No. 761,995. PATENTED JUNE 7, 1904.

M. I. PUPIN.

APPARATUS FOR REDUCING ATTENUATION OF ELECTRICAL WAVES.

APPLICATION FILED FEB. 6, 1903.

NO MODEL.

Fig. 1.

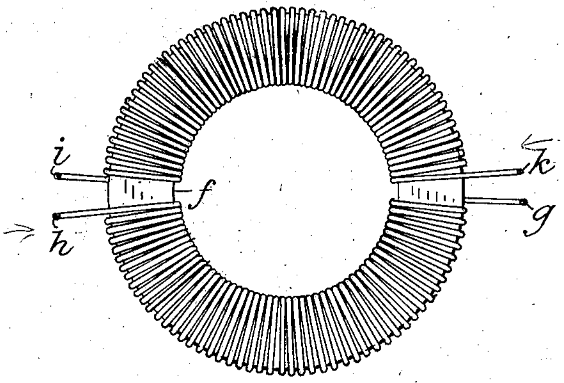


Fig. 2.

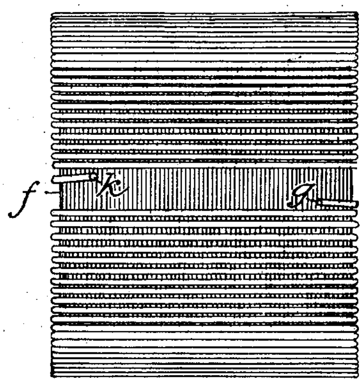


Fig. 3.

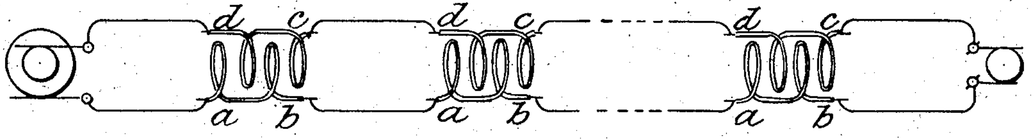


Fig. 4

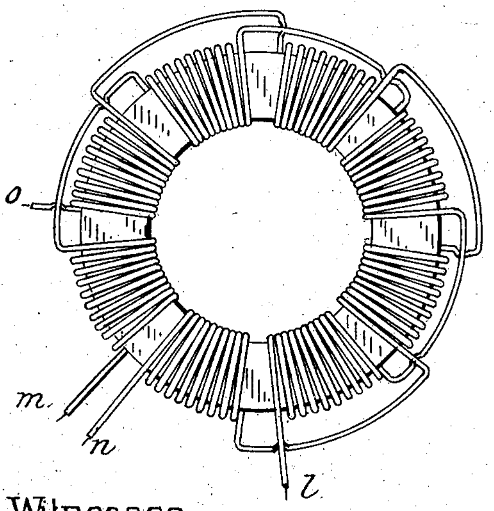
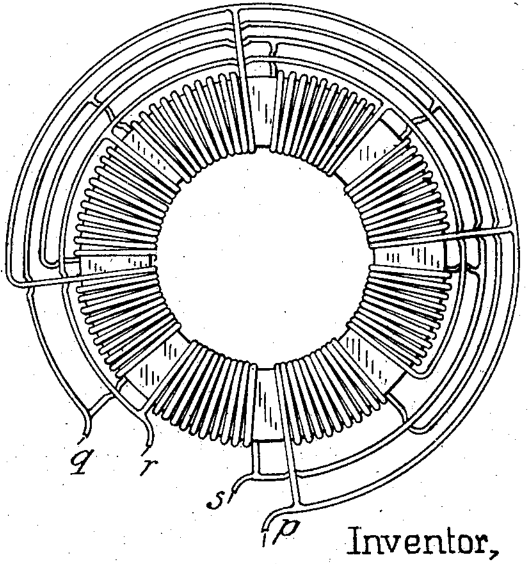


Fig. 5.



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No. 761,995. Patented June 7, 1904.

UNITED STATES PATENT OFFICE.

MICHAEL I. PUPIN, OF NEW YORK, N. Y., ASSIGNOR TO AMERICAN BELL TELEPHONE COMPANY, OF BOSTON, MASSACHUSETTS, A CORPORATION OF MASSACHUSETTS.

APPARATUS FOR REDUCING ATTENUATION OF ELECTRICAL WAVES.

SPECIFICATION forming part of Letters Patent No. 761,995, dated June 7, 1904.

Application filed February 6, 1903. Serial No. 142,193. (No model.)

To all whom it may concern:

Be it known that I, MICHAEL I. PUPIN, a citizen of the United States of America, and a resident of New York city, borough of Manhattan, in the county and State of New York, have invented certain new and useful Improvements in Apparatus for Reducing Attenuation of Electrical Waves, of which the following is a specification.

This invention relates to improvements of inductance-coils suitable for loading wave-conductors. The loading should be in accordance with the directions given in my United States Patents Nos. 652,230 and 652,231, dated June 19, 1900. It is known that such inductance-coils can be constructed with or without iron cores. Coils without iron cores occupy too large a volume for a given inductance to be suitable for loading telephone-cables. Iron cores, on the other hand, introduce internal losses of energy which increase rapidly with the frequency, and thus produce distortion of the transmitted complex harmonic waves—such, for example, as accompany speech transmission. It is known that iron-core losses can be diminished by a sufficiently-high degree of lamination and a suitable diminution of the ampere-turns of the winding. In the case of cores which do not form a closed magnetic circuit this is easily accomplished. If, however, the core forms a closed magnetic circuit, then a much stronger magnetization results from a given number of ampere-turns, and accordingly a much larger core loss. In order to reduce for a given inductance the core loss in this case to a predetermined limit, it is necessary to employ a much finer subdivision of the iron and a smaller number of turns.

In the accompanying sheet of drawings, which form a part of this specification, Figure 1 is an end view, and Fig. 2 is a side view, of a twin coil having a core made up of plates of iron. Fig. 3 represents a long-wave conductor having a number of twin coils, such as are illustrated in Figs. 1 and 2, inserted at periodically-recurring points along the conductor, preferably at equal distances, as the drawings indicate. Fig. 4 represents a twin coil, each coil of the pair consisting of four parts, which are connected in series and arranged symmetrically around the magnetic circuit. Fig. 5 represents a twin coil in which each coil of the pair consists of four parts connected in parallel and arranged symmetrically around the magnetic circuit.

I have shown that theoretically the lamination in a core forming a closed magnetic circuit can be sufficiently refined and the number of ampere-turns can be sufficiently reduced to obtain negligibly small iron-core loss of energy; but on account of its cost in many practical cases an inductance-coil constructed in this manner will not answer, although from a theoretical point of view it is an ideal type of coil. I find from a study of the practical conditions in telephonic and telegraphic transmission that coils with cores forming a closed magnetic circuit can be constructed which will fulfil all practical conditions and at the same time be efficient and economical. These practical conditions will now be discussed in their proper order. Then an inductance-coil with an iron core forming a closed magnetic circuit will be described which satisfies all these practical conditions. Finally, a method will be disclosed which will enable one skilled in the art to construct an efficient and economical coil of this kind. The inductance-coils constructed in accordance with this method and wave-conductors loaded with such coils form the invention disclosed herein.

First condition.—A coil suitable for loading a wave-conductor should for a given inductance be as small as possible. A coil of a given inductance will occupy a small volume if its winding is distributed over an iron core forming a closed magnetic circuit, as shown in Figs. 1 and 2 of the drawings and in the specification of my United States patents above referred to. A still greater reduction in the volume is obtained by placing two windings, one for the outgoing and the other for the return wire of the circuit, on the same core. In this manner the inductance of each winding is increased by the mutual inductance with the other winding. The core loss of energy per unit of inductance in compact coils of this kind is generally large. The principal object of this invention is to reduce this loss to an economical minimum by adopting a method of construction which will be described further below.

Second condition.—The insertion of inductance-coils should not disturb the symmetrical distribution of the current-wave with respect to the two sides of a symmetrical wave-conductor, because such a disturbance would produce external induction, which in the case of telephone-cables would result in cross talk.

The symmetrical distribution of a wave with respect to a symmetrical wave-circuit is not disturbed when for each coil in the outgoing wire there is an equal coil at a homologous point of the return-wire. This distribution of the coils preserves the symmetry of the wave-conductor.

When the windings of the two sides of the wave-circuit are placed on the same iron cores, they should be equal and stand in the same relation to the core. In other words, the two windings must have the same inductance and resistance. Their capacity should be negligibly small and can easily be made so, since the thickness of the insulation commonly employed is sufficiently great to insure this condition.

Third condition.—There should be no mutual inductance between inductance-coils belonging to different circuits when placed near each other, as in the case of loading a telephone-cable carrying a large number of circuits. This is accomplished by distributing the winding of a coil over the iron core in such a way that no appreciable external magnetic field is produced by the transmitted waves. Such a distribution is a solenoidal distribution. The most convenient form of a solenoidal winding is a uniformly-distributed winding over a ring-shaped or toroidal iron core.

There are conditions under which it is indispensable to employ coils with iron cores. For instance, in loading underground and submarine cables economy in space demands efficient coils of large inductance per unit volume. In such cases iron should be employed. Economy in space is not the only consideration which recommends the employment of iron cores. Two other very important considerations will be stated here. They are: First, for all frequencies which are of importance in telephony the resistance corresponding to a given inductance can be made considerably smaller in the case of a coil with a properly-constructed iron core than in one having no iron core; second, it is much more easy to construct a practical form of coil possessing no external induction when an iron core is employed than without it—all that is required is that the core should be uniform throughout and of symmetrical form and that the coil should be distributed over it symmetrically and uniformly.

I shall now briefly describe various forms of solenoidal windings. In the case of twin coils referred to above—that is, coils consisting of two equal windings on the same core—each winding can be uniformly distributed over the ring core, so that one winding covers entirely the other and each winding by itself will be solenoidal. This arrangement is the closest approach to the ideal solenoidal winding, but not quite as economical as some other solenoidal forms; but in this case it would be somewhat difficult to give each coil the same inductance and the same resistance. To obviate this difficulty, the following arrangement is recommended: Wind two coils of the same number of turns each of which is uniformly distributed over the uniform iron core. They will completely overlap and should be properly insulated from each other. Divide each coil into two equal parts and connect each inside coil to its diametrically opposite outside coil. We shall thus obtain two equal coils each of which is uniformly distributed over the uniform core.

Figs. 1 and 2 of the accompanying drawings represent an arrangement which under certain conditions will possess the properties of a solenoidal winding. A ring-shaped iron core *f* is built up of iron plates of predetermined thickness. Iron wire can be used for this purpose just as well, but not so economically as regards space. Two equal windings *ki* and *hg* are connected to the two sides of a circuit on this core. Each winding is distributed over one-half of the ring core. The two windings together form a solenoidal winding, and they will therefore produce no external field when properly connected in a symmetrical circuit. Other forms of windings to produce the same result are represented in Figs. 4 and 5 of the accompanying drawings. In Fig. 4 each winding is divided into four equal parts connected in series, and the various parts of each winding are distributed symmetrically over the ring core. The arrangement represented in Fig. 5 differs from that of Fig. 4 in the manner in which the various parts of each winding are connected. In the arrangement of Fig. 5 the connection is a parallel connection. In order to obtain the same inductance and resistance in the parallel arrangement, it is necessary to have in each part four times as many turns and sixteen times as much resistance as in the series arrangement. In this arrangement (represented in Figs. 4 and 5) each winding by itself is approximately solenoidal, and this approximation is the closer the larger the number of parts into which each winding is divided. When there are n parts to each winding, then for a given inductance there must be n times as many turns and n^2 as high resistance in each part of the parallel arrangement as in the series arrangement. It is easily seen that the weight of copper and the space occupied by it are very nearly the same in each case. The parallel arrangement would be preferable in the case of coils of high inductance and small ohmic resistance, such as are required in the loading of overhead telephonic long-distance wave-conductors of low resistance. In this case large iron ring cores are required and a heavy copper wire for the winding. A subdivision of such copper winding must be introduced in order to avoid eddy-current losses. These losses are serious, particularly for higher frequencies which occur in telephony, unless the diameter of the copper wire is suitably reduced. It is proportional to the cube of the diameter of the wire, as I have demonstrated mathematically and verified experimentally. A very safe rule to follow is this: Do not wind coils containing iron cores for loading telephone and telegraph wires with wire of a greater diameter than .09 cm. Copper wire of diameter equal to .05 cm. gives exceedingly good results. In ballast-coils containing no iron core the subdivision of the copper wire should be considerably higher—say one-half of the size given above—particularly when a low-resistance wave-conductor is to be loaded. This subdivision can be most conveniently effected in cases of this kind by using fine wire in the various parts of the two windings and then connecting these parts in parallel in accordance with the rule just given. The parallel arrangement requires more turns than the series arrangement; but where the coils are wound by a machine this is not of great moment.

Fig. 3 of the accompanying drawings represents by diagram a loaded wave-conductor, the loading-coils being twin coils. The left-hand part of this diagram represents the wave-conductor near the transmitting-station and the right-hand part represents the same conductor near the receiving-station. The dotted parts indicate merely the rest of the wave-conductor. The coils *ab cd* are the twin coils. One of the component parts is in the outgoing wire and the other is in the return-wire of the circuit. The connection, as represented in Fig. 3, is such that the currents which at any moment circulate in the two windings should magnetize the core in the same sense; otherwise the inductance of one winding will not be increased by the mutual inductance with the other winding. To illustrate this point, suppose that we replace the coils *ab cd* of Fig. 3 by the coils represented in Fig. 1 and Fig. 2, then the terminals *g h i k* will fall upon the terminals *a b c d*, respectively. If we replace it by the coils represented in Fig. 4, then the terminals *l m n o* will fall upon the terminals *a b c d*, respectively. Finally, if we replace it by the coil represented in Fig. 5 then the terminals *p q r s* will fall upon the terminals *a b c d*, respectively.

Fourth condition.—This condition refers to the lamination of the iron core and of the copper winding in order to reduce energy losses due to eddy-currents. It is a fact that in coils the construction of which satisfies the three conditions named above the energy losses due to eddy-currents in the winding can be easily made very much smaller than those in the iron core, which latter will therefore receive the principal attention here. These iron-core losses of energy are, as well known, due to Foucault currents and hysteresis. There are empirical formulæ which enable one to calculate these losses in any given apparatus working by varying magnetic fields, like dynamos, motors, and transformers. Certain experimental data must for each apparatus be previously determined. These formulæ all refer to apparatus working with high magnetizations, such as are usually employed in ordinary commercial work. They have no application to the construction of inductance-coils intended for loading wave-conductors considered in this application where extremely-weak magnetizations come into operation. Besides, the method of construction of iron cores for inductance-coils which forms the foundation of this invention takes into account not the absolute value of the iron-core loss of energy, but the exact increase in resistance of the coil-winding due to this loss. Since the increase in efficiency of transmission resulting from loading a wave-conductor depends on the amount of resistance introduced per unit of inductance by the inserted inductance-coils, it is evident that increase of resistance due to iron-core losses is a very important quantity. There is no basis whatever in the existing state of the art for exact calculations relating to this subject.

The question as to how much resistance given inductance-coils with iron cores will introduce into a properly-loaded wave-conductor cannot be answered broadly, not even in the case of the coils of so simple a construction as is considered here. I have found, however, by my own investigations and experiments that within limits of magnetization which by suitable precautions can be made to satisfy all practical requirements in properly-loaded wave-conductors for telephony and telegraphy this question can be answered with mathematical accuracy.

On pages six and seven of my United States patents above mentioned I have described an inductance-coil in which the increase in resistance due to iron-core losses is small per unit of inductance for all frequencies under consideration, particularly when unannealed iron plates are employed, which, as is ordinarily the case, have a permeability equal to 100.

Such inductance-coils are perfect from a purely technical point of view, because a properly-loaded wave-conductor—say a loaded telephone-cable—will have with these ideal inductance-coils the same attenuation constant for all frequencies which it is intended to transmit. Hence its transmission will be distortionless. As above stated, however, from an economic point of view these ideal inductance-coils are in many practical cases not acceptable on account of the expense which their construction involves.

It is a well-known fact that in telephony particularly and to a certain extent in telegraphy also a certain amount of distortion is necessarily introduced by the terminal apparatus without materially interfering with the quality of transmission. It is evident, therefore, that the resistance of the loading-coils due to iron-core losses need not be negligibly small, provided that the distortion caused by it is a small part of the distortion already existing in consequence of the terminal apparatus. The constructor of the inductance-coil must be guided, therefore, by the permissible distortion on the one hand and on the other hand by economic considerations which fix the cost of the coils within definite limits. It is evident, therefore, that between the extremes of an ideal coil of prohibitive cost and a cheap coil which introduces considerable distortion there must exist an interval of iron-core losses within which the coil will satisfy both the conditions of economy and of efficient distortionless transmission. This interval for telephonic transmission has been determined by me experimentally, and it can be described as follows: The increase of resistance due to energy losses in the iron cores of the loading-coils should for a frequency as high as 1,500 p. p. s. be smaller than the true ohmic resistance of the copper of the loaded wave-conductor and greater than one-tenth part of such true ohmic resistance. It is easily seen that in loading a high-resistance telephone-cable the lower-resistance limit will be approached, and in loading a low-resistance air-line an approach to the upper-resistance limit will be sufficient. The true ohmic resistance of the loaded wave-conductor includes the true ohmic resistance of the inductance-coil windings, which can always in practice be much smaller than the true ohmic resistance of the wave-conductor before loading and is, in fact, usually about one-fourth in the case of low-resistance air-lines and one-tenth in the case of high-resistance cables. It will therefore be seen that the rule that the increase in the resistance due to energy losses in the iron cores of the loading-coils shall be smaller than the true ohmic resistance of the copper of the loaded wave-conductor means, approximately speaking, that it shall not be greater in any coil than five times the true ohmic resistance of the winding of the coil, and the rule that the resistance due to energy losses in the iron cores shall be greater than one-tenth part of such true ohmic resistance means in the case of coils for loading cables that the increase of resistance due to iron-core losses shall be greater than the true ohmic resistance of the coil. Therefore, expressing the rule so as to refer to the coils themselves without reference to the loaded conductor, the rule of economical construction herein set forth requires that the increase of resistance due to iron-core losses of the coil shall for a frequency of 1,500 p. p. s. and for current strengths used in telegraphy and telephony be not less than the true ohmic resistance of the coil nor more than five times such true ohmic resistance.

The problem of loading telegraph-wires is much simpler than the problem of loading telephone-wires, because the frequencies involved are as a rule considerably lower than those involved in telephony. In considering the construction of coils for telephony I have taken a frequency of 1,500 p. p. s. as the standard. For telegraphy the standard frequency will be generally considerably lower, and the rules given here will be applied to the standard frequencies selected. These physical and economic considerations are necessary, because in order to satisfy the first, second, and third conditions mentioned above it is necessary to employ coils with iron cores forming practically-closed magnetic circuits over which the winding is symmetrically distributed. In such coils the iron-core losses of energy corresponding to a given inductance and magnetizing force are much greater than in coils with open iron cores. To reduce these, it is necessary to laminate and employ a much smaller number of turns in the windings. Hence the excessive cost of construction if the increase in resistance due to iron-core losses of energy is to be negligibly small. I have established by theoretical and experimental investigations two mathematical laws which enable one skilled in the art to construct inductance-coils, giving for any frequency and current strength for telephonic or telegraphic purposes a predetermined increase in resistance per unit of inductance and will therefore enable the constructor to build coils which will fall within the limits specified. These investigations will be published in the near future. The resulting laws will be found to be in harmony with everything disclosed in my prior patents and papers relating to loaded conductors. These two laws will be explained now.

First law.—In Figs. 1 and 2 of the accompanying drawing let the iron core be composed of ring-shaped iron plates, which are insulated from each other. Let a equal external diameter of the plates, b equal internal diameter of the plates, d equal thickness of one plate, n equal number of plates, μ equal permeability of the iron, σ equal specific resistance of the plates in C. G. S. units, f equal frequency of a simple harmonic magnetizing force, s equal number of turns in the winding, L equal inductance of the coil, R_1 equal resistance of the coil due to Foucault-current losses in the core. Then we shall have the following relations:

$$10^9 L = 2\, s^2\, n\, d\, \mu \log \frac{a}{b}$$

$$R_1 = \frac{4}{3\sigma}\, \pi^3 f^2\, d^2\, \mu\, L.$$

It will be found that in the case of the best iron plates available at present and working with ordinary telephonic and telegraphic frequencies and strength of current and with a proper adjustment of the number of turns as specified further below we can have μ equals 100, at least, and σ equals 1.3×10^4, in C. G. S. units at most.

As a specific example let L equal .2 Henrys, and let it be required that R_1 equals 8 ohms at a frequency of 1,500 p. p. s. The thickness of the plates will be d equals .0075 cm. Such coils placed every half-mile in a high-resistance telephone-cable (170 ohms per mile of circuit) or every two miles in a low-resistance telephone air-line (4 ohms per mile of circuit) will satisfy all the requirements of correct loading, and the increase in resistance due to Foucault currents will be within the interval specified above—that is, provided the hysteresis loss can be kept down to certain small values. The thickness of plates indicated is well within economic limits.

The construction of the inductance-coils considered here must satisfy the low hysteresis loss condition in order to keep the increase in resistance due to iron-core losses down to a predetermined limit. In order to avoid too high hysteresis losses and yet obtain the inductance given above, the size and number of plates and the number of turns in the winding must be properly determined.

It is a generally accepted belief that, according to Lord Rayleigh's investigations, there is no hysteresis loss in hard-drawn iron so long as the magnetizing force per centimeter is less than .04 in C. G. S. units. Under these conditions there would be then no increase in resistance in the magnetizing-coil due to hysteresis. I find, however, that this supposition is wrong and can lead to results which are very detrimental to the efficiency of the inductance-coils here considered.

Second law.—The loss is small and cannot be detected by Lord Rayleigh's methods; but nevertheless the increase in resistance due to it can be very large, particularly with the high-inductance coils considered here. According to my investigations the hysteresis loss per second in the case of weak sinusoidal magnetizations up to about 10 C. G. S. lines of force per square cm. is proportional to the cube of the amplitude of the induction density and also proportional to the frequency. The increase in resistance R_2 in ohms due to this loss can be expressed by the following formula: $R_2 = As^3 Cf$, where A is a constant to be determined experimentally, s is the number of turns in the coil-winding, C is the magnetizing-current in amperes, and f is the frequency of the current. The experimental constant A depends on the size and shape of the iron core. I have found that in the case of coils considered here, in which the core is laminated suitably, so that R_1 is about one-tenth of the true resistance of high-resistance telephone-cables and about equal to the true resistance of low-resistance air-lines for a frequency of 1,500 p. p. s., then for currents up to five milliamperes and a frequency of 1,500 p. p. s. R_2 will be a small fraction of R_1 as long as the number of turns per centimeter of the shortest magnetic line of force is not greater than 60. This much will suffice to give a practical approximation of the constant A and to enable one skilled in the art to adjust the size and number of the iron plates of the core and the number of turns in the winding.

To take the above example, let there be 666 plates. Since each one is .0075 cm. thick, we shall have in the formula for L the product $n\,d$ equals 5. Let the internal diameter of each plate be 4 cm. and the external diameter 8 cm. Hence $\log \frac{a}{b} = .7$ (approx.) Finally, since L equals .2 and μ equals 10^2, we shall have $.2 \times 10^9 = 2 \times s^2 \times 10^2 \times 5 \times .7$. Hence s equals 535 turns.

The shortest magnetic line of force is a little more than 12 cm. Hence there will be less than 60 turns per cm., and the increase in resistance due to hysteresis will be, up to 5 milliamperes and 1,500 p. p. s., a small fraction of 8 ohms, (R_1.)

In the construction of the cores for coils (represented by Figs. 1, 2, 4, and 5) iron wire can be employed in place of iron plates. Practically the same formulæ and the same general remarks will apply to iron-wire cores; but it should be observed then that in the mathematical formulæ given above d means the diameter of the iron wire and μ for cores of iron wire has only about one-half the value which it has for cores made up of iron plates on account of the small air-spaces between the various turns of the iron core. It should also be observed that in place of the numerical factor $\frac{4}{3}$ we should have in the case of iron wire the factor $\frac{1}{2}$; but it is to be understood that in the expression for this inductance L the factor $n\,d$ must be replaced by the actual height of the core.

Having now described my invention in the best way known to me for practicing the same, what I claim, and desire to secure by Letters Patent, is—

1. An inductance-coil having an iron core,

forming a closed magnetic circuit, in which the resistance due to hysteresis is smaller than the resistance due to Foucault currents for current strengths and for the highest important frequencies (about 1,500 p. p. s.) in telegraphy or telephony, substantially as described.

2. An inductance-coil having an iron core, forming a closed magnetic circuit, in which the resistance due to iron-core losses of energy is smaller than five times the true ohmic resistance of the winding of the coil for all telephonic frequencies up to 1,500 p. p. s. and for current strengths of importance in telegraphy or telephony, substantially as described.

3. An inductance-coil consisting of an iron core, forming a closed magnetic circuit and the winding of which is distributed over this core uniformly and symmetrically, the core and winding being adjusted in such a way as to give the coil for a predetermined frequency and current strength a predetermined inductance and resistance, substantially as described.

4. An inductance-coil consisting of an iron core, forming a closed magnetic circuit, the winding of which is distributed over this core uniformly and symmetrically, the core and winding being adjusted in such a way as to give to the coil for a predetermined frequency and current strength a predetermined inductance and resistance, and to give a resistance due to hysteresis, which is smaller than the resistance due to Foucault currents for the current strengths and for the highest important frequencies (about 1,500 p. p. s.) in telegraphy and telephony, substantially as described.

5. An inductance-coil consisting of an iron core, forming a closed magnetic circuit, and a winding which is distributed over this core uniformly and symmetrically, the core and winding being adjusted in such a way as to give to the coil for a predetermined frequency and current strength a predetermined inductance and resistance, and to insure that the resistance due to iron-core losses of energy is smaller than five times the true ohmic resistance of the windings of the coil for all telephonic frequencies up to fifteen hundred pulsations per second and for current strengths of importance in telegraphy and telephony, substantially as described.

6. A twin inductance-coil consisting of an iron core, forming a closed magnetic circuit, over which the winding is distributed uniformly and symmetrically, the core being adjusted in such a way as to give to the coil for a predetermined frequency and current strength a predetermined inductance and resistance, substantially as described.

7. A twin inductance-coil consisting of an iron core, forming a closed magnetic circuit, over which each winding is distributed symmetrically and uniformly, the core and the windings being adjusted in such a way as to give to the coil for a predetermened frequency and current strength a predetermined inductance and resistance, substantially as described.

8. In a system for electrical-wave transmission, a non-uniform conductor, consisting of a uniform conductor with inductance-coils, each consisting of an iron core forming a closed magnetic circuit, over which the winding is distributed symmetrically and uniformly, connected in the uniform conductor at periodically-recurring points, the inductance, resistance and capacity of the interposed inductance-coils being adjusted in such a way as to give for the highest frequency to be transmitted, with the inductance, resistance and capacity of the uniform conductor, a predetermined inductance, resistance and capacity per unit length, the resistance due to iron-core losses of energy in the coils being smaller than the true ohmic resistance of the loaded conductor for the highest frequency to be transmitted, substantially as described.

9. In a system for electrical-wave transmission, a non-uniform wave-conductor, consisting of a uniform conductor with twin inductance-coils each consisting of an iron core, forming a closed magnetic circuit, over which the winding is distributed symmetrically and uniformly, connected in the uniform conductor at periodically-recurring points, the inductance, resistance and capacity of the interposed inductance-coils being adjusted in such a way as to give for the highest frequency to be transmitted, with the inductance, resistance and capacity of the uniform conductor, a predetermined inductance, resistance and capacity per unit length, substantially as described.

10. In a system for electrical-wave transmission, a non-uniform conductor, consisting of a uniform conductor with twin inductance-coils, each consisting of an iron core forming a closed magnetic circuit, over which the winding is distributed symmetrically and uniformly, connected in the uniform conductor at periodically-recurring points, the inductance, resistance and capacity of the interposed inductance-coils being adjusted in such a way as to give for the highest frequency to be transmitted, with the inductance, resistance and capacity of the uniform conductor, a predetermined inductance, resistance and capacity per unit length, the resistance due to iron-core losses of energy in the coils being smaller than the true ohmic resistance of the loaded conductor for the highest frequency to be transmitted, substantially as described.

Signed by me in New York city, (borough of Manhattan,) New York, this 5th day of February, 1903.

MICHAEL I. PUPIN.

Witnesses:

JULIA MURPHY,
GEORGE H. GILMAN.