

N. G. WARTH.
TELEPHONE REPEATER.
APPLICATION FILED JAN. 28, 1910.

1,022,519.

Patented Apr. 9, 1912.

3 SHEETS—SHEET 1.

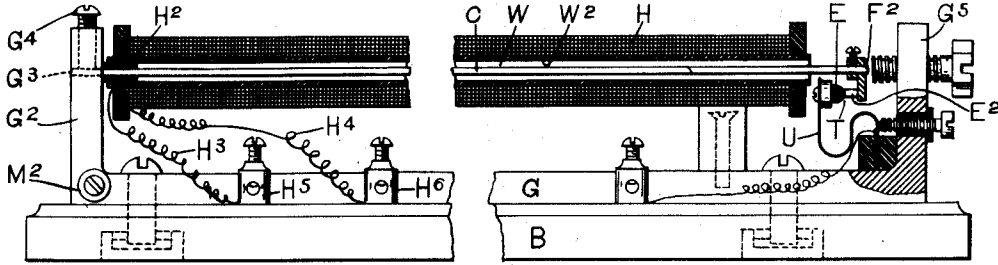


Fig. 1.

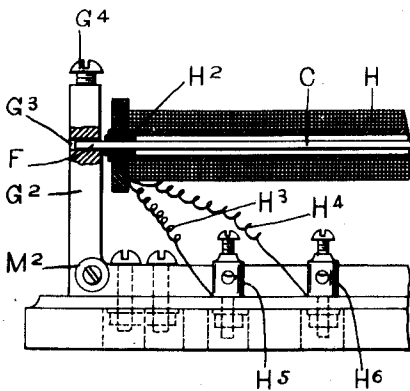


Fig. 2.

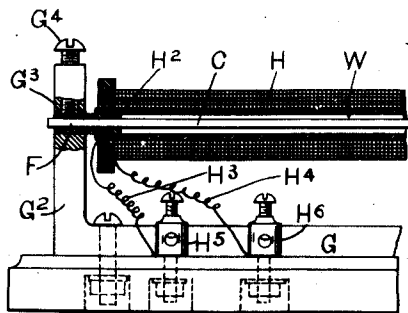
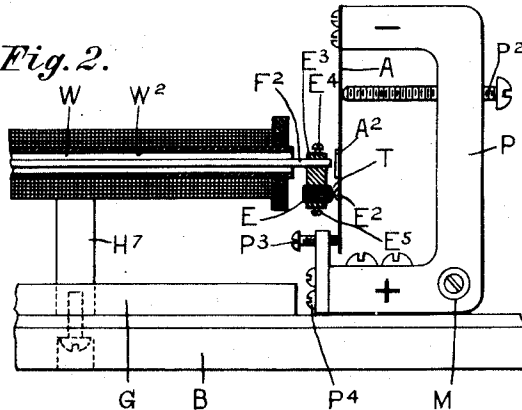
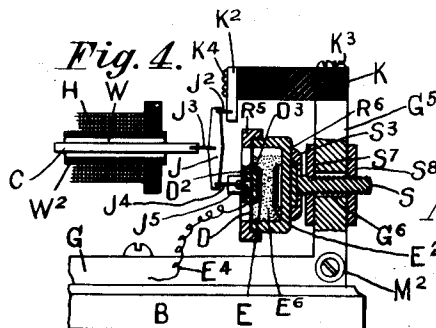
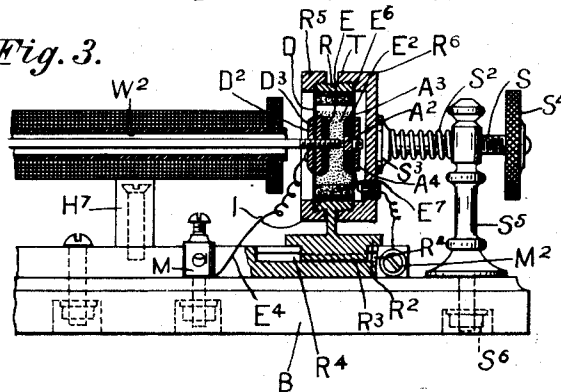


Fig. 3.



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3 SHEETS—SHEET 3.

Fig. 6.

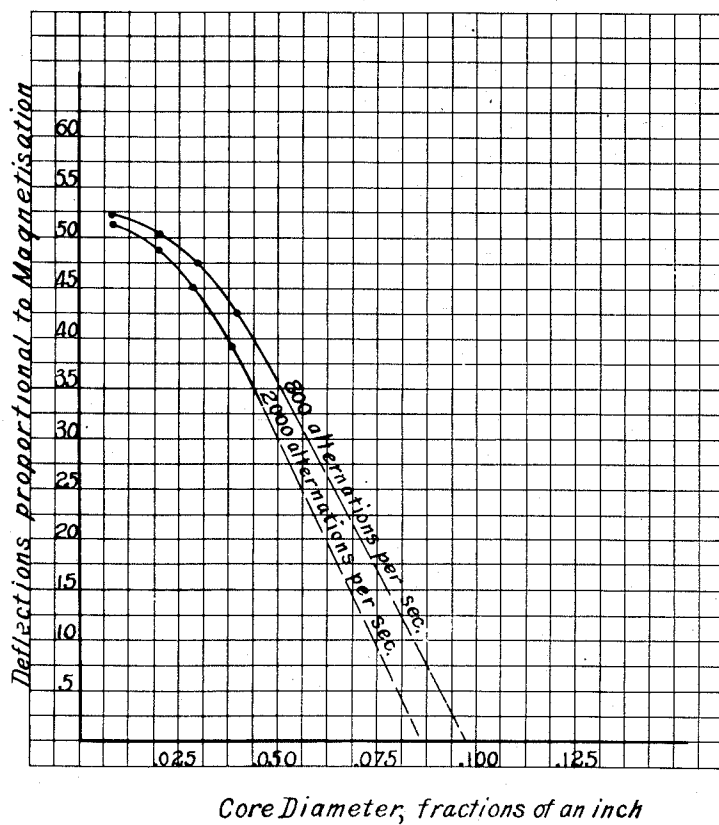
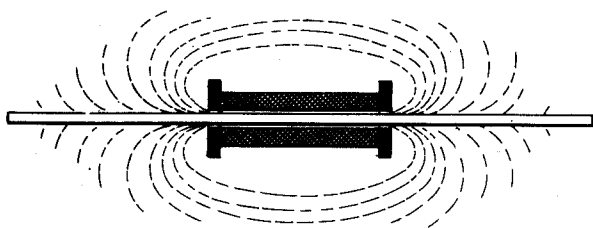


Fig. 7.

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TELEPHONE-REPEATER.

1,022,519.

Specification of Letters Patent.

Patented Apr. 9, 1912.

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To all whom it may concern:

Be it known that I, NATHANIEL G. WARTH, a citizen of the United States, residing at Columbus, in the county of Franklin and State of Ohio, have invented a certain new and useful Improvement in Telephone-Repeaters, of which the following is a specification.

The present invention is directed to a novel form of telephonic repeating relay for use in relaying or repeating and reinforcing telephonic currents with a view to increasing the practical distance, or range, of direct telephonic transmission beyond the distances ordinarily attained or feasible with a given circuit and for the various other classes of service to which repeaters may be beneficial.

By reason of the feebleness of speech and other telephonic currents generally, transmitters and receivers, or, the speech or current reproducing apparatus must be very sensitive and nicely proportioned to the forces involved. The transmission or line losses are relatively considerable, and seriously limit the range of direct transmission, so much so, that, for iron circuits the commercial distance is restricted to about 200 miles, and even with the best copper circuits transmission is not usual beyond 1000 miles. Thus, it is apparent that the volume of current available at the distant terminal of a very long circuit is vanishingly small, and even with the best commercial forms of telephone-receivers it is extremely difficult to secure sufficient movement or actuation of the diaphragm to produce audible articulate sounds. When that condition is true with a high class receiving telephone, the diaphragm of which is free, and not encumbered or impeded in its action by being attached to or connected with a repeating-transmitter, it will be clear, contrary to the usual arrangement of such apparatus, that a repeating-relay must be of extremely delicate and sensitive construction and its mobile parts must, as to their size and inertia, be so organized and proportioned as to be well within the moving power of the small forces available for their operation. Heretofore many attempts to so organize and proportion such parts, or elements, of re-

peating-relays to their available currents have been made, and most of such attempts have been absolute failures, for the reason, that, though constructed with a view to the above stated requirements, invariably they were much less sensitive than the ordinary receiving-telephone, being so burdened with multiplied parts and restraining diaphragms, that even an initial, or maximum current, undiminished by transmission, would be incapable of actuating them. Relays which have been considered fairly successful, are so inefficient that, to secure actuation, they must be connected to a line at a point well within the range of ordinary direct commercial transmission and from such location they have been unable to increase beyond about thirty per centum such ordinary transmission, or practical service distance.

The object of this present invention therefore is to increase the present range of commercial transmission for all classes of telephonic long-distance cross-country and cable circuits and to do so economically.

In practicing my invention I utilize an electro-magnetic principle and effect, based on what is known as the "Page effect" which, while well known to physicists, has not been practically utilized so far as I am informed, either in such apparatus or in any apparatus of the electro-mechanical arts. The peculiar electro-magnetic effect mentioned comports with the delicacy and exactness in construction of apparatus mentioned as requisite in such mechanisms, yet in practice its use accomplishes the results desired with comparatively great vigor and amplitude.

Heretofore in all practical or successful electro-mechanical repeating-relays an oscillatory magnetically attractive armature of some form, has been associated for actuation, with some form of electro-magnet, to be by it, mechanically vibrated in a manner to conform to the variations of the currents influencing the electro-magnet, and such armature, being the sole means of actuation, has been connected with, or has formed a part of, a microphonic or resistance-varying transmitter, adapted to re-transmit, or renew, the actuating currents.

In relays of such older type, the type explained as having a vibratory magnetically attractive armature only for actuation, the entire magnetic-effect available is that which is manifested or exerted in the magnetic-pull, or push, as the case may be, due to the attractive power of the core of the electromagnet, usually arranged as a pole attraction. This effect, for currents of the telephonic characteristic, is not, I find, efficient, mainly, I assign, for the following reason. The cores of such magnets are comparatively massive and are usually attached to permanent magnets which also have considerable mass. Such cores while largely impermeable to the highly transitory and quick-acting small magnetic-excitations caused by such telephonic-currents and in which the resulting magnetic effects are supposed to be confined to the metal adjacent the winding, do, because of the mass of the magnetic metal, permit many of the lines-of-force set up, to be completed and retained therein. Hence, the armature is deprived of much of the magnetic effect and is attracted with only the power of the lines-of-force straying or spreading to, or through it. To secure improved results in this respect I have greatly reduced the mass, or cross-section, of the core and have changed its form. I have found that a very elongated coil having a very slender core will, when arranged according to my invention give a longitudinal movement and a thrust of the end of the core in proportion, due to its magnetic-expansion when acted upon by the telephonic-currents and such action is highly effective as to sensitiveness, exactness and power. For communicating electro-mechanical vibrations to a repeating-transmitter for its actuation, I have satisfactorily combined this new instrument with the old thus retaining and utilizing the attractive vibratory armature and thereby producing an instrument of greatly increased efficiency.

In the accompanying drawing: Figure 1, is an illustration in side elevation with some parts in section of a simple form of my improved relay, embracing only the new features and arrangement of apparatus to secure the new operation and effect, according to the electro-magnetic and mechanical principles involved. Fig. 2 is a similar view illustrating a form of my improvement wherein is embraced the features and characteristics illustrated in the foregoing figure, together with an armature adapted to combine the operations and effects of my new mode with those of the usual form. Fig. 3 is a similar view illustrating a modification of what is shown in Fig. 2 with the microphone of the granular type instead of the ordinary type as shown in Fig. 2. Fig. 4 is a detail view of a modification wherein the

microphone is associated with the expandible core by means of an amplifying arm or lever to augment the movements or actions upon the transmitter. Fig. 5 is a view similar to Figs. 1, 2 and 3 illustrating the relay with its parts properly proportioned as to each other except as to the lengths of core, coils and base. Fig. 6 is an illustration depicting the cessation of magnetization in a core and extending beyond an energizing coil. Fig. 7 is a graphic illustration of curves showing the relationship and limitations of core diameters permissible with currents of telephonic characteristics.

In the type of relay shown in Fig. 1 the receiver winding or coil H and the core C for converting the energy of the incoming currents into motion for the actuation of the repeating-transmitter T, may be a foot or more in length. The effectiveness in the expansion of the core for a given current will be proportional to the length of the coil, dependent upon its resistance, in ohms and henries, until a critical or maximum winding, in depth and length of same, is reached. With a relay having a 12 inch coil, wound with No. 36 silk covered magnet-wire, measuring about 120 ohms and having a No. 14 circular steel core, 14 inches in length, I have secured very satisfactory results. With proper refinements in form, dimensions and in the exactness of construction, the efficiency may be increased. The efficiency of this relay resides particularly in the attenuated core, which must be of a length sufficient to secure a movement or forward thrust of its free end F^2 , the other end F being fixed or stationary, to actuate the transmitter. I prefer a solid core, cylindrical in form, but the core may be of irregular form, or tubular. If tubular in form it should be divided or split longitudinally, to prevent loss in effect from the setting up of eddy-currents therein. The core, of whatever cross-section as to form, should, preferably, be straight and very slender and of small mass, to enable the feeble forces available to have as complete a magnetizing effect as possible. Should the core be too thick or massive, the effects of completing the lines-of-force within it, as explained above, and hysteresis also will ensue. The unmagnetized section of the core will not expand with the magnetized portions, thus preventing the desired elongation of the core and dissipating much of the force received by the coil in molecular friction and heat set up within the core. The expansion and the extent of the expansion of the core is caused by its magnetization and the respective degree of magnetization and its contraction ensues by its proportional demagnetization. It is immaterial whether the core be of iron or steel, permanently magnetized or not, as, unless saturated

strongly, the molecular action and consequent expansion is relative. The action being magnetic-molecular, the effect, in actual longitudinal movement, even for a core 14 inches in length, is, of course, quite minute, but from my observation of the effects produced, I assume the movements are equal to the oscillations of the ordinary free receiver diaphragm when actuated by an equivalent force or current. While this core expansion and contraction-effect is possible even when the core has close extended contact with the bore wall W of the coil, I prefer that it should be free from contact throughout the bore of the coil by having the coil formed-up or wound on a non-magnetic non-metallic spool W² having a bore sufficiently large to just clear the core when alined through its center. The expansion of the core when apparently retarded or interfered with by contact with the bore wall of the coil, indicates its power as compared with the usual armature action. This demonstrates the fact that the force acting upon the coil is strongly concentrated within the core and when the core is, as to the force, of proportionate size and form, it can be utilized to secure its maximum effect in movement and power for the actuation of the repeating-transmitter. The elongation of such a core is an inherent or natural function under the circumstances, involving only a regular magnetic state given play, such as would normally be set up under usual conditions, entailing no loss of energy and although such a core has considerable weight, as compared with a small armature of the usual type, yet there is an entire absence of inertia as that term is usually applied, in its operation. The extent of the core-expansion and contraction, all other factors being at their maximum, will depend upon and be in proportion to the energy or force impressed through the coil. This will be true for telephonic currents, as, at a repeater-station they will never be of sufficient strength to magnetically over-saturate the core. In order to construct such a repeater, there are certain limitations on which its successful operation depends. These limitations do not appear ever to have been investigated with this object in view. It is therefore my purpose now to clearly establish and explain the conditions under which this apparatus may be constructed in order to successfully perform the function of a telephone repeater. They are as follows:

1. The core must be at least 10 inches long.
2. The coil, or solenoid, must be nearly as long as the core.
3. The core must be less than $\frac{1}{8}$ inch in diameter.

The result might be obtained indirectly, as, with a core only 5 inches long, but con-

nected to a beam, or lever, which would multiply the excursion of the microphone electrode by 2, as shown in Fig. 4.

The specified dimensions are necessary because:

1. A transmitter diaphragm vibrates through a distance of 25×10^{-6} inch for good transmission of speech. This figure is given as the result of extended experimental investigation by Cross, using a Blake transmitter. His observations included also the excursion of the diaphragm of the so-called "hammer and anvil" microphone, which, for good transmission amounted to from 10 to 20×10^{-6} inch. This shows generally less excursion than the Blake, but the latter represents the direct variation in distance between two points in contact due to the vibrations of a diaphragm connected to one of them, and it is therefore taken as bearing accurately on the present case. Even were an excursion of 10×10^{-6} inch entirely sufficient, the limits of construction set, would not be altered, as they are taken very conservatively.

2. The maximum possible elongation of the core requires a total length of 10 inches in order to equal 25×10^{-6} inch. This fact is demonstrated by the researches of Bidwell who showed that iron reaches a maximum elongation, under increasing magnetizing force, at a value for the latter of about 75 c. g. s. units. For smaller magnetizing forces the elongation is less, and is roughly proportioned to the value of the magnetizing force. The maximum elongation given is about 2.5×10^{-6} inch, per inch of length of the core. Therefore 10 inches of core would give a total elongation of 25×10^{-6} inch, which is required for successful telephonic transmission.

3. The magnetizing force of a coil such as could be used for the purposes of a relay is greatly inferior to that required to produce maximum elongation of a core. This is shown by the following numerical calculation, based on the fundamental approximate formula,

$$H = \frac{4\pi NI}{10 l}, \quad 115$$

where H=magnetizing force in c. g. s. unit, N=number of turns of wire of the coil, I=the current flowing through the coil in amperes, l=length of the coil, in cms., and

$$\frac{4\pi}{10}$$

is a numerical constant, =1.256. Let the coil be 10 inches long, of No. 36 B. & S. gage silk covered copper wire. This wire is 0.005 inch diameter, bare, and approximately 0.01 inch diameter, outside of insulation. This would allow a maximum of 100 turns per inch, per layer, and 1000 turns per layer of 10 inches. If the coil were

wound 25 layers deep, the total number of turns would be 25000.

4. Assuming a mean diameter of one turn to be $\frac{1}{4}$ inch, or a mean length of one turn to be $\frac{1}{2}$ inch (0.75 inch), the total length of wire of the coil would be $.75 \times 25000 = 18750$ inches = 1562 feet. The resistance of No. 36 wire is approximately 400 ohms/1000 feet. Therefore the resistance alone of the coil would be $400 \times 1.562 = 625$ ohms. The current flowing in the coil may be assigned a value of 10^{-4} ampere. This value is however high, as currents of 10^{-5} ampere are sufficient for telephone conversation and the limit of audibility extends beyond 10^{-7} ampere. The value of 10^{-4} ampere is taken as beyond the maximum limit which would be used in the coil of a repeater.

$$l = 10 \text{ inches} = 10 \times 2.54 \text{ cm.} = 25.4 \text{ cms.}$$

Supplying values in the above formula, we have

$$H = 1.256 \times 25000 \times 10^{-4} \div 25.4 = 0.124.$$

- 25 The magnetizing force of this coil is therefore about $\frac{1}{8}$ of a c. g. s. unit. Using this figure, and assuming that the elongation varies directly with the magnetizing force, up to a maximum elongation of 25×10^{-6} inch with a magnetizing force of 75 c. g. s. units, the elongation produced by the coil would be

$$25 \times 10^{-6} \div 75 \times 8 = 4.2 \times 10^{-3} \text{ inch,}$$

- 35 or about $1/600$ of the amount required for good transmission.

5. (*Resistance of coil*).—The reactance of the coil

$$Lw = \frac{2\pi nBN}{10^9} \text{ ohms, approximately,}$$

where n = frequency of the alternating current,

$$\frac{B}{10^9} =$$

- 45 the total magnetic induction through the coil in gaussses, and N = the number of turns = 25000. $w = 2\pi n$. If we take μ , the permeability of the medium inside the coil = 1, which is the value for non-magnetic material, we have $B = h$, where h is the magnetizing force when 1 ampere flows through the coil.

$$h = 10^{-4} \times H = 10^{-4} \times .124 = 1240.$$

The value $2\pi n$ may be taken as 5000 for normal operation, or 12500 for the limiting frequency. Therefore

$$Lw = \frac{5000 \times 1240 \times 25000}{10^9} = 1550 \text{ ohms,}$$

or using $w = 12500$,

$$Lw = \frac{12500 \times 1240 \times 25000}{10^9} = 3875 \text{ ohms.}$$

The impedance of the coil would then be, either

$$\sqrt{625^2 + 1550^2} = 1675$$

or,

$$\sqrt{625^2 + 3875^2} = 3920,$$

according to which value of w was used in the calculation. This is a low estimate of the impedance, as the value of μ would be greater than 1. Assuming no drop of voltage in the line between transmitter and relay, it would thus require $10^{-4} \times 3920 = 0.4$ volt approximately to magnetize the coil to the degree assumed. As this is far greater than the available voltage at the receiving end of the line, it is evident that a coil of more turns would be impracticable, owing to the great increase in its impedance. The coil could therefore not be so designed that the magnetizing force would be increased beyond the limiting value here given.

Condition 2.—It is necessary to have a long coil, as well as a long core. This is evident at once. With a short coil, the magnetic induction will not continue as dense in the extremities of the core as inside the coil. This condition is illustrated in Fig. 5. This will do no harm, except that the added length of the core will be ineffectual. To be effective, the whole length of the core should be magnetized.

Condition 3.—This depends on the following facts:

1. With an alternating magnetizing force of from 800 to 2,000 cycles per second, the magnetic induction will not penetrate into the bar sufficiently to produce the necessary elongation. The propagation of magnetic force through space takes place in a non-magnetic medium of unit specific inductive capacity. The force starts from the surface of the current carrying wire, and proceeds outward in a direction at right angles to the axis of the wire. When it encounters magnetic material, its velocity is retarded, and the penetration of the magnetic induction into the magnetic material takes place at a much slower rate than in air or non-magnetic matter. When the magnetic force is withdrawn, the induction returns into the wire, coming out of the magnetic material at the same rate at which it entered it. These facts are well established by the researches of Varley, Fleming and others. Thus, when a core is magnetized, the induction begins at the surface, and penetrates to the center. If the magnetizing force is a steady one, the distribution of induction over the cross-section of the core will be uniform, but if it is an alternating force, the outside region of the core will be more highly magnetized than the center. If the

alternation is quite rapid, the center of the core will not be magnetized at all. Again, with a given frequency of alternation of the magnetizing force, the degree to which the induction penetrates will depend on the diameter of the core. The distance penetrated will be constant, but this may be clear in to the center of a small core, and only a small part of the way in a large core. Fig. 6 in the accompanying drawings gives the relation between magnetization and diameter of core for a magnetizing force of 66 c. g. s. units, with alternations of 800 and 2,000. These curves were derived from those given by Varley. It is evident that the magnetization of the mere "skin" of a core is not sufficient to cause the comparatively inert mass of it to elongate to any extent sufficient to transmit telephonic messages. Therefore $\frac{1}{8}$ inch is the maximum limit to the permissible diameter of the core.

2. If the magnetization did penetrate into the core sufficiently to produce elongation, there would be effects of distortion of the waves transmitted, which would render unintelligible the messages received at the distant end. This follows at once from the consideration, that if magnetization of the outside region of the core could cause the entire mass of the core to elongate, then, when the magnetism had penetrated to the interior and had diminished at the surface, the elongation would be maintained by the force exerted at the center. This would cause hopeless distortion of the original wave. The only remedy for this would be to make the diameter of the core so small that the magnetism would be sensibly uniform throughout its cross-section. This would mean less than $\frac{1}{16}$ inch, as appears from the curves of Fig. 6.

It will be seen therefore from the above that the limits of construction set in this specification are ultra-conservative. No 10 inch core, $\frac{1}{8}$ inch in diameter, could possibly be made to work successfully as a relay.

It will be obvious when I fix one end of the core that I do so, not for the purpose alone of having it supported, but for the more important object of compelling the entire expansion or movement to be effective at its free or transmitter end. The apparatus will operate effectively without a better magnetic circuit-return than the air, from one end, or pole of the core to the other. But to secure greater efficiency a magnetic metal return may be provided as shown by attaching the core, at its fixed end F, to an iron bar G and extending the bar toward and almost into contact with the opposite end of the core. This last construction furnishes an almost closed path for the magnetic lines-of-force, they being completed from one pole of the core to the other and materially assisting in preventing stray

lines-of-force, and confining them to the core where they are effective in producing the relative maximum molecular and expansion effect. The auxiliary magnetic effect, or action upon the attractive armature, which will be more fully explained in connection with the other views is augmented also by this low-resistance magnetic return path, as, in the attractive-armature form of the apparatus, the armature is made to form a part of such return. The transmitter T (see Fig. 1) in this instance a platinum electrode E², mounted upon the core, and a carbon electrode E, mounted upon an adjustable spring U, may be of any preferred type, according to the service required, or the particular repeater system used and is operated by being attached directly to, or otherwise operatively associated with, the free end of the core. Several such embodiments of the invention are illustrated in other views.

In Fig. 2, the base B for supporting the working parts is, for clearness in illustration and convenience in electrically isolating or insulating the several parts necessary, is shown as of insulating material such as hard rubber. Supported upon the base B and fastened thereto by means of screws or bolts as shown, is the magnetic-return member or back armature G, of iron or steel, which serves also, by means of its rear upward extension G², to support at its fixed end F, the long straight slender core C. Said end F of the core is inserted for support and fastening in the aperture G³ and is clamped therein by means of the set-screw G⁴. With the length of core specifically described this may be the only support, as the core should have sufficient strength and rigidity to remain in the desired position. The receiving coil or helix H surrounding the core is supported upon the core at its fixed end F, as shown, by means of the bushing H² and rests otherwise upon the bridge or support H¹, mounted upon the central portion of the back armature G or on the base itself. The helix terminals are represented by the conductors H³ and H⁴ leading to terminal or binding-posts H⁵ and H⁶ respectively. With an ordinary length of coil say up to 12 inches one continuous winding will suffice. The carbon electrode E of transmitter T at the free end of the core is attached to the core by means of the small metal arm E³ that has at one end a perforation through which the core is extended and is therein secured by the set-screw E⁴. The electrode E is similarly fastened to the opposite end of the metal arm, being inserted or seated in a perforation parallel to the other perforation and fastened by the set-screw E⁵. The opposite electrode E² is of platinum but this may be of carbon and the electrode E may

be of platinum if desired and said electrode E^2 is attached to the vibratory tongue-armature A. This armature is supported by screws, as shown, upon the south pole of the polarizing permanent magnet P and is adapted to vibrate in the air-gap or polar space before the free end of the core C. The tongue armature A may be of spring metal other than steel and carry a small magnetic armature A^2 , or the tongue may itself be of magnetic metal and it is preferably so for its polarization and to avoid the extra weight of the part A^2 . The armature polarization magnet P is supported upon the base B by its angular extension or north pole which is fastened thereto by means of screws or bolts as shown. A brass adjusting screw P^2 is threaded through the polarizing magnet P and contacts with the tongue A near its fixed or upper end for regulating or adjusting the tongue which has an opposite set or tendency, in a forward direction toward the core. A brass adjusting screw P^3 , secured to the north pole of the magnet by a brass bracket P^4 , serves for regulating the extent of the movement of the tongue in the forward direction. The screw P^3 is placed near the opposite or lower end of the tongue and near the microphonic electrodes E and E^2 to better secure nice adjustments and delicate effects. The microphonic circuit through the instrument may be traced as follows: from binding post M on polarizing magnet P, through P, through A, through the microphonic contact E^2 and E, core C, magnetic support G^2 , to binding post M^2 .

The operation of this relay may be described as follows: The telephonic impulses received by the coil H varies correspondingly the magnetic state of the core C. The variations in the magnetism of the core produce two effects, that is, an expansion effect and an attractive effect. The expansion of the core being of corresponding proportions to the energizing currents, the physical effect is an elongation of the core with each magnetizing current and a contraction of same with the cessation of the current or impulse. As the core is made stationary at one end all the effects of expansion and contraction are made manifest and effective at the free or microphonic end, hence, for these particular movements the microphonic contact, or pressure between electrodes E and E^2 is increased by the core expansions and decreased by the core contractions, thus producing a repeating microphonic effect. The auxiliary or attractive effect is similar to the usual relay operation, in that, the variations in the magnetic state of the core correspondingly affect the vibratory armature to attract it toward the core with each increase in magnetism and in proportion thereto, and correspondingly diminishes the effect with

each cessation of current, when the retractile action of the adjusted spring armature restores the elements to their normal positions. Each attractive effect, or movement of the armature toward the core, increases the microphonic-contact or pressure between the electrodes and each cessation or reduction of attractive effect decreases the contact. It will be seen that the results of the two magnetic effects are cooperative, in that, the expansion effect of the one and the attractive effect of the other, while acting upon the electrodes oppositely in direction, thereby produce cooperative effects in increasing the microphonic contact, and the contraction effect and loss of attractive, or a repulsion effect, taking place in the opposite direction, or opposite sense, cooperate to decrease the microphonic contact. The polarization of the armature by the permanent magnet P augments the force and accelerates the movements of the armature and improves the effect in the following manner: When the receiving coil is energized by an impulse producing a magnetic state such as indicated, that is, the free end of the core being of north sign, the armature being of opposite, or south sign polarity, is strongly attracted to the core. When the impulse produces an effect of opposite sign in the core, the action is strongly repulsive and the armature moves from the core pole, the effect being assisted by the set of the spring armature in that direction. The expansion of the core assists in this repelling action also, as its advancement toward the armature causes the latter to move an equal distance farther in the same direction. Thus it will be seen that when the polarized armature is utilized the joint effects are to more completely compress the microphonic contacts for the impulses producing the attraction of the armature and to correspondingly decrease the contact for the alternate impulses, thereby producing a very wide range of action or variation in the microphonic contact. The advancement of the core toward the armature for all attractive movements also assists in the resulting effects of a wide range of action and compression in the microphone, as, in the relative and mutual advancement of the armature and the core toward each other the resulting movement is much increased over that of the old form of relay with its single attractive effect.

It is understood that good microphonic action, or effect, is now conceded as not being dependent so much upon variations in pressure between contacts or electrodes, as upon variation in the amount of contact, the superficial area, or number of points or particles in contact, that is, the variation of same from time to time, or from effect to effect. Variations in the pressure between electrodes, or any movement of an electrode

produces such a microphonic condition or effect; hence, as explained above, the joint action of the two magnetic effects producing variations in the pressure between the electrodes, or the movement due to the repulsion of the polarized armature will create a true microphonic action.

In Fig. 3 which is a modification of the instrument shown in Fig. 2, is illustrated an adaptation of the well known granular type of microphone or transmitter for operation with the expansion core. The transmitter T, of the so called granular button type, in this instance is formed of the hollow cylinder or chamber ring R, preferably of iron to improve the magnetic circuit of core C, by being included in that circuit. Ring R has the extension lug and foot R², also of iron, for supporting it upon the magnetic return member G. The foot R² has an extension or runner R³, slidable in the slot R⁴, in the member G, for aligning the transmitter with reference to the core C. The free or movable end of core C enters the center of the chamber ring R after passing through the center of a mica diaphragm D, which closes the granular chamber, forming a wall on the front or core side thereof. The mica diaphragm D is peripherally clamped to the granular chamber ring R by the clamping ring R⁵, both members being threaded, as shown, for that purpose. The core C is threaded at the end F and is flexibly supported by the mica diaphragm, being fastened thereto by front and back disk nuts D² and D³ respectively. The front disk electrode E is attached to the rear side of the disk nut D³, having an aperture in its center through which the core extends into the carbon chamber. The rear end or wall of the chamber formed by the ring R is closed by a diaphragm A³, which is also preferably of iron. This diaphragm is peripherally clamped to the ring R by the rear clamping ring or rear casing R⁶. The rear diaphragm A³ carries at its center and within the chamber a small iron disk or armature-piece A² and the latter is fastened to the diaphragm on its rear side by the clamping nut A⁴. The rear disk electrode E², like the front electrode, has a central aperture and is attached to the center of the rear diaphragm within the chamber by being copper plated and soldered to the armature stud A²; the latter passing through the central aperture. The armature A² and the pole end of the core C should be positioned or adjusted with reference to each other so as to have only a very small clearance, or air gap, just sufficient to give the rear diaphragm free movement when attracted toward the core. The pole end of the core should be slightly rounded to permit any granules of the carbon E⁶ to move easily from between the pole

and the armature and thus prevent interference of operation. To secure a rather large diameter of the diaphragms, which is advantageous, the chamber ring R is shown as being of greater diameter than necessary for the quantity of carbon granules requisite, hence I employ a space-filler or bushing E⁷, of wool, or similar fibrous and flexible material around the inner periphery of the ring, said material to occupy the waste space and yet permit free movement of the diaphragms. A close fitting insulating lining 1, of paper or shellac, is interposed between the inner periphery of the ring R and the chamber proper, to prevent connection between the ring and the carbon granules, should any sift through the wool bushing, to avoid any short circuiting effect between or around the electrodes, as it is desirable to confine the circuit through the transmitter as fully as possible between the electrodes directly through the granules. The front electrode E is connected by means of conductor E⁴ with the local binding-post, or terminal M and the rear electrode E², while connecting through the iron diaphragm A³ with the casing and support of the transmitter, has an additional connection through conductor E⁵ with binding-post or terminal M² threaded into the magnetic return member G. Such connection insures a circuit should the iron diaphragm be replaced by a diaphragm of mica. As the front electrode E is in electrical connection with the core C, a short circuit between the electrodes by way of the support or magnetic return member G, is avoided by inserting an insulating bushing between the fixed end of the core and its support. This bushing H² may be an elongation of that shown in Figs. 1 and 2, as supporting the coil at that end. An adjusting device for normally controlling the front diaphragm, consists essentially of a screw S and a retracting spring S² and is connected with the rear casing R⁶ of the transmitter by means of an ordinary swivel connection S³. The screw S is controlled by the thumb-nut S⁴ and is supported by and passes through a threaded aperture in the post S⁵ which latter is attached to the base by an ordinary bolt and nut S⁶ shown in dotted outline. The local circuit in this instrument may be readily traced as follows: from binding-terminal M through conductor E⁴ thence through the transmitter from the front electrode E to the rear electrode E², thence out through conductor E⁵ and binding-terminal M². The operation is similar to that of the construction shown in Fig. 1, excepting that the vibratory armature A² is not polarized and every impulse creates an attraction thereof toward the core end or pole and with the counter movement of the core end due to the core expansion, the carbon gran-

ules are caused to vary their positions by the actions of both electrodes.

In Fig. 4, the expansible core is utilized by reason of its comparatively greater power, to actuate the granular transmitting microphone T through the amplifying effect of a lever J. As in any similarly operating mechanism, motion is herein secured at the expense of power. The increased motion or amplified effects secured on the transmitter being according to the point of application of the power to the lever J. As illustrated in Fig. 4, the lever J is arranged so that the power from core C is applied thereto between the fulcrum J² and the transmitter T. As arranged in this view the transmitter is twice as far from the fulcrum as the point of power application and would have twice the movement of the lever at the point of power application with only half the force, but since movement at the transmitter is of more importance than power, the results in increased resistance variation of the transmitter are improved. Such amplified movements of the transmitter and greater variation in resistance permits the employment of smaller battery current and correspondingly there will be less heat set up in the transmitter. Referring particularly to the lever arrangement illustrated, it will be seen that the transmitter T is supported adjustably by screw S which passes through the front vertical extension G⁵ of the magnetic return member G. Screw S is slightly flattened on two sides and fits in and passes through a smooth aperture G⁶ in extension G⁵ to prevent the transmitter turning out of proper position when being adjusted forward or backward by the adjusting thumb-nuts S⁷ and S⁸. To the end of the extension G⁵ is attached by means of screws K³, a horizontal insulating and lever supporting member K. This member K is of insulating material to prevent the various metal parts from shunting the transmitter. For the same reason core C in this instance of construction must also be electrically separated from the member G as is shown at H² in Fig. 3. To the projecting end of member K is attached by means of screws K⁴ a brass supporting lug K². Lever J is elastically or pivotally supported at its upper end to the lower end of lug K² by a short thin flat spring J². The spring has its ends embedded and soldered in the lug and the lever in slots. The said spring should be as short as is consistent with a high degree of elasticity while preventing any relative movement of the lug and lever toward each other. Lost motion is by this arrangement avoided and an easy free movement or oscillation of the lever is secured. Lever J is attached at its middle to the free end of core C by means of a spring J³ to provide a mounting or coupling similar to that just

described, one end of the spring being embedded in a slot in the end of core C. To secure any other movement or a leverage different from that shown the connection between the lever and the core should be moved up or down accordingly as desired. The lower end of lever J is, for control, attached to the mica diaphragm D of transmitter T, in the manner presently to be described. The transmitter in this instance is also of the granular type having front and rear electrodes with carbon granules intervening within an inclosing chamber. The front electrode E is mounted on a brass disk D³, having a screw extension passing through the mica diaphragm and a locking bur D² for clamping the parts to the diaphragm. The screw of disk D³ extends forward and turns into the rear of stud J⁵. The front portion of the stud is slotted for the reception of one end of the spring coupling J⁴, which forms the attachment, or connection between the lever and the transmitter. The spring J⁴ is fastened into the lower end of lever J by a slot-connection similar to those of the other spring connections. This method of mounting the lever and its connections provides for the necessary high degree of sensitiveness and freedom of action, yet avoids any unnecessary play or lost motion between the parts. The electrical connections in Fig. 4 are similar to those shown in Fig. 3 and the operation is the same except that the motions are amplified by the lever intervening between the core and the transmitter. The lever arrangement can obviously be reinforced by a magnetic vibrating armature as in Fig. 2 co-operating with the expanding or elongating core.

In Fig. 5 the extra long core C has its fixed end supported by the member G² and because its length and thinness render it limber, it is provided with additional means of support to maintain it in good alinement through the bore of the winding H. These special supports are preferred to facilitate the longitudinal movement of the core but they are not indispensable as the core can rest loosely in the bore of the coils. The additional supporting means consists in the magnetic poles or extensions G⁵, rising from the return member G, similar to the extension G², said extension being disposed along the core between the coils. Each of these extensions G⁵ has a perforation G³ to provide free passage and space for the core. Each member G⁵ has mounted within the perforation a very small sheave G⁶ on which the core rides. Attached to the front end of member G is a post K⁴, of hard rubber or other suitable insulating substance, which carries at its top the spring support U for electrode E², said spring U is held in place by the binding post M the latter being

one of the transmitter terminals. Through the post K^4 is threaded the transmitter adjusting screw P^2 . The extra length coil or winding H , is preferably divided into two or more helices, each of similar resistance and each connected in the receiving circuit in parallel. This method of connecting the windings in the receiving circuit provides for simultaneous, as well as the cumulative action throughout the length of the core, the several sections or portions of the core being acted upon by the coil divisions H . This arrangement just described divides the magnetic effects, due to the several helices, into distinct or complete magnetic sections that are similarly and simultaneously acted upon. The coils H are supported upon the bridges or supports H^7 . The mounting base B and other features are like those in Figs. 1, 2 and 3. The coil terminals H^8 and H^4 are brought to terminal posts H^5 and H^6 as usual. These terminals permit the coils to be readily connected in parallel for joint resistance. Each coil being 12 inches long and having a resistance of, say, 120 ohms, the three when connected in series would have a resistance of about 360 ohms, and if connected in parallel would only equal about 45 ohms, which would give better core action and reduce the coil retardation.

Fig. 5, like Figs. 1, 2 and 3, is shown in the view as being broken out at the middle of each of the three coils because with the full size scale used in depicting the other dimensions of the parts its length precludes showing it in full. Drawn in full the coils would be 12 inches between heads, the three shown aggregating 36 inches in length and the core, because of the spacing between the coils and the protruding ends would aggregate about 39 inches.

With either form of instrument shown I have not found it necessary to initially magnetize the core, yet it will be obvious that the magnetic return member G may be utilized for such initial sensitization by forming it of magnet steel and having it permanently magnetized.

Other modifications may be made without departing from the gist of the invention.

What I claim is:

1. In a telephone device, the combination of a long receiving coil having a long thin core capable of being varied in its length by the magnetic influence of the coil and a reproducing element adapted to be actuated by the movements produced, together with a vibratory attractive armature associated with said reproducing element and confronting the free pole of said core to be actuated by the magnetic attraction of the core, substantially as specified.

2. In a telephone instrumentality, a long coil, a long magnetically molecular expandible core within the coil, a reproducing ele-

ment attached to an end of said core to move with same and another reproducing element confronting the same core end to be attracted and actuated magnetically by same, said elements moving coöperatively to reproduce the original vibrations.

3. In a telephone instrument, the combination with a long tubular receiving coil, a long slender magnetically expandible core therein, said core having a cross-section which in mass is so small as to be entirely permeated by the lines of force set up by the received telephone currents, and a microphone transmitter adapted to be actuated by the endwise or longitudinal expansion vibrations of said core in accordance with the degree of magnetization of said core by said receiver coil.

4. In a telephone reproducing device, an elongated coil in combination with a long attenuated core, said core being of a cross-section which in mass is so small as to be entirely permeated by the lines of force set up by the received telephone currents, said core extending through the bore of the coil and having one end fixed, with means adapted for reproduction effects associated with and operated by the free end of said core.

5. In a telephone relay, in combination, a long slender winding, a long and very slender magnetic core within said winding, said core being adapted to be expanded longitudinally or endwise by telephonic currents, a magnetic return member associated with said core and winding for confining the field of force, and a repeating microphone adapted to be actuated by the expansions of said core, substantially as specified.

6. In a telephone relay, in combination, a long slender winding, a long slender core within said winding, said core capable of magnetic elongation and being of a cross-section or mass so small as to be entirely permeable to lines of force set up by telephonic currents in said winding and be caused to expand and contract longitudinally, a repeating transmitter in operative relation to said core and means associated therewith for amplifying or increasing the effects upon the transmitter, substantially as specified.

7. In a telephone relay, the combination with a transmitter of an actuating core therefor, an energizing coil for said core, means for associating the transmitter with the core whereby the former may be actuated by the latter through its physical alterations in length due to and proportionate to the field variations of said coil; said coil and core having a length sufficient to produce the required amplitude of vibration of the transmitter, and the core also having a cross-section or diameter sufficiently thin to be entirely permeated by the instantaneous

field strength set up by the coil from the telephone currents received, substantially as specified.

8. In a telephone relay of the expansion
5 core type, the method of determining the
lengths of coil and core and the diameter
of the core, which consists in making the
lengths of coil and core physically approxi-
mately equal, the length of core being a
10 variable determined inversely as the cur-
rent strength and by the ratio per unit
movement of the core into the total required

movement; the radial thickness, or the cross-
section, of the core being a constant de-
termined by the speech frequency and so 15
thin as to be uniformly permeated by the
instantaneous field set up by the coil from
the telephonic impulses, substantially as
specified.

NATHANIEL G. WARTH.

Witnesses:

BENJ. FINCKEL,
MAYME FOARD.