effects in a line of practicable length is small compared with ordinary resonance phenomena.

D. A. BELL.

MARCONI NEWS AND NOTES

NEW BROADCASTING STATIONS FOR TURKEY.

IN face of keen competition Marconi's Wireless Telegraph Company Limited has secured an important contract from the Turkish Government for the installation of a long-wave high-power broadcasting transmitter, a high-power short-wave broadcasting transmitter and a Broadcasting House for Ankara.

The long and short-wave transmitters will be installed in one building at Etimessut, 15 miles from Broadcasting House at Ankara, the two points being connected by a high-class music cable.

Long-Wave Transmitter.

The long-wave transmitter will operate on a wavelength of 1,639 metres with an unmodulated aerial carrier wave of 120 kilowatts.

The station is designed to cover a waverange of 1,000—2,000 metres, so that a change of wavelength at any future date can be made without any difficulty.

Modulation will be by means of the Marconi high-level " Class B " system, and the permissible distortionless modulation amounts to 90 per cent.

Reduced Power.

By isolating certain valves in the transmitter the station can also operate at 60 kilowatts. At this energy the power supplies and rectifiers are completely duplicated.

A precision drive with a frequency constancy of one in one million stabilises the transmitter.

The main anode supply to the power valves will be from steel tank rectifiers.

The aerial system consists of two 250 metres insulated masts, supporting a " T " aerial.

The masts are tuned to give increased radiation in a particular direction.

Short-Wave Transmitter.

The short-wave broadcast transmitter is to work on a carrier energy of 20 kilowatts. It covers a waveband of 14 to 100 metres, and provision is made for quick change to any of two working waves. A crystal drive with two pairs of crystals for two spot wavelengths is employed.

High-level " Class B " modulation is also employed in this transmitter and the high-tension feed is again—as in the case of the long-wave transmitter—from a steel tank rectifier.

The performance of the short-wave transmitter is in accordance with most modern broadcast practice. Eighty per cent. modulation is available with less than 4 per cent. distortion, and the frequency response is linear within 30 to 10,000 cycles per second.

Aerials.

The two short-wave aerials will be suspended from one of the masts used for the long-wave aerial.

Broadcasting House.

Broadcasting House in Ankara, which will comprise five main studios, including one large Concert Hall, will naturally be equipped in the most up-to-date fashion, including listening rooms, gramophone and effects studio, echo room, control room and the general administrative offices. The latest of ribbon microphones are to be used and, as a matter of course, gramophone recording apparatus and film sound reproducing equipment will find a place in the new Broadcasting House.

Several outside broadcast equipments are to be provided so that programmes may be relayed from various points in the City of Ankara.

Training of Staff.

In order to acquaint the station staff with the handling of the transmitting and studio equipment the Turkish Administration is sending a number of their engineers to England for additional training at the Marconi College at Chelmsford, so that these engineers may have full advantage of the accumulated broadcasting experience of the Marconi Company.