May 21, 1940. J. D. BROWDER ET AL 2,201,472

COMMUNICATION SYSTEM

Filed April 26, 1937 3 Sheets-Sheet 1

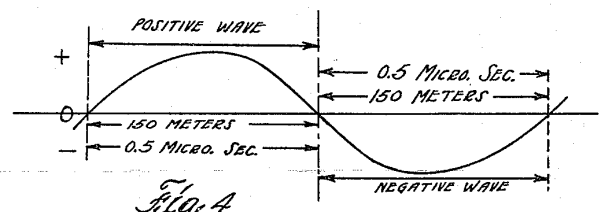


Fig. 4

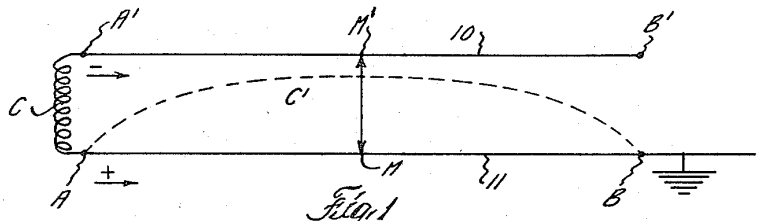


Fig. 1

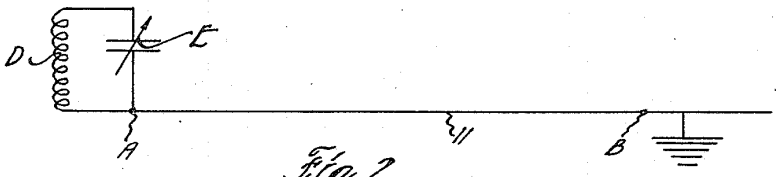


Fig. 2

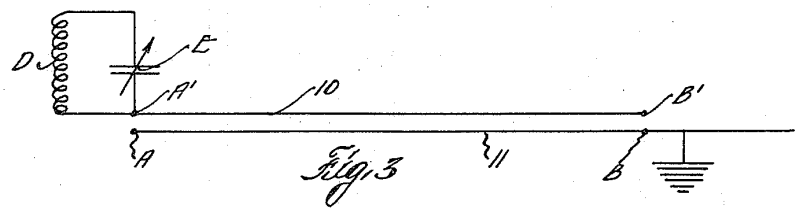


Fig. 3

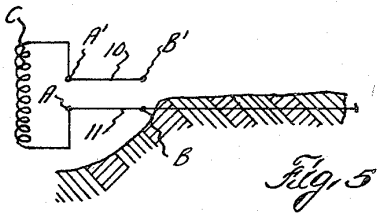
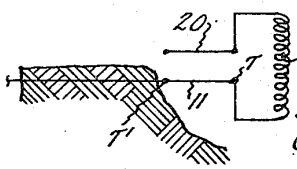


Fig. 5



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COMMUNICATION SYSTEM

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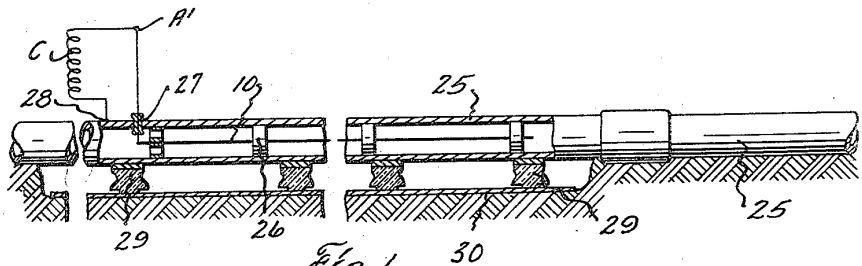


Fig. 6

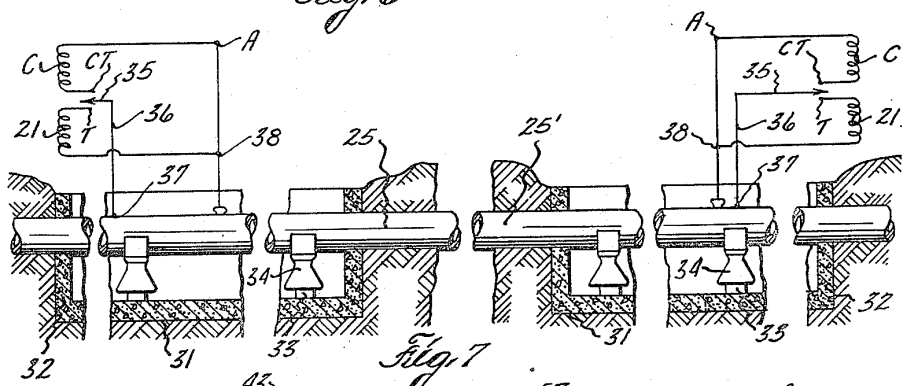


Fig. 7

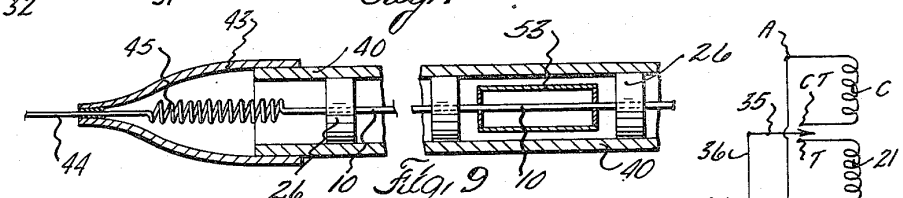


Fig. 9

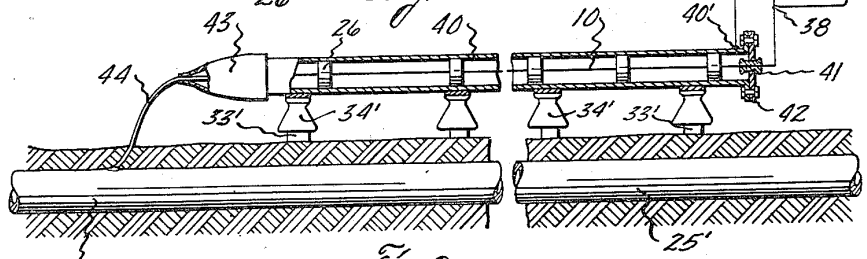


Fig. 8

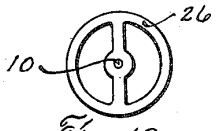


Fig. 10

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COMMUNICATION SYSTEM

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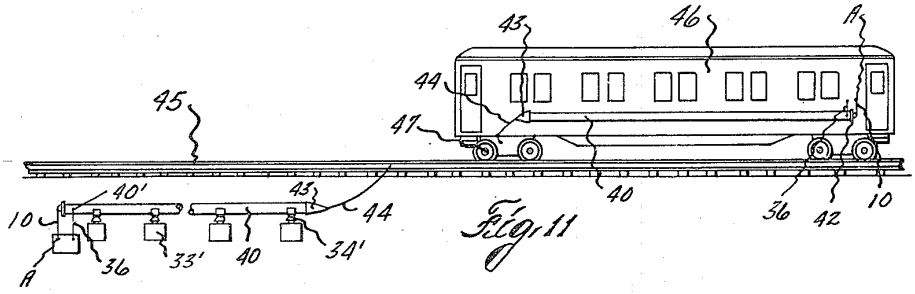


Fig. 11

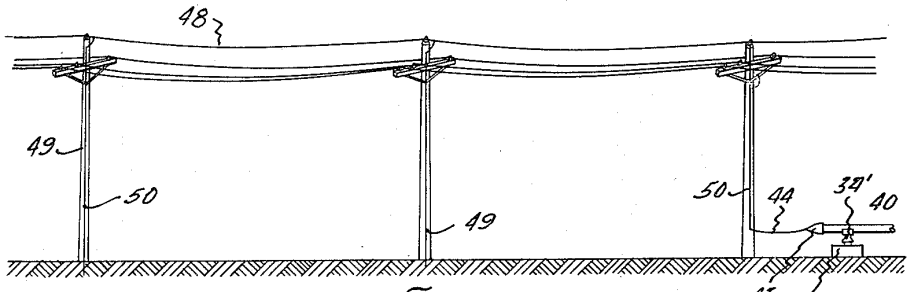


Fig. 12

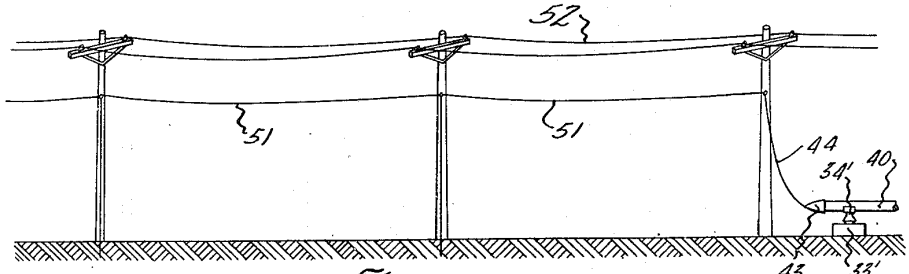


Fig. 13

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Patented May 21, 1940 2,201,472

UNITED STATES PATENT OFFICE

2,201,472

COMMUNICATION SYSTEM

Jewel D. Browder, Oklahoma City, Okla., and
Clifton W. Easley, Henrietta, Tex.

Application April 26, 1937, Serial No. 138,950

19 Claims. (Cl. 178—44)

This invention relates to new and useful improvements in communication systems.

This application is filed as a continuation-in-part of my co-pending application Serial No. 52,350 filed November 30, 1935.

One object of the invention is to provide an improved method of and means for propagating radio or electromagnetic waves along metallic conductors, which have been installed for other purposes, whereby efficient communication may be established through said conductors without interfering in any manner with the normal function or purpose of said conductor.

There are at present, thousands of miles of metallic conductors which have been installed for a given purpose and heretofore, no other use has been found for them. These metallic conductors include pipe lines, either surface or underground, which are utilized for the transportation of oil, gas, water or other fluids; the rails of elevated, surface and subway rails; overhead static and underground counterpoise wires employed for protecting high voltage transmission lines against lightning; steel messenger wires used for supporting aerial telephone and telegraph cables; and the metallic protective sheaths of underground cables employed in the telephone, telegraph and electric power industries. These, and many other forms of metallic conductors, grounded and ungrounded, are utilized only for the purpose for which they were manufactured. It is therefore, a most important object of the invention to utilize these various metallic conductors, which are already in place, for the transmission of radio or electromagnetic waves, whereby communication between distant points along the conductor may be established.

A particular object of the invention is to provide an improved communication system wherein radio or electromagnetic waves are generated and imparted on a metallic conductor so that said conductor acts as a guide for the waves and said waves traverse the path afforded by the conductor, rather than radiating in all directions as is the case of the popular free broadcast system, whereby said waves may be received at any point along said conductor to provide a more or less private communication system.

Another object of the invention is to provide an improved method of transmitting radio or electromagnetic waves along a metallic conductor which includes insulating a portion of the conductor adjacent the transmitter from the ground, whereby the generated radio waves are impressed upon the conductor and travel therealong in the exterior surrounding space thereof, the insulation of the conductor at this point preventing the earth from absorbing the radio frequency electrical current energy.

A further object of the invention is to provide an improved communication system wherein radio or electromagnetic waves are impressed on a metallic conductor and also wherein the transmitting antenna is arranged so as to minimize the radiation of "Hertzian" or free waves, whereby the transmitted waves travel along the path of and in the immediate vicinity of the conductor.

Still another object of the invention is to provide an improved system of transmitting electromagnetic waves, wherein a metallic conductor is utilized as a guide for the waves, said conductor co-acting with the sending antenna, similar to the earth co-acting with the sending antenna of the popular broadcast method, generally known as the "Marconi" system, whereby the radio waves are propagated along the conductor.

An important object of the invention is to provide an improved method of transmitting radio waves, which consists in sending radio or electromagnetic waves along a confined path or conductor, and then receiving said waves at any point along said conductor.

A particular object of the invention is to provide an improved means for establishing communication between two or more points along a metallic conductor which means comprises an antenna electrically insulated from the conductor but electrically coupled thereto and adapted for use in either sending or receiving radio waves, whereby a combination sending and receiving station may be established at any point along said conductor.

A still further object of the invention is to provide an improved communication system of the character described which may be employed on railroads, whereby the rails of the track act as a guide for the radio waves, which permits communication to be readily established between persons on the moving cars of a train and ground stations located in the vicinity of the railroad.

A construction designed to carry out the invention will be hereinafter described, together with other features of the invention.

The invention will be more readily understood from a reading of the following specification and by reference to the accompanying drawings, in which an example of the invention is shown, and wherein:

Figure 1 is a diagrammatical view of a simple

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form of radio wave generating equipment, constructed in accordance with the invention,

Figures 2 and 3 are similar views, showing other forms of generating equipment,

Figure 4 is a schematic view showing the action of a sinusoidal voltage,

Figure 5 is a diagrammatical view, showing both sending and receiving antennae,

Figure 6 is a view, partly in section and partly in elevation showing the invention applied to a surface pipe line,

Figure 7 is a similar view showing an underground pipe line,

Figure 8 is a view, partly in elevation and partly in section showing another practical method of applying the invention to an underground pipe line,

Figure 9 is a sectional view, showing slight modifications of the form of the invention shown in Figure 8,

Figure 10 is an elevation of one of the insulating antenna supports,

Figure 11 is a view, disclosing the invention applied to a railroad,

Figure 12 is a view, disclosing the invention applied to the grounded static wire or lightning conductor of an electric power line, and

Figure 13 is a similar view, showing the invention applied to a group of insulated aerial conductors.

Certain fundamental principles of the popular broadcast radio, generally known as the "Marconi" system have been recognized and a brief discussion of these principles and a comparison thereof with our improved communication system, is herewith included for the sake of clarity. It is well known that in the usual broadcast system, an elevated antenna is employed. In generating the radio or electromagnetic waves, this antenna and that portion of the earth's surface directly beneath and adjacent said antenna, is alternately electrically charged positively and negatively a number of times per second, corresponding to the frequency of the emitted waves; in other words, the earth is employed as one side of the antenna circuit or one plate of the condenser at a broadcast station. Assuming the wave frequency to be 1,000,000 cycles per second, then the relatively small area of the earth below and adjacent the elevated antenna, is electrically charged 2,000,000 times during each second, with 1,000,000 positive charges alternating, with respect to time, with 1,000,000 negative charges, as generally illustrated by the sine wave. From these rapidly applied charges of opposite character, arises the phenomenon known as radio or electromagnetic waves which is an electrical energy manifestation that detaches from its source and radiates at the speed of light.

The radio or electromagnetic waves which are so generated in the usual broadcast system are said to have their "feet" on the ground, that is, they are attached to the ground, being commonly referred to as the "ground waves" of a broadcast transmitter. The attachment of these electromagnetic waves to the ground is the reason for the radiation of said waves in all directions from the broadcast transmitter, for obviously, the earth's surface extends in all directions. It follows then that the ground or earth's surface forms one side of the antenna circuit and acts as a guide for the electromagnetic or radio waves which are generated as a result of the alternating voltage and current in the antenna circuit, and which detach themselves from their source. Manifestly, the alternating voltage and current does not act upon the entire earth's surface but is confined to that portion of the earth's surface beneath and adjacent the elevated antenna.

From the foregoing, it will be seen that in the usual type of broadcast system, particularly in those employing the lower frequencies, now in widespread use, the electromagnetic or radio waves are radiated in all directions from the transmitter mainly because the earth is the guiding medium for said waves. There have been attempts to control the direction of radiation of the electromagnetic waves by specially designed antennae, such as those generally known as the L type or T type aerial, but even with these specially constructed antennae, the earth's surface still forms one side of the antenna circuit and therefore, acts as the guiding medium.

Since the earth's surface, being a good electrical conductor, acts as a guide for radio or electromagnetic waves of the "Marconi" system, it is possible to employ a long distance metallic electrical conductor in a similar manner simply by electrically associating a part of it with an antenna so that the whole arrangement is comparable to the radiating equipment of the "Marconi" system. In order to utilize a metallic conductor in this manner, it is necessary to avoid free broadcasting of the usual grounded waves, or radiation of the waves in all directions as in the Marconi system. Further, in radio broadcasting there are also present ungrounded radio waves which are only generated at the elevated antenna and are generally known as "Hertzian" waves. These Hertzian waves are almost negligible at low frequency and gradually increase as higher frequencies are employed. Therefore, to make the use of a metallic conductor practical as a guiding medium for radio waves it is necessary to avoid free broadcasting of not only the "ground waves" as before stated, but also of the free or ungrounded Hertzian waves which latter are not guided by the earth's surface.

In carrying out the invention to permit a metallic conductor to guide the radio or electromagnetic waves, an antenna circuit, as diagrammatically illustrated in Figure 1, is provided. The numeral 10 designates an antenna which may take the form of a copper wire, or other metallic member, while the numeral 11 designates a grounded metallic conductor such as an underground pipe line. The end portion of the conductor from point A to the point B is electrically insulated from the ground by suitable means (not shown) and the remainder of the conductor is grounded. A coil C has one end connected to the terminal A of the conductor 11, while the other end of said coil is connected to the terminal A' of the antenna 10. The antenna preferably extends parallel to and overlies the insulated portion of the conductor 11, and the outer end B' of the antenna is open circuited. As shown in Figure 1, the length of the antenna is substantially equal to the length of the insulated portion of the metallic conductor. The disposition of the antenna with relation to the conductor is such that there is an electrostatic capacitance therebetween, as indicated as C'. Therefore, the arrangement forms a condenser, wherein the antenna 10 forms one plate thereof and the insulated portion of the conductor 11 forms the other plate.

A sinusoidal voltage is impressed across the terminals A and A' by the mutual inductance or

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transformer action between the coil C and a primary winding (not shown) which winding is excited from a source of electric power having a sinusoidal voltage. As the voltage in the coil C rises from zero value, acting in the positive direction into the metallic conductor 11, the vibratory motion imparted to the electrons causes some of them to migrate toward the terminal A' and out into the antenna 10. This action produces an excess of electrons in the antenna and a deficiency of electrons in the earth-insulated portion of the conductor 11, with the transfer of electrons from one plate (antenna) 10 to the other plate (earth-insulated section of conductor) of the condenser being affected through the metallic path afforded by the turns or the coil C. Since this movement of electrons constitutes an electric current, the current in this case is known as "charging current," simply because the condenser is being charged.

As the value of this charging current varies sinusoidally, the plates of the condenser likewise becomes charged with electricity of opposite polarities. The antenna 10 carrying the excess of electrons acquires a negative charge while the earth-insulated section of the conductor 11 acquires a positive charge. Accompanying the formation of these charges is a field of dielectric flux which is established in the space lying between and around the plates of the condenser which are formed by the antenna 10 and earth-insulated portion of the conductor 11. This field is generally assumed to consist of lines of electrostatic force which originate on the surface of the positively charged plate (conductor 11), extend across the intervening space and terminate on the negatively charged plate (antenna 10). The total force of this field also varies sinusoidally since it is produced by a similarly varying charging current, and since the charging current is driven by voltage induced in the coil C, the field of dielectric flux acts in opposition to this voltage. That is, when opposite charges of electricity are separated, work is done against the attractive force of the dielectric field; and if the electromotive force which separates the charges is suddenly removed, they will be drawn together again by virtue of the potential energy stored in the field. It does not matter which way the neutralization of the charges is effected; whether the plates of the condenser on which the charges reside are permitted to contact each other by actual movement or whether the excess of electrons on the negative plate are permitted to return to the positive plate through the conductive path of the coil C, the results are the same. Thus, the discharging of the condenser is indicative of the fact that the dielectric flux acts in opposition to the electromotive force which causes it.

While the charging current is flowing into the condenser, concentric lines of magnetic flux are also established around the two conductors or plates of the condenser. This is a well known fact. These flux lines are present only during the movement of electrons and no matter whether the condenser is charging or discharging, the circular direction of magnetic flux lines around one conductor is always opposite to the direction of magnetic flux lines around the other conductor. Energy is stored in the magnetic field as well as in the dielectric field so that when the condenser is being energized from a source of sinusoidal voltage, the total energy of the two fields is equally divided among them.

It is the present theory and general belief that a radio wave is detached electrical energy consisting of dielectric flux associated at right angles with magnetic flux, and the two fields of flux travelling through space and disposed at a right angle to each other. The two fields of flux become detached from their origin as the result of very rapid changes in their magnitudes and directions together with a peculiar property which gives them the effect of possessing inertia. Changes in their magnitudes and directions are, of course, associated with the sinusoidal electromotive force which imparts motion to the electrons contained in the transmitting antenna circuit.

From the foregoing, it will be seen that the impressing of a sinusoidal voltage across the terminals A and A' results in a generating of radio or electromagnetic waves which are attached to the conductor 11, just as the electromagnetic waves are attached or have their "feet" on the ground in the usual "Marconi" broadcast system. Waves of the latter system are said to be "vertically polarized" because their dielectric flux lines or electric field components are approximately perpendicular to the earth's surface, while the magnetic flux lines or magnetic field components are approximately parallel to the earth's surface. This relationship of the two components of a ground or surface wave of the Marconi system results from the fixed positional relationship of certain major elements of the wave generating apparatus, viz., elevated antenna and earth's surface. By the term ground or surface wave is meant that portion of total radiated energy which glides or propagates along the earth's surface with its electric field component being approximately perpendicular and attached thereto, in order to distinguish between Hertzian or space waves in which reside the remaining portion of total radiated energy. Regarding Hertzian or space waves, modern theory subdivides these waves into two classes, viz., (*a*) those proceeding between earth's surface and the ionized layer, and (*b*) those which practically detach themselves from earth's surface and are either reflected or refracted from the ionized layer toward the receiving aerial. Both surface and space waves are so inherently dependent upon each other that an energy loss in one causes the other wave to supply power to the weaker, since both are the result of the integration of the Maxwellian field equations with the true conditions of the ground taken into account. Because of attenuation due to wave spread, amplitudes of the waves experience a geometrical decrease as the waves pass away from their source. Additional attenuation also results from absorption in the ground itself, but in regions of good earth conductivity this absorption of energy is relatively small. In regions having high ground resistance the effect of absorption is rather pronounced for wavelengths shorter than 1 km., and a 1-km. wave over land is attenuated as much as a 30-m. wave over the ocean. With the ocean having a much higher electrical conductivity than land, the amplitude of a 300-m. wave over land at a distance of 150 km. from the transmitter is only 8 percent of the amplitude at an equal distance over the sea. Evidently, therefore, the effective electrical resistance of the conducting medium (land or sea) which physically interconnects the wave-generating apparatus of a transmitting station with wave-intercepting apparatus at a distant receiving station, plays a very essential and important role in the practical achievement of

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the Marconi radio system. Consequently the present invention takes advantage of the immensely greater electrical conductivities of various types of long distance metallic structures, since said metallic structures are therefore caused to serve as highly efficient guides or conductors of electromagnetic waves, particularly that class of waves which compares with ground or surface waves of the Marconi system.

To clearly explain the action transpiring in the vicinity of the antenna circuit during the generation of electromagnetic waves, as shown in Figure 1, reference is made to this figure as well as to Figure 4. It is a well known fact that a sinusoidal voltage varies both in value and in direction with respect to time. These variations together with a finite velocity of propagation constitute the elements of the familiar term "wave length." Thus, a million cycle voltage is represented in Figure 4 wherein:

$$\text{Wave length} = \frac{\text{Speed of propagation of 300,000,000 meters per second}}{\text{Number of cycles per second}}$$

Assuming a million-cycle voltage is induced in the coil C, and starting with zero time and voltage as represented by the origin of horizontal and vertical axes in Figure 4, the coil and both the antenna 10 and earth-insulated portion of the conductor 11 are at zero potential. Assuming that the voltage begins to rise in the positive direction into the conductor 11 from the terminal A, as indicated by the plus sign and arrow, motions of electrons within the coil C, conductor 11 and antenna 10 begin, so that the total movement is from the conductor through the coil and into the antenna. As time passes the electron movements become more intense, causing more electrons to become agitated and hence engulfed in the movement as the result of the voltage continuing to act in the same direction. Since it requires 0.5 microsecond to complete the positive wave, as indicated in Figure 4, and assuming the circuit's velocity of propagation to be equal to that of light, then upon the expiration of 0.25 microsecond the electron movement has spread or extended halfway of the earth-insulated portion of the conductor 11 and of the antenna 10, which is shown as 75 meters in distance, or points M and M' on said conductor and antenna respectively. In another 0.25 microsecond, the electron movement has reached a distance of 150 meters from the terminal A, as designated by points B and B' on the conductor and antenna. The total time elapsed for this movement is 0.5 microsecond which completes the positive wave, and movement of the electrons in this direction ceases, as will be explained.

This extension of the electron movement represents the rate at which the electric charges project themselves out on the antenna 10 and conductor 11. The positive charge flows out on the earth-insulated section of the conductor 11 while the negative charge flows out on the antenna 10, both travelling at the same rate so that corresponding instantaneous values are reached simultaneously. That is, the original zero potentials of both coil terminals start moving away at the same instant and continue at the same rate so that after the expiration of 0.25 microsecond they have reached the points M and at this same instant the coil terminals A and A' have maximum potential values. At the end of the following 0.25 microsecond interval, the original zero potentials have reached points B and B' on the conductor 11 and antenna 10, the maximum values have followed up to points M and M', and the potentials at the coil terminals A and A' have decreased to zero. Thus, at this instant the conductor and antenna have zero potentials at their coil terminals A and A' and at points B and B' but have maximum potentials at points M and M'; hence, the earth-insulated section of the conductor is charged positively and the antenna 10 is charged negatively. This means that the maximum excess of electrons is in the antenna 10 at point M', while the maximum deficiency of electrons is in the conductor 11 at point M; that only those electrons normally residing in the conductor and antenna between the terminals A and A' and points B and B' are directly affected by the voltage induced in the coil. The electrons residing in the conductor 11 beyond point B are not directly acted upon by the voltage induced in the coil simply because the electron movement caused by the induction ceases at points B and B'. Therefore, it is possible to ground the conductor 11 beyond point B without permitting the earth to absorb the electrical current energy generated by the coil and transmitted into the antenna circuit.

At the end of the positive wave or at the expiration of 0.5 microsecond the voltage induced in coil C has decreased to zero and it then starts to rise again but in the opposite direction. Upon the termination of the positive wave the electrostatic capacitance of the antenna 10 and earth-insulated section of the conductor 11 was left in a charged state, representing stored electrostatic energy due to work done in taking electrons away from the conductor 11 and adding them to those already present in the antenna 10. If the coil C remains at zero value, the excess electrons in the antenna would of their own accord flow back into the conductor by way of the coil C, owing to the tendency of the opposite charges on the conductor and antenna to equalize themselves. But instead of the induced voltage remaining at zero, it rises in the opposite direction thereby acting upon the electrons in the same direction as that possessed by their tendency to flow of their own accord through the coil. Consequently, the rising voltage during the negative wave assists the electrons in their reversed movement. At the end of the negative wave the electric charges and electron arrangement are exactly opposite to these at the end of the positive wave, said negative wave terminating at points B and B' just as did the positive wave. The rising voltage of the second positive wave also assists the electrons in their reversed movement. Thus, after a few cycles of transient conditions inevitably associated with the starting period, the system settles down to a uniform and stabilized condition, during which the electrons between points A and B on the conductor 11 and points A' and B' on the antenna are directly acted upon by two additive forces at each instant of voltage reversal. The two fields of flux, dielectric and magnetic as hereinbefore described, are thus detached from their source by the rapid changes in their magnitudes and directions and thus radio or electromagnetic waves are generated.

From the foregoing description, it is obvious that actually the electrons directly acted upon move a predetermined distance on the insulated section of the conductor 11, which is to the point B. Upon reaching this point their movement is reversed and from this it becomes evident that the insulated section of the conductor 11 represents one half wave length of the antenna cir-

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cuit. The electrons beyond this point in the conductor are not directly acted upon by the coil voltage and therefore, even though the remainder of the conductor is grounded, the normal operation of the antenna circuit is not affected by the absorption powers of the earth. With the remote ground point B located one-half wavelength from the coil, the earth's electrostatic capacitance is not permitted to absorb power directly from the antenna circuit, consequently there is no generation or propagation of free broadcast ground or surface waves as in the case of the Marconi system. However, if said ground point B is moved along conductor 11 toward the coil so as to fall within the half-wavelength section, then the coil voltage will act directly on electrons contained in adjacent surfaces of the earth and thus give rise to free broadcast of vertically polarized ground or surface waves identically as in the Marconi system, with the intensity of said waves increasing and with the intensity of the desired guided waves decreasing as said ground point B is mover closer to the coil terminal.

The antenna circuit shown in Figure 1 can be readily compared with the Marconi broadcast system, the antenna 10 representing the usual elevated antenna while the earth-insulated section of the conductor 11 is equivalent to the earth adjacent to and beneath the elevated antenna. Just as the generated radio waves attach themselves to the ground, so do the radio waves generated by the apparatus of Figure 1 attach themselves to the metallic conductor 11, whereby they are guided by said conductor and travel therealong. Experiments have proven that when the conductor is insulated from the earth for at least one half of the actual electrical wave length of the antenna circuit, the earth absorption powers are defeated and the resultant radio waves are then attached to and guided by said conductor. Said guided waves are detached electrical energy in exactly the same sense that free broadcast waves of the Marconi system consist of energy which has become detached from the elevated antenna. However, instead of being vertically polarized like waves of the Marconi system, said guided waves are polarized horizontally because their electric components are obviously parallel to conductor 11 and hence parallel to the earth's surface. Magnetic components of said guided waves are therefore perpendicular to conductor 11 and the earth's surface, which results in the relative phase positions of the two components of said guided waves being rotated approximately 90 degrees with respect to those of a Marconi ground or surface wave. Consequently the horizontal electric component of said guided wave is parallel to the direction of said wave's propagation onto and immediately along the long distance metallic structure which is utilized as a guide and which in reality constitutes an electrical continuation of conductor 11, it being understood that the antenna conductors 10 and 11 are located substantially parallel to and in the immediate vicinity of said long distance metallic structure. To serve as a guide for said horizontally-polarized waves generated by antenna conductors 10 and 11, it is not required that the said long distance metallic structure continue in an exactly straightforward course or in a straight line away from the point of electrical connection with conductor 11, because experiments have shown that said guided waves will follow changes in direction of said long distance metallic structure, particularly when such changes in direction are effected gradually by means of curves having large radii such as those employed in constructing railways and underground pipe lines.

The antenna circuit shown in Figure 1, wherein the antenna 10 lies parallel to the conductor 11 and has physical connection therewith through the coil C, is generally known as a "current fed" antenna, and is similar to the type commonly used at broadcasting stations. When the antenna 10 and conductor 11 are concentrically arranged, as described hereinafter, this circuit completely prevents the generation of Hertzian waves directly at the two conductors which waves are those ungrounded waves which are freely propagated independently of the ground waves. The concentric arrangement of antenna 10 and conductor 11, when electrically connected as in Figure 1, cannot radiate Hertzian waves because the electric power transferred by a concentric circuit is all confined to the inside since the outside acts as a shield. Because the generation of Hertzian waves is most pronounced when high frequencies are employed, this concentrically arranged antenna circuit has been found particularly adaptable and is therefore preferable.

When low frequencies are employed the Hertzian waves generated are substantially negligible and therefore, other types of antenna circuits may be efficiently used. A very simple arrangement of wave generating equipment is shown in Figure 2. In this form, the conventional output or oscillating circuit of a conventional radio transmitter is shown as indicated by the inductance D and variable capacitance E, in which the radio frequency current oscillates, and thus establishes a rapidly alternating voltage at the terminal A of the conductor 11. The antenna 10 is completely eliminated in this form. From the terminal A to the point B, the conductor is insulated from the earth just as in the form shown in Figure 1. This arrangement compares with the usual "voltage fed" short wave amateur antenna, so named because the insulated section of the conductor 11 is physically connected to a source of rapidly alternating voltage and is not electrostatically coupled to any other conductor having physical connection with the transmitter or oscillating circuit DE. This causes a relatively small current to flow in the earth-insulated portion of conductor 11, which is due to a relatively high voltage applied to said conductor only at terminal A. This arrangement when used with low frequencies is satisfactory because the emission of Hertzian waves at such frequencies is insignificant.

Another form of "voltage fed" antenna circuit is shown in Figure 3. In this form the oscillating circuit DE shown in Figure 2 is physically connected to the antenna 10 which is disposed above, beneath, or at any radius angle with respect to conductor 11, and is substantially parallel to the earth-insulated section of the conductor 11. There is no physical connection between the antenna and conductor as these parts are electrostatically coupled to each other, but the phases of the currents in the antenna and conductor will not be exactly opposite. However, this hook-up has been found more effective in suppressing Hertzian waves than that shown in Figure 2, particularly when the antenna 10 is co-axially disposed with respect to a tubular conductor which comprises conductor 11. Therefore any of the three types may be used to generate the electromagnetic or radio waves which are to be guided by a long distance con-

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ductor. The antenna 10 and conductor 11 may each consist of ordinary wire, tubing, cable, or strips of metal arranged parallel to each other. Such arrangement may be found satisfactory when very low frequencies are utilized, although there will be some radiation of Hertzian waves from said arrangement even if it is connected as in Figure 1, because the radiation from one conductor will not completely neutralize the radiation from the other conductor although the phases of the currents in the two conductors are generally regarded as being opposite.

Since the radiation of Hertzian waves is entirely eliminated by the use of a concentric arrangement of the antenna 10 and conductor 11, then the only radiation that might be expected must be that which comes directly from the long distance conductor employed. Experiments have shown this to be the actual case, and that the radiation from the long distance conductor is emitted at right angles from said conductor since the intensity of said radiation varies with the distance from said conductor. However, as long as low and medium radio frequencies are utilized, this radiation from the long distance conductor is of practically no consequence as tests have shown that the distance over which the said radiation may be detected is certainly insignificant as compared with the distance over which the waves are guided by the long distance conductor. Therefore a concentric arrangement of antenna 10 and conductor 11, connected as shown in Figure 1, is the type most desirable and will be hereinafter described in the practical use of the invention.

For receiving the waves propagated along the metallic conductor 11, any suitable radio receiving apparatus may be employed. Of course, the receiving apparatus must be located near or adjacent the metallic conductor 11 so as to pick up the radio waves guided thereby. In the practical application of the invention, it is desirable to physically connect the receiving apparatus directly with the metallic conductor and as shown in Figure 5, the hook-up is similar to the transmitting hook-up. The receiving antenna 20 has one terminal connecting through a coil 21 with the terminal T of the metallic conductor. A section of the end of the conductor from terminal T to point T' is insulated from the ground, exactly as is the opposite end A to B of said conductor at the transmitting station. Thus, the radio waves may be readily received at the opposite end of the conductor 11, regardless of the length of said conductor. Also, if desired, the antenna 20 may be employed as the sending antenna with the antenna 10 utilized as the receiving antenna, whereby communication in either direction may be had.

In Figure 6, the sending antenna circuit disclosed in Figure 1, is shown applied to a surface pipe line 25, whereby said line acts as the metallic conductor 11 of the circuit. The pipe line is of course, normally employed for the transportation of oil, gas and water, and may be of any desired length or diameter.

The sending aerial or antenna 10 is mounted axially within the pipe 25 and may consist of a single insulated wire which is supported by a plurality of insulating disks or spiders 26. The spiders may be constructed of "micarta" or "textolite," or other suitable material and have a diameter equal to the inner diameter of the pipe 25 whereby they will fit snugly therein. The spiders may be secured in the pipe in any suitable manner and it is manifest that said spiders support the antenna axially within the pipe and insulate said antenna therefrom. The spiders are constructed with a single diametrically extending web as shown in Figure 10 so that the flow of the fluid through the line is not interrupted thereby. The insulation on the antenna wire will, of course, make said wire impervious to the fluid flowing through the line.

The length of the antenna 10, as has been previously explained, is equal to at least one half of the actual electrical wave length of the circuit and has its outer end open circuited. The other end of the antenna 10 extends through an insulating bushing 27 mounted in the wall of the pipe 25 and has its terminal A' connected to the coil C. The coil C is physically connected to the surface of the pipe 25 at the point 28.

That section of the pipe 25 which surrounds the antenna or aerial wire 10 is mounted on insulators 29 which rest in a trench 30 which is formed beneath the pipe 25. The insulated portion of the pipe line 25 is the equivalent of the earth-insulated section of the metallic conductor 11 from the point A to B in Figure 1. Therefore, it will be seen that the antenna wire 10 which extends substantially one half wave length is physically connected to the coil C just as in Figure 1 while the earth-insulated section of the line 25 extends for at least one half wave length in both directions from terminals 27 and 28, whereby the antenna circuit disclosed in Figure 1 is provided. Manifestly, with this arrangement the radio or electromagnetic waves may be generated and will become attached to the metallic pipe line 25 and will be guided thereby. These waves will travel within the immediate vicinity of the pipe 25, whereby they may be received at any point therealong.

In establishing a communication system of the character described herein, whereby metallic conductors such as the pipe line 25 is employed as the guiding medium for the radio waves, it is preferable to establish stations at points along the conductor. Each of these stations would have a single antenna which may be utilized for either sending or receiving the radio waves. In Figure 7, the invention is shown as applied to an underground pipe line 25' and a pair of the receiving and sending stations is shown. Since each station is exactly alike, a description of one will suffice. The ground adjacent the section of the pipe 25' in which the antenna 10 is mounted is dug out to form an enlarged pit or ditch 31 and the inner walls and bottom of the pit are then covered with a thickness of concrete or brick 32. Transverse supporting bars 33 receive insulators 34, which are similar to the insulators 29 employed in Figure 1. The pipe 25' is of course, supported on the insulators 34. The terminal A of the antenna 10 is connected to the coil C which has its terminal CT open circuited. A switch 35 which is connected with a lead wire 36 is arranged to engage the terminal CT of the coil C. The other end of the wire 36 is atttached to the surface of the pipe 25' at the point 37 which is located adjacent to the antenna insulating bushing 27. This insulating bushing is not designated in Figure 7, but is designated 27 in Figure 6. Obviously, when the switch 35 is engaging the terminal CT of the coil, a hook-up as shown in Figure 6 is had, whereby the output element of the transmitter is joined in series with the enclosed antenna 10 and the insulated pipe section. Therefore the electrical constants,

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mainly inductance and capacitance, of the transmitting antenna circuit thus established determine the natural frequency which obviously is the fundamental frequency of the transmitted waves. Recognizing the fact that the velocity of current propagation in a conventional antenna circuit is generally less than the velocity of the emitted, or received, wave, the physical lengths of the antenna and insulated pipe section required to avoid dissipation of energy at the point of ground contact may, for economical reasons, be made materially less than one half wave length of the transmitted wave, such being accomplished by the proper proportioning of the inductance and capacitance in the antenna circuit which consists of the antenna 10, the coil C, and insulated section of pipe 25'. The proportioning of the inductance and capacitance may be accomplished in the customary manner by employing one of the four methods, namely; (1) by inserting a loading coil in series with the antenna; (2) by inserting a condenser in series with the antenna; (3) by the insertion of a coil and a condenser joined in series; and (4) by the insertion of a coil and a condenser joined in parallel.

The coil 21 of the receiving apparatus has one of its terminals connected to the antenna 10 at points 38 while its other terminal T is open circuited and adapted to be engaged by the switch 35. When the switch 35 is engaging the terminal T of the coil 21, it will be obvious that the antenna 10 may be utilized as a receiving antenna. When the switch 35 is dis-engaged from the coil 21 and electrically connected with the coil C, the antenna serves for transmitting waves exactly as in the form shown in Figure 6. In order to permit the sending antenna to generate the electromagnetic waves so that they may propagate in either direction from the station, it is necessary that the pipe 25' be insulated from the earth for a distance equal to one half of the actual electrical wave length of the antenna circuit in both directions from the connection of the antenna to the coil C and terminal 37 of the switch lead 36 so as to avoid absorption of electrical energy by the earth's electrostatic capacitance, since such absorption would hinder the generation of the desired radio frequency waves as well as prevent their detachment from the antenna circuit and consequently their directed passage along the pipe line 25'. Therefore, from the above it will be seen that a station such as just described may be placed at pre-determined points along the pipe line 25' and a communication system, or a so-called low energy electrical channel, between these points established.

In order to mount the antenna 10 within a pipe line and particularly within an underground pipe line, it would be necessary to disconnect a section of said line so as to insert said antenna. In order to avoid the time and trouble of inserting the antenna, it will in many cases be more desirable to utilize the equipment shown in Figure 6. In this form, the antenna 10 is mounted within a tubular conductor 40 which conductor may have almost any desired diameter within certain practical limits. The antenna is supported axially therein by the spiders 26. The antenna extends from one end of the conductor 40 through an insulating bushing 41 provided in a removable cap 42 which closes the end of said conductor. The antenna is connected to the coil C as in Figure 7. The other end of the coil is adapted to be engaged by the switch 35 which has the lead wire 36 extending therefrom. The other end of the wire 36 is of course fastened to the exterior surface of the conductor 40 at the point 40'. The conductor 40 is supported on insulators 34' which rest on suitable supports 33' on the surface of the ground. The length of the conductor and of the antenna 10 is equal to one half of the actual electrical wave length of the entire antenna circuit and the outer end of said conductor is closed by a conical cap 43 which cap is made of electrical conducting material such as metal. A cable, tube, or wire comprising a connecting link 44 electrically connects the end of the cap 43 with the exterior surface of the underground pipe line 25'. As shown in Figure 8, the end of the antenna 10 is open circuited just as in Figures 6 and 7.

With this structure, it will be apparent that it is not necessary to mount the antenna 10 within the pipe line 25'. The conductor 40 wherein said antenna is mounted is electrically connected through the cap 43 and connecting link 44 with the surface of the pipe so that said conductor actually forms a continuation or a part of the underground pipe line 25'. When the radio or electromagnetic waves are generated by the antenna circuit, it is apparent that they will travel from the conductor 40 onto the connecting link 44 and therealong onto the underground pipe line 25', after which they will travel therealong in the immediate vicinity thereof. With such arrangement, it is much simpler to apply the invention to the underground line for the only connection which is necessary is the attachment of the connecting link 44 to the pipe 25'. The rest of the apparatus is entirely above ground and readily accessible.

Although the antenna 10 has been shown and described as simply terminated and left open circuited at its outer end which corresponds to point B in Figure 1, two novel modifications of this arrangement have been devised for improving the process of generating the radio or electromagnetic waves which are to be propagated over the long distance conductor employed. Each of these make it possible to substantially reduce the length of the antenna 10 and yet produce results which are superior to those produced by the antenna arrangement previously described. Experiments show a considerable improvement in the wave generating process when the length of the antenna 10 is reduced to approximately one quarter wave length and terminated in a "lumped" capacitance at a point which roughly corresponds to the point M' in Figure 1. Such a lumped capacitance is obtained by connecting the antenna 10 to a metallic cylinder 53 as shown in the right portion of Figure 9. The diameter of this cylinder is somewhat less than the inside diameter of the tubular conductor 40 and its length is also proportioned with respect to the inside diameter of said tubular conductor so as to concentrate the electrostatic capacitance at the outer end of the antenna 10. This concentration of capacitance causes a more uniform distribution of electric current along the lengths of both the antenna 10 and tubular conductor 40 which lies between points corresponding to M, M' and A, A' respectively in Figure 1, which results in a more effective generation of the radio or electromagnetic waves which pass along the tubular conductor 40 to the half wave length point corresponding to B in Figure 1, and therefrom onto any long distance conductor which comprises a metallic continuation of said tubular conductor. With the antenna 10 so arranged, it

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is unnecessary for the tubular conductor to extend the full half wave length as previously shown and described, since for economy reasons it may be terminated with the conical cap 43 immediately beyond the lumped capacitance and then the less expensive connecting link 44 attached as previously shown and described but extended and kept insulated from the earth for the remainder of the required one half wave length before joining directly to the grounded long distance conductor to be employed, so as to provide a full half wave length of insulated conducting material which corresponds to conductor 11 which extends from A to B in Figure 1.

The other modification consists of terminating the outer end of the antenna 10 in an absorption resistance 45 as shown in the left portion of Figure 9. This resistance may be used singly, or in combination, with the lumped capacitance which has been previously shown and described, and is probably most effective when the length of the antenna 10 is approximately one quarter wave length as in the case of the lumped capacitance. For that reason it is shown to be installed in the outer end of the tubular conductor 40 where it conductively connects the outer end of the antenna 10 to the inner wall of the conical cap 43 which closes the end of said tubular conductor. When installed in this manner it is obviously necessary for the connecting link 44 to be extended and kept insulated from the ground for the remainder of the required one half wave length before it is joined directly to the long distance conductor to be employed, as previously explained, since with this arrangement the length of the tubular conductor 40 is approximately one quarter wave length. The object of this absorption resistance is to prevent the reflection of waves inside the tubular conductor 40 and thereby avoid the disturbing influence of stationary oscillations on the generation of the waves which are to be propagated over the long distance conductor. The resistance of the wave generating equipment or the entire antenna circuit which consists of the tubular conductor 40, the antenna 10, with connecting lead 36, switch 35, and connecting lead from terminal A to the connection of antenna 10 at the bushing 41, cause losses which must be taken into consideration with regard to dimensioning of the absorption resistance 45.

As before stated, the invention may be applied to any type of metallic conductor and in Figure 11 the same is shown as applied to a railroad and railway car so that communication can be established between ground stations located along the track and an occupant of the car. In this instance the conductor 40 and the hook-up shown in Figure 8 is employed. The connecting link 44 which leads from the cap 43 is connected to one or both of the rails 45 of the railway, whereby the electromagnetic waves generated by the antenna circuit are impressed upon and travel along said rail or rails. A similar conductor 40 together with the circuit shown in Figure 8 is mounted at some suitable place on the railway car 46 and insulated therefrom and the link 44 of this unit is electrically connected to the wheel truck 47 or to any other suitable metallic member of said car. Since the wheels are metallic and travel on the rails 45, it will be obvious that an electrical connection is had between said rails and the unit mounted on said car. In the case of fiber wheels, or rubber tired wheels as used on certain modern passenger cars, it will be necessary to install an electrical conducting brush for wiping or rubbing the top of the rail in order to assure a continuation of the electrical wave conducting path. Manifestly, waves generated by either one or the other of the units may be received by the other unit and such waves are guided by the track.

In Figure 12 the invention is shown as connected with the static or lightning conductor wire of a power line. This static or lightning conductor wire 48 is grounded at every pole 49 by a vertical wire 50 which is attached to the side of the pole and extends downwardly to the ground, whereby the conductor 48 is grounded. One of the units including the conductor 40 having the antenna 10 mounted therein is located preferably parallel to the power line and the connecting link 44 which extends from the cap 43 of the conductor 40 is electrically connected with the vertical wire 50 whereby it is thus physically connected to the static or lightning conductor wire 48. When the radio waves are generated by the antenna circuit they are impressed on the connecting link 44 and are propagated along it to the static or lightning conductor wire 48. They are then guided along this latter wire and may be picked up at any suitable point therealong.

The invention is not to be limited to its application to grounded metallic conductors as it has been found it may be applied to ungrounded conductors. Its application in this latter form is clearly shown in Figure 13 where the connecting link 44 from one of the units as shown in Figure 8 is connected with a metallic cable or conductor 51 which is mounted on the poles which support the earth-insulated conductors 52. Conductor 51 is thus mounted parallel to the insulated conductors 52 and in relatively close proximity thereof in order to effect a "wave inductive" coupling between conductor 51 and said insulated conductors. The said wave inductive coupling would ordinarily be considered as an electrostatic coupling but the latter term is apparently incorrect in this instance since experiments indicate that said coupling must extend over a distance at least equal to a considerable portion of a half wave length of the transmitted waves and that satisfactory results could not be obtained with said coupling replaced by an equal value of concentrated electrostatic capacitance contained in a usual type of small dimensioned coupling condenser. Thus the radio waves impressed on conductor 51 from the connecting link 44 are transmitted to the insulated conductors 52 through the medium of said wave inductive coupling, after which they travel along the said insulated conductors in the same manner as along a grounded conductor. Conductor 51 should be well grounded, preferably at each supporting structure or pole, in order to afford protection to the antenna circuit in the event of an accidental connection between it and the said insulated conductors.

From the above, it will be seen that the communication system herein described can be applied to any type of metallic conductor either grounded or ungrounded. So long as that portion or section of the metallic conductor which forms one plate of the antenna circuit or condenser is insulated from the ground for a length of at least one half of the actual electrical wave length of the antenna circuit the purpose of the invention will be accomplished. Therefore, the invention is not to be limited to its application to any particular type of conductor.

What we claim and desire to secure by Letters Patent is:

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1. The method of transmitting electromagnetic waves along a metallic conductor which consists in, employing the conductor as one side of an antenna circuit to generate electromagnetic waves in the immediate vicinity of the conductor, eliminating absorption of the radio frequency electrical current energy in the antenna circuit by the ground, and impressing the generated waves on that portion of the conductor which forms no part of the antenna circuit, whereby said waves are guided by said conductor.

2. The method of transmitting electromagnetic waves along a metallic conductor which consists in, generating said waves and directing them along the path of said conductor, and insulating said conductor from the earth adjacent the point at which said waves are generated for a distance of at least one half of the actual electrical wave length of the antenna circuit, whereby absorption of the radio frequency electrical current energy by the ground is eliminated and the waves are guided by said conductor.

3. A non-return electrical circuit including, an electromagnetic wave generating apparatus, a metallic conductor having a portion thereof forming a part of the generating apparatus, means for transmitting electromagnetic waves in the space immediately surrounding said conductor, and means for insulating that portion of conductor forming part of the generating apparatus from the earth for a distance sufficient to eliminate absorption by the ground of the radio frequency electrical current energy, whereby the generated waves are directed along the conductor and immediate exterior space surrounding it.

4. A non-return electrical circuit including, a metallic conductor, means for transmitting electromagnetic waves in the immediate vicinity of said conductor, means for insulating the conductor from the earth adjacent the point of origin for a distance sufficient to prevent absorption by the earth of the radio frequency electrical current energy, and means for transforming the waves into electrical voltages and currents at a point along the conductor remote from the point of transmission.

5. A transmission system including, a metallic conductor, a sending antenna disposed substantially in parallel relation to said conductor and electrically insulated therefrom, means for insulating the conductor from the earth for a predetermined distance adjacent the antenna, a transmitter, means for connecting one output terminal of the transmitter to the antenna and the opposite output terminal to the metallic conductor, whereby electromagnetic waves are set up in the immediate vicinity of said conductor and directed therealong, a receiving antenna mounted in substantially parallel relation to the conductor and insulated therefrom, and a receiver having electrical connection with the receiving antenna and conductor for picking up said waves at a point remote from their origin.

6. A transmission system including, an antenna circuit, a metallic conductor primarily used for purposes other than wave transmission and connected in the antenna circuit whereby electromagnetic waves are generated in the immediate vicinity of the conductor, and means for insulating that section of the conductor connected in the antenna circuit from the earth for a distance of at least one half the actual electrical wave length of the antenna circuit to eliminate absorption by the ground of radio frequency electrical current energy.

7. A transmission system including, an antenna circuit, a metallic conductor connected in the antenna circuit whereby electromagnetic waves are generated in the immediate vicinity of the conductor, and means for insulating that section of the conductor connected in the antenna circuit from the ground for a distance equal to one half the actual electrical wave length of the antenna circuit, whereby earth absorption of the radio frequency electrical current energy is eliminated.

8. An apparatus for transmitting electromagnetic waves along the path of an underground pipe line including, a pipe section mounted above ground and having metallic connection with the underground line, means for insulating said section from the ground, an antenna mounted within the section and insulated therefrom, a transmitter arranged to be electrically connected with said antenna, a receiver arranged to be electrically connected with the antenna, and means for selectively connecting either the transmitter or receiver with the antenna, whereby said antenna may be utilized to set up and direct electromagnetic waves into the pipe line or to intercept and pick up electromagnetic waves travelling therealong.

9. An apparatus for transmitting electromagnetic waves along the path of an underground pipe line including, a pipe section mounted above ground and having communication with the underground line, means for insulating said section from the ground, an antenna mounted within the section and insulated therefrom, a transmitter arranged to be electrically connected with said antenna, a receiver arranged to be electrically connected with the antenna, means for selectively connecting either the transmitter or receiver with the antenna, whereby said antenna may be utilized to set up and direct electromagnetic waves into the pipe line or to intercept and pick up electromagnetic waves travelling therealong, and means for closing off the interior of the pipe section from the underground line whereby the antenna is not subjected to the fluid passing through the pipe line.

10. A transmission system for directing electromagnetic waves along a metallic conductor including, a metallic tubular member having electrical connection with said conductor and insulated from the earth, an antenna mounted axially within said member and insulated therefrom, and means for connecting both the antenna and member to the output element of a transmitter whereby said member and antenna are parts of an antenna circuit for generating electromagnetic waves which are guided by the member and metallic conductor connected thereto.

11. A transmission system for directing electromagnetic waves along a metallic conductor including, a metallic tubular member having electrical connection with said conductor, an antenna mounted axially within said member and insulated therefrom, and means for connecting both the antenna and member to the output element of a transmitter whereby said member and antenna are parts of an antenna circuit for generating electromagnetic waves, said member being insulated from the earth for a distance equal to at least one half of the actual electrical wave length of the antenna circuit, whereby absorption of the radio frequency electrical current energy by the earth is eliminated and the generated waves are guided by the metallic conductor.

12. The method of transmitting electromagnetic waves along a metallic conductor which

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includes, generating said waves in an antenna circuit having one side thereof insulated from the earth for a distance equal to one-half wave length, whereby the radio frequency electrical energy current is not absorbed by the ground, and impressing said electromagnetic waves along a metallic conductor which has electrical connection with the insulated side of said antenna circuit, whereby said waves are guided along the path of said conductor.

13. The method of transmitting electromagnetic waves along a metallic conductor which includes, generating said waves in an antenna circuit having one side thereof insulated from the earth for a distance equal to one-half wave length, whereby the radio frequency electrical energy current is not absorbed by the ground, impressing said electromagnetic waves along a metallic conductor which has electrical connection with the insulated side of said antenna circuit, whereby said waves are guided along the path of said conductor, receiving said waves in the vicinity of the conductor waves at a point remote from their origin, and transforming the energy of said waves into suitable electric voltages and currents.

14. The method of transmitting electromagnetic waves along a metallic conductor which includes, generating said waves and impressing them on the conductor so that they are guided along the path thereof, and eliminating absorption of the radio frequency electrical current energy by the ground adjacent the point at which the waves are generated by insulating the conductor from the ground for at least one-half wave length at such point of generation.

15. In combination with a metallic conductor having a portion thereof insulated from the earth of, a non-return electrical circuit including, an antenna arranged so that the insulated portion of the conductor forms one side of the antenna circuit, and means for generating electromagnetic waves on said antenna circuit, the insulation of the conductor extending for at least one-half wave length to prevent absorption of the radio frequency electrical current energy by the earth.

16. In combination with a metallic conductor having a portion thereof insulated from the earth of, a non-return electrical circuit including, an antenna arranged so that the insulated portion of the conductor forms one side of the antenna circuit, means for generating electromagnetic waves on said antenna circuit, the insulation of the conductor extending for at least one-half wave length to prevent absorption of the radio frequency electrical current energy by the earth, and means for impressing the generated waves onto the uninsulated portion of the conductor, whereby said waves are guided therealong.

17. A transmission system including, a metallic conductor, a sending antenna disposed substantially in parallel relation to a portion of the conductor and forming one side of an antenna circuit, said portion of the conductor which is adjacent the antenna circuit being insulated from the earth for a distance of one-half wave length and forming the other side of the antenna circuit, a transmitter, and means for interposing the transmitter between the antenna and the insulated portion of the conductor, whereby electromagnetic waves may be generated in the antenna circuit, such waves being impressed upon the uninsulated portion of the conductor and guided therealong.

18. The method of transmitting electromagnetic waves along and in the vicinity of a metallic element which extends from the point of transmission to the point of reception which consists in, generating said waves in the immediate vicinity of the element and impressing the same on said element, and preventing absorption of the radio frequency electrical energy by the ground by insulating the element from the earth for a distance of at least one-half of the actual electrical wave length of the antenna circuit at the point of impression.

19. A transmission system including, a metallic element forming one side of an antenna circuit and insulated from the earth for a distance of at least one-half wave length of the actual electrical wave length of the antenna circuit, a sending antenna forming the other side of the antenna circuit and insulated from the element, a transmitter connecting one end of the antenna with one end of the conductor, whereby electromagnetic waves may be generated, and means for electrically connecting the other end of the element with a metallic conductor, whereby said waves are impressed on said conductor.

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