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D. C. JACKSON.

METHOD OF PROPAGATING WAVE FORMS.

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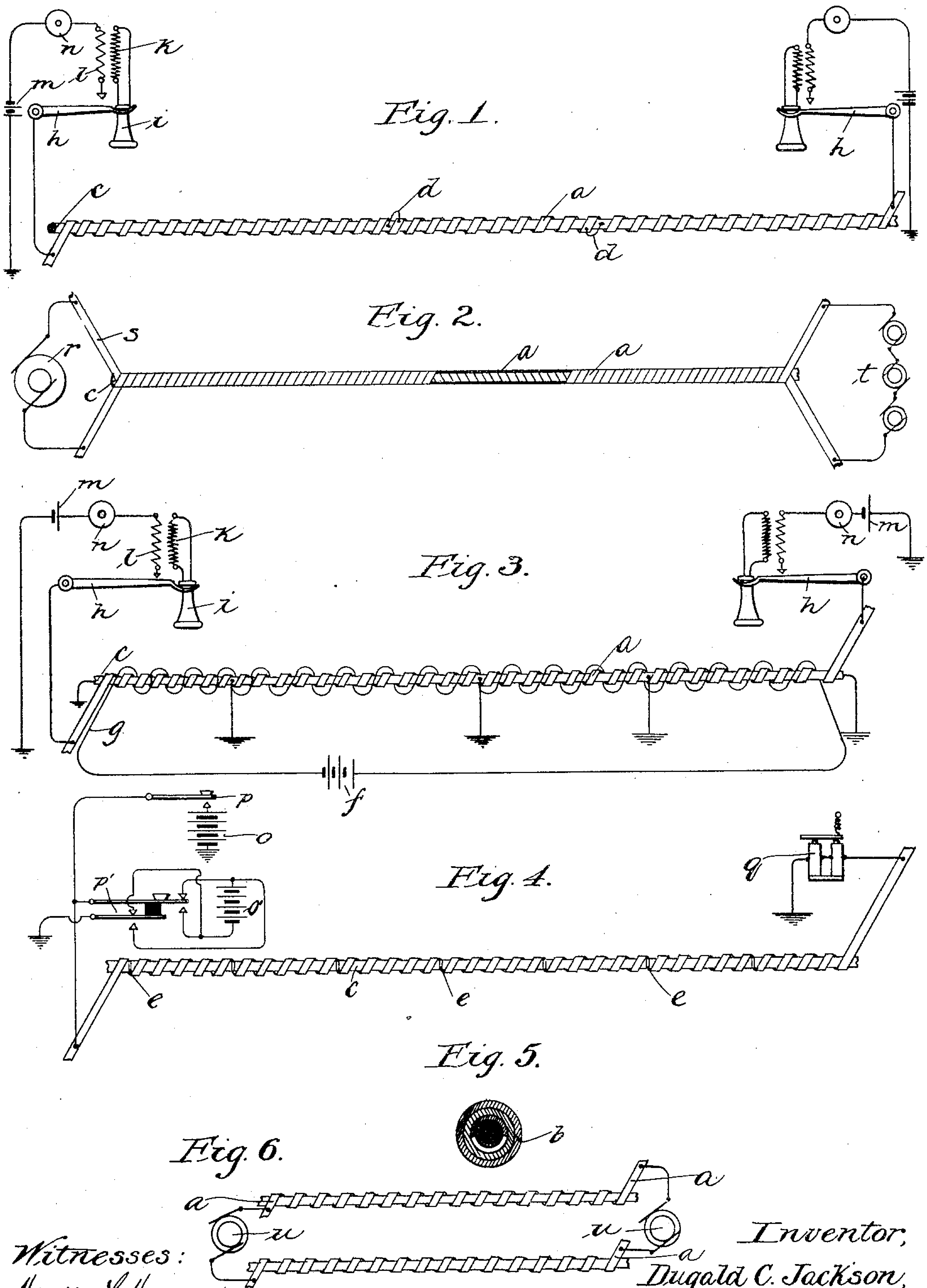

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UNITED STATES PATENT OFFICE.

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METHOD OF PROPAGATING WAVE FORMS.

SPECIFICATION forming part of Letters Patent No. 789,738, dated May 16, 1905.

Application filed September 23, 1901. Serial No. 76,248.

To all whom it may concern:

Be it known that I, DUGALD C. JACKSON, a citizen of the United States, residing at Madison, in the county of Dane and State of Wisconsin, have invented a certain new and useful Improvement in Methods of Propagating Wave Forms, (Case No. 12,) of which the following is a full, clear, concise, and exact description, reference being had to the accompanying drawings, forming a part of this specification.

My invention relates to circuits for propagating wave forms, such as alternating or intermittent currents, and has for its object the provision of an improved method of conducting such currents whereby the electrostatic condition or stress existing between the sides of the circuits, commonly known as "condenser effect," may be obviated.

Reference may be had to my copending application, Serial No. 76,247, filed of even date herewith.

It is well known to those skilled in the art that where the sides of a circuit for conveying currents of this character are located close together—as, for example, in the same cable in the case of metallic circuits or where the metal side of a circuit is located close to the ground or other common return—a decay and distortion of the current arises, due to the electrostatic capacity. The mathematical theory of such decay and distortion has been set forth by such writers as Heaviside, and various attempts have been made to embody theories proposing correctives in commercial form. Such commercial usage has not been obtained, though various expedients for correcting the evils have been discussed for many years. It has been proposed, for example, to solve the problem by introducing self-induction coils at regular intervals throughout the cables, the idea being to neutralize the electrostatic capacity by sections, leaving the conductors of sections between the self-induction coils free of any characteristic tending to counteract the electrostatic condition that may arise between the self-inductance coils. I propose to overcome these defects by creating lines of force due to that portion of the circuit subject to this objectionable capacity substantially throughout the length of this portion of the circuit, these lines of force extending longitudinally or parallel to the general direction followed by the conductor. Where grounded circuits are employed, these lines of force are set up by the portion of the metallic side thereof where the condenser effect is to be counteracted. Where metallic circuits are employed, both sides of the circuit where the condenser effect is to be counteracted are caused to create lines of force substantially throughout their length, which lines of force are caused to follow the same general direction in the circuit, so that the effect of the inductance in each side of the circuit may be additive. In carrying out this method I preferably form the conductor that is to carry the current in a spiral to create inductance, this spiral formation being practically continuous throughout the entire circuit or that portion of the circuit where the sides are closely associated physically, and are thus likely to superinduce the undesirable electrostatic condition, whereby I am enabled to overcome the stress between the sides of the circuit. The conductor may be wound about a core, that is preferably of magnetic material, composed of very fine wires of the softest iron; but, if desired, the core may be hemp or other like material or an air core may be employed. Where a magnetic core is employed, the subdivision thereof into wires or strands is for the purpose of avoiding eddy-currents, and the iron is made soft magnetically in order to avoid serious waste of energy through the effect of hysteresis.

The instrumentalities by which the method of my invention may be practiced may cover a wide range.

I will more fully describe my invention in connection with the preferred means of practicing the same in connection with the accompanying drawings, in which—

Figure 1 illustrates a grounded circuit, the major portion of its metallic side being in the form of a self-inductance spiral, telephonic apparatus being illustrated in the circuit as one type of current sending and receiving apparatus. Fig. 2 is a diagrammatic view of a metallic circuit both of whose sides are formed throughout their major portions as self-inductance spirals, in circuit with which is illustrated another form of alternating-current apparatus. Fig. 3 is a view similar to Fig. 1, a supplemental circuit in association with the core of the spiral being indicated for increasing the inductance. Fig. 4 illustrates a modification wherein the spiral is provided with a magnetic core composed of magnetically-separated sections. Fig. 5 is a cross-sectional view indicating one commercial form of cable embodying the invention. Fig. 6 is a view of a metallic circuit whose sides are separated, each wound about a core to create inductance.

Like parts are indicated by similar characters of reference throughout the different figures.

In the case of telegraph-lines extending by cables through large bodies of water it is customary to ground the circuits. In such circuits the self-inductance is comparatively small, the outgoing conductor in each circuit being immersed in or placed very near the return side of the circuit, as in the case of an ocean-cable, where the earth and the ocean-water form the return side. In such circuits signaling by means of intermittent or alternating current is limited in speed because of the great electrostatic capacity of the circuits and the decay of the signaling-current caused thereby. Such decay may be mathematically illustrated by the following formula:

$$C' = C\,\varepsilon^{-\frac{l}{10^3}(\pi f R s)^{\frac{1}{2}}}$$

or

$$\frac{C'}{C} = \varepsilon^{-\frac{l}{10^3}(\pi f R s)},$$

wherein C represents an alternating current sent into a circuit composed as above, C' represents the resulting current at a distance, say, of l miles from the source, ε is the numerical constant 2.7182+, π is the numerical constant 3.1416, f is the frequency of the alternating current, s is the electrostatic capacity in microfarads per mile of circuit, and R is the resistance in ohms per mile of circuit.

In telephony it is usual to employ complete metallic circuits; but the circuit-conductors in the cables are twisted together in pairs to avoid mutual interference of the circuits, (or cross-talk,) a consequence being that the self-inductance of each circuit is reduced to a comparatively small value, the mathematical formula above given applying approximately to such telephone-circuits.

To overcome the defects above pointed out, I introduce into the circuits substantially throughout the same in an approximately uniform manner self-inductance in a degree serving to partially or wholly neutralize the effect of the electrostatic capacity between the sides of the circuits and to sufficiently overcome the decay of the current. These undesirable features—the electrostatic capacity and its effect, the decay of the transmitted current—may be practically avoided if self-induction of the right value in comparison with the electrostatic capacity is chosen. The condition of decay of an alternating current in a circuit with self-inductance and capacity when the resistance is not too great may be shown by the following formula:

$$C' = C\,\varepsilon^{-\frac{R\,l}{2\times10^3}\left(\frac{s}{L}\right)^{\frac{1}{2}}}$$

or

$$\frac{C'}{C} = \varepsilon^{-\frac{R\,l}{2\times10^3}\left(\frac{s}{L}\right)^{\frac{1}{2}}},$$

wherein L is the self-inductance (coefficient of self-induction) per mile of circuit, given in henries, the other symbols having the same meaning pointed out in connection with the first formula.

In practicing my invention the necessary counteracting self-inductance is introduced into those portions of the circuit whose sides are close together—as, for example, when they are assembled in the form of metallic conductors in a single cable or where in a grounded circuit the metallic side lies close to the ground or other common return, so that the decay and distortion of the current may be reduced to any desired degree or entirely prevented.

The conductor of the cable is preferably in the form of a spirally-wound ribbon of copper or aluminium *a*, as indicated in each of the figures, particularly where grounded or common return-circuits are employed. In the case of common return-circuits the conductor may be insulated from its core or not, as preferred. If the cable is for underground or submarine use, it may be externally sheathed and insulated in the usual manner, as indicated in Fig. 5, an outer sheathing *b* of protecting material being illustrated. Any of the well-known ways of constructing the cable and insulating the same may be employed, and I do not, therefore, deem the detailed description thereof to be essential. The cable thus constructed may be laid with the same facility and by the same means as those now generally in use.

When the spirally-formed conductor is provided with a continuous metallic core *c*, as indicated in Fig. 1, the spiral conductor may be free of insulation, so as to come into metallic contact with the core, and may be united with the core at its ends and at intervals throughout the length of the core by means of jumpers *d d*, so that the core in addition to creating the required self-inductance may act as a part of the conductor, thus reducing the resistance in the circuit, the core being thus in parallel with the main spiral conductor, or, if desired, the core and spiral conductor may be conductively distinct, in which case the core may coöperate with the remaining side of the circuit and form a parallel path with the remaining side of the circuit. This arrangement is indicated in Fig. 3, where the metallic core is shown as being grounded at its ends and at intervals. The self-inductance of the conductor wrapped in a spiral, as described, may be derived with approximate accuracy from the following formula:

$$L = \frac{4\ \pi^2\ n^2\ D^2\ \mu}{10^{20}},$$

wherein L is the self-inductance per mile of circuit in henries, n is the total number of turns of conductor around the core per mile of circuit, D is the diameter of the core in mils, μ is the magnetic permeability of the core.

Submarine or other cables which serve to carry intermittent currents preferably should not be provided with a magnetic core, or if a magnetic core is employed it should be interrupted by narrow non-magnetic spaces at intervals which preferably do not exceed a foot in order that the retentiveness of the iron shall not reduce the apparent reactance with the intermittent current. This arrangement is illustrated in Fig. 4, where the non-magnetic gaps e are indicated between the short sections of the magnetic core c. To prevent the sections of the core from crowding together, these insulating-gaps may be filled with rubber or some insulating compound or material or with non-magnetic metal. It may be assumed that the iron has a permeability as high as two hundred units at the very low degree of magnetization which may be caused by the signaling-current; but the permeability may be increased to many times this value by introducing a special steady magnetizing-current. This arrangement is illustrated in Fig. 3, where the special steady magnetizing-current is furnished from a source of direct current f, which is included in circuit with a conductor g, a portion of whose length surrounds the magnetic core and is spirally disposed. This supplemental circuit, including the battery f and conductor g, serves to set up lines of force in the core and in this manner increase the permeability in accordance with laws of magnetism that are well understood.

To illustrate the effect of my invention, I will assume a submarine cable of the prior art that is required to span a stretch of sea between two cities which requires two hundred miles of circuit. If the cable is of the usual construction and the circuit has the following characteristics, (which are within the limits of the ordinary practice,) ten ohms resistance per mile, .3 microfarad capacity per mile, and negligible self-inductance, then the value of

$$\varepsilon^{-\frac{l}{10^3}(\pi f R s)^{\frac{1}{2}}}$$

becomes

$$\varepsilon^{-10.6} = .000025$$

when f is given the value of 300. In other words, if an alternating current which has a frequency of three hundred periods per second is delivered to one end of this cable only twenty-five millionths of that current will reach the far end. With a cable possessing the characteristics herein set forth having a core of four hundred mils effective diameter, while the spiral conductor has seventeen turns per yard of practically thirty thousand per mile of circuit, then

$$L = \frac{4 \times 9.9 \times 9 \times 10^8 \times 16 \times 10^4 \times 200}{10^{20}} = .0114 \text{ henries.}$$

The value of

$$\varepsilon^{-\frac{R\,l}{2 \times 10^3}\left(\frac{s}{L}\right)^{\frac{1}{2}}} \text{ becomes } \varepsilon^{-5.1} = .0061.$$

Thus when an alternating current is delivered to one end of the cable the portion which reaches the other end is over six one-thousandths of the original strength of the sending-current. Such a cable gives very high speed for telegraph-signaling, and the transmitted signals are very little distorted. Such a cable is also adapted for telephonic communication, Figs. 1 and 3 illustrating its application to this purpose, while Fig. 4 illustrates the application of the cable to telegraphic purposes.

In Figs. 1 and 3 I have illustrated well-known types of telephone-substation apparatus, each station being provided with a telephone switch-hook h, connected with a conductor a, a telephone-receiver i in a local circuit with the secondary k of an induction-coil, the primary l of the induction-coil being adapted for inclusion in the circuit with the conductor a when the switch-hook is relieved of the influence of a telephone-receiver, a branch conductor including the primary l, also containing in this instance a battery m in addition to the usual telephone-transmitter n.

Fig. 4 illustrates a source of current o in circuit with circuit-closing key p at one end and a relay-sounder q at the other end, only one receiving instrument being here illustrated to show the application of the invention.

The clearness of the transmission of telegraphic or telephonic signals may be improved to any desired degree by increasing the self-inductance of the cable up to the point of completely neutralizing its capacity. This may be done, for instance, by increasing either the diameter of the core or its permeability. It may be also done by increasing the number of wraps or turns which the conductor makes around the core in each mile. Suppose that the magnetic permeability of the core is increased fourfold by some such plan as has been suggested above. Then the value of the exponent in the expression

$$\varepsilon^{-\frac{R\,l}{2 \times 10^3}\left(\frac{s}{L}\right)^{\frac{1}{2}}}$$

is reduced by one-half, and for the example set forth above the expression becomes

$$\varepsilon^{-2.55} = .078.$$

A cable of this construction would admit of very effective telephonic communication.

Where the cable is used for telegraphy, it is preferable to construct it with a uniform core and use alternating currents for signaling. Satisfactory results may, however, be secured with intermittent currents, the core then being preferably interrupted, as already described. A periodically-intermittent function may be represented by a series of alternating functions, and therefore the deductions regarding the cables made heretofore with respect to the alternating-current flow through them also apply to the intermittent flow. The current supplied through the key p from the source of current o in Fig. 4 is intermittent. The current supplied by the key p' from the source of current o' may be considered alternating, as said key is a reversing-key. The use of these currents is well understood in telegraphy, and I have not deemed it essential to show a receiving instrument for the alternating current. The frequency of three hundred periods per second is the function of the highest frequency which need receive serious consideration when telegraphic signaling, even of comparatively high speed, is under consideration.

The foregoing description, while generically applicable to all circuits, is specifically applicable to circuits possessing grounded or common returns, (illustrated in Figs. 1, 3, and 4,) one-half of each of such circuits being made up of a metal conductor. It is desirable, especially in telephony and in the case of high-pressure alternating current, to employ complete metallic circuits, to which the invention is equally applicable.

The outgoing and incoming conductors are both preferably spirally wound around a common core or axis in such directions that the magnetic effects of the outgoing and incoming currents on the core are added. Then the self-induction of the cable is dependent on the square of the number of turns in the outgoing and incoming limbs of the circuit taken together. Such an arrangement is diagrammatically illustrated in Fig. 2, where a sender of alternating current r is illustrated in connection with one metallic side a of the circuit and the remaining metallic side s of the circuit, a responsive apparatus t being indicated in connection with the conductors a and s at the other end of the circuit. I have here illustrated but one sending and one receiving station; but the adaptation of the circuit between two stations, each of which is both sending and receiving, will be well understood by those skilled in the art.

To mathematically illustrate the phenomena of the circuit arrangement illustrated in Fig. 2, suppose an underground telephone-cable is made of copper wire or conductor which measures twenty-two ohms per mile and which from the construction used has an electrostatic capacity of .1 microfarad per mile of wire and that there is fifty miles of wire. Suppose that it is desired to construct this cable in such a way that the decay of the current is indicated by $\varepsilon^{-2.5}$. Then the cable must be made with suitable self-induction, so that the expression

$$\frac{R\,l}{2 \times 10^3}\left(\frac{s}{L}\right)^{\frac{1}{2}}$$

reduces to 2.50.

A solution of the equation

$$\frac{22 \times 50}{2 \times 10^3}\left(\frac{.1}{L}\right)^{\frac{1}{2}} = 2.50$$

shows that L must be .0061 henries per mile of wire. Inserting this value of L and an assumed value of n (say thirty thousand turns per mile of wire) in the expression for the self-inductance, which has been set forth above, it becomes possible to determine the diameter of the iron core that is required for the purpose. This gives

$$.0061 = \frac{4 \times 9.9 \times 9 \times 10^8 \times D^2 \times 200}{10^{20}}$$

and D equals two hundred and ninety mils, which is the theoretical diameter of the iron core if the permeability of the iron is two hundred units. It is not necessary to make the diameter of the core so great, however, in the case of telephony, because the self-inductance of the telephone instruments at each end of the line serves to assist in counteracting the effect of the capacity. This effect would make it possible to reduce the diameter of the core to perhaps not much exceeding two hundred mils, without greatly injuring the telephonic transmission or the diameter of the conducting-wire, thus effecting a proportionate reduction in cost.

If it be assumed that the highest voice-harmonic which it is necessary to preserve for satisfactory telephonic transmission results in an alternating current which has a frequency of one thousand periods per second in a telephonic circuit, then the strengths of the telephonic transmission for the adjusted cable of the immediately-preceding example and a cable of equal length of the usual form made of wires of equal size would be in the relative proportions of

$$\varepsilon^{-2.5} = .081 \text{ and } \varepsilon^{-4.1} = .017$$

The first formula indicates a condition for satisfactory communication, while the latter indicates a condition that would be totally inoperative for telephonic purposes.

In Fig. 2 I have indicated the conductors forming the sides of the metallic circuit in the shape of ribbons; but these conductors may be of any cross-section desired.

In Fig. 6 I have indicated alternating-current devices *u u*, included in metallic circuit whose sides are spaced apart, each wound to create inductance, each being preferably provided with a core.

Any predetermined distribution of the resistance, self-inductance, and capacity may be obtained. To this end the diameter of the conductor may be changed or the size of the core varied or the pitch of the spiral adjusted or various combinations of these changes may be effected to produce the required result.

By providing inductance continuously throughout the cable I am enabled to secure far superior results to those hitherto attained.

Obviously my invention is designed to remove the objection heretofore existing to that part of an alternating-current circuit likely to give rise to capacity. Those portions of an alternating-current circuit that are not likely to cause objectionable capacity obviously need not be arranged in accordance with the invention, the invention herein relating, primarily, to that part of the circuit where the objectionable capacity is likely to exist, the inductance existing substantially continuously throughout this circuit portion.

By the arrangement herein set forth the metallic parts or sides of the circuits where capacity is to be counteracted are caused to create magnetic flux acting to produce impedance, this conducting-wire being in the nature of the helix of an electromagnet, so that the axis of magnetization is substantially parallel with the general course of the conductor.

I have herein particularly described my invention as adaptable for use in connection with cables containing conductors forming circuits including telephonic and telegraphic instruments; but I do not wish to be limited to the use to which the cables may be put; but,

Having thus described my invention, I claim as new and desire to secure by Letters Patent—

1. The method of counteracting capacity in wave-form circuits, which consists in creating inductance substantially continuously throughout the wire of the circuit to suitably neutralize the capacity of the circuit, substantially as described.

2. The method of counteracting capacity in wave-form circuits, which consists in creating a magnetic field substantially throughout the wire of the circuit to suitably neutralize the capacity, the axis of the field being substantially coincident with the general direction of the wire, substantially as described.

3. The method of counteracting capacity in metallic wave-form circuits, which consists in creating a magnetic field substantially throughout the length of each side of the circuit, the axis of the magnetic field being substantially coincident with the respective sides of the circuit in direction, substantially as described.

4. The method of counteracting capacity in metallic wave-form circuits, which consists in creating a magnetic field substantially throughout the length of each side of the circuit, the axis of the magnetic field being substantially coincident with the respective sides of the circuit in direction and causing the said magnetic fields to act cumulatively, substantially as described.

5. The method of counteracting capacity in wave-form circuits, which consists in creating a magnetic field by the transmitted current substantially throughout the wire of the circuit to suitably neutralize the capacity, the axis of the field being substantially coincident with the general direction of the wire, substantially as described.

6. The method of counteracting capacity in metallic wave-form circuits, which consists in creating a magnetic field by the transmitted current substantially throughout the length of each side of the circuit, the axes of the magnetic fields being substantially coincident with the respective sides of the circuit in direction, substantially as described.

7. The method of counteracting capacity in metallic wave-form circuits, which consists in creating a magnetic field by the transmitted current substantially throughout the length of each side of the circuit, the axes of the magnetic fields being substantially coincident with the respective sides of the circuit in direction and causing the said magnetic fields to act cumulatively, substantially as described.

8. The method of counteracting capacity in wave-form circuits, which consists in creating a magnetic field by the transmitted current substantially throughout the wire of the circuit, the axis of the field being substantially coincident with the general direction of the wire, and creating independently a second magnetic field coaxial with respect to the first, substantially as described.

9. The method of counteracting capacity in wave-form circuits, which consists of creating inductance substantially continuously throughout the wire of the circuit, and in adjusting the inductance of the circuit in such

relation with the capacity of the circuit that the attenuation of the current-flow is reduced to any appropriate degree, substantially as described.

10. The method of counteracting capacity in wave-form circuits, which consists in creating a magnetic field substantially throughout the wire of the circuit, the axis of the field being substantially coincident with the general direction of the wire, and in adjusting the strength of the field to produce inductance to suitably neutralize the capacity, substantially as described.

11. The method of counteracting capacity in metallic wave-form circuits, which consists in creating inductance substantially throughout the wires of the circuit, and adjusting the inductance with respect to the capacity to produce a desired degree of neutralization of the capacity, substantially as described.

12. The method of diminishing the attenuation constant of a uniform wave-conductor which consists in increasing the inductance of the conductor sufficiently to secure the required diminution of the attenuation constant, by distributing uniformly along the entire conductor a continuous inductance source.

In witness whereof I hereunto subscribe my name this 26th day of August, A. D. 1901.

DUGALD C. JACKSON.

Witnesses:
C. F. BURGESS,
CHARLOTTE B. NORTON.