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January-February, 1937

CONTENTS

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THE MARCONI REVIEW

No. 64. *January-February, 1937.*

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POLICE WIRELESS

The ever increasing facilities for speedy transport have given the modern criminal a means of removing rapidly from the scene of a crime. It is necessary therefore that the Police should have at their disposal a means of disseminating information and instructions at a speed which will discount these facilities.

Wireless communication forms an invaluable aid to the Police Force as it enables information to be given over a widely spread area far more rapidly than is possible by telephone. Road patrols can be instructed to move to any strategic position with a minimum of delay and their efficiency is thus enormously increased. So valuable has radio proved that it is already looked upon as a part of the normal routine of police work.

A new field has been opened up for the radio engineer by the acceptance of wireless communication as an essential part of a police force equipment, as he is confronted in police work with conditions and requirements not heretofore encountered. Low efficiency aerials on moving motor vehicles, in many cases unskilled operators, limited power supplies, etc., make the task of providing a reliable service more difficult.

Wavelengths Available.

THE waveband at present allotted to Police Forces in this country is 2,115 to 2,030 kilocycles (141.84 to 147.8 metres).

This band is extremely limited and, while it is large enough to cover the police wireless schemes in existence at present, it is inevitable that extension of the frequencies available will be required before long. The regional scheme being put into operation at the present time is rapidly filling up all the channels available in the present band. From the foregoing it can be seen that frequency stability is of the greatest importance if interference between two adjacent stations is to be avoided.

In America a number of Police Forces have been using the higher frequencies in the band 30 to 42 megacycles with some success, but little work has been done in this country in this direction as yet. Where a comparatively small area has to be covered these frequencies can be used with success, but regional schemes preclude their adoption at present in this country.

Systems of Working.

At the present time continuous wave telegraphy is used in the majority of established Police Force radio systems. This method of working is favoured in preference to telephony because some degree of secrecy is introduced and a record of each message is automatically taken by the operator.

Telephony, however, possesses several advantages, the greatest being that every member of a force is a potential operator, whereas with telegraphy a considerable amount of training is necessary. Messages can also be passed much more rapidly with telephony.

For small Forces and where the area to be covered is not large, telephony is probably the better system in view of the difficulty of training of personnel. In congested areas and where a large district is to be covered telegraphy is more suitable, and in cities where there is a large degree of electrical interference C.W. telegraphy is definitely more practicable as it can be more easily distinguished through a high noise level.

Service Requirements.

To prove of the greatest value as a Police service it is essential that the wireless system is absolutely reliable and easily maintained. The apparatus must be designed for continuous working under all conditions. The equipment fitted in cars, vans, etc., must also be sufficiently robust mechanically and electrically to withstand any shocks likely to be met with during patrol work.

Transmitters and receivers must be as simple as possible in operation while providing the highest obtainable efficiency. The frequency stability must be of a very high order so that the instruments do not continually require adjustment to maintain the service.

Equipments for cars, etc., must be small in size in order to make fitting a simple matter, and the power consumption must be kept down as low as possible.

From the foregoing it will be seen that the essential features of a Police equipment are :—

1. Great mechanical strength.
2. A high order of frequency stability.
3. The greatest obtainable efficiency.
4. Reliability and ease of operation.
5. In the case of mobile equipments small physical dimensions.

The Marconi Company for many years has been actively engaged in the development of wireless equipments for military, naval and air services. As a result of the experience thus gained, a series of equipments, both fixed and mobile, have been developed and produced to fulfil in every respect the exacting requirements of a Police service.

The equipments are extremely flexible and all classes of Police service are catered for in the range of transmitters and receivers available.

Headquarters Transmitters.

The power output of the transmitter at Headquarters, of course, depends upon the service area to be covered. Two transmitters have therefore been developed to meet different service requirements. These transmitters are known as the Marconi Types T.P.2 and T.P.3. In order to meet demands for transmitters from Forces abroad these sets cover a greater frequency band than that allotted to the Police services in this country.

A crystal drive master oscillator for a pre-selected wavelength is incorporated in both transmitters, thus ensuring the high degree of frequency stability so essential. Both sets provide for the transmission of continuous wave, tonic train and telephone signals. They are simple in operation and are designed for continuous working.

The transmitters are designed primarily for operation from a 50 cycle A.C. supply, but can alternatively be run from suitable motor generators where no A.C. source is available.

The type T.P.2 has an aerial power rating of 100 watts on C.W., tonic train or telephony carrier. The total input power required is approximately 2 kilowatts. The waverange covered is 120 to 180 metres when using a valve drive and the crystal frequency may be selected anywhere in this band.

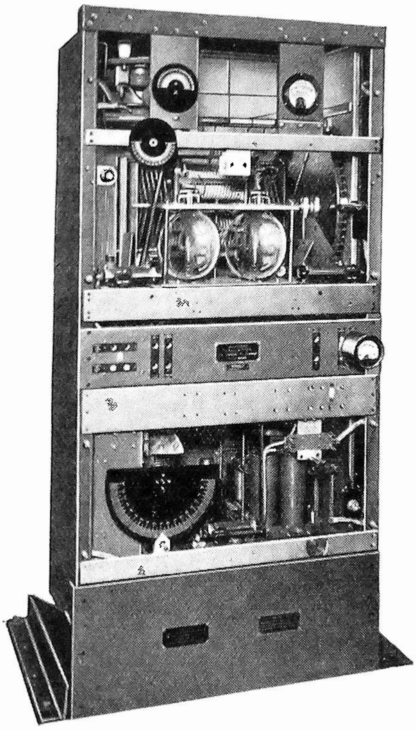

FIG. 1.

Both the crystal and valve drives are thermostatically controlled so that the frequency stability is of a very high order over the whole waveband. When using the crystal the controlled valve drives an isolator stage, which is followed by an intermediate magnifier, and this in turn drives the main magnifier. Modulation is by the choke control method through two modulator valves and the depth on both telephony and tonic train is 70 per cent. Tonic train is provided by means of an oscillator continuously variable from 600 to 1,200 pps.

The transmitter is designed for remote operation and is particularly suited for use in unattended stations, as all circuits are provided with safety trip devices. Thus in the event of a fault occurring on any circuit the transmitter is automatically closed down.

The type T.P.3 is rated at 650 watts to the aerial on continuous wave telegraphy and 250 watts on tonic train or telephony carrier. The total input power required is approximately 3 kilowatts. It is continuously adjustable over the waveband 120—180 metres when using the valve drive.

In the T.P.3 the crystal drive is thermostatically regulated and the frequency stability reaches the high order of one part in 20,000. A spare crystal is also provided for the pre-selected frequency.

The component parts of the transmitter are mounted in a number of cubicles which are carried in a metal framework. The cubicles are provided with removable cover plates at the front and safety switches are fitted to all panels. Fig. 1 shows the T.P.3 with the front cover plates removed.

The radio frequency circuits are similar to those in the T.P.2, but modulation is effected by the D.C. grid method. The depth of modulation on telephony is approximately 75 per cent. and on tonic train 80 per cent. The tonic train is provided by means of a note oscillator and three frequencies are available.

This transmitter can be fully controlled remotely either from an operator's table in the transmitter room or through suitable land lines and amplifiers from a distant control room. The control includes starting up and the selection of telephony or telegraphy transmission as required. All adjustments to the transmitter are made from the front and after these are completed the tuning controls can be removed, thus preventing interference with the settings by unauthorised persons.

Mobile Transmitters.

The mobile transmitter has imposed upon it the necessity of working under very adverse conditions. It is required to work day after day under conditions of extreme shock and vibration with a minimum of attention. In cars it must usually be placed in the trunk at the rear, and this is the point of greatest vibration when riding over rough roads.

The transmitter must impose little drain on the battery when not in use, and must be ready for operation at a few seconds' notice. Thus no warming up period can be allowed and the frequency stability must be as high as possible. It must be as efficient as possible in order to ensure maximum power output with minimum input. Frequency stability, ruggedness and efficiency cannot be overstressed in this class of equipment.

To meet all requirements two types of mobile transmitter have been produced by the Marconi Company. These are known as the types T.P.4 and T.P.5, and both are rated at 25 watts to the aerial circuit on continuous waves. The waverange in both cases is 100 to 150 metres. A valve drive designed for maximum frequency stability is followed on these sets by a two valve magnifier stage.

The type T.P.4 is designed for operation on telegraphy only by continuous waves or interrupted continuous waves. Keying for telegraphy is effected by simultaneously interrupting the grid circuits and the negative high tension supply. I.C.W. is provided by means of an interrupter disc mounted on the generator shaft and connected in series with the key.

The type T.P.5 provides, for telephony in addition to C.W. and I.C.W. Modulation is effected in the grid circuit of the magnifier valves through a microphone transformer and modulation up to 80 per cent. can be obtained. The carrier power on telephony transmission is of the order of 10 watts.

The transmitters are contained in robustly constructed dust-proof containers and covers are fitted over the fronts of the transmitters to protect the controls, which are mounted on the front panels. These controls are provided with locking arrangements to obviate any shifting once the transmitter has been adjusted. The overall dimensions are 9 by $12\frac{3}{4}$ by $8\frac{3}{4}$ inches for the T.P.4 and 9 by $16\frac{1}{4}$ by $8\frac{3}{4}$ inches for the T.P.5. Fig. 2 shows a complete T.P.5 equipment and Fig. 3 the internal arrangement of the components and circuits.

The equipments operate entirely from a 12 volt battery, the high tension supply for the valve anodes being obtained through a rotary converter. The converter unit also contains relays for starting up the machine and for the transmitter filament circuits, smoothing circuits and protecting fuses. The brush gear, fuses and other parts which may require attention are readily accessible, while being well protected against dust, etc. The overall dimensions of the supply unit are $8\frac{1}{2}$ by 11 by $6\frac{1}{2}$ inches.

The sets are controlled from a small control unit which may be mounted in any convenient position in the vehicle. Thus unit contains switches for the control of the high tension and filament circuits through the relays contained in the rotary converter unit and also switches for selecting the type of transmission required. A main switch changes over from transmit to receive, its functions being to operate the aerial change over relay and the relays controlling the rotary converters. Pilot

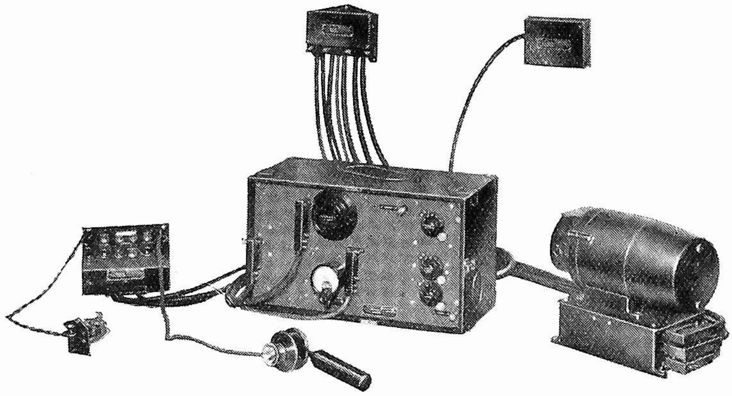

FIG. 2.

lamps are included to indicate the closing of the filament circuits on both transmitter and receiver and sockets are provided for the microphone and key.

Headquarters Receivers.

The receivers used in headquarters stations must combine the highest obtainable order of sensitivity with a good noise discrimination, as, while they can generally be used with an efficient aerial system, they are often of necessity installed in buildings where the electrical interference level is very high.

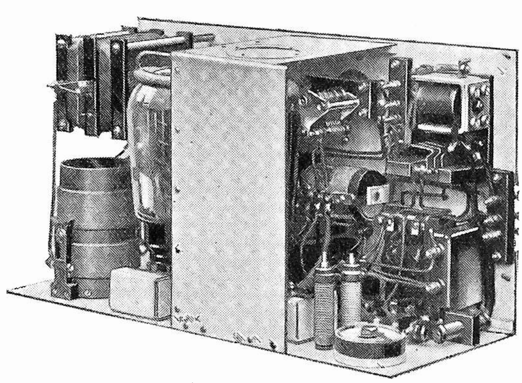

FIG. 3.

Four types of receiver have been produced for fixed station use. Two of these, namely R.P.17 and R.P.25, have been developed for headquarters service, and the others, the R.P.24 and R.P.27, have been designed primarily for use in country Police Stations, etc. These receivers all cover the frequency band 3,000 to 1,500 kilocycles (100 to 200 metres), are provided with single handle control for simple operation and are all capable of receiving telephony or C.W. telegraphy.

The circuit design of the R.P.17 and R.P.25 is practically identical, but whereas the former operates only from A.C. mains, the latter can be used on A.C. or D.C. mains with no changes to the receiver.

In these two receivers full use is made of the latest multiple purpose valve technique and ease of operation is combined with a high order of performance. The audio frequency response is so adjusted that while the speech band of approximately 200 to 3,000 pps. is flat there is an appreciable loss in output outside these limits. This gives the receivers some additional discrimination against noise interference which is of value when working a telephony service. Adequate automatic volume control is also provided for telephony work.

A conventional superheterodyne circuit is used and careful mechanical design and lay out ensure that the receivers operate with complete stability. One stage of signal frequency amplification is used, this being followed by a single valve "mixer" or frequency changing stage. The intermediate frequency amplification is carried out at 115 kilocycles and three tuned circuits ensure that adequate adjacent channel selectivity is provided. The second detectors are diodes, one providing the audio output and the other the automatic volume control which is operative on both the S.F. and I.F. amplifiers. The audio detector is followed by one amplifying stage, which in turn drives the pentode output. A separate oscillator, which may be switched in or out as required, provides the beat note for C.W. reception.

The receivers are arranged for use with both telephones and loud-speakers. When using the latter an undistorted speech output of approximately 2½ watts can be obtained. The loud-speaker is of the moving coil type with a permanent magnet field.

The performance of the sets is extremely good. The sensitivity is such that a total modulated signal input at the aerial terminal of 6 microvolts will give an output of 50 milliwatts. The adjacent channel selectivity provides an attenuation of at least 35 decibels to signals differing in frequency by more than 12 kilocycles from the wanted signal. The image signal is attenuated by at least 45 decibels with respect to the wanted signal.

The receivers are mounted on aluminium chassis and all components are readily accessible once the sets are removed from their cases. The R.P.17 is fitted in an aluminium case and the R.P.25 in one of cellulosed teak. Both sets are protected by fuses incorporated in the supply circuits.

The R.P.24 and R.P.27 are both straight circuit three valve receivers employing a signal frequency amplifier, a detector with reaction and a pentode output stage. The former has been designed for operation primarily from batteries, but can also be used on A.C. mains with an A.C. eliminator if required. The R.P.27 is arranged to operate direct from an A.C. or D.C. mains supply, and except for the loud-speaker and telephones the receiver is completely self-contained.

Mobile Receivers.

Two types of receiver have been produced to meet the exacting requirements of mobile Police work. Careful design ensures that the mechanical strength is more than adequate and the sets are capable of continuous operation for long periods without attention,

These receivers are the types R.P.20 and R.P.32. Both are superheterodyne receivers covering the waveband 140 to 150 metres with single handle control. The former, however, has two preset controls so that the circuits can be tuned to the frequency required and cannot then be tampered with. In the R.P.32 all circuits are tuned simultaneoutly by the control knob. The R.P.20 is particularly suitable for use with the T.P.4 or T.P.5 as a complete two-way mobile communication equipment. The receiver is small in size and light in weight and is carried in two metal brackets so that it can be mounted in any suitable position in the car or van. Fig. 4 shows an R.P.20 receiver fitted below the dashboard of a car with the loud-speaker mounted beside it. In the compartment above will be seen the control unit used with a complete transmitting and receiving equipment.

The circuit used comprises one signal frequency amplifier followed by a two valve frequency changing stage. One stage of intermediate frequency amplification at 115 kilocycles follows, and three tuned circuits are used at this frequency. The second detectors are of the metal rectifier type, one providing the audio output and the other the delayed automatic volume control. The control is operative on both

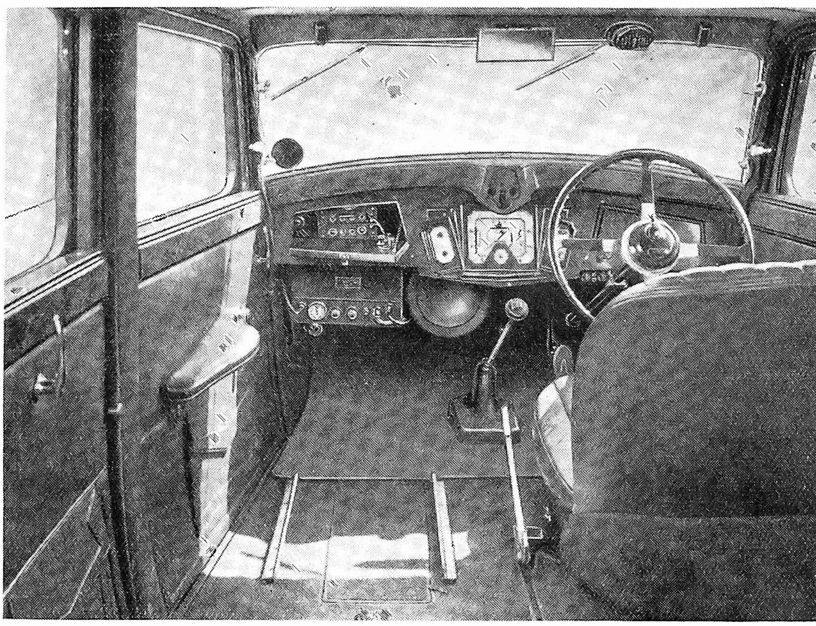

FIG. 4.

signal frequency and intermediate frequency amplifier valves. The audio output is amplified and then passed on to a pentode output stage. For the reception of C.W. a separate beat oscillator is introduced, the triode valve for this purpose being contained in the same envelope with the A.F. amplifier. Reception is on either loud-speaker or telephones and adequate volume is available on the former for use in any car or van,

The performance is of a high order in view of the extremely small dimensions of the receiver. An output of 50 milliwatts is obtained for a total modulated signal input at the aerial terminal of 6 microvolts, The adjacent channel selectivity is such that signals differing by more than 12 kilocycles from the wanted signal are attenuated by at least 35 decibels. The image signal is attenuated by at least 50 decibels by comparison with the wanted signal.

The receiver chassis is strongly constructed to resist vibration on the road and the accessibility of all components is extremely good. Fig. 5 illustrates the robust construction and the arrangement of the coils, all of which are contained in screening pots. The chassis slides into an aluminium case, which has a hinged front flap.

By raising this flap the valves are all visible and can be easily changed if necessary. The overall dimensions of the receiver unit are $8\frac{1}{2}$ in. high by $10\frac{3}{4}$ in. wide by $6\frac{1}{4}$ in. deep.

The receiver operates entirely from a 6 or 12 volt battery through a supply unit. The receiver valves are of the 2 volt directly heated type and are supplied through a suitable dropping resistance contained in the supply unit, while the anode supply is obtained through a rotary converter. The high tension supply is suitably smoothed in the supply unit, which also contains low and high tension fuses and a relay for starting the rotary converter.

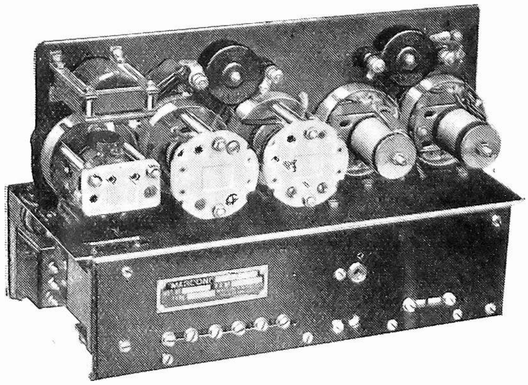

FIG. 5.

The R.P.32 has been primarily produced for installation in vehicles where no transmitter is to be used. It will operate directly from the starting and lighting battery of the vehicle and is extremely compact and easy to fit. The equipment consists of three units—receiver, combined loud-speaker and supply unit and remote control unit.

Indirectly heated universal type valves are used, these being supplied direct from the battery, while the anode supply is obtained by means of a vibrator converter. The remote control unit may be mounted in any accessible position. This unit contains the tuning control, in which is incorporated the C.W./telephony switch and a combined volume control and On/Off switch. The tuning scale is calibrated directly in metres and kilocycles.

The overall dimensions are $8\frac{1}{4}$ by $5\frac{1}{2}$ by $6\frac{7}{8}$ inches for the receiver unit and $8\frac{1}{4}$ by 5 by 7 inches for the loud-speaker and supply unit. The cases are of steel and are mounted by means of two metal straps in the desired position. The receiver chassis can be easily withdrawn from the case while in position in the vehicle. A complete R.P.32 equipment is shown in Fig. 6.

The performance is of the same order as for the R.P.20, but an undistorted output of 2 watts is available. The total consumption from the battery is approximately 4 amperes.

Aerials.

The design of the aerial for a mobile equipment is of primary importance. The aerial on a car must be as nearly as possible invisible or at least sufficiently inconspicuous as not to attract attention to the vehicle. Unfortunately the aerial that is most efficient is invariably too conspicuous to suit the requirements of a Police Force. While, therefore, in any case it will be extremely inefficient and have an almost negligible effective height, every effort must be made to make the aerial on a car as good as possible.

A number of aerials have been used on cars with varying degrees of success. The most efficient type is undoubtedly the rod aerial. This consists of a metal tube 5 feet long mounted in insulators on the side of the car so that about 3 feet of its length projects above the roof when raised. In order to permit the car to be driven under cover this rod can be lowered when not in use. It can also be provided with a telescopic top section so that the aerial may be lengthened while the car is stationary if required.

Unfortunately the rod aerial is considered to be too conspicuous, and a type known as the "luggage grid" has been adopted as the best compromise between efficiency and invisibility. This aerial consists of a copper tube formed into a

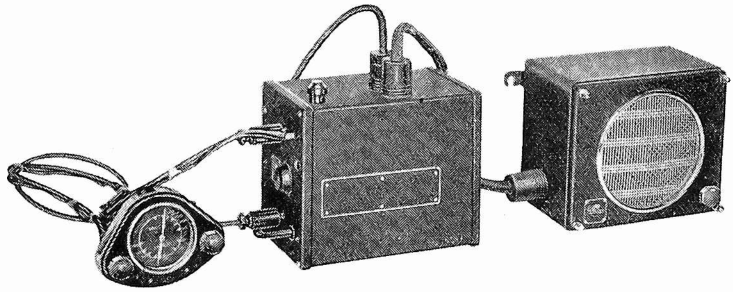

FIG. 6.

rectangle and mounted about 4—5 inches above the roof of the car by means of four or six insulators. It may be shaped to the roof curves, is very inconspicuous and looks exactly like the luggage rail fitted to some large cars. A car fitted with one of these aerials is illustrated in Fig. 7.

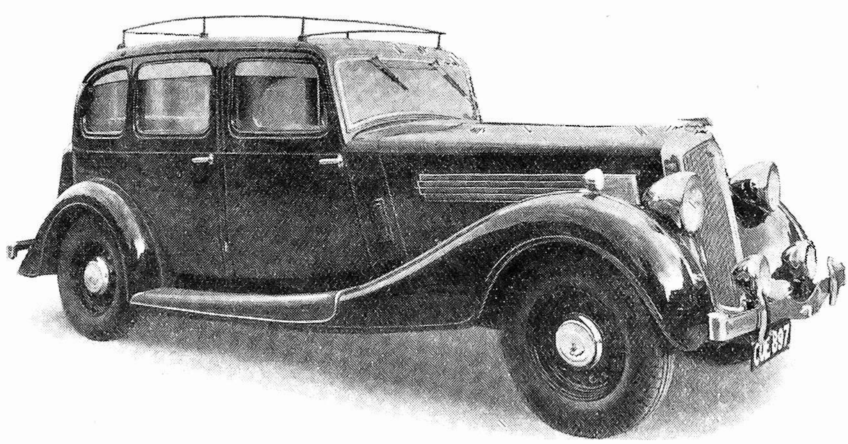

FIG. 7.

These types are the only aerials suitable for both transmission and reception. There are other types which have been used for reception only, where the aerial must be completely concealed. These usually consist of a metal gauze mat or copper sheet mounted beneath the running board or in the roof of the car. They are very inefficient and are much inferior to the "luggage grid" type.

Typical Installation.

The equipment supplied to the City of Glasgow Force by the Marconi Company is an excellent example of a police installation. Here the headquarters station serves not only the City of Glasgow alone, but under the Regional scheme is the source of information for the surrounding county and burgh forces. Most of the service area to be covered lies within a radius of about 60 miles, but some stations lie as far as 90 miles from the transmitter.

The installation at the Police Headquarters comprises a T.P.3 transmitter and R.P.17 receiver. In order to obtain the best possible aerial the transmitter is situated about $1\frac{1}{2}$ miles from headquarters. A half-wave aerial suspended almost vertically is used and the transmitter is entirely remotely controlled from the control room at headquarters. The arrangement of the transmitter room is seen in Fig. 8. In the event of a breakdown in the landlines the transmitter can be operated locally from the control table in the foreground.

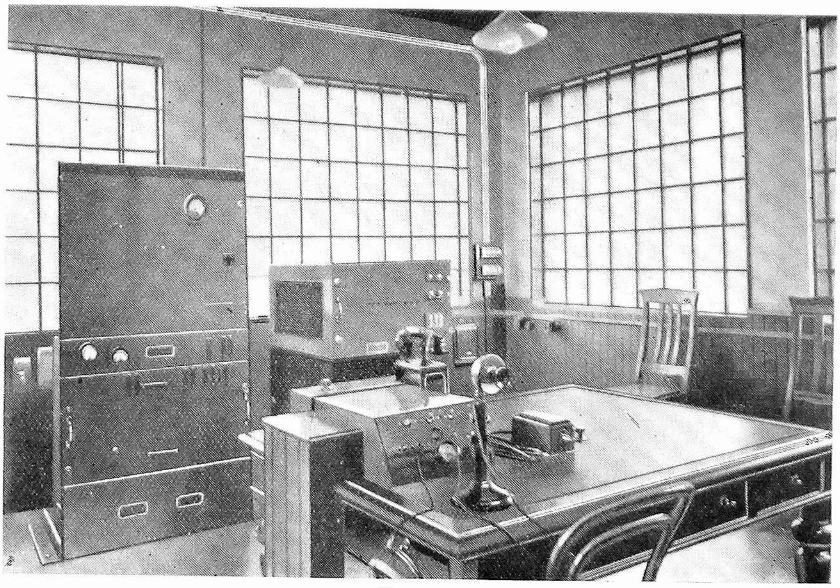

FIG. 8.

At headquarters a sound-proof room has been erected, and in this are installed the receiver and the remote control gear. Fig. 9 shows the control table, the R.P.17 receiver being on the right with its loud-speaker above it. Mounted in the table top on the left are the control panels and behind in the rack are the microphone line amplifier, the tone generator for calling, and the recifier equipment. The complete installation is operated direct from the A.C. mains.

The mobile equipments include a T.P.5/R.P.20 equipment mounted in a van and a number of R.P.20s and R.P.32s. Under the Regional scheme a number of fixed station receivers have also been installed at county and burgh headquarters stations.

Both telephony and C.W. telegraphy working is carried on, telephony being used only for the outward city service, and C.W. for working back to headquarters and also for the Regional scheme. Tonic train is used for calling purposes, the note being so chosen as to be audible through extremely bad electrical interference.

The noise level is very high in Glasgow, but it has been found possible to cover the whole of the City on telephony on the outward service.

Future Developments.

The ultra short waveband around 30 to 42 megacycles has been used to some extent in America. Extremely good results are claimed for services operating on these frequencies. There has, however, been little demand for this system in this country mainly owing to the comparatively restricted ranges that can be obtained.

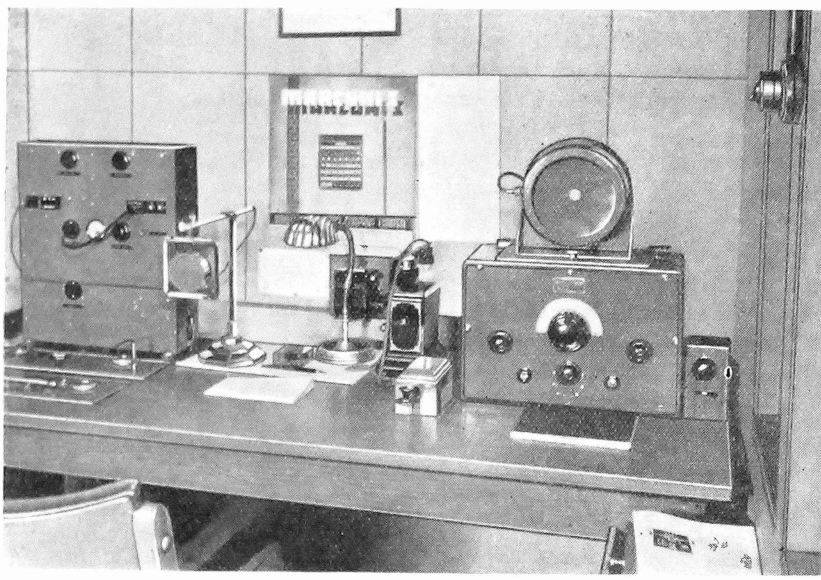

FIG. 9.

The Regional scheme where one central transmitter serves a widely spread area definitely prohibits the use of the 30—42 megacycle band, but there may be a field for equipments operating on these frequencies for local area work only. Owing to the congestion which will inevitably arise before long in the medium waveband any further expansion must of necessity take place on the higher frequencies.

The question of price for local area services is of paramount importance and operating costs must be kept as low as possible. The comparative simplicity of apparatus for the ultra short wavelengths enables equipments to be reduced correspondingly in price.

A further refinement which becomes a comparatively simple matter on ultra short waves is the provision of duplex telephony. The large frequency band available permits the use of many channels without overcrowding and thus facilitates the possibility of duplex working. The use of duplex telephony makes every member of a Police Force an operator without the necessity of any training, since this system is as simple to use as the Post Office telephone.

E. R. BURROUGHES.

THE CALCULATION OF INPUT, OR SENDING-END IMPEDANCE OF FEEDERS AND CABLES TERMINATED BY COMPLEX LOADS*

To facilitate the calculation of driving point impedances of feeders and cables terminated by complex loads a chart has been prepared in the Research Laboratories of the Marconi Company, instructions for using which are given below, together with a reduced facsimile of the original chart.

The type of problem which is here presented, and to which the chart is applicable, is also capable of solution by means of Dr. A. E. Kennelley's charts of complex Hyperbolic Functions, but with the latter it is necessary to enter the chart twice for every complete calculation.

Further in H.F. feeder computations many cases arise in which the Kennelley charts do not give very close interpolation without the additional use of interpolation formulæ.

The chart here presented represents an attempt to eliminate the use of interpolation formulæ in practical computations, and also facilitate entering the chart with the polar co-ordinates of the receiving-end impedance ratio, and emerge with those of the sending-end impedance ratio (or vice versa) *without the need for intervening calculations.*

As it was considered desirable to give the practical examples and uses of the chart first, the theory and formulæ will be given in a later issue of THE MARCONI REVIEW.

Purpose of the Chart.

(A) The chart is intended to reduce the time and tedious work involved in computing input, or sending-end impedance.

(B) It is also intended that the chart should be sufficiently general to cover all frequencies from audio frequencies to ultra short wave frequencies, and that it should be applicable to input, or sending-end impedance computations for any case within a certain practical limit whether it be for audio or radio frequency filters, delay networks, phase-shift networks, telephone cables and lines, power transmission cables and lines, high-frequency feeders with aerial terminations, etc. The limiting condition is that the total attenuation of the system must be less than 3 nepers.

Description of the Chart.

(A) The master chart measures 20 inches by 30 inches high and consists of a system of intersecting semi-ellipses and other curves having the appearance of semi-sine waves. It is geometrically symmetrical about the unity ordinate of quarter-waves. The ϕ curves are positive and negative arithmetically on the left hand side and right hand side, respectively, of the unity ordinate of quarter-waves.

(B) The chart can be regarded as a semi-infinite cylinder of circumference two quarter-waves, which has been cut down one side and opened out flat.

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* The term "input impedance" is used in these notes consistently with radio transmission usage to denote the impedance between the terminals at one end of a feeder or line, the other end of which is terminated by any impedance. "Sending-end impedance" is used in the sense in which the telephone engineer uses that term.

(c) ϕ has been plotted with suitable interpolation throughout the range of angles from $-90°$ to $+90°$. Where subdivisions of a degree are plotted fractions have been used instead of minutes and seconds. The curve corresponding to $+90°$ is the baseline between 0 and 1, that corresponding to $\phi = 0°$ is the central axis perpendicular to the baseline, together with the two perpendicular edges of the chart; the $-90°$ curve is the baseline between 1 and 2.

(D) r, which is the ratio of terminal or load impedance modulus to characteristic impedance modulus of the cable or line, or feeder, is plotted with suitable interpola-tion between $r = .05$ and $r = 20$. Unity r-values are given by the two per-pendicular lines standing upon the baseline at 0.5 and at 1.5.

The extremities of the baseline correspond to $r = 0$, whilst at 1.0 on the baseline $r = \infty$.

How to Use the Chart.

(I) *Application to Telephone Cable.*

A detailed method will be suggested first, using for example the following problem :—

Find the sending-end impedance of a telephone cable whose length at a given frequency is 0.32 quarter-waves and attenuation $\alpha = 0.3$ neper. The cable has a characteristic impedance $Z_0 = 600 \overline{/35°}$, and is terminated by an impedance $Z_a = 500 /15°$ at the particular frequency considered. Set these data out as below for clearness :—

$$\left.\begin{array}{l} Z_a = 500 /15° \\ Z_o = 600 \overline{\backslash 35°} \end{array}\right\} r = \left|\frac{Z_a}{Z_o}\right| = \frac{500}{600} = .834$$

$$\phi = 15° + 35° = +50°$$

$$l = 0.32 \text{ quarter-wave}$$

$$\alpha = 0.3 \text{ neper}$$

Take a pointer and place it on the peak of the curve $\phi = +50°$ (on the left-hand side of the chart). This position corresponds to a value of $r = 1$. Now proceed along the curve $\phi = +50°$ to the left, through $r = .9$, down to $r = .834$, from this point measure horizontally along the background 0.32 $\frac{1}{4}$-wave to the right (that is 3.2 large squares). Next, from this new point measure 0.3 neper perpendicularly upwards (that is, 3 large squares). Now at this point on the chart read off the sending-end impedance ratio :—

$$r = 1.428 \text{ and } \phi = +21.8°$$

from which the sending-end impedance Z_1 is given by

$$\begin{aligned} Z_1 &= rZ_o /(+21.8° - 35°) \\ &= 1.428 \times 600 /-13.2° \\ &= 856.8 \backslash 13.2° \end{aligned}$$

(II) *General Method.*

The above method (I) has been described in close detail, and in the process the essential operations may not have been clearly visualised. Therefore, it may be desirable to state concisely the essential process :—

(I) Given $r = \left|\frac{Z_a}{Z_o}\right|$ and $\phi = (\phi_a - \phi_o)$, find the point on the chart where these values coincide.

THE CALCULATION OF INPUT, OR SENDING-END IMPEDANCE OF FEEDERS AND CABLES TERMINATED BY COMPLEX LOADS*

To facilitate the calculation of driving point impedances of feeders and cables terminated by complex loads a chart has been prepared in the Research Laboratories of the Marconi Company, instructions for using which are given below, together with a reduced facsimile of the original chart.

The type of problem which is here presented, and to which the chart is applicable, is also capable of solution by means of Dr. A. E. Kennelley's charts of complex Hyperbolic Functions, but with the latter it is necessary to enter the chart twice for every complete calculation.

Further in H.F. feeder computations many cases arise in which the Kennelley charts do not give very close interpolation without the additional use of interpolation formulæ.

The chart here presented represents an attempt to eliminate the use of interpolation formulæ in practical computations, and also facilitate entering the chart with the polar co-ordinates of the receiving-end impedance ratio, and emerge with those of the sending-end impedance ratio (or vice versa) *without the need for intervening calculations.*

As it was considered desirable to give the practical examples and uses of the chart first, the theory and formulæ will be given in a later issue of THE MARCONI REVIEW.

Purpose of the Chart.

(A) The chart is intended to reduce the time and tedious work involved in computing input, or sending-end impedance.

(B) It is also intended that the chart should be sufficiently general to cover all frequencies from audio frequencies to ultra short wave frequencies, and that it should be applicable to input, or sending-end impedance computations for any case within a certain practical limit whether it be for audio or radio frequency filters, delay networks, phase-shift networks, telephone cables and lines, power transmission cables and lines, high-frequency feeders with aerial terminations, etc. The limiting condition is that the total attenuation of the system must be less than 3 nepers.

Description of the Chart.

(A) The master chart measures 20 inches by 30 inches high and consists of a system of intersecting semi-ellipses and other curves having the appearance of semi-sine waves. It is geometrically symmetrical about the unity ordinate of quarter-waves. The ϕ curves are positive and negative arithmetically on the left hand side and right hand side, respectively, of the unity ordinate of quarter-waves.

(B) The chart can be regarded as a semi-infinite cylinder of circumference two quarter-waves, which has been cut down one side and opened out flat.

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* The term " input impedance " is used in these notes consistently with radio transmission usage to denote the impedance between the terminals at one end of a feeder or line, the other end of which is terminated by any impedance. " Sending-end impedance " is used in the sense in which the telephone engineer uses that term.

(c) ϕ has been plotted with suitable interpolation throughout the range of angles from $-90°$ to $+90°$. Where subdivisions of a degree are plotted fractions have been used instead of minutes and seconds. The curve corresponding to $+90°$ is the baseline between 0 and 1, that corresponding to $\phi = 0°$ is the central axis perpendicular to the baseline, together with the two perpendicular edges of the chart; the $-90°$ curve is the baseline between 1 and 2.

(D) r, which is the ratio of terminal or load impedance modulus to characteristic impedance modulus of the cable or line, or feeder, is plotted with suitable interpolation between $r = .05$ and $r = 20$. Unity r-values are given by the two perpendicular lines standing upon the baseline at 0.5 and at 1.5.

The extremities of the baseline correspond to $r = 0$, whilst at 1.0 on the baseline $r = \infty$.

How to Use the Chart.

(I) *Application to Telephone Cable.*

A detailed method will be suggested first, using for example the following problem :—

Find the sending-end impedance of a telephone cable whose length at a given frequency is 0.32 quarter-waves and attenuation $\alpha = 0.3$ neper. The cable has a characteristic impedance $Z_0 = 600 \,\underline{/35°}$, and is terminated by an impedance $Z_a = 500 \,\underline{/15°}$ at the particular frequency considered. Set these data out as below for clearness :—

$$\left.\begin{matrix} Z_a = 500 \,\underline{/15°} \\ Z_o = 600 \,\overline{\backslash 35°} \end{matrix}\right\} \quad r = \left|\frac{Z_a}{Z_o}\right| = \frac{500}{600} = .834$$

$$\phi = 15° + 35° = +50°$$

$$l = 0.32 \text{ quarter-wave}$$

$$\alpha = 0.3 \text{ neper}$$

Take a pointer and place it on the peak of the curve $\phi = +50°$ (on the left-hand side of the chart). This position corresponds to a value of $r = 1$. Now proceed along the curve $\phi = +50°$ to the left, through $r = .9$, down to $r = .834$, from this point measure horizontally along the background 0.32 $\frac{1}{4}$-wave to the right (that is 3.2 large squares). Next, from this new point measure 0.3 neper perpendicularly upwards (that is, 3 large squares). Now at this point on the chart read off the sending-end impedance ratio :—

$$r = 1.428 \text{ and } \phi = +21.8°$$

from which the sending-end impedance Z_1 is given by

$$\begin{aligned} Z_1 &= rZ_o \,\underline{/(+21.8° - 35°)} \\ &= 1.428 \times 600 \,\underline{/-13.2°} \\ &= 856.8 \,\overline{\backslash 13.2°} \end{aligned}$$

(II) *General Method.*

The above method (I) has been described in close detail, and in the process the essential operations may not have been clearly visualised. Therefore, it may be desirable to state concisely the essential process :—

(I) Given $r = \left|\frac{Z_a}{Z_o}\right|$ and $\phi = (\phi_a - \phi_o)$, find the point on the chart where these values coincide.

(II) From this point measure horizontally to the right the cable or line length in quarter-waves at the frequency considered.

(III) From the point resulting from (II) measure perpendicularly upwards the cable or line attenuation in nepers or hyps at the frequency considered. This gives a new point of intersection of r and ϕ from which the sending-end or input impedance

$Z = r \cdot Z_o \underline{/\phi + \phi_o}$ in ohms and degrees.

(III) *Reverse Case.*

i.e., Given the sending-end impedance, and cable, or line characteristics at any frequency it is possible to find the terminal impedance by measuring cable, or line length in the opposite direction (i.e., leftwards instead of rightwards), and measuring attenuation downwards instead of upwards.

(IV) *High Frequency Feeders.*

(A) *General Case.*—Here the problem is identical with that for telephone cables so far as principles are concerned. The particular values are usually different. It may frequently occur that the feeder is many quarter-waves long while the chart is computed for only two quarter-waves ; but as impedance values repeat themselves after every two quarter-waves, more than two would be unnecessary for the chart.

In general, if the given number of quarter-waves is $(2n + x)$, where n is a positive integer, and x a proper fraction, that number may be regarded as equal to x in using this chart.

Further, if in any particular case the value of x extends beyond the right-hand edge of the chart, the excess of x may be measured inwards from the left-hand edge of the chart, the right and left-hand edges of the chart being regarded as contiguous.

(B) *Example on Feeders for Ultra Short Waves.*

Given

$$\left.\begin{array}{l} Z_a = 20 \underline{/25^\circ} \\ Z_o = 80 \underline{/\ 0^\circ} \end{array}\right\} r = \left|\frac{Z_a}{Z_o}\right| = .25$$

$$\phi = +25^\circ$$

l = 11.5 quarter-waves (=1.5 quarter-waves)

a = 0.5 neper.

Find Input Impedance.

Place pointer at intersection of the two curves $\phi = + 25^\circ$ and $r = 0.25$.

From this point measure horizontally to the right 1.5 quarter-waves (i.e., 15 large squares), and then measure upwards 0.5 neper (i.e., 5 large squares), then read off $r = .885$ and $\phi = -26.1^\circ$.

Hence $Z = .885 \times 80 \overline{\backslash 26.1^\circ}$

$= 70.80 \overline{\backslash 26.1^\circ}$

(C)* *To determine the length of feeder, of given Z_o, required to make a quarter-wave transformer for a given terminal impedance*—Given

$$\left.\begin{array}{l} Z_a = 50\ \underline{/30^\circ} \\ Z_o = 40\ \underline{/\ 0^\circ} \end{array}\right\} r = 1.25\ ;\ \phi = +30^\circ$$

* The attenuation of the feeder does not affect the answer in any way.

Find the point of intersection of $r = 1.25$ and $\phi = +30^\circ$ on the chart, and measure the horizontal distance between this point and the nearest zero ϕ-curve to the right (in this case the middle perpendicular axis). The distance is 0.365 quarter-waves. Therefore the feeder should be 0.365 quarter-waves long at the frequency or wavelength considered.

(D) *Application for Television Feeder Correction.*

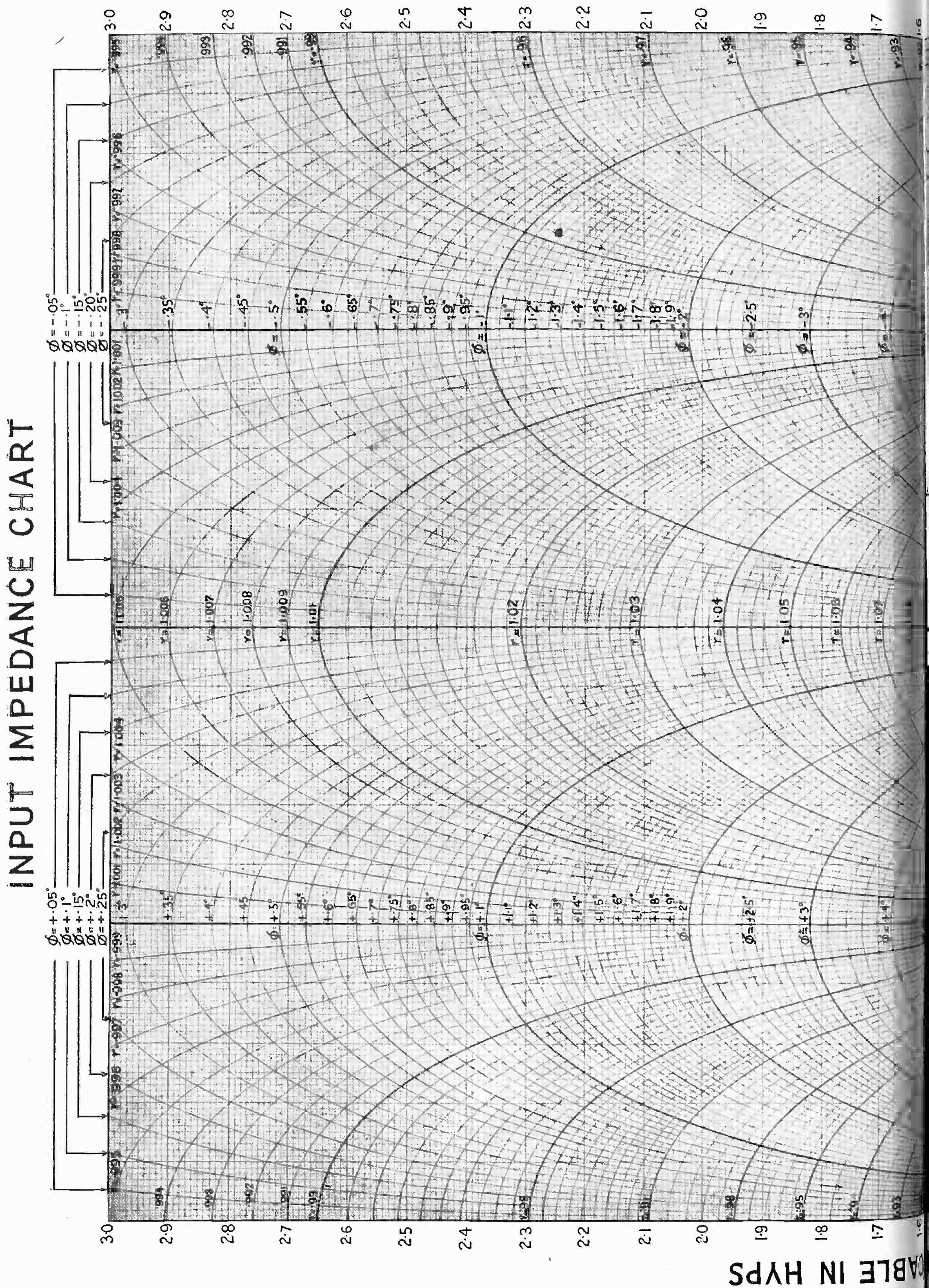
$\frac{1}{4}$-Wave Transformer Section.		
$f_1 = 43$ Mc	$f_2 = 45$ Mc	$f_3 = 47$ Mc
$Z_{a1} = 25.1\ /21.2^\circ$ $Z_o = 42\Omega$ $\left.\right\} r = .598,\ \phi = +21.2^\circ$ $l_1 = .821$ Quarter Waves $a_1 = 0$	$Z_{a2} = 25.1\ /14.85^\circ$ $Z_o = 42\Omega$ $\left.\right\} r = .598,\ \phi = +14.85^\circ$ $l_2 = .86$ Quarter Waves $a_2 = 0$	$Z_{a3} = 22.7\ /13.65^\circ$ $Z_o = 42\ \Omega$ $\left.\right\} r = .541,\ \phi = +13.65^\circ$ $l_3 = .898$ Quarter Waves $a_3 = 0$
From Chart by Method iv (b) above $r = 1.915$ and $\phi = -0.6^\circ$ $\therefore\ Z_1 = 1.915 \times 42\ \backslash 0.6^\circ$ $= 80.5\ \backslash 0.6^\circ$	From Chart by Method iv (b) above $r = 1.785$ and $\phi = 0^\circ$ $\therefore\ Z_2 = 1.785 \times 42\ /0^\circ$ $= 75\ /0^\circ$	From Chart by Method iv (b) above $r = 1.935$ and $\phi = -0.9^\circ$ $\therefore\ Z_3 = 1.935 \times 42\ \backslash 0.9^\circ$ $= 81.3\ \backslash 0.9^\circ$
II $\frac{1}{4}$-Wave Modulus—Corrector Section.		
$Z_{a4} = Z_1$ $= 80.5\ \backslash 0.6^\circ$ $Z_o = 75\Omega$ $\left.\right\} r = 1.072,\ \phi = -.6^\circ$ $l_4 = \frac{43}{45} \times 11 = 10.5$ Q.W. $= .5$ Q.W. $a_4 = 0$	Eleven Quarter Wavelengths [at the above frequency (45 Mc)] of 75 Ω feeder added on to Z_2 above do not alter the value of Z_2.	$Z_{a6} = Z_3$ $= 81.3\ \backslash 0.9^\circ$ $Z_o = 75\Omega$ $\left.\right\} r = 1.083,\ \phi = -.9^\circ$ $l_6 = \frac{47}{45} \times 11 = 11.5$ Q.W. $= 1.5$ Q.W. $a_6 = 0$
By Chart as before $r = .9903$ and $\phi = -4^\circ$ $\therefore\ Z_4 = .9903 \times 75\ \backslash 4^\circ$ $= 74.5\ \backslash 4^\circ$	Therefore the Chart is not needed to give the result :— $Z_5 = 75\ /0^\circ$	By Chart as before $r = 1.0161$ $\phi = +4.6^\circ$ $\therefore\ Z_6 = 1.0161 \times 75\ /4.6^\circ$ $= 76.2\ /4.6^\circ$

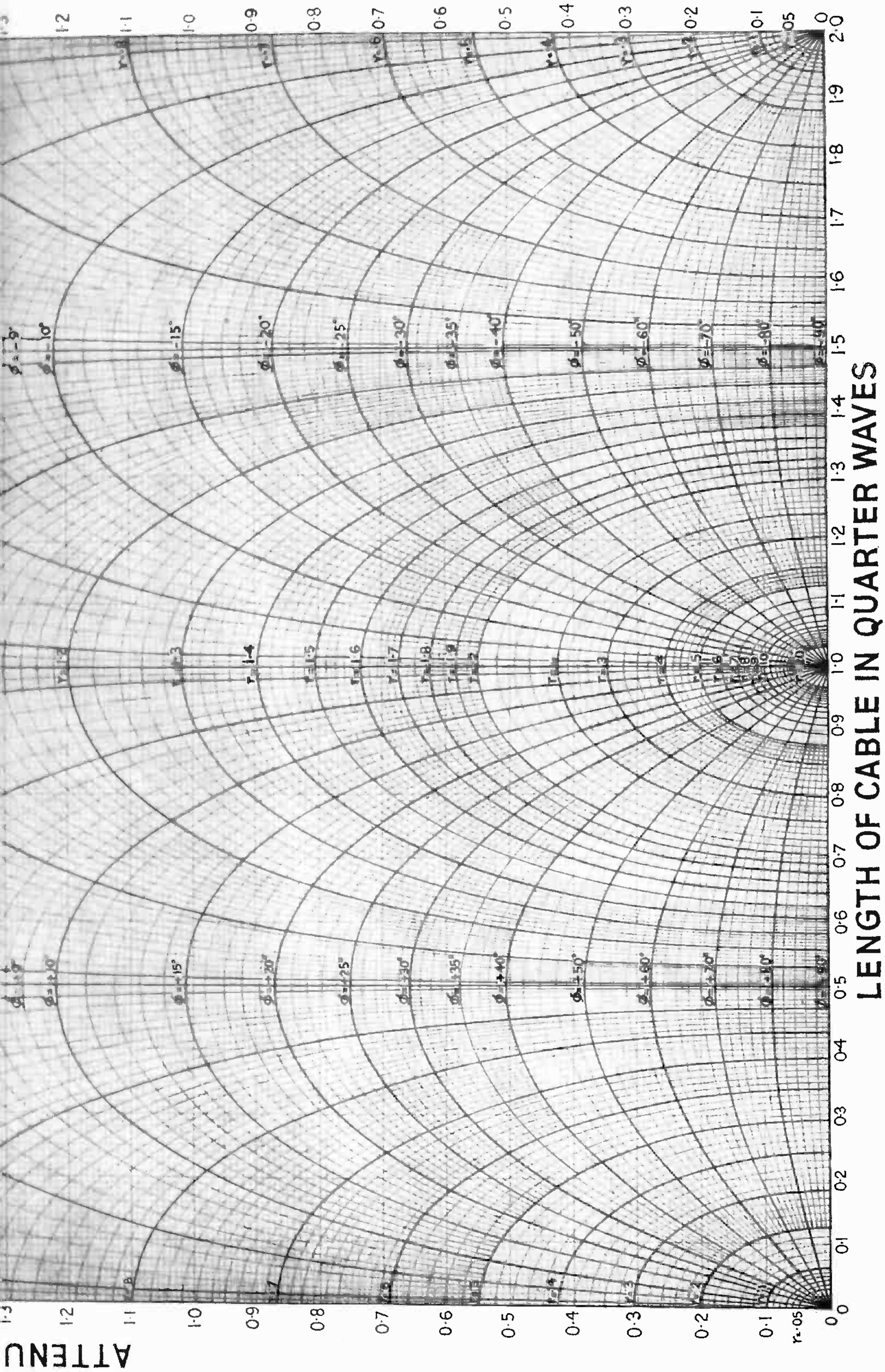
The above table gives the complete application of the chart to the quarter-wave method, though in the actual work a further correction of the feeder for angle would be necessary by means of tuned circuits.

(E) *To find Z_o and Length of Feeder to Transform a Reactive Load, Z_a, into a given Pure Resistance R.*

Let $\phi_a = /30^\circ$ = angle of the load impedance,

$$\left.\begin{array}{l} ,,\ |Z_a| = 50 \text{ ohms} \\ ,,\ R = 72.8\ ,, \end{array}\right\}\ \left|\frac{Z_a}{R}\right| = \cdot 687\ ;\ \left|\frac{R}{Z_a}\right| = 1.458$$


INPUT IMPEDANCE CHART


LENGTH OF CABLE IN QUARTER WAVES
ATTENU

First it is necessary to calculate Z_o from the formula

$$Z_o = R. \sqrt{\frac{x - \operatorname{Cos} \phi_a}{\operatorname{Cos} \phi_a - \frac{1}{x}}}$$

where $x = \left| \frac{Z_a}{R} \right|$

i.e. $Z_o = 72.8 \times \sqrt{\frac{.687 - .866}{.866 - 1.458}}$

$= 40.1$ ohms.

To find the required feeder length next calculate

$$r = \left| \frac{Z_a}{Z_o} \right| = \frac{50}{40.1} = 1.248$$

Then find the quarter-wave value corresponding to the point $r = 1.248$, $\phi_a = +30°$; this is .635. Subtract this from unity* and the result is the required length of feeder in quarter-waves.

$l = 1 - .635$

$= .365$ quarter-waves.

The above results will be found to be in close agreement with the values given in example (c).

(A) FILTER EXAMPLE.

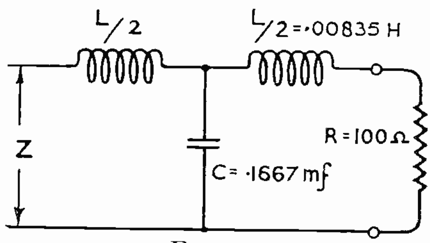


FIG. 1.

Find the input impedance Z, of a single section prototype low pass filter (Fig. 1) at a point in the pass band defined by $\frac{f}{f_c} = .834$, where f_c is the cut-off frequency. Let the attenuation below the cut-off frequency be zero. The load R is a pure resistance of value 100 ohms; L = .0167 henry; C = .1667 μF. The iterative impedance, Z_i, of the filter is intended, in this example, to be correctly matched to R at very low frequencies: thus $Z_i = \sqrt{\frac{L}{C}} = 100$ ohms, at very low frequencies.

Other data required for finding Z by means of the chart are Z_i at $\frac{f}{f_c} = .834$ and Z_d (i.e. impedance looking in at the sending-end of the filter with the load, R, disconnected) at $\frac{f}{f_c} = .834$. These can be found for a pure filter from

$$Z_i = \sqrt{\frac{L}{C}} \cdot \sqrt{\left(1 - \left[\frac{f}{f_c}\right]^2\right)} \quad \text{and}$$

* In general, subtract from next higher integer above quarter-wave value obtained from chart.

$$Z_d = \frac{j}{wc} \cdot \left(2\left[\frac{f}{f_c}\right]^2 - 1\right)$$

By equivalent line theory the ratio $\frac{Z_i}{Z_d}$ is taken to find the "electrical length" of the filter at the frequency considered. This can also be obtained from the chart. After obtaining this l-value the calculation proceeds in similar manner as in the other examples.

METHOD :—

$$\text{At } \frac{f}{f_c} = 0.834 \begin{cases} Z_i = 100\sqrt{(1 - .834^2)} = 55.176 \\ Z_d = j \times 0.6 \times 10^2\,(2 \times .834^2 - 1) = j \times 60 \times .39 = j\,23.4 \end{cases}$$

$$\therefore \frac{Z_i}{Z_d} = \frac{55.176}{j\,23.4} = -j\,2.36$$

$$= 2.36\ \overline{\backslash 90^\circ}$$

From the chart at the point $r = 2.36$, $\phi = -90^\circ$ read off

$$l = 1.256 \text{ quarter-waves}$$

$$\text{Then at } \frac{f}{f_c} = .834$$

$$r = \left|\frac{R}{Z_i}\right| = \frac{100}{55.176} = 1.81$$

$$\phi = 0$$

$$l = 1.256 \text{ quarter-waves}$$

$$a = 0$$

On the chart find the point $r = 1.81$, $\phi = 0$, then measure off to the right $l = 1.256$ (i.e. 12.56 large squares). (This length passes off the right-hand edge and continues in from the left-hand edge 2.56 large squares). From this point read off

$$r = .68, \qquad \phi = +24.5^\circ$$

$$\text{Hence} \quad Z = r.Z_i\,\underline{/\phi}$$

$$= .68 \times 55.176\,\underline{/24.5^\circ}$$

$$= 37.5\,\underline{/24.5^\circ} \ \ldots\ldots\ldots \text{ at } \frac{f}{f_c} = .834$$

Any network may be treated in the same way provided l is obtained as above from $\frac{Z_i}{Z_d}$ at the required frequency. If attenuation is present $\frac{Z_i}{Z_d}$ will be a complex number instead of a pure imaginary number, and putting this into the chart will produce the value of the attenuation as well as the "electrical length." Both of these would be used in finding the input impedance in the ordinary way.

In composite ladder networks each section must be treated separately, but for a recurrent network of n identical sections a and l for the whole network will be n times that for each section.

H. CAFFERATA.

GENERAL EQUALISER THEORY, TWO TERMINAL AND CONSTANT RESISTANCE STRUCTURES

These notes are the outcome of intermittent study over some years and were collated primarily for instructional purposes, since the subject has but a small technical literature. Indeed when this study began the only known references to the types of equaliser here described were in K. S. Johnson's "Transmission Circuits for Telephone Communication" and O. J. Zobel's paper "Distortion Correction in Electrical Circuits with Constant Resistance Recurrent Networks" in the Bell System Technical Journal of July, 1928. In both cases the subject is but scantily treated and scarcely reduced to a basis for design.

Inaugurated by Mr. W. P. Wilson's use of a resistance to decide the maximum attenuation and to provide an intelligible relation between reactance and attenuation for constant resistance structures, the development of this subject has engaged a number of the research staff of Marconi's Wireless Telegraph Company. In particular, Mr. C. D. Colchester has been involved in checking calculations and computations.

Introduction.

UNDESIRED departures from uniform frequency response are liable to arise in systems transmitting a relatively wide frequency range, or providing sharp discrimination between neighbouring frequencies. Attenuation equalisers are commonly used to correct these undesired departures from uniformity, and it is with the design of such equalisers that the present notes are concerned.

The principle upon which equalisers fulfil their purpose is the introduction of losses of such value and frequency characteristic that, when added to the response of the rest of the system, the total response is constant within the required limits. It follows that such equalisers degrade the transmission efficiency at any frequency to the minimum in the required frequency range. In practice, this degradation is exceeded, by an amount dependent on design and on component performance.

For purposes of classification these equalisers may be described as either two-terminal or four-terminal equalisers. Two-terminal equalisers being connected in series or shunt between the generator and its load, rely upon their variation of impedance with frequency to cause a similar variation in the power supplied to the load. Hence, this class of equalisers can occasionally serve the additional purpose of impedance equalisation. Four-terminal equalisers may or may not be of constant characteristic impedance, and the effects, to which their insertion gives rise, may be considered as attenuation and losses due to mismatching, precisely as in filter sections. All types of equaliser are open to cause phase changes on insertion.

General Formulæ—Two Terminal Networks.

The classes of equaliser mentioned can be shown to obey general laws according to their type. For the two terminal types, in the general case of an impedance Z, inserted in series or in shunt with a circuit between a generator and load of impedances Z_a, Z_b respectively, the ratios of the load current before to that after the insertion are :—

$$\text{Series insertion, } 1 + \frac{Z}{Z_a + Z_b} \qquad \text{(1)}$$

$$\text{Shunt insertion, } 1 + \frac{Z_a\ Z_b}{Z(Z_a + Z_b)} \quad \ldots \quad (2)$$

These ratios are generally complex, showing both an attenuation and a phase shift.

For simplification, the generator and load impedances may be made equal and pure resistances, R_o, while the inserted impedance may be equated to $R + jX$. With these provisos, and writing $\lambda(\sigma)$ for the modulus of the current ratio, it may be deduced that :—

$$\lambda^2(\sigma) = \left[1 + \frac{R}{2R_o}\right]^2 + \left[\frac{X}{2R_o}\right]^2 \text{ for the series insertion,} \quad \ldots \quad (3)$$

$$\lambda^2(\sigma) = \left[1 + \frac{R_o}{2R\left(1 + \frac{X^2}{R^2}\right)}\right]^2 + \left[\frac{R_o}{2X\left(1 + \frac{R^2}{X^2}\right)}\right]^2 \text{ for the shunt insertion.} \quad (4)$$

While if $\Psi(\sigma)$ be the phase shift in these cases,

$$\Psi(\sigma) = \tan^{-1}\frac{X}{2R_o + R} = \cos^{-1}\frac{1}{\lambda(\sigma)}\left[1 + \frac{R}{2R_o}\right] \text{ for the series insertion,} \quad (5)$$

$$\Psi(\sigma) = \tan^{-1}\frac{-XR_o}{RR_o + 2(R^2 + X^2)} \text{ for the shunt insertion,} \quad \ldots \quad (6)$$

The symbol σ is chosen to represent a normalised frequency function.

General Formulæ—Four Terminal Networks.

The use of four-terminal networks provides the possibility of arranging the equaliser to have a constant iterative impedance which is purely resistive. This possibility is valuable, and the four-terminal types having this property are alone considered here. It has been shown that, to obtain this property, the various types of network may be arranged as shown in Fig. 1, where $Z_1 Z_2 = R_o^2$ and R_o is the constant iterative impedance and a pure resistance. These arrangements are not exclusive, but form the best known types.

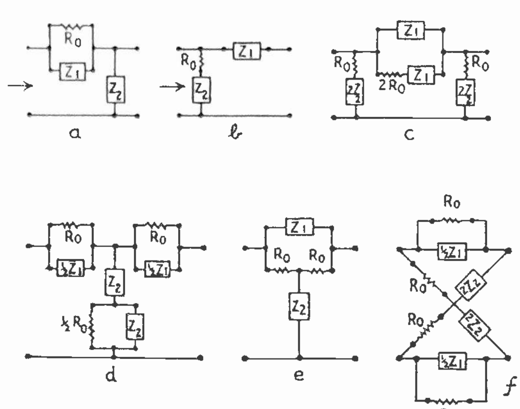


FIG. 1.

With the exception of the type designated (f), all these networks may be used in balanced or unbalanced form. All these sections are found to have a propagation constant.

$$\Gamma = 2\sinh^{-1}\tfrac{1}{2}\sqrt{\frac{\left(\frac{Z_1}{R_o}\right)^2}{1 + \frac{Z_1}{R_o}}} \quad (7)$$

The expression for the propagation constant is of course complex, implying an attenuation and phase shift on insertion of the equaliser. Separating these effects and using the same nomenclature as for the two terminal equalisers, the following equations are found :—

$$\lambda^2(\sigma) = \left[1 + \frac{R_1}{R_o}\right]^2 + \left[\frac{X_1}{R_o}\right]^2 \qquad \Psi(\sigma) = \tan^{-1}\left[\frac{\frac{X_1}{R_o}}{1 + \frac{R_1}{R_o}}\right] \quad .. \quad (8)$$

General Design Formulæ.

The formulæ mentioned in preceding sections are of a form more adapted to foretelling the effects produced by the insertion of a given network than for the purpose of designing a network to fulfil given requirements. The adaptation of the formulae to the latter purpose with the aid of approximations is the purpose of this section.

Practical requirements usually include frequencies at which the loss caused by the insertion of the equaliser is a maximum or minimum. From this arises the suggestion that where a maximum is available in the design data, series arms should be composed of a resistance in shunt with a reactance, since in such a case the maximum attenuation will occur when the reactance is infinite and the value of this maximum will be decided by the resistance value alone. Conversely, in the absence of a series arm, a resistance in series with a reactance is suggested for the shunt arm, the reactance becoming zero at maximum attenuation.

This conception of a loss controlled by a resistance and reactance which reduces to resistance at maximum loss allows simplification. For, if the maximum required attenuation is known, the series or shunt resistance is at once determined, the design reducing to choice of the reactance.

Employing this method, then, a series arm comprising a resistance R_{11} in shunt with a reactance X_{11} is first found to have an impedance

$$Z_1 = \frac{1}{R_{11}^2 + X_{11}^2}\left[R_{11} X_{11}^2 + jR_{11}^2 X_{11}\right] \quad .. \quad .. \quad .. \quad .. \quad (9)$$

Putting these values of resistance and reactance in the formula given for the series insertion equaliser,

$$\lambda^2(\sigma) = \frac{X_{11}^2}{R_{11}^2 + X_{11}^2}\left[\frac{R_{11}^2}{4R_o^2} + \frac{R_{11}}{R_o}\right] + 1 \quad .. \quad .. \quad .. \quad .. \quad (10)$$

Now it has been presumed that the maximum loss is known. Let this loss be $\lambda^2(1)$. Further at this maximum loss the reactance X_{11} is infinite, hence

$$\lambda^2(1) = \left[1 + \frac{R_{11}}{2R_o}\right]^2 \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (11)$$

Using this relationship to substitute for R_{11} in the previous equation, and solving for X_{11}^2,

$$X_{11}^2 = 4R_o^2 \frac{[\lambda(1) - 1]^2 \quad [\lambda^2(\sigma) - 1]}{\lambda^2(1) - \lambda^2(\sigma)} \quad .. \quad .. \quad .. \quad .. \quad .. \quad (12)$$

Thus, provided R_o and the maximum attenuation are given, the reactance X_{11} necessary to give any loss $\lambda^2(\sigma)$ can be found.

Adopting the same procedure for the shunt insertion equaliser, but using a resistance R_{21} and reactance X_{21} in series, with the reactance becoming zero at maximum attenuation, the relation is

$$X_{21}^2 = \frac{R_o^2}{4} \frac{\lambda^2(1) - \lambda^2(\sigma)}{[\lambda^2(\sigma) - 1]\,[\lambda(1) - 1]^2}, \text{ where } \lambda(1) = 1 + \frac{R_o}{2R_{21}} \quad \ldots \quad (13)$$

Similarly, the constant resistance structures yield

$$X_{11}^2 = R_o^2 \cdot \frac{[\lambda(1) - 1]^2\,[\lambda^2(\sigma) - 1]}{\lambda^2(1) - \lambda^2(\sigma)}, \text{ where } \lambda(1) = 1 + \frac{R_{11}}{R_o} \quad \ldots \quad \ldots \quad (14)$$

Considering the phase-shift formulæ for these three types of equaliser, it is similarly possible to replace the reactance and limiting resistance values by the effective and limiting current ratios. In this operation it is to be expected that the value R_o should disappear.

This operation results in precisely the same form for all three types of equaliser, viz. :—

$$\cos \Psi(\sigma) = \pm \frac{\lambda(1) + \lambda^2(\sigma)}{\lambda(\sigma)\;[\lambda(1) + 1]}$$

The ambiguity of sign is due to the sign of the reactance being irrelevant to the effective attenuation ratio, $\lambda(\sigma)$. It will be noticed that $\Psi(\sigma)$ is zero when the attenuation is zero or the maximum, while $\Psi(\sigma)$ has a maximum value when $\lambda^2(\sigma) = \lambda(1)$.

The above formulæ, for the structures mentioned, relate the reactance required for any given loss provided that :—

(A) The maximum attenuation required is known.

(B) The equaliser is used between a generator and load each of resistive impedance R_o.

This second requirement needs modification. If the generator and load be resistive but R_a and R_b respectively, the series and shunt insertion formulæ still hold if $(R_a + R_b)$ be written in place of $2R_o$. The constant resistance type, designed to match the load so that $R_b = R_o$, will show a constant loss added to that dependent on the reactance value.

Taking the formulæ (12), (13) and (14) together it will be seen that, for a given value of maximum attenuation $\lambda(1)$ and actual attenuation $\lambda(\sigma)$ if the reactance be written $\phi(\sigma)$ in all cases,

$$\left|\frac{\phi(\sigma)}{2R_o}\right| \text{ Series insertion } = \left|\frac{R_o}{2\phi(\sigma)}\right| \text{ Shunt insertion } = \left|\frac{\phi(\sigma)}{R_o}\right| \text{ Constant}$$

resistance. The square of the phase angle cosine will be the same for all three cases.

Hence it is possible to prepare one set of curves for all three cases, using attenuation as one axis, maximum attenuation as a parameter and a common impedance ratio as the other axis. The meaning of the impedance ratio will then depend only on the form of equaliser chosen.

In the same way, if the resistance used to determine the maximum possible attenuation be written as R for all cases, $\frac{R}{2R_o}$ Series insertion $= \frac{R_o}{2R}$ Shunt insertion $= \frac{R}{R_o}$ Constant resistance. Hence a curve relating the maximum attenuation to a resistance ratio can be drawn, the meaning of the ratio depending as before on the structure chosen. The phase shift can be similarly generalised.

Charts of these types are provided in Figs. 2, 3 and 4.

Use of Charts.

The first steps in using the charts are to determine the generator and load impedances and then to estimate the maximum attenuation required. Given this information, the next step is to take the attenuation required at any frequency and

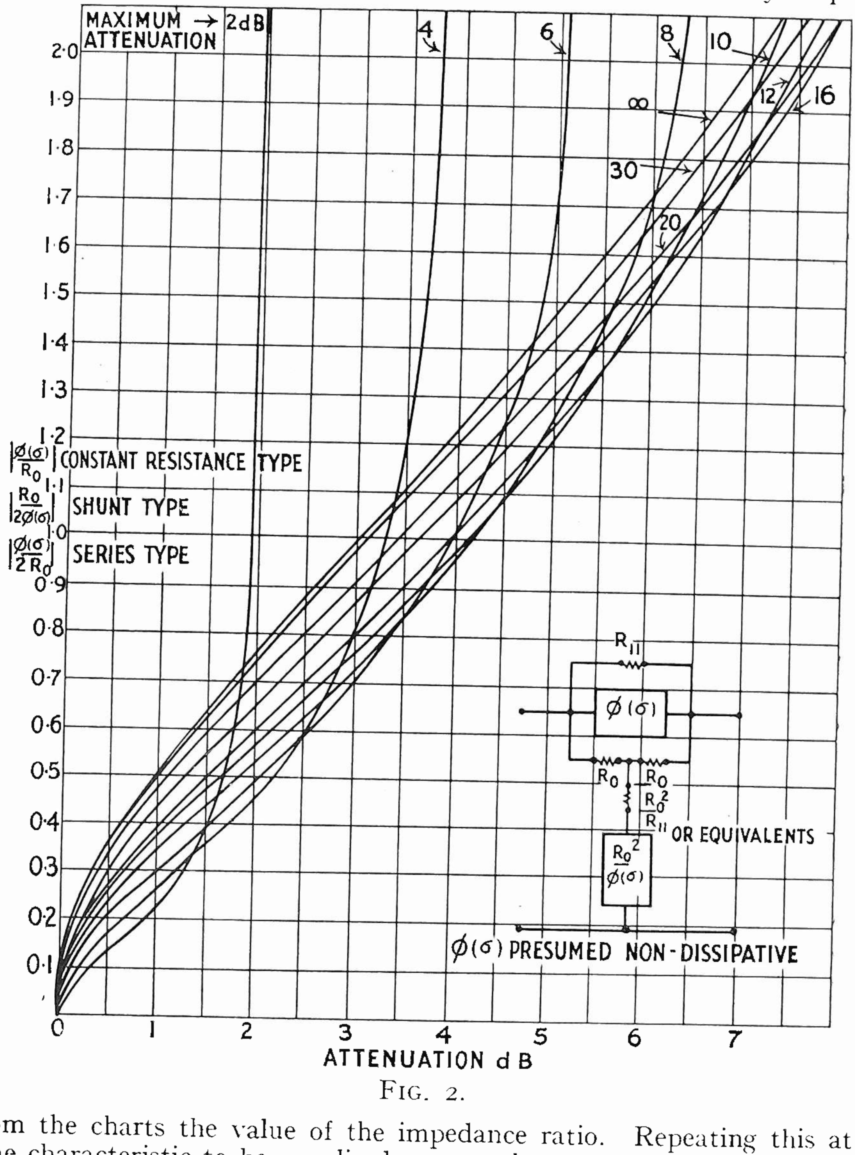


FIG. 2.

read from the charts the value of the impedance ratio. Repeating this at points along the characteristic to be equalised, a curve becomes available for the required behaviour of the impedance ratio with frequency.

To proceed, one of the three types described must next be chosen. This choice will then enable the absolute reactance-frequency characteristic required to be determined. The sign of the reactance is not indicated by the method, but as pure reactances only are involved this sign can be immediately determined from the rule that positive reactances increase, negative reactances decrease as the frequency is raised.

The resistance values are directly available from the maximum attenuation chart and the knowledge of the structure chosen and terminating resistances. The

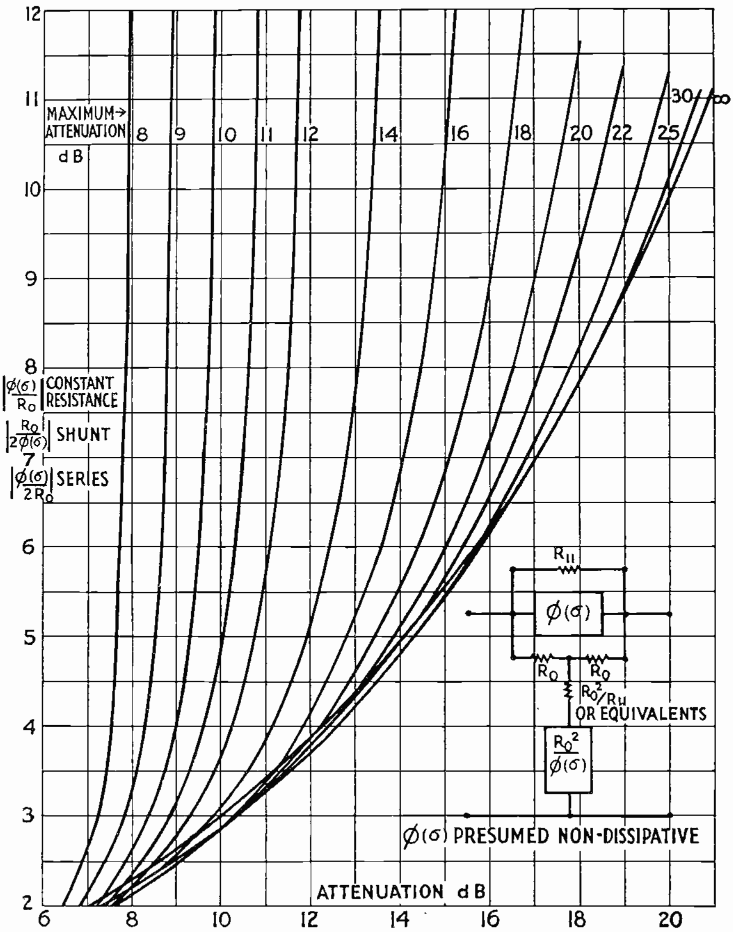


FIG. 3.

relation between the maximum attenuation and the resistance values for the matched case is shown in Fig. 5.

This chart can, of course, be used for unmatched cases by virtue of formulæ (1) or (2). For constant resistance structures, the mismatch between resistive terminations causes a loss or gain independent of frequency.

Reactance Characteristics.

The process described provides translation between attenuation and reactance behaviours with frequency. To proceed, the suggested method is to consider networks of increasing numbers of components, expressing their reactance-frequency characteristics in convenient form. This approach is simplified by the fact that only two types of reactance-frequency characteristic are possible for a given number of components without dissipation. A further simplification, arising from a study of these two reactance-frequency possibilities, is that if the two possible reactance expressions be multiplied together, when the frequencies of infinite reactance of the one coincide with those of zero reactance of the other and vice versa, the product is independent of frequency.

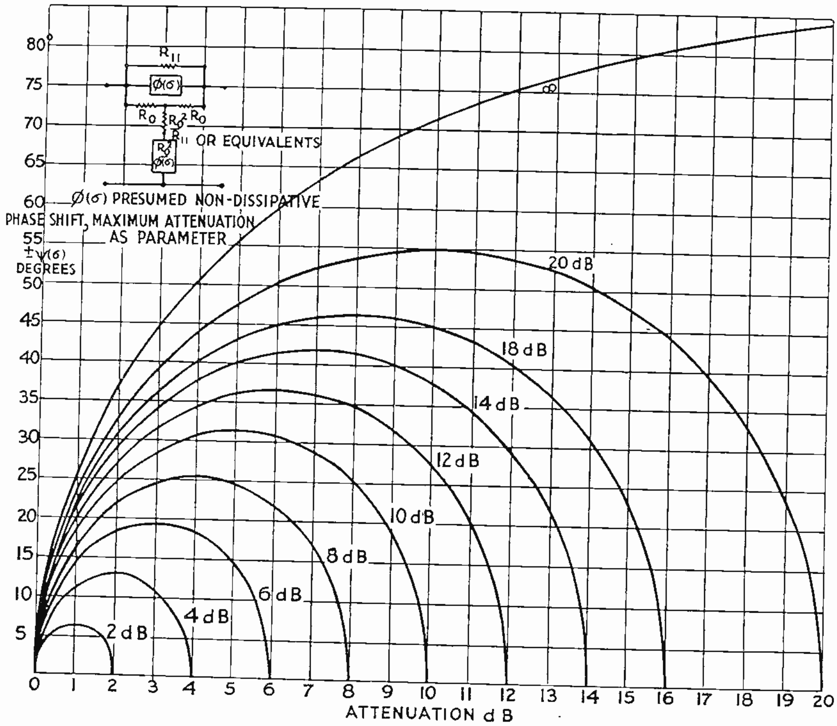


FIG. 4.

These statements may be more clearly seen from a study of Fig. 6, where possible alternative networks and the corresponding reactance expressions are arranged in vertical order of increasing numbers of components. Of the alternative forms, those on the left (A) have infinite reactance at zero frequency, those on the right (B) zero reactance at zero frequency.

For the purpose in view, the implications are important. In the first place, only two attenuation-frequency behaviours are possible for a given number of components without dissipation. In the second place, since the terms involving frequency for type A are the inverse of those for type B, it follows that the same attenuation-frequency behaviour holds for type A in series insertion, or in the series arm of a constant resistance structure, as for type B in shunt insertion. The converse is, of course, true. Further, in a constant resistance structure, if type A is used for the series arm, the shunt arm is type B and vice versa.

There will, of course, be a change of constants according to the use. If the attenuation-frequency characteristic obtained with a given network as the series arm of a constant resistance equaliser is to be procured by a series insertion, the same network form applies, but its reactance must be doubled, i.e., all inductances doubled and all condensers halved in value. The shunt arm of the constant resistance structure will be formed by the alternative to that used for the series arm, the

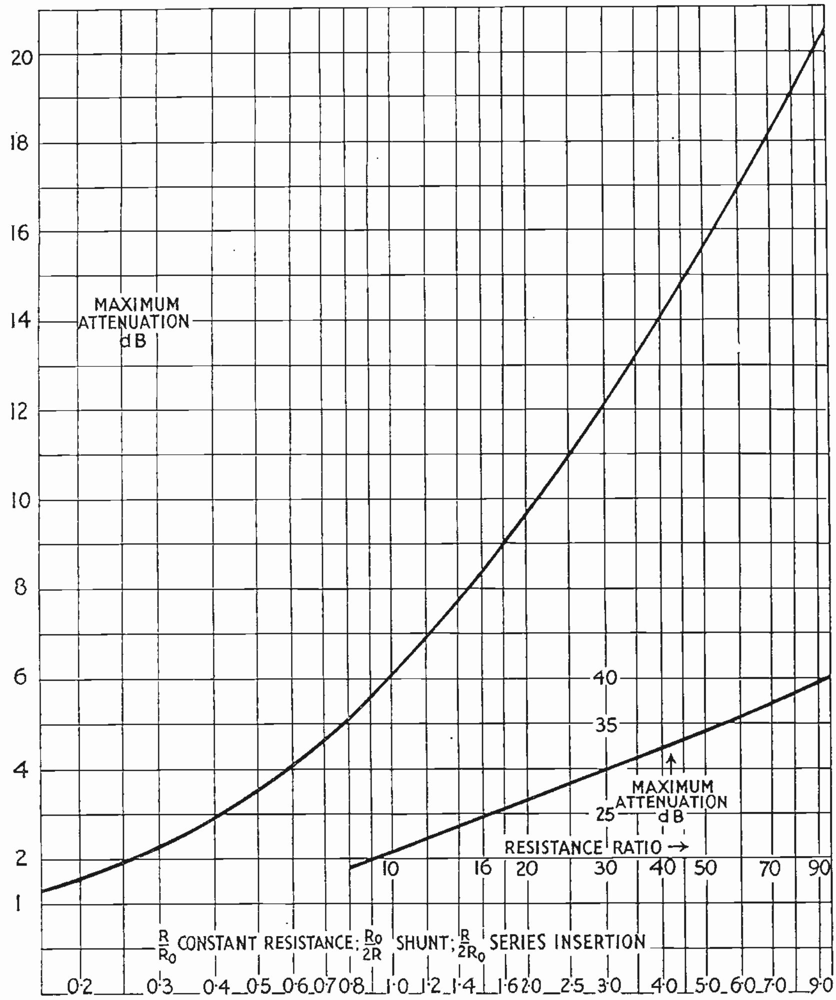


FIG. 5.

component values in this shunt arm bearing to those of the series arm the usual relations for inverse networks. To procure the same attenuation-frequency characteristic by a shunt insertion, the network forming the shunt arm in the constant resistance structure is required, but with all the inductances halved and the condensers doubled in value.

Performance Charts.

Since the attenuation of an equaliser depends only on the maximum attenuation chosen and a reactance-resistance ratio, the limited possibilities for the latter that have just been mentioned suggest that general charts should be prepared. On such charts, attenuation will form one axis, some function of frequency the other. The maximum attenuation chosen will be one parameter, the ratio of a component

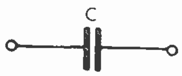
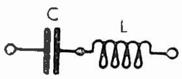
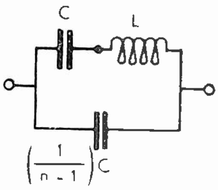
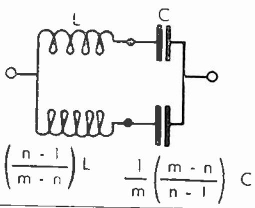
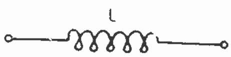
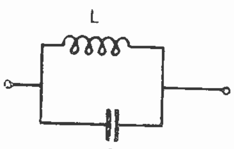
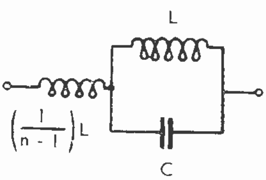
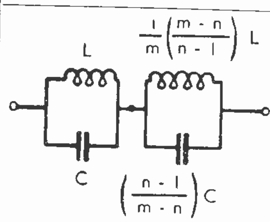
	Type	Class	Reactance	Conventions
	A	1	$\frac{1}{j\omega C}$	
	A	2	$\frac{1}{j\omega_0 C} \cdot \frac{1-\sigma^2}{\sigma}$	$\omega_0^2 LC=1,\ \sigma=\frac{\omega}{\omega_0}$ $X=0$ at $\sigma=1$
	A	3	$\frac{1}{j\omega_0 C} \cdot (n-1) \cdot \frac{1-\sigma^2}{\sigma(n-\sigma^2)}$	$\omega_0^2 LC=1,\ \sigma=\frac{\omega}{\omega_0}$ $X=0$ at $\sigma=1$ $X=\infty$ at $\sigma^2=n$
	A	4	$\frac{1}{j\omega_0 C} \cdot \frac{n-1}{m-1} \cdot \frac{1-\sigma^2}{\sigma} \cdot \frac{m-\sigma^2}{n-\sigma^2}$	$\omega_{0_1}^2 LC=1,\ \sigma=\frac{\omega}{\omega_{0_1}}$ $X=0$ at $\sigma^2=1\ \&\ m$ $X=\infty$ at $\sigma^2=n$
	B	1	$j\omega L$	
	B	2	$j\omega_\infty L \frac{\sigma}{1-\sigma^2}$	$\omega_\infty^2 LC=1,\ \sigma=\frac{\omega}{\omega_\infty}$ $X=\infty$ at $\sigma=1$
	B	3	$\frac{j\omega_\infty L}{(n-1)} \cdot \frac{\sigma(n-\sigma^2)}{1-\sigma^2}$	$\omega_\infty^2 LC=1,\ \sigma=\frac{\omega}{\omega_\infty}$ $X=\infty$ at $\sigma^2=1$ $X=0$ at $\sigma^2=n$
	B	4	$j\omega_\infty L \frac{m-1}{n-1} \cdot \frac{\sigma}{1-\sigma^2} \cdot \frac{n-\sigma^2}{m-\sigma^2}$	$\omega_{\infty_1}^2 LC=1,\ \sigma=\frac{\omega}{\omega_{\infty_1}}$ $X=\infty$ at $\sigma^2=1\ \&\ m$ $X=0$ at $\sigma^2=n$

FIG. 6.

value to the terminating resistances will be another and further parameters will occur as the network components become more numerous. The number of parameters rapidly becomes too great for clarity, but, fortunately, complicated equalisers are rarely needed.

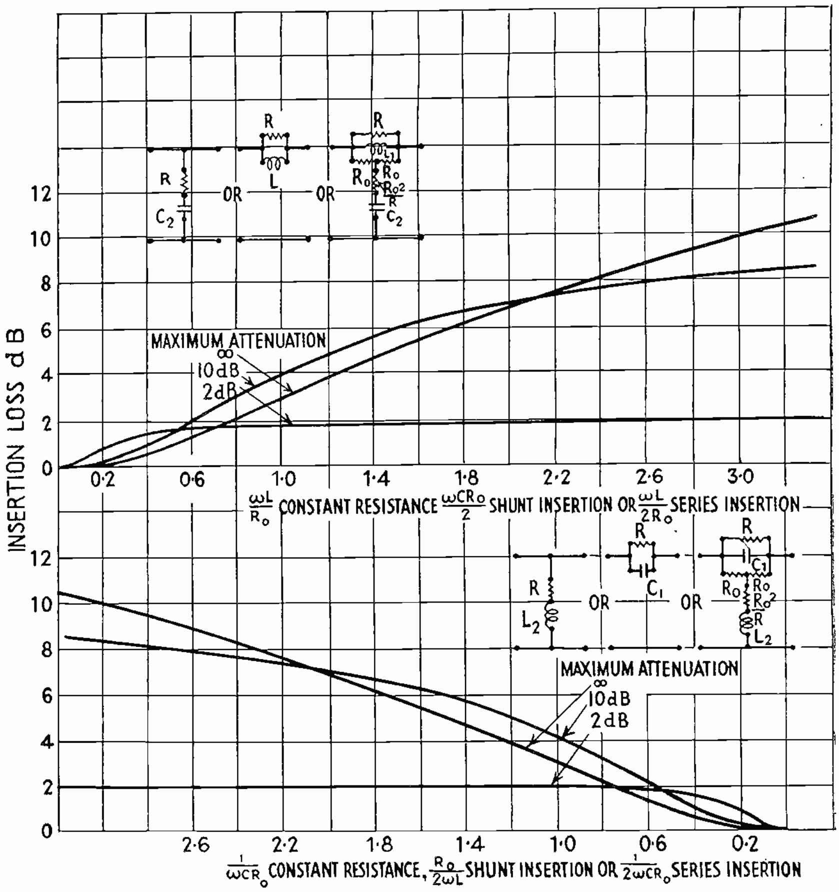


FIG. 7.

The simplest cases of these charts have been prepared and are shown in Figs. 7, 8 and 9.

These charts merit individual explanation when first examined. In Fig. 7 the upper set of curves refers to a constant resistance structure having a series inductance, the shunt insertion of a condenser or the series insertion of an inductance. The maximum attenuation is, of course, the parameter, and the axes are effective attenuation and a scale directly proportional to frequency, since these equalisers have no attenuation to d.c. and have their maxima at infinite frequency.

The lower set on the same sheet covers a constant resistance structure having a series condenser, the shunt insertion of an inductance or the series insertion of a condenser. The arrangement is precisely as that of the upper set, but the abscissæ are inversely proportional to frequency, since d.c. experiences the maximum attenuation, infinite frequency none.

Fig. 8 covers the shunt insertion of a parallel resonant circuit, the series insertion of a series resonant circuit or the use of a series resonant circuit for the series arm of a constant resistance structure. Here, the frequency scale is in terms of the frequency of zero attenuation, while the values of one component at this

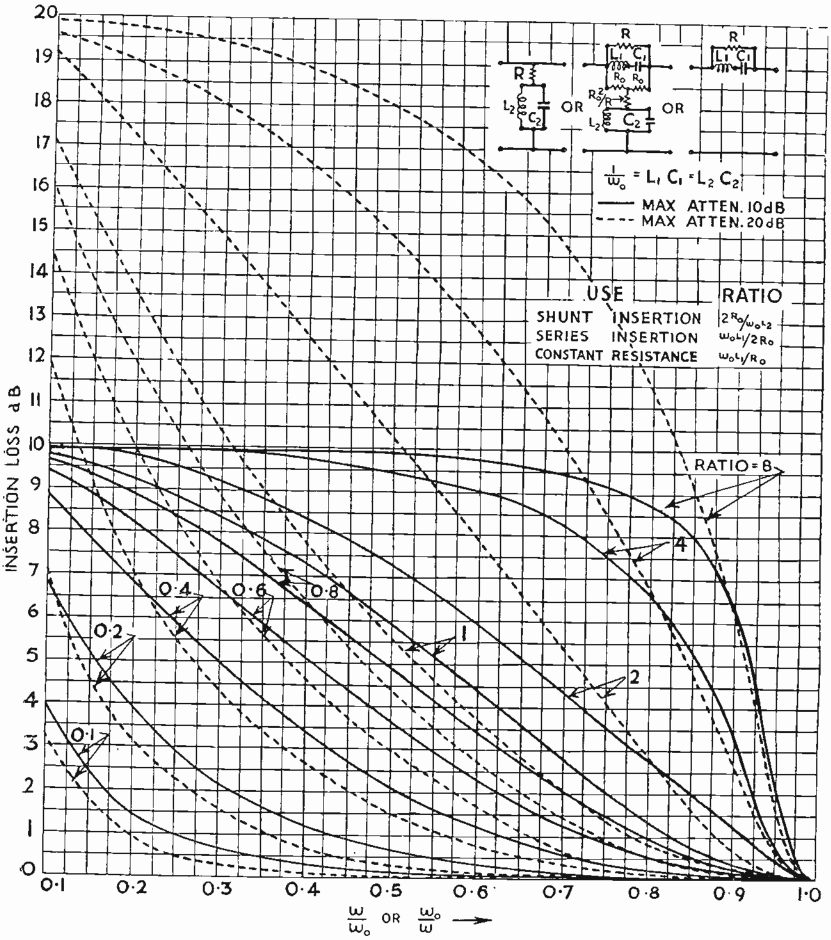


FIG. 8.

frequency provide a family of curves for every assigned maximum attenuation, two of which are drawn.

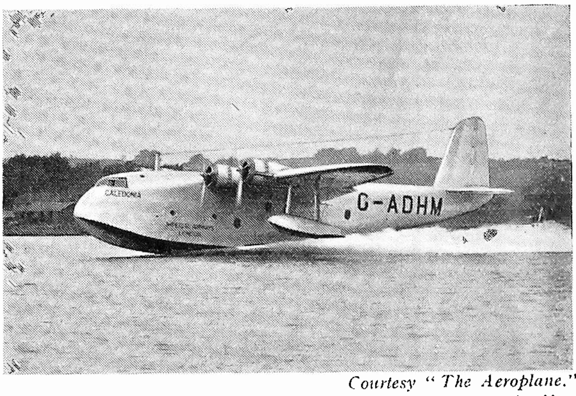
Fig. 9 is similar to the preceding chart, but covers the shunt insertion of a series resonant circuit, the series insertion of a parallel resonant circuit and the use of the latter as the series member for a constant resistance structure. Here the frequency of maximum attenuation and the value of one component at this frequency are the bases for the abscissæ and the family of curves for each assigned maximum attenuation.

(*To be continued.*)

MARCONI NEWS AND NOTES

WIRELESS AND THE NEW EMPIRE FLYING BOATS.

On February 18th "Caledonia," one of Imperial Airways new Empire flying boats, made a notable non-stop flight from Southampton to Alexandria.



Courtesy "The Aeroplane."

Imperial Airways flying boat "Caledonia."

"Caledonia," like her sister flying boat "Cambria," has been specially designed and equipped for long-range experimental flights across the Atlantic, preparatory to the opening of regular services between Great Britain and America. It is fitted with comprehensive wireless equipment of Marconi manufacture.

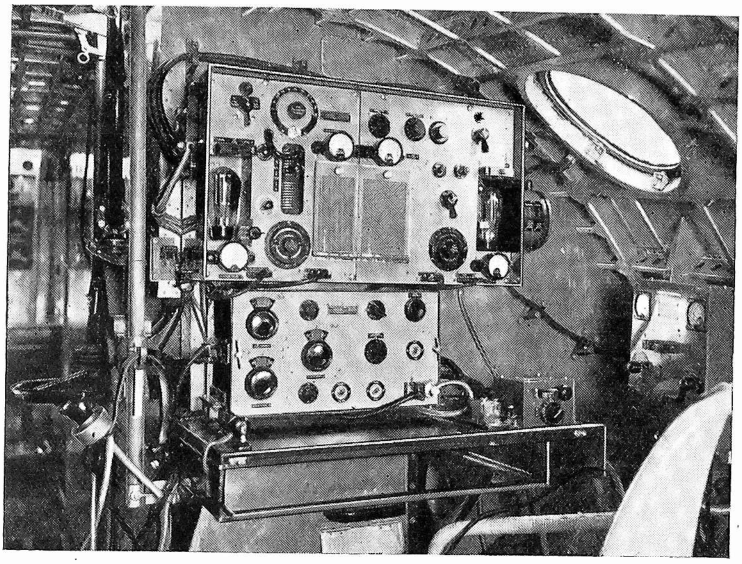
On the non-stop flight from Southampton to Alexandria "Caledonia" demonstrated the speed as well as the range of these vessels by covering the 2,300 miles in 13 hours and 35 minutes, an average, therefore, of 170 miles per hour.

On February 21st "Cambria" made a non-stop flight round Great Britain, circling over many cities in England, Scotland, Ireland and Wales. The flight, which started from Southampton at eight o'clock in the morning, ended at 4.45 in the afternoon, when a distance of 1,200 miles had been covered.

On both trips exhaustive tests were made of the wireless equipment. Constant communication between the flying boats and the ground, and with other machines in the air, was maintained. Information of weather conditions ahead of the machines was continuously wirelessed to them, and on occasions weather reports were in the hands of the captains before the boats had actually arrived in the bad weather zone, thus enabling course adjustment to be made as required.

The wireless transmitting installations on "Caledonia" and "Cambria" include a combined transmitter operating on two wavebands—one from 95 to 185 metres and the other from 500 to 1,000 metres; and a second transmitter operating on waves from $16\frac{1}{2}$ to 75 metres.

The associated receivers cover a waveband of 15 to 2,000 metres in stages. A separate direction finder with visual indicator for "homing" is used as an aid to navigation.



Marconi Equipment on Imperial Airways flying boat.

The flying boats carry experienced wireless operators, and as the wireless installations are fitted just behind the pilots' seats, messages can be passed to and fro without delay.

The experience gained and the thorough tests will naturally be of the utmost value when experimental flights across the Atlantic start.

"Cambria" has also made a special preliminary flight from the new Atlantic air base on the Shannon. In addition to flying along the Irish coast the flying boat flew out over the Atlantic, and during the whole time she was in the air wireless communication was maintained with the ground stations and proved most efficient.

The accompanying photograph illustrates the Marconi installation specially designed for these new aircraft.