W. F. GRADOLPH & W. C. HAHNE.

TELEPHONE SYSTEM.

APPLICATION FILED FEB. 1, 1908.

958,868. Patented May 24, 1910.

4 SHEETS—SHEET 1.

Fig. 1

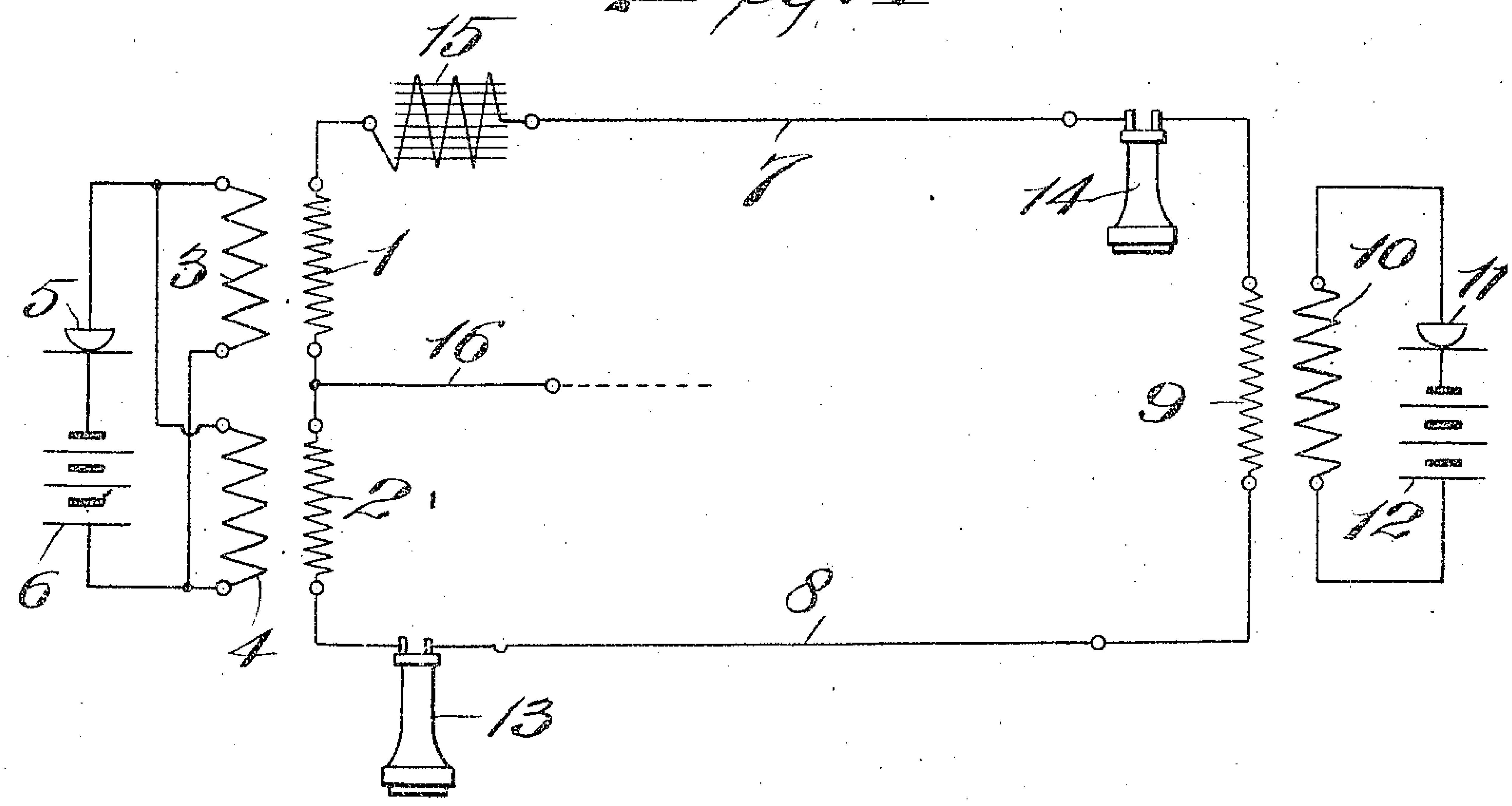
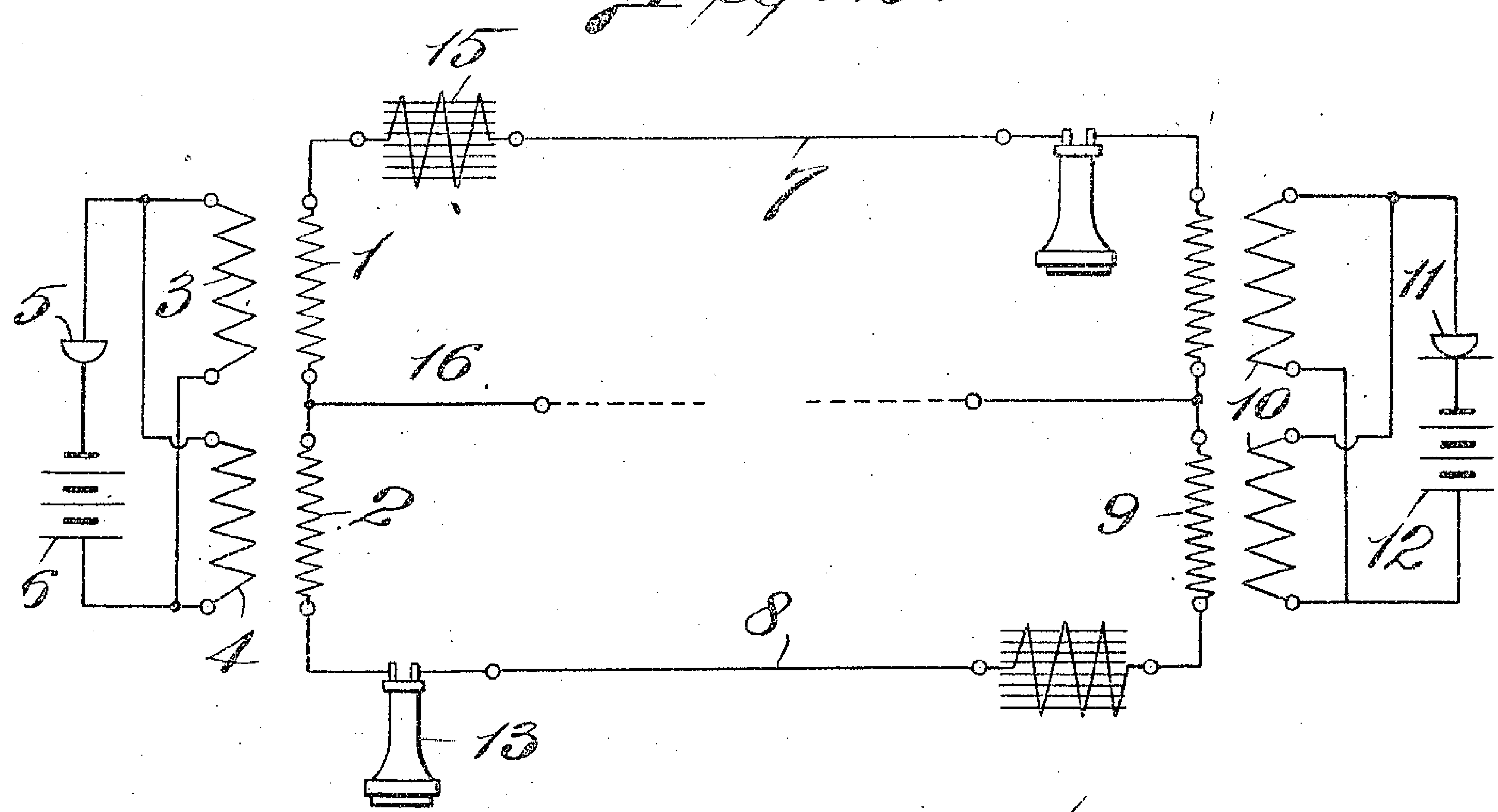


Fig. 2.



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4 SHEETS—SHEET 2.

Fig. 3.

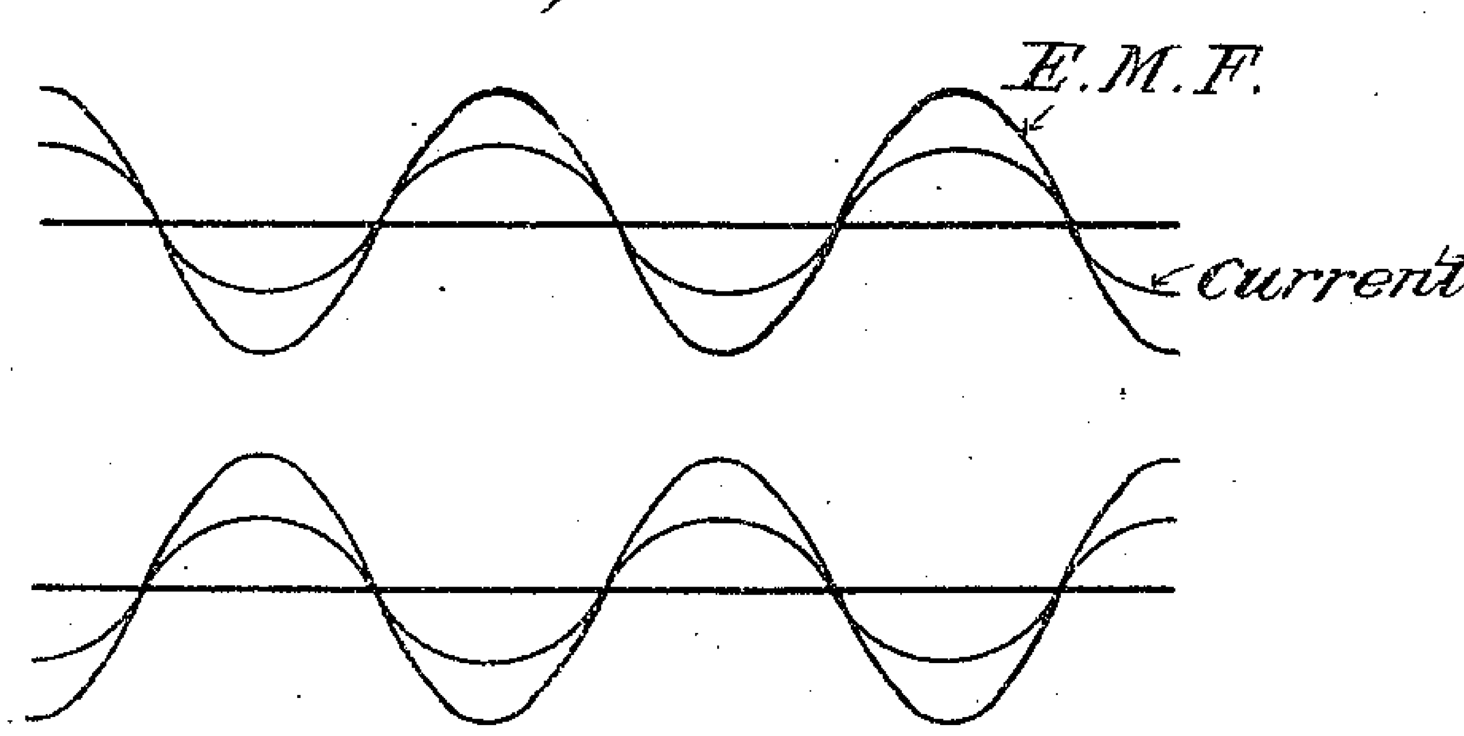


Fig. 4.

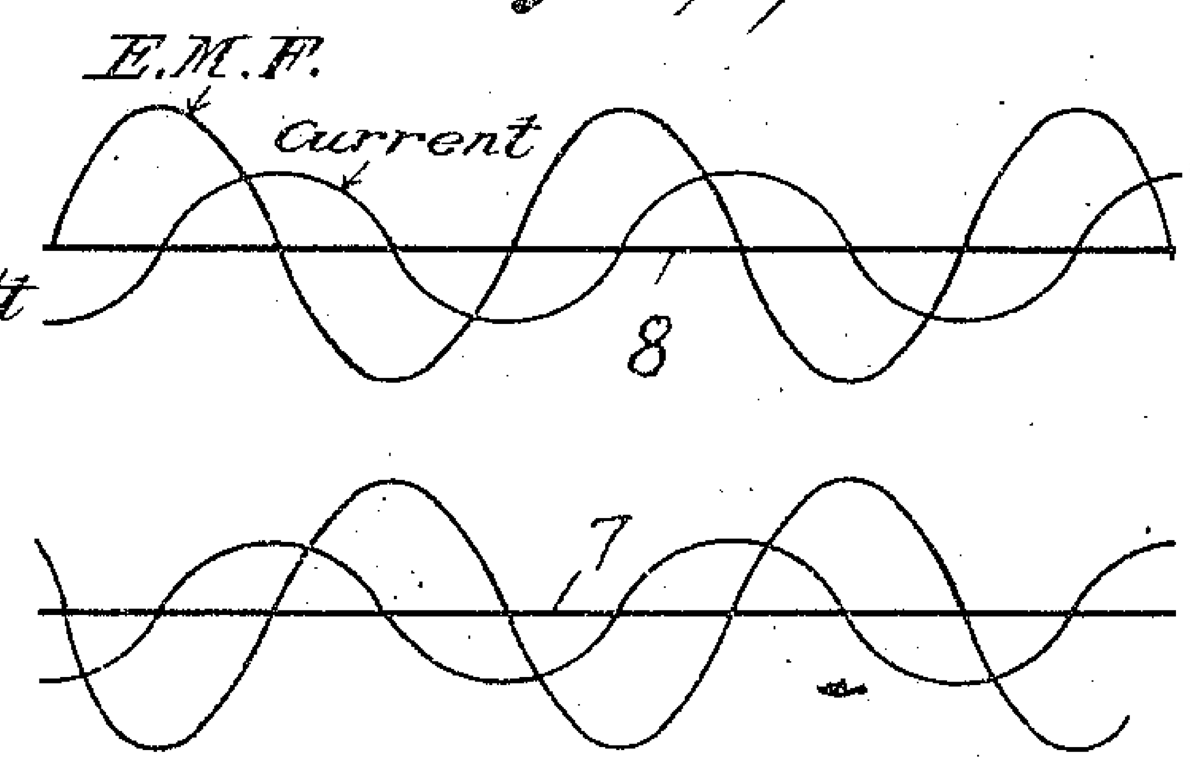
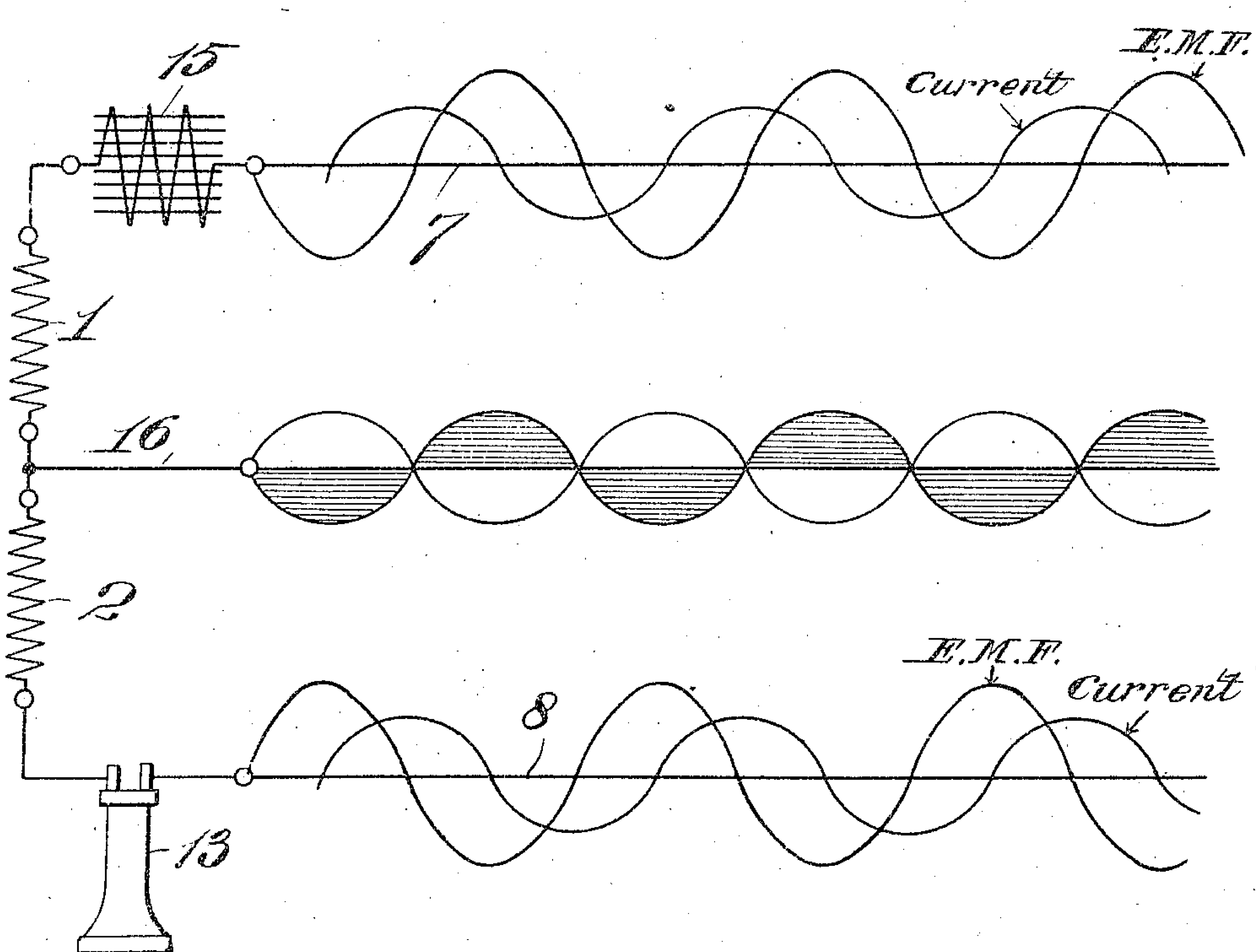


Fig. 5.



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4 SHEETS—SHEET 3.

Fig. 6.

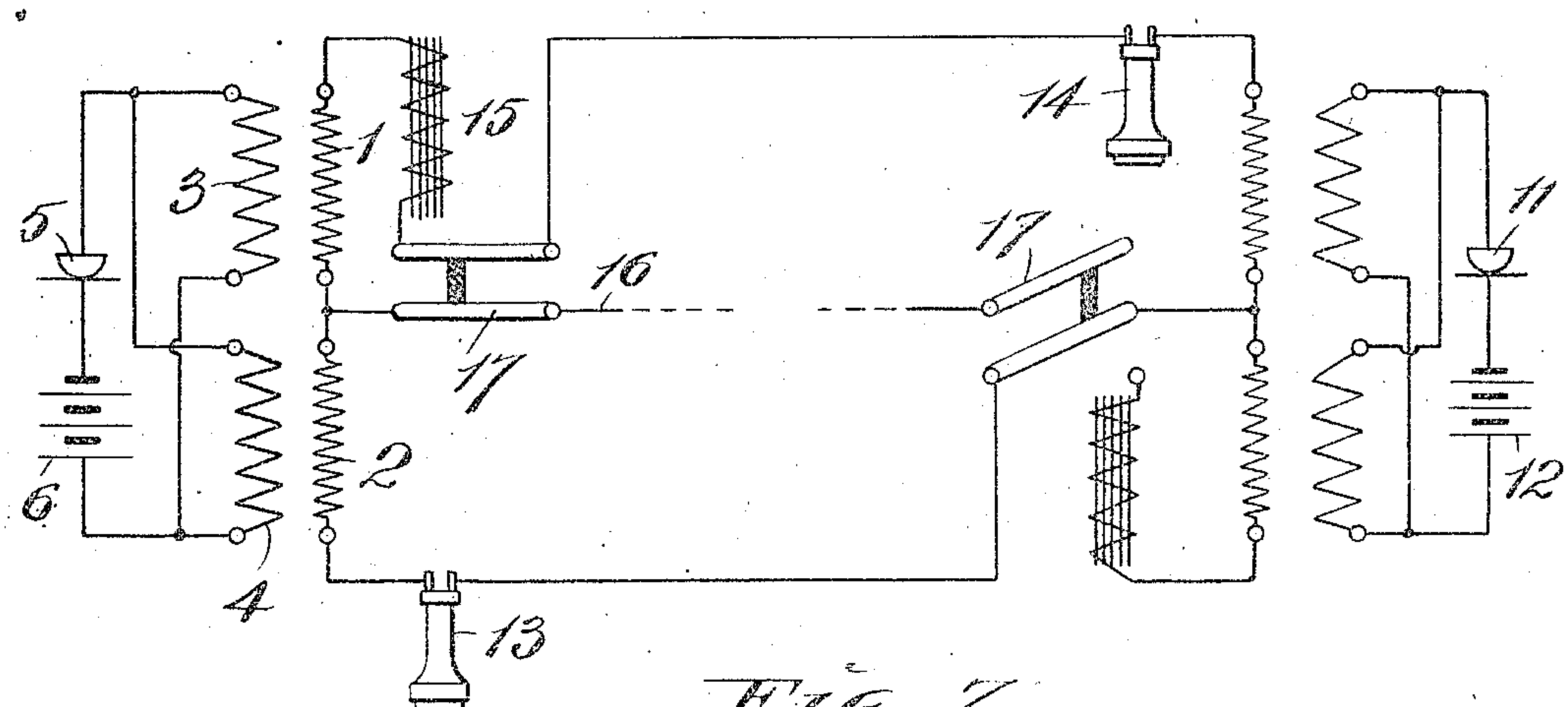
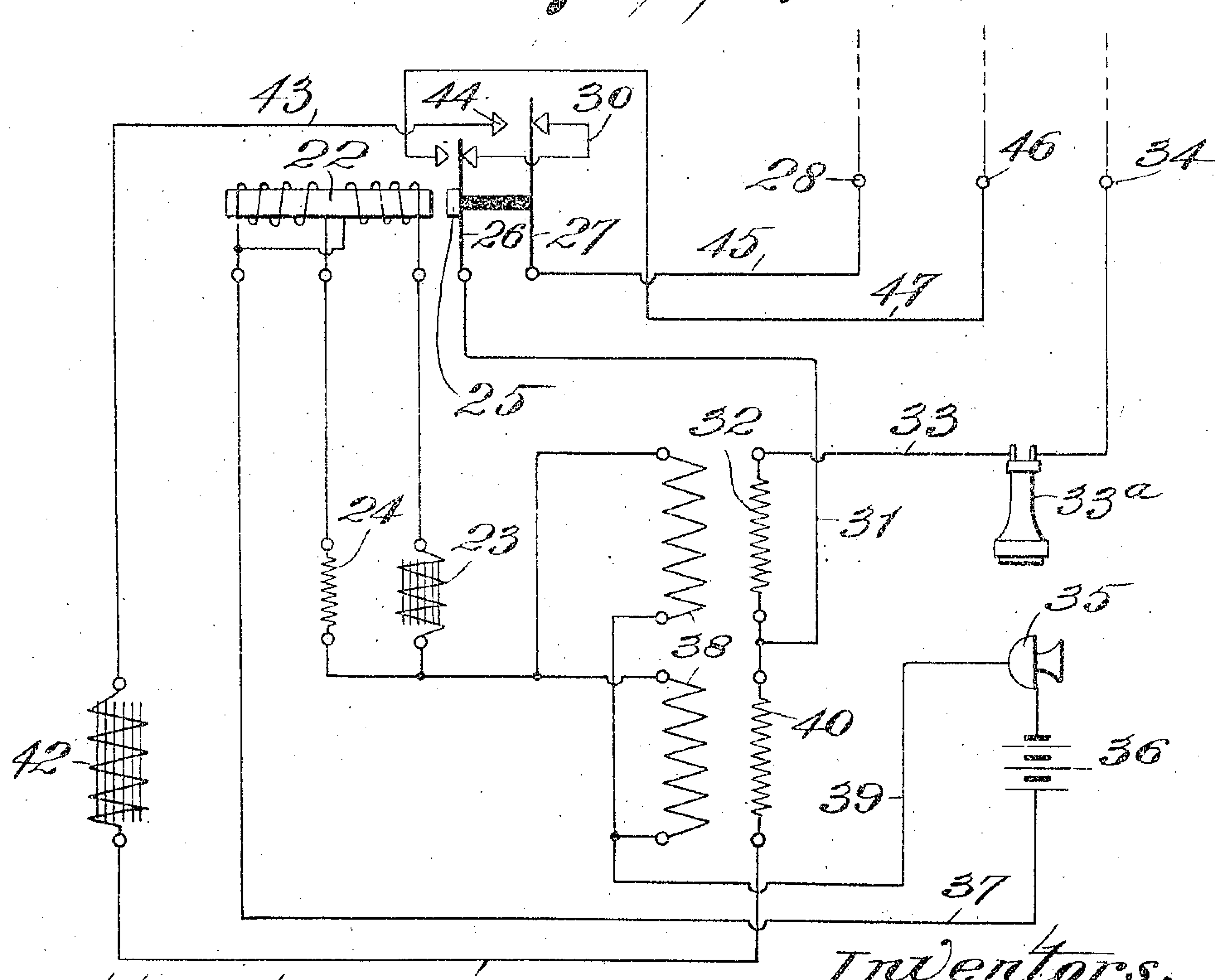


Fig. 7.



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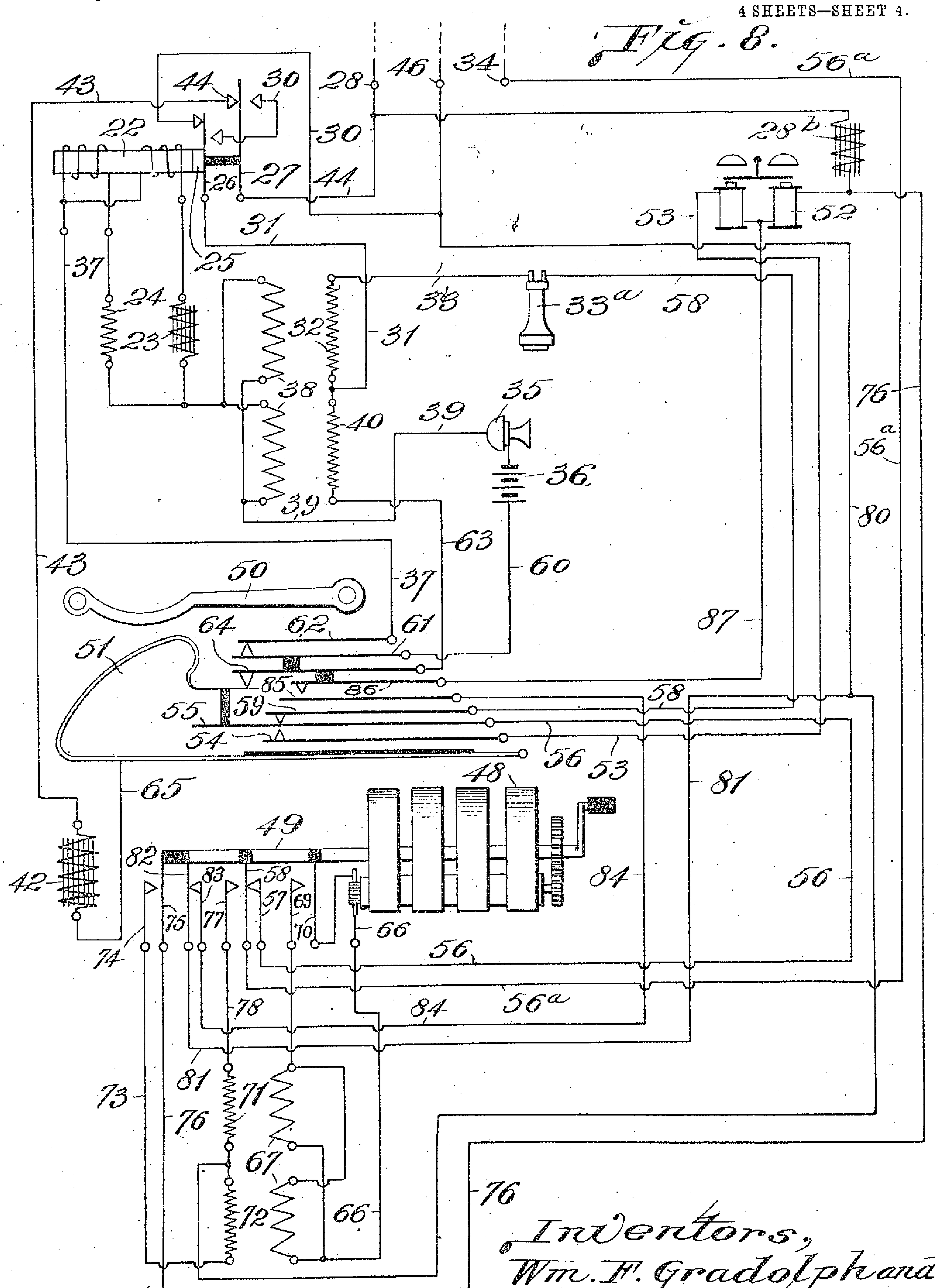
4 SHEETS—SHEET 4.

Fig. 8.



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UNITED STATES PATENT OFFICE.

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TELEPHONE SYSTEM.

958,868. Specification of Letters Patent. Patented May 24, 1910.

Original application filed December 20, 1905, Serial No. 292,529. Divided and this application filed February 1, 1908. Serial No. 413,854.

To all whom it may concern:

Be it known that we, WILLIAM F. GRADOLPH and WILLIAM C. HAHNE, both citizens of the United States, and residents of St. Louis, Missouri, and Chicago, Illinois, respectively, have invented certain new and useful Improvements in Telephone Systems, of which the following is a specification containing a full, clear, and exact description, reference being had to the accompanying drawings, forming a part hereof.

Our invention relates to the transmission of electrical energy by means of electrical waves of alternating, intermittent, or undulating currents, and particularly such waves as are employed in the electrical transmission of speech or sonorous sounds, and comprises various features of novelty hereinafter more particularly described and claimed.

Our invention is applicable to a great variety of generating or translating devices; for instance, the transmission of speech, for power, and for electric signaling.

The present application is a divisional application from the application filed by us December 20, 1905, Serial No. 292,529.

It is well understood that the successful transmission of speech depends not only on the volume or loudness of the sound produced by the telephone receiver, but also, and to a greater degree, on clearness or distinctness. The telephone current is essentially alternating, but its waves or impulses are exceedingly complex, due to the fact that the sound waves of the human voice, which produce the current waves, are not simple waves but are composite, being the resultants of numerous waves, corresponding to overtones and harmonics, as well as fundamentals, of different amplitudes and periodicities. These composite sound waves may be quite accurately translated into electrical waves by the transmitter; and if the current waves be transmitted over the line with their characteristics substantially unimpaired or unmodified, the sound waves into which they are translated by the receiving apparatus will be substantially identical, at least as regards distinctness or clearness, with the sound waves which affected the transmitter. Consequently anything which disturbs the inter-relation of the component waves of the resultant complex current waves causes loss of clearness in the reproduced sound waves; while anything that causes a loss of current, as by dissipation, causes a loss of volume or loudness. These disturbing influences have been largely overcome as regards their effect in the transmitting and receiving devices, but the numerous attempts to overcome them in the external circuit have been, so far as we are aware, only partially successful. The disturbing influences which we here have more particularly in mind are the self-inductive and the electrostatic capacity of the line or external circuit. Both of these influences reduce the amplitude of the current waves and consequently cause a loss of volume; and both also cause a loss of clearness or sharpness; the effect of electrostatic capacity, or static induction, being to round off the crests of the waves, and the effect of both self and static induction being to produce an unequal retardation of phase for vibrations (the component waves) of different periods, thus causing interference and a resultant deformed wave. It will therefore be seen that if good transmitting and receiving apparatus be employed, the successful telephonic transmission of speech depends on the self-inductive and the electrostatic capacity or condenser effect of the external circuit, and hence it is desirable to reduce these characteristics of the line to the minimum.

In the transmission of a simple electrical wave over an electrical conductor of great length characterized by high resistance, electrostatic capacity and inductive leakages, the energy lost or dissipated is proportional to and expressible in simple terms of the reactive constants of the systems, and there is no distortion of the wave form. Such, however, is not the case for a complex electrical wave composed of a plurality of co-existing waves, such as the waves involved in the telephonic transmission of the human voice or other sonorous sounds composed of a prime or fundamental and an ascending series of partials corresponding to overtones or characteristics of articulation and quality. In the latter case, each constituent wave of the series is differently and independently affected, and hence the resultant wave form at the distant end or terminus of transmission is no longer identical with the initial wave form impressed upon the conductor. This is due to the physical fact that each wave is oppositely as well as differently affected by the electro-magnetic and electrostatic constants of the system, though both conspire to discriminate in favor of the lower while retarding or attenuating the upper harmonics directly as the frequency, resulting in the loss of articulation and the natural characteristics of speech which are dependent upon the transmission of the upper harmonics or overtones, and while conceding that the greatest losses are properly chargeable to the dissipation of the main line conductors, owing to their electrical characteristics, as outlined above, our researches of the subject experimentally with commercial and artificial circuits have confirmed us in the opinion that, so far as long aerial or cable lines are concerned, operating under actual conditions, which might be called existing "meteorological" conditions, little if anything of average or permanent value is to be obtained by tuning or readjustment of the line constants, and, so far as we are aware, there exists at the present time no commercially successful method or system of transmission, telephone relay, or repeater.

Various attempts from time to time have been made to devise electromechanical apparatus capable of replenishing the current at some intermediate point of the circuit, or adapted to transfer the messages of one telephone circuit to another, and thereby either to increase the length of line that can be operated satisfactorily, or under other conditions to enable the receiver to reproduce the transmitted message with increased loudness. These efforts, however, have uniformly been unsuccessful and unproductive of practical result, and it is a fact that nothing of the kind is in practical or commercial use at the present time in connection with telephone circuits anywhere, for though in some instances the sounds reproduced by the receiver actuated by the replenished current have, indeed, been characterized by increased loudness, such increase has invariably been at the expense of clearness and has always involved the loss of quality and the consequent introduction of so much distortion as to render the utterances of the receiving instrument inarticulate and unintelligible.

In the transmission of alternating, undulating, or intermittent currents, it is well known that the high capacity of closely associated conductors is a great hindrance to economic transmission and a preventive of transmission through underground cables of any great length. The limit of distance to which speech can be telephonically transmitted, so as to be commercially intelligible is: for 22 gage cable 17 miles; 19 gage cable 25 miles; 16 gage cable 44 miles. This is not caused by any losses due to capacity itself, which is a function of the medium surrounding the conductor or pair of conductors, by which it is capable of storing up and restoring energy to the circuit. There is a certain amount of loss, known as dielectric hysteresis, due to this process, which, however, is trifling when compared to the other losses of energy in the cable. This may be more thoroughly understood by considering that there are two components of current present in the conductor, one in phase with the electro-motive force, and tending to do useful work at the receiving end, and the other a capacity current, a quarter period in advance of the electro-motive force, representing a successive charging and discharging of the medium surrounding the conductor. This latter current may be, and is, in a telephone cable, many times greater than the useful current. The resultant current at the transmitting end is therefore larger than the useful current transmitted to the receiving end. This produces C^2R losses throughout the entire length of the conductor, far greater than would occur if the current at the transmitting end were the same as that at the receiving end. It is obvious, therefore, that anything which will diminish the attenuation of the current flowing through the conductor, by lowering the amount of current necessary to charge the surrounding medium, will increase the efficiency of the circuit.

It has been proposed for a number of years, to obviate the excessive charging current existing in a circuit of this kind, by introducing into the circuit, in various manners, reactance coils which should cause the current of equal and opposite effect to the capacity current in the cable or circuit, and annul it. None of these proved effectual when tried in actual service until recently, when the theory of the design and placing of such "loading" coils was evolved, and it was found that if they were arranged in series with the conductors, at proper intervals, which are determinable by mathematics, the efficiency of transmission was increased. There are many disadvantages of this arrangement, however, prominent among which is the expense of the coils themselves, and in underground telephone cable work, the expense of the frequent building of vaults and boxes to contain these coils. To this we may add the difficulty of access to these coils which are embedded in an insulating compound, and cannot be repaired without removing the entire containing box, and the difficulty due to magnetic induction between different circuits due to the overlapping magnetic fields of these reactive coils, and again circuits loaded with these coils are very difficult to operate over, that is to say, when loaded circuits are connected together, transmission of speech is poorer, due to the fact that the circuits have different time constants and so cause a reflex action to the voice currents.

The object of our invention is to avoid the objectionable features of the aforesaid arrangements, and to secure the effective reactance in long conductors and cables, necessary to neutralize the capacity thereof, in a simple, inexpensive, and practical manner.

The nature of our invention will be more readily comprehended in connection with the preferred type of apparatus, and therefore reference will now be made to the annexed drawing wherein such apparatus is illustrated diagrammatically.

Figure 1 shows a system involving the application of our invention to telephonic transmission; Fig. 2 is a diagrammatic view of a telephone system involving the application of our invention, and showing the transmitting and receiving appliances at each end of the line; Fig. 3 is a diagram showing graphically the current waves when in phase; Fig. 4 is a diagram showing current waves as displaced in phase by our invention; Fig. 5 is a diagram which shows graphically the condition of the current waves in the external circuit arising from the application of our invention; Fig. 6 shows diagrammatically a system of two stations, each adapted to transmit or receive at will, the necessary changes in connections being made by a manually operated switch; Fig. 7 shows diagrammatically a single station adapted to transmit or receive at will, and equipped with an automatic switch for effecting the necessary changes in the connections; Fig. 8 shows diagrammatically a system like that of Fig. 7, but provided also with signaling devices.

Referring now more particularly to Fig. 1; 1 and 2 designate the secondaries of two transformers; or, stated otherwise, 1 and 2 may be considered a single secondary which is split at its center. 3 and 4 are primary windings, connected in multiple with each other and in series with a telephone transmitter 5 and a battery 6. 7 and 8 are the two wires of the external circuit, and in series therewith is the secondary winding 9 of the transformer at the other end of the circuit. 10 indicates the primary of the transformer, in series with the transmitter 11 and battery 12. The receivers at the two ends of the circuit are in series with the transformer secondaries and are designated by 13 and 14. 15 is an impedance coil of proper value, as will be fully explained presently, inserted in either line, and preferably close to the secondary 1' or 2, as the case may be. 16 is a surging or buffer line, open or grounded, by preference open, and preferably of a length greater than one wave length. This surging line is connected at the neutral point between the secondaries 1 and 2.

The operation of this system is to the best of our knowledge and belief, as follows: The currents produced in the primaries 3 and 4 by the sound waves entering the transmitter 5 are reproduced in the secondary windings 1 and 2. These induced currents are of course in phase, and would, in a simple single phase circuit, add up; but the line 16 permits a surge to take place in it, thus operating like a buffer, as it were, so that the independence of the two secondary currents is preserved. The current from secondary 1 is, by the impedance 15, caused to lag approximately 90° behind the E. M. F., while the current in the other line, flowing from the secondary 2, is by the electrostatic capacity or condenser effect existing between line 8 and the surging line 16 caused to lead the E. M. F. by approximately 90° in the line 8, until the impedance at the receiving station is reached. The result is an out of phase condition to the extent of approximately 180° difference between the two currents in lines 7 and 8. This condition is indicated graphically in Figs. 4 and 5. Fig. 3 illustrates the phase relation of the currents in an ordinary system; and it will be noted that the polarity of the current wave in one line is always of contrary sign to the current wave in the other, and consequently the capacity effect between the two is maximum. On the other hand, it will be seen that in Figs. 4 and 5, which represent what would be the ideal conditions of our method, the polarities in the two lines are always of the same sign; and, consequently, if such ideal conditions could be attained in practice, the self-induction and capacity effect between the lines would be zero. When the currents reach the secondary 9 of the transformer at the other end of the line, the impedance of the secondary causes the phase relation to be restored, at least partially, to the original relation, so that there is produced a difference of potential across the receiving transformer, and the current waves are consequently translated into sound waves.

It will be understood, of course, that the more nearly the currents in the two lines are kept 180° out of phase, and the more nearly they are brought into phase at the receiving transformer, the better the speech transmission; and it is therefore desirable to approximate these conditions as far as possible. It is obvious for various reasons, chiefly the fact that the components of the waves are of different periodicities and are therefore differently affected by the impedance and by the electrostatic capacity or condenser effect between the surging line and the circuit, the current waves, which reach the receiver at the other end of the line are never identical with those produced in the transmitter; but it is possible to so proportion the values of the impedance and the condenser effect just mentioned that a considerable phase displacement may be produced without deforming the current waves to an impracticable extent. The periodicity of the telephone current is usually assumed to be 750; and on this assumption, with a transmitter transformer of .6 ohms resistance in its primary and 175 ohms in its secondary, and a primary current of 4 volts, extensive experiments and practical tests have indicated an impedance of 100 ohms as the best value, whatever be the length of the external or transmission circuit. In general, we prefer, as already stated, to make the surging line, 16, slightly longer than a wave length, assuming the periodicity of the current to be 750, but different conditions may make a different length advisable, either longer or shorter as the case may be, or it may even be extended and connected with the distant station.

Fig. 1 is designed to represent in the simplest way the operation of our invention, and no provision is made in this figure for transmitting from the transmitter 11. It will be understood, of course, that this end of the line must for that purpose be equipped like the other end, as clearly shown in Fig. 2. Under some circumstances it is found desirable that when either set of instruments is receiving, the impedance, (as 15), at that end of the line should be cut out. It may be advisable at times to cut out half of the transformer secondary when receiving. A complete system for transmitting and receiving from each end of the line is shown by means of the simple diagram, Fig. 6. It will be seen that each station is equipped alike. At each there is a double pole switch 17, in the neutral line, and in the main line, by which the impedance, the neutral line, and half of the secondary winding may be cut out at will. When it is desired to receive, this switch is opened, as at the right of Fig. 6; and when transmitting, the switch is closed, as at the left. When the user is through talking, he opens his switch 17, and if the person at the other end desires to talk, he opens his switch, the conditions being thus reversed.

In lieu of the manually operated switch 17, Fig. 6, for changing the instruments from the receiving to the transmitting condition, and vice versa, we may use an automatic switch which operates whenever the operator speaks into the transmitter, as shown in Fig. 7. It consists of a differential relay 22, of the ordinary form, one branch of which contains an impedance 23, balanced by a non-inductive resistance 24 in the other branch.

As long as the station is receiving, the relay remains neutral; but whenever the user speaks into the transmitter, the pulsating current thereby set up unbalances the branches, so that the magnet now draws over its armature 25, and with the latter the contact springs 26 and 27.

In the position for receiving, as shown in Fig. 7, the circuit is as follows: from the distant station to terminal 28, spring 27, wire 30, spring 26, wire 31, secondary 32, wire 33, receiver 33ª, and terminal 34, back to the other station. When the switch is thrown, as above explained, the primary transmitting circuit is through transmitter 35, battery 36, wire 37, relay coils and branches, primary windings 38 of the transmitting transformer, and wire 39 back to the transmitter. The secondary circuit is then as follows: secondaries 32 and 40, wire 41, impedance 42, wire 43, contact 44, spring 27, wire 45, terminal 28 through the distant station to terminal 34, then wire 33 back to the secondary winding 32. As soon as the user ceases speaking into the transmitter 35, the balance of the relay branches is restored, and the springs 26, 27 are restored to the position shown in the figure. It will be observed that when the switch is in the transmitting position, the wire 31, from the neutral point between the secondary windings, is connected with the neutral or surging line extending from terminal 46, by spring 26, and wire 47. When the switch is thrown over, this path to terminal 46 is broken by spring 26 leaving the contact or wire 47.

Fig. 8 is a diagram showing a station equipped with the switch just described, and also with a convenient arrangement of signaling devices, utilizing our invention in the latter as well as in the telephone system. In this figure, 48 designates a hand-operated magneto machine of ordinary type, in which turning the crank to call the other station causes the crank shaft to actuate a switch at the other end of the same, indicated by 49. This method of operating the magneto switch is common and well understood. The hook on which the receiver hangs when not in use is indicated at 50. The weight of the receiver depresses the switch arm 51, thus changing the connection thereat in the usual manner. The distant station is connected by line wires to the terminals 28 and 34, and from terminal 46 extends the neutral or surging line.

When the system is not in use, the receiver hangs on the hook 50, and the relay switch is in the normal, or receiving position, as in Fig. 7. If now the other station signals, the circuit is established as follows: terminal 28, wire 28ª, impedance 28ᵇ, bell coils 52, wire 53, springs 54 and 55 at the hook switch, wire 56, springs 57 and 58 at the magneto switch, wire 56ª, to terminal

34, back to the signaling station. The person called then removes his receiver, establishing the following receiving circuits: from the other station to terminal 28, wire 44, spring 27, wire 30, spring 26, wire 31, secondary winding 32, wire 33, receiver 33ª, wire 58, springs 59 and 55 at the hook switch, wire 56, springs 57 and 58 at the magneto switch, wire 56ª, and terminal 34 back to the other station.

When the user at the station at this end of the line desires to reply, he speaks into the transmitter, whereupon the relay is unbalanced and the armature drawn over, as previously explained, to the position shown in Fig. 8.

The primary transmitting circuit is thus established through transmitter 35, battery 36, wire 60, springs 61 and 62 at the hook switch, wire 37, relay coils 22 and branches, primary windings 38, and wire 39 back to the transmitter. The secondary transmitting circuit is then as follows: secondary windings 32 and 40, wire 63, spring 64 at the hook switch, arm 51, wire 65, impedance 42, wire 43, spring 27 at the relay, wire 44, terminal 28 to the other station, then back through terminal 34, wire 56ª, spring 58 and 57 at the magneto switch, wire 56, spring 55, spring 59, wire 58, receiver 33ª, and wire 33 back to the secondary winding 32.

When the system is in its normal condition, that is, with the receiver on the hook, and with the relay switch in the position shown in Fig. 7, the other station is signaled in the following manner: The hand generator or magneto machine 48 is operated, which not only supplies the signaling current, but also operates the switch 49, as already explained, resulting in the following circuit being established: from the armature through wire 66, primary windings 67 of the signaling transformer or repeating coil, wire 68, springs 69 and 70, at the magneto switch, and back to the armature. The secondary signaling circuit is then as follows: secondary windings 71 and 72, wire 73, springs 74 and 75, wire 76, impedance 28ᵇ, wire 28ª, through terminal 28 to the distant station, then back to terminal 34, wire 56ª, springs 58 and 77 at the magneto switch, wire 78 back to the secondary 71.

When the relay switch is in the position shown (Fig. 8,) that is, in the transmitting position, the neutral point between the secondary windings 32 and 40 is connected by wire 31, spring 26 and wires 47 and 79 to the terminal 46, from which extends the neutral or surging line. When the system is not in use, that is, with the receiver on the hook 50, the surging line which extends from terminal 46 is connected between the bell magnets by wires 79, 80, 81, springs 82 and 83 at the magneto switch, wire 84, springs 85 and 86 at the hook switch, and wire 87. Removing the receiver from the hook breaks this connection by separating springs 85 and 86, so that the surging line extending from terminal 46 will not be effective through wire 28ª, one of the bell magnets 52, wire 87, etc.

The line losses in telephone transmission circuits, due to self and static induction, are of vital importance; and, inasmuch as our invention overcomes these effects to so considerable a degree, we are enabled to deliver to the translating device, whatever it may be, a larger proportion of the generated current than has, so far as we are aware, been possible in the systems heretofore proposed.

While we have shown automatic and manually operated switches in connection with our improvement, it will be readily understood that, in so far as the transmission and receiving of electrical energy is concerned, the action, as contemplated by our invention, may be carried out with equal success by the simple arrangement of lines and connections, as shown in Figs. 1 and 2, wherein such appliances are not employed.

In conclusion, it should be stated that while the line conductors may be in any inductive position relative to each other, they must, in every case, be arranged in inductive relation to the surging line, because the action between this line and the transmission lines is, as already explained, essential to the invention.

It is of course evident that where the surging line extends to the receiving or translating devices, the line conductors, if in inductive relation thereto, are also in inductive relation to each other.

We claim:—

1. In a telephone system, the combination with a metallic circuit, and a plurality of stations thereon each provided with transmitting and receiving apparatus, of means at each station for impeding the current in one side of the circuit, and means at each station for cutting the impeding means in or out of the circuit at will.

2. In a telephone system, the combination with a metallic circuit, and a plurality of stations thereon each provided with transmitting and receiving apparatus, of means at each station for altering the phase relation of the currents, and means at each station for cutting said phase-altering means in or out of the circuit at will.

3. In a telephone system, the combination with a circuit and a plurality of stations thereon, each provided with transmitting and receiving apparatus, a differential relay at each station, dependent for operation upon actuation of the transmitting apparatus by sound waves entering the same, for changing the station from receiving to transmitting condition.

4. In a telephone system, the combination with a metallic circuit, and a plurality of stations thereon, each provided with transmitting and receiving apparatus, of means at each station for altering the phase relation of the currents in the two sides of the circuit, said phase-altering means being normally out of circuit, and means at each station, dependent for actuation upon operation of the transmitting apparatus, for putting said phase-altering means in circuit.

5. In a telephone system, the combination of a metallic circuit the sides of which are in inductive relation to each other, a plurality of stations thereon, transmitting and receiving apparatus at each station, and means in series with the circuit coöperating with means in inductive relation with both sides of the circuit for producing in both sides of the circuit at the same time currents of like polarity, and for restoring said currents to their original polarity.

6. In a telephone system, the combination with a circuit, a plurality of stations thereon each provided with a transmitting and receiving appliance, and means for producing in the opposite sides of said circuit between connected stations of the circuit at the same time currents of like polarity.

7. In a telephone system, the combination with a circuit, a plurality of stations thereon each provided with a transmitting and receiving appliance, of means for producing in the opposite sides of said circuit between connected stations at the same time currents of like polarity, and means for restoring said currents to their original polarity at the receiving station.

8. In a telephone system, the combination with stations, each provided with transmitting and receiving appliances, a circuit connecting said stations, of means interposed between the stations for altering the phase relation of the currents during their transmission over the lines of the circuit.

9. In a system of telephony, the combination with stations, each provided with transmitting and receiving appliances, a metallic circuit connecting said stations, the sides of which are in inductive relation to each other, of means in series with the circuit coöperating with means in inductive relation with both sides of said circuit for producing in both sides of said circuit at the same time currents of like polarity, and for restoring said currents to their original polarity.

10. In a system of telephony, the combination of a metallic telephone circuit, the sides of which are in inductive relation to each other, a plurality of stations thereon each provided with transmitting and receiving appliances, of means in series with said circuit for retarding the current in one branch of said circuit and correspondingly advancing the current in the other side of said circuit, and means in inductive relation to the circuit for correspondingly advancing the retarded current and retarding the advanced current.

11. In a telephone system, the combination with an all metallic circuit the sides of which are in inductive relation to each other, and a plurality of stations thereon each provided with transmitting and receiving appliances, of an impedance coil in each side of said circuit, and a surging line in inductive relation to both sides of said circuit.

12. In a telephone system, the combination with an all metallic circuit, the sides of which are in inductive relation to each other, and a plurality of stations thereon each provided with transmitting and receiving appliances, of an impedance coil in said circuit, and a surging line in inductive relation to both sides of said circuit.

13. In a telephone system, the combination with a metallic circuit and a station thereon provided with both telephone transmitting and receiving appliances, of means arranged adjacent to the said station, comprising an impedance in the circuit, and a surging line in inductive relation to both the lines, the said means coöperating to change the phase relations of the currents on the line.

14. In a telephone system, the combination with a metallic circuit and stations thereon each provided with both telephone transmitting and receiving appliances, of means arranged adjacent to a sending station for altering the normal phase relations of the currents passing over the line of the circuit, and other means located adjacent to a receiving station for restoring the normal phase relations of the currents before being delivered to the receiving appliances.

15. In a telephone system, the combination with a circuit, a plurality of stations thereon, telephone transmitting and receiving apparatus and signaling devices at each station, and means for bringing the said telephone apparatus or signaling devices into the circuit at will, of means arranged adjacent to one station for altering the normal phase relations of the currents sent over the circuit, and means near another station for restoring the normal phase relations of the currents before they are delivered to the receiving appliances.

16. In a telephone system, the combination with a circuit, a plurality of stations thereon, telephone transmitting and receiving apparatus, and signaling devices at each station, the signaling devices being normally in the circuit when the system is at rest, and the telephone apparatus being arranged to be brought into the circuit when the system is in use, whereby any station may become a sending station and another a receiving station, of means arranged adja-

cent to a sending station for altering the normal phase relations of the currents sent over the circuit, and means near a receiving station for restoring the phase relations of the currents.

17. In a telephone system, the combination with a circuit, a plurality of stations thereon, telephone transmitting and receiving apparatus and signaling devices at each station, and means for bringing the said telephone apparatus or the signaling devices into the circuit at will, of means in permanent coöperative relation with the circuit arranged adjacent to a station for altering the normal phase relations of the currents sent over the circuit, and other means also in permanent coöperative relation with the circuit arranged near another station for restoring the normal phase relations of the currents.

In testimony whereof, we have signed our names to this specification, in presence of two subscribing witnesses.

WILLIAM F. GRADOLPH.
WILLIAM C. HAHNE.

Witnesses:
A. R. KELSO,
HOUSTON BOND.