

## The Production of Small Variable Frequency Alternating Currents suitable for Telephonic and other Measurements

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XVIII. *The Production of Small Variable Frequency Alternating Currents suitable for Telephonic and other Measurements.* By B. S. COHEN, A.M.I.E.E.\*

[Plates XVII.-XX.]

*INTRODUCTION.*—The devices described in the latter part of this paper are the outcome of experiments carried out in the Investigation Branch of the Engineering Department of the National Telephone Company, in order to obtain suitable alternating currents both of simple and complex wave form to act as substitutes for the voice in telephonic measurements. Although primarily designed for this purpose, it is considered possible that the apparatus to be described is capable of more extended use.

A short summary of the methods known to the author of obtaining small alternating currents of the kind suitable for telephonic measurements may prove of interest as an introduction.

*Statement of the problem.*—The ordinary telephonic current is a few milliamperes at a potential of about 2 to 10 volts and is of complex wave form. The frequency of the fundamental harmonic generally lies between 100 and 300 complete periods per second, *i. e.* it varies from 100~ to 300~, the highest harmonic having a frequency of 4000~ to 5000~, although all harmonics above 1500~ are comparatively unimportant. The average frequency of the whole wave is about 800~. From consideration of these data it follows that the ideal device for supplying such alternating current is one which will give currents of any frequency lying between 100~ to 500~, singly or in combination. The output of this apparatus should be about 1 watt, and it is necessary that it should be capable of working uniformly over a fairly considerable period of time.

Simplicity and portability are also highly desirable.

*Alternators.*—A sine wave alternator coupled to a motor, the combination being capable of running at a constant speed for a considerable period, is a very useful form of apparatus

\* Read May 22, 1908.

for investigations in connexion with telephony. A suitable machine is, however, difficult to obtain.

The Western Electric Company build a machine with an output of about 30 watts at frequencies varying from 800~ to 1800~, and the wave form is stated to resemble a sine curve closely at all loads.

Messrs. Siemens and Halske also make a machine with an output of 3 or 4 watts at about the same frequencies. Both these machines are of the inductor type, the purity of the wave form being secured by the shape of the teeth and pole faces.

Mr. Duddell's work with high frequency alternators is well known. He has also made several medium frequency machines, one of which, with a wound rotor, gives an output of about 20 watts, but only runs up to about 500~.

In the Investigation Department of the National Telephone Company we have built a small alternator of the inductor type on the lines of the Siemens machine. This is illustrated in Pl. XVII. fig. 1.

With a 30 volt battery connected to the field windings, the output is only about 3 watt, but the wave form is fairly good, *i. e.* it approximates to a sine wave. By decreasing the air gap, the output can be considerably increased at the expense of the purity of the wave form.

With the best air gap (about 0.15 mm.) the P.D., which is independent of the frequency, is 10.5 volts.

Fig. 2 (Pl. XVII.) shows the wave form of this machine when the frequency is 800~. Measurements of the capacity of small mica condensers made with the current from this alternator on the assumption that it is a pure sine wave, are accurate to within about 3 per cent., and this forms a very good test.

For more accurate measurements this machine has been used with a wave filter, consisting of series inductances of low effective resistance and parallel capacities, similar to that described by G. A. Campbell (Phil. Mag. March 1903). The wave form when at a frequency of 800~ this filter is used is shown in fig. 3 (Pl. XVII.).

*Humming Telephone.*—The interaction between a receiver and a transmitter setting up an alternating current whose frequency depends on the free period of the apparatus

can be utilized. The method, however, is untrustworthy, and the output small.

The wave form is also far from sinusoidal, as might be expected when it is considered that it is influenced by the action of the polarized electromagnet in the receiver. Fig. 4 (Pl. XVII.) shows the wave form using the local battery type of telephone instrument.

Mr. A. Campbell's modification of the humming telephone consists of a steel bar with a free period of the frequency desired, and this is set in motion by a polarized electromagnet, which has attached to it a light microphone, which maintains the interaction and supplies current to the external circuit through a transformer. This apparatus is more reliable than the humming telephone. The output, however, is limited by the transmitter, and the wave form is similar to that of the ordinary humming telephone\*.

*Organ Pipes etc.*—Organ pipes, other wind instruments, and tuning forks sounding in transmitters, were experimented on for a short time, and might under certain conditions give satisfactory results. It is difficult to avoid trouble, however, with all such arrangements, owing to irregularities introduced by the transmitters and to their limited output.

*Vibrating Wire Interrupters.*—The vibrating wire interrupter described by Wien, Orlich, Campbell, and others, has when suitably modified given very satisfactory results, and I propose to describe a special form of this apparatus†. It has been found very difficult to construct a vibrating wire which will run reliably at a frequency much above 300~, and I have been unable to find references to wires which could be maintained in vibration at a frequency higher than 500~. The output is also very limited, and the frequency difficult to determine and vary.

\* For further particulars of these devices see Note by R. Appleyard, *Elect. Rev.* pp. 57 & 656, vol. xxvi. 1890; Paper on Humming Telephones, F. Gill, *Journal I. E. E.* vol. xxxi. 1901; A. Campbell, *Proc. Royal Soc.* p. 208, June 12th, 1906; J. E. Taylor, *Journal I. E. E.* p. 396, vol. xxxi. 1901; F. Dolezalek, *Zeitschrift für Instrumentenkunde*, p. 240, Aug. 1903.

† (1) Max Wien, *Wied. Ann.* xlii. p. 593 (1891).

do. do. xliv. p. 681 & p. 689 (1891).

(2) Orlich, *Electrotechn. Zeitsch.* vol. xxvi. (1903).

In order to overcome these drawbacks the instrument illustrated in fig. 5 (Pl. XVIII.) has been designed. The upper figure shows details of mercury cups and electromagnet, and the lower figure gives a general view of the whole instrument. The wire is steel, 1.06 mm. in diameter, and supports a soft iron armature which is maintained in vibration by an electromagnet with a laminated core of stalloy, which is an alloy of iron much used in electrical work, a mercury cup and a platinum wire contact. The wire is provided with a tension adjuster, and will run steadily at frequencies varying from 100~ to 250~.

The frequency of the alternating output is quite independent of the wire frequency, and is obtained by means of a separate circuit, mercury cup, and contact. The mercury cups are made from glass tube 4 mm. in internal diameter, and these are enclosed in brass tubes to which the mercury is connected by means of a platinum wire fused into the glass.

The cups thus made slip into brass adjustable carriers from which they can readily be removed for cleaning purposes, and the carriers admit of a fine vertical adjustment.

Experiments have been made with cups of varying diameter. Those with the smallest diameters gave the best results.

It would appear that the mercury in the small cups remains much steadier under the action of the vibrating contact than in those of larger diameter, owing possibly to the greater surface-tension effect.

*Single Action Circuit.*—Several forms of oscillating circuit have been used of which the two principal ones may be described as “single action” and “double action” respectively.

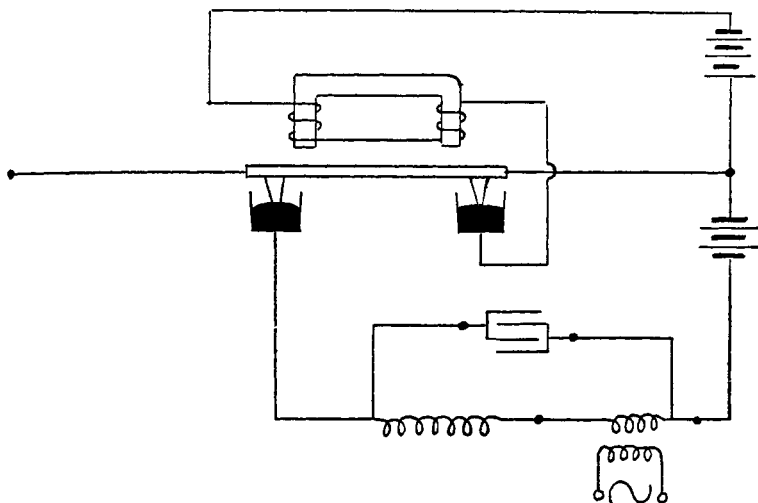
Fig. 6 shows the single action circuit and also the wire driving circuit. The latter requires no explanation. The former consists of a platinum contact and mercury cup which in the make contact position connects a battery to a capacity in parallel with an inductance and transformer primary.

On the break between the cup and contact an oscillation occurs in the circuit.

By this method a series of damped trains of oscillations of

any frequency can be produced, the trains following each other with the frequency of the wire vibrations.

Fig. 6.—Single Action Circuit.



*Theory of Action.*—Oscillations will occur when  $\frac{R^2}{4L} < \frac{1}{K}$ , their frequency being given by  $\frac{1}{2\pi} \sqrt{\frac{1}{LK} - \frac{R^2}{4L^2}}$ . With the values of  $L$ ,  $K$  and  $R$  used, the last term can be neglected and formula becomes  $\frac{1}{2\pi} \sqrt{\frac{1}{LK}}$ .

The total output in watts, excluding all losses, will be the energy stored, divided by the interval of time between each succeeding train of waves.

The equation to the line joining the peaks of the damped waves is  $Y = e^{-\frac{aR}{2L}}$ , so that for small damping  $L$  must be large and  $R$  small, which also gives the maximum output.

In one of the circuits used the inductance is .037 henry, and its effective resistance which is practically invariable over the range of frequency used is 10 ohms. (These figures include the resistance and inductance of the primary of transformer.)

Fig. 7 (Pl. XVIII.) shows an oscillogram of damped wave trains produced in the manner just described.

The three frequencies are 490~, 959~, and 2880~ produced by using the three capacities, 2.88 mfd, .8 mfd, and 1 mfd respectively.

The frequency of the vibrating wire was 90~ in all three cases. It will be observed that only part of a complete train is utilized in the lower frequency waves.

*Problem of Output.*—The transformer used in this circuit is a small one of the telephone type, with a few turns and a somewhat loose coupling. By reason of this, variations in the frequency and damping of the output caused by variations of the load on the secondary affecting the effective self-induction of the oscillating circuit are rendered small, but at the same time the output is reduced.

In cases where the load is constant it is possible to use a more efficient transformer and so obtain a considerable increase in the output.

It is worthy of mention that in the apparatus as constructed, the chief storage of energy occurs in the coil and not in the condenser. The single action circuit has proved of value for telephonic purposes.

*Double Action Circuit.*—The double action circuit previously referred to is illustrated in fig. 8.

This circuit, unlike the single action one, gives a pronounced oscillation on the make contact, as well as on the break.

On referring back to fig. 6 it will be seen that no oscillation can occur on the make contact as the battery short-circuits the oscillating circuit during that period.

By introducing resistance into the battery circuit, however, an oscillation on the make contact can be obtained in addition to the break oscillation. This oscillation is of the frequency of the main oscillating circuit.

Although the results might have been predicted theoretically, the following series of oscillograms (Pl. XIX. fig. 9) are inserted as they show in a rather interesting manner the effect of insertion of resistance.

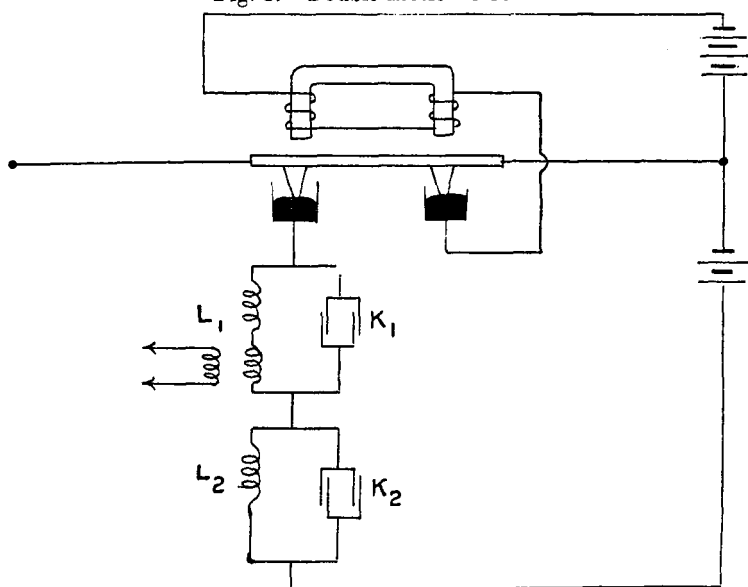
This series shows the variations obtained in the make contact oscillations in a circuit as shown in fig. 6, when the resistance in series with the battery (which is of negligible internal resistance) is varied from 4000 to 0 ohms.

The make oscillation is most evident when the resistance is reduced to 1000 ohms.

At 300 ohms the oscillation begins to appear during the current rise on the make contact, whilst at 100 ohms the oscillation is entirely confined to the rise during the make contact.

The resistance is still large enough to cause the current to rise very quickly to its maximum value, thus giving a nearly square shouldered wave.

Fig. 8.—Double Action Circuit.



As the resistance is still further reduced the current takes longer to rise to its maximum value and at the same time the oscillation is reduced, until ultimately at 0 ohms the familiar current rise curve with no superimposed oscillation is produced.

In the double action circuit as illustrated (fig. 8) a capacity shunted by an inductance is introduced in place of the simple resistance. This somewhat modifies the action of the circuit. If the inductance  $L_2$  is inserted as shown in the figure and the capacity  $K_2$  omitted, the effect is to give



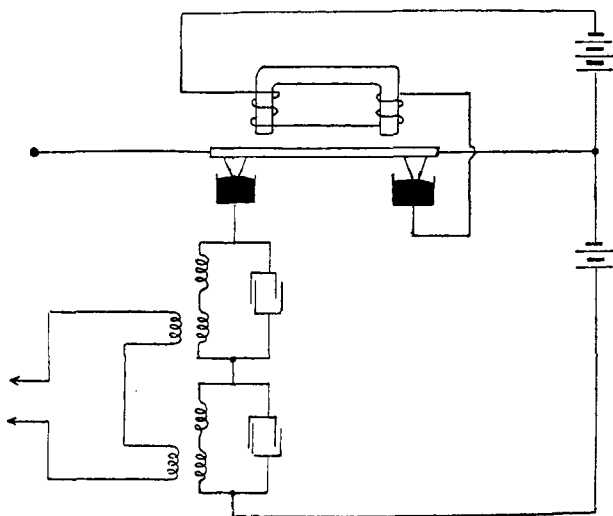
an oscillation on the make contact, the frequency of which is determined by the combined inductance of  $L_1$  and  $L_2$  and the capacity  $K_1$ . When the capacity  $K_2$  is added a similar effect is produced. The resulting make frequency being due to the combined effect of both inductances and capacities. The break oscillation will be that due to  $L_1$  and  $K_1$  only.

Fig. 10 (Pl. XIX.) shows two waves produced by this circuit. The following small table gives the necessary data:—

Wave.	Values of				Frequency of oscillation :	
	$L_1$ henrys.	$L_2$ henrys.	$K_1$ mfd.	$K_2$ mfd.	make contact.	break contact.
<i>a</i> .....	·037	·037	1·67	·167	1020~	715~
<i>b</i> .....	·037	·037	·167	1·67	1020~	2160~

*Double Action Circuit with two Transformers.*—By inserting a second transformer in circuit as shown in fig. 11, two

Fig. 11.—Double Action Circuit with Two Transformers.



separate and distinct oscillations can be obtained. If the circuits are similar two separate waves will be produced the shape of which will be exactly similar.

By joining up the two secondaries so that these two waves either assist or oppose each other, some interesting results are obtained.

Fig. 12 (Pl. XIX.) shows two 900~ break oscillations assisting one another. The make oscillations oppose each other and are therefore wiped out, the result being to give a wave exactly similar to that obtained with the single action circuit, but with about double the amplitude.

When the secondaries are joined up so that the break oscillations oppose each other, whilst the make oscillations assist, the result, if these oscillations are equal in frequency but unequal in amplitude, is to give a continuous and more or less uniform wave.

The first wave in fig. 13 (Pl. XIX.) shows the effect of opposing two 850~ oscillations, and the second the effect with two 490~ oscillations. The continuous waves resulting are 850~ and 490~ respectively.

The regularity of the continuous wave can be best modified by slightly varying one of the inductances, which have air cores by inserting in the cores one or two strands of fine iron wire.

It is obvious since the output depends on the difference between the two circuits that it will not be large. To increase the output, different inductances for each of the two circuits can be used, and the capacities adjusted so as to get the same frequency in each circuit.

It is of course impossible to obtain a pure sine wave by this method, and the extent of the impurity has not yet been examined analytically. Some tests have, however, been made by using these waves for measurement purposes. These are given further on.

*Complex Wave Form.*—It is worth noticing that a number of double action circuits can be operated by means of a single mercury-cup and contact. From fig. 11, it will be seen that any number of oscillating circuits can be joined in series. The oscillations which ensue on break are quite independent, each having the frequency of its particular circuit.

The make oscillations will depend on the total capacity and inductance of all the circuit.

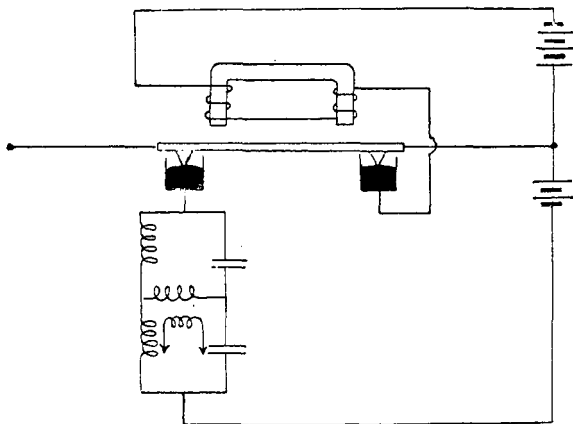
The secondaries of the transformers can be joined up in

series or in parallel to suit the external circuit conditions, and can also be joined to oppose or assist each other. By this means complex waves of definite formation can be built up.

Fig. 14 (a) Pl. XX. shows only the make oscillations when three oscillating circuits were used, and (b) gives the resulting complex wave, including both make and break oscillations. The three break frequencies are 415~, 590~, and 1442~ respectively.

*Modified Double Action Circuit.*—Fig. 15 shows a modified form of double action circuit which has been found to give a greater output when obtaining continuous oscillations by opposition than the circuit previously described.

Fig. 15.—Modified Double Action Circuit.



The two transformers are replaced by a single one put in such a position that both oscillations pass through it.

Fig. 16 (Pl. XX.) shows continuous waves of 1020~ and 3700~ produced by this method.

The variation in the three 1020~ waves shown are produced by the insertion of iron in the core of one of the inductances.

(a) No iron.

(b) One strand, } No. 22 S.W.G. Soft Iron Wire.

(c) Two strands, }

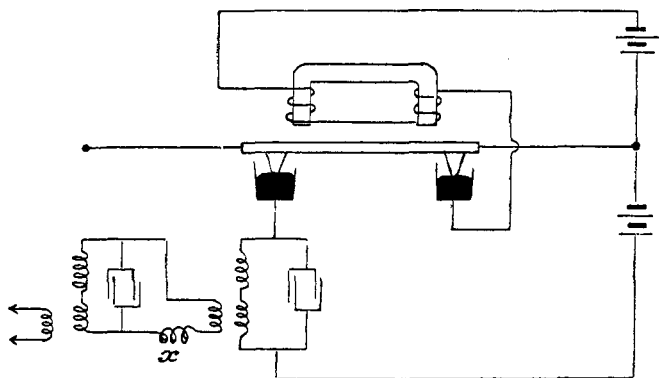
*The effect of superimposing an Oscillation on an Oscillatory Circuit of similar period.*—If the oscillations produced by

one circuit are superimposed on a second similar circuit, as shown in fig. 17, a continuous oscillation results.

Fig. 18 (Pl. XVII.) shows the resulting wave forms when each of the two circuits is tuned to 830~, (a) being the applied oscillation, and (b) the resultant. The *modus operandi* appears to be as follows :—

The damped oscillation applied to the second circuit causes resonance in the latter, and the oscillation set up will be in the reverse direction of the original oscillation inasmuch as it will tend to rise to a maximum whilst the latter is falling.

Fig. 17.—Continuous Oscillation Circuit.



By suitable adjustment of a series resistance, or preferably an inductance placed at  $x$ , therefore, it is possible to obtain in the second transformer a wave which is the resultant of two equal and opposite trains of waves. This resultant wave is practically continuous.

*Mercury Contact effect.*—A phenomenon, in connexion with a vibrating-point contact in a mercury cup, has been noticed to which I have not been able to find any reference. I refer to a series of sparkless points which occur at regular intervals as the distance between the contact and the mercury is varied. With the vibrator described in this paper the contact point has an amplitude of motion of about 4 mm.

If the cup is adjusted whilst the contact is vibrating until the point just makes contact on the mercury surface, a spark is observed.

If then the distance between the mercury and the contact

is slowly decreased, a series of sparkless points will be reached which are very sharply defined, as when such a point is reached, a variation either way of about .07 mm. gives the sparking condition again.

The writer has not so far made any investigation into the reason for this action.

It is, however, most probable that this action is partly mechanical as at the sparkless points the vibrating surface of the mercury seems to be set in a rigid condition.

*Use of continuous Waves for Absolute Measurements.*—The wave forms illustrated in fig. 13 (Pl. XIX.), fig. 16 (Pl. XX.), and fig. 18 (Pl. XVII.) might conceivably be accurate enough for use when making absolute, as opposed to merely comparative, measurements.

The following table gives some results arrived at by measuring the current and p.d. with standard condensers subjected to these waves.

Wave form used.	Frequency.	Standard Capacity tested.	Percentage error.
Wave similar to that illustrated in fig. 13 .....	1442	.167	-1.8
	854	.33	-1.7
	523	1.0	-1.0
Wave similar to that illustrated in fig. 16 (a) .....	833	.167	+3
	1442	.167	+4.2
Wave similar to that illustrated in fig. 18 (b) .....	833	.33	+2.4
	833	.167	+1.8
	1440	.167	+ .5

These results were determined by inserting a non-inductive resistance of known value in series with the condenser, taking the potential-difference across both by means of a sensitive electrostatic voltmeter, and then calculating the capacity by the formula  $A \cdot 10^{16}/pV$ , where A and V are the effective values of the charging current and potential-difference respectively. This is very satisfactory as very little time was spent in adjusting the waves.

So far as these tests go it would appear that the amount of

the departure from the sine shape in these continuous waves is comparatively inconsiderable.

*Telephonic Measurements.*—The special form of vibrating wire described was primarily designed for telephonic measurements; and although the tests carried out in this direction are far too extensive to describe in any detail in this paper, a brief outline may perhaps be given.

Telephonic measurements are now mainly carried out by expressing the attenuation of speech-waves in any line circuit or apparatus in terms of the attenuation over a given length of a certain type of cable line settled on as a standard.

It has been found that the words representing the numbers 1, 2, 3, 4, 5, embody all the frequencies of telephonic importance, and these numbers are invariably used for testing purposes.

Inspection of the oscillograms of these five words as spoken by a number of persons shows that they may be approximately represented by fig. 19 (Pl. XVII.), which is given by the equation

$$y = \cdot 29 \sin pt + \cdot 32 \sin 2 pt + \cdot 39 \sin 3 pt + \cdot 55 \sin 4 pt \\ + 1 \cdot 06 \sin 5 pt + 6 \cdot 5 \sin \left( 6 pt - \frac{\pi}{2} \right) - 1 \cdot 06 \sin \\ 7 pt - \cdot 56 \sin 8 pt - \cdot 39 \sin 9 pt - \cdot 32 \sin 10 pt \\ - \cdot 29 \sin 11 pt,$$

$$\text{where } p = 2\pi \times 145.$$

The general resemblance of this wave to some of those produced artificially, see figs. 7 and 12, is obvious on inspection.

It has been found that by replacing the human voice and transmitter by the vibrating wire producing these waves, and by using the correct frequencies, similar results to those produced by the voice can be obtained.

Having obtained a satisfactory substitute for the human voice, it is next necessary to replace the ear and receiver by some measuring instrument.

Simple measurements of the comparative current attenuation over the standard line and the line or apparatus under test do not give accurate results, and it was suggested by my assistant Mr. A. J. Aldridge, to whom I take this opportunity

for expressing my indebtedness for considerable help given in carrying out the investigations embodied in this paper, that direct measurements of the comparative volumes of sound issuing from the telephone receiver could be made by allowing the receiver to sound into a transmitter connected up in the usual manner to a battery and induction-coil, and to measure the current in the secondary of the induction-coil.

This method has been found to solve most of the difficulties, and with the vibrating wire at the sending end of the line and at the other end of the line a receiver sounding into a transmitter, the latter being connected to a barretter used as an alternating current milliammeter, it has been found possible to carry out comparative telephonic measurements with greater accuracy than with the voice and ear, owing to the elimination of the personal equation and the greater sensibility to volume variation of the apparatus used.

This method can be used for such diversified tests as comparison of loaded with unloaded lines, comparison of standard and non-standard apparatus, such as receivers, transmitters, induction-coils.

*Conclusion.*—Apart from telephonic measurements, the modified vibrating-wire interrupter may possibly have a field for both comparative and absolute electrical measurements, and especially for use with the vibration galvanometer. The ease with which the frequency can be varied together with the steadiness of the resulting wave and the simplicity of the apparatus are certainly great recommendations. The author must express his indebtedness to the National Telephone Co. for the facilities afforded to him, to Dr. A. Russell for great help in the revision of this paper, to Mr. A. Campbell for references to humming and vibrating wires, and a tribute must also be paid to the oscillograph which has been of such great assistance in these investigations.

#### DISCUSSION.

Mr A. CAMPBELL mentioned that with his vibrating-bar microphone hummer he had found it easy to obtain more than one frequency from the same bar by altering the supports to suitable nodal points and tuning the magnet circuit with a condenser. Harmonics of the fundamental

frequency are thus produced. He asked if any of the composite wave forms shown gave vowel sounds in the telephone.

Dr RUSSELL congratulated the Author on his interesting and valuable paper, and thanked him for the instructive demonstration he had given of methods of producing high-frequency currents suitable for telephonic and other measurements. He understood that the Author's main object was not the obtaining of currents of excessively high frequency, but obtaining currents having frequencies varying between 100 and 5000 which followed the harmonic law. Some of the methods described, in particular the Author's "double action circuit" method, seemed well adapted for this end. In some of these circuits there are two free periods of vibration, and it was exceedingly interesting to see the accuracy with which the oscillograph gave the resultant of two slightly damped trains of high-frequency waves of different periods. Tuning for resonance the Author obtains a very perfect sine wave. He thought that the thanks of the Meeting were also due to the National Telephone Company for the facilities they had afforded Mr. Cohen.

Mr. COHEN expressed his interest in Mr. Campbell's statement that it was easy to get more than one frequency from his vibrating bar hummer. The currents shown, when passed through a telephone receiver, did not produce vowel sounds.

XIX. *A Vacuum-Tube Model for Demonstrating the Propagation of Alternate Currents in Cables.* By Dr. C. V. DRYSDALE\*.

[Plates XXI. & XXII.]

As is well known, the propagation of electric waves along conductors can be conveniently shown on the small scale by means of a helix, fed from a suitable source of high frequency, high potential oscillations. In this case the helix is found to glow with brush discharges at the antinodes of potential, remaining dark at the nodes. Experiments of this kind have been shown by Prof. J. A. Fleming and by G. Seibt†. The glow is, however, very faint, and may be rendered much more visible by the use of a vacuum-tube, as Prof. Fleming himself suggests.

When experimenting lately in this direction, the present writer noticed that if a long vacuum-tube was laid parallel to

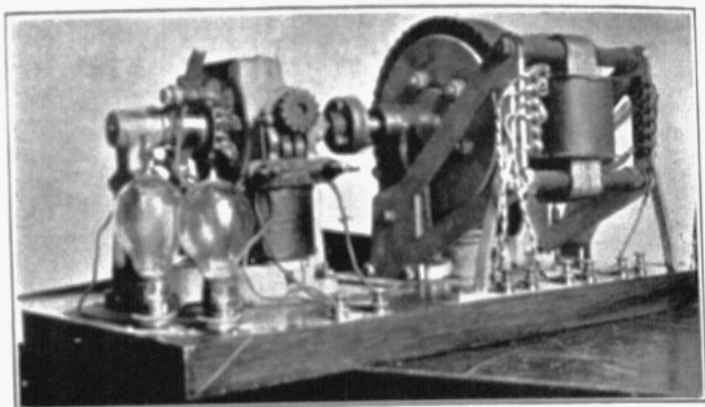
\* Read March 27, 1908.

† See 'The Principles of Electric Wave Telegraphy,' by Dr. J. A. Fleming, pp. 251-261.



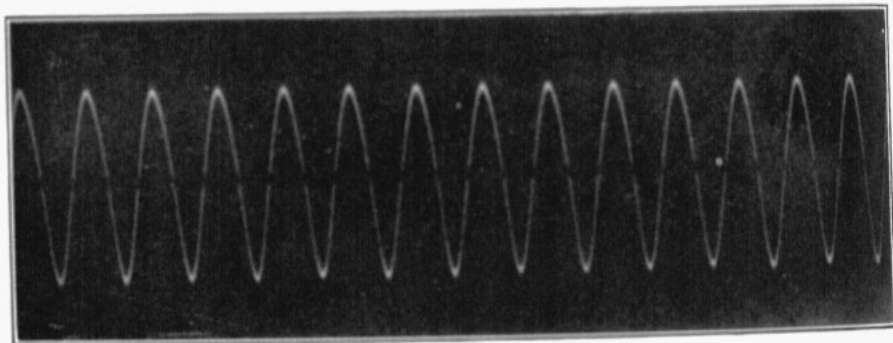
COHEN.

FIG. 1.



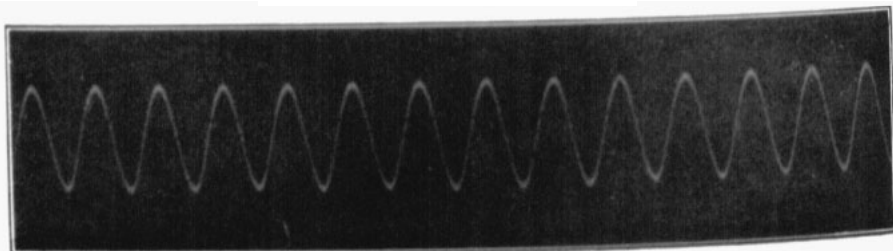
N. T. Co. ALTERNATOR.

FIG. 2.



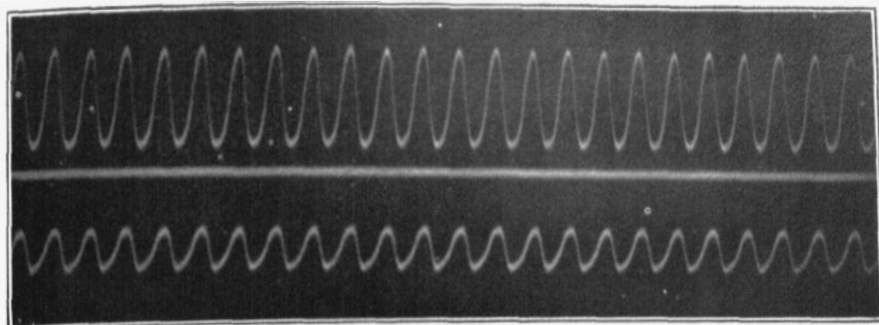
UNFILTERED WAVE.

FIG. 3.



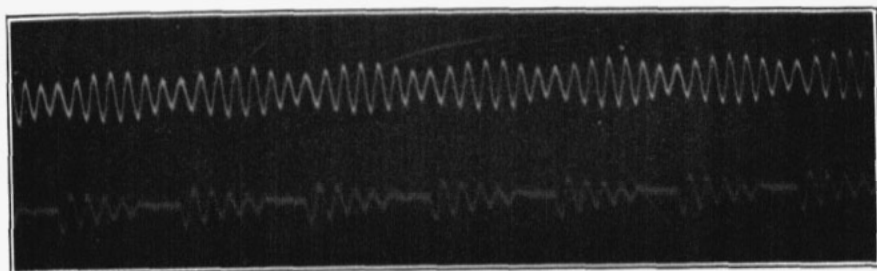
FILTERED WAVE.

FIG. 4.



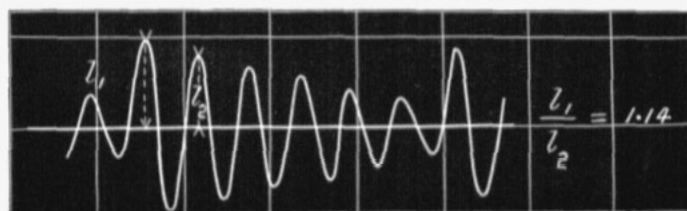
WAVES in primary and secondary of humming telephone instrument.

FIG. 18.



WAVE FORMS. Continuous oscillation circuit.

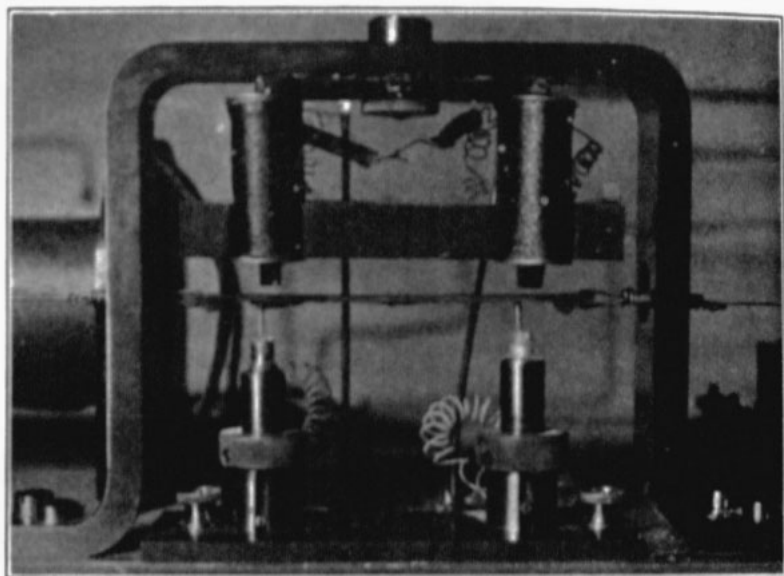
FIG. 19.



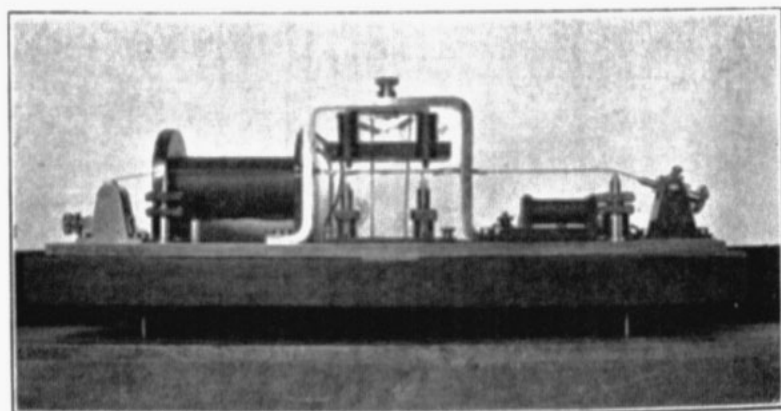
MEAN SPEECH WAVE.

CORDEX.

FIG. 5.

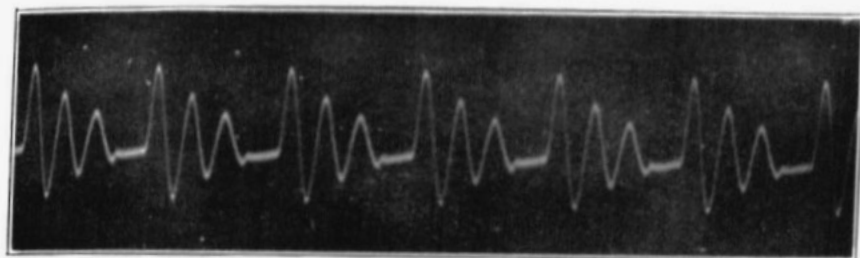


VIBRATING WIRE.  
Details of mercury cups, etc.

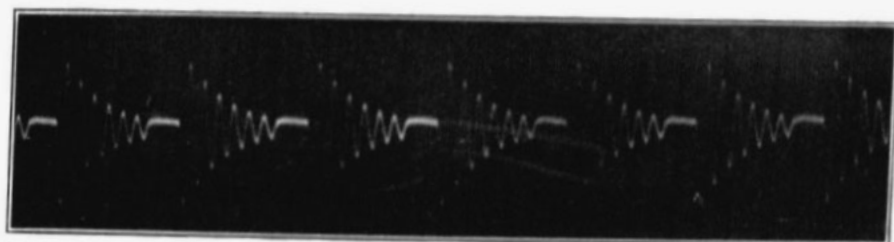


VIBRATING WIRE INTERRUPTER.  
General View.

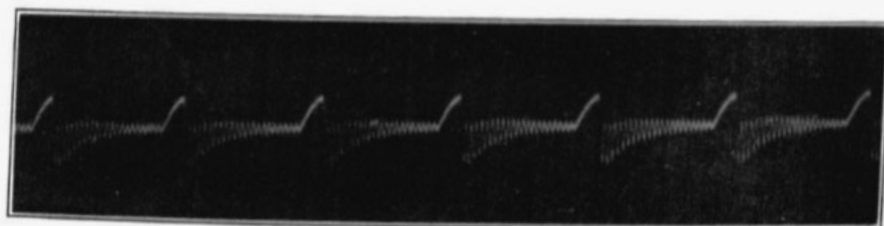
FIG. 7.



490 ~.



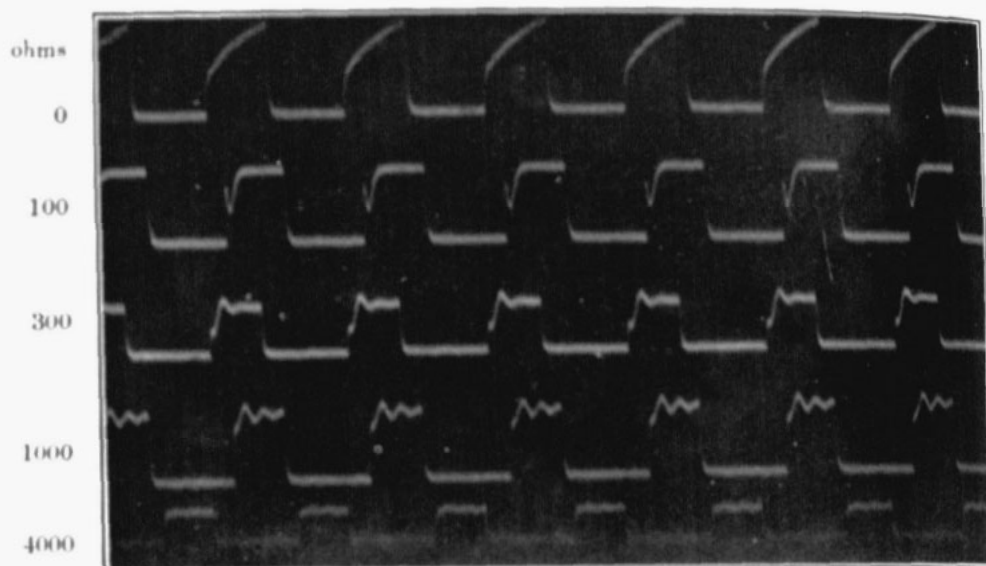
950 ~.



2880 ~.

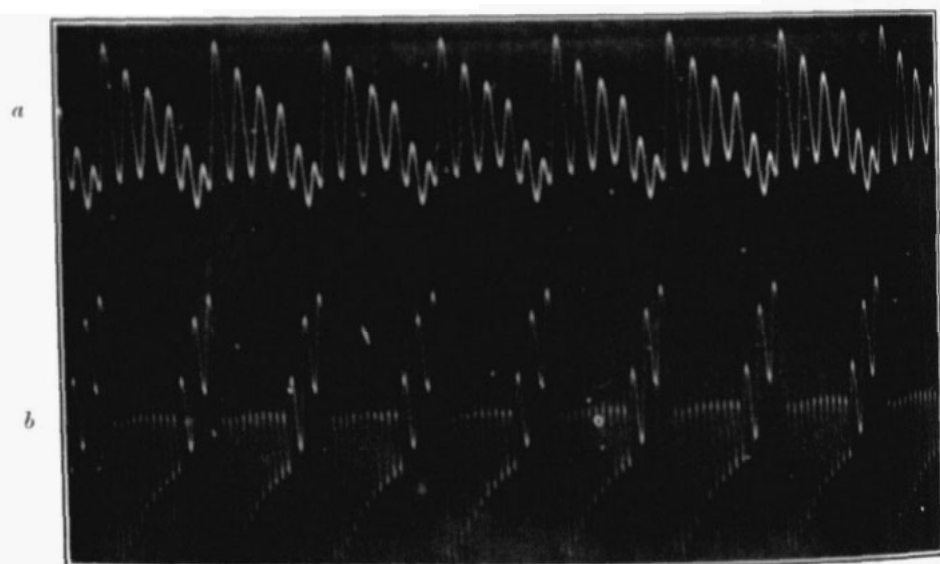
SINGLE ACTION CIRCUIT WAVES.

FIG. 9



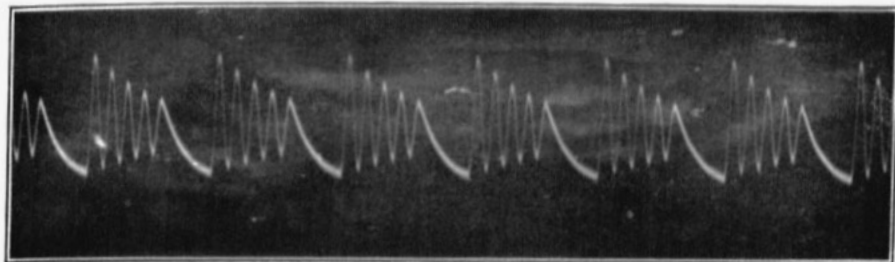
EFFECTS OF RESISTANCE IN SINGLE ACTION CIRCUIT.

FIG. 10.



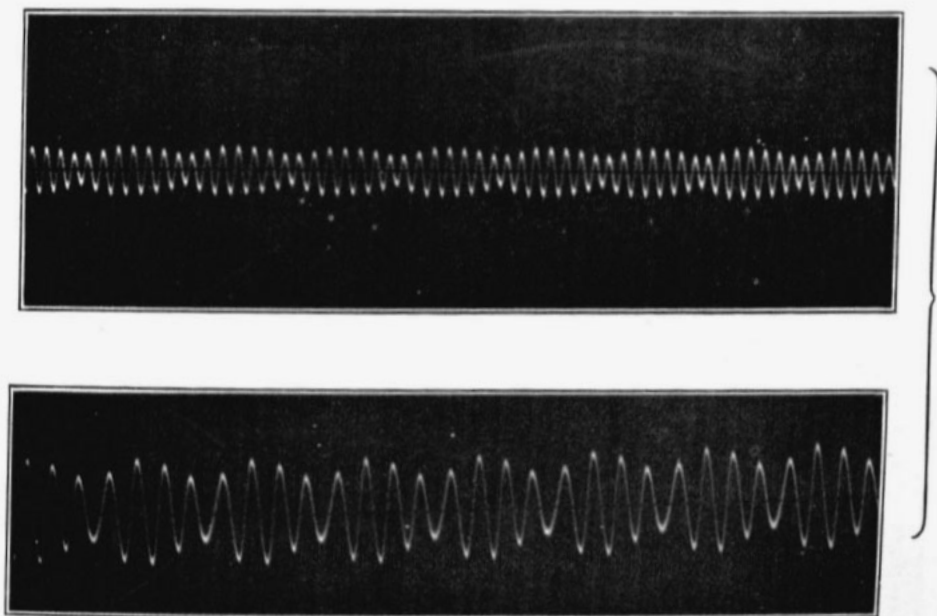
DOUBLE ACTION CIRCUIT WAVES.

FIG. 12.



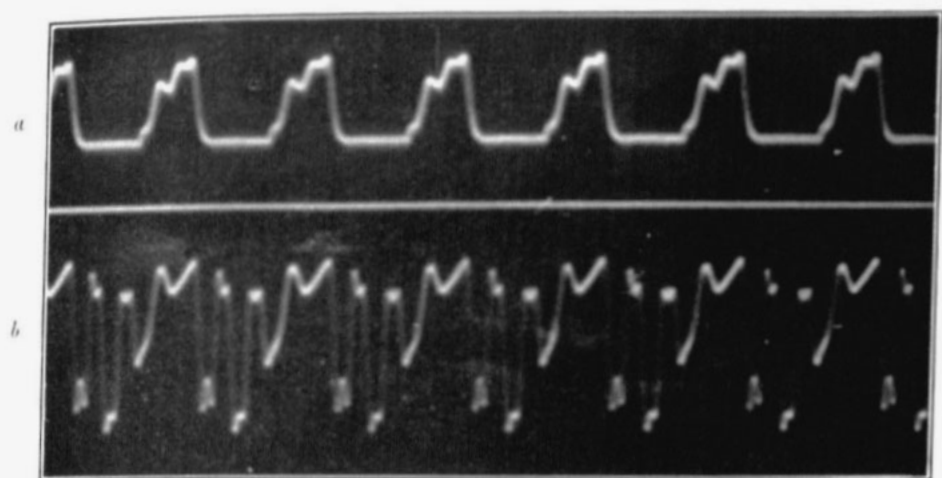
ASSISTING WAVES.

FIG. 13.



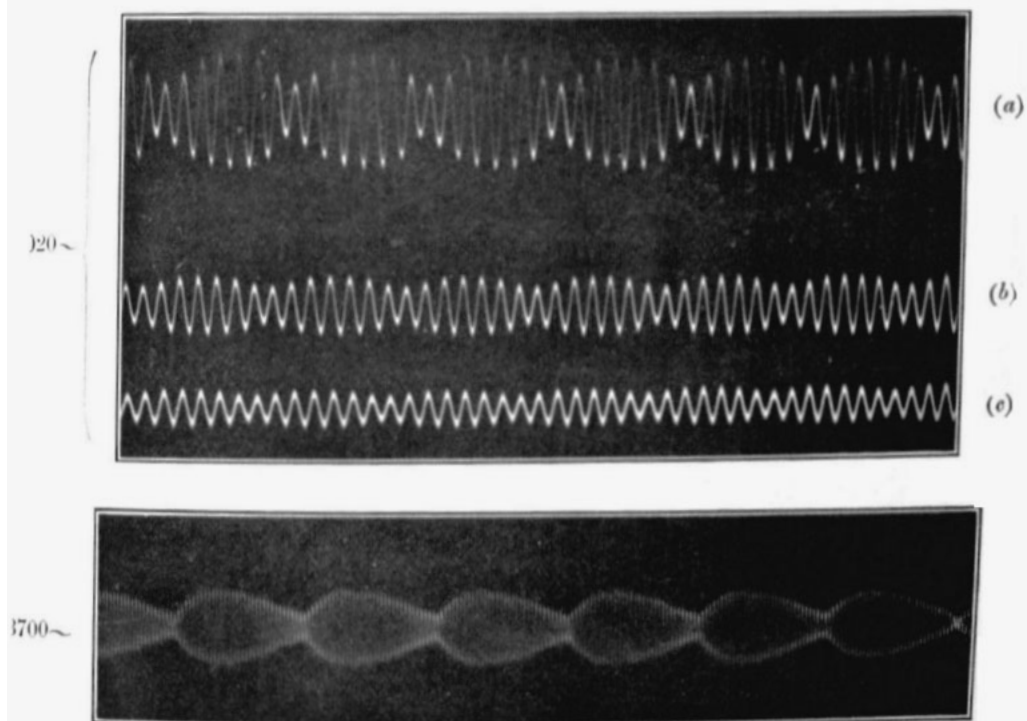
OPPOSING WAVES.

FIG. 14.



COMPLEX WAVE FORM.

FIG. 16.



WAVE FORMS, Modified double action circuit.