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RADIATION FROM A SHORT WAVE VERTICAL AERIAL

The question of the distribution of radiation from vertical aerials is of extreme importance in many short wave problems.

In the following article the effect of the earth on the vertical polar diagram and of the radiation efficiency of a short wave vertical aerial is discussed, and a practical method is given of obtaining a figure for the radiation efficiency of such an aerial.

Energy Losses.

THE polar radiation diagrams of vertical short wave aerials have recently been worked out by the writer, Journal I.E.E., Vol. 65, No. 366, June, 1927, by M. J. O. Strutt, Annalen der Physik 1929, 5 Folge Band, Heft 6, and by W. Howard-Wise, Bell Technical Journal, October, 1929, Vol. 8, No. 4.

These investigations all agree in the final formula which shows that at great distances there is no horizontal radiation and that the remaining radiation energy distribution is a pure polar diagram in as much as the energy radiated over any two hemispheres is the same. Thus in Fig. 1 the energy radiated over A and B is the same if A and B are at a sufficient distance from the Transmitter T, but this is not true of C if C is sufficiently close to T. The difference is, of course, the energy radiated through C and lost in the ground between C and A.

The whole of this energy has to be supplied to the aerial and the question arises what fraction of the total energy supplied to the aerial remains in the final polar diagram after the earth has taken its quota.

This may be calculated as follows if we know the distribution of electric and magnetic forces over the surface of the earth. Let T be the transmitter, Fig. 2, and S be a hemisphere at such a distance from T that the pure polar diagram is wholly established.

Then the whole of the energy supplied to T is radiated through the closed surface surrounding T consisting of the hemisphere S and the part of the plane of the earth covered by the hemisphere. The part of the energy radiated through the earths surface may be considered as lost, and the radiation efficiency, so to speak, of the aerial is the ratio of the power radiated through S, which is usefully employed, to the sum of this and the energy radiated through the earth's surface or rather wasted in the earth's surface.

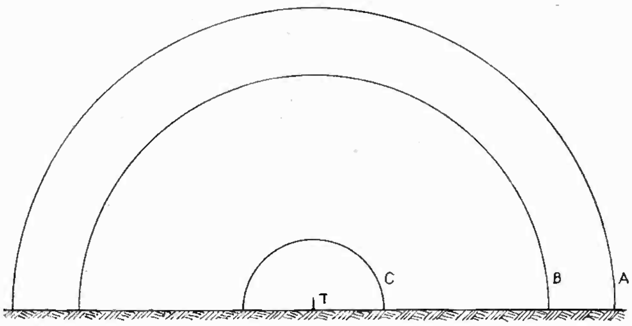


FIG. 1.

This radiation efficiency may be determined semi-experimentally if the total resistance of the aerial can be measured.

For the total power supplied to the aerial is as before stated partly radiated through S and partly wasted in the earth's surface.

Now the amount radiated through S may be easily found. It is only necessary to calculate the final polar diagram and to integrate this to obtain the useful power radiated from the aerial and hence the useful radiation resistance r say.

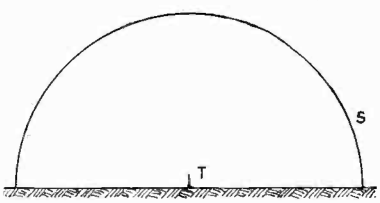


FIG. 2.

This polar diagram can now be calculated from the aerial disposition and earth constants as indicated in the first paragraph.

If the total resistance can be measured, the radiation efficiency is the ratio of r to the total measured resistance R. This method has been applied to the calculation of the radiation efficiency of a $\frac{1}{2}$ wave aerial placed just above the earth's surface as shown in Fig. 2.

In the first place we have to calculate r, which depends on the radiation polar diagram of this aerial.

An element dx at a height x above the earth's surface will produce a field

$$dF = \cos\theta \left(e^{-i\phi} + \frac{n\alpha - n^{\mathrm{I}}}{n\alpha + n^{\mathrm{I}}} \cdot e^{+i\phi} \right) I_0 \operatorname{Sin} \frac{2\pi x}{\lambda} \, dx$$

Where $\phi = \dfrac{2\pi\, x \operatorname{Sin}\theta}{\lambda}$

Where $n = \operatorname{Sin}\theta$

$n^{\mathrm{I}} = \sqrt{\operatorname{Sin}^2\theta + \epsilon - 1 + 2i\sigma\lambda c}$

$$\alpha = \epsilon + 2i\sigma\lambda c$$

ϵ = Earth Inductivity

σ = ,, Conductivity

λ = Wave length

c = Velocity of light

$\dfrac{n\alpha - n^{1}}{n\alpha + n^{1}} = R_{\theta}$ the reflection coefficient of the earth for the angle of elevation θ

The total electric field is therefore proportional to

$$\int dF = F = I_0 \operatorname{Cos}\theta \int_{0}^{h} \left\{ e^{-i\phi} + \left(\frac{n\alpha - n^{1}}{n\alpha + n^{1}}\right) e^{+i\phi} \right\} \operatorname{Sin}\frac{2\pi x}{\lambda}\, dx$$

after some reduction this integral may be put in the form (suitable for computation)

$$F \propto \operatorname{Cos}\theta \frac{I_0 \lambda}{4\pi} \left\{ \left[\frac{2\left(\operatorname{Cos}\zeta(1+\operatorname{Sin}\theta) - 1\right)}{1+\operatorname{Sin}\theta} + \frac{2\left[\operatorname{Cos}\zeta(1-\operatorname{Sin}\theta) - 1\right)]}{1-\operatorname{Sin}\theta} \right] \right.$$
$$\left. + (R_{\theta} - 1) \left[\frac{e^{-i\zeta(1-\operatorname{Sin}\theta)} - 1}{1 - \operatorname{Sin}\theta} + \frac{e^{-\zeta(1+\operatorname{Sin}\theta)} - 1}{1+\operatorname{Sin}\theta} \right] \right\}$$

for a perfect conductor $R_{\theta} = 1$ and the last term vanishes.

The first term therefore represents the polar diagram for a perfect conductor and the second gives the correction for imperfect conductivity.

Fig. 5 curve B gives the results of the computation for

$$\alpha = \frac{\lambda}{2} \qquad \sigma = \frac{1}{2 \times 10^{12}} \qquad \epsilon = 2 \qquad \lambda = 22m$$

Curve A is the polar diagram for perfectly conducting earth.

Now the radiation resistance corresponding to A has been calculated by Stuart Ballantine, who found it to be 103 ohms.

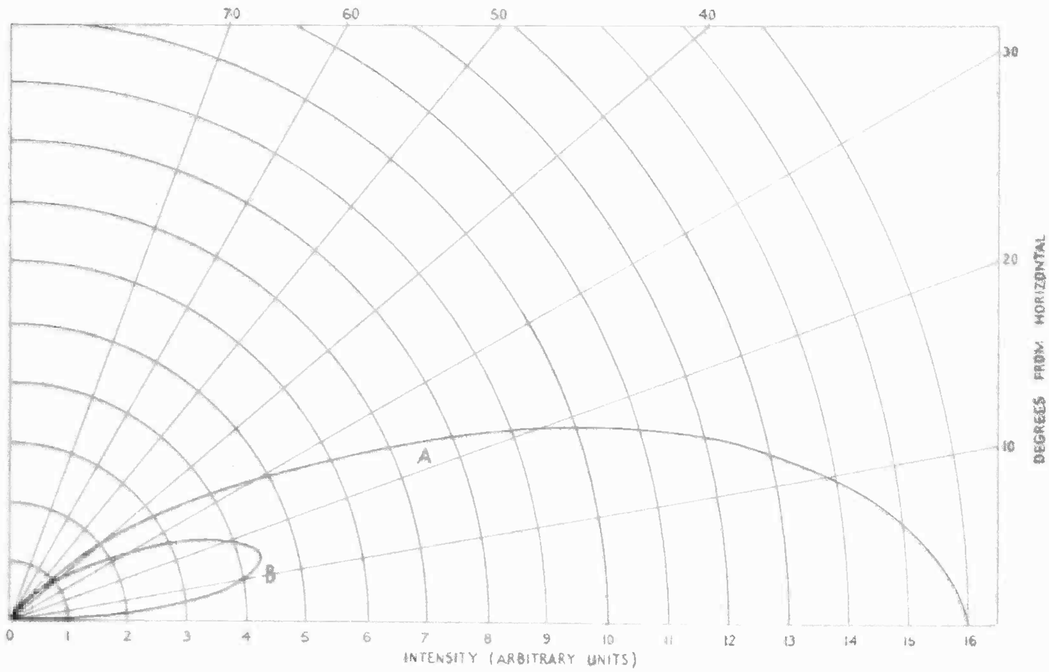
Hence $\dfrac{2}{103}$ = ratio of area enclosed by B to that of A, from which we find r = 31 ohms.

Measurement of Total Resistance of $\frac{1}{2}\lambda$ aerial.

The short wave signal measuring apparatus has been used to determine the resistance.

The method used may be explained with reference to Fig. 4.

It consists essentially in calculating the electric and magnetic forces at or near the surface of the aerial and determining in essence the total radiation from the aerial. The value of this method is that it indicates that the resistance over and above that of a $\frac{1}{2}\lambda$ aerial on a perfectly conducting plane increases practically in proportion to the square root of the frequency. Now accurate measurements of this difference have been made on a 288M. wave and it is found to be 12 ohms. If this is increased in the ratio of the square roots of the frequency a value of 45 ohms is obtained for the added R and the total resistance in the 21M. case is $103 + 45 = 148$ which though less than the measured 165 is sufficient to indicate that the measured resistance is a representative value. A recent measurement of a $\frac{1}{2}\lambda$ aerial gives a value for this of 180 ohms.)



The analysis of the first method is not yet complete but preliminary computation shows that the earth loss is a considerable proportion of the total resistance and thus confirms the measured results which show low radiation efficiency. One result of importance emerges which can be stated without carrying out the full integration. It is that the earth loss decreases with the height of the aerial above the ground.

The expression for the earth loss varies as

$$e^{-\frac{4\pi h}{\lambda}} \frac{1}{(1 + \epsilon + 2i\sigma\lambda c)^{\frac{1}{2}}}$$

Where h = height of aerial above the earth.

λ = wave length.

ϵ = specific inductive capacity of earth.

σ = conductivity of earth.

c = velocity of light or approximately

$$e^{-\frac{2\pi h}{\lambda}\frac{1}{\sqrt{\sigma\lambda c}}}$$

and taking $\lambda = 30$, $\sigma = \frac{1}{2 \times 10^{12}}$

this becomes $e^{-\frac{h}{\lambda}0{\cdot}662}$

To reduce the loss to one-tenth of its surface value, the aerial must be raised to 3.5 wave lengths above the surface of the earth. With the earths resistivity increased tenfold the necessary height is 1.1 λ so that in practice between 1 and 3 wave lengths height is necessary to obtain good radiation efficiency.

Further confirmation of these results is obtained from certain transmission tests.

In the first place there are the results published in the writer's "Short Wave Telegraphy" Journal I.E.E., Vol. 65, No. 366, June 1927. These show that the effect of raising a ½ wave doublet from just above the earth's surface to a height of about 80 M. results in a quite appreciable gain in the signals received in Sydney on a 15M. wave. The average gain was of the order of 10T.U. This is rather more than might be expected. Part of the gain may be attributed to the fact that not only does raising the aerial increase the total radiation efficiency but also improves the low angle radiation which is required for long distance transmission.

Recently some rough signal measurements have been made on the short wave band.

As the result of a years interception of signals at Broomfield, Chelmsford, the attenuation suffered by the rays on various short wave lengths is now fairly accurately known, the path of the rays having also been disclosed by facsimile measurements.

With this data it should be possible to calculate approximately the signal strength if the radiated power is known. Or we can work backwards and calculate radiated power. In nearly every case this calculated power is a small fraction of the nominal power of the station. These results therefore suggest that in general the radiation efficiency is small.

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A current was introduced into the circuit under test Z (part of the circuit A B C) through the calibrated mutual M which is part of the signal measuring set. The circuit A B C was loosely coupled to a sensitive receiver and the output of this recorded at D.

Let M be the value of M required to give a certain measurable output ; then the EMF in A B C is proportional to M, now let a known resistance R be inserted in series with Z. The output will be reduced. M_1 is now increased to M_2 to give the same output reading as before. The current i in A B C is therefore the same in both cases.

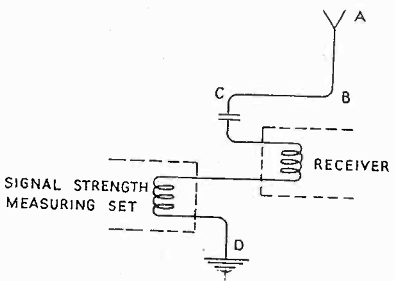


FIG. 3.

Now $$i_1 \propto \frac{M_1}{Z} \qquad i_2 \propto \frac{M_2}{Z + R}$$

$$\frac{M_1}{Z} = \frac{M_2}{Z + R}$$

so that $$\frac{Z + R}{Z} = 1 + \frac{R}{Z} = \frac{M_2}{M_1}$$

and $$Z = \frac{R}{\frac{M_2}{M_1} - 1}$$

from which the impedance Z can be obtained. If the circuit under test is tuned $Z = R_1$ the resistance of this circuit, so that $R_1 = \dfrac{R}{\frac{M_2}{M_1} - 1}$

In the tests the aerial arrangement was as follows. Fig. 3. AB was a vertical stretch of wire 10.5M. approximately which tuned to 21M. wave.

BCD was a $\frac{1}{4}$ wave tail at about 1M. above the earth's surface. The added resistance was inserted at R (Fig. 4) and it was assumed that the reflection points in the system were insufficient to make any appreciable difference in the current at R and that in the centre of the stretch AB. DBC was first tuned to $\frac{1}{4}$ and measured ; it was 15 ohms. After preliminary testing the correct length for DB was found, and when connected at B the total resistance was found to be 179.5 ohms. (The mean of several readings.)

The resistance method was checked by measuring a known resistance of 54 ohms, the measured mean was 56.25.

The effective resistance of the aerial AB itself is therefore approximately 165 ohms and the radiation efficiency

$$\frac{31}{165} = 18.8\ \%$$

This means that only 18.8 % of the power supplied to the aerial is usefully employed for long distance communication.

This is a surprising small value, and depends to a certain extent on the assumed values of the earth's inductivity and conductivity. No reasonable alteration of these would materially effect the results, and we may feel confident therefore that in the particular case measured the radiation efficiency is only of the order of 20 %. Some doubt as to the generality of this result may be entertained. It is possible for instance that there were large local dielectric losses in the wooden masts and support to the measured resistance. A theoretical calculation of the power wasted in the earth is therefore of value as a check.

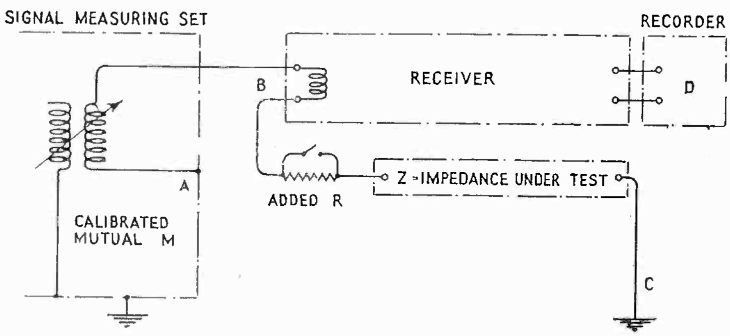


FIG. 4.

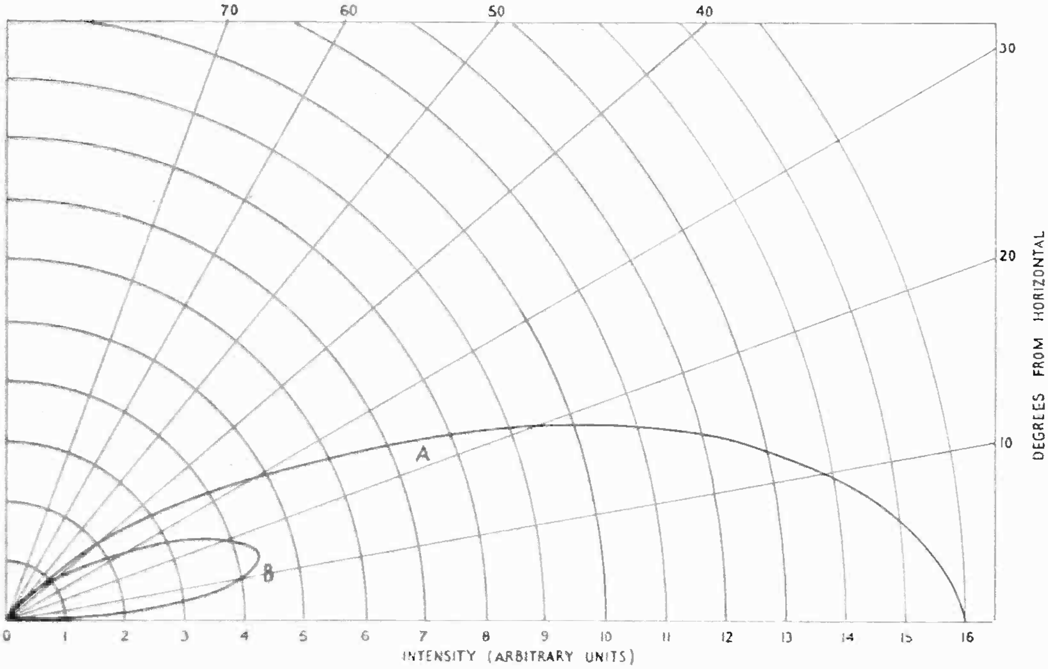
Sommerfeld's analysis serves as a starting point for the theoretical analysis.

Two methods may be employed.

The first is to calculate the electric and magnetic forces at the surface of the earth, form the product $\frac{1}{4\pi} E_\lambda H_\alpha$ and integrate this over the surface of the earth.

This represents the earth loss from which a corresponding resistance may be obtained, R_ϵ say, then the total resistance of the aerial will be $R_\epsilon + r$ (r defined as before) and the radiation efficiency will be $\frac{r}{R_\epsilon + r}$. There is a certain amount of doubt as to whether Sommerfeld's analysis represents the electromagnetic forces accurately up to the neighbourhood of the transmitter and this must await a more rigorous analysis but the calculation will at least give an approximate value for the loss R_ϵ. The second method also based on Sommerfeld's theory has already been used to calculate the resistance of a $\frac{1}{2}\lambda$ aerial in the broadcast range.

It consists essentially in calculating the electric and magnetic forces at or near the surface of the aerial and determining in essence the total radiation from the aerial. The value of this method is that it indicates that the resistance over and above that of a $\frac{1}{2}$ λ aerial on a perfectly conducting plane increases practically in proportion to the square root of the frequency. Now accurate measurements of this difference have been made on a 288M. wave and it is found to be 12 ohms. If this is increased in the ratio of the square roots of the frequency a value of 45 ohms is obtained for the added R and the total resistance in the 21M. case is $103 + 45 = 148$ which though less than the measured 165 is sufficient to indicate that the measured resistance is a representative value. A recent measurement of a $\frac{1}{2}$ λ aerial gives a value for this of 180 ohms.)



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THE MARCONI SPEECH CONTROL EQUIPMENTS FOR BROADCASTING

The term Speech Control Equipment is intended to cover the whole chain of apparatus between the Microphone proper and the input terminals of one or more Broadcast Transmitters, its function being to repeat to the transmitter a faithful and distortionless copy of the currents generated in the microphone at a power level sufficiently high fully to modulate the transmitter.

In this sense speech input or speech control equipment includes a consideration of the microphone and the studio, the various amplifiers and their associated monitoring and quality checking devices, frequency correction equipment, and a study of the interconnecting lines and cables.

Modern broadcasting technique shews an increasing tendency to group various transmitters into national or even international networks with the result that a growing proportion of the total programme material is transmitted from cultural centres by landwire and radiated from distant transmitters.

It is obviously necessary to ensure that these programmes are equal to or have a near approach to the fidelity of transmission obtainable on local circuits and this again depends on the speech control equipments and lines.

The Engineers of the Marconi Company have made a special study of the many problems involved and have designed and developed the complete series of equipments now to be described.

THE simplest possible equipment is the case of one programme from one studio radiated by one local transmitter. The essential parts of the equipment are clearly shewn in the schematic line diagram, Fig. 1.

Speech currents generated in the Microphone are amplified by the Microphone Amplifier (A) and the Control Amplifier (B) is used to increase the power level to the degree required by the transmitter. Auxiliary apparatus in the form of a modulation indicator gives a continuous check on the degree of modulation, and a monitoring or check receiver and loud speaker for checking the quality are shewn in the diagram.

Standard Equipment

An elaboration of the simple equipment as shewn in Fig. 2 is a very useful group and is, in fact, the equipment standardised for supply to all normal broadcast studios. Two microphones and one gramophone pick-up are shewn, but several alternative arrangements are possible; for example three microphones or one microphone and two gramophones and all three inputs may be faded and mixed together.

The B Amplifier has also a triple input circuit with Fading Potentiometers and such extraneous effects as time signals, etc., may be superimposed on the main programme by their use.

Outside Broadcast

When it is desired to radiate items of interest from places outside the studios, an "outside broadcast equipment" is necessary, which is connected to the Standard Speech Equipment as shown in Fig. 3.

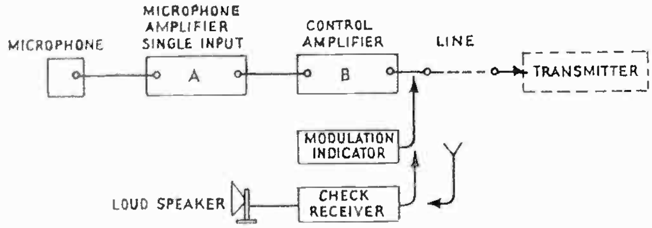


FIG. 1.

The outside broadcast may take the form of an operatic performance, an orchestral concert, religious service or dance music, and the provision of a triple input circuit to the portable A Amplifier enables several microphones to be disposed in the auditorium, the combined output being mixed to obtain a satisfactory balance of the various performers or speakers.

Transmitter Equipment

In the simple equipments so far considered it has been assumed that the transmitter was sufficiently near to the control centre for the connecting lines to be neglected. If this is not the case an additional B Amplifier may be necessary at the Transmitting Station. A further study of the quantitive aspect will be made in a later paragraph.

In all cases it is of course advisable to have suitable control and monitoring facilities at the transmitter, but where the line is long it is frequently also desirable to instal a local testing and emergency studio.

The equipment shewn diagrammatically in Fig. 4 has been developed for this purpose, and it will be seen that it is substantially similar to the simple studio equipment of Fig. 1. Actually the difference is that studio equipments have a polished hardwood table or desk for convenience of the seated control operator, whereas the transmitter equipment, being only for occasional use, is not so equipped.

It is usually recommended that an equipment as shewn in Fig. 4 be installed at the transmitter even where additional magnification is not essential, as the large reserve of amplification gives a good margin of safety and the test studio facilities are available in case of failure of the landlines from the main studios.

Simultaneous Broadcast

It is frequently required in broadcast schemes to connect a number of regional transmitters to a common national or sometimes international network and to radiate items or programmes from any or all of the transmitters simultaneously. The main control room them becomes a kind of nerve centre for the system and a more complex speech control equipment becomes necessary, the actual complexity depending of course on the scope of the scheme.

Obviously it is impossible to deal with the many combinations that may be required, and each particular proposal must be studied on its own merits, but in order to demonstrate a typical case, a hypothetical simultaneous broadcast network has been set out in Fig. 5.

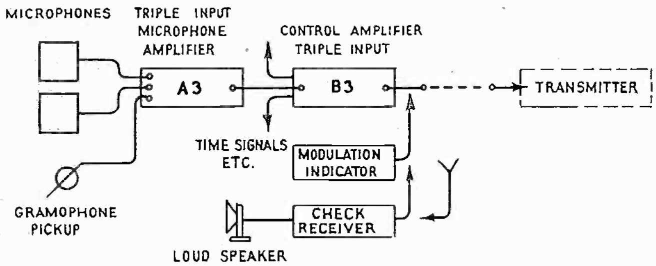


Fig. 2.

The control centre is shewn connected to two local transmitters X and W by short landlines and to three distant regional transmitters by long trunk lines. International trunk lines connecting to neighbouring countries are also shewn. Let it be supposed that the following programme arrangements are required at some particular time :—

(A) A dramatic play originated at the central studio is to be radiated simultaneously from the local transmitter X, the short wave transmitter W and the distant regional transmitter Z.

(B) An educational talk is to be broadcast from regional station Y only, the talk being given by a professor in the central studio.

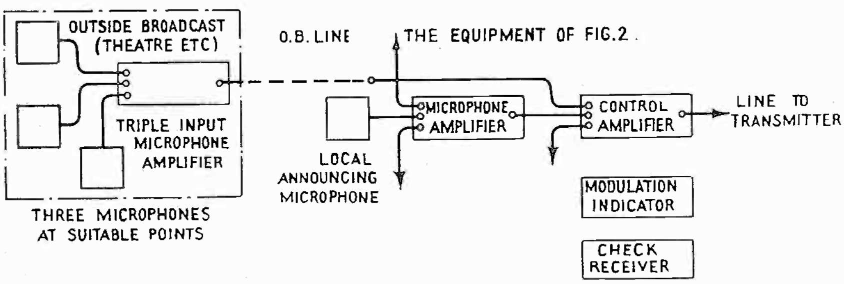


Fig. 3.

(C) A programme received from a neighbouring country is to be amplified, corrected for line distortion and re-transmitted over a second trunk line to regional transmitter V.

(D) During the time that the programmes as outlined are in progress a time signal from an observatory is to be radiated from all stations, and the play is to be interrupted at another time for an important speech or other outside broadcast.

The set-up necessary at the control centre for such a scheme is shewn in diagrammatic form in Fig. 6.

It should be noted that the rather elaborate interconnecting and line switchgear has been omitted as it would tend to obscure the diagram.

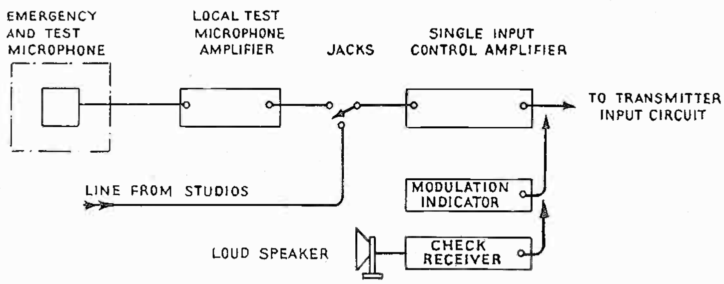


FIG. 4.

The dramatic play microphones are connected to amplifier A2, and control amplifier B1. The distribution unit D enables up to three separate circuits to be loaded in a single B amplifier without destroying the balance of circuit impedances, and divides the outgoing signal to its three channels X, W and Z. Attenuator networks ensure that the load put on the amplifier by varying lines is substantially constant. In the case of X and W the lines are short and the programme goes direct, but as Z is supposed to be a long line it is assumed to be necessary to correct the frequency characteristic by means of the equaliser network EQI and to compensate for the equaliser losses by means of the line or level raising amplifier CI. The important outside broadcast which is to interrupt the play is shewn connected to the second input circuit of the B1 amplifier, ready to be faded up when the time arrives.

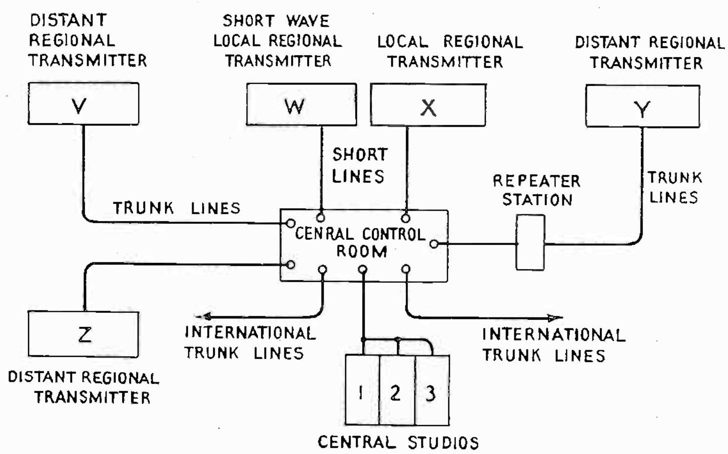


FIG. 5.

Connected to the third B1 input and also to all the other outgoing circuits is shewn the time signal oscillator with its direct observatory line.

The professor gives his talk in studio 3 which is connected to the line outgoing to transmitter Y by amplifiers A3 and B2, equaliser EQ2 and level raising amplifier C2.

The international trunk line simply connects through C3 amplifier and distributing unit and equaliser EQ3 to the outgoing V line. As an indication of the physical arrangement of an equipment such as has been described, Fig. 7 shews a photograph of a typical assembly.

Power Levels

Modern types of Marconi broadcast transmitters, for example Types P.A.13 and P.B.2 have been standardised so that a peak input signal voltage of 3·5 volts will fully modulate the transmitter.

The input circuit is a transformer of 600 ohms primary impedance, this figure having been selected to match the average line impedance.

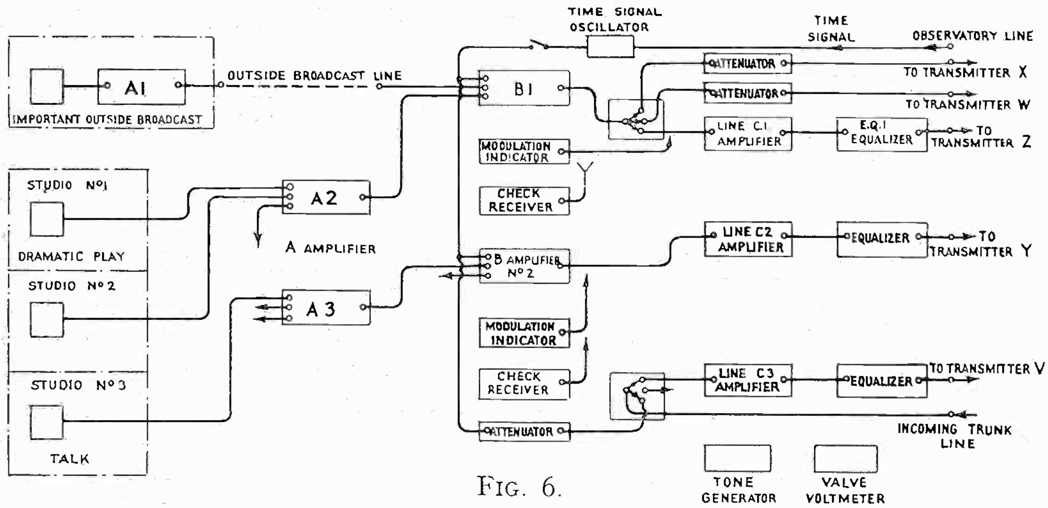


FIG. 6.

The peak power level required therefore, at the input terminals of the transmitter is 10 milliwatts. In the following consideration of the power levels of the various circuits, all levels are related as a certain number of decibels or transmission units above or below 10 milliwatts, which power is called zero or datum level.

The standard testing frequency is 1,000 cycles.

Table I. gives the approximate power levels and gains or losses of the various items of the equipment, the figures being chosen as typical figures and not representing the utmost limits of the apparatus.

TABLE I.

TYPICAL POWER DISTRIBUTIONS IN DECIBELS.

(ZERO LEVEL 10 MILLIWATTS).

Apparatus.	Normal Maximum Output Level.	Normal Maximum Gain.	Average Loss.
Marconi Reisz Microphone . .	−50/−70	—	—
A Amplifier	−10	+40	—
B Amplifier	+ 5	+45	—
C Amplifier	+10	+35	—
Equaliser	—	—	−5/−20
Distribution Unit	—	—	−5/−10

The normal power level distribution to be expected in a typical case of simple broadcast from a local studio is shewn in Fig. 8.

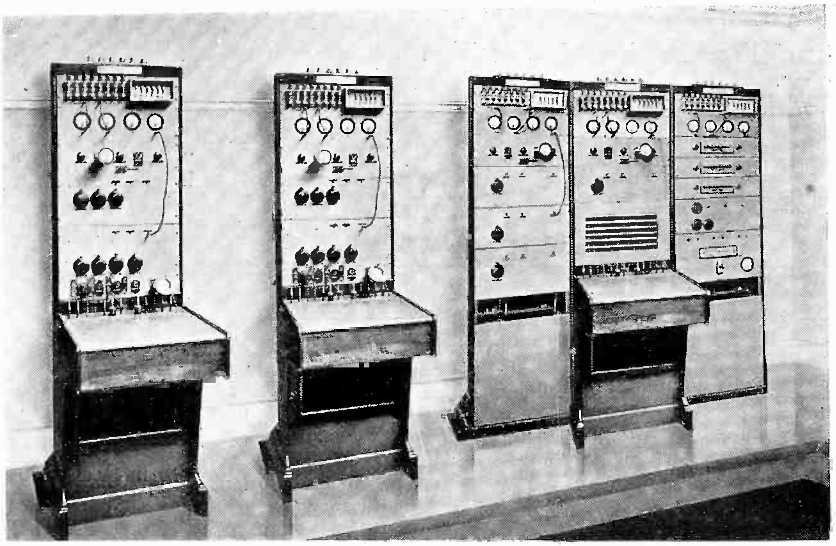


FIG. 7.

An allowance of 5 decibels has been made between the A and B amplifiers to cover switchboard and cord losses and the permissible loss in the transmitter landline is 5 decibels. With an outside broadcast the average levels change as shewn in Fig. 9.

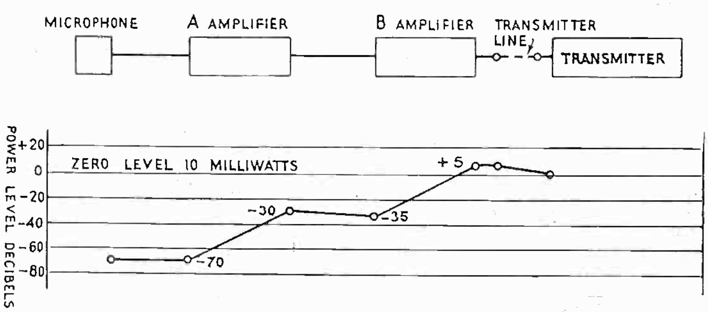


FIG. 8.

The losses in the outside broadcast line have here to be considered, and 5 decibels is given as an average case for a permanently erected line.

In practice a temporarily installed line might give considerably more loss than 5d.b., but it will be noticed that the B amplifier is working comfortably within its maximum gain and could compensate for a much greater loss in the O.B. line.

Considerations of noise level and cross talk, however, make it undesirable to work with too feeble a signal on the line and it is unwise to allow the level to drop much below—25. The third condition shewn in Fig. 10 obtains in simultaneous broadcasting where the line between the central control and one of the distant transmitters is a long trunk.

Simultaneous Broadcast Levels

It is assumed that the above diagram shews only one circuit of a fairly complex system and two distribution units (D) are shewn, each giving a loss of 10 decibels.

The trunk line has a loss of 20 decibels at its corrected level, a further 15 decibels being lost in the correcting network or equaliser (EQ).

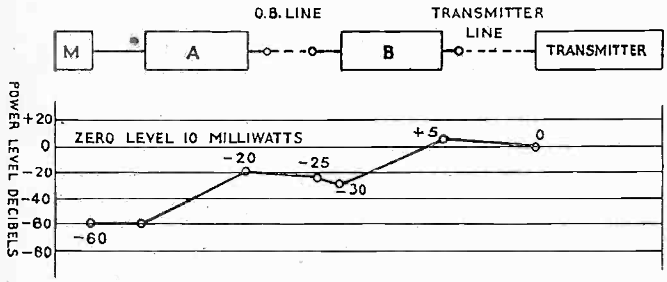


FIG. 9.

Restrictions of Line Input Level

In certain countries the Post Office or the particular authority controlling the use of telegraph or telephone lines for broadcasting will not allow a signal above a stated level to be put on its lines. For example, in England the British Broadcasting Corporation is officially restricted to an input of 3·5 milliwatts R.M.S. or—4·4 decibels.

This level corresponds with the average peaky mixture of speech and music to a peak value of the order of +2 or +3 decibels. The normal line input level in this paper has been taken as 5 decibels peak so that if a limit is imposed it will be necessary to reconsider a particular case.

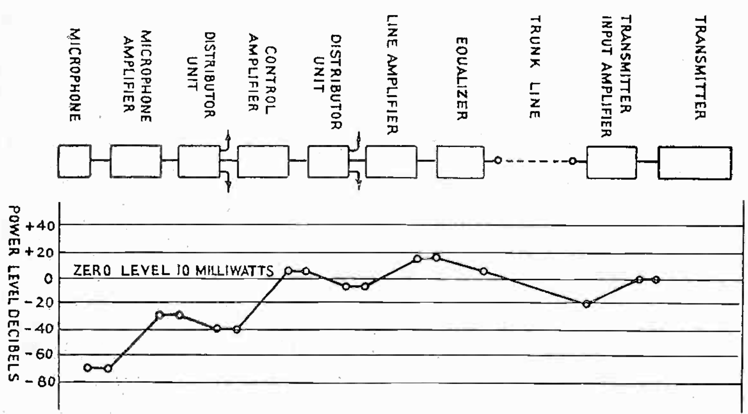


FIG. 10.

In general, however, there is a sufficient margin of safety in all the equipment to work with the lower level.

Landlines and Cables

The landlines or cables used to transmit broadcast music and speech present a very important part of the input circuits.

It is often the case that existing lines must be used for high quality broadcasting even though they be poor ones, but where it is possible to erect special lines or cables the following short study will give an indication of the results to be expected.

Many of the same conditions apply to broadcast lines as apply to ordinary telephone lines, that is to say, a good telephone line is a good broadcast line in so far as freedom from noise and extraneous inductions, insulation, etc., is concerned, but whereas quite intelligible speech is possible on a telephone line having a frequency cut off at 2,500 cycles, for broadcasting the whole band between 30 and 10,000 cycles is required in an ideal case.

Overhead Air Lines

Heavy gauge overhead lines have usually a good frequency characteristic, but an increasingly large proportion of the longer lines are being put underground so that it is generally difficult to use air lines.

Where special overhead air lines can be run for connecting a broadcast studio and transmitter, they are recommended to be erected as follows :—

The conductors should be of bare copper spaced at least 12 inches (30 cms.) apart and supported on stout poles so that the lowest wire is at least 12 feet (4 metres) from ground.

The poles should be spaced about 80 yards (75 metres) apart, depending of course on local circumstances, and the conductors should be transposed at each fifth pole with symmetrical twist. It is recommended that at least four pairs of conductors should be run on each route to ensure spare lines and service wires.

Table II. gives some of the chief characteristics of various sizes of conductors and also the attenuation in decibels per mile loop at 1,000 cycles.

TABLE II.

Characteristics of Air Lines.

Conductor.	Diameter M/M.	Resistance Ohms.	Capacity Mfds.	Attenuation d.b. per mile loop.	Miles loop per d.b.
40 lbs. Bronze ..	1·2	91	·0075	0·355	2·8
100 lbs. Copper ..	2	17·6	·0081	0·14	8·8
200 lbs. ,, ..	3	8·8	·0086	0·065	15·3
400 lbs. ,, ..	4	4·4	·0092	0·036	27·4

It will be noticed that for a permissible drop of 5 decibels the theoretical distance between the studio and transmitter varies from 14 miles for the 40 lbs. bronze line to 137 miles for the 400 lbs. copper line.

In practice, however, the theoretical attenuation is considerably exceeded due to leaky insulators, damp atmospheric conditions, etc., and also the cut off of the higher frequencies becomes very pronounced with long lines, so that the practical limits (without amplification or correction) are :—

For the 40 lbs. bronze line	3 miles.
For the 100 lbs. copper line	12 miles.
For the 200 lbs. copper line	25 miles.
For the 400 lbs. copper line	50 miles.

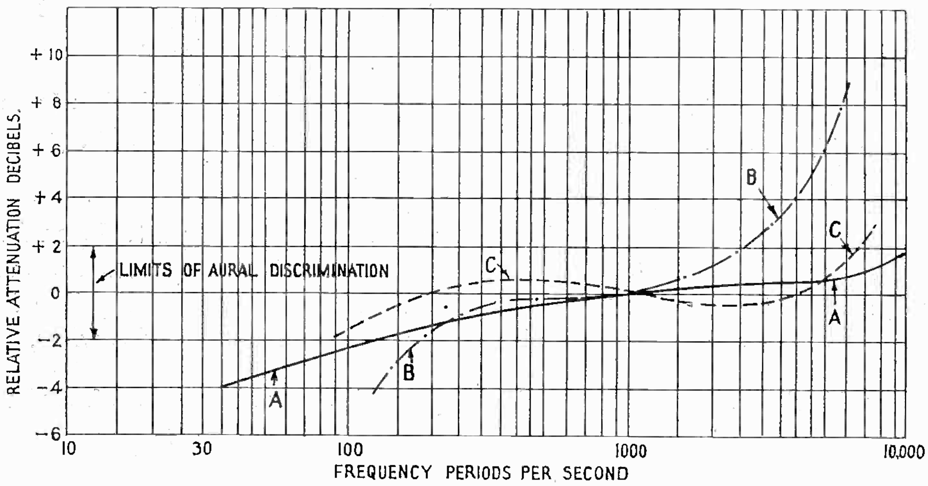


FIG. 11.

Underground Cables

Buried cable has the considerable practical advantage over air line in that it is not affected by blizzards or storms, but for broadcasting it requires considerably more care in selection.

The chief difficulties are, first that the high capacity and small core size give frequency cut off at quite a low point and a high attenuation, and secondly as the cable is usually run in the form of a multicore cable, much trouble may be experienced in selecting a reasonably quiet pair, free from cross talk and induction from the other circuits in the cable. Table III. gives a list for underground cables of similar characteristics to those for air lines in Table II.

TABLE III.

CHARACTERISTICS OF AIR SPACED PAPER CORE CABLES.

Conductor.	Diameter. M/M.	Resistance. Ohms.	Capacity. Mfds.	Attenuation d.b. per mile loop.	Miles loop per d.b.
6½ lbs.	0·5	270·7	·065	2	0·5
10 lbs.	0·7	176·0	·065	1·56	0·64
20 lbs.	0·9	88·0	·065	1·1	0·91
40 lbs.	1·2	44·0	·065	0·76	1·32

It is apparent from the Table that the permissible run for 5 decibels loss is much less than with air lines. Although the cables are not affected by climate, considerations of frequency distortion prevent in practice the theoretical lengths being attained so that the practical limits of distance for cables between the studio and transmitter (as before, without correction or additional amplification) are :—

For 6½ lbs. cable, ... 1 mile.
For 10 lbs. cable, ... 1·5 miles.
For 20 lbs. cable, ... 2·5 miles.
For 40 lbs. cable, ... 4 miles.

Special Broadcast Cables for High Quality

Where a special line must be run for broadcast purposes, and where the relatively cheap overhead lines, either because of climatic conditions or æsthetic considerations are not permissible, a specially made broadcast cable is strongly recommended.

Such a cable is laid up with air spaced paper insulated cores, the separate pairs being screened with one or more wrappings of metallized paper.

The cable is lightly Pupinized or loaded with series inductance coils at points about 1 kilometre apart and gives an extremely good frequency characteristic, the cut off frequency being higher than 10,000 cycles.

The attenuation for cross talk between separate pairs is greater than 100 decibels so that with the levels used for the broadcast no interference is caused by induction from other circuits.

A characteristic frequency distortion curve of such a cable 20 kilometres long is given in Fig. 11 (Curve A).

It is interesting to compare this curve with that of an ordinary cable of the same length (Curve B) and the same cable when corrected with equalizing networks (Curve C). See Fig. 11).

Repeater Stations

When the trunk line to a distant transmitter is very long, it becomes necessary to raise the level of the signal at one or more intermediate points by means of a repeater station, and also to insert intermediate correction networks.

The type of one way repeater station used for this purpose consists in its essential parts of a C amplifier for raising the level of the signal to compensate for the attenuation of the incoming line section and of the equalizer used for correcting the characteristics of the outgoing line section. Generally speaking a repeater will be necessary if the attenuation of the line exceeds 20 decibels, and where a number of repeaters are necessary, it is generally satisfactory to instal a repeater for each 10 decibels loss. This gives a comfortable margin for correction and for exceptionally noisy sections.

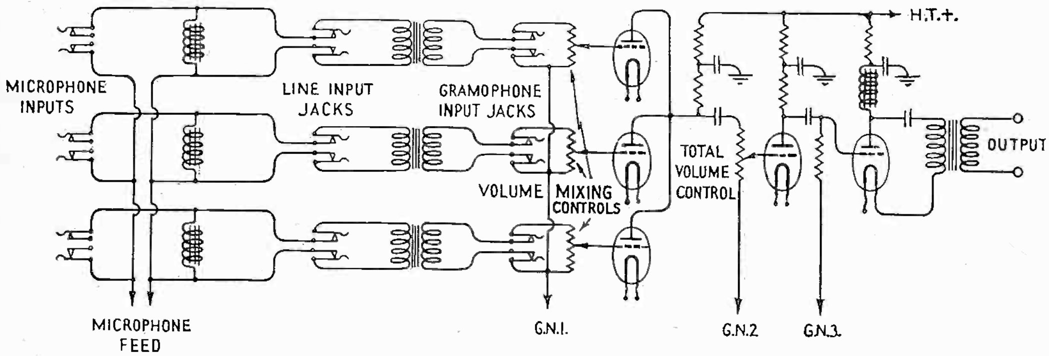


FIG. 12.

If frequency correction is necessary a further loss of anything up to 15 decibels will be occasioned by the network and the repeating amplifier must therefore have a gain of at least 25 decibels. The C amplifier has a gain of 35 decibels and is therefore ample for the purpose.

When a repeater is installed a 1,000 cycle generator is usually provided for adjusting the levels and correcting the lines, the whole equipment being mounted in a standard rack. It is obviously economical and convenient to group repeater stations at existing test points or broadcast control centres where this can be done, and also to run several trunks through the same point, as these arrangements enable common batteries, testing equipment, etc., to be used for all lines.

Layout and Design of the Equipments

All the equipments described are arranged for mounting vertically in steel racks of standard bay width. The amplifiers are supported on vertical brass panels with screening covers fitted in easily accessible positions on the back of each panel. The general finish of all the parts is the standard Marconi cellulose grey enamel, giving a uniform and satisfactory appearance.

The arrangement in racks gives an exceptionally easy control and unlimited flexibility. It is quite a simple matter to extend an existing equipment when desired either by adding additional bays to the racks or by adding additional units to spaces in existing bays.

Battery busbars and connecting leads are all located in uniform position at the top of the racks and neat cables cleated to the channels carry the battery leads to their respective points.

Assemblies of Unit Parts

All the equipments are assembled from a combination of the Units listed below :—

1. The Marconi Reisz Microphone.
2. The Microphone Amplifier (A Amplifier).
3. The Control Amplifier (B Amplifier).
4. The Line Amplifier (C Amplifier).
5. The Modulation Indicator.
6. The Equaliser.
7. The Check or Monitoring Receiver.
8. The Distribution Unit.
9. The Low Frequency Variable Tone Generator.
10. The Valve Voltmeter and 1,000 cycle Generator.
11. The Metering Panels and Control Desk.
12. The Line Control Switchboard.

1. The Marconi Reisz Microphone

This high quality microphone which has been standardised by broadcast authorities all over the world, is fully described in Pamphlet 238, on pages 24 and 25.

2. The Microphone Amplifier (A Amplifier)

The relatively small output from the microphone is amplified to a power level as previously discussed, of about one-tenth of one milliwatt by means of the three stage microphone amplifier.

The amplifier has three stages, resistance-capacity coupled, and each anode circuit is isolated from the common battery by means of decoupling resistances and condensers. Special attention has been given to the problems of microphonic noises and the amplifier is substantially free from trouble in this respect.

Three models are standardised, a rack mounting model with single input, for one microphone, a triple input rack model for three microphones, and a portable model for outside broadcast in a travelling case. Each input circuit of each model is arranged with three jacks, so that the input impedance conditions can be arranged :—

(A) For a Reisz Microphone.

(B) For a high impedance source primarily intended for high impedance gramophone pick-ups.

(C) For a low impedance source suitable for emergency landline use, or a suitable low impedance pick-up, or a special microphone circuit.

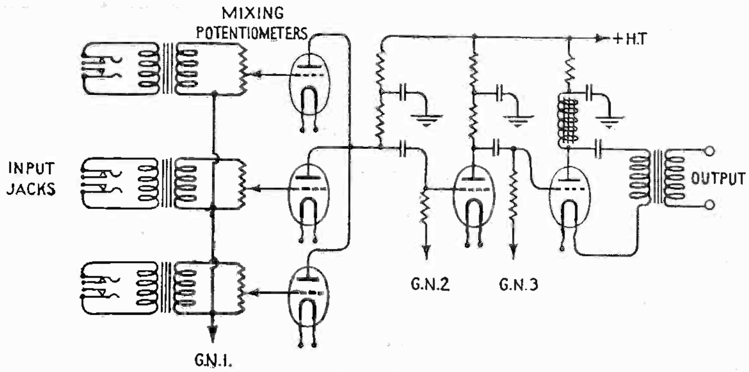


FIG. 13.

The circuits are automatically matched by the insertion of the correct plug. The triple input model thus has nine separate and distinct input circuits, in groups of three. Each group is connected to a special fading potentiometer to control the volume, so that three separate programmes can be faded or mixed together in any desired proportions. The potentiometer controls are arranged so that the volume can be faded up or down with an entire absence of clicks.

The output circuit of the rack models is arranged to match the impedance of the input to the B amplifier. The portable model for outside broadcast has a transformer output matching the impedance of an average line. When used with the normal battery equipment the A amplifier has a maximum gain of 40 decibels and an undistorted power output of 50 milliwatts.

The frequency characteristic is substantially linear from 30/10,000 cycles. Fig. 12 gives a diagram of connections of the triple input A amplifier.

3. The Control Amplifier (B Amplifier)

The purpose of the B amplifier is to accept the output from the A amplifier or from a line and to magnify the signal to the final level required by the transmitter line or transmitter input circuits.

The amplifier is three stage resistance coupled and is substantially similar to the A amplifier except that it is capable of dealing with much higher power levels.

A single input and triple input model have been standardised, the single input circuit being suitable for direct connection to the " A " output, and the triple input model having in addition two 600 ohm line inputs for outside broadcast.

The inputs are equipped with fading potentiometers and the three inputs of the triple model can be mixed together as in the case of the A amplifier.

A simplified schematic diagram is given in Fig. 13.

The amplifier, when used with normal battery equipment gives a gain of about 45 decibels and is capable of a completely undistorted power output of 60 milliwatts. If distortion of 5 per cent. is allowed this output can be increased to 500 milliwatts. By changing the output valve and increasing the battery voltage these levels can be substantially increased. The frequency characteristic is substantially linear between 30 and 10,000 cycles.

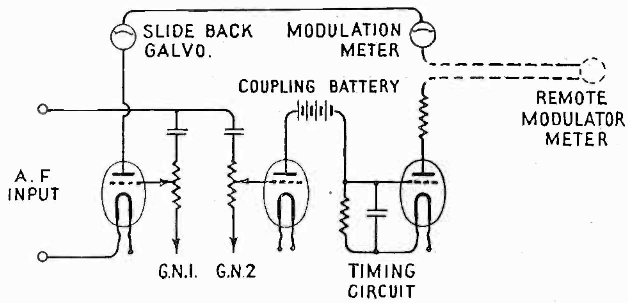


FIG. 14.

4. The C. or Line Amplifier

The Line Amplifier, used for compensating for line losses caused either by a long line or by correcting equalisers, is a two stage resistance capacity coupled amplifier with transformer input and output to suit the average lines.

The connections are similar to the B amplifier, except of course for the fact that it has only one output, one volume control and two valves.

The normal main of the C amplifier is about 35 decibels and the undistorted power output is of the order of 250 milliwatts, depending upon the type of output valve used and the battery voltages, which are arranged to suit any particular case.

The amplifier is substantially linear in frequency characteristic between 30 and 10,000 cycles.

5. Modulation Indicator

The modulation indicator is necessary on a speech control equipment in order that the general level of the programme may be kept within the limits of the transmitter modulation and " blasting " prevented.

The circuit used consists essentially of a linear rectifier valve coupled through a battery and timing circuit to a reversing valve with a comparatively heavy anode feed.

In the anode circuit of the second valve is an indicating instrument calibrated in percentage modulation. A condenser-resistance timing circuit having a quick charging period and slow discharging period enables the device to respond quickly to the peaks of modulation. The return action is slow enough for the peaks to be read and the peak conditions to be continuously observed. A third valve is also included which functions as a " slide back " or valve voltmeter. The indicating meter in the anode circuit of the third valve is normally steady at zero, but any peak modulation over a certain predetermined limit will be indicated on the scale. A special feature of the modulation indicator is that provision is made for the connection of a large meter with 6 inch scale which can be mounted in any position desired. The scale of this instrument is also marked in percentage modulation.

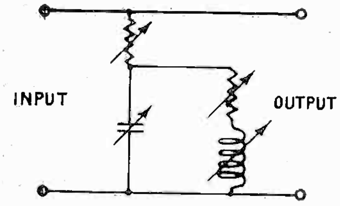


FIG. 15.

6. Equaliser

The equaliser or line correction unit consists essentially of a combination of variable inductance, variable capacity and variable resistance which can be connected to the input of a line in order to modify its frequency characteristic in any desired manner. The simplest and perhaps most generally used equaliser circuit is shown in Fig. 15, but the instrument is arranged so that more complex circuits using both shunt and series arms can be employed when required.

7. Check Receiver

The Check Receiver or monitoring amplifier is used for observing the quality of the signal radiated by means of a moving coil loud speaker. Its circuit consists of a low sensitivity tuning circuit and radio frequency detector coupled to a two stage high quality L.F. amplifier.

Arrangements are made so that the amplifier can be used separately to observe the quality of the signals at any point of the speech control system, or alternatively, with the detector to observe the quality of the radiated signal by wireless. When the check receiver is supplied at a studio, the radio frequency pick-up is by a short outside aerial, but at the transmitter a small inside aerial is used.

A schematic diagram is shewn in Fig. 16.

8. Distribution Unit

The Distribution Unit is used in simultaneous broadcasting when the output of the B amplifier is required to feed more than one circuit at the same time. It comprises an arrangement of jacks and resistances so that the insertion of any number of loads on the output side can be effected without disturbing the total load of the unit as a whole.

A schematic diagram is shewn in Fig. 17.

The resistances R are made equivalent to the load they replace when the plugs are withdrawn, so that the total load on the input circuit is always constant.

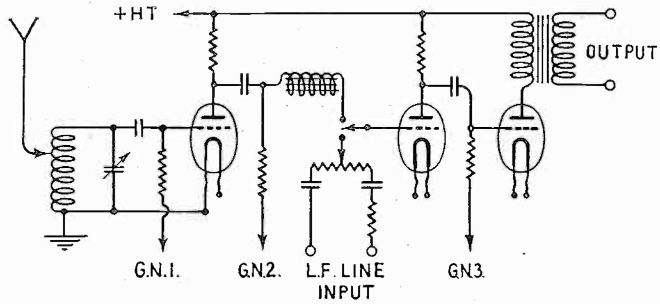


FIG. 16.

9. Low Frequency Tone Generator

The low frequency tone generator is required when taking frequency characteristics of apparatus and lines.

The electrical circuits were fully described in the March Number of the MARCONI REVIEW.

10. Valve Voltmeter and 1,000 Cycle Generator

The circuits of this instrument which is also required for use in line measurements, were fully described in the abovementioned issue of this journal.

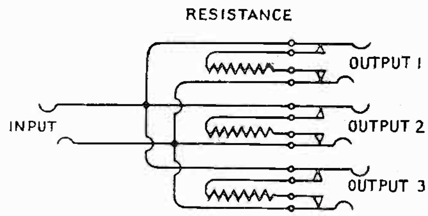


FIG. 17.

11. Metering Panels and Control Desk

At the top of each rack is mounted a narrow panel with all the necessary battery switches and fuses for service on the particular rack.

Below the switch panel is a similar panel containing all necessary indicating meters for the power circuits of the particular rack.

All racks intended for use at a control centre to which studios are attached, have hardwood desks on the power part, to form a convenient table for the seated operator.

Above the control desk are the plugs and cords for inter-connecting the various circuits, and the modulation indicator may be taken from its normal position and plugged in at table height if desired for greater convenience in control.

12. Line Switchboards

The simple equipments are each provided with a jack strip and cord shelf for dealing with the lines and inter-connections. Although the apparatus has been so designed that the necessary inter-connections can be carried out without the use of an external switchboard, in the larger simultaneous broadcast schemes it is sometimes better to use a separate central control board to avoid the necessity of walking from rack to rack when inter-connecting. Such a switchboard obviously calls for special treatment on the merits of the particular case considered, and no standard has been developed.

A STUDY OF WAVE SYNTHESIS BY MECHANICAL MEANS—IV

PART I.—THE PHASE OF CARRIER TO SIDE BANDS AND ITS RELATION TO A SYNCHRONOUS FADING PHENOMENON

In a previous paper, " A Study of Wave Synthesis by Mechanical Means," an investigation of the effect of the phase shift of carrier to side bands was made for the case of a 100% sine modulated carrier. From this investigation it appeared that small shifts of carrier phase resulted in considerable signal distortion, a phase shift of the order of 90° created distortion taking the form of frequency doubling and a phase shift of 180° reversed the signal. The particular case chosen, however, was not really representative of the majority of the modulated waves used in practice for two reasons :—*

(1) *In practice the percentage modulation rarely approaches 100%.*

(2) *The signal wave is seldom a pure sine wave in character.*

With a view to getting a better idea of what is happening, a further investigation by mechanical means has been made with waves having shallow modulation and using signal envelopes both of a pure tone and having a complex shape.

WHEN dealing with a group of waves having different frequencies it is necessary to understand clearly the meaning of phase relationship. One can only talk about phase relationship between waves of different frequencies at some point of reference and in the particular case under discussion this is the phase of carrier at the instant of time when the side band waves are in phase opposition ; such a point of reference in the case of a sine modulated wave indicates the commencement of the signal envelope. Thus in Fig. 5 vector C represents the carrier and vectors S^1 S^2 represent the side bands and this group of vectors is rotating at high frequency in an anti-clockwise direction C at the carrier frequency, S^1 losing on C and S^2 gaining by an equal amount. The moment represented indicates the maximum value of the high frequency cycle, in this case equal to the carrier maximum alone (since the other two cancel) that is, it depicts the condition as at " x " Fig. 1a, this being the reference point.

Phase change with pure tones.

Before considering a signal of complex shape it will be of interest to show the effect of carrier phase shift on a sine modulated wave with deep and shallow modulation and the curves for this case are shown in Figs. 1, 2 and 3.

Fig. 1 is reproduced from the previous article and shows that with deep modulation (100%) and a pure tone signal, considerable distortion occurs with very small

* The first five articles in this series appeared in the MARCONI REVIEW Nos. 9, 10, 11, 12, and 13.

phase shifts of carrier. Figs. 2 and 3 depict the case where the percentage modulation is 50% and 25% respectively. The latter curves show two remarkable features. First as the depth of modulation decreases the distortion decreases, in fact with shallow modulation such as 25% the distortion almost entirely disappears except with phase shifts approaching quadrature.

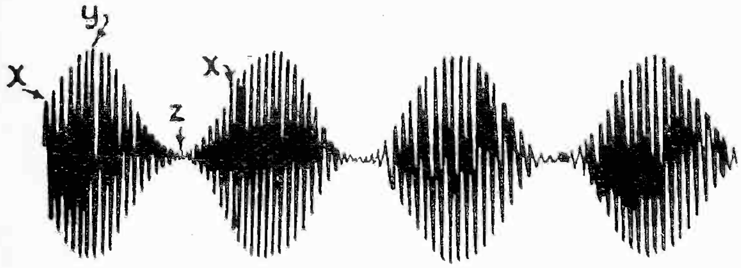


FIG. 1A. *Sine signal. Carrier correct frequency. Both side bands. Carrier correct phase.*

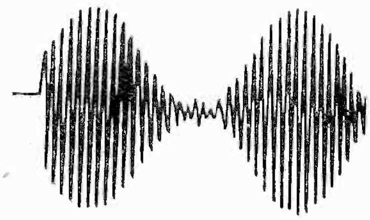


FIG. 1B. *Both side bands. Carrier 10° advance.*

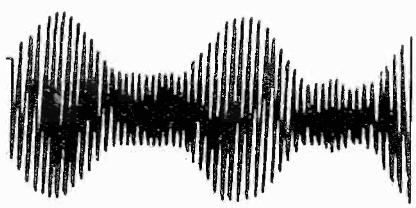


FIG. 1C. *Both side bands. Carrier 45° advance.*

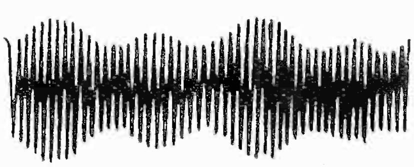


FIG. 1D. *Both side bands. Carrier 90° advance.*

The second remarkable feature is that the effect of shifting the phase of carrier is not to alter the position of the modulating signal on the time base but all that happens is a decrease in the effective depth of modulation ; thus considering the case of a signal 25% modulated, as the carrier phase is shifted from 0 to 90°, the depth of modulation progressively decreases, slowly at first, but rapidly as the phase shift approximates to quadrature until with a phase shift of exactly 90° the modulation has almost completely disappeared.

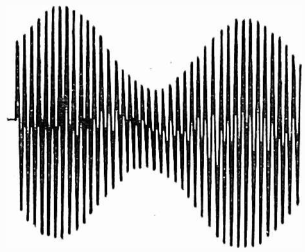
If the shift of phase is increased beyond 90° the modulation re-appears with a reversed sense and with a phase shift of 180° of carrier, the signal resumes its original depth of modulation but with a reversed sense. It can be imagined that for a signal envelope to go through a process of being turned inside out as it were, necessitates a transition stage where the effective modulation is decreased as shown. With the pure tone signal this reduction of effective modulation is accompanied by distortion as observed. It is important to observe that this decrease of the effective modulation is not the only effect present, for a careful examination of the resulting wave form will show that the wave radiated is now not quite constant infrequency but varies between limits which increase as the apparent depth of modulation decreases. This will be referred to later.

Phase change with complex tone.

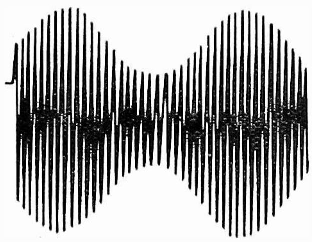
If the signal is not a pure tone but a complex signal the distortion is less marked as would be expected and this is shown in Fig. 4 where an example is given of a signal having a third harmonic. Fig. 4, a, b, c and d show the case of a carrier wave 50% modulated by a signal having a strong third harmonic, the phase shift of carrier being indicated on the diagram. These figures show how little distortion appears as the carrier phase is changed, and it is seen there is no relative phase shift of harmonic to signal fundamental as there is in single side hand working, that is to say, the effect of a shift of carrier phase for shallow modulation in ordinary telephony is not to produce serious distortion, but merely to alter the effective depth of modulation, the more complex the signal the less distortion there is apparent ; that is assuming such a wave be received by a system which responds to amplitude changes only. For at present almost all systems operate on amplitude change and any small frequency variation would pass unobserved.

Vector Analysis.

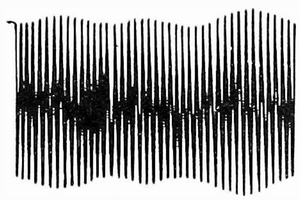
It is of interest to analyse exactly how it is these results can come about and we can best discuss the sine signal case. A sine modulated carrier may be thought of as being built up of a carrier wave, on either side of which is a single side band wave, each side band having the same difference of frequency above and below the carrier. Thus we have to think of the addition of three rotating vectors, a carrier vector and two side band vectors, one gaining and one losing an equal amount on the carrier vector as shown in Fig. 5 ; for the case of 25% modulation the amplitude of the carrier vector will be eight times each side band vector. Now since at all moments one side band is gaining on the carrier as much as the other side band is losing, we can for convenience consider the carrier vector stationary and the side band vectors rotating, the faster one in an anti-clockwise direction and the slower one in a clockwise direction at the same rate that of the modulation ; thus the vector *resulting from the side* band vectors will always be exactly in phase or in phase opposition to the carrier vector but it will vary in amplitude from zero (that is when each side band is in quadrature with the carrier but in phase opposition to the other) to a vector which will be 25% of the amplitude of the carrier and in phase ; to a vector 25% the amplitude of a carrier but in phase opposition, this cyclic variation of the resultant side band vector producing the modulation envelope. Such a method of looking at a modulated carrier provides a simple analysis, for the addition of any group of upper side band vectors to its corresponding group of lower side band vectors must always produce resultants which are exactly additive to, or must be subtracted from the carrier directly. This vector group will be rotating at a constant speed of the carrier frequency and since the resulting side band vector is always in phase or in phase opposition to the original carrier, it is clear that the resulting wave is one of constant frequency but changes in amplitude.



50% *modn.* *Carrier* 0°.

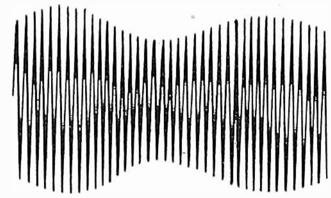


50% *modn.* *Carrier* 30°.

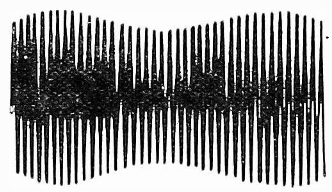


50% *modn.* *Carrier* 90°.

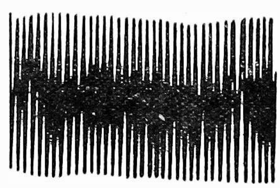
FIG. 2.



25% *modn.* *Carrier* 0°.



25% *modn.* *Carrier* 70°.



25% *modn.* *Carrier* 90°.

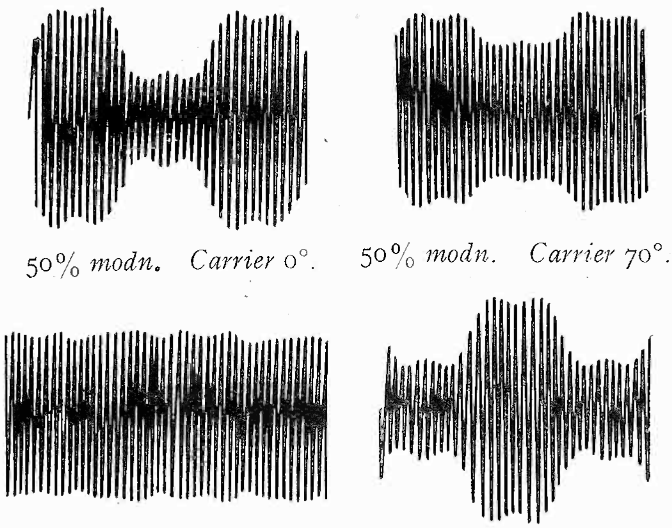
FIG. 3.

If we now consider a carrier having a phase shift of say 90° it means that the sum of the side band vectors must not be added directly to the carrier, but in quadrature, as shown in Fig. 5 ; because of this if the carrier vector is large compared to the side band vector (as it will be for shallow modulation) the resultant amplitude of these two vectors added in quadrature will always be approximately the same, for a small vector added in quadrature to a large vector gives a resultant vector of almost the same amplitude as the larger vector, as shown in Fig. 6.

Considering the rotation of this group of vectors, our carrier vector is the reference point and it is clear that the vector resulting from the carrier and the side bands no longer maintains a constant position relative to the carrier but it is at one time leading it and another time lagging it ; in fact there is a cyclic variation at the modulation rate and we therefore come to the conclusion that the resulting wave is no longer constant in frequency but varies cyclicly with the modulation frequency, this frequency variation being additional to the small cyclic change of amplitude.

From this vector consideration it is also clear why with a phase shift of carrier the decrease of modulation is slow to commence with but changes more rapidly as the phase shift approximates to 90°. For the relationship of the resultant side band vector to the carrier is dependent upon a sine function of carrier phase shift.

Summing up we reach the following conclusions, that the effect of phase shifting the carrier wave of an ordinary amplitude modulated carrier has the effect of reducing the amplitude modulation and introducing a frequency modulation, and that under conditions of shallow modulation the change of amplitude may become negligible with a carrier phase shifts approaching quadrature although a change of frequency will have been introduced which may become fairly considerable.



50% *modn.* *Carrier* 0°. 50% *modn.* *Carrier* 70°.

50% *modn.* *Carrier* 90°. 50% *modn.* *Carrier* 180°.

FIG. 4.

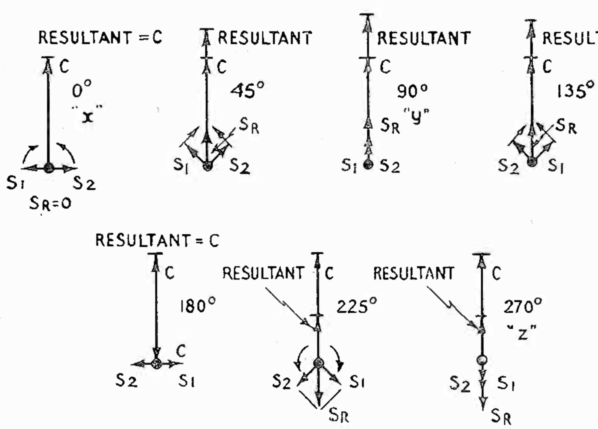
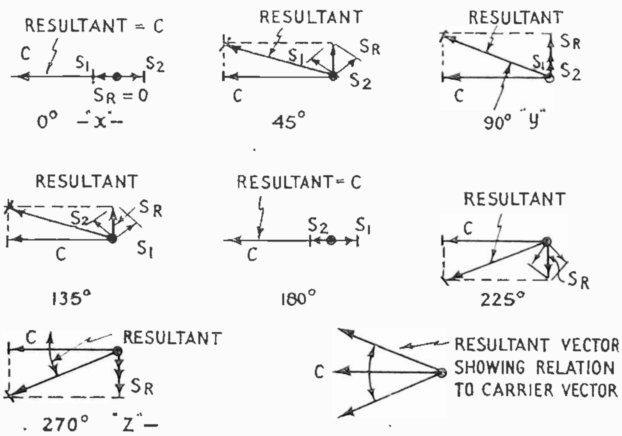


FIG. 5.

With an ordinary receiving system designed to detect amplitude modulation, the signal will have disappeared, and if it is desired to obtain intelligence some form of demodulation which will respond to frequency changes in addition to amplitude changes becomes necessary.

Asynchronous Fading.

It is now of interest to discuss whether such phase shifts of carrier can occur in practice and there is considerable evidence that such a phenomenon can and does exist. Hitherto we have always considered that æther waves are propagated with the velocity of light and hence we have assumed that a complex modulated wave radiated from a transmitter, which may be considered as consisting of a spectrum of waves, is propagated through the æther at the velocity of light and that the phase relationship of each wave of the group will be unchanged when it arrives at the receiver.



THE RESULTANT VECTOR SWINGS EITHER SIDE OF CARRIER BETWEEN LIMITS DETERMINED BY THE PERCENTAGE MODULATION THIS CONSTITUTING A FREQUENCY VARIATION.

FIG. 6.

Continued observations of short wave signals, however, have suggested that this idea may not be correct; for instance there is a well-known type of fading which may be observed on long distance short wave telephony where but small distortion appears with fading and the fading of the carrier wave does not synchronise with the fading of the modulation; in fact there have been occasions when the modulation has weakened or faded out but the carrier, far from fading, has appeared actually to strengthen. This effect was observed by Mr. Langridge, and the writer in 1926 and at the same time no marked distortion was noted.

Generally speaking, fading is considered to be a phenomenon due to the reception of multiple rays interfering with one another. If one considers fading of the type described above it is very difficult to understand how addition of multiple spectra can produce a fading of side bands without carrier and further the addition of multiple spectra will usually involve distortion. It is suggested that a simple phase shift of carrier relative to side bands as the spectrum passes through the medium is sufficient to explain this particular type of fading. Although the idea that electromagnetic waves of different frequencies have different velocities of propagation is not one usually considered, when it is remembered that short waves are not propagated solely through a pure æther medium but through an ionised layer, then a variable wave velocity is a probabilty ; in fact the idea is allied to some extent to the low frequency case of the propagation of low frequency waves along a transmission line where the different frequencies suffer different attenuation and different phase shifts.

If such a phenomenon is existent, what we require to overcome this type of fading is a receiving system which has two separate functions, first to respond to change of amplitude and secondly to change of frequency, the signals being added after demodulation. Theoretically this would be a solution but with present-day apparatus it is very doubtful whether any such receiver would operate owing to the difficulty of obtaining sufficient frequency constancy. For the effect we are discussing is resultant upon a small phase change of carrier frequency of an amount commensurate with the modulation and although our carrier waves are reasonably constant, they are not sufficiently so to think of phasing them. When one is dealing with frequencies of the order of 10,000,000 cycles one requires a constancy of one part in 50,000,000 at least before we can hope successfully to operate a system which depends for its action upon the relative phases of the waves comprising the signal.

A. W. LADNER.

MARCONI NEWS AND NOTES

BROADCAST TO UNITED STATES FROM THE "ELETTRA."

Marchese and Marchesa Marconi with Signor Mussolini on board the S.Y. "Elettra."

MARCHESE MARCONI'S new short-wave telephone apparatus on board his yacht *Elettra* was used for an unusual broadcast on July 28th, when newspapermen delivered eye-witness accounts of Italian earthquake disaster for American listeners.

The transmissions from the *Elettra*, which was lying off Civita Vecchia, were picked up by the receiving station of the National Broadcasting Company of America near New York and successfully rebroadcast throughout the United States.

The speakers were representatives of the International News Service, who hurried straight from the scene of the earthquake to the *Elettra* to deliver their accounts of the scenes in the stricken areas.

This is the second occasion on which Marchese Marconi's new telephone has been heard by American listeners. On April 30th Marchese Marconi on board the *Elettra* in the Mediterranean was "interviewed" by Mr. Karl Bickel, President of the United Press of America, who was in New York 4,400 miles away, and the interview was rebroadcast throughout the United States.

Marchese Marconi Speaks to Melbourne Radio Exhibition.

The interest aroused throughout Australia by the experiments recently carried out by Marchese Marconi on his yacht while in Italian waters, and by his demonstration in switching on the lamps at the Sydney Radio Exhibition and speaking by wireless telephone to Sydney at the opening ceremony, led to a request that he should take part in the opening of the Melbourne Radio Exhibition on July 18th.

Acceding to this request, Marchese Marconi spoke to the Chairman of the Melbourne Exhibition by wireless telephone from his yacht *Elettra*, following the opening of the Exhibition by the Lord Mayor of London, who, by pressing a button at the Mansion House, London, lit a sign declaring the display open.