

March 30, 1948.

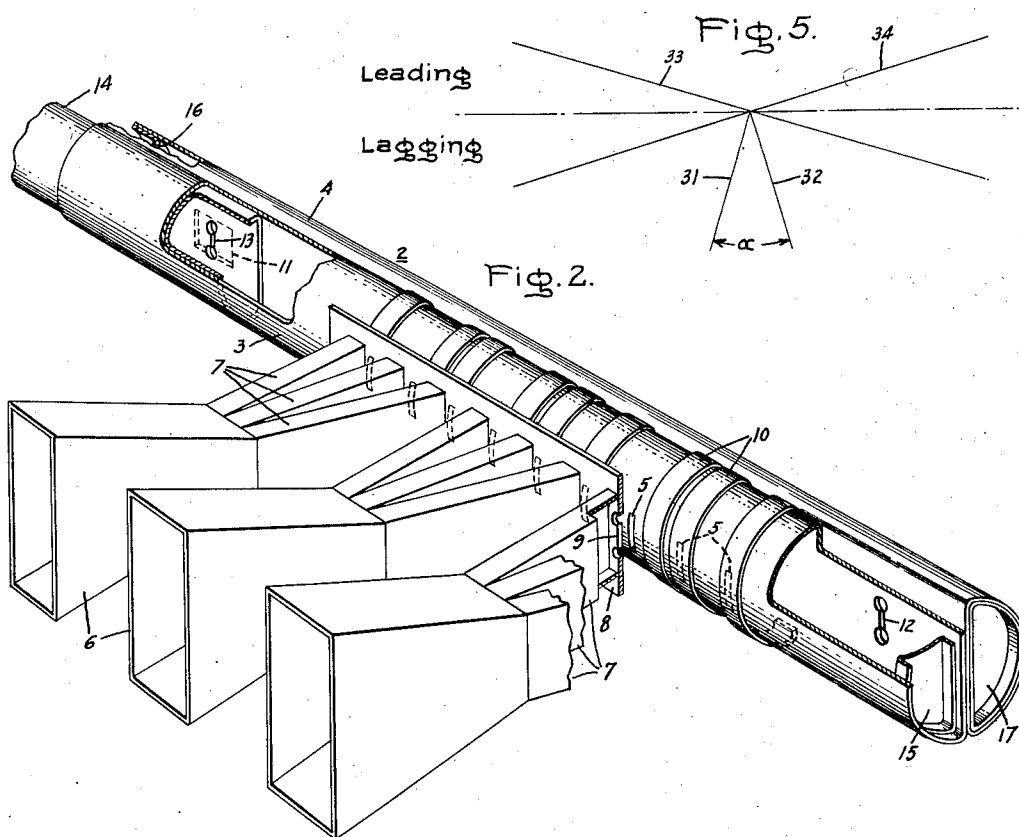
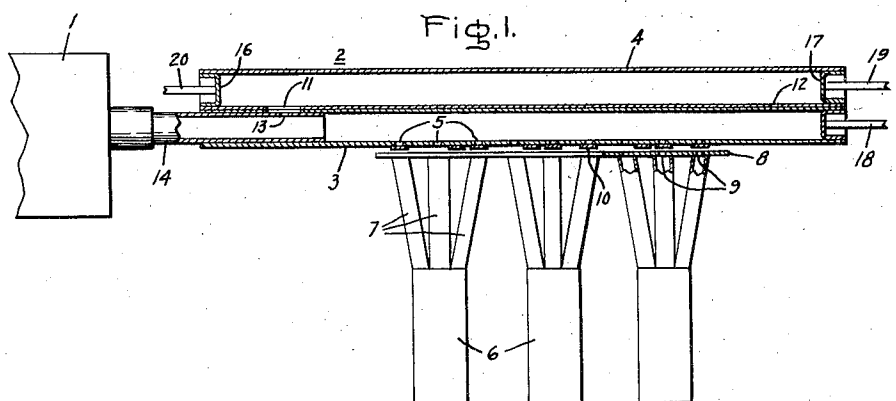
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2,438,735

HIGH-FREQUENCY WAVE TRANSMITTING APPARATUS

Filed Oct. 2, 1944

2 Sheets-Sheet 1



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March 30, 1948.

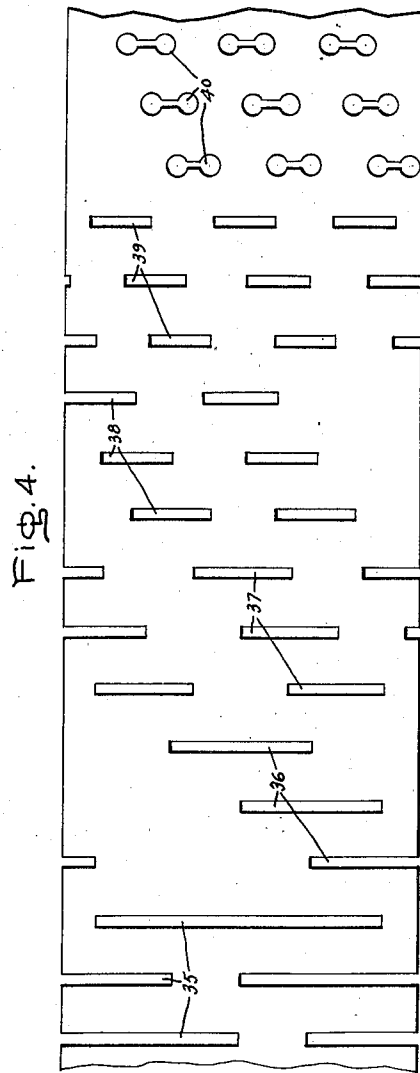
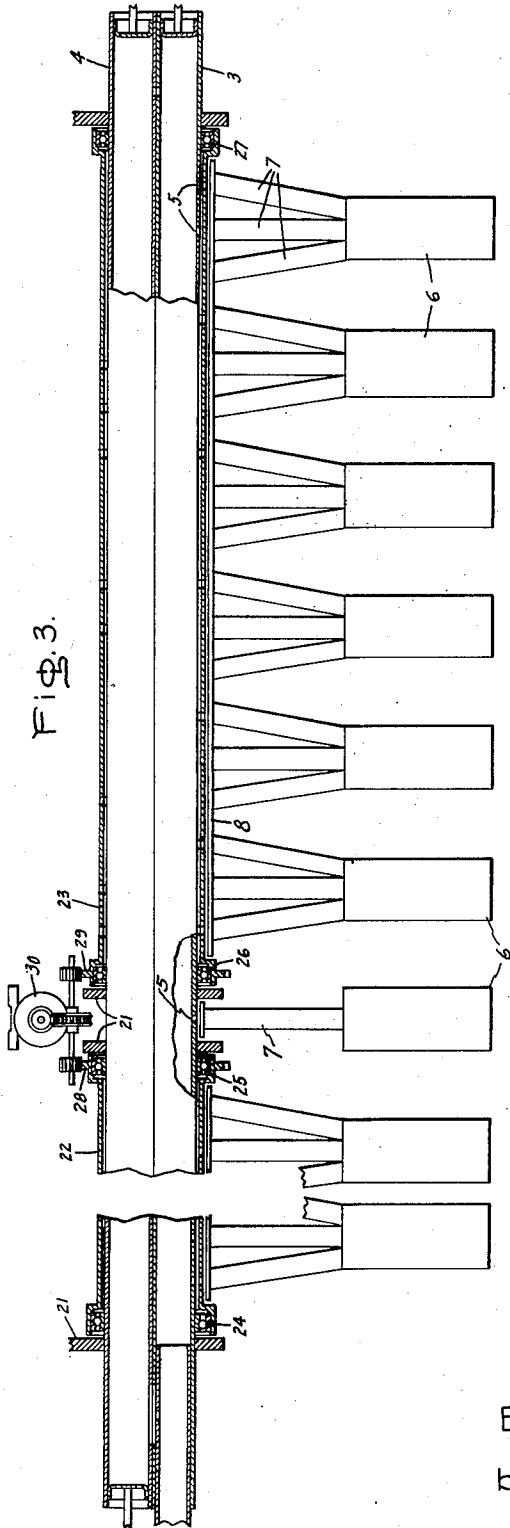
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HIGH-FREQUENCY WAVE TRANSMITTING APPARATUS

Filed Oct. 2, 1944

2 Sheets-Sheet 2



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UNITED STATES PATENT OFFICE

2,438,735

HIGH-FREQUENCY WAVE TRANSMITTING
APPARATUSErnst F. W. Alexanderson, Schenectady, N. Y., as-
signor to General Electric Company, a corpora-
tion of New York

Application October 2, 1944, Serial No. 556,865

14 Claims. (Cl. 250—33.63)

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My invention relates to apparatus for transmitting high frequency electric wave energy and particularly to high frequency wave radiating apparatus employing wave guides of the hollow pipe type.

It is sometimes desirable to provide a wave conductor wherein wave energy of uniform amplitude moves forward continuously so that at any selected position on the conductor the energy has continuously changing phase displacement. For example, such conductor may be desirable in the design of a radio beam antenna. In order to provide a conductor or source of this type the conductor must be so arranged that the energy flows continuously in one direction and there are no reflected standing waves. This unidirectional energy flow may be attained in a transmission line by terminating the line with a surge impedance. The effect of such impedance is to absorb the energy at the end of the line and prevent reflection. The objection to this solution of the problem is that the absorbed energy is lost. Accordingly it is an object of my invention to provide a high frequency wave transmitting apparatus including an improved source of wave energy in which the wave moves forward at uniform amplitude and with continuously changing phase displacement.

It is another object of my invention to provide a high frequency wave transmitting apparatus for radiating energy with minimum losses of energy in the apparatus.

It is another object of my invention to provide a wave conductor from which energy may be radiated and in which the energy not radiated is fed back to be recirculated through the conductor.

It is a further object of my invention to provide an apparatus for transmitting high frequency wave energy including an improved arrangement for radiating a beam of energy in a predetermined direction.

It is a still further object of my invention to provide a wave energy radiating apparatus including an improved arrangement for selectively sweeping the beam along a predetermined line.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims. My invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawings in which Fig. 1 is a plan view, partly

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in section, of a beam antenna embodying my invention; Fig. 2 is an enlarged perspective view, partly in section, of the antenna shown in Fig. 1; Fig. 3 is a plan view, partly in section and partly broken away, of another embodiment of my invention; Fig. 4 is a developed plan view of a cylindrical commutator shown in Fig. 3; Fig. 5 is a graph illustrating an operating characteristic of the apparatus of Fig. 3.

Briefly, the apparatus illustrated in the drawings comprises a main wave guide of the hollow pipe type and an auxiliary or feedback guide associated with the main guide in a manner such that high frequency wave energy supplied to one end of the main guide travels through that guide and then through a communicating opening at the other end into the auxiliary guide through which it is returned to the main guide in proper phase to reinforce the energy supplied to the main guide. This feedback characteristic of the two guides is made possible by adjusting the distance between the communicating openings at the two ends of the guides in accordance with the wave length of the energy supplied to the apparatus and by further adjusting closed ends of the guides so that the auxiliary guide offers a lower impedance path for the return of the energy than does the main guide and reflected standing waves are prevented. A similar adjustment of the guides at the supply end causes the energy to flow from the auxiliary guide back to the main guide. Openings may be provided intermediate the ends of the main guide for radiating energy therefrom, and suitable apparatus, such as radiating horns, may be utilized to facilitate the radiation of a beam, the direction of radiation of the beam depending upon the relative phases of the energy supplied to the several horns. Since the main wave guide provides energy flowing past each point of the guide with continuous progressive phase displacement, the phase of the energy supplied to each horn may be determined by the position of the outlet opening along the main guide. Furthermore, a commutating arrangement may be provided to change the phase relation of the energy supplied from each horn so that the beam may be caused to change direction in a manner to sweep back and forth along a predetermined line.

The electric wave transmitting apparatus shown in Figs. 1 and 2 comprises a very high frequency wave generator 1 arranged to supply wave energy to one end of a wave guide assembly 2 comprising two elongated semi-cylindrical guides 3 and 4 of the hollow pipe type. The

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guides 3 and 4 are arranged with their flat walls in face engagement and are adjusted in a manner to be described below so that wave energy flows continuously through the guides in series. With this type of energy flow the phase displacement of the energy at any cross section of the guide changes progressively. A plurality of openings 5 are provided in the guide 3 intermediate its ends for radiating energy from the apparatus at positions selected to provide predetermined phase differences such that a beam of energy may be radiated in a predetermined direction. In order to facilitate the directing of the radiation of the energy removed from the guide through the openings 5, a plurality of horns 6 are mounted adjacent the guide at one side thereof, and each of the horns is coupled to three successive ones of the openings 5 through coupling guides 7. The guides 7 are secured to a supporting plate 8 arranged near and parallel to the guide 3 and having openings 9 registering with respective ones of the openings 5. Each of the horns 6 may therefore receive energy from one or more of three successive ones of the openings 5. The openings 5 are preferably arranged at equal distances corresponding to 120° phase displacement so that three-phase energy is available at each of the horns 6. The amount of energy from each phase which is coupled to each of the horns may be selectively varied by placing straps or clamps 10 over one or more of the openings 5 in positions to block all or a portion of each of the openings from which less than the full intensity of the wave energy is to be radiated. By a proper combination of the energy coupled to a horn 6 from each of its associated three openings 5, it is thus possible to select any desired phase displacement of the energy radiated from that horn. It has thus been made possible to secure any desired relative phase displacement of the energy radiated from each of the three horns 6, and the direction of the beam radiated by the combination of the three horns may therefore be controlled. The horns 6 radiate energy in a more or less wedge-shaped pattern determined by the contours of the horns, and in the drawings the apparatus has been illustrated in a position to direct the wedge-shaped beam of energy generally in a horizontal direction so that the central line of the wedge is horizontal. When the energy radiated from all three horns is in phase, the beam is radiated straight out from the guide 3 at an angle of 90° to the axis of the guide. However, by changing the relative phase displacements of the energy radiated from the three horns, it is possible to direct the beam toward either side of the normal axis. This is accomplished as indicated above by selective positioning of the clamps 10.

In order to insure uniform and efficient operation of the apparatus it is necessary that the energy flowing in the wave guide 3 be of uniform amplitude and of continuous progressively changing phase displacement. In order to provide this operating characteristic the guides 3 and 4 are arranged so that there is a minimum of loss of energy within the guides, energy not radiated from the guide through the openings 5 being returned to the guide 3 through the guide 4 in proper phase so that this energy reinforces the energy supplied from the generator 1. The wave guides 3 and 4 thus operate in the manner of a flywheel, the losses through radiation being made up by the energy supplied from generator

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1. This feedback characteristic is attained by adjusting the length of the feedback path and the effective lengths of the guides so that there are no standing waves. The guides 3 and 4 are arranged in communication through openings 11 and 12 in the adjoining flat side walls of the guides near the two ends of the guides. The opening 11 is an elongated slot which registers with a radiating slot 13 formed in a tubular guide 14 which couples the generator 1 and the guide 3. The guide 14 is slidable so that the distance between the openings 12 and 13 may be adjusted within the limits of the length of the slot 11. The end of the guide 3 remote from the generator 1 is provided with an adjustable closure plate 15 and the ends of the guide 4 are provided with adjustable plates 16 and 17. The plates 15, 16, and 17 may be connected through rods 18, 19, and 20 respectively to suitable adjusting screws or other mechanism (not shown). The distance between the communicating slot 12 and the ends of the guides 3 and 4 is a fraction of a wave length, and the end plates 15 and 17 are adjusted to determine the direction of energy flow through the slot 12. For example, the distance between the slot 12 and the plate 15 may be made greater than the distance between the slot and the plate 17 thereby creating a higher voltage on the side of the guide 3 which compels the energy to flow into the guide 4 through the slot 12. At the ends of the guides near the generator the closure plate 16 is adjusted in a manner similar to the adjustment of the plate 15 so that a high impedance is presented to the flow of energy toward the plate 16 and the energy therefore flows through the slot 13 back to the guide 4. The distance between the opening 12 and the slot 13 is adjusted so that the energy returning to the guide 4 is in correct phase to reinforce the energy flowing through the guide 4 from the generator 1. It has been found that by proper adjustment of the closed ends of the guides in combination with correct spacing of the communicating slots between the guides, the ends of the guides may be made to act in the manner of surge impedances in that they prevent standing waves. The wave energy thus flows from the generator 1 through the guide 3, a portion being removed by radiation through the openings 5 and the remainder flowing back through the guide 4 to again enter the guide 3 in proper phase to reinforce the energy being supplied by the generator 1.

In some types of radio systems it is desirable to provide a beam which is continuously swept back and forth over a predetermined area, and in Fig. 3 I have illustrated an antenna similar to that of Fig. 1 and arranged to accomplish this purpose. The apparatus of Fig. 3 employs a wave guide system similar to that of Fig. 1, and corresponding parts have been designated by the same numerals. The wave guides 3 and 4 are made considerably longer than in the arrangement of Fig. 1 in order to accommodate a greater number of horns 6 and have been shown mounted on insulating supports 21. The two insulating supports 21 near the center of the assembly are spaced apart sufficiently to permit a central horn 6 to be coupled to the center one of the slots 5 through its coupling guide 7 mounted on a short length of plate 8. The two slots 5 normally provided on either side of the central slot are omitted since it is desired to radiate energy only at the phase displacement at the center of the guide. The central slot 5 is

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always in communication with the central horn 6 and the radiation from this horn is continuous throughout the operation of the apparatus. In Fig. 3 there is a series of six horns on either side of the central horn, each of the horns in the two series being connected through coupling guides 7 for communication with three successive openings 5 and each assembly of six horns being mounted on a plate 8 in the same manner as the assembly of three horns in Fig. 1. The adjustment of the apparatus of Fig. 3 to provide the continuous flow of wave energy within the guides is the same as that of the apparatus of Fig. 1 and provides the same flywheel effect which insures the maintaining of an adequate supply of wave energy of progressively changing phase displacement for facilitating the continuous radiation of a directional beam. In order to control the relative phase displacement of the energy supplied to each of the horns, commutators in the form of cylinders 22 and 23 are mounted on bearing assemblies 24, 25, 26, and 27 secured to the guide structure adjacent the insulating supports 21. The two cylinders 22 and 23 thus surround the two main radiating portions of the guide. The cylinders 22 and 23 take the place of the clamps 10 in Fig. 1 and make it possible to vary the phase displacement continuously in a manner such that a beam may be swept back and forth along a predetermined line. In order to rotate the cylinders about the guides, ring gears 28 and 29 are secured to the ends of the guides 22 and 23 respectively and are arranged to be driven through a suitable gearing by a motor 30.

As explained in connection with the apparatus of Fig. 1, a beam of energy may be radiated in a predetermined direction by selecting a suitable phase relationship of the energy radiated from each of several horns. By progressively changing the phase relationship of the energy radiated from the successive horns, it is possible to cause the beam to change in direction and thus sweep back and forth along a desired line. The rate of the sweep depends upon the rate at which the relative phase displacements of the several horns are changed.

The cylinders 22 and 23 are constructed of sheet metal and are provided with slots or radiating openings the lengths of which determine how long during each rotation of the cylinders each of the openings 5 is in communication with its respective coupling guide 7. An arrangement of one suitable grouping of openings for the cylinder 23 is shown in Fig. 4 in which the cylinder is represented in the flat before being bent into its final form, the ends of the sheet being shown broken off. The cylinders 22 and 23 are identical except that they are arranged symmetrically with respect to the center of the guide structure, the shorter openings being at the outer ends of the cylinders. The openings in the cylinders 22 and 23 are designed so that the phase displacement of the energy radiated from the horns varies progressively in relation to the phase displacement of the energy radiated from the central horn in a manner to provide the desired sweeping action.

Fig. 5 illustrates how a beam may be swept through a desired angle, it being assumed that the beam is to move from a position 31 through an angle α to a position 32 and thence back to the position 31. The direction of the resultant beam formed by the combination of the beams radiated from the several horns 6 depends upon

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the relative phase displacement of the several individual beams, and the resultant beam may be said generally to occur in a direction normal to a line along which the energy from all the beams is substantially in phase. It will be understood however that individual horns may vary considerably from this phase relationship and without changing the direction of the beam, provided the majority of the horns radiate energy sufficient to determine the direction. Thus in Fig. 5 if all the horns at a selected instant have radiated energy which is in phase along a line 33, then the beam will be radiated in the direction 31 which is normal to the line 33; and if at some later time the energy from all the horns is in phase along the line 34, the beam will be radiated in the direction 32 normal to the line 34. Intermediate positions of the beam are attained when the horns radiate energy which is substantially in phase along lines intermediate the lines 33 and 34. The diagram of Fig. 5 is drawn with respect to the phase displacement of the energy radiated from the central opening 5. It will be understood that this opening which is open throughout the operation of the apparatus, determines the phase displacement at any instant with respect to which the phase displacements of the several horns must be aligned to obtain a predetermined direction of the beam. In sweeping from the position of the line 33 to that of the line 34 the phase displacements must change more rapidly for positions more remote from the center if these displacements are to be substantially the same as that at the center. This progressive change of phase displacement may be somewhat clearer by considering the operation of the sweep as generally analogous to the operation of a hinged door having small wheels arranged to engage the floor at intervals along the bottom of the door. For such an arrangement it is obvious that when the door swings, the wheels farthest from the hinge must turn the fastest, and the others progressively slower as they are nearer the hinge.

The openings in the cylinder 23, as illustrated in Fig. 4, have been designed to approximate the desired phase displacement relationship. The three openings for the horn nearest the center horn 6 and indicated at 35 are of such length that the corresponding three openings 5 are coupled for radiation throughout the major portion of each revolution of the cylinder. The staggered relation of the three openings 35 is selected to provide the desired rate of change of phase displacement of the energy radiated, it being remembered that this phase displacement depends upon the resultant phase of the energy supplied through the three coupling horns 7. The remaining sets of three openings have been indicated at 36, 37, 38, 39, and 40. The openings 40, which are the shortest and are located at the outer end of the cylinder, have been shown as of the dumbbell slot type which facilitates the obtaining of the desired phase displacements during the short period of coupling. During the operation of the commutator the energy supplied to the horns 6 changes in phase displacement at progressively greater rates toward the outer ends of the cylinders. The continued rotation of the cylinders causes the lines of substantially equal phase displacement to oscillate back and forth between the positions of the lines 33 and 34.

The particular selection of dimensions and locations of the openings in the cylinders as shown

in Fig. 4 has been illustrated merely as an example of one arrangement for approximating the desired continuous and progressive change of phase displacement of the successive horns.

The arrangement of the wave guides 3 and 4 to provide a continuous supply of wave energy of continuously changing phase displacement, together with the resulting "flywheel" effect, makes it possible to supply a large number of radiating horns with a minimum loss of energy in the antenna. The absence of standing waves makes it possible to secure the desired phase relationships at all times and to sweep the beam continuously along a predetermined line.

From the foregoing it is readily apparent that I have provided a simple and easily constructed arrangement for maintaining a continuous supply of wave energy of progressively changing phase displacement. I have also provided a simple and effective arrangement for utilizing a continuous supply of wave energy of varying phase displacement for sweeping a beam of radiated energy over a predetermined line or area.

While I have illustrated my invention in connection with a particular arrangement for securing a directional beam, other applications will readily be apparent to those skilled in the art. I do not therefore desire my invention to be limited to the particular constructions described and illustrated and I intend by the appended claims to cover all modifications which fall within the spirit and scope of the invention.

What I claim as new and desire to secure by Letters Patent of the United States, is:

1. An apparatus for transmitting high frequency electric energy comprising an elongated wave guide of the hollow pipe type closed at one end, means for supplying high frequency electric wave energy to said guide at the other end thereof, means for radiating wave energy from said guide, and means for minimizing reflection of wave energy from said one end back through said guide, said last mentioned means including an external path arranged for returning reflected energy from said one end to said other end in correct phase to reinforce the energy supplied to said guide.

2. An apparatus for transmitting high frequency electric energy comprising a wave guide of the hollow pipe type, means for supplying high frequency electric wave energy to said guide at one end thereof for transmission through said guide, means for closing the other end of said guide, means intermediate the ends of said guide for withdrawing a portion of the energy supplied thereto, and means for returning reflected energy from said other end to said one end externally of said guide whereby the returned energy reinforces the energy supplied to said guide and loss of energy in said apparatus is minimized.

3. An apparatus for transmitting high frequency electric energy comprising an elongated wave guide of the hollow pipe type, means for supplying high frequency electric wave energy to said guide near one end thereof for transmission through said guide, means for closing the other end of said guide, means intermediate the ends of said guide for radiating wave energy therefrom, and means including a second wave guide of the hollow pipe type for returning reflected energy from said other end to said one end whereby the returned wave energy reinforces the wave energy supplied to said first mentioned

guide and loss of energy in said apparatus is minimized.

4. An apparatus for transmitting high frequency electric energy comprising a first wave guide of the hollow pipe type closed at one end and having lateral openings near both ends, means at the other end of said guide for supplying high frequency electric wave energy thereto, means intermediate the ends of said guide for radiating energy therefrom, and a second wave guide of the hollow pipe type closed at both ends and having lateral openings in communication with the lateral openings in said first guide for returning reflected wave energy from said one end to said other end, the positions of said lateral openings with respect to the closed ends of said guides being selected in accordance with the frequency of the high frequency energy so that wave energy tends to flow from the closed end of said first guide through said second guide to the other end of said first guide and so that said returned energy is in correct phase to reinforce the energy from said supplying means.

5. An apparatus for transmitting high frequency electric energy comprising a pair of elongated wave guides of the hollow pipe type, means for supplying high frequency wave energy to one of said guides near one end thereof, adjustable end walls for closing the other ends of said guides, means providing communication between said guides near both ends thereof, each of said adjustable walls being positioned with respect to the adjacent one of said communication means to facilitate continuous circulation of wave energy through said guides in series, and means for radiating energy from one of said guides.

6. An apparatus for transmitting high frequency electric energy comprising a pair of elongated wave guides of the hollow pipe type, means for supplying high frequency wave energy to one of said guides and for maintaining a continuous traveling wave of energy therein, adjustable end walls for closing the other end of said one guide and both ends of the other of said guides, means providing communication between said guides near both ends thereof, means for adjusting the distance between said communication means, the distance between said communication means being selected with respect to the wave length of the energy supplied to said one guide and each of said adjustable walls being positioned with respect to the adjacent one of said communication means to facilitate continuous circulation of wave energy through said guides in series, and means for radiating energy from one of said guides.

7. An apparatus for transmitting high frequency electric energy comprising a pair of wave guides of the hollow pipe type, means for supplying high frequency wave energy to one of said guides near one end thereof, adjustable plates for closing the other end of said one guide and the two ends of the other of said guides, means providing communication between said guides near both ends thereof, said one guide having an opening intermediate the ends thereof for radiating energy therefrom, each of said adjustable plates being positioned with respect to the adjacent communicating opening between said guides so that wave energy tends to circulate through said guides in series and the energy returned from said other guide reinforces the energy supplied to said one guide whereby a continuous traveling wave is maintained in said

one guide and the energy radiated through said opening varies in phase progressively.

8. An apparatus for transmitting high frequency electric energy comprising a pair of wave guides of the hollow pipe type arranged in longitudinal juxtaposition, means for supplying high frequency wave energy to one of said guides near one end thereof, adjustable plates for closing the other end of said one guide and the two ends of the other of said guides, said guides having registering openings near both ends for providing communication between said guides, means for adjusting the longitudinal distance between the registering openings at one end of said pair of guides and those at the other end of said pair of guides, the distance between said registering openings being selected with respect to the wave length of the energy supplied to said one guide and each of said adjustable plates being positioned with respect to the adjacent registering openings between said guides so that wave energy tends to circulate through said guides in series and the energy returned from said other guide reinforces the energy supplied to said one guide whereby a continuous traveling wave is maintained in said one guide, and means intermediate the ends of said one guide for radiating energy therefrom.

9. An apparatus for transmitting high frequency electric energy comprising a pair of semi-cylindrical wave guides of the hollow pipe type arranged with their flat sides in face engagement, means for supplying high frequency wave energy to one of said guides near one end thereof, adjustable plates for closing the other end of said one guide and the two ends of the other of said guides, said guides having openings in their flat sides near both ends to provide open communication between said guides, an opening intermediate the ends of said one guide for radiating energy therefrom, each of said adjustable plates being positioned with respect to the adjacent communicating opening between said guides so that wave energy tends to circulate through said guides in series and so that energy is returned from said other guide to said one guide to reinforce the energy supplied to said one guide whereby a continuous traveling wave is maintained in said one guide and the energy radiated through said intermediate opening varies in phase progressively.

10. An apparatus for transmitting high frequency electric energy comprising a pair of wave guides of the hollow pipe type, means for supplying electric wave energy of a predetermined frequency to one of said guides near one end thereof, adjustable plates for closing the other end of said one guide and the two ends of the other of said guides, means providing communication between said guides near both ends thereof, each of said adjustable plates being positioned with respect to the adjacent communicating opening between said guides so that wave energy of said predetermined frequency circulates through said guides in series and the energy returned from said other guide to said one guide reinforces the energy supplied to said one guide whereby a continuous traveling wave is maintained in said one guide, and a plurality of openings intermediate the ends of said one guide and spaced apart longitudinally thereof for radiating energy therefrom whereby each of said intermediate openings radiates energy of progressively changing phase, and said openings being spaced apart at distances to provide predetermined instantaneous differ-

ences in phase of the energy radiated from said openings.

11. An apparatus for transmitting high frequency electric energy comprising a wave guide of the hollow pipe type, means for supplying high frequency wave energy to said guide and for maintaining a continuous traveling wave of energy therein, said guide having a series of energy radiating openings arranged therein longitudinally thereof and spaced at distances corresponding to predetermined equal phase intervals of the wave energy in said guide, and commutating means arranged selectively and progressively to change the amount of radiation of energy from each of said openings for producing a beam of radiation and for angularly changing the direction of radiation of the beam to sweep the beam back and forth along a predetermined line.

12. An apparatus for transmitting high frequency electric energy comprising a wave guide of the hollow pipe type, means for supplying high frequency wave energy to said guide and for maintaining a continuous traveling wave of energy therein, said guide having a series of energy radiating openings arranged therein longitudinally thereof and spaced at distances corresponding to predetermined equal phase intervals of the wave energy in said guide, and means including a cylindrical commutator surrounding said wave guide and mounted on an axis parallel to the longitudinal axis of said guide for rotation with respect to said guide, said commutator having openings arranged to register with said openings in said guide at preselected positions of said commutator with respect to said guide, said openings in said commutator being arranged selectively and progressively to change the amount of radiated energy from said openings in said guide to produce a beam of radiation and to sweep said beam back and forth along a predetermined line during rotation of said commutator.

13. An apparatus for transmitting high frequency electric energy comprising a wave guide of the hollow pipe type, means for supplying high frequency wave energy to said guide and for maintaining a continuous traveling wave of energy therein, said guide having a series of energy radiating openings arranged therein longitudinally thereof and spaced at distances corresponding to 120-degree phase intervals of the wave energy in said guide, a plurality of radiating horns arranged adjacent said guide in alignment with said openings, means coupling each of said horns to a respective group of three successive ones of said openings, and means for proportioning the amount of energy supplied to each of said horns from each of the openings coupled thereto whereby said horns cooperate to transmit a beam of energy in a predetermined direction.

14. An apparatus for transmitting high frequency electric energy comprising a wave guide of the hollow pipe type, means for supplying high frequency wave energy to said guide and for maintaining a continuous traveling wave of energy therein, said guide having a series of energy radiating openings arranged therein longitudinally thereof and spaced at distances corresponding to 120-degree phase intervals of the wave energy in said guide, a plurality of radiating horns arranged adjacent said guide in alignment with said openings, means coupling each of said horns to a respective group of three successive ones of said openings, and means including a

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continuously movable commutator arranged between said guide and said horns for selectively proportioning the amount of energy supplied to each of said horns from each of the openings coupled thereto whereby said horns cooperate to transmit a beam of energy along a predetermined line and in a direction determined by the instantaneous position of said commutator, the continuous movement of said commutator causing said beam to sweep back and forth along said predetermined line.

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