No. 773,472. PATENTED OCT. 25, 1904.

G. A. CAMPBELL.
ELECTRIC CIRCUIT.

APPLICATION FILED JULY 7, 1904.

NO MODEL.

Fig. 1.

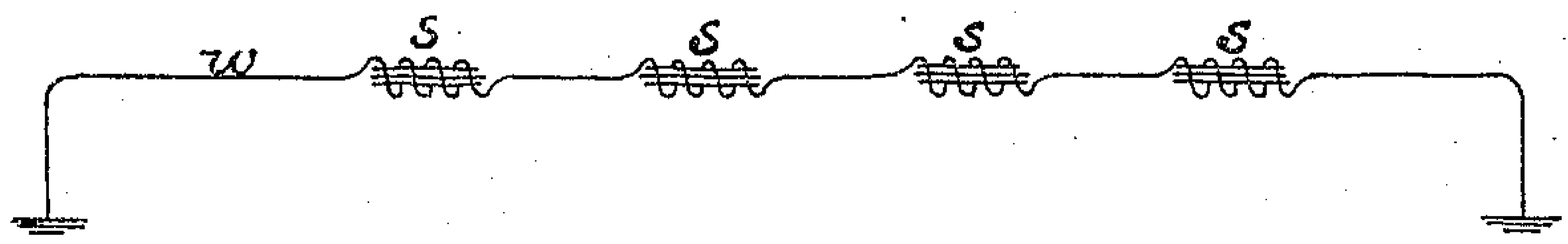


Fig. 2.

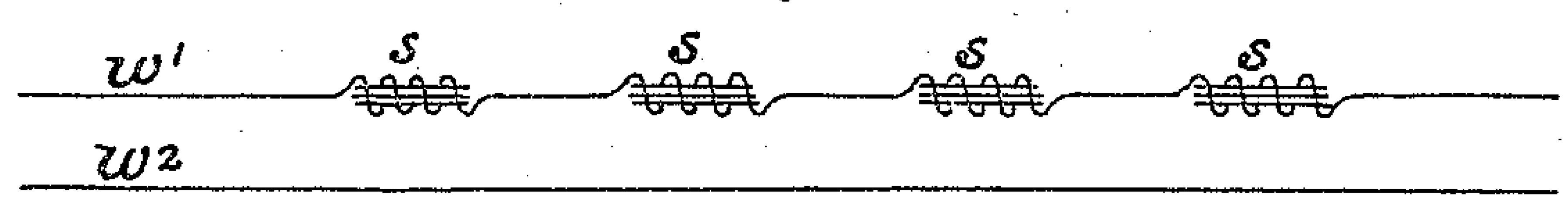


Fig. 3.

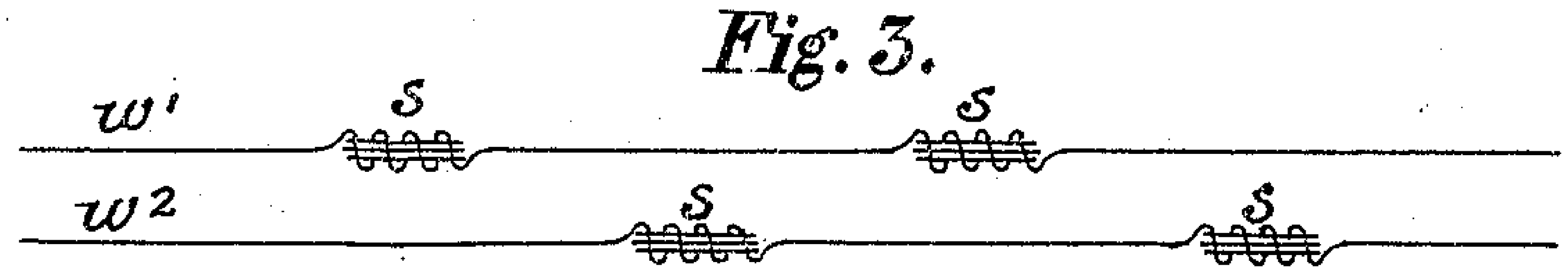


Fig. 4.

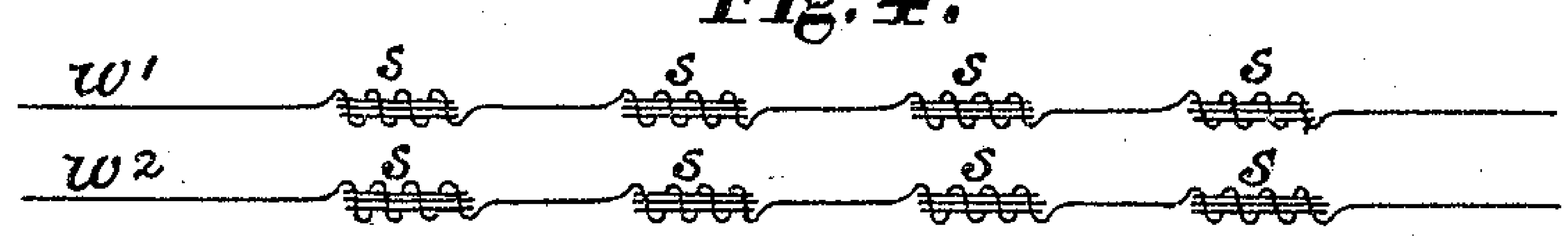


Fig. 5.

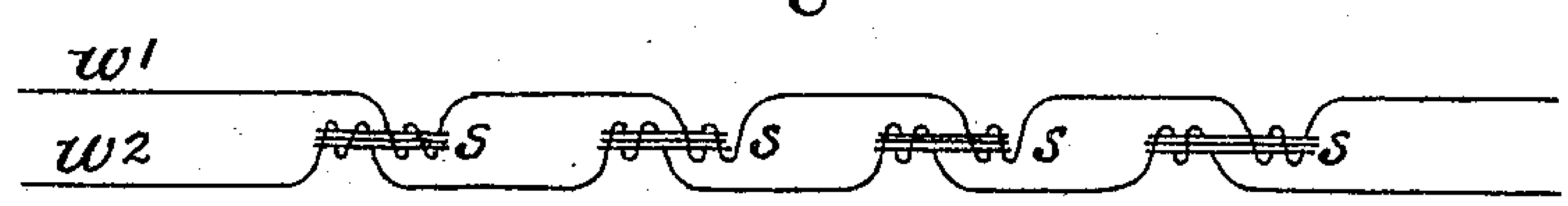


Fig. 6.

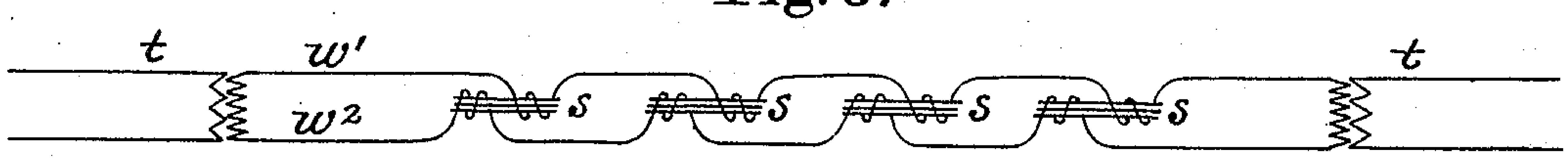
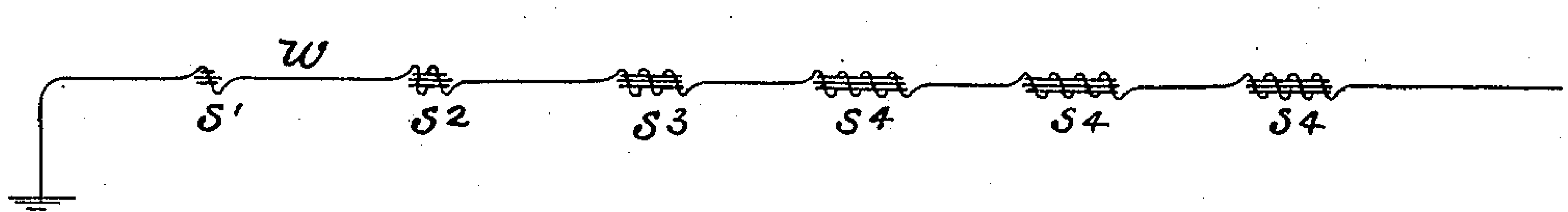


Fig. 7.



WITNESSES:

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No. 773,472. Patented October 25, 1904.

UNITED STATES PATENT OFFICE.

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ELECTRIC CIRCUIT.

SPECIFICATION forming part of Letters Patent No 773,472, dated October 25, 1904.

Original application filed March 5, 1900, Serial No. 7,281. Divided and this application filed July 7, 1904. Serial No. 215,671.

(No model.)

To all whom it may concern:

Be it known that I, George A. Campbell, a citizen of the United States, residing at Newton, in the county of Middlesex and State of Massachusetts, have invented a new and useful Improvement in Electric Circuits for the Transmission of Energy by Varying Currents, of which the following is a specification.

Circuits embodying the invention may be advantageously employed in many applications of varying currents. In particular they are important for power transmission, telephonic transmission, and telegraphic transmission.

It is well known theoretically that for the transmission of energy by alternating currents over long well-insulated lines of given resistance and capacity distributed self-induction is beneficial. Up to the present time attempts to increase artificially the self-induction of lines have not met with practical success, although numerous methods employing iron have been proposed and tested. These methods have distributed the self-induction with perfect uniformity along the lines; but while this is an ideal arrangement it imposes apparently inherent practical limitations. My investigations, however, have shown that absolute uniformity in the distribution of self-induction is not essential. Self-induction massed in series along the line at frequent intervals is sufficient for practical applications provided several inductances fall within a single electromagnetic wave. Each massed inductance can be obtained by the use of a properly-proportioned self-induction coil. A perfect electric circuit for electromagnetic-energy transmission over long distances is furnished by the combination of terminal step-up transformers with a line of high self-induction properly distributed. Whatever be the line resistance and capacity, with perfect insulation the transmission efficiency may be made as high as desired, the distortion may be made as small as desired, and the terminal reflection reduced to a minimum by the introduction of sufficient self-induction properly distributed and the addition of suitable terminal transformers. In this combination the distributed self-induction plays the more important part upon long lines, while the transformers are more important in the case of short lines. High-potential-power transmission over distances of a few score miles has demonstrated the efficiency of high potentials and low currents and the adequacy of step-up transformers. Long-distance telephony has shown that aerial lines are much more efficient than cable-lines of the same resistance and capacity, the difference here being due to the greater self-induction uniformly distributed along the aerial circuits. Accordingly the invention in which the present invention is embodied consists in the combination, with an electric conductor, of self-induction coils of low resistance and high inductance inserted in said conductor in series at intervals determined by the length and form of the transmitted electromagnetic waves or at intervals which are short when compared with the length of the electromagnetic waves and fluctuations.

The present invention consists in the combination, with an electric circuit made up of a conductor provided with self-induction coils of low resistance and high self-induction inserted in said conductor in series, several within a wave length, and terminal apparatus or connecting-lines, of means, substantially as described, at points of heterogeneity or abrupt transition in such circuit for overcoming reflection losses, and more particularly in the combination, with an electric conductor provided with self-induction coils of low resistance and high inductance inserted in said conductor in series at short intervals, of a step-up transformer at the terminal thereof.

I proceed to describe the manner in which my invention may be practically employed.

In the drawings, Figure 1 shows a conductor with ground return having self-induction coils inserted in series at frequent intervals. Fig. 2 shows a metallic circuit having self-induction coils inserted in series at frequent intervals in one side of the circuit. Fig. 3 shows a metallic circuit having self-induction coils inserted in series at frequent intervals alternately in the two sides of the circuit. Fig. 4 shows a metallic circuit having self-induction coils inserted in series at frequent intervals in the two sides of the circuit, the coils in one side being opposite those in the other side. Fig. 5 shows a metallic circuit having self-induction coils inserted in series at frequent intervals in the two sides of the circuit, the coils in one side being opposite those in the other side, and opposite coils being wound upon the same core or spool and connected for maximum self-induction. Fig. 6 represents the circuit shown in Fig. 5, with the addition of step-up terminal transformers. Fig. 7 represents a grounded line embodying the main invention in combination with coils of gradually-diminishing inductance at one end.

In grounded circuits the line-wire is marked w. In metallic circuits the two wires are marked w' and w^2. The self-induction coils in the main line are in all cases marked s, the step-up transformers t, and self-induction coils of varying or diminishing self-inductance at the end or ends of the main line are marked s^3 s^2, &c. In construction for all the purposes indicated above the lines employed need not differ from present constructions in ordinary use, and the coils being structurally independent of the line can be given the most economical proportions. The transformers shown at Fig. 6 might be added to any of the other circuits shown.

The coils, as stated above, are of low resistance. I find it good engineering practice in general to make the resistance of each coil approximately equal to one-half of the resistance of the interval of line between two coils. The higher the self-induction of the coil the smaller the attenuation, and the same is true of distortion. The self-induction desirable in practical applications is therefore large. The limit is primarily a matter of expense or economical consideration. The coils within the same wave length need not be of uniform inductance, nor need the intervals or stretches of line between the coils within the same wave length be of equal length. It is not a question of tuning; yet in some instances it may be of advantage to have the circuit, like any other circuit, tuned as a whole. If iron cores are used in the coils, they must be such as to introduce small iron losses. The capacity and insulation leakage between layers of the windings should be sufficiently small to prevent appreciable shunting. Similarly when coils are wound upon the same core or spool it is important that the capacity and insulation leakage between the two coils should be negligible, and to effect this the two coils are kept quite distinct and as far apart as may be. This is quite permissible, since the effect of the inductance in the circuit depends only upon the total self-induction, irrespective of the proportion of mutual induction between the two sides of the circuit.

I have said that the self-induction coils are inserted in the circuit in series at intervals which are short when compared with the length of the transmitted electromagnetic waves or fluctuations. This is a general statement and has a general application to all cases. If it is not observed, the coils become positively harmful and may greatly reduce the efficiency of the line. The practice of this invention with telephony presents perhaps its most severe application. In telephony there are overtones, and in both telephony and telegraphy there are abrupt fluctuations which are of such importance in the transmission that the number of coils is determined not so much by the length of the fundamental wave as by the overtones and abrupt fluctuations. Cables now in general use for telephony and telegraphy can be materially improved by the insertion of the coils having a time constant of one one-hundredth of a second at intervals of half a mile.

The form and proportions of the transformers herein referred to are to be determined by the special application to which the circuit is to be put according to established engineering practice. The terminal transformers by furnishing a suitable ratio of transformation effect an almost complete transfer of energy between a line in which self-induction is thus properly distributed and any terminal apparatus at either end of the line or any connecting line at either end. The gain due to the transformers increases with the amount of the distributed self-induction added to the line and is great compared with the gain resulting from their use with ordinary lines. When transformers cannot be introduced, the self-induction may be diminished toward the ends of the line so as to obviate an abrupt transition to the terminal apparatus or connecting-lines. This construction is illustrated at Fig. 7, showing one end of a grounded circuit where self-induction coils of gradually-diminished inductance at the ends or approaches of the main line in a measure take the place of the transformers; but in some instances it may be desirable to employ both transformers and self-induction coils of varying or diminishing resistance at the ends of the main line. In general the main line is made uniform throughout, all coils being alike and equally spaced from end to end of the line. The tapering inductance exhibited at Fig. 7 may be thus explained: The self-induction coils inserted in the conductor in series according to the main feature of this invention give to the conductor a higher inductance than an ordinary circuit. Now when an electric circuit for transmitting energy consists of two sections in one of which the inductance is higher than in the other then a wave suffers reflection at the junction of the two sections. The amount of the reflection depends upon the ratio of the inductances in the two sections. My investigations show that if a current is obliged to pass abruptly from an unloaded section to a loaded section or from a loaded section to a more or a less loaded section greater reflection occurs than would be the case if the transition took place by steps. The amount of reflection at any given point of transition may be theoretically determined, but without appealing to mathematical or to quantitative results the branch of the invention under consideration may be understood in the following manner.

The coils inserted as above directed introduce inductance and resistance into the circuit. The first is in general entirely beneficial and the second entirely harmful. As appears above, the amount of inductance in the coils is limited by expense or commercial considerations, and the higher the inductance of the coils thus inserted the smaller the attenuation and distortion. The resistance of the coils has throughout the length of the circuit the same uniform harmful effect in frittering away the energy of the wave. An ohm's resistance is equally harmful wherever it be introduced. The inductance comes in somewhat differently. Throughout the circuit the inductance inserted as above directed is beneficial in carrying on the energy-wave; but at the ends of the line a second element comes in. The inductance-coils add inertia to the line, thereby reducing the wave which the impressed force is able to impress on the line, since they not only increase the resistance and inductance of the line, but cause a reflection at the point of discontinuity between such loaded and unloaded sections. In this the inductance near the ends of a loaded section of the line is much more active than that near the center of such loaded section. Accordingly it is not advisable to continue the introduction of inductance at the ends as far or to as great an extent as near the center. If a given amount of copper be put in each coil, then the inductance and resistance best suited for the center of the line will require modification near the ends. Moreover, as reducing the inductance will allow us to reduce the resistance the tapering of the inductance at the ends presents a double advantage to reduce the inertia of the line where such reduction is required and reduce the resistance of a part of the line. So likewise the terminal transformers when used at the ends of the loaded section, as above described, effect a reduction in the reflection of energy, and this causes an increase of current upon the line.

This application is a division of my application, Serial No. 7,281, filed March 5, 1900, and I disclaim for the purposes of this divisional application the taper construction specifically claimed in said original application.

I claim—

1. The combination with an electric circuit made up of a conductor provided with self-induction coils of low resistance and high self-induction inserted in said conductor in series several within a wave length, and terminal apparatus or connecting-lines, of means substantially as described at points of heterogeneity or abrupt transition in such circuit for overcoming reflection losses.

2. The combination with an electric conductor provided with self-induction coils of low resistance and high inductance inserted in said conductor in series at short intervals, of a step-up transformer at the terminal thereof, substantially as described.

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Witnesses:

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