J. H. CUNTZ.
ELECTRIC WAVE TRANSMISSION.
APPLICATION FILED MAR. 11, 1905.

995,588. Patented June 20, 1911.

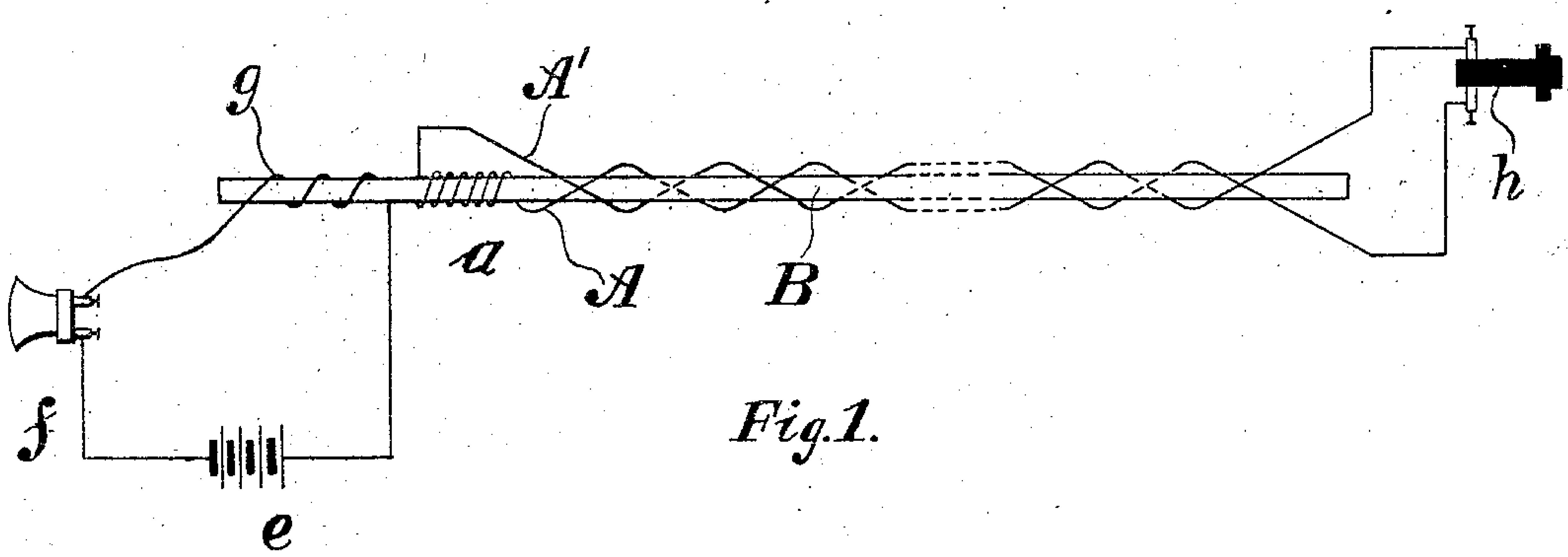


Fig.1.

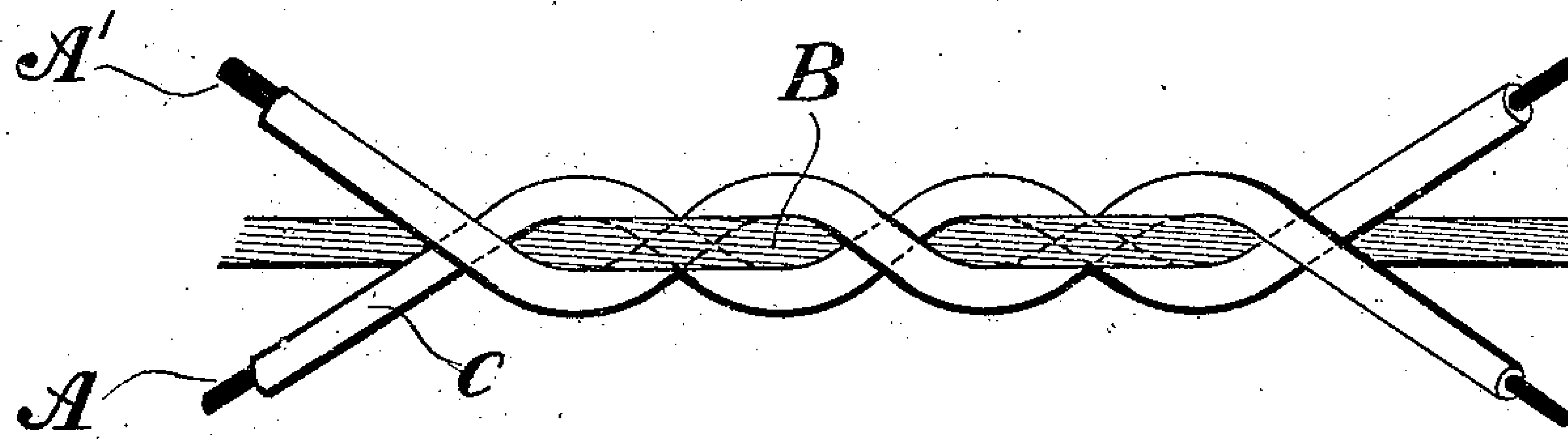


Fig. 2.

Fig. 4.

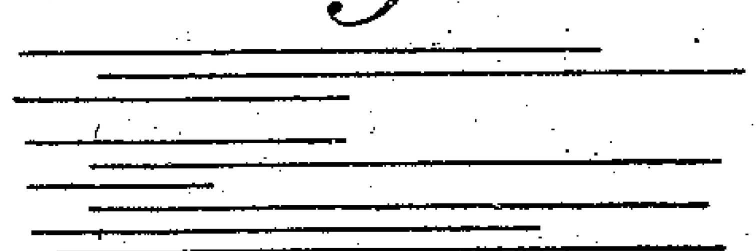
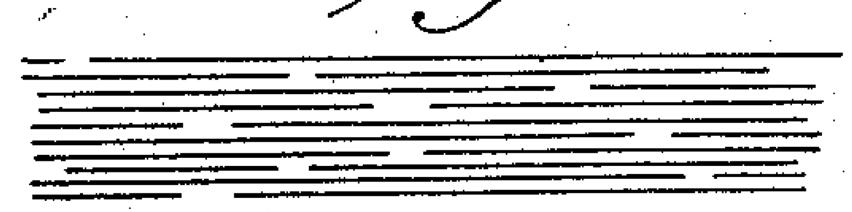


Fig. 4.a



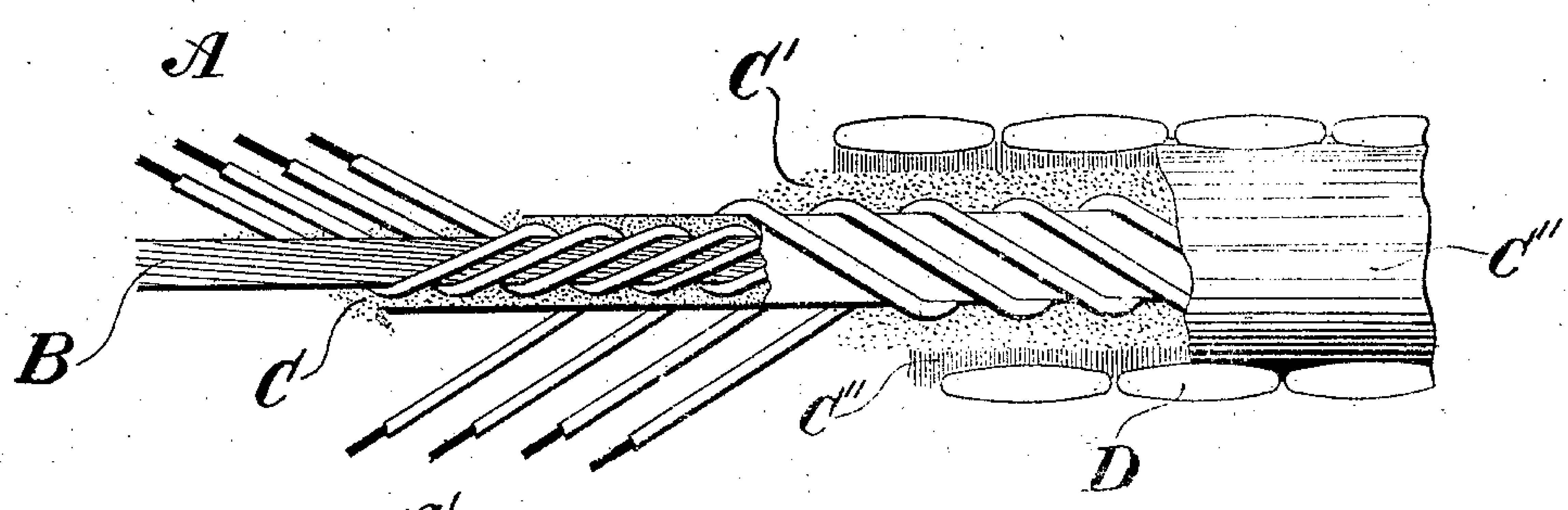


Fig. 3.

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UNITED STATES PATENT OFFICE.

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ELECTRIC-WAVE TRANSMISSION.

995,588. Specification of Letters Patent. Patented June 20, 1911.

Application filed March 11, 1905. Serial No. 249,543.

To all whom it may concern:

Be it known that I, JOHN H. CUNTZ, a citizen of the United States, residing at Hoboken, Hudson county, State of New Jersey, have invented certain new and useful Improvements in Electric-Wave Transmission, of which the following is a specification.

This invention relates to systems of electric circuits in which inductance is distributed in such a manner as to suitably counteract the effect of the distributed capacity.

This invention relates more particularly to complete metallic circuits, having outgoing and returning conductors, and the inductance is produced or increased by disposing the conductors in helical form, with or without a core, and winding the outgoing and returning conductors in opposite senses, so that their inductive effect will be multiplied.

When varying electric currents are transmitted over long circuits they are attenuated in a manner which is indicated by the formula e^{-px} or

$$\frac{1}{e^{px}};$$

that is, at any distance x from the source of current, its strength will have decreased from unity to e^{-px}, or in that proportion, where e is the base of the Napierian system of logarithms, x is the distance, in any convenient units of length, and p, which is termed the attenuation constant, is equal to

$$\sqrt{\frac{C\omega}{2}\left\{(R^2+L^2\omega^2)^{\frac{1}{2}}-L\omega\right\}}$$

In this formula "C" is the electrostatic capacity, "R" the resistance and "L" the inductance, all per unit length, and ω is equal to 2π times the frequency of the current.

When a current is composed of waves of different frequencies, these component waves will be attenuated in different degrees, and the resulting current or combined wave will be not only attenuated but distorted. This is notably the case in telephonic transmission.

When the inductance of a circuit, "L," is practically zero, the above formula reduces to

$$p=\sqrt{\frac{C\omega R}{2}}.$$

When, however, the inductance, "L," is made large compared with the resistance, "R," the expression for p becomes

$$\frac{R}{2}\sqrt{\frac{C}{L}},$$

which is independent of the frequency, so that currents made up of waves of different frequencies will have their components attenuated in the same degree and will not suffer distortion. And also, by increasing "L," the attenuation can be minimized.

I have invented a method for increasing the inductance of a circuit without proportionately increasing its resistance and electrostatic capacity, and this I accomplish by winding my conductor in a helical form, and, where desirable, disposing it about a core, which may be of magnetic or non-magnetic material. The inductance of the circuit can be calculated by the formula

$$L=\frac{4\pi N^2 l\mu A}{10^9},$$

where "L" equals the inductance in henries; "N" equals the turns of the helix per centimeter; "l" equals the length of the portion of circuit under consideration in centimeters; μ equals the permeability of the medium inclosed by the helix, or of the core, and "A" equals the cross-sectional area of the core.

Figure 1 shows, in diagrammatic form, a complete metallic circuit with telephone transmitting and receiving instruments. The outgoing and returning conductors are wound in opposite directions about a core or support. The primary and secondary windings of the induction coil of the microphone transmitter are shown wound on the core of the line circuit, but I do not confine myself to this special construction, and, in general, Fig. 1 is intended to be diagrammatic and the transmitting and receiving apparatus may be any telephone, telegraphic or other suitable apparatus. Fig. 2 shows a portion of a complete metallic circuit, with a core composed of finely stranded material, straight or twisted, and with outgoing and return conductors wound about the core in opposite senses. Fig. 3 shows a portion of a cable with a complete metallic circuit. The outgoing and return legs of the circuit consist each of a plurality of conductors, wound in opposite senses about a core of a finely stranded material. The two legs of the circuit are in different layers, with insulation between, and on the outside is more insulation and a protective sheathing and armoring. Figs. 4 and 4ª show forms of the core in which the individual wires break joints.

In Fig. 1 "A" and "A'" represent the two legs of a circuit, wound in opposite senses about the core, or support, "B." "a" represents the secondary winding of the induction coil of the telephone transmitter, and "g" represents the primary winding of the same induction coil. In practice they would be preferably wound over each other, but are shown separate in the diagram for the sake of clearness. "e" represents an electric battery or other source of current, and "f" represents a microphonic or other telephone transmitter. "h" represents a telephone receiver. Although I have here shown telephone transmitting and receiving apparatus, I do not wish to confine myself to these, but my transmitting and my receiving apparatus may be any suitable telephone, telegraph or other apparatus.

In Fig. 2, "A" and "A'" represent the conductors forming the two sides of a circuit, wound in opposite senses about the core "B" which is composed of finely stranded material. "C" represents insulation about each conductor.

In Fig. 3, "A" and "A'" represent respectively the plurality of conductors forming the two sides of a circuit, wound in opposite senses about a core "B" consisting of finely stranded material. "C" represents insulation between the outgoing and return conductors; "C'" represents insulation outside the outer layer of conductors; "C''" represents sheathing or jute or other protective material; and "D" represents armor or similar material for protecting the cable.

To show the benefits secured by my invention, I will take as an example an underground telephone or telegraph circuit between two points 250 miles apart. I will assume a circuit composed of conductors each of which has a resistance of 11-ohms per mile and the mutual electrostatic capacity between which is .08 microfarads per mile. When constructed in the usual way, with the outgoing and return conductors twisted up together in the same direction so as to avoid inductive effects, such a circuit will have negligible inductance, and the attenuation constant "p" will equal

$$\sqrt{\frac{C\omega R}{2}}$$

For a wave frequency of 1000, ω will equal 6280, approximately. "C," in the present case, is .08 microfarads per mile, and "R" is the sum of the resistances of both sides of the circuit, or 22-ohms per mile. Substituting these values in the above formula, we obtain a value for "p" equal to .074 per mile, approximately. Currents having a frequency of 1000 per second will therefore be attenuated, on such a circuit, in the proportion of

$$1 \text{ to } \frac{1}{e^{px}} \left(= \frac{1}{e^{250}p} = \frac{1}{e^{18.5}} = \frac{1}{107,000,000} = \frac{1}{10^8}, \text{ approximately.} \right)$$

That is to say, less than

$$\frac{1}{100,000,000}$$

of the current will arrive at the receiving end, when the frequency is 1000. For other frequencies the current will be attenuated in greater or less degree, and when the current is composed of waves of different frequencies, as in telephonic transmission, the resultant wave will be distorted.

Now, constructing the above circuit according to my method, I take the outgoing and return conductors and wind them, in opposite senses, about a core. As an illustration I will take a core composed of fine iron wires, having a total cross-sectional area of 0.125 square centimeter and whose permeability at the magnetizations employed will be about 180. I wind my conductors helically, with a pitch of 2 centimeters, so that taking both sides of the circuit together, there will be one turn per centimeter. The value of the inductance per mile of this line will therefore be, by the formula already given for "L", 0.045 henry. By winding the conductors in the manner described, I have increased their average length, and therefore their resistance, by about 50 per cent., and the capacity will be increased in no greater degree, if as great a one. The mutual capacity of this circuit as now constructed will therefore not be more than 0.12 microfarad per mile, and the sum of the resistances of both sides of the circuit 33-ohms per mile. Substituting all these values in the formula

$$p = \frac{R}{2}\sqrt{\frac{C}{L}},$$

we obtain

$$p = \frac{33}{2}\sqrt{\frac{.12 \times 10^{-6}}{.045}} = .027,$$

which is the attenuation constant per mile. The attenuation for the whole line, 250 miles long, will therefore be

$$e^{-(250 \times .027)} = e^{-6.75} = \frac{1}{850};$$

or in other words,

$$\frac{1}{850}$$

of the current will arrive at the receiving end, and moreover, waves of different frequencies will be attenuated in the same degree.

As another example, take a submarine cable 100 nautical miles long. Let each side of the complete metallic circuit have a resistance of 5-ohms per nautical mile and let the mutual electrostatic capacity be 0.3 microfarads per nautical mile. When constructed in the usual non-inductive manner, the inductance of such a circuit will be practically zero. The attenuation constant, for a frequency of 1000, will therefore, by the formula

$$p=\sqrt{\frac{C\omega R}{2}}, .097$$

per mile, and the attenuation e^{-px} will equal

$$e^{-(100\times.097)}=e^{-9.7}\doteq\frac{1}{16200},$$

approximately, for the 100 mile cable. If this cable is constructed according to my method, using a core of fine iron wires with a permeability of 180 and a cross-sectional area of 0.25 square centimeter, and winding the conductors with a helical pitch of 2 centimeters, the inductance will be 0.1048 henry per nautical mile. I can use a single conductor for each side of the circuit, or a plurality of conductors, and their cross-section may be circular, rectangular, and any other shape. Assuming that I use a single conductor, of circular section, the length of circuit will be about doubled by winding both sides in the manner indicated, and the resistance and capacity will be taken as increased in the same ratio. The value for the attenuation constant per mile, will therefore be

$$p=\frac{R}{2}\sqrt{\frac{C}{L}}=\frac{20}{2}\sqrt{\frac{0.6\times10^{-6}}{0.1048}}=.024.$$

The attenuation for the 100-mile cable will then be

$$e^{-(100\times.024)}=e^{-2.4}=\frac{1}{11},$$

approximately, and waves of all frequencies will be attenuated in the same degree.

As a third example, let us take another submarine cable 100 miles in length, but having smaller conductors with a resistance, for each leg of the circuit, of 15-ohms per nautical mile, and a mutual capacity of 0.1 microfarad per nautical mile. The attenuation, when constructed in the usual non-inductive manner, will be the same as before, or

$$\frac{1}{16200}$$

for the 100-mile cable. When constructed according to my method, with the same core as before, and wound with the same helical pitch, the length of the conductors, owing to their smaller section, will be increased only about 70 per cent. Taking the resistance and the capacity as increased in the same ratio, the attenuation constant per mile will be

$$\frac{51}{2}\sqrt{\frac{.17\times10^{-6}}{.1048}}=.032;$$

and the attenuation for the 100-mile cable will be

$$e^{-(100\times.032)}=e^{-3.2}\doteq\frac{1}{24.5}$$

approximately, and waves of all frequencies will be attenuated in the same degree.

From these examples the great advantages of my method of constructing electric circuits can readily be seen. When desirable, the inductance of my circuits can be increased by increasing the number of turns of the conductor, by increasing the cross-sectional area of the core, by using core material of higher permeability, or by increasing the permeability in other ways.

The electric circuits of the present application may be constructed with or without a core, and the latter, if used, may be of magnetic or non-magnetic material. When composed of conducting material, the core should be finely divided in order to minimize eddy currents, and if of magnetic material it should have the qualities of low hysteresis and high permeability.

When used for telegraph and telephone purposes, the currents are so small and the turns of the conductor are so few, that very feeble magnetic fields are created, and the cyclic changes of magnetism, whether occurring by themselves, or superposed upon stronger steady currents, are so small as to reduce hysteresis to a minimum, the hysteresis curve becoming practically a straight line, inclosing no area.

Longitudinally, the core may be constructed in separate sections in order to diminish magnetic retentivity and electrostatic effects; but, in order to preserve mechanical continuity and tensile strength, the core, if divided longitudinally, may have its individual wires "break joints" as shown in Figs. 4 and 4[a].

In my circuits, as already stated, I may use conductors having cross-sections of any suitable shape. Different shapes possess various advantages. For the same sectional area, single circular conductors have the smallest surface, and will have a minimum area of contact on their insulation with each other, and so will have a small mutual capacity. On the other hand, circuits composed of a plurality of small circular conductors, or with flat, ribbon-shaped conductors will have the advantage of compactness, will require less outside insulation and will make a smaller and stronger cable. An advantage of increased surface of the conductors is that for rapidly alternating currents, which are mainly confined to the surface layers of conductors, conductors with relatively large surface offer less resistance, in proportion to the total cross-section, than conductors with less surface.

Any suitable insulation may be used, it being desirable, of course, to use that which will have the lowest specific inductive capacity compatible with other requirements. For instance, particularly on land lines, I may use paper insulation with as much air space as possible, and when a plurality of wires is employed, the two sides of the circuit being wound in layers, I may use a perforated or continuous insulating strip between the layers, made of paper or other material. In some cases I may use a strip or a cylinder of paper or of some other insulating material as a core or support to wind my conductors upon. A plurality of circuits, such as have been described herein, may be made up into one cable.

The electric circuits herein described may be used for telephone, telegraph, power transmission and all other purposes, and I do not limit myself to any special use, nor to the precise apparatus and construction shown herein, but

What I claim and desire to secure by United States Letters Patent is as follows:

1. In a line for the transmission of varying electric currents, a paramagnetic core, and outgoing and returning continuous conductors disposed helically in opposite senses about said core, so as to counteract suitably the electrostatic capacity of the line.

2. In an electric cable, a core of paramagnetic material, a conductor wound helically about said core and insulated therefrom, a second conductor wound in the opposite direction about said core and insulated therefrom and from the first-named conductor, so as to counteract suitably the electrostatic capacity of the cable.

3. An electric circuit in which the outgoing and returning parts of the circuit consist of continuous conductors disposed helically in opposite senses about a supporting non-current carrying core, said core consisting of stranded paramagnetic material, so as to counteract suitably the electrostatic capacity of the circuit.

4. In an electric circuit, outgoing and returning conducting wires substantially continuously wound, in opposite senses, to create inductance sufficient in amount to suitably counteract the capacity of the circuit, and a magnetizable core for said wires extending substantially throughout the length thereof, the said core being metallically discontinuous.

5. In a system of telephone transmission, a complete metallic circuit, a magnetic core extending substantially throughout the circuit, and windings of the induction coil of the microphone transmitting apparatus disposed about said core.

In testimony whereof, I have signed my name to this specification, in the presence of two subscribing witnesses, this 10th day of March, 1905.

JOHN H. CUNTZ.

Witnesses:
WM. C. CUNTZ,
HERMANN F. CUNTZ.