Nov. 24, 1925. **1,562,961**

R. A. HEISING

DIRECTIVE RADIO TRANSMISSION SYSTEM

Filed May 16, 1921 4 Sheets-Sheet 1

Fig. 1

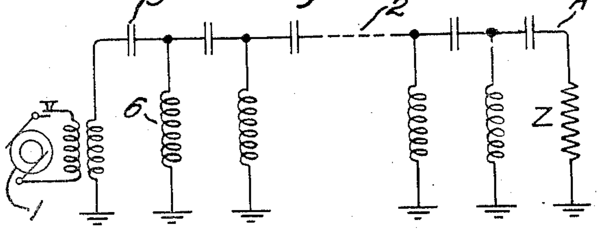

Fig. 2

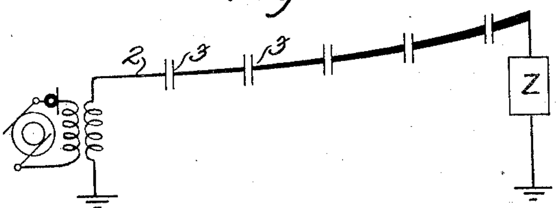

Fig. 4

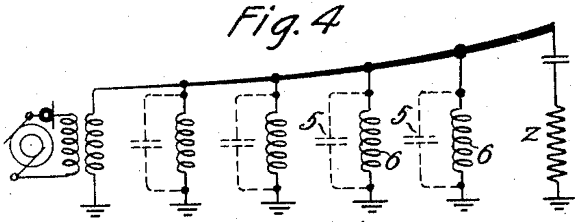

Fig. 5

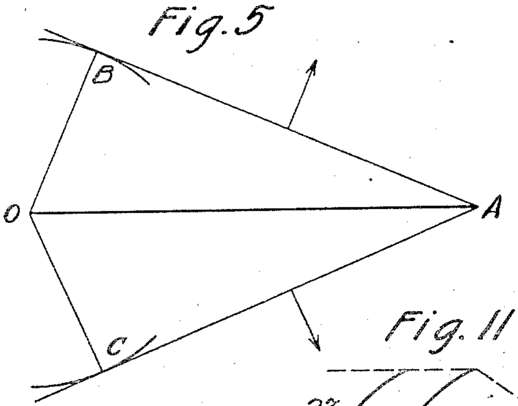

Fig. 3

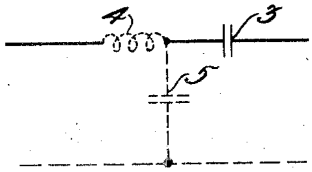

Fig. 11

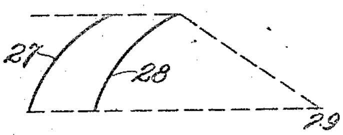

Fig. 6

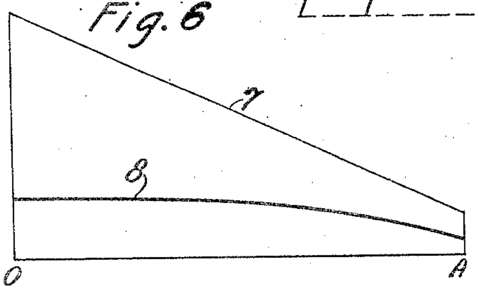

Fig. 10

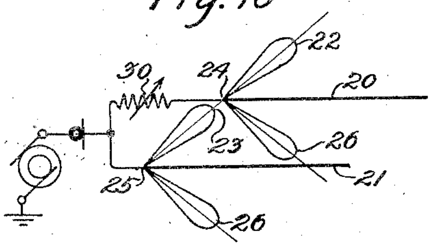

Fig. 7

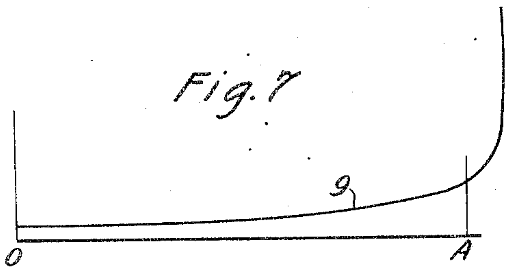

Fig. 12

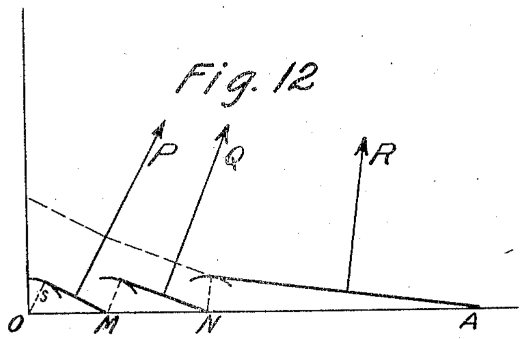

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Fig. 8

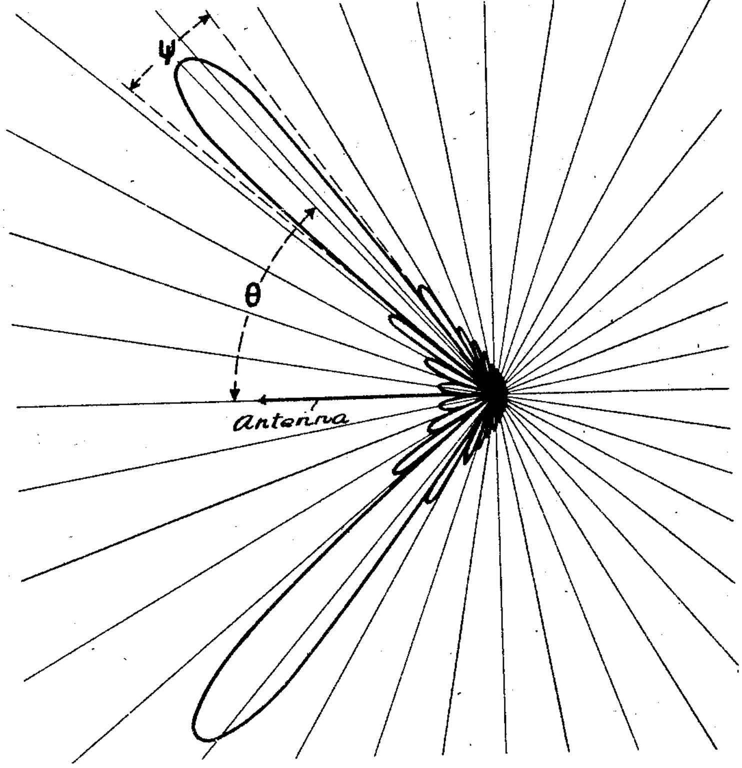

Fig. 9

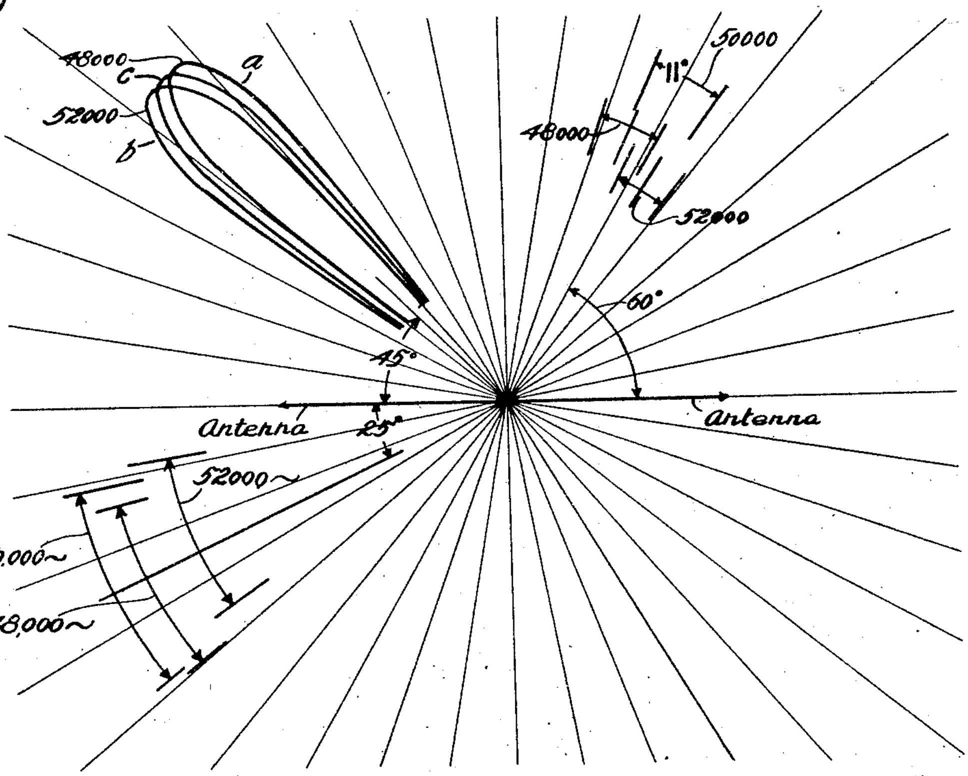

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Fig. 13

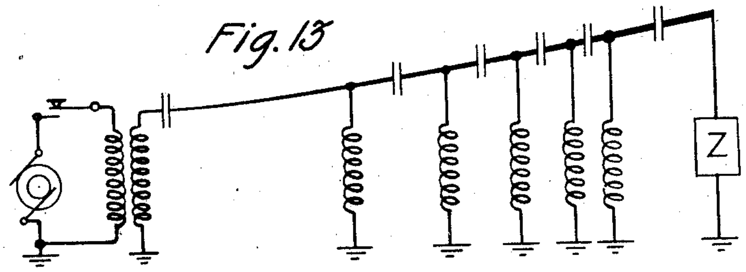


Fig. 14

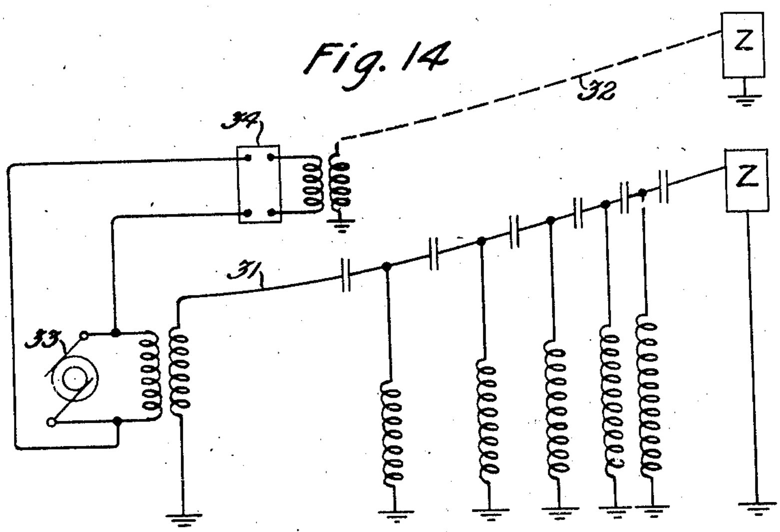


Fig. 16

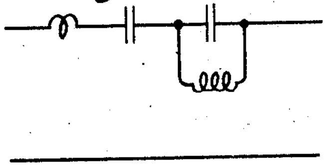


Fig. 15

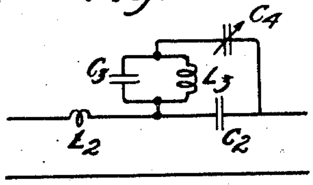
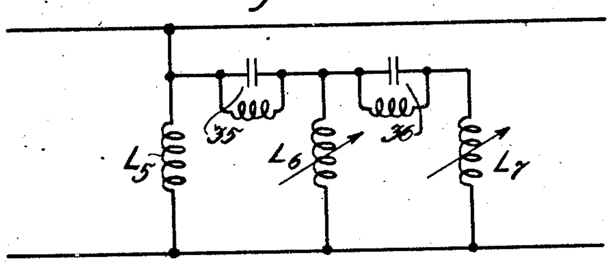


Fig. 17



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DIRECTIVE RADIO TRANSMISSION SYSTEM

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Fig. 18

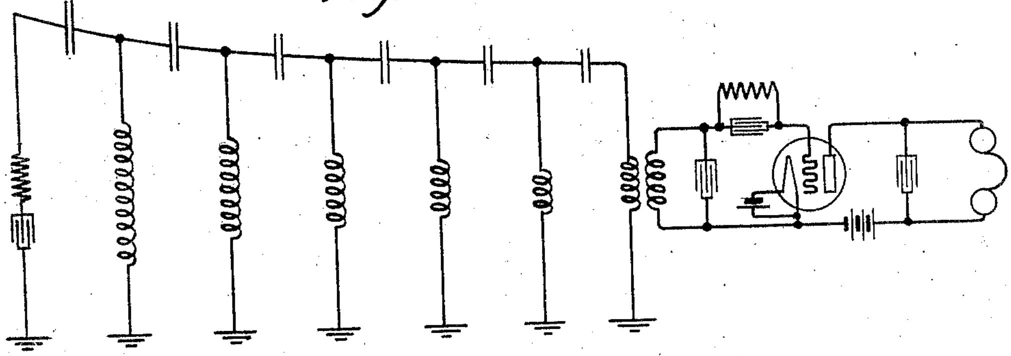
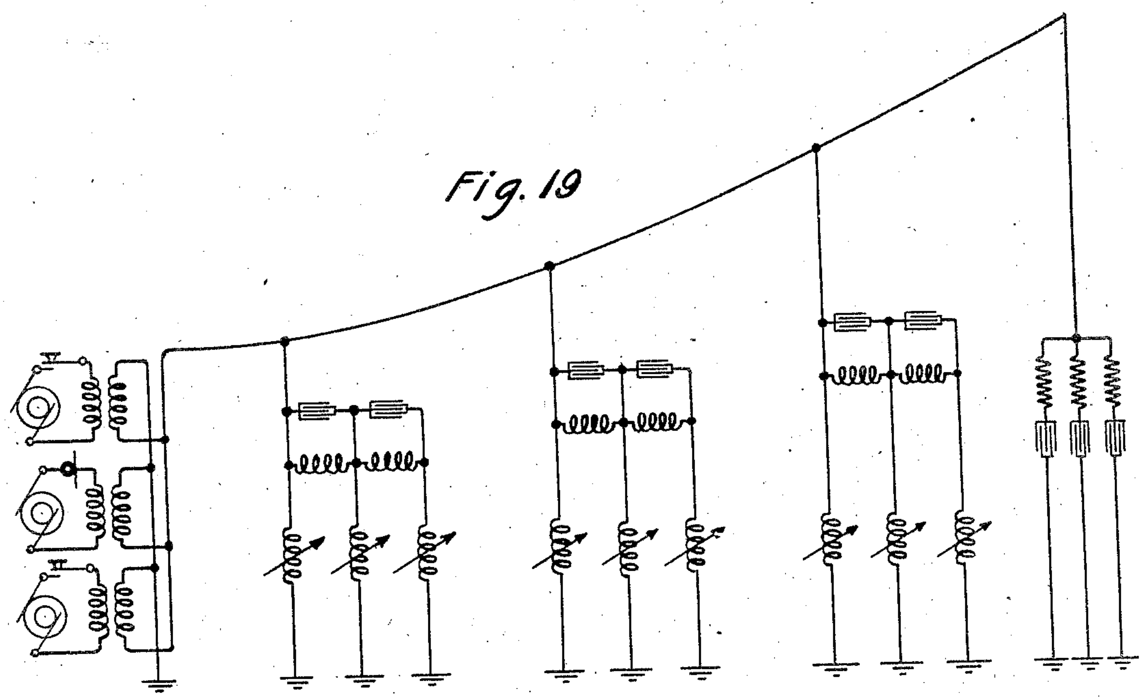


Fig. 19



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Patented Nov. 24, 1925. 1,562,961

UNITED STATES PATENT OFFICE.

RAYMOND A. HEISING, OF MILBURN, NEW JERSEY, ASSIGNOR TO WESTERN ELECTRIC COMPANY, INCORPORATED, OF NEW YORK, N. Y., A CORPORATION OF NEW YORK.

DIRECTIVE RADIO TRANSMISSION SYSTEM.

Application filed May 16, 1921. Serial No. 470,042.

To all whom it may concern:

Be it known that I, RAYMOND A. HEISING, a citizen of United States of America, residing at Milburn, in the county of Essex, State of New Jersey, have invented certain new and useful Improvements in Directive Radio Transmission Systems, of which the following is a full, clear, concise, and exact description.

This invention relates to directive transmission of energy and more particularly to methods of and systems for directively radiating and absorbing electric waves.

An object of the present invention is to provide a transmission system for radiating energy directively. Another object of the invention is to provide a focussing antenna which will concentrate the radiated energy at a distant point.

The propagation velocity of wave in any medium is in general the product of its frequency and its wave length in that medium. In the case of free electric waves, the propagation velocity is approximately 300,000,000 meters per second. In the case of guided electric waves, the wave length and the wave propagation velocity are functions of the electrical constants of the guiding transmission conductors. As given by Heaviside, the wave lengths of a sustained wave over a circuit having uniformly distributed inductance and capacity is

$$(1)\quad \lambda=\frac{2\pi}{\sqrt{\frac{1}{2}\left\{\sqrt{(SR+\omega^2LC)^2+\omega^2(LS-CR)^2}-(SR-\omega^2LC)\right\}}}$$

where λ is the wave length, ω is the angular velocity or the wave frequency multiplied by 2π and S, R, L, and C are respectively the shunt conductance, series resistance, series inductance, and shunt capacity of the circuit per unit length. This wave length evidently depends upon the magnitudes of these four electrical characteristics per unit length of the circuit. By varying these it is possible to increase or decrease the wave length of the sustained wave and accordingly to vary the wave propagation velocity along the circuit. If a loaded circuit of this character is used for radiating or absorbing electric waves, the waves, if sustained sine waves, may be propagated along the circuit at a greater velocity than that at which they progress in the ether. If a definite small part of a transmitting antenna be considered, the energy of the wave proceeding from that part will be partly propagated along the circuit as a guided wave and partly radiated and propagated out through the surrounding space. The shape of the resultant wave front in the ether will be dependent upon the relative velocities of wave propagation in the two media. It is, therefore, possible to give a radiated wave variously directed fronts depending upon the loading of the antenna circuit. It is likewise possible to so absorb the directed radiant wave at a receiving antenna as to cause all of the absorbed energy to cumulatively affect the receiving device.

According to the present invention a radio transmitting or receiving antenna is made long with respect to the wave-length of the wave to be transmitted or received. In order to make this antenna behave as a conductor of infinite length and thereby avoid the production of a reflected wave, it is desirable to terminate it in an impedance element having an impedance equivalent in magnitude and character to the iterative or surge impedance of the antenna itself at the terminating point. At intervals corresponding to a fraction of a wave-length, the antenna is loaded by inserting series capacity or shunt inductance or both to make its wave propagation velocity for the waves to be transferred higher than the corresponding wave propagation velocity in ether. Since the energy in a radiating antenna decreases with increasing distance from the source, it is desirable in order to secure the best results to progressively increase the radiating factor of the antenna and this is done by increasing its height.

The invention permits radiation in one lateral direction to the substantial exclusion of radiation in any other by an arrangement of parallel antennæ. For focussing on a fixed receiving point the loading of the transmitting antenna may be progressively increased so as to progressively change the direction of the wave front of the emitted wave. The antenna may also be curved laterally to add to the focussing effect. For multiplex operation, waves of a plurality of different frequencies may be focussed at the same or different points by loading the antenna in different manners for waves of each of the different frequencies.

Other objects of the invention will be apparent upon consideration of the following detailed description taken in connection with the accompanying drawing in which Figure 1 illustrates diagrammatically a loaded antenna long with respect to the wave length of the emitted wave; Figure 2, a radio transmission arrangement including series capacity loading for increasing the wave propagation velocity; Figure 3, a unit section of the conductor of Figure 2; Figure 4, an antenna system provided with shunt inductance loading; Figure 5, a diagram indicating the directive operation of loaded antennæ; Figure 6, a diagram of current and energy distribution in antennæ of the type disclosed; Figure 7, the radiating coefficient diagram for antennæ of this type; Figure 8, a polar diagram showing the distribution of the radiated wave amplitude in various angular zones; Figure 9, a polar diagram showing the distribution of energy of a modulated carrier wave; Figure 10, an antenna system for neutralizing the directed energy in one direction; Figure 11, an arrangement of laterally curved antennæ for focussing energy at a distant receiving station; Figure 12, a diagram indicating the operation of a second type of focussing system depending upon progressive change in loading; Figure 13, an antenna arrangement for this second type of system; Figure 14, a directive focussing system employing both capacity and inductance loading; Figures 15 to 17 illustrate details of loading arrangements applicable to any of the foregoing systems; Figure 18, a receiving system with a loaded antenna; and Figure 19, a multiplex system for focussing a plurality of different waves.

Referring to Figure 1, a source 1 is associated with an antenna 2 to supply energy thereto for radiation. Antenna 2 is preferably of a length several times the wave-length defined in equation (1). This wave-length depends upon the inductance and capacity per unit length of the radiating circuit. In loaded telephone lines with inductances, as is the common practice, the wave-length is greatly shortened. In fact, in loaded line telephone practice, the wave-length multiplied by the frequency may give a velocity of the order 90,000,000 meters per second instead of 300,000,000 meters per second which is the velocity of light and of free electric waves. Since increasing the inductance per unit length which is done in loading telephone lines, shortens the wave-length at a given frequency, it will be evident that it is possible by reducing the inductance per unit length, to increase the wave-length of a unit circuit. If the resistance and shunt conductance of the circuit are made zero, equation (1) reduces to

$$(2) \quad \lambda = \frac{2\pi}{\omega\sqrt{LC}}$$

From equation (2) it would appear that, with circuits of negligible series resistance and shunt conductance per unit length, either reducing the series inductance per unit length or the shunt capacity per unit length, should increase the wave length and, therefore, increase the velocity at which a given frequency wave is propagated along the circuit. This can actually be accomplished in several ways it being remembered that the long antenna with its capacity to ground and the return ground conducting path may, if uniform and if properly terminated, be treated as any other alternating current conducting circuit. One simple way to increase the velocity of the wave propagation is illustrated in Fig. 1 in which series loading capacities 3 and shunt inductances 6 are inserted in the conducting line and are spaced much in the same manner as are the loading inductances in loaded telephone lines. These loading inductances and capacities should be separated by distances small compared to a wave length, so that the effect of uniform distribution of the capacity is approximated. Although the exact number of such elements may vary greatly, it is desirable to use eight or more per unit length. For simplicity only a few elements are shown. The action of this capacity loading is to introduce series reactance opposite in sign to that of the natural series inductance, and accordingly to produce lower effective series inductance per unit length. The action of the inductance loading is to introduce shunt reactance opposite in sign to that of the natural shunt capacity and hence to produce lower effective shunt capacity reactance per unit length. It will, of course, be understood that either series capacity loading or shunt inductance loading alone may be used.

As has been previously mentioned, a circuit of this character of finite length must be properly terminated to avoid having a wave reflected from the free terminal. A reflected wave produces nodes along the circuit and introduces complications of various sorts. If the transmitted wave gives directive radiation in the general direction of its transmission the reflected wave will give directive radiation in the opposite direction. To eliminate the reflected wave and prevent this reverse transmission, it is only necessary to terminate the line with a proper impedance Z, the value of which may be computed from well known transmission equations.

Fig. 2 illustrates a modification of the arrangement of Fig. 1 in which series capacity loading is employed. Conductor 2 is progressively elevated to increase the radiating factor so as to maintain the energy radiation as nearly equal as possible at all points along the antenna. To maintain the unit shunt capacity constant with increasing height a conductor of increasing size is employed. An element of the recurrent network thus formed is illustrated in Figure 3, in which the natural series inductance 4 and shunt capacity 5 of the conductor, both indicated by dotted lines, constitute together with the loading capacity 3 a uniform section of the line.

Fig. 4 illustrates another method of antenna loading which consists in reducing the effective shunt capacity of the circuit. This is accomplished by connecting between the line and ground, loading inductances 6 which are preferably spaced eight or more to the wave length, although in this case as well as in the case of the series capacity loading, a considerable variations in this number may be permitted. It is a well known fact that the effective capacity of a condenser is reduced by connecting in parallel with it a large inductance. The effective reactance of the condenser is increased. At a given frequency the natural capacity 5 of a unit section of the conductor with the inductance 6 shunted around it has several times the capacitative reactance which the capacity 5 alone has. Resistance tends to shorten the wave length. It is accordingly desirable to make the resistance of the antenna conductor very low. In loading systems of the kind described, the variations in effective capacity or effective inductance will be particularly marked for a given frequency, and wave velocities for such frequencies may be attained exceeding that of light.

The fact that a wave may be made to travel over a circuit with a velocity greater than that of free electric waves or light, may be made use of in directive transmission. Referring to Figure 5 in which OA represents a plan or top view of a long loaded antenna of the type illustrated in Figures 2 and 3, suppose that the source of waves is located at terminal O. An electrical disturbance occurring as an alternation of electrical potential at this point travels along the circuit to a point A. By radiation point O becomes the center of a disturbance of like form which emanates in all directions through space. If the space velocity i. e., the velocity of free electric waves is such that the radiated wave travels a distance OB during the time that the guided wave travels the distance OA, the wave front of the radiated wave in the space surrounding the antenna will take the directions BA and CA. The direction of propagation of the radiated wave being perpendicular to this front is indicated by the arrows. The angle between this wave front and the antenna evidently depends upon the ratio of the guided wave velocity to the free wave velocity. If right angle triangles are drawn similarly to Fig. 5 for the case where the base OA equals the radii OB and OC, the hypothenuses AB and AC will be infinitely short and at right angles to the base OA. This illustrates the critical case in which the ratio of velocities is unity. When this ratio is unity, the wave will accordingly be propagated in the direction of transmission along the circuit, i. e., OA. The physical basis for the phenomenon when the ratio is unity is made readily apparent by noting that as the wave is radiated in the direction of antenna OA, since the wave is propagated along the antenna at the same velocity, new centers of oscillation are continuously being established on the wave front which in turn gives rise to waves which travel in the direction OA coincidentally with those from the original wave source O and having the same phase. There accordingly results a reenforcing of the wave in the direction OA. The original wave and the waves radiated from these centers of oscillation in the opposite direction are opposed in phase and mutually extinguish each other. When the ratio is infinite the wave front will obviously be parallel to the conductor and the direction of propagation will be perpendicular to the antenna. When this ratio is less than unity, the antenna is not directive.

In Figure 4, the terminating element Z is shown as comprising series resistance and capacity. That the terminating impedance may be closely approximated by resistance alone will be evident from a consideration of the specification of United States patent to Heising 1,313,483, patented August 19, 1919.

In order to secure best results, the directed wave should be of uniform intensity throughout its wave front. This requires that the radiation in power should be the same for each unit length along the line. In a line having uniform resistance, inductance, and capacity, the current decreases logarithmically, and the radiation will accordingly be non-uniform. If the energy is to be uniformly radiated, the remaining energy in the guided carrier wave should decrease uniformly from the terminal O of the antenna to the terminal A, where the remainder of the energy should be absorbed by the terminating impedance Z. In order to secure an energy distribution of this character as illustrated by line 7 of Figure 6, the current along the circuit must vary as the square root of the energy as represented by curve 8 of Figure 6. In order that the radiated power may be uniform along the line with decreasing current, it will be evident that the radiating constant of the antenna or its radiation resistance must be gradually increased along the line. It should vary according to the reciprocal of the square of the current amplitude, as indicated by curve 9 of Figure 7 which represents the radiation coefficient or radiation resistance. Since the radiation resistance varies approximately as the square of the height of the line, this variation in resistance may be secured by varying the height of the line so as to make this height approximately proportional to the square root of the required radiation resistance. This is indicated in Figures 2 and 4 in which the height of the line increases from the source to the remote terminal in accordance with the requirement just stated. The gradually increasing height with decreasing current will produce uniform radiation throughout the length of the conductor. Inasmuch as the energy remaining at A is absorbed in the terminating network Z, it is possible to terminate the line at such a point that the height of the antenna will not, because of the very small current, be required to exceed practical limits in order to maintain constant radiation.

With an antenna of varying height and a constant size conductor, the inductance and capacity per unit length will change. It is possible to progressively vary the magnitudes of the loading reactances along the line so as to maintain the wave velocity constant. As an alternative method the diameter of the conductor itself may vary progressively with the height. With this latter arrangement the loading inductances and capacities may remain the same per unit wave length if a constant wave velocity is to be maintained throughout the length of the conductor. Figures 2 and 4 indicate a variation in the diameter of the conductor to maintain the capacity per unit length substantially constant.

Figure 8 shows a complete radiation curve with the wave amplitude as a function of its angular direction from a particular loaded line antenna of twelve times the wave length. The position and direction of extension of the antenna is indicated by the arrow. The principal energy falls within a sector of a 14° angle marked ψ. Small amounts fall in other directions due to interference. Increasing the length of the antenna to twenty-four wave lengths would cut the angular width of the transmission loop in two and would reduce the size of the small loops representing power transmitted in other directions.

In radio telephony when modulating a carrier wave in accordance with speech, a band of waves of different frequencies results. If for example, a carrier wave of 50,000 cycles frequency is used and the range of the frequency of essential speech currents is about 2,000 cycles, the modulated energy will have frequencies ranging from 48,000 to 52,000 cycles. In a system of this kind these various frequency waves will travel along the loaded antenna with different velocities due to the fact that the effective inductive reactance or effective capacitive reactance per unit length changes with frequency. If a carrier wave of 50,000 cycles frequency is radiated from an antenna twelve wave lengths long, at a 45° angle, as shown by the curve of Figure 9, the 48,000 and 52,000 cycle frequency waves will be spread out in different directions, as shown by curves *a* and *b* respectively of the same figure. In this case the dispersion is not particularly harmful as there is sufficient amplitude of both of the extreme frequency waves occurring in the 45° angle direction to give a very good signal. Similary, if waves of this frequency are radiated in a 25° direction, as shown in the same figure, there will be a good quality of speech transmitted from the energy produced over an angle several degrees in width. If, however, the transmission angle is 60°, as shown in the same figure, the 52,000 and 48,000 cycle waves overlap very slightly and a change in quality is apt to result. In Fig. 9, the position and direction of extension of the antenna is indicated, for the respective directions of maximum directivity, in a manner similar to that of Fig. 8.

The transmission angle depends upon the propagation velocity. A larger transmission angle accordingly requires a larger propagation velocity which in turn causes a larger difference between the propagation velocities along the line, of the different frequency components. Accordingly the differences in direction of the various frequency components, are accentuated as the transmission angle of the band as a whole is increased. If waves of frequencies lower than 50,000 cycles are used as a carrier, these variations will become still larger and it is, therefore, of advantage to use high carrier frequencies.

As is diagrammatically indicated in Fig. 5, there is directive radiation in two lateral directions. An arrangement of multiple antennæ for suppressing radiation in one of these directions is illustrated in Figure 10 in which parallel directive antennæ 20 and 21 are so spaced that their respective energy transmission loops 22 and 23 from the terminals 24 and 25 connected with the source extend in the same direction, and neutralize in space. If energy of the same phase is simultaneously supplied at points 24 and 25, and if these points are a half wave length apart in one direction in which their respective antennæ radiate most powerfully, the effect of the energy radiated from point 25 will be to oppose and neutralize that radiated from point 24 in this direction. This is for the reason that for all points in space in this direction these radiated energies will be opposite in phase. In other words loop 22 will neutralize loop 23. If the distance between the points 24 and 25 does not correspond to a half wave length, the phase of the energy supplied to one of the antennæ may be so shifted by a variable impedance device 30 that the points 24 and 25 will tend to radiate energies which will neutralize in space in the direction of the loops 22 and 23. This will leave only the loops 26 which are similarly directed and which are additive.

If it is desired to focus on a distant station, the directive antenna may be curved in direction as indicated in Figure 11 in which the two curved antennæ 27 and 28 are each given such curvature as to focus the radiated energy on a receiving station at 29. In general, in the case of curved antennæ it will be possible to obtain only roughly approximate neutralization by the use of two antennæ. Certain special cases, as for example, that where the antennæ extend along arcs of concentric circles and are arranged to focus their radiated energy at the center may give fairly exact neutralization.

A focussing effect could also be obtained by increasing the wave propagation velocity along the line so that in the region of one terminal of the line, the wave will be propagated at a greater rate than in the region of the other terminal. The operation of this will be clear from an inspection of Figure 12, in which an antenna OA is so loaded that a wave of given frequency applied at O will be propagated, in the first unit of time from O to M, in the second unit from M to N, in the third unit from N to A. Suppose that each portion OM, MN, and NA is, throughout its length, composed of like recurring sections. If the propagation velocity of the unguided waves when radiated be OS per unit of time, the radiated wave from portion OM will have a front, the direction of propagation of which is indicated by arrow P. The direction of the radiated wave of portion MN will be as indicated by Q, and that from portion NA as indicated by R. If the loading is made to progressively vary so that the wave length progressively varies, a smoothly curved wave front will obviously result. Figure 13 indicates diagrammatically an antenna loaded in this manner by a progressively closer spacing of the loading capacity or shunt inductance elements, or both. Instead of closer spacing of capacity elements of the same size the capacitances of the successively capacity elements may be progressively smaller, thus giving the same series capacity effect. In a similar manner instead of closer spacing of the shunt inductance elements, the shunt inductance elements may be uniformly spaced and their reactances may be progressively dimished in magnitude.

A desirable form of loaded antennæ is shown in Figure 14 in which the two antennæ 31 and 32, which may be either straight or laterally curved according to the arrangement of Figures 10 or 11, are arranged with corresponding points equidistantly spaced. A source 33 supplies energy to both these antennæ over parallel circuits one of which includes a phase changing device 34. This serves, as in the arrangement of Figure 10, to maintain the energies emitted from corresponding points of the two antennæ at the proper relative phases such that the energy radiated from one antenna will neutralize that radiated from the other in one direction. Each antenna comprises both series capacity and shunt inductance loading, thus combining the arrangement of Figures 2 and 4. The antennæ are progressively varied in height from the source to their remote terminals in order to maintain constant the energy radiated per unit length. Each antenna terminates in an impedance element Z which is designed to absorb the residual unradiated energy reaching the remote terminal.

Figure 15 illustrates a section of an antenna circuit loaded for waves of two different frequencies. L_2 and C_2 indicate respective series inductance including the natural inductance of the circuit and series capacity which together give a capacity reactance at one of the desired frequencies. The shunt path L_3 C_3 C_4 does not affect current of this desired frequency, since L_3 and C_3 constitute an antiresonant loop having substantially infinite impedance at that one frequency. The shunt path may, therefore, be regarded as open for the frequency considered. For current of a second frequency, the path L_3 C_3 is conductive and the net reactance of the whole unit at this frequency may be varied by varying C_4 so as to give any reactance desired for the record frequency current. Of course, an additional shunt path such as L_3 C_3 C_4 could be used for another frequency by shunting such a path about condenser C_4 and including in it a tuned loop or antiresonant circuit to exclude current of the second frequency. In this manner, the number of different frequency currents may be increased as much as desired.

Figure 16 represents a circuit having two degrees of freedom and which can be adjusted to give the same desired reactances as are given by the arrangement of Fig. 15. This circuit may accordingly replace that of Fig. 15. Its exact adjustment is, however, considerably more difficult.

Figure 17 illustrates an adaptation of the principle of Figure 15 applied to shunt inductance loading. L_5 represents a unit shunt loading inductance designed in accordance with the principles previously laid down for currents of one given frequency. The antiresonant loop 35 tuned to this one frequency effectively cuts off the other shunt paths for such currents. The loop 35 admits currents of the second frequency and a variable inductance L_6 permits the network L_5, 35, L_6 to give the proper inductive reactance for the second frequency current. Loop 36 in the third path is antiresonant to and effectively excludes currents of the second given frequency for which variable inductance L_6 provides the desired reactance. It conducts a third frequency for which L_7 together with the rest of the network may determine the desired reactance.

Figure 18 illustrates a receiving system with progressively changing loading elements. The conventional receiving element is coupled to the antenna in the ordinary manner and is preferably designed to introduce therein the proper terminating resistance to avoid reflection loss in accordance with the principle previously stated.

Figure 19 shows a multiplex transmitting system equipped with three carrier wave sources and an antenna loaded in the manner of Figure 17. Transmitting keys are associated with two of the sources and a microphone with the third, but it is to be understood that these are merely representative of any desired arrangements for modification of the carrier waves.

Throughout the specification the various features of the invention have been explained from the standpoint of radiation at a transmission station. The principles of wave absorption are in general the same as those of wave radiation. It is, therefore, to be understood that the various features of the invention are equally applicable to receiving systems and the various circuit diagrams may each be considered as representations of a receiving system with the simple substitution of receiving apparatus for the carrier wave source.

In the appended claims the transfer of energy either by radiation from an antenna to the ether or by absorption from the ether to the antenna is analogous to the transfer of energy between media of different characteristics. In telephone parlance the term "transducing" is commonly used to describe generally a transfer of energy without limitation as to the nature of the transfer. Wherever this term occurs in the appended claims, it will be understood that it is intended to be generic both to radiation and absorption of wave energy as well as to the transfer generally of energy from a medium of certain characteristics to media of different characteristics.

What is claimed is:

1. A method of directive radio transmission, utilizing a source of carrier waves and a linear radiating conductor connected therewith, which comprises the steps of radiating a portion of the waves from said source into space, transmitting another portion of said waves along the conductor, absorbing a portion of the energy thus transmitted at points in the conductor, radiating the absorbed energy from said points and preventing reflection of the unabsorbed transmitted waves at the remote terminal.

2. The method of wave transmission which comprises radiating from a conductor very long with respect to the wave length of the radiating energy an amount of energy per unit length of said conductor substantially uniform throughout the entire length of said conductor.

3. The method which comprises propagating an electric wave along a linear conductor at a wave propagation velocity exceeding that of light and radiating a substantially uniform amount of wave energy from each unit length of said conductor.

4. The method of directive radio transmission, utilizing a conducting element, which comprises propagating said waves along the conductor, causing the propagated velocity to differ in a systematic manner at different points in said conducting element, absorbing a portion of the energy from the wave propagated thereacross at each element of the conductor, and radiating said absorbed energy.

5. The method of directive transmission comprising propagating waves along a conductor at a velocity exceeding that of light and progressively varying the velocity of propagation throughout the length of the conductor.

6. The method of electric wave transmission, using a long conductor, which comprises supplying periodic energy to said conductor and propagating it at progressively increasing velocities throughout the length of the conductor.

7. A loaded circuit having loading reactances progressively varying in magnitude throughout its length so as to vary the wave propagation velocity for waves of a given frequency.

8. A directive transmitting antenna comprising a loaded circuit having its loading constants so adjusted that waves of a given frequency are propagated thereover at a velocity exceeding that of light and a termi-

nating impedance connected thereto for absorbing, without reflection, energy transmitted to said impedance.

9. In a directive radio transmitting system in combination, a transmitting antenna, a source associated therewith for supplying continuous waves to said antenna and a terminating element connected to said antenna for preventing reflection of said waves back toward said source.

10. In a directive radio transmitting system in combination, a transmitting antenna, means for supplying periodic energy thereto, said antenna being so loaded as to transmit the wave form of said energy at a velocity exceeding that of light and a terminating impedance connected to said antenna to prevent retransmission of energy back to said means.

11. In combination, a long horizontal antenna, a source of periodic energy associated therewith for supplying energy thereto, and means for causing said antenna to radiate a uniform quantity of the supplied energy per unit length of the antenna.

12. In combination, a long antenna, means connected to one terminal thereof for supplying periodic energy thereto, and means for changing the radiation resistance of said antenna progressively throughout its length so as to keep the quantity of radiated energy constant per unit length.

13. An antenna, means for supplying a periodic wave of a given frequency thereto and means for progressively varying the wave propagation velocity of said antenna whereby the radiated energy of said wave may be directively focussed upon a distant point.

14. A conductor curved upwardly throughout its length, and means for so loading said conductor as to cause it to radiate energy directively throughout its length.

15. A method of directive radio transmission, utilizing a source of carrier waves and a linear radiating conductor connected therewith, which comprises the steps of radiating a portion of the waves of said source into space, transmitting another portion of said waves along the conductor, absorbing a portion of the energy thus transmitted at points in the conductor, radiating the absorbed energy from said points, neutralizing the radiation from said conductor in one direction, and preventing deflection of the unabsorbed transmitted waves at the remote terminal.

16. The method which comprises propagating an electric wave along a linear conductor at a wave propagation velocity exceeding that of light, radiating a substantially uniform amount of wave energy from each unit length of said conductor, and neutralizing the radiation from said conductor in one direction.

17. The method of directive radio transmission, utilizing a conducting element, which comprises propagating said waves along the conducting element, causing the propagated velocity to differ in a systematic manner at different points in said conducting element, absorbing a portion of the energy from the wave propagated thereacross at each element of the conducting element, radiating said absorbed energy, and neutralizing the radiation from said conducting element in one direction.

18. The method of directive transmission comprising propagating waves along a conductor at a velocity exceeding that of light, progressively varying the velocity of propagation throughout the length of the conductor, and neutralizing the radiation from the conductor in one direction.

19. A loaded circuit having loading reactances progressively varying in magnitude throughout its length so as to vary the wave propagation velocity for waves of a given frequency, whereby said circuit tends to radiate directively in lateral directions, and means for neutralizing the radiation in one of said directions.

20. A directive transmitting antenna comprising a loaded circuit having its loading constants so adjusted that waves of a given frequency are propagated thereover at a velocity exceeding that of light, whereby said circuit tends to radiate directively in lateral directions, a terminating impedance connected to said circuit for absorbing, without reflection, energy transmitted to said impedance, and means for neutralizing the radiation in one of said directions.

21. A loaded circuit having loading reactances progressively varying in magnitude through its length so as to vary the wave propagation velocity for waves of a given frequency, whereby said circuit tends to radiate directively in lateral directions, and means for neutralizing the radiation in one of said directions, said means comprising a second loaded circuit arranged in parallel with the first loaded circuit.

22. In combination, a source of energy and connected thereto a loaded circuit having loading reactances progressively varying in magnitude throughout its length so as to vary the wave propagation velocity for waves of a given frequency, whereby said loaded circuit tends to radiate directively in lateral directions, and means for neutralizing the radiation in one of said directions, said means comprising a second loaded circuit arranged in parallel with the first loaded circuit with respect to said source and including a phase shifting means, whereby the energies supplied to said loaded circuits have a desired phase difference.

In witness whereof, I hereunto subscribe my name this 13th day of May A. D., 1921.

RAYMOND A. HEISING.