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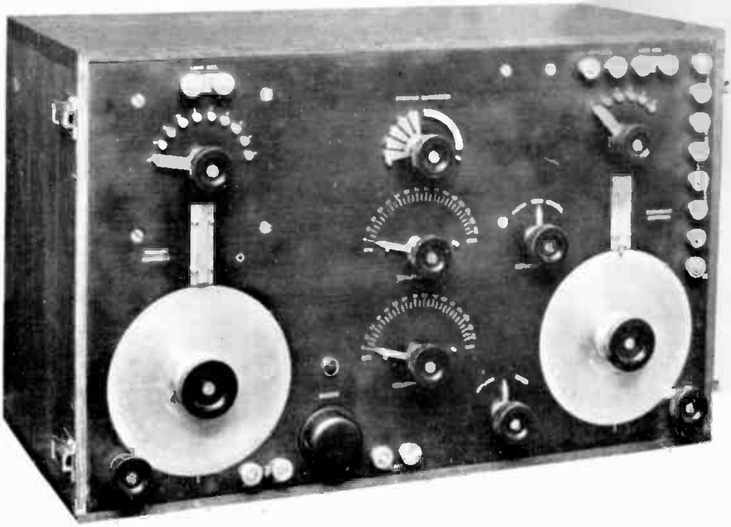

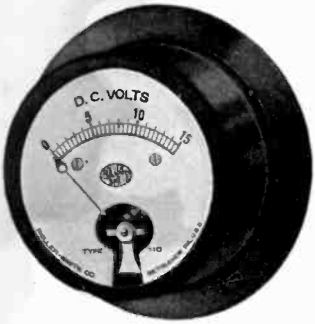
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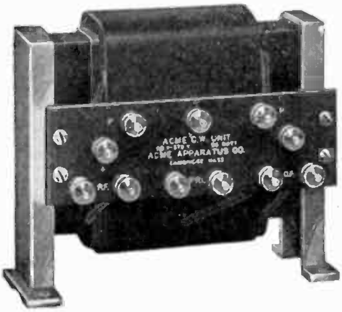
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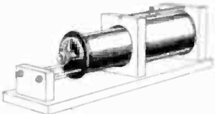

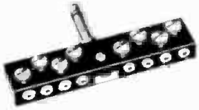

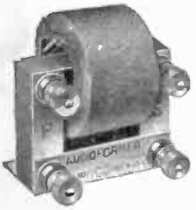

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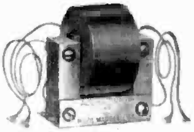

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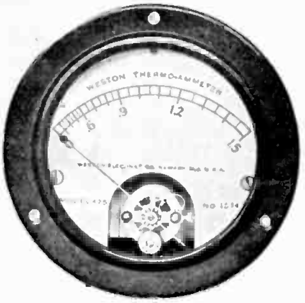

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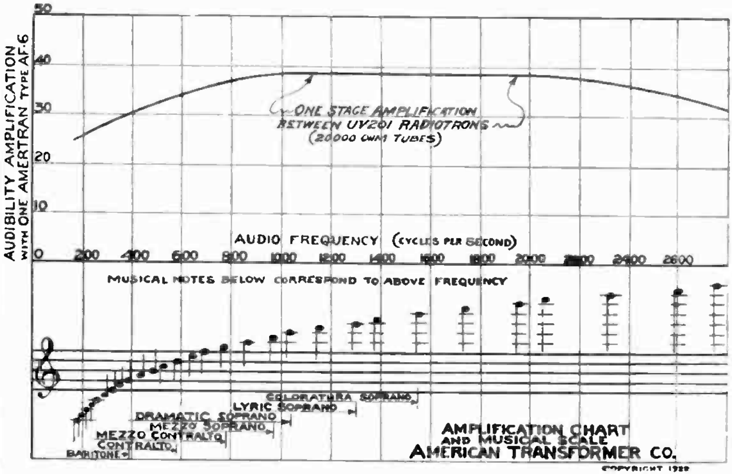

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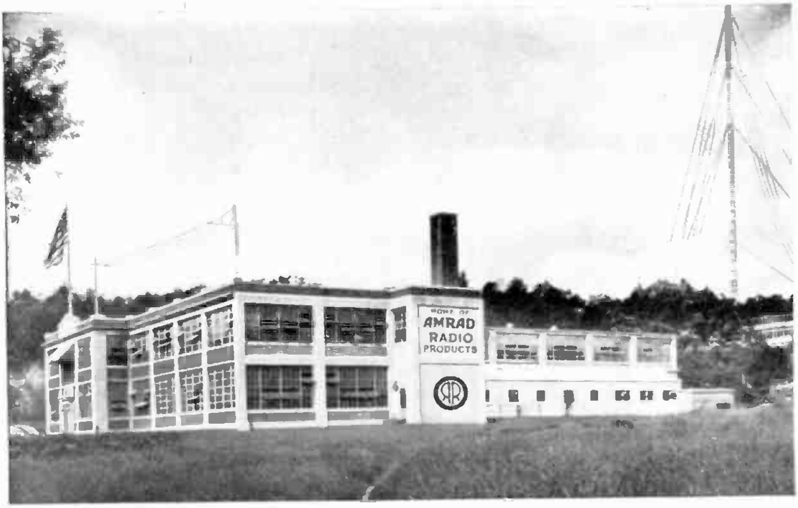

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Volume 11 FEBRUARY, 1923 Number 1

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RECEIVING MEASUREMENTS AND ATMOSPHERIC DISTURBANCES AT THE UNITED STATES NAVAL RADIO RESEARCH LABORATORY, BUREAU OF STANDARDS, WASHINGTON, SEPTEMBER AND OCTOBER, 1922*

By

L. W. Austin

(United States Naval Radio Research Laboratory, Washington, D.C.)

(Communication from the International Union for Scientific Radio Telegraphy)

The observations are taken according to the method briefly described in the PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS for the month of June.

Radio Central on Long Island has proved to be the most satisfactory of the American stations for comparison purposes, as Annapolis and New Brunswick are too close for measurements with the telephone comparator on the low antenna, while Sayville and Marion have shown themselves somewhat variable as received at the laboratory.

The small table shows the ratios of the various averages, and indicates the disappearance of the summer conditions of strong afternoon fading and severe disturbances. It is seen that the extreme fading persists later with the shorter wave station, and it will be remembered that it began earlier in May and June.

The field intensities, 2 micro-volts per meter, given in a number of places in the tables, lie at the lower limit of the telephone comparator, and are to be considered approximations. Such signals were marked "too weak to measure" in former reports.

The signal measurements in the forenoon still indicate field intensities of approximately twice the calculated values.

The calculated intensities for the signals, assuming 480 amperes at Lafayette and 380 amperes at Nauen, are

$$E\,(\text{Lafayette}) = 31.5 \,.\, 10^{-2} \text{ volts/meter}$$
$$E\,(\text{Nauen}) = 15.3 \,.\, 10^{-2} \text{ volts/meter}$$

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* Received by the Editor, December 4, 1922

FIELD INTENSITY OF LAFAYETTE AND OF DISTURBANCES ($\lambda = 23{,}400$ m.) IN SEPTEMBER, 1922, IN MICRO-VOLTS PER METER

Date	10 A. M.		3 P. M.	
	Signal	Disturbances	Signal	Disturbances
1	80.0	200	50.0	1,000
2	90.0	300	....	....
5	100.0	200	60.0	80
6	80.0	100	50.0	200
7	60.0	300	50.0	400
8	50.0	200	....	....
9	70.0	150	....	....
11	80.0	200	....	....
12	60.0	150	40.0	300
13	95.0	100	35.0	300
14	85.0	100	40.0	400
15	75.0	80	....	....
16	80.0	30	....	....
18	65.0	50	....	....
19	60.0	40	....	....
20	75.0	60	50.0	60
21	110.0	40	55.0	80
22	70.0	20	....	....
23	100.0	30	45.0	60
25	*	20	*	60
26	*	20	55.0	150
27	65.0	40	....	....
28	*	50	45.0	150
29	70.0	150	35.0	300
30	85.0	100	45.0	300
Average	77.5	109	46.8	256

* Not heard.

.... Not taken.

Field Intensity of Nauen and of Disturbances ($\lambda = 12{,}500$ m.) in September, 1922, in Micro-volts per Meter

Date	10 A. M.		3 P. M.	
	Signal	Dis-turbances	Signal	Dis-turbances
1	26.0	100	*	80
2	30.0	80	....	....
5	26.0	60	*	40
6	*	60	2.0	60
7	34.0	40	25.0	80
8	25.0	100	....	....
9	43.0	40	....	....
11	34.0	60	....	....
12	38.5	80	2.0	100
13	60.0	50	15.0	100
14	43.0	50	2.0	300
15	30.0	30	....	....
16	30.0	30	....	....
18	6.0	20	2.0	600
19	26.0	15	....	....
20	30.0	30	25.0	30
21	38.5	20	*	40
22	26.0	80	*	100
23	56.0	60	2.0	200
25	30.0	100	....	....
26	38.5	10	30.0	80
27	34.0	15	13.0	200
28	34.0	15	13.0	50
29	26.0	60	17.0	80
30	26.0	40	17.0	100
Average	33.8	49.8	12.7	131.7

* Not heard.

.... Not taken.

Field Intensity of Lafayette and of Disturbances ($\lambda=23{,}400$ m.) in October, 1922, in Micro-volts per Meter

Date	10 A. M.		3 P. M.	
	Signal	Disturbances	Signal	Disturbances
2	75.0	50	20.0	200
3	35.0	50	40.0	150
4	75.0	80	....	....
5	60.0	100	35.0	200
6	*	100	30.0	600
7	*	80	50.0	200
9	*	40	70.0	100
10	*	40	60.0	80
11	*	30	55.0	80
12	85.0	15	50.0	150
13	*	40	60.0	50
14	*	50	*	100
16	*	80	60.0	150
17	*	40	40.0	200
18	95.0	30	50.0	80
19	*	30	55.0	60
20	*	40	50.0	100
21	95.0	30	45.0	80
23	*	30	40.0	60
24	*	15	45.0	300
25	*	15	70.0	40
26	*	300	45.0	300
27	*	150	25.0	400
28	*	150	20.0	200
30	*	80	19.0	50
31	44.0	60	50.0	130
Average	70.5	66.3	45.2	162

* Not heard.

.... Not taken.

Field Intensity of Nauen and of Disturbances ($\lambda = 12{,}500$ m.) in October, 1922, in Micro-volts per Meter

	10 A. M.		3 P. M.	
Date	Signal	Disturbances	Signal	Disturbances
2	26.0	20	2.0	80
3	26.0	30	8.5	50
4	38.5	30	....	....
5	26.0	40	13.0	80
6	26.0	50	13.0	300
7	38.5	30	30.0	50
9	34.0	20	*	60
10	34.0	15	21.0	40
11	30.0	10	26.0	30
12	26.0	8	17.0	40
13	26.0	15	30.0	20
14	*	20	17.0	60
16	43.0	30	34.0	50
17	30.0	20	21.0	50
18	38.5	15	26.0	30
19	*	8	26.0	30
20	38.5	10	21.0	60
21	34.0	10	26.0	50
23	34.0	8	21.0	30
24	*	8	21.0	100
25	26.0	80	21.0	40
26	21.0	100	17.0	150
27	21.0	30	*	100
28	4.0	50	....	....
30	17.0	40	9.3	30
31	32.0	20	4.0	43
Average	28.7	27.6	19.3	65.6

* Not heard.

.... Not taken.

RATIOS OF AVERAGES

SEPTEMBER

	Signal $\frac{\text{P. M.}}{\text{A. M.}}$	Disturbance $\frac{\text{P. M.}}{\text{A. M.}}$	$\frac{\text{A. M. Signal}}{\text{Disturbance}}$	$\frac{\text{P. M. Signal}}{\text{Disturbance}}$
$\lambda = 23{,}400$	0.604	2.34	0.771	0.183
$\lambda = 12{,}500$	0.376	2.74	0.679	0.096
OCTOBER				
$\lambda = 23{,}400$	0.641	2.45	1.06	0.279
$\lambda = 12{,}500$	0.672	2.38	1.04	0.294

SUMMARY: Field intensities of the signals from the Lafayette and Nauen stations, together with the simultaneous strength of the atmospheric disturbances, are given for September and October, 1922.

THE OSCILLATION ENGINEERING DESIGN OF SUBMARINE ACOUSTIC SIGNALING APPARATUS

By

Walter Hahnemann

(Signal Gesellschaft, Kiel, Germany)

In submarine sound signaling, we are concerned with phenomena which are highly similar to those of radio telegraphy. In each case the problem is to transmit energy for signaling or any other similar purpose from a transmitting station to a receiving station. Accordingly, there are transmitters and receivers in submarine signaling, exactly as in radio telegraphy. At the transmitter, the energy in question must be produced in the form of convenient oscillations, and then transferred to a suitable radiating system (sound antenna), from which it is imparted to the medium. At the receiver, a similar radiating system must pick up the energy from the medium, and must then transform it into such a form that it will give perceptible indications to the observer on a suitable indicating instrument. This process, in the case of radio telegraphy, is very well known. In this paper we shall describe the acoustic or oscillation engineering design of typical transmitting and receiving apparatus for submarine signaling.

Altho acoustics is a much older subject than radio telegraphy, the necessity for solving engineering problems in the field of oscillations first arose in radio telegraphy, and before the necessary oscillation engineering basic laws were used clearly and consciously in the field of acoustic engineering. The application of these laws to the field of submarine signaling engineering has taken place only during the last ten years. That is, the basic laws of oscillation engineering were first necessarily developed in radio telegraphy, the elder brother of submarine acoustic engineering, and before the necessary investigations could be carried out in the field of submarine signal engineering. It is, therefore, not accidental that, for example, here in the

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* Received by the Editor, November 10, 1922. Presented before The Institute of Radio Engineers, New York, November 21, 1922. Translated from the German by the Editor.

United States a radio engineer and investigator of the eminence of Professor Fessenden has produced the submarine signaling transmitters which are known by his name. Similarly, in Germany, the development of submarine signaling apparatus first became possible thru the experience and knowledge which we had gained in the field of radio telegraphy. We have here an excellent sample of how scientific advances in one field may be of great benefit to other fields.

At this point I wish to remark that this continual progress in submarine signaling apparatus is having a beneficial influence on related fields, as, for example, in the application of the same principles to apparatus for signaling thru the air by sound methods which are now being investigated along analogous lines. In particular, we have already succeeded in applying the results of submarine signaling investigations satisfactorily to one of the most important aerial signaling instruments, namely, the telephone. In this way we acoustic engineers hope to recompense our closely related field—radio telegraphy—to some extent for what it has done for us, and for this reason we feel in duty bound to investigate telephonic problems.

A simple and most generally employed example of oscillatory systems for transmitting and receiving in radio telegraphy is that consisting of two coupled oscillatory circuits. This familiar arrangement is shown in Figure 1. At the left we see the transmitter, with the receiver at the right. Both transmitter and receiver consist of two oscillating circuits, one of which is a closed circuit, and the other consists of the radiating system or antenna. At the transmitter, the energy is transformed into oscillations in the closed circuit: circuit 1. In addition to the oscillation generator proper, which consists of a generator and spark gap in the illustration, the primary circuit of the transmitter contains

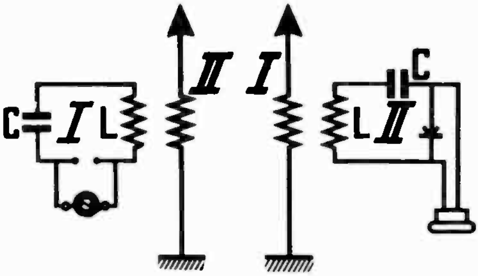

FIGURE 1

the capacity *C* and the inductance *L*. The antenna is coupled to the inductance *L* thru a suitable coil and forms the second oscillatory circuit of the transmitter. The receiver is quite similar. Energy is absorbed from the electric magnetic field by the antenna 1 and is transferred thru a suitable coupling to the secondary circuit 2, which also consists of a capacity *C* and an inductance *L*, and which further contains in this case a detector and telephone to give suitable indications of the incoming energy. Thus, in both cases we have a coupling of a radiating system with a closed oscillatory circuit. The closed circuits serve for the transformation of energy, and the radiating systems for the transfer of energy to or from the medium.

We shall now show how the same oscillation engineering design is applied to a typical submarine signaling system. Before doing this, we must mention the mechanical and acoustic analogues of closed electrical oscillatory circuits and of radiating antennas.

In Figure 2 there is shown schematically a well-known acoustic oscillation system: the tuning fork. The dotted lines show the way in which the shape of the tuning fork is altered when prongs *b b* are set into oscillation in any way. The points *a a* of the fork, however, remain at rest, and are therefore nodal points, whereas the remaining portions of the fork, and particularly the handle at the middle point of the fork *c*, also swing up and down. If, for example, the prongs *b b* move inward, the point *c* and the handle will move downward.

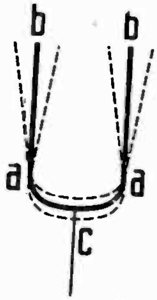

FIGURE 2

For our purpose, it seemed natural to use the tuning fork which is already generally known in acoustics, or a similar system as, for example, a reed. This was accordingly done. It very soon appeared, however that the desired results could not be obtained in this way. The reason for this is the following: In these systems, *mass and elasticity are not separated from each other*, but instead are distributed over the entire system. An electrical analogue of this is well known to all radio engineers, and consists of coils oscillating in their own free period and in which inductance and capacity are also distributed over their entire surface. Such systems are, in general, unsuitable for use as closed circuits. Thus, if we apply an exciting or retarding force to such oscillatory systems, they tend to shirk the work by correspondingly shifting their nodal points. We were therefore forced to discover a mechanical acoustic oscillatory system in which, as far as possible, elasticity and mass were fully separated from each other, exactly as in the usual closed electrical systems with concentrated inductance and capacity. Only after we had actually obtained such systems were we ready to solve the problems which faced us.

The arrangement of such a closed oscillatory system with separated mass and elasticity is shown in Figure 3. It consists of two masses (represented by the squares) and an elastic member connecting them (represented by the zig-zag line). A mechanical oscillation system consisting of one mass and elastic element has been previously frequently considered as typical of mechanical oscillatory systems. This is, however, not the general case of a closed mechanical-acoustic oscillatory system, but only a special case of the more general form shown in the figure, from which it is assumed, sometimes unconsciously, that one of the masses is infinitely large.

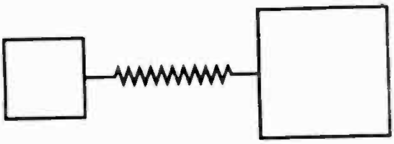

FIGURE 3

The generalized system consists rather of two masses and a single elastic element joining them. Assuming that such a system does not give out any energy, it oscillates about its center of mass. It follows, therefore, that the amplitudes as well as the velocities of both masses are in inverse proportion to their respective masses, from which it also follows that the energy of oscillation in each of the masses is inversely proportionately to the mass. These are very important facts. For example, this property of an oscillatory system leads to the possibility of a mechanical-acoustic transformation without the use of a lever.

The lever—the mechanical analogue of the electrical transformer—can be applied only in a limited way at frequencies of about 1,000 cycles per second and more, such as are under consideration, because at such frequencies it is only too likely to become an oscillatory system itself, and thereby loses more or less of its property of transforming amplitudes of vibration. Furthermore, it is not possible at such high frequencies to use the usual forms of pivoted links.

A practical attempt to produce such oscillatory systems for the high frequency of 1,000 cycles which is used in practice soon showed that elastic springs, having the necessary large elastic force, could not be built to have a sufficiently small mass. We had to employ a new arrangement of an elastic element which combined the smallest possible mass with the greatest possible elastic strength. This was the longitudinally strained rod or tube. In Figure 4 is shown such a mechanical-acoustic oscillatory system consisting of two masses with a longitudinally strained rod between them. In this form, it has been possible to make such systems which even for frequencies of more than 1,000 cycles per second had for practical purposes separated mass and elasticity.

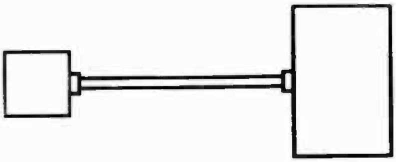

FIGURE 4

The coupling of such oscillatory systems to each other can be most readily carried out by supplying a mass which is common to each of them. In Figure 5 are illustrated schematically two such coupled systems. Herein a and b are the masses of one system; f the connecting elastic element; c and b the masses of the other system; and f the elastic element connecting them. The mass which is common to both systems, or the coupling mass, is b. The magnitude of the coupling mass, as compared to that of the other two masses, determines the coupling coefficient.

The expression

$$\frac{a\,c}{(a+b)\,(c+b)}$$

gives the product of the ratios of the oscillation energy present in the coupling member to the total energy present in each of the systems, and is called k^2. If the common mass b is small compared to each of the free masses a and c, practically all the oscillating energy is concentrated in the coupling element and we have the case of a strictly closed coupling or k^2 is equal to unity. If, on the other hand, b becomes larger than a and c, the coupling becomes more loose, and we have approximately

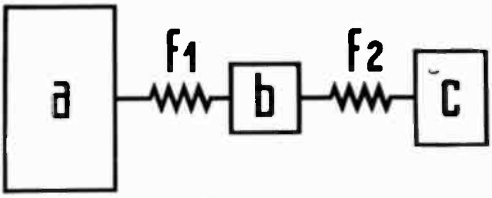

FIGURE 5

$$k^2 = \frac{a\,c}{b^2}.$$

We see here clearly the analogue to the coupling coefficient of two electrical circuits with their common inductance, which is well known to be

$$k^2 = \frac{M^2}{L_1\,L_2},$$

where L_1 and L_2 are the free inductances, and M the common or mutual inductance. As a and c become small compared to the coupling mass b, we reach the case of extremely loose coupling, and k^2 approaches zero. Numerous experiments verified these formulas thru the widest range of conditions. It should also be mentioned that the consideration of these mechanical oscillatory systems not only gives us a simple picture of the production of the two oscillation frequencies caused by coupling, but also enables us mentally to follow without difficulty the oscillation phases of the separate masses. This coupled oscillation system is particularly suited for the examination of all the phenomena which occur because of coupling, and is particularly convenient for those who find it difficult to think along purely electrical lines.

In studying and investigating the more or less complicated electrical oscillatory systems, it is customary to subdivide them into separate closed electrical circuits which are coupled to each other in some fashion. In exactly the same way it is possible to study the design of complicated acoustic oscillatory systems by using closed mechanical-acoustic oscillatory systems as the basic form. It became possible only thru this means to get a clear idea of the oscillatory phenomena in sound signaling apparatus.

In addition to the closed systems, we have open or radiating systems, which are known as antennas in radio telegraphy. In acoustics, a radiating system is one which has surfaces that move into and out of the medium periodically. The simplest example of such an acoustic radiating system is the pulsating or "breathing" sphere. The laws of radiation for such a system were worked out by Lord Rayleigh. In practice, however, the vibrating diafram is of principal importance. We have succeeded, using Rayleigh's work as a basis, in calculating the radiation damping and equivalent oscillating mass of radiating systems and in particular for diaframs, just as this is possible for antennas in radio telegraphy.

For the pulsating or "breathing" sphere, it is found that the oscillating mass of the medium is

$$M = 4\pi R^3 \rho \frac{1}{1+\left(\frac{2\pi R}{\lambda}\right)^2}$$

where R is the radius of the sphere, ρ is the density of the medium, and λ is the wave length corresponding to the frequency in question. It can be seen from this that, in the practical and common cases, in which the radiator is small compared to the wave length, the associated oscillating mass of the medium is independent of the frequency, and approximately

$$M_{R \ll \lambda} = 4\pi R^3 \rho.$$

The radiation damping (logarithmic decrement) of the pulsating sphere is given by

$$\delta = 2\pi^2 \frac{R}{\lambda}.$$

It is assumed herein that the sphere itself is without mass; if it possesses a mass m, at its outer radius, it is found that

$$\delta = 2\pi^2 \frac{R}{\lambda} \cdot \frac{M}{M+m}$$

For the diafram, we have

$$M_{R \ll \lambda} = 0.4\, R^3 \rho \text{ and } \delta = 5\frac{R}{\lambda} \cdot \frac{M}{M+m},$$

where R is the radius of the diafram, M is the associated oscillating mass of the medium, and m is the mass of the diafram itself, all of these being referred to the amplitude of the center of the diafram. These last formulas have been well substantiated by numerous measurements and experiments on diaframs.

In Figure 6 there is illustrated a cylindrical body which is closed on one side by a diafram. This is the simplified form of a radiating system for submarine signal engineering. We imagine this body to be surrounded by water, and its interior to contain air and the necessary exciting apparatus. The effect of this radiating system on the medium is due to the inward and outward vibrations of the diafram, whereby the medium is alternately subject to compression and rarefaction, and is moved to and fro. In the diafram, mass and elasticity are distributed over the surface in some fashion, quite as in the case of inductance and capacity distributed over an antenna. Just as we carry out our calculations for the operation of coupled systems containing an antenna by reducing the antenna to an oscillating circuit with equivalent capacity and inductance, we have learned also to reduce this diafram system to an equivalent closed mechanical-acoustic oscillating system. For this purpose, we refer the mass of the diafram and the associated vibrating water mass of the free medium to the middle point of the diafram. The elasticity is referred to the same point, and thus we obtain the arrangement shown in Figure 7. Herein *b* is the sum of the masses supposedly concentrated at the middle point of the diafram, *a* is the mass of the housing or container, and *f f* is the elastic restoring force of the diafram also referred to its middle point. We see that we again have two masses in this case, which are connected to each other thru an elastic element. So that we have succeeded in reducing the diafram radiating system to the equivalent of a closed oscillating system. Thus we are able, for any desired acoustic apparatus, to produce the correct circuit diagram by successively representing each of the vibrating systems by the method given.

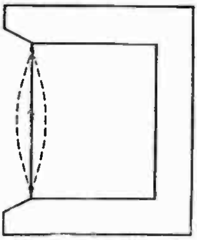

FIGURE 6

In Figure 8 there is shown a microphone such as is widely used as a receiver in submarine signaling. It consists of two electrodes between which powdered carbon is placed. The right hand electrode is fastened to the housing of the microphone and the left hand electrode to the microphone diafram. On the latter

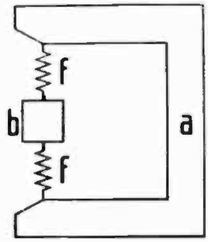

Figure 7

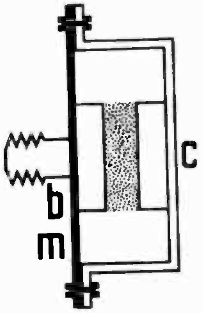

Figure 8

electrode there is also an arrangement for connecting to the middle point of the diafram. The microphone is a closed vibrating system. The two masses are those of the mass *c* and the mass *b*, and the elasticity is that of the microphone membrane *m*. A practical form of submarine signaling receiver is illustrated in Figure 9. There can be seen the housing of the receiver which is closed at one end by a diafram. The previously described microphone is fastened internally to the center of the diafram. The current is conducted to the microphone electrodes thru two flexible wires which lead to a cable passing thru a waterproof inlet into the housing of the receiver. The housing is, of course, surrounded by water, and contains air. The whole system consists of two coupled oscillation systems. The free mass of one portion is that of the receiver housing, and the other free mass is that of the housing of the microphone and the electrodes fastened to it. The common coupling mass of the

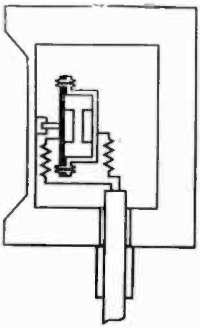

FIGURE 9

two oscillating systems consists of a number of connected parts and includes the other microphone electrode, the mass of the attachment element of the microphone at the diafram, the oscillating mass of the diafram referred to its center, and the associated oscillating mass of water also referred to this central point. From the magnitude of the two free masses and of the common coupling mass which is connected to them, the coupling coefficient of the two vibrating systems can be calculated according to the previous formula. This gives one of the important characteristics of the two oscillating systems.

In the case of submarine transmitters we are similarly concerned largely with coupled oscillating systems.

This will be illustrated by a description of the electromagnetic transmitter which was developed in the laboratory of the Signal-Gesellschaft at Kiel. In Figure 10 we have a schematic diagram of a construction thereof, in which *g* is the housing of the transmitter and *a* is the diafram which shuts the housing *g* at one side. The oscillation energy is produced by excitation of the magnetic parts *b* and *c* by means of coils which are not shown. The masses *b* and *c* are connected by means of the elastic elements *f f*.

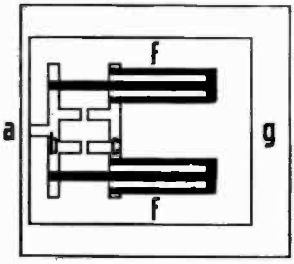

FIGURE 10

Each of these elements consists of a cylindrical rod and a tube, of equal cross-section. Their function is to bring together parts *b* and *c*, and yet to obtain for the longitudinally strained rods or tubes a length given by the desired oscillation amplitudes. We are dealing here with two vibrating systems which are coupled by a common mass and each of which has its own free mass. One vibrating system consists of the diafram *a* in the housing *g*; the other vibrating system consists of both magnetic portions *b* and *c* connected by the elastic elements *f f*. The free masses are *c* and *g*. The common mass consists again of different portions, and includes the magnetic portion *b*, the diafram mass referred to its center, and the associated oscillating mass of water also referred to the center of the diafram.

In Figure 11 is shown a schematic "circuit diagram" of this arrangement. Both free masses are given by the mass *c* and the mass of the housing *g* (which is drawn as a ring). The common mass is indicated as *b*. The two elastic elements are represented by the springs *f f* and *e e*.

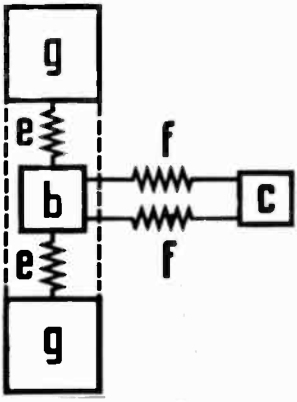

FIGURE 11

As will be seen, we are dealing here with two oscillating systems, one of which consists of the masses *b* and *c* and the spring *f f*, the other of the masses *g* and *b* and the spring *e e*. The coupling coefficient is again determined by the relation between the common mass and the two others. To obtain the best coupling coefficient and other desired results it is also necessary to tune the separate systems and to have suitable damping in each of them in relation to the coupling employed, just as is usually done in radio telegraphy.

In conclusion there will be shown a number of illustrations which will give typical examples of the employment of the submarine signaling transmitters which have been described.

In Figure 12, a transmitter in its actual form is shown. At the left is visible the transmitter which consists of two portions, between which the coils for exciting the transmitter are placed. This transmitter can be excited either with direct and alternating currents (polarized transmitter) or with alternating current alone (unpolarized trsnamitter). In the former case, the acoustic and electric frequencies are the same: whereas in the latter case the acoustic frequency is twice the electric frequency. It may be mentioned briefly that the unpolarized transmitter is especially desirable in cases where a long cable is necessary for transmitting energy since there are then only needed two conductors in the cable, and in the case of ground return only one conductor.

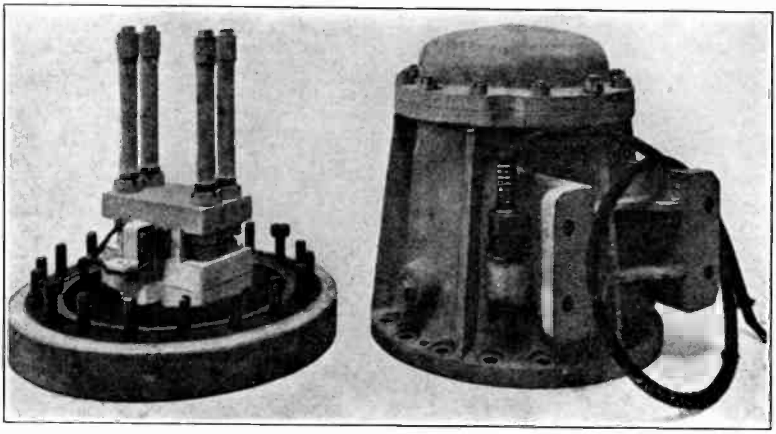

FIGURE 12

Both magnetic portions are connected thru an elastic tube and rod system which consists of four such elastic members. The entire apparatus is screwed to a diafram, the outer rim of which is provided with fastening screws. By means of these screws the diafram can be fastened to the housing shown at the right. An electric cable is led into the housing thru a water-tight opening, and an alternating current from a generator, or the necessary direct current for polarization in addition (in the case of polarized transmitter) is sent thru the cable.

In Figure 13 such a transmitter is shown attached to a tripod which is suitable for location on the sea bottom in the open ocean. The cable passes from the transmitter down one leg of the tripod and then over the sea bottom to a land point.

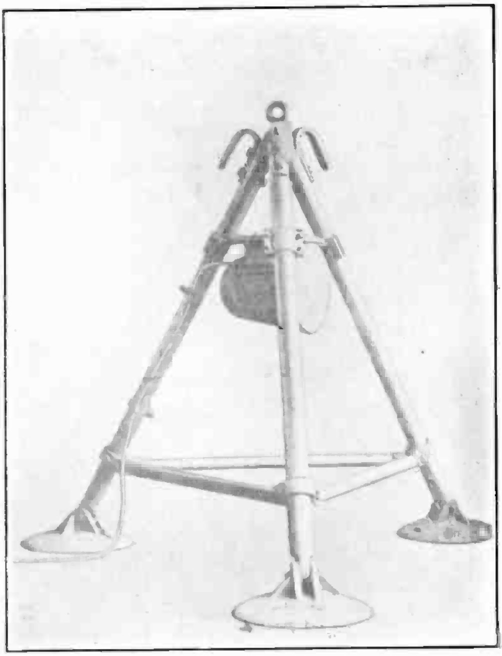

FIGURE 13

An entire installation of this sort is illustrated in Figure 14. The tripod stands on the sea bottom and the cable runs from it to the power station on land which is assumed to be located in in the neighborhood of a lighthouse. The transmitter sends sound waves out in all directions. Consequently all ships passing this point are able to receive the signals of the sound transmitter. They can even steer their course in accordance with these signals, as is nowadays done in foggy weather by utilizing the signals from submarine bells on lightships.

The first installation of this type was installed on the island of Rügen, near the German harbor of Sassnitz, several years ago. The railway ferry to Trellborg, a Swedish harbor, leaves this point. The transmitter is placed close to the lightship "Jasmund" and is intended to replace the latter.

The power installation of this transmitter is given in Figure 15 which, at Rügen, is located in the machinery room of a lighthouse. In the background can be seen the switchboard, and in the foreground the converter. In this case, 50 cycle polyphase power was available. This is first transformed into direct current. A motor generator then produces the 1,000 cycle single phase alternating current. The direct current is also used for polarizing the transmitter and for operating various pieces of auxiliary apparatus.

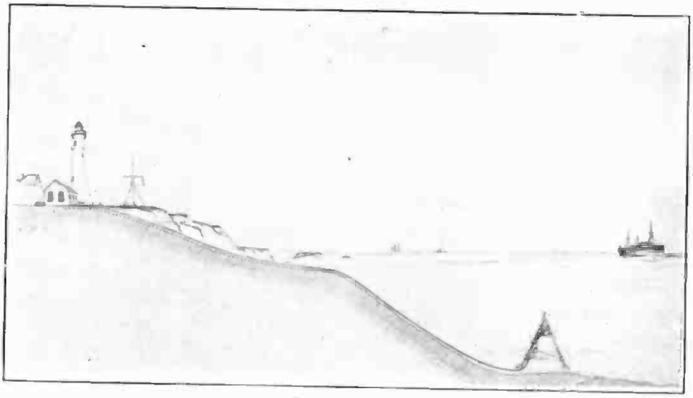

Figure 14

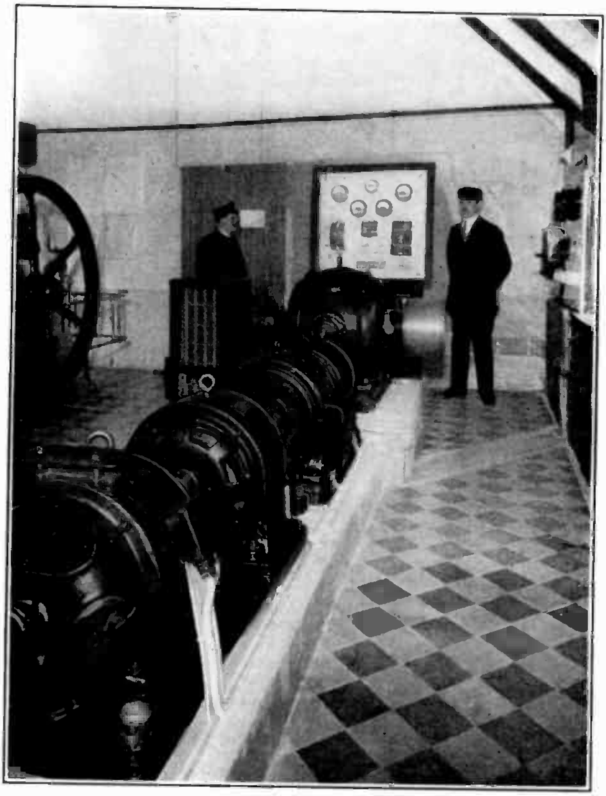

Figure 15

The laying of the cable is shown in Figure 16, and illustrates the beginning of the process at the land end. In the background are seen the well known chalk cliffs of the island of Rügen. Figure 17 shows the laying of the cable in the ocean, Figure 18 the cable reel during the laying process, while Figure 19 shows the transmitter on its tripod during attachment of the cable and shortly before its submersion and setting up on the sea bottom.

Figure 16

Figure 17

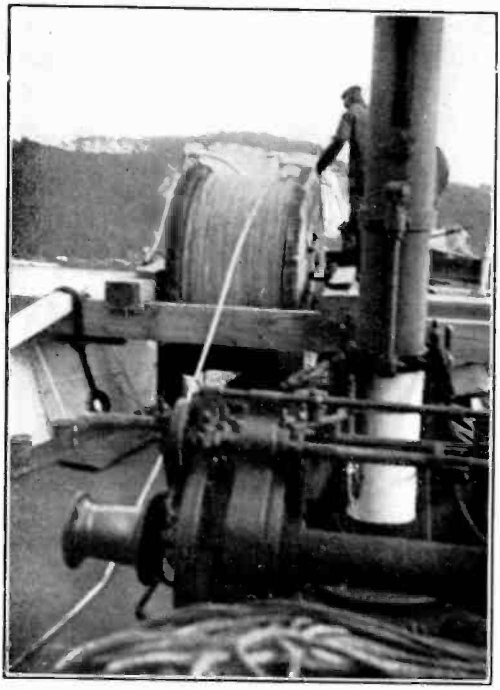

Figure 18

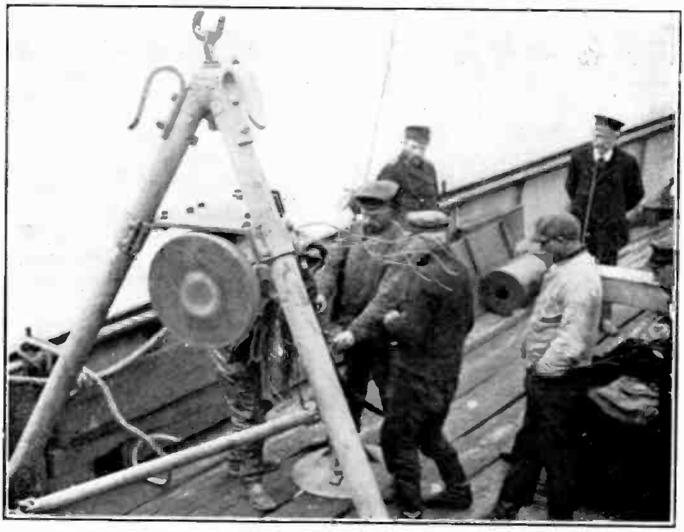

Figure 19

All the various sorts of submarine signaling apparatus are by no means covered by these two examples. There are several other forms of such apparatus which differ more or less from those described. But they almost always involve mechanical-acoustic oscillations which are produced or absorbed by means of oscillating systems. It is therefore desirable in the design and improvement of all such apparatus to proceed from the fundamental principles given above and to use the suitable "circuit diagrams" for determination of the oscillation engineering design of such apparatus.

The problems which have to be solved in submarine signal engineering are numerous, and to a large extent their field of application is similar to that of radio telegraphy. In some cases their applications are identical, as for example, in the methods of determining distance which depend upon the simultaneous reception of radio telegraphic signals and submarine signals from a certain point, such signals being sent, for example, from a lightship. There are other important cases where these two methods of signaling powerfully supplement each other, and their reciprocal contributions are therefore not only to be expected in the field of theoretical and experimental investigations, but also in the direction of practical application. I therefore hope that the material given here has been of interest to radio engineers.

SUMMARY: The acoustic systems corresponding to closed oscillatory electric circuits, to radiating electric systems, and to coupled circuits, are described. The design of submarine signaling transmitters and receivers on an engineering basis is described, and actual installations are discussed.

The resemblance of submarine signaling engineering and radio engineering, and the relation between these fields are considered.

NOTE ON THE MEASUREMENT OF RADIO SIGNALS*

By

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In 1917 (Proceedings of The Institute of Radio Engineers, volume 5, page 248, 1917) the writer advocated the method of measuring radio signals where a measured local input is compared with the signal to be measured. Such measurements have since been made in several quarters, but it is only recently that the writer himself has had the opportunity of working out the details for a successful measurement. In the following brief discussion this particular method and results are described.

Introduction

It is doubtful if any direct method of measuring radio signals of present-day intensities can be devised, the more so as with the increasing number of stations, a highly selective receiving apparatus is necessary for selecting the desired radiation. This leaves the indirect method of which the two variations are, a calibrated receiving set, and a local generator comparison, respectively. These two variations differ only slightly since the calibration of a receiving set requires the construction of a generator capable of delivering a minute measured input and the construction of such a generator automatically allows of the calibration of receiving sets. This calibration has been found readily possible, but at present the local comparison method appears the better for routine work, leaving the particular type and adjustment of the receiving set arbitrary.

Three means of identifying signal equality have been used in this laboratory, namely, the telephone receiver, the Braun tube, and a direct current meter. The former is usually, in telephone work, considered good for an accuracy of ± 1 mile of standard cable or approximately ± 12 percent. For radio work, with static present, this comparison is less accurately made. The telephone is particularly applicable to measurements during

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regular operation using as comparison source a local generator with its output broken up by a key as with the ordinary "omnigraph." The accuracies obtainable by a meter are limited only by the errors in reading the scale when static is absent, but fall off rapidly as static increases. A meter can only be used by pre-arrangement with the sending station, in telegraphic transmissions, as the sending key must be held down several seconds, but is immediately applicable for radio telephone measurements where the antenna current remains unbroken.

The accuracies obtained by the Braun tube have not been fully determined. Under moderate static conditions it excels the telephone on telegraphic signal measurements, but it becomes useless with excessive static. In practice the beam of electrons is deviated by a local alternating current source so as to give a bright line on the target and the incoming signals used to sweep this line at right angles to itself. The edges of the resulting rectangle are then easily defined thru moderate static.

Comparison methods may be listed as:

(a) Primary—where a local emf. is induced in the receiving antenna equal to the total emf. induced in this antenna by the signal to be measured; and,

(b) Secondary—where an emf. drop across an impedance favorably located in the antenna and associated circuits, and due to the resulting signal currents, is compared with the locally generated emf. In the first case, a knowledge of the antenna constants is unnecessary (except for such geometrical data as will allow a calculation of the ether electric field from the induced voltage resulting) and static is always present as it must be for telephonic comparisons. It is however more difficult to generate and control, at exactly the signal frequency, the smaller emf. thus needed. In the second case much larger and more easily measured inputs (not necessarily of signal frequency) may be used, but the antenna system must be carefully measured as a knowledge of its circuit constants is required. In either case the only requirement for the rest of the receiving set is that it be able successfully to select and amplify the desired signal.

For telephonic comparison it is necessary to switch rapidly from one input emf. to the other, and this can only be done for case (a), by using a rotating directive antenna (loop), or a pair of similar ones at right angles, unless by pre-arrangement the signals are regularly "on" and "off." At times the directivity of the static will give different interfering inputs on crossed directive antennas. For case (b) the local input can, if desired, be of a different frequency if applied directly to the detecting element. This is very easily obtained by beat reception, as for example by adjusting the beating oscillator frequency so that by adding a key and fixed reactance to this oscillator, the operation of the key will alternately "zero beat" the signal and local generator frequencies.

EXPERIMENTAL WORK

This particular work was begun in October, 1921, at Cliffwood, New Jersey, and for several reasons Nauen, Germany (POZ), was chosen as the original signal source. While theoretically the receiving set used is immaterial, practically this was not found to be the case, since other interfering radiations differed too little in frequency from that of Nauen. The following table of stations and their nominal frequencies illustrates this.

Marion	WSO	26,100 cycles
Stavanger	LCM	25,000 cycles
Nauen	POZ Number 1	23,800 cycles
Bolinas	KET	22,470 cycles
New Brunswick	WII	22,050 cycles
Carnarvon	MUU	21,130 cycles

The worst interference came of course from Marion and New Brunswick. The primary requirement of the final measuring system was that it must be reasonably simple and portable, and this made a portable loop antenna necessary. Attempts were first made to obtain such a good loop zero on New Brunswick (distant about 11 miles or 17.6 km.) that this station would be eliminated, after which Marion could be sufficiently reduced by tuning so as not to interfere at the high pitched beat note resulting. This balancing out of New Brunswick was successfully accomplished out of doors, but in the laboratory the outside telephone line and the conduits for the power and lighting supply made a zero balance impossible. Accordingly a decided sharpening of the selectivity of the receiving set was made and the shielding of the set very carefully carried out. The resulting apparatus is shown in the wiring diagram of Figure 1 and gave excellent results. No other station but the desired one is heard during the measurements. A frequency-output curve for the set from loop to meter is given in Figure 2. The width of this resonance curve can be altered at will by adjusting the coupling condensers (4) of Figure 1, and the resonance frequency by varying condensers (5). With the constants given, an ether

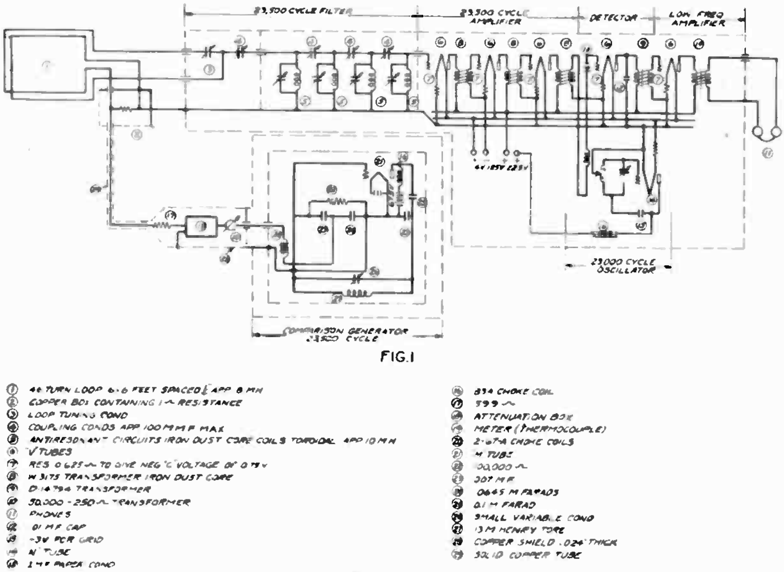


FIG. I

FIGURE 1

electric field intensity of 48.6 microvolts per meter gives a loop emf. of 3.66 microvolts and an effective 500 cycle power output at set terminals of 2.33×10^{-4} watts at 23,400 cycles signal frequency. An ether electric field intensity of 3.5 microvolts per meter is audible.

The method of obtaining the local emf. is shown in Figure 1. The generator is a Colpitts type vacuum tube oscillator, and by reason of the capacity across the plate—filament terminals and the capacity shunt-choke coil series output circuit gives a substantial reduction of harmonics in the output. This output current of about 1 milliampere is led thru a thermo-couple meter and an attenuation box of constant impedance and the frequency is thus kept invariant during the measurement. The generator is enclosed in two concentric copper boxes (0.061 cm. or 0.024 inch thickness) and is completely shielded from the loop antenna when two meters (6 feet) away. The batteries for plate and filament are singly shielded, the generator itself doubly so. It is interesting to observe that raising the cover slightly so as to expose a crack allows the stray magnetic field of the generator toroid coil to flow out much as water escapes from a similar crack. The same effect occurs if the side of the box is pushed in so as to separate from the overlapping cover. In either case the loop picks up the generator. The meter and attenuation box give little stray magnetic field and the electrostatic field is very easily shielded out.

The attenuation box is a carefully constructed artificial line of pure resistances and gives key settings of 1, 2, 3, 4, 10, 20, 30, and 40 miles of standard cable and combinations of these. Its surge impedance is 600 ohms and its construction shown in Figure 3.

$$\left[\frac{I_o}{I_{(N\ miles)}} = 10^{\frac{(N\ miles)}{21.12}}\right]$$

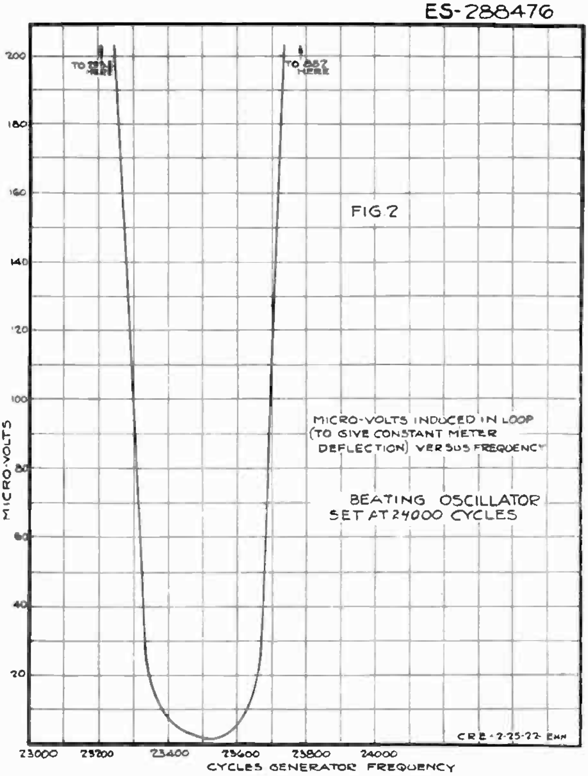
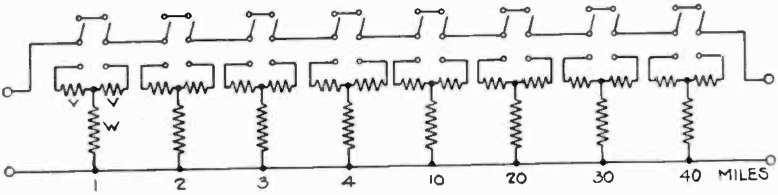
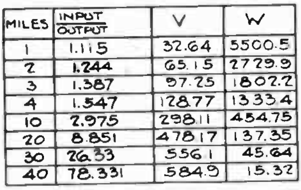


Figure 2

It gives very satisfactory results at the moderate radio frequencies used here, the key combinations checking against each other, and input and output current ratios being correct to the degree of accuracy with which meters can be read.

From the attenuation box the current is carried thru a copper tube to a copper terminal box on the loop base, and the drop across a non-reactive 1 ohm resistance inserted in the loop. The conductor in the tube can be short circuited in the terminal box, and after removing the loop connections three milliamperes sent thru the tube without giving an audible response in the set. The total capacity between the central connector and the tube is about 200 micro-microfarads. With the heavy central conductor used, the series resistance and inductance are so small that with a terminal impedance of 1 ohm the current attenuation thru the tube is, by calculation, considerably less than 0.1 percent. Three sources of error may be encountered. They are, in order of importance, inaccuracy in making the comparison, the distortion of the ether field by adjacent conductors, and the off-balance to ground of the loop. It is also probable that the use of too high attenuations in the attenuation box is risky, but this source of error can only be exposed by an independent method of accurately attenuating a small current to values unmeasurably directly. It has been found possible mostly to make aural comparisons to an accuracy of two miles of standard cable (24.4 percent.) and three miles (39 percent.) is never exceeded. Measurements on Nauen are never quite free of static, and so far a meter reading has not been possible. With the Braun tube, settings to better than 1 mile of standard cable are possible with moderate static.





MILES	INPUT / OUTPUT	V	W
1	1.115	32.64	5500.5
2	1.244	65.15	2729.9
3	1.387	97.25	1802.2
4	1.547	128.77	1333.4
10	2.975	298.11	454.75
20	8.851	478.17	137.35
30	26.33	556.1	45.64
40	78.331	584.9	15.32

FIGURE 3

The effect of adjacent conductors has so far only been noticed in connection with the local ungrounded wire telephone line, but it is probable that power circuits and conduit would show up in more accurate measurements. Incidentally a source of much

Date 1922	Time	Frequency Approximate	Microvolts per Meter
Feb. 14	....	....	35
16	11.15 A. M.	23,600	37
16	3.45 P. M.	23,600	36
17	10.00 A. M.	23,600	53
18	10.00 A. M.	....	36
20	10.00 A. M.	....	29 and 35
21	10.00 A. M.	....	33
23	P. M.	....	22
24	9.35 A. M.	....	40
25	P. M.	23,500	39
27	P. M.	23,510	49
28	A. M.	23,450	28
28	3.15 P. M.	23,540	27
March 1	9.45 A. M.	23,400	50
7	9.10 A. M.	23,540	44
7	4.40 P. M.	23,600	..
8	11.10 A. M.	23,540	48
10	11.35 A. M.	23,500	49
11	11.45 A. M.	23,560	44
14	2.45 P. M.	23,640	43
15	9.15 A. M.	23,590	49
16	12.25 P. M.	23,460	49
17	4.15 P. M.	23,480	35
18	12.30 P. M.	23,440	61
31	4.46 P. M.	23,466	38
April 1	9.05 A. M.	23,487	48
3	4.30 P. M.	23,560	42
4	11.35 A. M.	23,532	43
5	1.45 P. M.	23,488	20
8	11.05 A. M.	23,517	39
10	2.10 P. M.	23,576	22

trouble is due to the careless manner in which the electric power companies insulate their conductors, and on some days of strong wind and rain the New Jersey coast region becomes an extended source of severe interference to every receiving station having outside power or telephone connections.

The circuit shown in Figure 1 does not allow of a balancing of the loop to ground, but the unbalance effect has been shown to be negligible.

The apparatus described was, as stated, designed to measure Nauen's radiation and possesses enough flexibility to follow the rather marked variations in Nauen's frequency, but cannot cover any extended frequency range. For these, other condenser-coil combinations will be necessary, a change now being made.

The method of manipulation is as follows: a reading on a vacuum tube voltmeter or Braun tube connected to the output of the set is obtained with the loop end-on into the radiation and the same deflection duplicated by the local generator with loop broadside to the radiation. Or the vacuum tube voltmeter is replaced by a telephone and the two inputs alternately compared by turning loop and throwing the local generator on, the latter meanwhile, being broken up into signals if necessary as with Nauen. The voltage induced in loop is given by

$$V = \frac{2\pi f A N E}{3 \times 10^{10}}$$

where

f = frequency
A = loop area in cm.^{2}
N = number of turns
E = ether electrical field $\left(\frac{\text{volts}}{\text{cm.}}\right)$

A table of some observations on Nauen is attached. These are "key down" or peak field measurements.

SUMMARY: A portable compact measuring unit for incoming signal strengths has been worked out, capable of measuring from 3.5 microvolts per meter up, at 23,500 cycles, and giving satisfactory results. The measurements are made by a primary comparison with a locally generated emf. by means of a highly selective receiving unit and a 600-ohm artificial line box especially made for this purpose. The method is equally applicable to other frequency ranges and should be especially convenient at the higher radio frequencies where the absence of static allows of meter comparisons and the use of the double detection method of reception. This latter method allows of a fixed filter adjustment for all frequencies and is very flexible.

RELATIONS OF CARRIER AND SIDE-BANDS IN RADIO TRANSMISSION*

By

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As indicated by the title, this paper will discuss some of the phenomena associated with radio transmission in terms of the carrier currents and side-bands into which a modulated wave may be resolved. The use of these terms implies a point of view which perhaps is employed less commonly in radio engineering than in some of the other branches of the communication art. For this reason, I shall, at the risk of repeating much that is already in the literature,[1] review such of the fundamentals of this viewpoint as are necessary to an understanding of what is to follow.

Analysis of a Signal Wave

Briefly stated, the point of view is that any signaling wave may be resolved into sustained sinusoidal components, which may be thought of as traversing the system as individual currents and recombining at the receiving end to form the reproduced signal. The possibility of such a resolution has been demonstrated mathematically and the formulas for evaluating the amplitudes and phases of the components are well known. A periodic wave may be expressed as a Fourier series, that is, as the sum of an infinite series of components the frequencies of which may be thought of as harmonics of a fundamental frequency which is equal to the frequency of repetition of the wave. Such a resolution, however, is not directly applicable to the waves employed in communication, for by their very nature they are not periodic. A communication system must be capable of transmitting any individual symbol regardless of what precedes or follows it. We

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[1] "Carrier Current Telephony and Telegraphy," by E. H. Colpitts and O. B. Blackwell; "Transactions of the American Institute of Electrical Engineers," volume XL, page 205, 1921. "Application to Radio of Wire Transmission Engineering," by L. Espenschied; presented before The Institute of Radio Engineers, January 23, 1922.

may, however, resolve such an aperiodic wave by the mathematical device of assuming it to be one cycle of a periodic wave in which the interval between successive occurrences of the disturbance in question approaches infinity. The frequency of repetition is then infinitesimal. The fundamental frequency of the Fourier series and the frequency interval between adjacent components are also infinitesimal; that is, the series of discrete lines of the Fourier series spectrum merge into a continuous spectrum. Mathematically this continuous spectrum is represented by the expression

$$F(t) = \int_0^\infty S \cos (q t + \Theta)\, dq, \qquad (1)$$

which is known as the Fourier integral. Physically we are to picture this infinite series of sustained sinusoids as having such amplitudes and phases that the algebraic sum of their instantaneous values is zero for all instants before and after the disturbance in question, and equal to the instantaneous value of the wave thruout its duration. In Figure 1, curve A represents a telegraph dot, curve B gives the relative amplitudes, S, of its components plotted against their frequencies, and curve C, their phase, Θ, also as a function of frequency. The so-called "dot frequency" corresponding to a sustained succession of such dots is indicated on curve B.

It is obvious that if either the amplitudes or the phases of the components be distorted, their instantaneous sum will be changed; that is, the wave resulting from their re-combination will be a distorted reproduction of the original wave. Also, those parts of the frequency range in which the amplitude is negligibly small can contribute little to the reproduced wave, and the elimination of all components in those ranges will have little effect on the quality of reproduction. Just what ranges it is essential to retain depends upon the nature of the signal and the standard of reproduction that is set up. What is important for present purposes is the fact that the faithfulness with which a system will reproduce any arbitrary signal disturbance is deducible, in theory at least, from a knowledge of its transmission of sustained single frequencies. By this is meant a knowledge of how the relation, both in amplitude and phase, between the input and output sinusoidal wave varies as the frequency of the wave is progressively varied thruout the frequency range.

Analysis of a Modulated Wave

Let us assume now that a radio system is called on to transmit such a signal wave, $F(t)$, which may be either a telephone or a telegraph signal. If, as is commonly assumed, the modulator causes the amplitude of the carrier wave, $C \cos pt$, to be varied in accordance with the signal, the resulting modulated wave may be expressed as

$$m = C\,[1 + kF\,(t)]\cos pt, \tag{2}$$

where k is a factor which measures the so-called degree of modulation. If the largest negative value of $k\,F(t)$ is just equal to

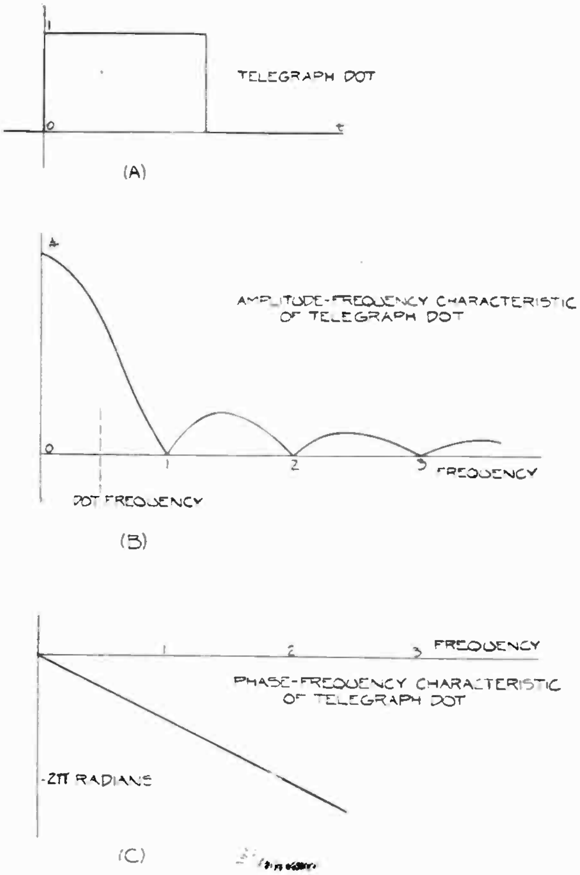

FIGURE 1

unity, so that the instantaneous amplitude of the carrier wave just falls to zero, the modulation is said to be complete. The significance of complete modulation will be discussed later.

Now let us resolve the signal wave into its infinite series of components, each of the form $S \cos (qt + \Theta)$, where S and Θ vary with the frequency $\frac{q}{2\pi}$. Neglecting non-essential frequencies, q may be considered to cover a range from q_1 to q_2. If this value of $F(t)$ be substituted in (2) we get

$$m = C\ cos\ pt + k\ C\ cos\ pt \int_{q_1}^{q_2} S\ cos\ (qt + \Theta)\ dq. \qquad (3)$$

The first term, which is independent of the signal, represents a component having the carrier frequency, $\frac{p}{2\pi}$. The second term represents an infinite series of terms each derived from only one component of the signal. Hence each component of the signal is represented in the modulated wave by an expression of the form,

$$k\ C\ S\ cos\ (qt + \Theta)\ cos\ pt = \frac{1}{2} k\ C\ S\ [cos\ [(p+q)t + \Theta] + cos\ [(p-q)t - \Theta]. \qquad (4)$$

This represents two sinusoidal components, the frequencies of which differ from that of the carrier by the frequency of the particular signal component. The similar expressions for the other signal components each yield a pair of components similarly placed with reference to the carrier. All of these taken together form a pair of spectra or frequency bands extending on either side from the carrier frequency in the same way that the spectrum of the signal extends from zero frequency. These bands of frequencies are spoken of as "side-bands" and the component currents of these frequencies as "side-band currents," or, more often, simply as "side-bands." The side-band which extends upward in frequency from the carrier is called the "upper side-band," and the other, which extends downward, the "lower side-band."

The form of these side-bands is shown schematically in Figure 2, where purely arbitrary curves are used to represent the amplitudes and phases of the signal components over a limited frequency range. It will be seen that the corresponding curves for the upper side-band are derived from these by displacing them along the frequency axis by the amount of the carrier frequency. The amplitude curve of the lower side-band is derived by inverting that of the upper with respect to the carrier frequency. For the phase curve of the lower side-band that of the upper is to be similarly inverted and also reversed in sign. The actual magnitude of the side-band currents relative to the carrier depends on the degree of modulation, k, of equation (2). For commercial telephony the limits of the essential band may be taken roughly as 200 and 2,000 cycles. If high quality speech or music is to be transmitted, a wider band is required. For telegraphy the band width required varies widely with the speed of sending and the type of apparatus used. In general, it is desirable to preserve very low frequencies, which means that the two side-bands practically meet at the carrier frequency.

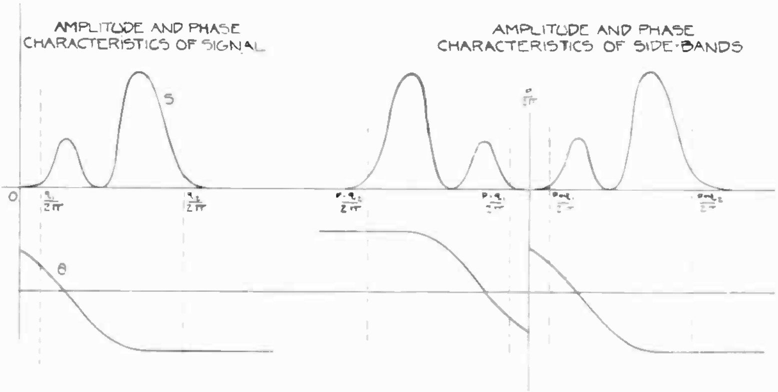

Figure 2

Reproduction of the Signal Wave

Having arrived at a picture of the modulated wave as given by equation (4), we shall first discuss the reproduction of the signal from this as it stands, and then consider the effect on this reproduction of various modifications to which the modulated wave may be subjected before or during the process of detection. While any device in which the current voltage characteristic is non-linear may be used as a detector, the operation of the vacuum tube lends itself to analysis because of its approximation to a parabolic current voltage relation. That is, we may write,

$$i = a_0 + a_1 v + a_2 v^2, \tag{5}$$

where v is the voltage impressed on the grid, in this case the modulated wave, and i is the resulting current. As the first term is independent of v and the second represents simple amplification, detection[2] can result only from the third term, $a_2 v^2$. Since a_2 multiplies all components of v^2 alike, we may neglect it and simply consider the square of the expression for the modulated wave. This results in a series of terms which are the squares

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[2] In practice this parabolic law seldom holds strictly, and secondary contributions are made to the detected wave by terms of higher power.

of the individual components and another which are their products taken in pairs. Since

$$cos^2 x = \frac{1}{2}(1+cos\ 2x), \tag{6}$$

the square terms will yield only direct current, and currents of approximately twice the carrier frequency. The product terms, each of which contains the product of two cosines, may, as in the case of the modulated wave above, be transformed into the sum of two cosine terms the frequencies of which are respectively the sum and difference of the component frequencies. Of these only the difference frequencies can lie in the range of the original signal. In other words, we may think of the reproduced wave as made up of the sum of all the heterodyne beat notes resulting from all the pairs of component sinusoids of the modulated wave.

The carrier component, $C\ cos\ pt$, beating with a component of the upper side-band, $\frac{1}{2}\ k\,C\,S\,cos\,[(p+q)\,t+\Theta]$, equation (4), gives the beat note or reproduced component,

$$r_{+} = \frac{1}{2} k\,C^2\,S\,cos\,(qt+\Theta), \tag{7}$$

which is identical in frequency and phase with the corresponding component of the signal, and has an amplitude proportional to that of the signal component. Exactly the same expression results from beating the carrier and the corresponding component of the lower side-band. These two low frequency components, being in phase, add directly to give

$$r = k\,C^2\,S\,cos\,(qt+\Theta) \tag{8}$$

as the reproduced component. As the factor $k\ C^2$ is independent of q, all of the signal components are reproduced with the same relative amplitudes and phases, as in the original signal. Their sum is therefore $k\,C^2\,F\,(t)$, and the signal is accurately reproduced.

However, there are still other components of the modulated wave to be considered. Every pair of components in one side-band beat to give the difference of their frequencies, which is also the difference of the corresponding signal components. The corresponding pair of components of the other side-band yield an identical component and the two add in phase. Similarly every component of one side-band beats with every component of the other, giving in each case the sum of two component frequencies of the signal wave. Like the difference frequencies, each of these sum frequencies is produced twice. The combination of the components of the two side-bands which were derived from the same signal component yields a component of twice the frequency of the signal component. The addition of these extraneous components serves to distort the reproduced wave in a manner quite similar to that of external interference. It is of interest therefore to consider the magnitude of these distorting components relative to the reproduced signal. The product of two side-band components of amplitudes $\frac{1}{2}kCS$ and $\frac{1}{2}kCS'$, equation (4), gives as the amplitude of one of the two components of the difference frequency $\frac{q-q'}{2\pi}$, $\frac{1}{4}k^2C^2SS'$. Comparing this with the amplitude, $\frac{1}{2}kC^2S$, equation (7), of one of the two reproduced signal components of frequency $\frac{q}{2\pi}$, the ratio of the undesired to desired component is found to be $\frac{1}{2}kS'$. It is evident that this type of distortion increases with the degree of modulation, k, or, as will be discussed more fully later, with the ratio of carrier to side-band.[3]

SINGLE SIDE-BAND TRANSMISSION

So far it has been assumed that the wave applied to the detector is identical with that produced by the modulator, a condition seldom encountered in practice. For, in addition to the undesired modifications which the modulated wave undergoes because the transmission characterictics of practical circuits are not ideal, there are other changes which when properly made yield distinct advantages. These intentional changes will be discussed first.

It will be remembered that any component of the signal can be reproduced by the combination of the carrier with either side-band. Hence it is unnecessary to transmit both side-bands. Suitably designed electrical filters make it possible to transmit one side-band and effectively suppress the other.[4] This makes possible a very great saving in the frequency range required per channel. It is of particular importance for long wave radio telephone transmission where the width of a single side-band is so large a fraction of the total frequency range available that the

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[3] A similar form of distortion generally occurs in modulation, resulting in new components being produced in the frequency range of the side-band.

[4] For a description of such filters see the Colpitts and Blackwell paper referred to above.

number of independent channels is at best very limited. The intensive development of a limited frequency range by the use of single side-band transmission has probably progressed farthest in connection with carrier telephony over wires. Here commercial service is being given over circuits on which the carrier currents of adjacent channels are separated by only 3,000 cycles. It is obvious that the transmission of both bands would nearly double this separation, thereby halving the number of channels per circuit. There is, of course, no reason why similar savings may not be effected in the field of radio transmission. In addition to this major advantage there is an incidental improvement in the quality of reproduction, for the distorted components resulting from beats between components of the two side-bands, that is, the sums of the signal frequencies, are eliminated.

CARRIER SUPPRESSION AND HOMODYNE RECEPTION

The other important modification has to do with the so-called "unmodulated" component of carrier frequency, $C \cos pt$, in equation (3). As already pointed out, good signal reproduction requires that at the detector this shall not be too small relative to the side-bands. However, it is merely a continuous alternating current, and does not itself partake of the signal variations. It is therefore immaterial whether it is transmitted from the modulator or is supplied to the detector by a local source such as an oscillator. The elimination of this component from the modulated wave at the sending station is spoken of as "carrier suppression," and its re-introduction at the receiving end as "homodyne" or "zero beat" reception. The term homodyne implies supplying the same wave as distinguished from heterodyne, meaning another. Zero beat refers to the bringing of the local carrier into synchronism with the sending carrier by reducing the beat note between them to zero frequency. While homodyne reception is essential to carrier suppression, the reverse is not true. The reception of an ordinary modulated wave may sometimes be improved by the addition of carrier at the receiving end.

The primary advantage of carrier suppression lies in the saving of sending power which it makes possible, or, what is equivalent, the increase in range made possible when all the power of a given station is utilized in the side-band. Of the various ways in which this suppression may be accomplished, the simplest is by the use of a so-called balanced modulator as shown schematically in Figure 3. Carrier frequency from the source C is applied to the grids of two vacuum tubes in the same phase, while signal currents, indicated at S, are applied to the two in opposite phase. The two plate circuits are differentially connected with a common output citcuit. In the absence of signaling current the amplified carrier frequency currents from the two tubes neutralize each other and nothing is transmitted. With the application of signaling current one grid is raised in potential and the other lowered, with the result that more radio frequency is developed by the first tube than by the second and the excess appears at O. The magnitude of this radio frequency current is proportional to the instantaneous value of the signaling current. Upon reversal of the direction of the signaling current the effect of the second tube predominates and radio frequency is again transmitted, this time with the phase reversed, owing to the differential connection. The wave form of a signaling current and the resulting output current are roughly as shown in Figure 4, *A* and *B*. If this output be amplified for transmission there will be no load on the amplifier and antenna except during actual speech, when it will be proportional to the intensity of the speech.

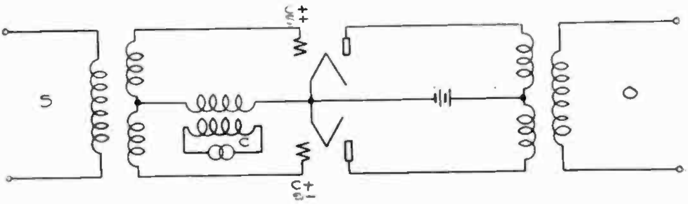

FIGURE 3—Balanced Modulator

That these intermittent pulses of carrier frequency produced by a balanced modulator are equivalent to a modulated wave from which the carrier frequency component has been removed, may be easily shown. Consider a single sinusoidal component $S \cos (q t+\Theta)$, of the signaling wave which is applied to the balanced modulator. The resulting output current is a wave of carrier frequency, the amplitude of which is proportional to C and to S and varies cyclically with a frequency $\frac{q}{2\pi}$ between the values $+K C S$ and $-K C S$, where K is a constant of proportionality and the negative amplitude indicates a reversal of phase during half of the audio frequency cycle. Such a variation may be represented by the expression

$$i = K C S \cos (q t+\Theta) \cos p t. \tag{9}$$

Taking the sum of these expressions for all the components of the signal gives the second term of Equation (3) which was shown to represent the side-bands.

In estimating the power saved by carrier suppression the comparison should be made with a system transmitting the carrier which has been so adjusted that the power is used to the best advantage. So far as a single signal component is concerned this would call for making the carrier and side-band equal, as their product would then be a maximum. This, however, would imply that the distorting currents from the interaction of two side-band components would be as large as the signal currents themselves. That is to say, quality considerations require that the major part of the transmitted power be in the carrier component. Quantitative data on the relation between the ratio of carrier to side-band and the quality of transmission has been secured in the laboratories of the Western Electric Company, and it is hoped it will be published in the near future. Briefly, the results indicate that the good quality which is obtained when the carrier component is large falls off very rapidly as the magnitude of the carrier component is reduced so as to approach that of the side-band, the latter being measured when a sustained "ah" sound is used as the signal. Under these conditions the side-band is sustained at a value about equal to the maximum occurring in ordinary speech. That is to say, even the peak power in a carrier suppression system is less than the carrier component alone in an ordinary system adjusted to give the same side-band. From these considerations it appears that there has been a tendency to attach undue significance to "complete modulation," as a more or less unique and ideal condition of operation. For nothing revolutionary occurs as the carrier is decreased thru the value corresponding to that condition. The distortion due to interaction between the side-bands is present for larger values of carrier and continues to increase progressively for smaller values. The exact degree of modulation to be permitted therefore depends upon the standard of quality to be met. In a carrier suppression system the degree of modulation, k, approaches infinity more or less closely depending on the completeness of the suppression.

In addition to making possible the use of carrier suppression, homodyne reception presents other advantages. It furnishes a ready means of increasing the intensity of the reproduced signal, since this is proportional to the carrier component at the receiver as well as to the side-band. Also, by making the carrier large, *k* is made very small and the distorting currents due to interaction of the side-bands become negligible. The use of a large local carrier in homodyne radio telephony assists in frequency selection in the same way as does the hetrodyne wave in radio telegraph reception. Suppose an interfering message is separated from the desired one by only a few thousand cycles and so is not entirely suppressed by the receiving selective circuits. Currents of voice frequency can be reproduced from its side-bands only by interaction with its own carrier, and hence they will be small compared with those of the desired message, which are proportional to the local carrier. On the other hand, the large currents due to the interfering message and local carrier will all have frequencies above the voice range, and so can be suppressed by selective circuits in the output of the detector.

The same general reasoning applies also to static interference. Appreciable interfering currents of signal frequency can result only from those components of the static wave which lie in the frequency range of the side-bands. Moreover, they will bear the same ratio to the signal currents as do the static components to the side-band components. We may conclude, then, that when means are provided for eliminating all of the static except that which is inherently inseparable from the signal, the disturbing effect of the residue is determined solely by the relative magnitude of the *side-band* components and the static components which lie in the same frequency range. As the object of high power stations is to make the signals large compared with the static, the importance of concentrating the power in the side-bands rather than in the carrier is obvious.

Effect of Radio Distortion

Let us pass now from the intentional modifications of a modulated wave and consider the effects of unintentional distortions. Limiting our attention first to systems in which the carrier is transmitted, we have to consider the effect of distortion such as might be introduced by the sending and receiving circuits and the transmitting medium. Assuming the characteristics of these to be known in terms of their transmission of sinusoidal components of various radio frequencies, we wish to determine their effect on the amplitudes and phases of the components of the reproduced wave. We shall assume the current voltage relations in the transmission system to be linear, so that no new frequencies are introduced. Then any possible distortion in the modulated wave may be represented by assigning the proper amplitudes and phases to all of the components. Corresponding to a single component of the signal we may write for the received wave

$$m = B\cos(pt-\phi) + B_{+}\cos[(p+q)t+\Theta-\phi_{+}] + B_{-}\cos[(p-q)t-\Theta-\phi_{-}] \tag{10}$$

where the amplitude, B, and phase lag, ϕ, may vary in any arbitrary manner for the different components of the modulated wave. We shall assume that B is always large enough compared with B_{+} and B_{-} that the interaction between the side-band components may be neglected. It will be seen that the single frequency components reproduced from the two side-bands are not in general equal nor in phase and may either aid or tend to neutralize each other. They will be of the form,

$$B\left[B_{+}\cos[qt+\Theta-(\phi_{+}-\phi)]+B_{-}\cos[qt+\Theta-(\phi-\phi_{-})]\right]. \tag{11}$$

Taking the resultant of these two gives as the component of the reproduced wave,

$$r = R\cos(qt+\Theta-\psi) \tag{12}$$

where

$$R = B\sqrt{B^2_{+}+B^2_{-}+2B_{+}B_{-}\cos[(\phi_{+}-\phi)-(\phi-\phi_{-})]} \tag{13}$$

$$\tan\psi = \frac{B_{+}\sin(\phi_{+}-\phi)+B_{-}\sin(\phi-\phi_{-})}{B_{+}\cos(\phi_{+}-\phi)+B_{-}\cos(\phi-\phi_{-})}. \tag{14}$$

It is evident that both the amplitude, R, and the phase shift, ψ, of the reproduced component depend upon both the amplitudes and phases of the corresponding components of both side-bands and on the phase of the carrier. The amplitude depends also on the amplitude B of the carrier, but as variations in this affect all components alike, they do not alter the wave form of the reproduced signal, but only its magnitude.

The expressions for the reproduced wave become much simpler for a system in which one side-band, say the lower, is suppressed. Then

$$B_{-} = 0 \tag{15}$$

and equations (13) and (14) reduce to

$$R = B\,B_{+} \tag{16}$$

$$\psi = \phi_{+} - \phi. \tag{17}$$

The amplitude of the reproduced component is independent of the phases in the modulated wave, and is proportional to the amplitude of the side-band component. Hence amplitude distortion of the reproduced wave can result only from unequal transmission of the different component frequencies of the side-band. The change in the amplitude curve for the signal will be identical with that of the side-band. The phase shift, ψ, is independent of amplitude distortion of the modulated wave. It is equal to the difference between the phase lags of the side-band component and the carrier. Fortunately the quality of telephone reproduction is not seriously impaired by shifting the phases of the various components by even as much as several cycles. In telegraphy, however, the shape of the signal current which operates the relay depends very much on the preservation of the proper phase relations of the components, and the entire nature of the signal may be changed by phase shifts of even a fraction of a cycle.

It is worth while then to examine some of the phase shifts which are likely to occur in practice. Transmission of a sinusoidal wave thru the free ether involves a phase lag proportional to the distance and to the frequency. Hence the phase lags, ϕ_+ and ϕ, due to this cause, will be proportional to $p+q$ and p respectively, and their difference, ψ, will be proportional to q. Replacing ψ by $h\,q$ in equation (12) and regrouping terms gives

$$r = R\cos\left[q\,(t-h)+\Theta\right]. \qquad (18)$$

By displacing the origin of time by h this becomes identical with the original signal component. Also, since h is independent of q, the same time shift brings all the components into agreement; that is, a phase shift proportional to the frequency does not distort the wave, but merely delays it by the corresponding time of transmission.[5] In considering the terminal circuits then it is only the departure of their phase lag versus frequency curve from a straight line that need be considered as a source of distortion. It is of interest to note here that for most filters this relation is approximately linear thruout the range of free transmission. The actual curves for a particular band filter are shown in Figure 5, where there is plotted against frequency the relation of the amplitude and phase of the current at the third section of an infinite filter to those of the voltage applied to the first section. It will be noticed how the phase curve departs

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[5] For a fuller discussion of this point see a paper by T. C. Fry on "Theorie des binauralen Hörens nebst einer Erklärung der empirischen Hornbostel-Wertheimerschen Konstanten," "Physikalische Zeitschrift," 23, page 273, 1922.

abruptly from a straight line at the edges of the band where the sudden drop in the amplitude curve occurs. Similarly Figure 6 shows how in the current voltage relation of a simple resonant circuit, the distortion of phase and of amplitude occur together.

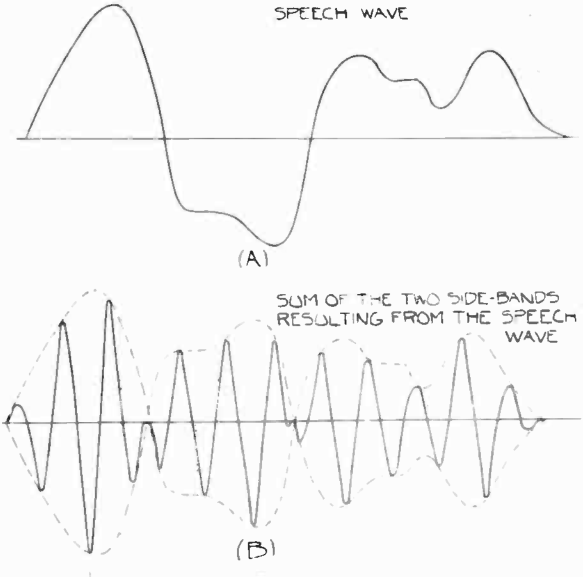

Figure 4

In case both side-bands are transmitted, a simple relation is found if the distortion is symmetrical with respect to the carrier frequency. By this is meant that, however the different components are distorted relative to each other, for every signal component the two corresponding side-band components are equal in amplitude and are shifted in phase relative to the carrier by the same amount; that is to say, for every value of q considered separately,

$$B_{+} = B_{-} = B_{\pm} \tag{19}$$

$$\phi_{+} - \phi = \phi - \phi_{-} = \delta. \tag{20}$$

Then

$$R = 2\, B\, B_{\pm} \tag{21}$$

$$\psi = \delta. \tag{22}$$

The same considerations as to distortion of the side-band apply here as for the single side-band. There is one point, however, of some practical significance. As is evident from Figure

6, the characteristics of a resonant circuit come very close to satisfying these symmetrical conditions if the carrier coincides with its resonance frequency. Its effect on the amplitude and phase curves of the reproduced signal may therefore be derived independently from the amplitude and phase curves of the tuned circuit. If, however, the circuit be detuned, this symmetry is upset and we are forced to the complicated relations of equations (13) and (14), from which it is difficult to draw general conclusions.

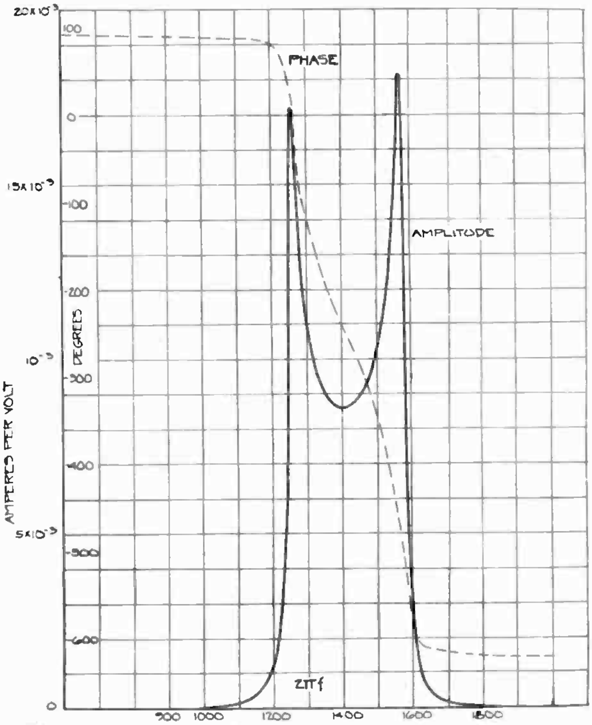

Figure 5—Amplitude-Frequency and Phase-Frequency Characteristics for Band-Pass Filter

An interesting case of unsymmetrical transmission is that in which one side-band is only partially suppressed owing to insufficient selectivity. Let us assume that the upper side-band is transmitted without distortion. Then for a given amplitude of the lower side-band its effect on the amplitude curve of the reproduced signal will be worst when the phase relations are such that for some frequencies it aids the upper side-band and for others it opposes. The greatest fractional change in the amplitude of any one signal component due to the presence of the lower side-band occurs when the two oppose. It is then reduced in the ratio

$$\frac{B_+ - B_-}{B_+} = 1 - \frac{B_-}{B_+}. \tag{23}$$

Thus, if the lower side-band component were a tenth of the upper, the most it could do would be to change the amplitude of the

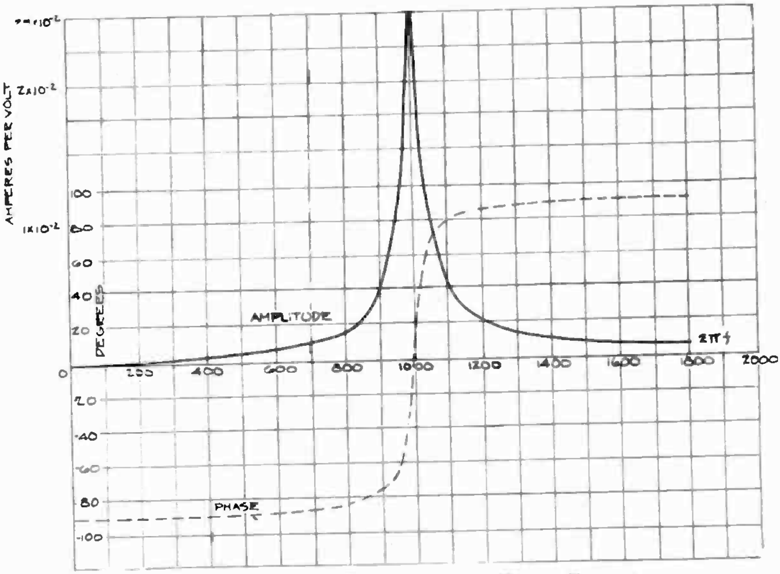

FIGURE 6—Amplitude-Frequency and Phase-Frequency Characteristics of Simple Resonant Circuit

signal component by a tenth. Such a change would have little effect on telephone quality, particularly as it would have this maximum value at only a few frequencies. The case of telegraphy is rather different. Here the two side-bands lie so close together that it is practically impossible to separate them by radio selective circuits, and even when, as in wire transmission, so low a carrier frequency is used that the two may be separated fairly well by filters, the side-bands corresponding to the lower signal components differ so little in frequency that even a sharp filter does not produce very great discrimination between them. This, coupled with the fact that the phase shift of a filter ceases to be linear near the edge of the transmitted band, leads to very considerable amplitude distortion.

The effect of the unsuppressed side-band on the phases of the reproduced components is also rather complicated. Equation (14) shows that it is a maximum when

$$\begin{aligned} \phi_+ - \phi &= 0 \\ \phi - \phi_- &= 90°, \end{aligned} \tag{24}$$

in which case the presence of the lower side-band changes *tan* ψ from 0 to $\frac{B_-}{B_+}$. As in the case of amplitude, this effect is unimportant in telephony, but would need to be considered in telegraphy.

Phase of the Local Carrier

Coming now to homodyne reception, the important new factor to be considered is the fact that the carrier component is now perfectly arbitrary in amplitude and phase. This is true even tho the sending carrier is not suppressed, for, by suitably choosing the local carrier, the resultant of the two may be given any desired value. Since the amplitude of the carrier affects only the magnitude of the reproduced signal as a whole, we need consider here only the effect of arbitrary values of its phase, ϕ. For simplicity we shall assume that the modulated wave reaches the receiver unchanged except for the phase lags involved in undistorted transmission. Let us designate by ϕ_1 the phase lag of the carrier which is received from the transmitting station or would be received if it were not suppressed. Then

$$\phi = \phi_1 + \eta, \tag{25}$$

where η may be regarded as the phase displacement of the local carrier.

Consider first a system in which one side-band is suppressed. From equation (16), the amplitudes of the reproduced signal components are independent of the phase of the carrier. From equation (17), the phase,

$$\psi = \phi_+ - \phi_1 - \eta. \tag{26}$$

But $\phi_+ - \phi_1$ represents only the phase shifts of undistorted transmission; that is, the delay suffered by the signal as a whole. Hence the net result is that all components have their phases shifted by the same amount; namely, the phase displacement of the carrier, which can never be more than a single cycle. For telephony this is of no practical importance, but it is evident that in a telegraph system using side-band suppression and homodyne reception the phase of the local carrier would have to be very carefully controlled.

Consider now the case of homodyne reception of both side-bands received without distortion; that is,

$$B_{+} = B_{-} = B_{\pm} \tag{27}$$

and

$$\phi_{+} - \phi_1 = \phi_1 - \phi_{-} = h\,q. \tag{28}$$

From these relations and equations (13) and (14) we get

$$R = 2\,B\,B_{\pm}\,\cos\eta. \tag{29}$$

$$\psi = h\,q. \tag{30}$$

This shows that the amplitude of every component varies as $\cos\eta$; that is, when the local carrier is in phase or 180° out of phase with the received carrier the reproduced components are maximum for intermediate values they decrease, becoming zero when the two carriers are in phase quadrature. The phase lag, $k\,q$, is that due to transmission alone; that is, the phases of the reproduced components are independent of the phase of the local carrier. Since the phase of the local carrier affects only the amplitudes and affects these the same for all components, it does not alter the wave form of the reproduced signal, but does affect its magnitude very materially.

Thus in a carrier telephone system fluctuations in the phase of the local carrier are much more serious when both side-bands are transmitted than when one is suppressed, the only effect then being an unimportant phase distortion. In a carrier telegraph system, however, the amplitude fluctuations which occur when both side-bands are transmitted may not be particularly troublesome since telegraph receiving apparatus is designed to operate over quite a range of signal intensity. The phase distortion occurring in single side-band transmission is however serious. It may perhaps be considered fortunate that the requirements as to phase regulation are least severe in telephony with a single side-band and in telegraphy with both side bands, since these modes of operation appear on other grounds to be the most practical for the two cases.

In comparing single and double side-band transmission it is interesting to note that for equal sending power, the power of the reproduced signal component is twice as great with two side-bands as with one. However, the power of the same frequency resulting from static is also twice as great, so that the ratio of signal to interference is the same in both cases. To show this, let B_1 be the amplitude of a component of the single side-band and B_2 that of each of the corresponding components of the double side-band. Then equality of power gives

$$B_1^2 = 2B_2^2. \tag{31}$$

For the single side-band the amplitude of the reproduced component is

$$R_1 = g\, B_1, \tag{32}$$

where g is a constant of proportionality. The power,

$$P_1 = \frac{1}{2} g^2\, B_1^2 = g^2\, B_2^2. \tag{33}$$

(The resistance is here omitted as it is assumed constant thruout.) For the double side-band, since the two components are in phase, the resultant amplitude,

$$R_2 = 2\, g\, B_2, \tag{34}$$

and the power,

$$P_2 = 2\, g^2\, B_2^2 = 2\, P_1. \tag{35}$$

If the static be assumed to approximate an impulse, the amplitudes of all its components will be sensibly the same. If we call this amplitude S, then, in the case where the receiving circuit admits only one side-band, the amplitude of the reproduced interfering current of the frequency of the signal component is

$$I_1 = g\, S, \tag{36}$$

and its power,

$$W_1 = \frac{1}{2} g^2\, S^2. \tag{37}$$

With both side-bands this interfering current is made up of two equal components derived from the static components of frequencies $\frac{p+q}{2\pi}$ and $\frac{p-q}{2\pi}$ respectively. The phase difference ε between these two will be accidental, so for any one case the resultant amplitude,

$$I_2 = 2\, g\, S \cos \varepsilon, \tag{38}$$

and the power,

$$W_2 = 2\, g^2\, S^2 \cos^2 \varepsilon. \tag{39}$$

As all values of ε are equally probable, we may average W_2 with respect to ε, whence

$$\overline{W}_2 = g^2\, S^2 = 2\, W_1. \tag{40}$$

There is then no choice between one and two side-bands on the basis of the ratio of signal to interference, With a single side-band, the major advantage of economy in frequency range is secured at the expense of the minor disadvantage that to give the same response the amplification of the receiving set must be greater by a factor of two in power, or about three miles of standard cable.

USE OF NON-SYNCHRONOUS LOCAL CARRIER

In practice, however, unless the receiving carrier frequency is controlled by the same source as the sending carrier, it is rather difficult to maintain even the frequencies alike, to say nothing of the phases. Let us suppose that the local carrier is out of synchronism by a small amount, *n*. Consider first the simplest case where the carrier is suppressed and one side-band only is transmitted. The local carrier beating with each component of this side-band gives a component of normal amplitude, but of a frequency differing from that of the original signal component by *n*. That is, all the frequencies of the speech are raised or lowered by the same amount, *n*. This must alter the wave form very decidedly, but the surprising thing is that in telephony the intelligibility is not seriously affected when the difference is made as much as fifty cycles or so. The apparent pitch of the voice changes, of course, as *n* is varied.

If the carrier is transmitted, either intentionally or thru incomplete suppression, the situation is less favorable to asynchronous reception. The two carriers then beat together, giving a component of frequency *n* which may be troublesome if the received carrier is large. However, its frequency is generally below the voice range, and so it can be suppressed by a filter in the detector output. In addition the received carrier beating with the side-band gives the components of the original signal. These are superposed on the displaced speech from the local carrier, the corresponding components of the two differing in frequency by *n*. As a result, the two sounds beat together just as two tuning forks would. For very small differences in frequency a periodic rise and fall in intensity is heard. When the difference is increased so that the individual beats can no longer be distinguished, a sensation of roughness results. And when the difference is made still greater the two waves may be heard as separate sounds of noticeably different pitch. The prominence of this beating effect depends, of course, upon the relative magnitude of the two carriers, since the two sets of speech currents are in the same ratio as the two carriers.

This effect of the received carrier may be very much reduced, and in the ideal case entirely eliminated, by the use of a balanced detector similar in structure to the balanced modulator of Figure 3. It can be shown that with such a circuit the combination frequencies resulting from any two components applied at S are neutralized in the output circuit, while the combination of each with the carrier applied at C is transmitted. Thus if the side-band and received carrier enter together at S, the components having the original signal frequencies are eliminated and only the displaced components remain.

When the other side-band is added, the situation is still further complicated. In the absence of received carrier the local carrier and one side-band give a set of components the frequencies of which are greater than those of the signal by n, while the carrier and other side-band give a set less by the same amount. These two sets combine in much the same way as do the displaced and normal speech obtained with a single side-band and received carrier. Here, however, the beat frequency is $2n$. Also, as the two sets are equal in amplitude, the beats will be much more pronounced, the intensity falling to zero each time the two waves are in opposition. For slow beats the apparent pitch of the sound is half way between the frequencies of the two equal components, and so the normal voice frequency will be heard. With large frequency displacements of the carrier the two displaced speech waves, being of equal intensity, will be more easily distinguished than in the case of the single side-band.

It is interesting to note that this result, as well as the frequency shift that occurs with a single side-band, follows directly from the relations arrived at above for the phase displacement of a synchronous carrier. The non-synchronous carrier may be thought of as a synchronous one the phase of which is varied with the frequency of the departure from synchronism. With a single side-band it was shown that a phase displacement of the carrier affects only the phase of the reproduced component and that it changes this by an amount equal to its own displacement. This progressive phase displacement in all the components of the reproduced wave is, of course, equivalent to a change in their frequencies equal to the frequency displacement of the carrier. With both side-bands present, a phase displacement was shown to have no effect on the phases but to change the amplitudes of the reproduced components by the factor $\cos \eta$. Thus a progressive change in η will cause a cyclic variation in amplitude having two minima for each cycle of η; that is, a frequency of $2n$.

If the two side-bands are accompanied by the carrier there are added the beat note of the two carriers and the components of the original signal. The addition of a small amount of this speech of uniform amplitude to that of varying amplitude already present merely tends to make the variation slightly less pronounced. From the foregoing it appears that for telephony the most favorable condition for using a local carrier which is out of synchronism is that in which only one side-band is transmitted. Fairly considerable frequency variations are then permissible and asynchronous operation appears to have practical possibilities.

For telegraphy the case is quite different. In the first place the important components of telegraph signals are much lower in frequency, so that the side-band lies closer to the carrier, and a much smaller absolute displacement of the carrier frequency is needed to give the same effect as in the telephone case. Considering only such small displacements, it appears that the general addition or subtraction of frequencies which occurs with a single side-band will alter the shape of the signals quite seriously. The slow fluctuations in signal intensity which occur with both side-bands are probably less serious over most of the cycle. However, they might well cause some signals to be lost entirely each time the intensity passed thru zero.

For asynchronous reception, then, just as for the case of a local carrier displaced in phase, single side-band transmission is preferable for telephony and double side-band for telegraphy. The difficulties are of the same general nature in the two cases, but with the asynchronous carrier they are considerably greater. This is in agreement with the idea expressed above, that lack of synchronism may be looked upon as an aggravated case of phase displacement.

Research Laboratories of the American
Telephone and Telegraph Company,
and the Western Electric Company,
Incorporated.

October 9, 1922.

SUMMARY: The modulation of a carrier wave by a signal wave and the subsequent reproduction of the signal wave are discussed in terms of the sustained sinusoidal components into which the various waves may be resolved. The conception of a modulated wave as being made up of a carrier component and two side-bands is explained.

The saving in frequency range resulting from transmitting a single side-band is emphasized. Carrier suppression and homodyne reception are shown to save sending power, increase receiving sensitiveness and aid in suppressing interference from both stations and static.

Equations are derived for the distortion of the reproduced wave in terms of that of the modulated wave. In general, both the amplitude and phase of each component of the signal depend on both the amplitudes and phases of the corresponding side-band components and of the carrier.

The effect on the signal of various typical distortions of the radio wave is examined for both single and double side-band transmission, as is also that of altering the phase of the locally supplied carrier and of altering its frequency. The resulting distortion of the signal is found, in general, to be more serious for telephony when both side-bands are used and for telegraphy when only one is used.

It is also shown that the reproduced signal has twice the power when both side-bands are transmitted as when the same sending power is concentrated in one. The signal to static ratio is, however, the same in both cases.

FURTHER DISCUSSION
ON
"RESISTANCE AND CAPACITY OF COILS AT RADIO FREQUENCIES"*

BY

J. H. MORECROFT

A. Press (by letter): The experiments of Professor Morecroft in endeavoring to check up the work of Dr. Breit are so important a matter for radio science that it may be of value to emphasize the crowning assumption of Dr. Breit's mathematical developments.

Turning to "The Physical Review" for June, 1921, equation (4) of the article on "The Distributed Capacity of Inductance Coils," it will be seen that the assumption is made that the charge density at any point x is a function of x times the rate of change of the current at any point taken as a standard. The formula in question is

$$Q(x) = a(x) \cdot \frac{d i_1}{d t} \tag{4}$$

In reality from the experiments of Professor Townsend of Oxford, and others, the wave distribution of current, so far as its plural nodal distances are concerned, is a function of the frequency. This frequency function can be of the resonant type, or even of the *dissonance* type as the writer has indicated elsewhere. Much depends on the geometrical constants of a coil with respect to the particular frequency. It would be too much to expect that a formula of the simplicity (1)

$$L(C+C_o) = \frac{1}{w^2} \tag{1}$$

should hold for both cases indicated herewith.

G. Breit (by letter): Referring to the second paragraph of Mr. Press' letter: "Turning to . . . at any point x is a function of *x times the rate* . . ." The part in italics is wrong, as is seen from

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*See page 287 of the August, 1922 (volume 10, number 4), issue of the PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS.

the formula (4) quoted. This formula is reproduced not quite correctly by Mr. Press; the Latin a being used for the Greek α.

I do not think it is correct to call the assumption discussed by Mr. Press the *crowning* (?) assumption of my deduction. The first paragraph of my synopsis introduces C_0 as the quantity which is experimentally known to satisfy: $L\,(C+C_o)=\frac{1}{\omega^2}$. My problem was to calculate C_0 within the range of ω for which the above relation is reasonably true. The same point of view is brought out in the summary. The absolute validity of the equation $L\,(C+C_o)=\frac{1}{\omega^2}$ would be, of course, untrue. The factors which make this equation a good approximation I tried to consider in the section: "Explanation of constancy of C_0" (pages 669-671, "Physical Review"). As shown there within a certain range the formula may be expected to hold.

The assumptions underlying my derivation I tried to summarize on page 650 under 1, 2, 3, 4, 5. These are essentially reviewed on the bottom of page 656 and the top of page 657. The point of view taken towards C_0 is brought out particularly under (*h*) (page 657).

In Mr. Press' letter $\frac{1}{w^2}$ in (1) should be $\frac{1}{\omega^2}$.

It is difficult for me to be sure that I understand correctly the section of Mr. Press' latter just after (4). He certainly cannot mean that I do not consider the dependance of current distribution on the frequency because this is the fundamental point in my derivation. It would seem then that he considers the fact that a coil can vibrate in different modes. This fact has been known to Drude and is generally obvious by analogy with an organ pipe. The difficulty is taken care of by the fact that the range in which $L\,(C+C_0)=\frac{1}{\omega^2}$ is used deals only with one mode.

DIGESTS OF UNITED STATES PATENTS RELATING TO RADIO TELEGRAPHY AND TELEPHONY*

Issued October 31, 1922–December 19, 1922

By

John B. Brady

(Patent Lawyer, Ouray Building, Washington, D. C.)

1,433,599—R. Brown, filed July 2, 1921, issued October 31, 1922. Assigned to American Telephone and Telegraph Company.

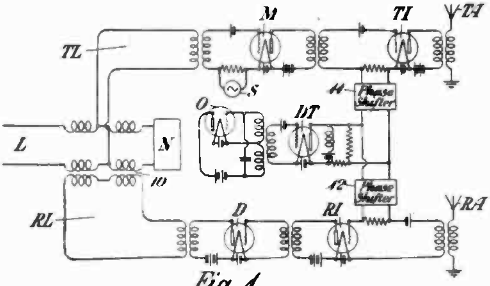

Fig. 1

Number 1,433,599—Radio Circuits

Radio Circuits for an electron tube transmitter and receiver whereby the transmitting and receiving apparatus may be operated in close proximity to each other at the same station without interference, and wherein two-way communication may be had without mechanical switching from transmitter to receiver. In this circuit Figure 1, advantage is taken of the commutating characteristic of an electron tube for shifting the operation of the system from transmission to reception. *R A* indicates the receiving antenna connected to circuit *R I* functioning as an interrupter and from thence to receiving apparatus which may transmit the signal energy to a line wire telephone circuit *L*. *T A* represents the transmitting antenna connected to circuit *T I* which also functions as an interrupter and from thence to a suitable modulator *M* and source of continuous wave energy *S* with the line wire system *L*. An oscillator *O* generates an oscil-

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*Received by the Editor, January 5, 1923.

lating current which is passed thru a distorting circuit *D T* and is then alternately superposed on the two interrupters *T I* and *R I*. If a wave of proper polarity is superposed on the normal potential of the grid circuit of the tube *T I*, the tube may be caused to operate upon the straight amplifying portion of its characteristic during the flat topped interval of the supplied wave, so that the modulated radio frequency will be freely transmitted thru the interrupter *T I* to the antenna *T A*. The tube *R I* will at the same moment have a pulse of current supplied to its grid, of such a character as to prevent transmission. The next succeeding half-wave will be in the opposite direction, however, and will shift the operating point of the tube *R I* to the amplifying portion of its characteristic, so that the received radio oscillations will be free to be passed thru the interrupter and impressed upon the detector *D*. Transmitting and receiving will, therefore, take place alternately at a high frequency rate determined by the frequency of the oscillator *O*.

1,434,064—A. Monteilhet, filed September 15, 1913, issued October 31, 1922.

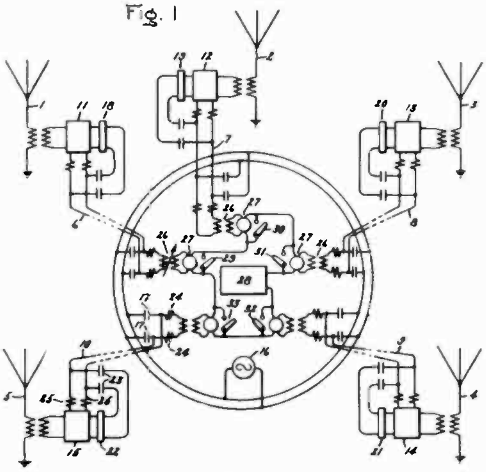
METHOD OF AND APPARATUS FOR FACSIMILE TELEGRAPHY, in which synchronized means are provided for periodically varying the local circuit of both the transmitter and receiver with means for sending a signal energy impulse of constant value from the transmitter to the receiver at the time the transmitter energy reaches a predetermined value. A galvanometric optical receiver is employed for the reception of cliches, reliefs, photographs, and the like transmitted.

1,434,707—E. W. Kellogg, filed April 21, 1921, issued November 7, 1922. Assigned to General Electric Company.

RADIO RECEIVING SYSTEM, in which a plurality of receiving antennas are located at widely separated points having their receiving circuits interlinked by line wires with a central receiving station to which the signals may be conveyed and read. The transmission lines connecting the several receiving stations with the central station serve to transmit the local generator frequencies for each of the receivers from a single generator at the central station.

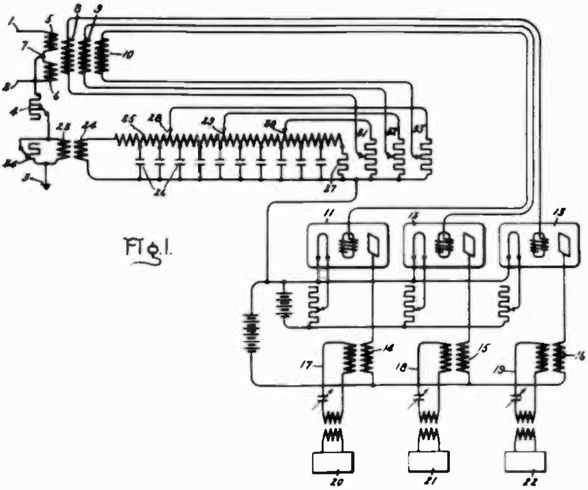
1,435,009—E. W. Kellogg and C. W. Rice, filed April 27, 1921, issued November 7, 1922. Assigned to General Electric Company.

Fig. 1



NUMBER 1,434,707—Radio Receiving System

FIg.1.



NUMBER 1,435,009— Radio Receiving System

RADIO RECEIVING SYSTEM employing a plurality of receiving sets connected to an antenna system at selected points along the antenna whereby disturbing signals do not interfere with reception in the different receivers. The antenna is aperiodic, so that the strength of the signaling currents produced therein is substantially independent of the wave length. Incoming signals are impressed upon the input circuits of a plurality of electron discharge amplifiers at potentials produced in the antenna at different selected points. In order to improve the reception, means are provided for impressing upon each of these input circuits a current selected from another point in the antenna which will be of the proper intensity and phase to neutralize in each receiving set disturbing currents produced therein either by interference from undesired waves or by strays. Each of the output circuits of the amplifiers has associated therewith a resonant circuit which is tuned to the frequency of one of the signaling waves which it is desired to receive, and these resonant circuits are associated with the respective receiving sets.

Reissue 15,495—I. Langmuir, filed January 29, 1920, issued November 21, 1922. Assigned to General Electric Compant.

"WIRELESS" SIGNALING SYSTEM. This patent relates to a heterodyne receiver employing an electron tube circuit with a coupling between the grid and plate circuits, one of the circuits being resonant, whereby local oscillations may be produced of a different frequency from that of the oscillations to be received. Each of the circuits are coupled with the antenna system. This patent was originally granted as 1,313,093, dated August 12, 1919, on an application filed March 11, 1916.

1,435,455—H. P. Donle, filed February 2, 1920, issued November 14, 1922. Assigned to the Connecticut Telephone and Electric Company, Incorporated.

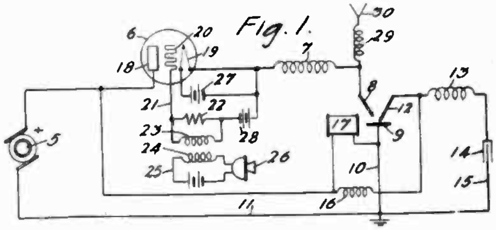
ELECTRIC CURRENT CONTROLLING DEVICE in the form of a tube construction having a filament contained within an exhausted vessel and two outer electrodes spaced apart on the outer surface of the tube, one serving as an anode or plate and the other as a control electrode.

1,435,941—J. Robinson, filed November 12, 1918, issued November 21, 1922.

RADIO DIRECTION FINDER in which a pair of coils in vertical planes are set at an angle to one another, preferably at a right angle, and are rotated about a vertical axis until no appreciable difference in strength of signal is found, when the effect of that coil lies at right angles to the direction of arrival of the waves, the bearing of which is desired, is superposed positively or negatively upon the effect of the other coil. The bearing can then be determined by the position of the first coil. A switching arrangement is provided so that one coil may be temporarily cut out and an equivalent inductance inserted in the circuit.

The invention is illustrated in connection with a direction finder installation in the fuselage in an aircraft.

1,436,252—R. A. Heising, filed December 27, 1918, issued November 21, 1922. Assigned to Western Electric Company, Incorporated.



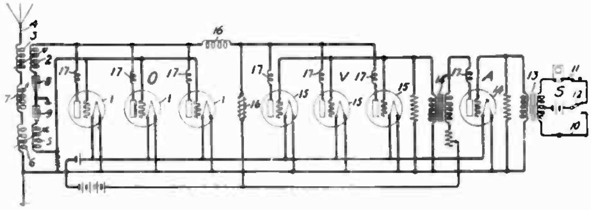
Number 1,436,252—System for Producing Modulated Waves

System for Producing Modulated Waves, utilizing an arc generator for telegraphy. An electron tube is connected in circuit with the arc system. Referring to the drawing, the generator 5 supplies a direct voltage to the circuit 15 and condenser 14 which periodically discharges across the electrodes 9 and 12 and causes simultaneous discharge across the electrodes 8 and 9. The amplitude of the discharge across the electrodes 8 and 9 will depend largely upon the instantaneous condition of the device 6. Thus while the amplitude of the discharge may be made to vary, the frequency thereof will remain substantially constant. Altho the discharge across electrodes 9, 12 may consist of a small amount of energy, it may serve to control the discharge of a much larger amount of energy across the electrodes 8, 9. The device 6 acts as an amplifier and reproduces in amplified form the impedance changes in or the current changes thru the device 26.

1,436,676—M. H. Petersen, filed October 21, 1921, issued November 28, 1922.

System for "Wireless" Transmission of Writing, Pictures, and the Like, in which part of the current circuit of an alternating current generator connected to the transmission leads is short-circuited by means of a contact arrangement, which is so actuated by means of the writing at the sending station that the short-circuiting is started or interrupted by means of a contact needle passing over the written lines. The received oscillating current energy is combined with the energy of a separately produced auxiliary current the frequency of which is slightly different from the frequency of the received current, producing a beat frequency operating an oscillograph. Another beat frequency is produced differing from the first beat frequency and the second beat frequency combined to produced synchronized mechanical movement.

1,437,021—J. C. Schelleng, filed May 11, 1921, issued November 28, 1922. Assigned to Western Electric Company, Incorporated.

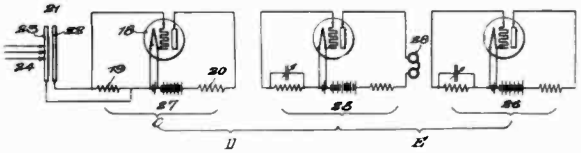


Number 1,437,021—Electron Discharge Device Circuits

Electron Discharge Device Circuits. This patent shows a circuit for an electron tube transmitter in which small inductance coils are connected in the individual plate circuits of the several vacuum tubes in the system. In the case of 50 watt tubes in parallel for radio transmission, these inductances have a value of the order of 10 microhenries. These inductances serve as choke coils for preventing the production of undesired or parasitic oscillations. In the diagram the choke coils are indicated by reference number 17.

1,437,240—E. C. Hanson and W. L. Carlson, filed May 28, 1920, issued November 28, 1922.

Fig. 2.



Number 1,437,240—Apparatus for Detecting Minute Values of Energy

Apparatus for Detecting Minute Values of Energy. This invention relates to an apparatus for detecting slight variations in frequency of an oscillating current which might be brought about by slight forces, such as light rays striking the plates of a condenser suitably connected in the oscillating circuit. The principle involved in the apparatus is the heterodyning of two or more oscillating electric currents to produce a beat, the frequency of which will be determined by the natural constants of the circuits and the external influence of a particular frequency acting upon one of the circuits. The apparatus is intended, among other things, as a measuring device for minute forces such as light rays.

1,437,400—W. W. Conners, filed June 12, 1919, issued December 5, 1922.

Method and Apparatus for Indicating the Geographical Location or Movement of Bodies, employing a similitude board on which the movement of a body in miniature at the transmitter causes a reproduction of the movement at the receiver.

1,437,498—L. De Forest, filed June 16, 1916, issued December 5, 1922. Assigned to De Forest Radio Telephone and Telegraph Company.

Oscillion, in which the filament, grid, and plate electrodes are arranged with the filament lengthwise in the tube, the grid wound around a frame which carries the filament and the plate supported on the interior of the wall of the tube surrounding but out of contact with the grid.

1,437,607—E. L. Mueller, filed November 18, 1920, issued December 5, 1922.

Electron Tube, in which a mercury arc is formed within a refractory chamber disposed within a grid electrode surrounded by a plate electrode in the usual form of an electron tube. The mercuty arc is used as a source of electrons for the purpose of avoiding the limited life of the usual filamentary cathode tube.

1,437,772—J. B. Nowland, filed June 13, 1922, issued December 5, 1922. Assigned two-thirds to Simon Bitterman.

Radio Apparatus. This invention relates to a vernier tuning coupler for a radio receiver. The coupling system is arranged with a primary winding in the antenna ground circuit and a set of two secondary windings each of which can be adjusted independently relative to the primary winding. One of the secondary windings permits a broad adjustment of coupling for tuning purposes while the other secondary winding permits a vernier adjustment of coupling whereby the secondary circuit is accurately tuned for reception of incoming signals on different wave lengths.

1,438,290—W. E. Beakes, filed July 1, 1918, issued December 12, 1922. Assigned to United Fruit Company.

AN ANTENNA SYSTEM is shown in this patent whereby an antenna conductor may be reeled on and off of a metallic drum to secure the desired period of antenna system. The antenna conductor is normally contained upon a metallic drum. One end of the conductor is secured to an insulated cord which is wrapped upon another drum. By winding or unwinding the cord different optimum length of the antenna is secured for a particular wave length.

1,438,347—R. A. Weagant, filed March 6, 1920, issued December 12, 1922. Assigned to Radio Corporation of America.

RECEIVING APPARATUS FOR RADIO SIGNALS for use with a plurality of antennas situated at a distance from each other and connected to the same receiving circuit. The system may employ large loop collectors constructed at great physical distances apart. In a system of this kind it is usual to have long horizontal leads going into the receiving station, but these leads pick up undesired signals and static. In the present invention electron tube amplifiers are arranged immediately adjacent each of the antennas for amplifying the energy received on the antenna system and conducting it to the receiving station located at a distance. The idea is to amplify the signal and static current derived from the cages so that they will be large compared with those derived from the leads. In a modified circuit the energy of each of the antennas is converted to audio frequency and then conducted over the leads to the receiver.

1,438,567—R. E. Winstanley, Jr., filed February 1, 1919, issued December 12, 1922.

RADIO SIGNALING APPARATUS in which the transmitter is controlled by an automatic circuit closer for causing the transmission of any selected number of a plurality of pre-determined signals or messages. The apparatus is particularly intended for the transmission of distress signals from ships at sea without the attention of an operator. The transmitter is contained within a cabinet which is normally closed, the apparatus therein being inoperative. When the cover of the cabinet is opened the transmitter circuit is closed and start signals are transmitted. By the movement of control switches different messages may be transmitted by the automatic circuit closer sending out such expressions as "S O S," "All is well," "Sinking," or other expressions.

1,438,969—L. R. Spengeman, filed September 17, 1918, issued December 19, 1922. Assigned to Western Electric Company, Incorporated.

VACUUM TUBE in which a resilient wire spring in the shape of a *V* with spring coils between its ends is arranged in the tube for maintaining the filament taut at all times.

1,438,988—L. Espenschied and Herman A. Affel, filed September 30, 1919, issued December 19, 1922. Assigned to American Telephone and Telegraph Company.

HIGH FREQUENCY TRANSLATING CIRCUITS for telegraphy, in which an iron core modulating device is employed having a plurality of windings. An input circuit containing a source of current of one frequency is connected with one winding on the core and a second input circuit containing a source of current of a different frequency is connected with another winding on the core. Filters are interposed in each circuit adapted to transmit only the current of the frequency generated by the source associated with the respective circuits. A third circuit containing a source of direct current is connected with a third winding with a filter interposed in the circuit. A fourth winding on the modulating device is connected with the transmitting system such as an antenna ground.

1,438,989—L. Espenschied and Herman A. Affel, filed September 30, 1919, issued December 19, 1922. Assigned to American Telephone and Telegraph Company.

HIGH FREQUENCY TRANSLATING CIRCUITS, employing an arc generator as a source of oscillations. An input circuit is arranged to modulate the oscillations of the arc circuit in accordance with voice frequencies with a filter so connected in the input circuit as to exclude therefrom undesired oscillations.

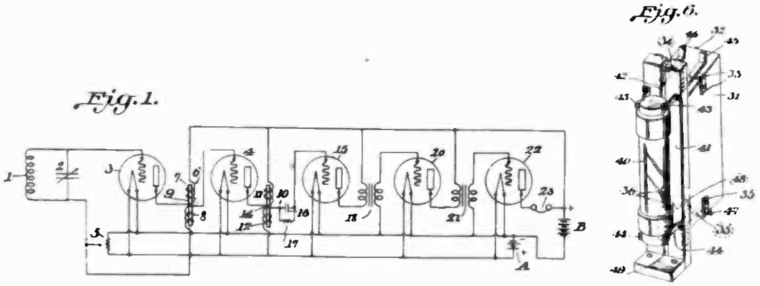
1,439,363—J. H. Hammond, Jr., filed December 13, 1919, issued December 19, 1922.

Receiving System for Radiant Energy, particularly adapted for submarine vessels. The antenna is arranged with an entering insulator with adjacent ring contacts on the insulator which when submerged in salt water establishes a circuit which renders inoperative control apparatus within the submarine. The idea is to render the control unresponsive to interfering signals which would normally be caused by salt water washing over the antenna during transmission of control signals.

1,439,495—H. M. Williamson, filed September 25, 1922, issued December 19, 1922.

Radio Receiving Apparatus, including a thermionic amplifier with a high reactance and a condenser shunted across the grid filament circuits for preventing inherent oscillations in the grid circuits.

1,439.562—P. D. Lowell, filed September 9, 1921, issued December 19, 1922. Assigned to Radio Instrument Company Incorporated.

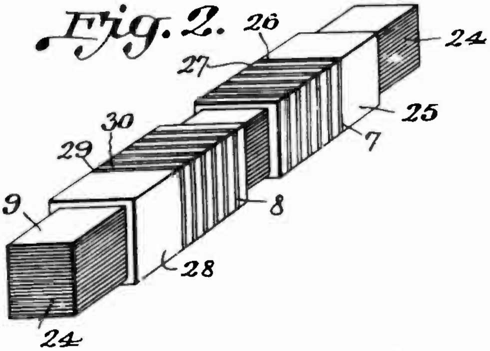


Number 1,439,562—Amplifying System

Amplifying System, comprising a plurality of electron tube stages with interchangeable coupling means between the output circuit of one tube and the input circuit of a succeeding tube whereby a coupling transformer wound for a particular band of wave lengths may be quickly removed from the circuit and a different transformer wound for a different band of wave lengths may be plugged in. The invention contemplates a series of transformers efficiently transparent to one band of frequencies while opaque to another band of frequencies which may be substituted one for another to transfer efficiently the different bands of frequencies from one electron tube stage to another.

1,439,563—P. D. Lowell, filed September 9, 1921, issued December 19, 1922. Assigned to Radio Instrument Company, Incorporated.

Fig. 2.



NUMBER 1,439,563—Radio Frequency Transformer

RADIO FREQUENCY TRANSFORMER, in which the primary and secondary windings each comprise a group of coils, each coil having a plurality of fine wire turns wound along the periphery of an insulation material and spaced from an adjacent coil, the one group of coils being spaced from the other group of coils to determine the coupling of the windings for a particular band of frequencies. The transformer is designed to operate over a limited band of frequencies. Several different transformers are provided having different coupling characteristics and arranged to be plugged in between the electron tube stages to pass the different waves of wave lengths.

1,440,142—G. Fuegel and Herman Schmid, filed December 27, 1918, issued December 26, 1922. Assigned to Apollo Magneto Corporation.

ELECTRICAL CONDENSER designed particularly for magneto installations. The condenser is supported by a binding screw passing thru one of the sets of armatures and securing the condenser unit in position within a casing.

LIST OF RADIO TRADE MARKS PUBLISHED BY PATENT OFFICE PRIOR TO REGISTRATION

(The numbers given are serial numbers of pending applications)

161,010—"MATCHED TONE" for telephone head sets. C. Brandes Inc., New York, N. Y. Claims use since about March, 1914. Published October 31, 1922.

161,028—"SIMPLEX" arranged in ornamental design—for radio apparatus. Simplex Radio Co., Philadelphia, Pennsylvania. Claims use since on or about March 16, 1921. Published October 31, 1922.

151,143—"BEACON" arranged in ornamental design—for current rectifiers, transformers and batteries. Beacon Rectifier Company, Hyde Park, Massachusetts. Claims use since January 1, 1918. Published November 7, 1922.

160,500—"RADIOBAT" arranged in ornamental design—for radio receiving apparatus. Multiple Storage Battery Corporation, Dover, Delaware, and New York, N. Y. Claims use since March 6, 1922. Published November 7, 1922.

165,194—"BESTONE" arranged in ornamental design—for radio receiving apparatus. Henry Hyman and Co., Inc., New York, N. Y. Claims use since April, 1922. Published November 7, 1922.

168,367—"RESUNDA" in ornamental letters, for radio receiving apparatus. Jones-McKee, Inc., New York, N. Y. Claims use since July 15, 1922. Published November 7, 1922.

168,368—"HY-TONE" for radio receiving apparatus. Jones-McKee, Inc., New York, N. Y. Claims use since July 15, 1922. Published November 7, 1922.

168,529—"THE CLARION" in ornamental letters—for loud speakers. Maurine W. Hirshfield, doing business as Marfield Radio Mfg. Co., New York, N. Y. Claims use since July 1, 1922. Published November 7, 1922.

168,683—"L M" in ornamental design—radio transmitting and receiving apparatus. Maline-Lemmon Laboratories, New York, N. Y. Claims use since May 5, 1922. Published November 7, 1922.

168,768—"HUSH-A-PHONE" in ornamental design—for telephone muffler. Hush-A-Phone Corporation, New York, N. Y. Claims use since March 3, 1922. Published November 7, 1922.

161,691—"LONG DISTANCE" for radio apparatus. Chicago

Radio Laboratory, Chicago, Illinois. Claims use since on or about July 1, 1919. Published November 14, 1922.

161,728—"PEERLESS" for radio apparatus. Thompson-Levering Company, Inc., Philadelphia, Pennsylvania. Claims use since January, 1909. Published November 14, 1922.

162,947—"DAYTON" for radio apparatus. The A-C Electrical Mfg. Co., Dayton, Ohio. Claims use since on or about August 1, 1922. Published December 26, 1922.

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The Supreme Insulation

Radion is a special quality of hard rubber developed exclusively for radio use. It possesses certain mechanical, electrical and other physical advantages which distinguish it as superior to other mouldable materials, of whatever nature, offered for use in the radio industry for panels or moulded parts. Exhaustive tests made at the Electrical Testing Laboratories (New York), than whom there is no more capable or unbiased authority, in competition with twelve other standard materials offered, have established the fact that—

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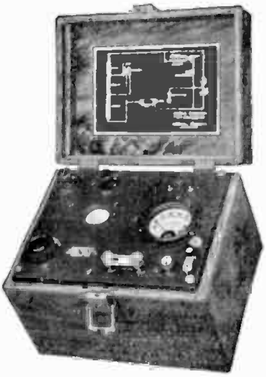

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Type 174-B

DIRECT READING WAVE METER

RANGE 150-3000 METERS

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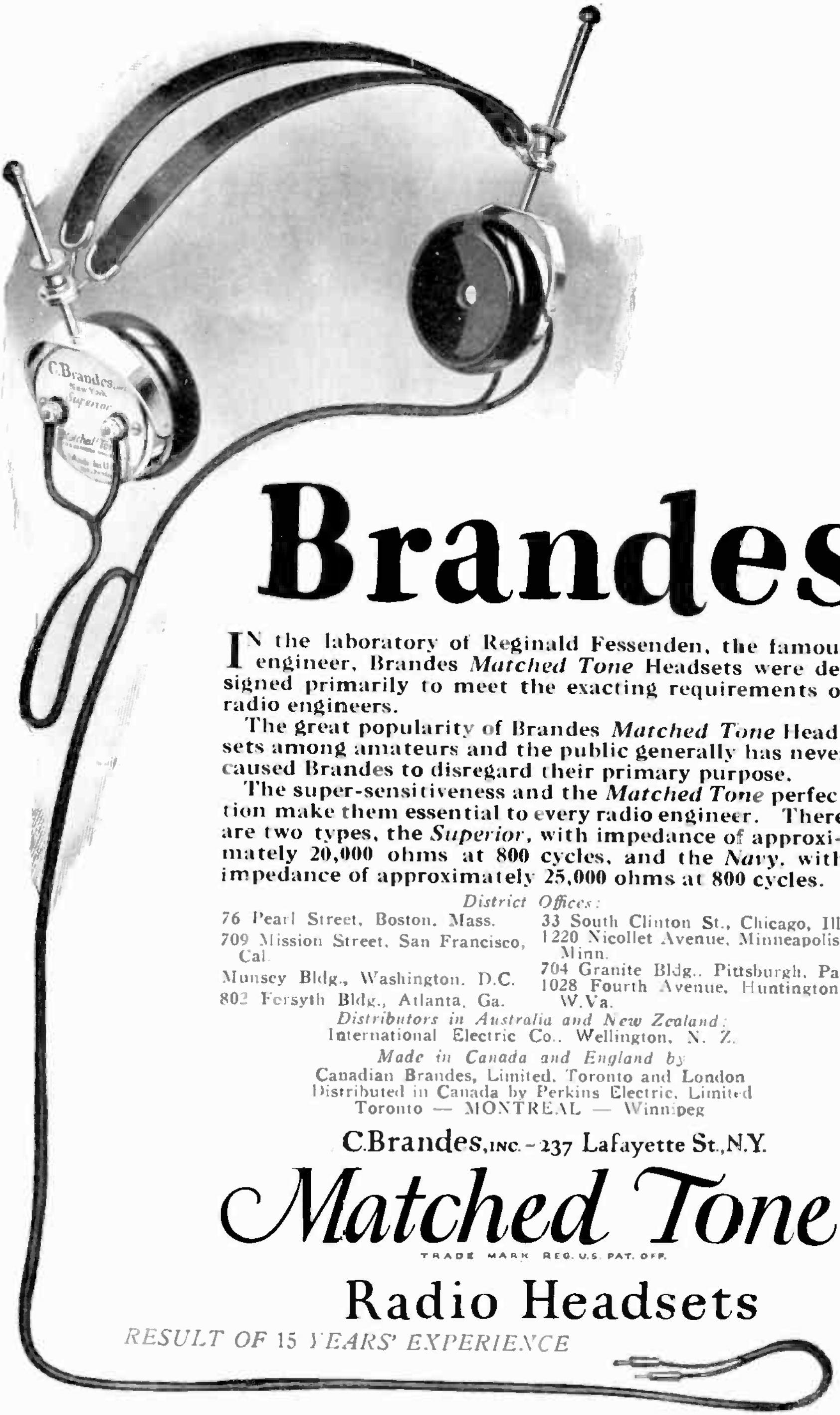

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IN the laboratory of Reginald Fessenden, the famous engineer, Brandes *Matched Tone* Headsets were designed primarily to meet the exacting requirements of radio engineers.

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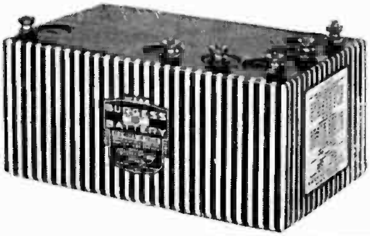

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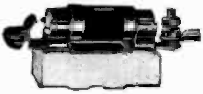

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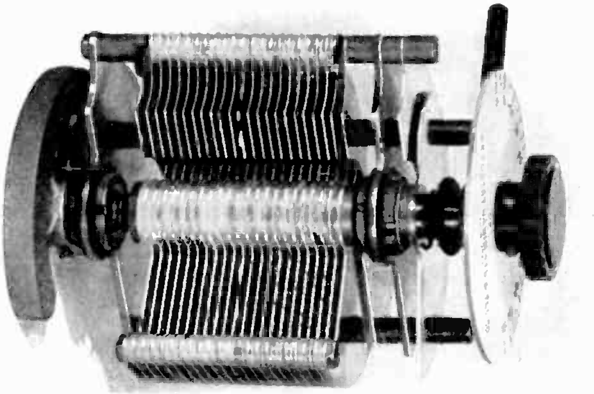

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