C. D. LINDRIDGE.

TELEPHONE REPEATER.

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979,012. Patented Dec. 20, 1910.

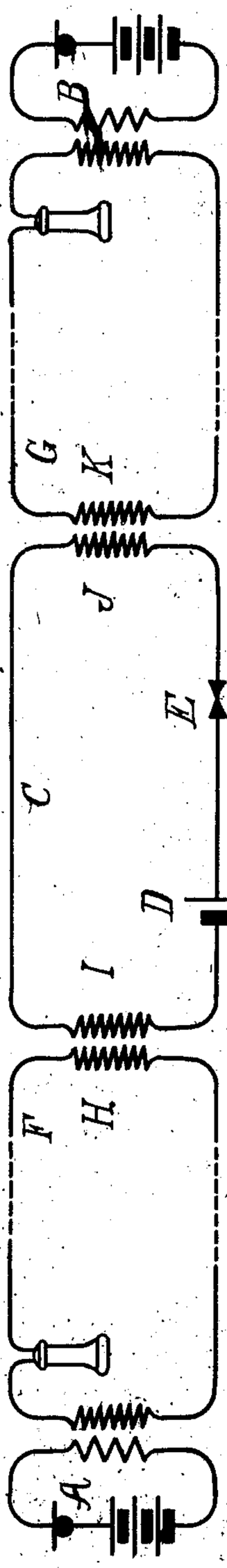

Fig. 1.

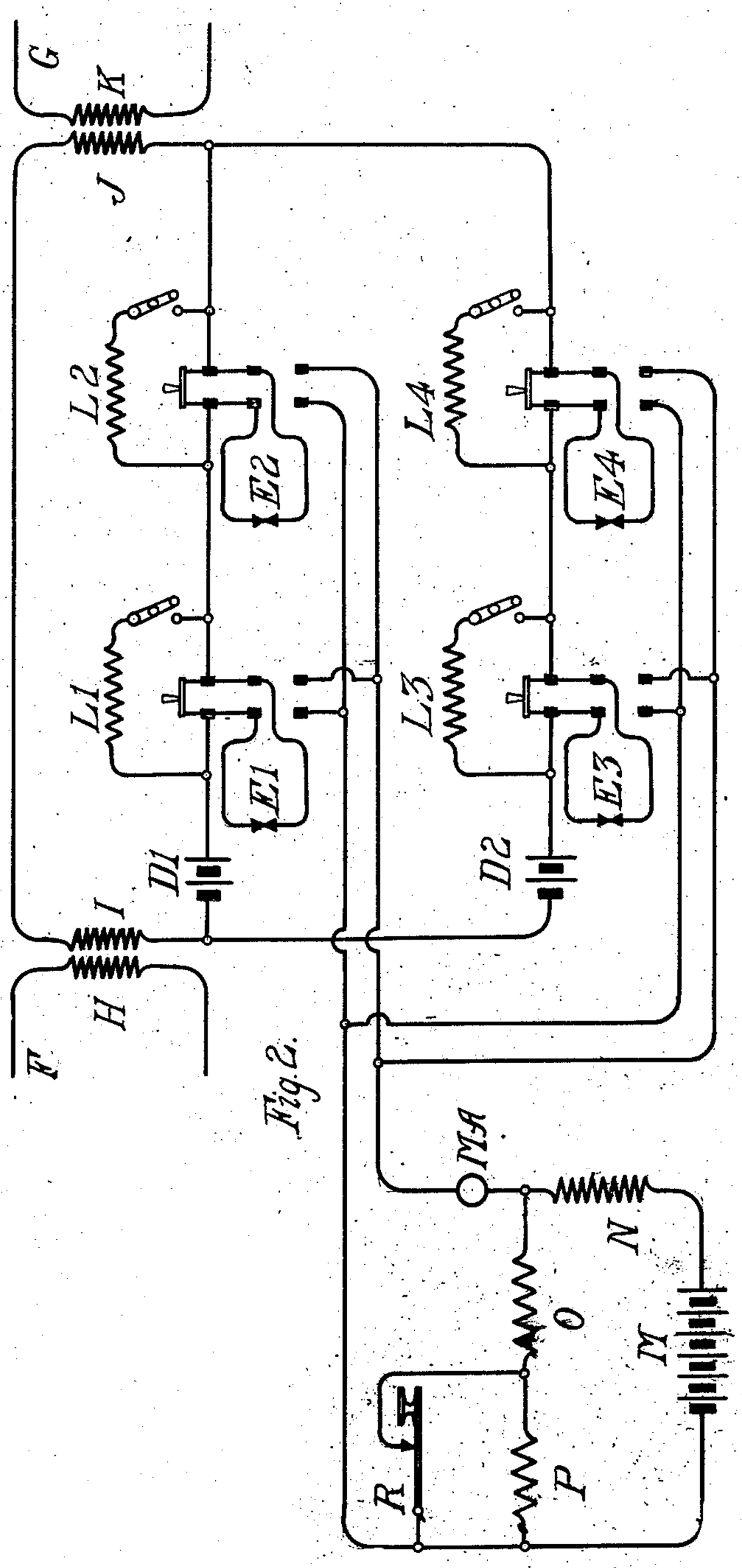

Fig. 2.

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UNITED STATES PATENT OFFICE.

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TELEPHONE-REPEATER.

979,012. Specification of Letters Patent. Patented Dec. 20, 1910.

Application filed February 10, 1909. Serial No. 477,091.

To all whom it may concern:

Be it known that I, CHARLES D. LINDRIDGE, a subject of the King of England, and a resident of Providence, county of Providence, and State of Rhode Island, have invented a new and useful Improvement in Telephone-Repeaters, of which the following is a specification.

My invention relates to systems for the reinforcement of telephone currents wherein means are provided for adding energy to transmission currents without subjecting them to the distorting influence of mechanical inertia and momentum.

It particularly relates to reinforcing systems in which negative resistances are made use of at the reinforcing station, and it consists of an improvement in telephone reinforcing apparatus whereby greater facilities are provided for the application of the principle involved, by increasing the sensitiveness, uniformity and reliability of the negative resistance, as hereinafter described. Such systems for the reinforcement of telephone currents rely to a considerable extent for their successful operation upon their adjustment. Hitherto, in the systems to which this invention particularly relates, viz., those which make use of break-down resistances, or mediums which present a decreasing resistance to a current of increasing E. M. F., it has been necessary to rely for satisfactory results upon random adjustment. That is to say, it has been necessary that the parts of the combinations made use of in these systems be subjected to various unknown relationships until an acceptable one can be found. Considerable difficulty is presented and uncertainty experienced by this means.

My invention consists of an improvement in these systems wherein the essential parts of the combination are subjected to and maintained in a definite and predetermined relationship, thereby making the application of the system less difficult and providing means by which a high degree of transmission reinforcement may be rendered permanent.

A source of direct current in combination with an induction coil and a conducting medium having the characteristic of presenting a decreasing resistance to a current of increasing E. M. F. is shown in Figures 1 and 2 of the drawings which accompany and form a part of this specification. The combination shown in these drawings and described hereinafter is given as an example of those to which my invention may be applied.

The term "telephone repeater" used herein, is intended to describe the apparatus which is used to increase the power of the voice currents. This term is used irrespective of whether the telephone currents are renewed, or renewed and reinforced, or reinforced only.

In the drawings, A and B represent subscribers' stations, and C represents the reinforcing station.

Referring to Fig. 1 the operation is as follows: The currents received at the induction coil F from the station at A cause fluctuations in the current in the circuit D E J I, which cause the potential across the conducting medium E to be varied. The potential across the medium E is increased or decreased, according to whether the induced E. M. F.'s oppose or reinforce the E. M. F. of the battery D. When a current is induced in the winding I of the induction coil F in the same direction as the current passing through the circuit D E J I, the potential across E is increased. As the resistance of the circuit D E J I is thereby reduced, due to the resistance-varying action at E, a current is induced in the winding K of the induction coil G which is partly directly due to induction from A and partly caused by a change in the negative resistance of the circuit D E J I. The resistance of the circuit D E J I is changed in the same way when currents are transmitted from B to A.

Before considering the character of negative resistance, consideration may be given to resistance which is not negative in character, but which, similar to the negative resistance in telephone repeaters, is subject to variations in resistance corresponding to sound waves. The resistance of a telephone transmitter when the transmitter is spoken into, varies in a similar manner to that in which negative resistance varies when a varying current is passed through it. The resistance of telephone transmitters and the negative resistance in telephone repeaters, are also similar in the respect that they have both hitherto been adjusted in the same manner.

When a telephone transmitter falls out of adjustment from any cause, it is the practice in re-adjusting it, to transmit, or to attempt to transmit speech through it before altering its resistance, so that an idea may be obtained of the extent to which its resistance must be varied, in order to put it into proper working order. Its resistance is then varied, and a second attempt is made to transmit speech through it. If, when its resistance is increased the transmission is made worse, its resistance is decreased, and made less and less, until any further decrease in resistance is found not to improve, but to impair transmission. Its resistance is then left unchanged and the transmitter is in working order.

When telephone repeaters wherein negative resistance is used have hitherto been constructed, it has been the practice of those skilled in the art to make such adjustment in like manner. The negative resistance has been subjected to variations in adjustment while telephone currents have been transmitted through the repeater. The result of these variations has been noted and used as a guide as to what further adjustment should be made. This method of adjustment is satisfactory for all telephone apparatus which requires adjustment, except negative resistance in telephone repeaters. The fact that this method of adjustment is not the most suitable for negative resistance in telephone repeaters has hitherto laid hidden from vision, and it is upon this fact that this invention is based. The fact that the conductance of negative resistance varies when a current passing through it varies, is known; but it has not been realized that because of this character telephone repeaters wherein negative resistance is used, should be constructed in such manner that the adjustment of the negative resistance is made in a different manner to that in which the adjustment of other telephone apparatus is made. The reason why they should be constructed in this manner, may be more readily perceived, after considering the manner in which they are constructed when use is made of this invention. The nature of the conducting medium made use of in these systems, which may be made to present a varying resistance to a battery and the transmission currents, may be such as to be dependent for its operation upon thermo-electric action or polarization. A polarized conductor, to have the required characteristic, must of course be subjected to an E. M. F. sufficiently great to break down its effective resistance. Besides these there are other groups of conductors which may be used. For example, those consisting essentially of electrodes differing either in size, form, material or in the nature or density of surrounding gas. It would appear that all asymmetrical conductors have the characteristic of presenting a decreasing resistance to a current of increasing E. M. F.

Mediums of the character which depend for their operation upon either thermo-electric action or polarization are dealt with in the *Bulletin of the United States Bureau of Standards*, No. 2, Vol. 2, in the article, "On the Platinum Point Electroyltic Detector for Electrical Waves," by L. W. Austen. In some subsequent investigations made by Mr. Austen upon the silicon detector, tests were made which show this medium to be of the required character for use to be made thereof in these systems. These investigations are described in a letter written to the editors of the "*Electrical World*" and published at New York in that publication, Vol. 51, No. 3, dated January 18, 1908. This type of medium is readily endowed with the required degree of sensitiveness, but it would appear that mediums dependent for their operation entirely upon thermo-electric action or polarization are in some respects better suited for use in these systems. A method of constructing the silicon detector will however be described as the results obtained from its use have been satisfactory.

The silicon in granulated form may be more easily handled when embedded in solder. A convenient method of holding it is by means of a tool-makers' pin vise, a drop of heated solder and flux being allowed to fall into a tray of granulated silicon, and the mass so formed held in the teeth of the vise. The vise may be supported horizontally in some form of metal mounting to which a binding post is attached.

A micrometer head of the type constructed for use in calipers, measuring to one-thousandth of an inch, may be supported in a similar metal mounting on an insulated base in such a position that the steel measuring surface of the spindle may be brought to bear upon the silicon. By being provided with a number of pellets of silicon formed as above, the point of contact may be readily changed. A number of such sets however, considerably in excess of the number intended for use at one time, should be provided and subjected to constant adjustment, in order that those most suitable for use may be selected.

It will be observed that a number of contacts may be grouped together to produce a greater variation of resistance than may be produced by a single contact. If it is desired that the resistance of the group be the same as the resistance of a single contact, it is necessary to use four contacts, two strings each with two contacts in series, in order that the amount of resistance variation may be approximately doubled. If it is desired to again approximately double this amount of resistance variation, it is necessary to use

sixteen contacts, four strings each with four contacts in series. Owing to the rapidly increasing number of contacts required for higher degrees of resistance variation, it would not appear desirable that more than four strings of contacts be used. The number of contacts in each string may however with advantage be higher than four, providing a higher normal resistance of the group may be allowed.

As previous to this application no systems of the character described herein have been put to commercial use, the foregoing description has been considered necessary to enable one skilled in the art to construct a combination of the type to which this invention may be applied. The improvement effected in these systems by use of this invention consists of adjusting preliminarily to a predetermined degree the E. M. F. of the local source of current and the resistance of the local circuit, so that the fluctuations in potential across the electrically controlled resistance medium will fall within the range to which the medium is responsive and to which it is preliminarily adjusted.

Telephone repeaters wherein negative resistance is used, have hitherto been open to the objection that the telephone currents have not been subjected to a sufficient degree of reinforcement. This invention has for its object the use of negative resistance in a condition of greater sensitiveness than hitherto, thereby subjecting the telephone currents to greater reinforcement, by arranging the parts of the repeater as follows: The resistance which the negative resistance is to present to the source of current, and the potential of current which is to be presented to the negative resistance, are determined before the repeater parts are arranged in accordance with this invention. Then if e be taken to represent the electromotive force of the source of current, v to represent the potential of current which is determined to be that to which the negative resistance will be subjected, r_c to represent the resistance of the repeater circuit, and r_n to represent the resistance which is determined to be that which the negative resistance will present to the source of current, the circuit is arranged to make

$$e = v \times \frac{r_c}{r_n}.$$

For example,—the circuit shown in Fig. 1 may be used to reinforce telephone currents arranged so that—the electromotive force of the source of current=6 volts, the predetermined potential of current subjected to the negative resistance=4 volts, the predetermined resistance of the negative resistance=200 ohms, the resistance of the circuit=300 ohms.

The fact which has laid hidden from vision and upon which this invention is based, is that by constructing the repeater in such manner that the negative resistance is subjected to a potential of current which is known to be suitable for the reinforcement of telephone currents, at the same time that the negative resistance presents a resistance to the source of current which is also known to be suitable for the reinforcement of telephone currents, more satisfactory results can be obtained than is possible when the repeater is constructed so that the resistance of the negative resistance and the potential of current presented to it are not predetermined values.

This owing to—

1. The negative resistance producing the greatest reinforcement of the telephone currents of which it is capable of producing, only when it is adjusted to a certain resistance, being at the same time subjected to a certain potential of current. It does not produce the greatest reinforcement of the telephone currents of which it is capable of producing, if it is adjusted to any other than the one resistance, regardless of the potential of current to which it is subjected, or if it is subjected to any other than the one potential of current, regardless of its resistance.

2. The fact that if the negative resistance is in a moderately sensitive condition, and the potential of current to which it is subjected is increased, or if its resistance is decreased, its sensitiveness is increased up to a certain point where its character and resistance suddenly break down without warning.

3. The difference between the values of r_n and r_c, such as there must necessarily be in a telephone repeater, causing a variation in either the resistance of the negative resistance, or the potential of current presented to it, to produce considerable variation in the other.

Although these conditions do not make it impossible for the negative resistance to be adjusted to unknown values which are such as to cause it to produce the greatest reinforcement of the telephone currents of which it is capable of producing, yet they do make it impossible for the negative resistance to be utilized when it is adjusted to unknown values, in its condition of greatest sensitiveness in the art of telephony. They make this impossible, owing to the fact that when the negative resistance is adjusted to a moderately sensitive condition, there is no means of knowing by any variation exhibited in its character, what variation in its resistance and the potential of current presented to it should be made, in order to increase its sensitiveness, and whether the slightest increase in the potential of current presented to it, or the slightest decrease in its resistance, will destroy its character. Consequently under these conditions, there is some

uncertainty of operation experienced in adjusting it to even a moderate degree of sensitiveness, and such a degree of uncertainty is experienced in adjusting it to a highly sensitive condition that it has not been found possible to use it in this condition. I have found that it may be used in this condition if its resistance and the potential of current presented to it are predetermined, which may be done in the following manner: It may be connected into a testing circuit and adjusted to a high resistance. It may then be subjected to a gradually and constantly increasing potential of current from zero up to a sufficiently high value to break down its character as a negative resistance. A curve may be plotted describing the variations in its conductance throughout this range of potential. Its conductance may then be slightly increased and the same operation performed, a second curve being plotted describing the variations in its conductance throughout the range of potential at this slightly increased value of conductivity. Its conductance may then be again slightly increased, and so on, until its character breaks down at a potential which is known to be lower than that to which it should be subjected in the repeater. By this means it is possible to obtain a large number of curves, and when it has been determined what resistance the negative resistance will be adjusted to, the potential to which it should be subjected may readily be found by inspection of the curves. It should be slightly below the potential at which the negative resistance loses its character. The conductance to which it should be adjusted may also be determined by inspection of the curves. It should be such that small variations in the current passing through it, produce large variations in the resistance of the repeater circuit. By this means the determined values v and r_n may be established. The value of r_c may be determined by adding the resistance of the induction coil windings which are connected to the negative resistance to r_n. e may then be found by solving the above equation.

The curves obtained by the investigation of a single negative resistance, may be used to determine a desirable resistance at which all negative resistances of the type may be used, and the potential of current to which they should be subjected when at this resistance. For example—when a silicon-steel negative resistance (see *Bulletin of the United States Bureau of Standards*, Vol. 5, page 133) has been investigated, a desirable resistance at which all silicon-steel negative resistances may be used, and the potential of current to which they should be subjected when at this resistance are determined by the one investigation, providing they do not differ in construction, and that they are all used under the same conditions. Two or more negative resistances may be grouped together in a repeater to produce a greater variation in the resistance of the repeater circuit than may be produced by a single negative resistance.

A repeater including four negative resistances is shown in Fig. 2 of the drawings. Referring to this drawing—the negative resistances E^1 E^2 E^3 and E^4, are connected in the repeater circuit with the batteries D^1 and D^2. Switches are provided to enable connection to be established between any negative resistance and the adjusting circuit M N O P, and also to provide means by which a non-inductive resistance may be connected across a negative resistance before removing it from the repeater circuit to be adjusted. This non-inductive resistance should approximately equal the resistance to which the negative resistance is adjusted, and allows one negative resistance to be disconnected from the repeater circuit without throwing others out of adjustment. By the use of this non-inductive resistance, moreover, a negative resistance may be removed from the repeater circuit to be re-adjusted if a sufficient number are in use, without seriously imparing the transmission.

The repeater may be adjusted in the following manner: The two-pole switch of the negative resistance E^4 may be thrown to connect the negative resistance to the adjusting circuit M N O P. This allows current from the battery M to pass through the negative resistance and the mil-ammeter M A. The potential across the resistance O may equal the predetermined potential to which the negative resistance is to be subjected. Means should be provided to allow the resistance O to be readily subjected to slight variation in resistance. O is shown in Fig. 2 subject to slight increase in resistance, by means of the strap key R. When this key is in its normal position, the negative resistance may be adjusted to a resistance which is such as to bring the needle of the mil-ammeter to a point on the scale to correspond to the predetermined resistance to which the negative resistance is to be adjusted. The number of scale divisions over which the needle moves when the key is depressed, and when a resistance other than negative is connected at E should be known. If this number is increased sufficiently by the current-varying character of the negative resistance when the key R is depressed, the two-pole switch may be reversed, thereby connecting the negative resistance into the repeater circuit. The circuit through the non-inductive resistance L^1 may then be opened. The negative resistances E^2 E^3 and E^4 may afterward be adjusted in like manner.

In the foregoing description I have shown

the character of this invention and described means by which it may be used to render an improvement in telephone transmission. I will now describe the best mode in which I have contemplated applying the principle thereof.

I provide a combination of the character shown in Fig. 2 having sixteen mediums, four strings each with four mediums in series, in place of the four mediums E^1 E^2 E^3 and E^4 shown in the drawing. I provide in each string of mediums, corresponding to the position at D, a storage battery, the cells of which are a sufficient size that the voltage may be maintained at 8 volts without a deviation of $\frac{1}{4}$ volt therefrom until it is convenient to replace it. I use the silicon-steel type of medium described heretofore, the passage of the current being in the direction from steel to silicon, and find by investigation that the lowest E. M. F. to which it should be subjected is .91 volt, the highest resistance to which it should be adjusted is 140 ohms, the highest E. M. F. to which it should be subjected is 1.10 volts, and the lowest resistance to which it should be adjusted is 100 ohms. I therefore provide at each position L in the circuit a non-inductive resistance of 120 ohms. I provide at F and G induction coils, each having two windings, one of 80 ohms connected to one of the transmission lines, and one of 50 ohms connected to the local circuit. I provide in the testing circuit M N O P a battery of 100 volts at M, a resistance of 98.8 ohms at N, a resistance of 1 ohm at O, and a resistance of .2 ohm at P. I provide at M A a mil-ammeter of the portable direct-reading type having a range of 50 mil-amperes and 100 scale divisions. I mark a point upon the scale of this mil-ammeter at 7.14 mil amperes to show the highest resistance to which the medium is adjusted in this particular application of this invention, and another at 10 mil-amperes to show the lowest resistance to which the medium is adjusted. I provide a strap key and switches as shown in Fig. 2.

I first bring all the resistances L into the circuit D J I, and throw a double pole switch to bring one medium into the testing circuit M N O P. The measuring surface of all the mediums before adjustment will be out of contact with the silicon. The measuring surface of this first medium to be adjusted is gradually brought to bear upon the silicon until the needle of the mil-ammeter is brought up to within the above points marked upon the scale. The strap key is then depressed and the movement of the needle noted. If this moves over more than four scale divisions the resistance of the medium is decreased. A movement of the needle over 3.75 scale divisions may or may not show a decrease in resistance of the medium according to whether the needle is nearer the highest or lowest point marked upon the scale when the strap key is up. Greater refinement in the adjustment of the medium will be obvious after having considered this specification. If the movement of the needle when the strap key is depressed is considered to be sufficient, the double pole switch is reversed and the resistance L disconnected. If this movement is not considered sufficient, or if difficulty is experienced in adjusting the medium to a resistance which will bring the needle of the mil-ammeter between the points marked upon the scale, it should be replaced. The same method of testing may be followed with the remaining mediums until sixteen are connected into the circuit D E J I. It is of course necessary that they be frequently tested during the time they are in use, in order that the potential normally across each medium may remain unchanged.

It is to be understood from the foregoing description that this invention is not limited to any particular type of medium, but may be used to effect an improvement in any system making use of the characteristic of a medium presenting a decreasing resistance to a current of increasing E. M. F. It is also to be understood that the particular combination to which the invention is herein shown to effect an improvement is only given as an example, and without this improvement is not considered itself to be a part of the invention. Other combinations to which this invention may be applied will readily occur to one skilled in the art. For example, the windings H I J K of the induction coils F and G, shown in the drawings, may be wound about a single core, or one coil with three windings only may be used. Instead of intersecting the stations A and B, the reinforcing station may be connected in series with them, and a coil with only two windings be used.

Therefore, without limiting myself to the use of any particular combination described heretofore, what I claim as new and desire to secure by United States Letters Patent is:

1. In a telephone repeater, a source of unidirectional current and a negative resistance element included together in a repeater circuit; means for impressing incoming voice currents on said circuit; means for translating the amplified currents flowing in said circuit on an outgoing circuit; and a non-inductive resistance adapted to be substituted in said circuit for said negative resistance element, substantially as described.

2. In a telephone repeater, a source of unidirectional current and a negative resistance element included together in a repeater circuit; means for impressing incoming voice currents on said circuit; means for translating the amplified currents flowing in said circuit on an outgoing circuit; a non-induc-

tive resistance having approximately the same resistance as the proper working resistance of said negative resistance element; and means for substituting said non-inductive resistance in said circuit in place of said negative resistance element.

3. In a telephone repeater, a source of unidirectional current and a negative resistance element included together in a repeater circuit; means for impressing incoming voice currents on said circuit; means for translating the amplified currents flowing in said circuit on an outgoing circuit; a testing circuit; means for switching said negative resistance element out of said repeater circuit and into said testing circuit; and means for closing said repeater circuit while said negative resistance is switched onto said testing circuit.

4. In a telephone repeater, a source of unidirectional current and a negative resistance element included together in a repeater circuit; means for impressing incoming voice currents on said circuit; means for translating the amplified currents flowing in said circuit on an outgoing circuit; a non-inductive resistance; a testing circuit for said negative resistance element; and means for substituting said non-inductive resistance for said negative resistance element in said repeater circuit when said negative resistance element is connected with said test circuit.

5. In a telephone repeater; a local circuit; translating devices in said local circuit; a plurality of negative resistance elements and a source of direct current connected together in said local circuit; a plurality of non-inductive resistances; and means for substituting one or more of said non-inductive resistances for one or more of said negative resistance elements.

6. In a telephone repeater; a local circuit; translating devices in said local circuit; a plurality of negative resistance elements and a source of direct current connected together in said local circuit; a plurality of non-inductive resistances; a testing circuit; and means for substituting one of said non-inductive resistances for one of said negative resistance elements and connecting said negative resistance element with said testing circuit for test and adjustment.

7. In a telephone repeater; a local circuit containing translating devices; a string of negative resistance elements connected with a battery in said local circuit; a plurality of non-inductive resistances associated with said negative resistances; and means for substituting one of said non-inductive resistances for one of said negative resistances, for the purpose herein described.

8. In a telephone repeater; a local circuit containing translating devices; a source of current in said local circuit; a plurality of strings of negative resistance elements; said strings of negative resistance elements being connected in multiple in the local circuit including said translating devices; substitute resistances for each of said negative resistances; and means whereby said substitute resistances may be introduced into said local circuit.

9. In a telephone repeater; a local circuit containing translating devices; a source of current in said local circuit; a plurality of strings of negative resistance elements; said strings of negative resistance elements being connected in multiple in the local circuit including said translating devices; non-inductive resistances for each of said negative resistance elements; a testing circuit; means whereby one or more of said negative resistances may be removed from said local circuit and introduced into said test circuit; and means for substituting said non-inductive resistance for said negative resistance in said local circuit.

10. In a telephone repeater; a local circuit. containing translating devices; a plurality of strings of negative resistance elements connected in said local circuit in series parallel relation; substitute resistances for each of said negative resistances; and means whereby said substitute resistances may be introduced into said local circuit.

11. In a telephone repeater; a local circuit containing translating devices; a plurality of strings of negative resistance elements connected in said local circuit in series parallel relation; non-inductive resistances for each of said negative resistances; a testing circuit; means whereby one or more of said negative resistances may be removed from said local circuit and introduced into said testing circuit; and means for substituting said non-inductive resistance for said negative resistance in said local circuit.

Signed by me at Providence, county of Providence and State of Rhode Island in the presence of two witnesses, and dated February 1st 1909.

CHARLES D. LINDRIDGE.

Witnesses:

GILMAN E. JOPP,

SIDNEY E. LINDRIDGE.