

March 29, 1949.

R. ADLER

2,465,827

COMMUNICATION SYSTEM

Filed Feb. 5, 1945

3 Sheets-Sheet 1

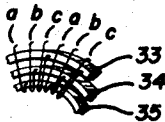
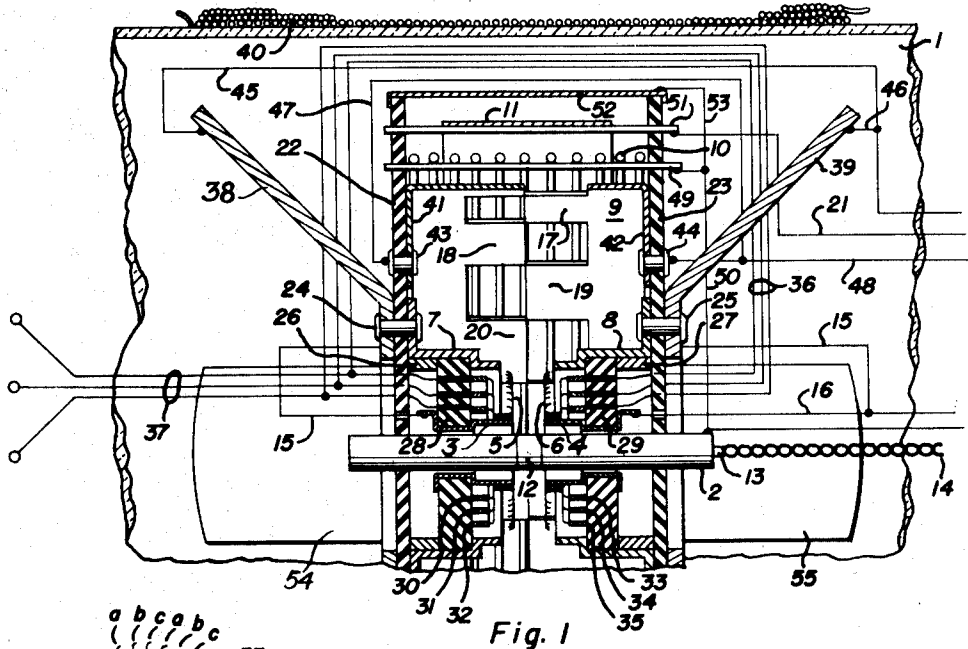


Fig. 2

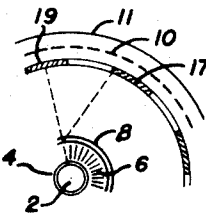


Fig. 7

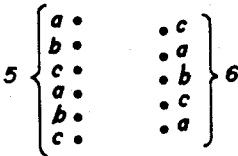


Fig. 3

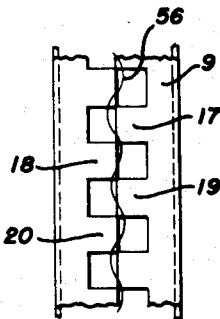


Fig. 4

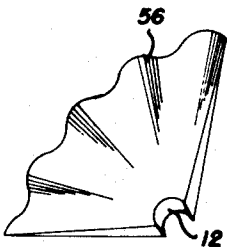


Fig. 5

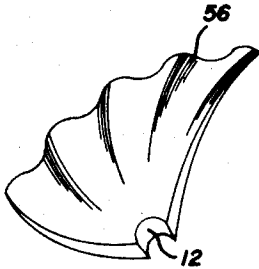


Fig. 6

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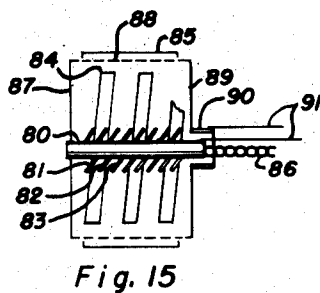
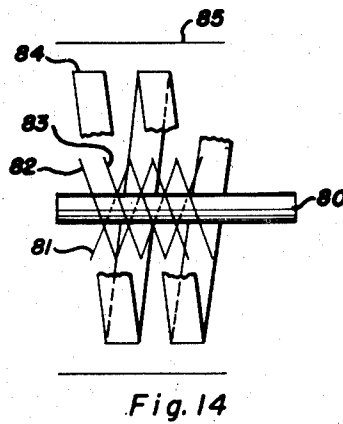
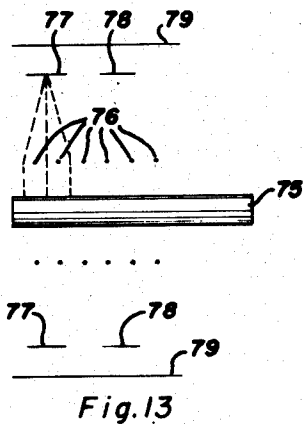
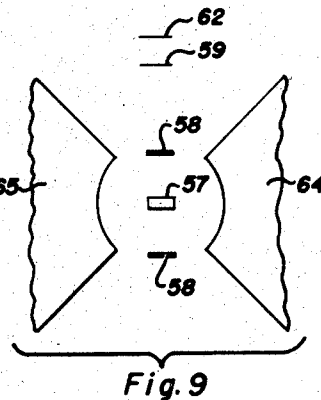
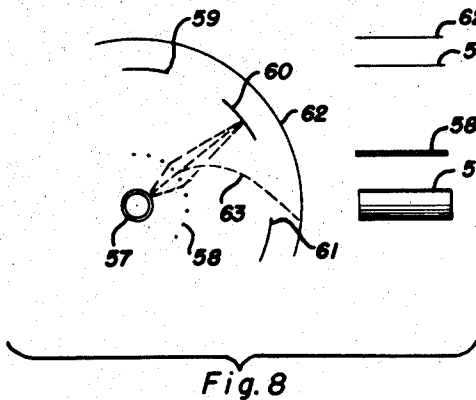
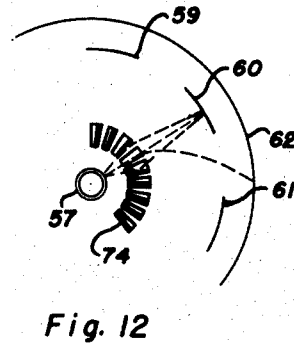
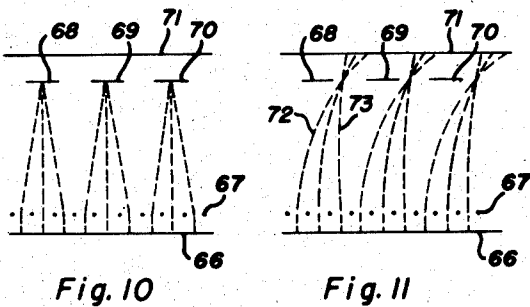
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3 Sheets-Sheet 2



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3 Sheets-Sheet 3

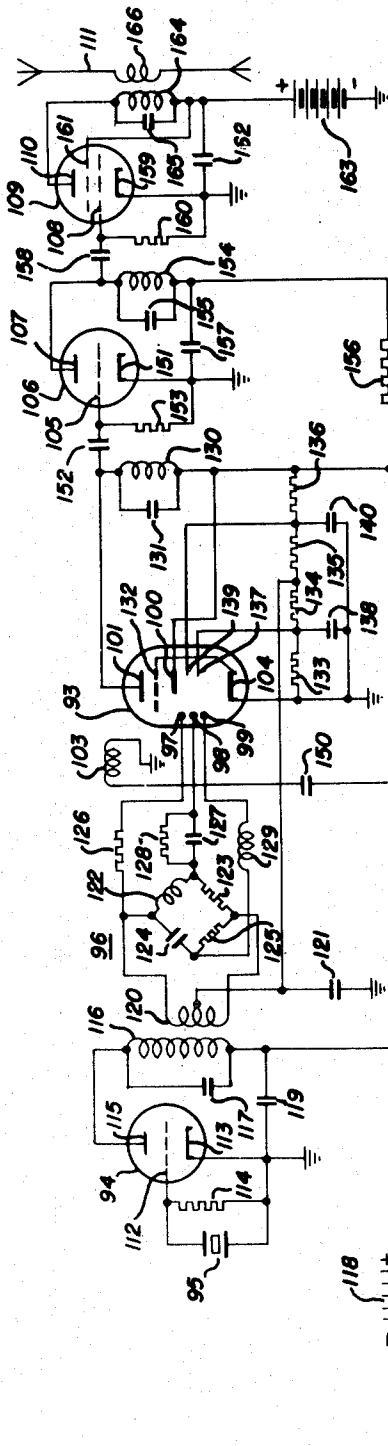


Fig. 16

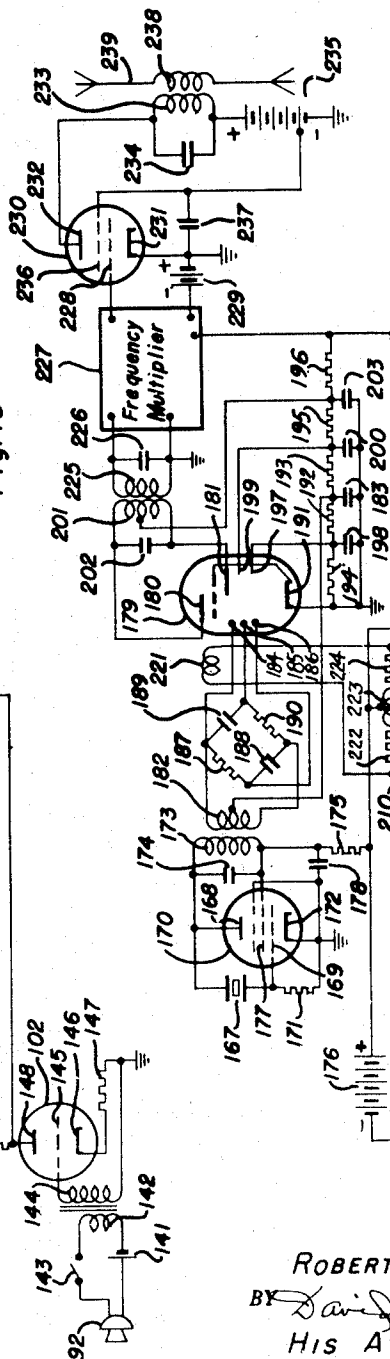


Fig. 17

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UNITED STATES PATENT OFFICE

2,465,827

COMMUNICATION SYSTEM

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Application February 5, 1945, Serial No. 576,227

20 Claims. (Cl. 332-25)

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This invention relates to communication systems, and more particularly to such systems in which the phase or frequency of a carrier wave is modulated in accordance with intelligence to be transmitted.

It is usual to modulate the frequency of the carrier wave by causing the oscillation generator which generates the carrier wave to change its operative frequency in accordance with the signal or intelligence to be transmitted. Such a system is inherently liable to allow the average or center frequency of the modulated carrier wave to drift, since the oscillator cannot be crystal controlled but must be sensitive to influences which cause its frequency to change. For communication work, and particularly for broadcast work, it is highly desirable to have the oscillation generator of a transmitter crystal controlled so that its average or mean frequency is maintained constant with a high degree of accuracy.

It is usual in phase modulation systems to provide a crystal controlled oscillation generator which maintains a mean or average frequency of the transmitter constant with a high degree of accuracy, but there are other undesirable complications. Phase modulation, if used without modification, requires enormously wide frequency bands for its operation if any but relatively low signal frequencies are transmitted. That is, it is a characteristic of a phase modulation system that carrier wave frequency is shifted in an amount proportional not only to instantaneous signal intensity but also to instantaneous signal frequency. Of more practical importance is the fact that arrangements so far known for producing phase shift of the carrier wave in response to the instantaneous intensity of a signal have been capable of shifting the phase of the carrier wave only a fraction of one-half cycle at the most, and to obtain substantial frequency modulation it has been necessary to multiply the carrier wave frequency many times, making it necessary to use large numbers of multiplier tubes in any system in which it was desired to provide a substantial amount of frequency modulation in comparison with the highest signal frequency to be transmitted. Furthermore, it has been necessary to provide special circuit arrangements for modifying the modulating signal voltage in such phase modulation systems if it were desired to make them operate in such a way as to produce frequency modulation.

It is an object of my invention to provide a new and improved system for producing such types of modulation in which fewer parts are required

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and over-all simplicity and cheapness is obtained.

It is also an object of my invention to provide an arrangement which is capable of producing timing modulation (such as phase or frequency modulation) with a minimum number of vacuum tubes and with sufficient simplicity that a transmitter incorporating my invention may be readily utilized in vehicles and will require that minimum power be supplied by such vehicles.

It is a more specific object of my invention to provide a phase modulation system in which the need for large amounts of signal frequency modification is obviated.

Another object of my invention is to provide a frequency modulation system in which crystal control of the oscillation generator equivalent to that heretofore obtained in phase modulation systems is provided with a maximum of simplicity and a minimum number of discharge devices.

In general, it is also an object of my invention to provide such a system and its various component parts, in which the parts are especially designed to cooperate with each other in the system to carry out a maximum number of functions necessary and desirable in such systems with a minimum number of such parts.

The features of the present invention which are believed to be novel are set forth with particularity in the appended claims. The present invention itself, both as to its organization and manner of operation, together with further objects and advantages thereof may best be understood by reference to the following description taken in connection with accompanying drawings in which:

Figure 1 illustrates a section, partly broken away, of a special electron discharge device useful in carrying out the invention:

Figure 2 is a perspective view of a detail of Figure 1;

Figure 3 is a developed view of a portion of the device of Figure 1;

Figure 4 is a developed view of another portion of the device of Figure 1;

Figure 5 is a perspective view which is helpful in understanding certain operating characteristics of the device of Figure 1;

Figure 6 is a view similar to Figure 5 under certain different operating conditions;

Figure 7 is an elevational view of a detail of Figure 1;

Figure 8 illustrates an alternative form of a special electron discharge device useful in the invention, and shows sections of the device taken at right angles to each other;

Figure 9 shows a modified form of the device somewhat similar to that illustrated in Figure 8;

Figures 10 and 11 illustrate a simple form of the special discharge device useful in the invention and shows certain operating characteristics thereof;

Figures 12 through 15 illustrate still other modified forms of the special electron discharge device useful in the invention;

Figure 16 shows schematically a circuit arrangement including a special discharge device and arranged together therewith to carry out certain of the aspects of the invention; and

Figure 17 illustrates still another circuit arrangement including a similar special electron discharge device and arranged together therewith to carry out certain other aspects of the invention.

Hereinafter, the term "timing modulation" is used to mean any modulation of a carrier wave in which a time dependent characteristic of the wave is modulated in accordance with a signal, as, for example, phase or frequency but not amplitude.

In a timing modulation system arranged according to this invention a special electron discharge device is utilized in which a beam of electrons is generated, the electron distribution of such beams being periodically altered thereby to cause an electron density wave, which may be either transverse or longitudinal, to move past or across an output electrode recurrently at a speed controlled in accordance with frequency of a carrier wave whose phase or frequency is to be modulated. This wave is advanced or retarded in its passage recurrently past or across the output electrode by a magnetic field produced in response to modulating signals. When the magnetic field is of one polarity the electron density wave is advanced ahead of the position it would assume in the absence of the magnetic field, such position being recurrently moved past the output electrode, and current generated from the output electrode by the passage of the wave past it is correspondingly advanced in phase. Similarly, when the magnetic field is of the opposite polarity, the wave is retarded during its passage across the electrode and the phase of the current generated in the electrode is correspondingly retarded.

In Figure 1 a preferred form of this special electron discharge device is illustrated in which within an evacuated envelope 1, a cathode 2, focusing anodes 3 and 4, electron beam generating and altering control electrodes 5 and 6, focusing anodes 7 and 8, a first anode electrode 9, a suppressor electrode 10, and a second anode electrode 11, are supported. Cathode 2, as illustrated, is of the indirectly heated type and includes a metal cylinder around the central portion of which an electron emissive layer 12 is coated, and inside of which a filamentary heating element 13 is placed. The filamentary heating element 13 is supplied with suitable heating current through a twisted pair of conductors 14, so that the tubular cathode 2 is heated sufficiently to cause the electron emissive coating 12 to emit electrons.

The two focusing anodes 3 and 4 surround the tubular cathode 2 and are coaxial therewith, and they present adjacent edges toward one another between which there is a gap through which electrons from the emissive surface 12 may be projected radially from the tubular cathode 2. The focusing anode 3 is connected through a

suitable conductor 15 to a conductor 16 which is connected between the focusing anode 4 and a suitable source of potential which is positive with respect to the cathode 2, so that electrons which are attracted by the focusing anodes 3 and 4 from the surface 12 to a large extent pass through the gap between the anodes 3 and 4 and are thus projected radially from the layer 12.

The control electrodes 5 and 6, to be described more fully hereinafter, lie on opposite sides of the circular disc of electrons emitted radially from the surface 12. These control electrodes 5 and 6 are suitably sub-divided into small control elements or surfaces to which suitable multiphase high frequency potentials are applied to cause the formation of an electron beam and to alter the electron distribution of the electron beam so formed thereby to cause an electron density wave, which is of a transverse nature in this preferred embodiment, to move circumferentially around the emissive layer 12.

The focusing anodes 7 and 8 are similar in shape to the focusing anodes 3 and 4 and are also concentric with the cathode 2. These focusing anodes 7 and 8 have adjacent edges facing each other across a gap just outside of the control electrodes 5 and 6 and they are maintained at a positive potential with respect to the cathode 2 so that electrons emitted radially from the cathode surface 12 and projected between anodes 3 and 4 are further attracted by the positive electrodes 7 and 8 past the control electrodes 5 and 6 and projected further in the form of a disc. The potentials of the focusing anodes 3, 4 and 7, 8 are adjusted so that this radial disc of electrons is focused so that the disc has a sharp edge like that of a discus at a certain radius from the cathode 2. The anode 9 surrounds the cathode 2 concentrically therewith and its radius is such that it intercepts the disc of electrons in a sharply defined line except where there are cut-out portions between the elemental areas 17, 18, 19 and 20, etc. These elemental areas of the anode 9 are alternately disposed along opposite sides of a line defined by the sharply focused edge of the disc of electrons formed without any potential applied to the control electrodes 5 and 6.

Electrons pass through the apertures in the first anode 9 and then through the suppressor electrode 10 and are finally collected upon the second anode electrode 11 which is connected through a suitable conductor 21 with a source of potential which is positive with respect to the cathode 2.

The entire assembly of elements is maintained in proper spaced relation for the described operation by a pair of mica discs 22 and 23 which are centrally apertured to maintain the cathode 2 in coaxial relation with the envelope 1. The focusing anodes 7 and 8 are respectively fastened to these mica sheets 22 and 23 by suitable fastening means such as the illustrated rivets 24 and 25. Two spacing rings 26 and 27, of suitable material, lie concentrically within the focusing anodes 7 and 8 against the mica sheets 22 and 23 and maintain a pair of insulating rings 28 and 29 within suitable folds of the focusing anodes 7 and 8. Rings 28 and 29 in turn support the focusing anodes 3 and 4. The control electrodes 5 and 6 are respectively supported on conducting and supporting rings 30, 31, 32, 33, 34 and 35, which are in turn supported respectively on the insulating rings 28 and 29. The conducting and supporting rings 33, 34 and 35 are connected through suitable conductors 36, which

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extend through the insulating ring 29 and through the mica disc 23 to three corresponding conductors 37, which extend through the mica disc 22 and through the insulating ring 28 to respective connections with the conducting and supporting rings 30, 31 and 32. Multi-phase voltages impressed on the three conductors 37 form an electrostatic field between the control electrodes 5 and 6 in such a manner as to modify the shape of the electron disc passing between them as described more fully hereinafter.

The focusing electrodes 7 and 8 not only act in focusing the disc of electrons projected radially from the surface 12 but also act to concentrate magnetic flux between their adjacent edges through the electron disc. To this end the focusing anodes 7 and 8 are made of ferromagnetic material. The rivets 24 and 25 respectively hold magnetic flux directing members 38 and 39 against the mica pieces 22 and 23 in such a position that magnetic flux developed by current flowing through a coil 40 wound around the envelope 1 concentrically with the cathode 2 passes inwardly through the flux directing member 38 and focusing anode 7, and then across the gap between the focusing anodes 7 and 8 and onward through the focusing anode 8 and flux directing member 39, and thus back around the coil 40. The action of this flux across the gap between focusing anodes 7 and 8, upon the electron disc is to impart to individual electrons within the disc velocity components which are tangential to circles centered around the cathode 2.

The anode 9 is formed with inwardly turned flanges 41 and 42, which are respectively fastened to the mica discs 22 and 23 by fastening means such as rivets 43 and 44.

The focusing anodes 7 and 8 are maintained at a potential positive with respect to cathode 2 by connection through the rivets 24 and 25 and the flux directing members 38 and 39 and conductors 45 and 46 to a suitable source of such positive potential. The anode 9 is connected through suitable conductors 47 and 48, connected with rivets 43 and 44, to a suitable source of potential positive with respect to cathode 2.

The suppressor electrode 10 is wound on suitable supporting posts, such as the post 49, which have ends projecting respectively through the mica disc 22 and 23, and the suppressor electrode is connected through those posts and through a conductor 50 to the cathode 2.

The second anode electrode 11 is supported on similar supporting posts such as the post 51 whose opposite ends project through the mica discs 22 and 23 and this electrode 11 is connected through the post 51 and conductor 21 and through a load to a suitable source of potential sufficiently positive with respect to the cathode 2 to assure that no electrons passing through the suppressor electrode 10 can return to the electrode 9.

A cylindrical shielding element 52 is fastened around the edges of the mica discs 22 and 23 and is connected through a conductor 53 and through conductor 50 to the cathode 2.

The entire assembly is supported by conventional means, not illustrated, concentrically within the envelope 1, and such conventional means may, for example, be spring strips punched out of the shield 52 and bent outwardly to press against the envelope 1 and maintain the whole assembly substantially concentric within the envelope.

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The sectional view shown in Figure 1 shows the flux directing members 38 and 39, which are only two of eight similar members. Two others 54 and 55 are illustrated extending outwardly from the mica discs 22 and 23 in a direction at right angles to that in which the members 38 and 39 extend. It is to be understood that the entire arrangement is symmetrical about the cathode 2.

By way of example, with the particular construction shown, which is one of the preferred forms of the special electron discharge device required for the use of this invention, the following electrode potentials are approximately those necessary to form the described electron disc. The anodes 3 and 4 are maintained about 12 volts positive with respect to cathode 2. The control electrodes 5 and 6 are maintained about 35 volts positive with respect to cathode 2, and the anodes 7 and 8 are maintained about 55 volts positive with respect to cathode 2. The second anode electrode 11 is preferably maintained at a higher positive potential with respect to the cathode 2 than any other electrode in the device in order to maintain a uniform electrostatic field inside the anode electrode 9, and a voltage of about 250 volts positive with respect to cathode 2 is suitable where the anode electrode 9 is maintained at about 100 volts positive with respect to cathode 2. The voltage of the anode 9 should be adjusted along with the voltages of the focusing anodes 3, 4, 7 and 8 to cause the formation of the electron disc described so that the electrons in the disc focus in a sharp line at the surface of the anode 9. With such electrode potentials poly-phase alternating voltages of the order of 10 volts may be impressed on control electrodes 5 and 6. In Figure 2 a detail of one portion of the control electrode 6 is illustrated in which the conducting and supporting rings 33, 34 and 35 appear in large scale to show the manner of their connection with the individual elements of the control electrode 6. These individual elements are labeled a, b and c, consecutively and recurrently, and all elements labeled a are connected with the conducting and supporting ring 35. Similarly, all elements labeled b are connected with ring 34 and all elements labeled c with ring 33. Upon the application of a three phase voltage to the conductors 37 and thereby to the rings 33, 34 and 35, the control electrode elements which are labeled in groups a, b and c are excited in groups with the respective individual phase voltages of that three phase voltage. The entire control electrode 6, and similarly the control electrode 5, where it is to be excited with a three-phase voltage is formed of a number of the elements a, b and c which is a multiple of 3, so that the numbers of elements in the three groups a, b and c are equal.

In Figure 3, there is shown a developed view around the circumference of control electrode 5 and 6 showing the individual elements of the control electrodes 5 and 6. The elements a, b and c of control electrode 5 are arranged in staggered relation with respect to the elements a, b and c of the control electrode 6 so that a three phase voltage applied to these two control electrodes creates an electrostatic field between them which at one point bends the electron disc toward electrode 5 and at another point circumferentially around cathode 2 from that first point bends the electron disc in the opposite direction toward electrode 6. That is, an element c of electrode 6 is opposite a point midway between ele-

ments *a* and *b* of electrode 5, and an element *a* of electrode 6 is opposite a point midway between elements *b* and *c* of electrode 5. Similarly, an element *b* of electrode 6 is opposite a point midway between elements *c* and *a* of electrode 5.

Consequently when voltages of three equally displaced phases are applied to the elements *a*, *b* and *c*, at a particular instant when the elements *c* are most negative, the elements *a* and *b* are approximately at a potential which is half of their maximum positive value, and electrons passing between one element *c* and the opposite elements *a* and *b* are deflected sideways toward the elements *a* and *b*. Since in all cases electrons are therefore deflected in a direction parallel to the cathode 2 away from every element *c* in either of the control electrodes 5 and 6, the electron disc is warped so that its edge, when it is viewed edgewise, appears scalloped.

If three phase voltages are applied to the element groups *a*, *b* and *c* of the electrodes 5 and 6, the potentials of the three groups constantly change so that the electrons of the disc are deflected in a direction parallel to the axis of cathode 2 alternately in succession from each of the three element groups *a*, *b* and *c* of the control electrodes 5 and 6. In consequence, the convolutions or scallops on the edge of the electron disc appear to rotate around the cathode 2 as an axis in a manner analogous to the rotation of the magnetic field developed in a multiphase electric motor armature. In other words, periodic axial electron displacement in response to application of multiphase potentials to the control electrodes 5 and 6 causes a uniform velocity electron density wave to progress continuously and recurrently along the path of the anode segments 17, 18, 19, 20, etc.

Usually the three phase voltage applied to the conductors 37 will be of high frequency, such as is commonly used for carrier wave purposes, and the apparent revolution of the convolutions or scallops of the outer edge of the electron disc will be extremely rapid.

The apertures between the alternating opposite areas 17, 18, 19, 20, etc., of the anode 9 correspond exactly to the convolutions or scallops in the edge of the electron disc as described. That is, there are as many of the areas 17, 18, 19, 20, etc., in the anode 9 as there are elements in any one of the groups *a*, *b* or *c* of both of the electrodes 5 and 6 taken together. For example, as illustrated, there are twenty-four of the areas 17, 18, 19 and 20 of the anode 9, and there are twelve elements in each of the groups *a*, *b* and *c* in each of the control electrodes 5 and 6.

In Figure 4 the anode 9 is shown in developed form and a sinusoidal line 56 is drawn about the line dividing the areas 17, 19, etc., on one side of the anode 9 from the areas 18, 20, etc., on the other side of the anode 9. The line 56 represents the thin convoluted edge of the electron disc where it is focused sharply on the anode 9. Of course, the line 56 represents the edge of the electron disc only at one particular instant. At such an instant inspection of the line indicates that some electrons from the disc impinge upon the segmental areas 17, 18, 19 and 20 of the anode 9 and other electrons of the disc pass through the apertures between those areas. At the instant represented by the line 56 more electrons pass through the apertures than impinge on the segmental areas and if the sequence and amplitude of the three phase voltage applied to conductors 37 is such that the line 56 advances

upwardly as shown on the anode 9, after a small fraction of a cycle the number of electrons impinging on the anode 9 increases and the number of electrons which pass through the apertures in the anode correspondingly decreases until such numbers are equal. At succeeding instants of time the number of electrons impinging on the anode 9 continues to increase until the line 56 intersects the contiguous corners of the areas 17, 18, etc., at which time all of the electrons in the electron disc impinge upon anode 9.

Thereafter, as the line 56 advances further electrons in increasing numbers again pass through the apertures in anode 9 and the number of electrons impinging upon anode 9 decreases with respect to time until the line 56 again intersects contiguous corners of the areas 17, 18, etc., at which time substantially all electrons pass through the apertures in anode 9 and a minimum number impinge upon it.

This action continues recurrently so that an alternating electron current is produced in the anode 9 of a frequency equal to the frequency of the three-phase voltage impressed on conductors 37.

As explained briefly in connection with a description of the coil 40 and the ferromagnetic focusing anodes 7 and 8, whenever current traverses the coil 40, flux passes between the edges of anodes 7 and 8 and thus through the electron disc. Since electrons in this disc are moving radially outward from the cathode 2, magnetic flux perpendicular to their path of travel induces additional electron motion in a direction mutually perpendicular to the magnetic flux and to the initial direction of electron travel, with the result that the convolutions of the edge of the electron disc at the anode 9 are advanced or retarded with respect to the positions they would have occupied in the absence of such a magnetic field. In consequence, current flowing through the coil 40 in one direction or the other produces a corresponding advance or retardation in the phase of the current in the anode 9. Viewed in another way, the electron density wave progressing along the path of the anode segments 17, 18, 19, 20, etc., is accelerated or decelerated in accordance with amplitude variations of the modulating signal impressed on coil 40.

In Figure 5 there is a perspective view of a portion of the described electron disc as it would appear if it could be seen, at a time when no current is going through the coil 40. The line 56 forms the outer edge of the convoluted disc and the central portion of the disc is illustrated as having substantially a thickness equal to the length of the emissive cathode surface 12.

In Figure 6 the electron disc illustrated in Figure 5 is shown in the manner in which it would be modified in the presence of current flowing through the coil 40. As illustrated, individual electrons take paths to the line 56 which depart from the radii of the disc, that is electrons emitted from the emissive cathode surface 12 and thereafter deflected to one side or the other by the respective elements of the control electrodes 5 and 6 are further deflected circumferentially around the disc so that its edge convolutions are displaced circumferentially from the positions they would have occupied in the absence of current in the coil 40. Comparison of the shapes of the discs in Figures 5 and 6 makes immediately evident this deformation in the electron disc due to the flow of current in coil 40.

In Figure 7 a view in elevation of the control electrode 6, together with surrounding electrodes, taken from a plane perpendicular to the axis of cathode 2 illustrates more clearly the action of the second focusing anodes 7 and 8 in concentrating magnetic flux from coil 40 to cause displacement of the point of impingement of an electron substantially in proportion to the change of magnetic flux intensity. In this figure elements corresponding with those in Figure 1 are given like reference numerals. The straight dotted line extending between cathode 2 and anode element 19 indicates the path of travel of an electron in the absence of a magnetic field, and the dotted line extending from the interception of the first line with the ferro-magnetic focusing anode 8 to the anode element 17 indicates how the path of electron travel is changed in the presence of a concentrated magnetic field between the ferro-magnetic focusing anodes 7 and 8. It is evident from the geometry of this figure that if the path of every electron were to extend radially from cathode 2 in the presence or absence of a magnetic field the displacement of the point of impingement of such path on one of the anodes would be proportional to the intensity of the magnetic flux inducing such displacement. To produce such displacement and maintain electron travel radial, magnetic flux would have to be concentrated at cathode 2. It is also evident that if the path of an electron is caused to deviate gradually from the straight dotted line extending to anode element 19 as by flux throughout the electron path, that path where it intercepts one of the anodes 9, 11 would be curved, and, by reason of the gradual curvature of the electron path, the displacement of the point of infringement from the point where the dotted line intercepts anode segment 19 would be greater than the displacement which would occur if the electron path deflection were concentrated at the surface of the cathode 2. This can be seen more readily if it be first considered how this displacement would be affected if the two anodes lay in plane surfaces rather than in cylinders. Obviously, if the anode elements lay in plane surfaces there would be a critical amount of magnetic flux which would cause the electron path to curve sufficiently that it would never reach either anode and slightly less flux would cause the electron to reach one of the anodes at a point far removed from the point at which it would have impinged in the absence of magnetic flux. The same is true of cylindrical anodes.

By concentrating the curved portion of the path of electron travel in as short a distance as possible as near as possible to the center of the cathode 2 by means of concentrating the magnetic flux at such position, as for example by members 38 and 39 or by other suitable means, non-linearity caused by the disproportionality between magnetic flux intensity and resultant displacement of the point of impingement of an electron on one of the anodes is reduced substantially, with the result that in a practical discharge device of this type a sufficient amount of magnetic flux may be utilized with reasonably good proportionality between the total amount of that flux and resulting electron displacement to cause that displacement to be as much as the circumferential distance around three adjacent anode elements which correspond to two complete cycles of the alternating anode current which is generated in the anode elements by the passage of the electron density wave thereacross. That is, this discharge device is capable of pro-

ducing a phase shift in a carrier wave transferred through it at least two full cycles (720°) in either direction in response to modulating signal currents flowing through coil 40.

There is one important characteristic of a system which utilizes any of the special forms of electron discharge device in this invention in order to minimize distortion. In any form of such discharge device the electrostatic field pattern created by the control electrode structure must rotate at all points within itself at substantially uniform velocity. This can be achieved most easily by making the control electrode structure symmetrical with respect to the cathode and by placing the control electrode elements out of the path of the electron beam, as is done in the form of discharge device illustrated in Fig. 1, or by skewing the control electrode elements to make them appear substantially continuous with respect to the electron emission, or by utilizing both of those two measures.

That is, in the form of electrode structure shown in Fig. 2 the individual control elements *a*, *b* and *c* should be positioned, not radially, as shown but each at some substantial angle to a line through the center of the cathode 2, the angle being just enough so that each element *a*, for example, subtends an angle, whose apex is at the center of the cathode 2, approximately equal to 360° divided by the total number of the control elements *a*, *b* and *c*. It is preferred to arrange the control elements *a*, *b* and *c* in Fig. 2 in this fashion when they are used in the device illustrated in Fig. 1.

In Fig. 8 there is illustrated an alternative form, shown schematically, of a discharge device similar to that shown in Fig. 1 but having the control electrode structure formed of wires lying within the electron stream coming from the cathode. In the schematic view a cathode 57 acts as a source of electrons and is surrounded by a control electrode structure 58 in the form of a squirrel cage. In the electrode structure 58 every third conductor or control element is connected together and to one phase conductor of a three phase voltage supply in a manner similar to the connections of the elements *a*, *b* and *c* of Figs. 1 and 2. It is to be understood that any multiphase source of voltage may be utilized to energize any of the control electrode structures illustrated, provided those structures are connected in a suitable manner to create a smoothly rotating electrostatic field pattern.

Surrounding the control electrode structure 58 there is a first anode which includes anode elements 59, 60, 61, etc., corresponding in number to the number of groups of three of the control electrode structure 58. These anode elements are spaced apart by distances substantially equal to their circumferential widths. A second anode 62 surrounds the anode formed of elements 59, 60, 61, etc., and both of the anodes 59, 60, 61 and 62 are maintained at positive potentials with respect to cathode 57 so that electrons projected from cathode 57 and formed into a beam by the control electrode structure 58, as the electron density wave progresses around the cathode 57, all electrons impinge simultaneously either on the anode elements 59, 60 and 61 or on the second anode 62. The action of the electrode structure 58 in setting up the electron density wave is substantially identical with the action of the electrode structure 5 and 6 of Fig. 1 and need not be explained here in detail. It is to be noted that the electron density wave set up by the structure of Fig. 8 is longitudinal in nature, as contrasted with the

transverse electron density wave induced by the structure of Figure 1.

Suitable provision, not illustrated in Fig. 8, is made for the production of alternating magnetic flux extending parallel to the long axis of cathode 57 in the space between cathode 57 and the first anode so that the electron paths, of which one is diagrammatically illustrated, are bent in one direction or the other as illustrated by line 63.

In the right hand portion of Figure 8, like numbers being given to the elements illustrated in the two portions of that figure, cathode 57, control electrode structure 58, first anode 59, and second anode 62 are illustrated as having substantial length in the direction of the axis of cathode 57. While it is possible to induce a magnetic field in the space between cathode 57 and the first anode 59 by means of a simple coil placed coaxially with cathode 57 at one end of the device, such a coil has a disadvantage generally that the magnetic flux is distributed more or less uniformly through the space between cathode 57 and anode 59.

It is preferred to concentrate that magnetic flux, which acts to modulate the direction of travel of the individual electron paths, as indicated by line 63, and thereby to modulate the phase of alternating current induced in the anode elements 59, 60, 61 and in the anode 62. It is preferred to concentrate that magnetic flux as much as possible in the region directly around the control electrode structure 58. Such concentration of the magnetic flux in the initial part of the path of such an electron beam as is generated in the special discharge devices described herein reduces distortion to a great extent. To increase the magnetic flux in any discharge device of the kinds herein described, tends to bend the path of electrons away from the position it would have in the absence of a deflecting magnetic flux more and more rapidly as the amount of such flux increases. That is, the amount of displacement of the point on the anodes at which an electron impinges increases at a rate greater than proportional to the increase of magnetic flux intensity where the magnetic flux is distributed through a substantial part of the space between the cathode 57 and the tube output anode.

If, on the other hand, the magnetic flux is applied only to the initial part of the path of an electron, the electron is deflected initially and follows a substantially straight line thereafter, with the result that the amount of displacement of the point where the electron impinges on one of the anodes is much more nearly proportional to the intensity of the magnetic flux. This reasoning follows the same line as that set forth with respect to Figure 7 in which it is explained how the action of focusing anodes 7 and 8 in concentrating the magnetic flux produces this greater proportionality.

It should be noted that the amount of deflection need not be decreased by such concentration of the magnetic flux provided the total amount of the flux is the same.

In Figure 9 there is illustrated an arrangement in which a discharge device similar to that illustrated schematically in Figure 8 is provided with flux concentrating means including iron pole pieces 64 and 65. Although the electrodes illustrated in Figure 9 are substantially shorter in the direction of the axis of the cathode than are those in the device of Figure 8, they are given like reference numerals because their action in producing rotating electron density waves which

generate alternating currents in the output anodes is substantially the same. These pole pieces 64 and 65 have cupped faces adjacent the control electrode structure 58 which act to concentrate substantially all of the magnetic flux within or near the cylinder formed by the control electrode structure 58. The electrodes of this device are made short in order that the distance between these cupped faces of the pole pieces 64 and 65 may be kept small with respect to the area of the faces of those pole pieces in order that they shall act efficiently in producing the desired flux concentration.

All of the forms of the special discharge device described herein may be regarded as modifications of a simple form illustrated in Figures 10 and 11. In the device shown schematically in Figure 10, a flat or plane cathode 66 serves as a source of electrons and a control electrode structure 67 lying in a plane parallel to the cathode 66 is arranged to form electrons from the cathode 66 into beams moving linearly across the surface of the cathode 66. First anode elements 68, 69 and 70, corresponding in number to the number of groups of three of the elements of the control electrode structure 67 lie in the path of the electron density wave set up by these electron beams and are spaced apart in the direction of travel of the wave by an amount substantially equal to their length in that direction. A second anode 71 parallel with cathode 66 lies beyond the anode elements 68, 69 and 70 and intercepts any electrons which do not impinge upon those first anode elements.

As illustrated in Figure 11, a magnetic field traversing the space between the cathode 66 and the two anodes bends the electron beam in a direction mutually perpendicular to the direction of motion of the electron density wave and to the direction of motion of individual electrons in the beam, as illustrated by the dash lines 72 and 73 which define the boundaries of one electron beam. If the magnetic field extends in the same direction with the reverse polarity, the bending of the electron beams is opposite to that illustrated. The phase of alternating currents induced by the impingement of electron beams upon the anode elements 68, 69 and 70 or upon the anode 71 is respectively advanced or retarded in the presence of such magnetic flux.

In Figure 12 an alternative form of the device shown in Figure 8 is illustrated in which like elements are provided with similar reference numerals and in which a somewhat different control electrode structure 74 is provided. This control electrode structure, instead of being composed of substantially round wires, is formed of substantially flat strips of metal with their longest width dimensions lying radially from cathode 57 and with their long dimensions skewed helically around cathode 57 enough to present a substantially unbroken electrostatic surface to the cathode. These skewed strips aid in causing the electrostatic field pattern which they produce to rotate at uniform velocity, as explained in connection with a possible modification of Fig. 1. It is preferred to use such flat strips in forming a control electrode structure for such a device because the controlling action of the composite control electrode structure so formed is more efficient in producing a smoothly rotating electron density wave.

In Figure 13 still another form of the special discharge device is illustrated schematically in which electron beams are formed in the shape

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of discs which are caused to travel linearly from one end of the cathode to the other, remaining coaxial with the cathode. In this form of the device a cathode 75 is surrounded by a control electrode structure which includes several rings 76, each of these rings being concentric with cathode 75 and lying in parallel equally spaced planes all perpendicular to the axis of cathode 75. The rings 76 are grouped for multiphase connection and are suitably connected to a source of multiphase voltage so that they cause the electron emission from cathode 75 to be formed into electron beams in disc form as mentioned and so that they cause these electron beams or discs to move linearly from one end of the cathode to the other. Surrounding the control electrode structure which includes the rings 76 is a first anode including anode elements 77, 78, etc., corresponding in number to the number of groups of rings 76 in which each ring is connected with a different phase conductor. Surrounding the anode elements 77, 78, there is a second concentric anode 79 upon which all electrons which pass between the anode elements 77, 78, etc., impinge. Since the operation of this device is substantially identical with that of the simple form illustrated in Figure 10, it is not explained in detail. Current flowing axially through cathode 75 produces deflection of the electron beams or discs, thereby to induce an acceleration or deceleration of the longitudinal electron density wave progressing along the path of anode segments 77, 78, etc., as explained later.

In Figure 14 a special form of the discharge device is illustrated which is similar to that shown by Figure 13 except that the control electrode elements and the first anode elements are formed spirally or helically instead of circularly around cathode 80. That is, three helical coils of wire 81, 82 and 83 are illustrated interwound one with another, the pitch of any one of the helices being three times the distance between adjacent wires in the control electrode structure. The three control elements 81, 82 and 83 are connected respectively with the three phase conductors of a suitable source of three phase voltage and thereby act to form an electron beam in the shape of a helicoid which is coaxial with the cathode 80 and which moves linearly along it. Outside of the control electrode structure a helical strip 84 of metal is placed concentrically with the cathode 80, the pitch of this helical strip 84 being the same as the pitch of any one of the control elements 81, 82 and 83 and being the same as that of the helicoidal beam of electrons formed by the control electrode structure. The width of the strip 84 is approximately one-half of the pitch of the helix formed by it. An anode 85 in the shape of a cylinder is placed around the strip 84 concentric with the cathode 80 and collects all electrons from the helicoidal beam which do not impinge upon the strip 84 which forms the first anode system.

A practical embodiment of the form of the device illustrated schematically in Figure 14 is shown in Figure 15 in which like elements are given the same reference numerals. The cathode 80 may be formed of a metal tube coated with electron emissive material and indirectly heated by current supplied through twisted conductors 86. A disc 87 fastened centrally to one end of cathode 80 supports at its periphery a cylindrical suppressor electrode 88 which lies between the cylindrical outer anode 85 and the helical inner anode electrode 84, and which serves, being main-

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tained by the disc 87 at cathode potential, to prevent the return of electrons from anode 85 to anode electrode 84. At the other end of the suppressor electrode 88 a second disc 89 is connected peripherally, the disc 89 being insulated at its center from the cathode 80 and connected with a small conducting cylinder 90.

A helicoidal electron beam is formed in the device shown in Figure 15 in the same way as that shown in Figure 14 by the application of three phase potentials to the control elements 81, 82 and 83, and the electron density wave set up by the helicoidal electron beam is caused to advance or to be retarded in its passage along the cathode 80 and across the helical strip 84 by the production of a cylindrical magnetic field around the cathode 80 parallel with the axis of the cathode. This cylindrical magnetic field flux is produced by the passage of modulating current through the cathode 80 in one direction or the other by means of two conductors 91 connected respectively to the small conducting cylinder 90 and to that end of the cathode 80 nearest the cylinder 90. Current is caused to flow from one of the conductors 91 through cathode 80, disc 87, suppressor electrode 88, disc 89, cylinder 90 and thus back to the other conductor 91 to cause the helicoidal electron beam to be bent in one direction and current is caused to flow reversely through that circuit to cause the electron beam to be bent in the opposite direction whereby phase changes are produced in the anodes 84 and 85.

Although no means is illustrated in connection with Figures 13 and 14 for the production of magnetic flux to cause such advancing or retarding of the electron density wave in those structures, an arrangement such as that illustrated in Figure 15 may be utilized to produce the magnetic flux lying in a cylinder concentric with the cathodes 75 and 80 respectively.

In connection with the magnetic flux concentrating means illustrated in connection with the device shown in Figure 1 and in connection with Figure 9, these flux concentrating means can be arranged to reduce residual non-linearity which remains even when such flux concentrating means is used. Even when such a flux concentrating arrangement, as shown in one of these figures, is utilized, magnetic electron deflection occurs at some distance from the center of the electron discharge device and furthermore occurs over a substantial length of the path traversed by individual electrons, and accordingly, the displacement of the point where the electrons impinge on the respective anodes increases at a rate somewhat greater than proportional to the increase of magnetic flux intensity. By causing the magnetic flux intensity to increase at a rate correspondingly less than proportional to the increase of modulating current which generates the magnetic flux, by selecting a proper ferromagnetic material from which the flux concentrating means are fashioned, and by properly dimensioning the flux concentrating means, an amount of magnetic saturation can be caused to occur in the ferromagnetic material which will substantially offset this residual non-linearity.

This residual non-linearity may also be corrected by other means, one of which is described hereinafter, which cause the rate of increase of modulating current in the coil which produces the magnetic flux to be less than proportional to the rate of increase of intensity of the modulating signal potential.

In Figure 16 there is shown the circuit diagram

of a radio transmitter arranged to transmit a carrier wave whose frequency is modulated in accordance with a modulating signal from a microphone 92. This type of transmitter is particularly useful in point to point communication because of its simplicity and the small number of discharge devices utilized in it, which is made possible by the utilization of the discharge device 93 which may, for example, be like the device illustrated in Figure 1. In this transmitter certain measures are taken to reduce the non-linearity heretofore described, but certain of the measures which are possible if it be desired to attain maximum linearity have been dispensed with in order to make the number of discharge devices as small as possible.

In this transmitter a carrier wave is generated in an oscillating circuit including an electron discharge device 94 and a piezoelectric frequency determining element 95. The carrier wave generated in the device 94 is impressed through a phase splitting network 96 upon the three phase control electrodes 97, 98 and 99 of the device 93, in which, as explained previously, an electron density wave is caused to move alternately at carrier frequency across the first anode 100 and the second anode 101 of the device 93. Signals from the microphone 92 are amplified through an electron discharge amplifying device 102 and are then impressed upon a magnetic flux producing coil 103, the flux from which acts in the space between cathode 104 and anode 100 of device 93 to cause phase shift, either advancing or retarding the passage of the electron density wave as it moves alternately across the anodes 100 and 101 of the device 93.

The amplifying device 102 has a substantially constant voltage output characteristic, in the presence of constant input voltages of varying frequency, and consequently by reason of the inductance of coil 103 current flowing through the coil and magnetic flux produced by it within the device 93 are substantially inversely proportional to frequency. Correspondingly, the phase shift produced as a result upon the anode 101 of device 93 is substantially inversely proportional to the frequency of signals from the microphone 92, which means that the modulation of the phase of the carrier wave current in the anode 101 is such that the frequency of that carrier wave current is modulated substantially proportionally to instantaneous modulated signal voltage from the microphone 92 regardless of the frequency of that voltage. It is therefore a frequency modulated carrier wave which is developed upon the anode 101 of device 93.

This frequency modulated carrier wave is impressed upon the control electrode 105 of an electron discharge amplifying device 106, which is arranged to produce a frequency multiplication of, for example, four times the frequency of the carrier wave impressed upon its control electrode 105. This multiplication of frequency in the device 106 serves two purposes. In the first place it increases the amount of frequency modulation of the carrier wave to an amount such that the frequency shift of the carrier wave in relation to the maximum frequency of modulating signals from the microphone 92 is sufficient to provide substantially noise free reception of the signals in a suitable frequency modulation receiver which incorporates an efficient limiter. In the second place it makes possible the transmission of a high frequency carrier wave, for example, at 40 megacycles, while operating the discharge de-

vice 94 and the associated piezoelectric crystal 95 at a much lower frequency where frequency stability under varying temperature conditions and the like can be more readily attained than at higher frequencies.

The high frequency carrier wave, modulated in frequency in substantial amount by alternating signal potentials from the microphone 92, after it appears upon the anode 107 of discharge device 106 is impressed on the control electrode 108 of a relatively high power electron discharge amplifying device 109, from the anode 110 of which the frequency modulated high frequency carrier wave is impressed upon a radiating element 111 which may, for example, at high frequencies take the form of a dipole or of a relatively short rod antenna working against a counterpoise.

The oscillator including the device 94 is of conventional form in which the two electrodes of the piezoelectric frequency determining element are respectively connected to the control electrode 112 and the grounded cathode 113. A grid leak resistance 114 is also connected between the control electrode 112 and the cathode 113 and the anode 115 of the device 94 is connected through a tuned circuit including an inductance 116 and a condenser 117 in parallel with each other to the positive terminal of a source 118 of suitable operating potential for the device 94, the negative terminal of the source 118 being grounded. A by-pass condenser 119 is connected between ground and that end of the tuned circuit 116, 117 opposite to the anode 115. The tuned circuit 116, 117 is resonant at the fundamental frequency or some "mechanical harmonic frequency" of the piezoelectric device 95 and the oscillator maintains oscillations of highly constant frequency by reason of voltage feed-back through inter-electrode capacity between anode 115 and control electrode 112 and by reason of the well known large frequency stability of piezoelectric frequency determining elements such as the device 95.

The inductance coil 116 is magnetically coupled with an inductance 120 whose center tap is connected to ground through a by-passing condenser 121 with the result that balanced highly stable carrier voltages are induced in coil 120. The phase splitting network 96 includes a bridge circuit in which an inductance 122 and a resistance 123 are connected serially between the terminals of coil 120 and in which a condenser 124 and a resistance 125 are also connected serially between the terminals of coil 120. The inductance 122 and the condenser 124 are connected to the same terminal of the coil 120 and the resistances 123 and 125 are connected to the opposite terminal. A resistance 126 is connected between a control element 97 of the device 93 and that terminal of the coil 120 to which inductance 122 and condenser 124 are connected. The control element 98 of the device 93 is connected through a condenser 127 to a point in the bridge circuit between inductance 122 and resistance 123, and a grid leak resistance 128 is connected in shunt with condenser 127 in order to maintain the control element 98 at substantially the same potential as the control elements 97 and 99. The resistance 128 should be large compared with the reactance of the condenser 127 at carrier wave frequency. An inductance 129 is connected between control element 99 of device 93 and a point in the bridge circuit between condenser 124 and resistance 125.

This phase splitting network 96 is arranged to

produce carrier wave voltages on the control elements 97, 98 and 99, the phases of which voltages are equally displaced one from the other by 120° so that the voltages appearing on these three control elements form what is commonly termed a three phase voltage. The network also has the characteristic that it has the same output impedance measured at any one of the three control elements 97, 98 and 99 and impresses on those three control elements voltages of equal intensity. It should be understood that it is within the scope of my invention to use more than three electrodes, and to impress on such electrodes whether they be three or more any kind of multi-phase voltage whose individual phases are correlated with the physical positions of the control elements with respect to one another and with respect to the cathode 104 so as to form a uniform velocity electron density wave. For example, one or two of the control elements 97, 98 and 99 might be physically displaced from the positions illustrated in Figures 1 and 2 provided the relative phases of the voltages impressed on them are correspondingly changed.

In order to have such characteristics the phase splitting network 96 must have certain impedance relations between its elements. Resistances 123 and 125 must be equal and they must be one-third greater than resistance 126. The reactance at the carrier wave frequency in question of inductance 122 must be equal to the reactance at that frequency of condenser 124 and must also be equal to resistance 123 multiplied by the square-root of 3. The reactance at the carrier wave frequency in question of inductance 129 must be equal to the reactance at that frequency of the condenser 127 and must also be equal to the resistance 123 multiplied by one-fourth of the square-root of three.

By way of a practical example of such a network the seven elements may be constructed to have the following impedances. Inductance 122 may be of 588 ohms, resistance 123 of 340 ohms, condenser 124 of 588 ohms, resistance 125 of 340 ohms, resistance 126 of 255 ohms, condenser 127 of 147 ohms, and inductance 129 of 147 ohms.

Operating current and bias potentials are supplied to the device 93 as follows. The first anode 100 is connected to the positive terminal of source 118 and the anode 101 is connected to that same positive terminal through a tuned output circuit including an inductance 130 and a condenser 131 in parallel relation. A suppressor electrode 132 within the device 93 is connected with the cathode 104. Four resistances 133, 134, 135 and 136 are connected between ground and the positive terminal of source 118 and a first focusing anode 137 in device 93 is connected to a point between resistances 133 and 134 and is by-passed to ground through a condenser 138. A second focusing anode 139 in the device 93 is connected to a point of higher positive potential between resistances 135 and 136 and is by-passed to ground through a condenser 140. The center tap of the coil 120 is connected to a point between resistances 134 and 135 whereby the control elements 97, 98 and 99 are maintained at a potential positive with respect to cathode 104 and intermediate the potentials of the focusing electrodes 137 and 139.

Modulating signals from the microphone 92, which as illustrated may be a carbon microphone, are impressed serially across a source 141 of biasing potential for the carbon microphone, the

primary winding 142 of a voltage step-up transformer and a switch 143. The secondary 144 of that transformer is connected between the control electrode 145 of the device 102 and ground, the cathode 146 of the device 102 being connected to ground through a biasing resistance 147. This biasing resistance 147 is only sufficiently large to provide proper bias potential between the control electrode 145 and cathode 146 and a small amount of degeneration to improve the linearity of amplification of the device 102 and it is not large enough to introduce enough degeneration to produce any substantial change in the constant voltage characteristic of the output circuit of device 102. The anode 148 of device 102 is connected through a resistance 149 to the positive terminal of source 118 and the anode 148 is also connected through a coupling condenser 150 to one terminal of the coil 103 of which the other terminal is grounded.

As mentioned briefly above signals from microphone 92 are amplified through the device 102, connected as described to act as a power amplifier, and are caused by the coil 103 to produce magnetic flux in device 93 whose intensity is substantially inversely proportional to signal frequency. This relation between flux intensity and instantaneous signal voltage cannot be maintained at all signal frequencies from zero to some high frequency such as 10,000 cycles, but for point to point communication work in which most of the intelligence is speech, such a wide frequency range is not necessary or desirable. Actually it is usually necessary to transmit signal frequencies within a range for example between 200 and 3000 cycles and within that range it is not difficult to maintain substantially the desired relation between the magnetic flux intensity and instantaneous signal voltage. At the lower signal frequencies there is a tendency for the amplifier including device 102 to act less like a power amplifier so that the current in coil 103 at such lower frequencies may not be quite as great as it should be and consequently the phase shift in carrier wave currents in the anode 101 may be somewhat less than desired. This means that the frequency shift of the carrier wave in response to such lower signal frequencies is somewhat less than linearly proportional to instantaneous signal voltage, which in turn means that some higher signal frequencies are transmitted in greater intensity than signal voltages of lower frequency. This may not be undesirable and may in fact lead to somewhat better speech understanding in the system.

The non-linearity between instantaneous magnetic flux intensity applied by coil 103 to the device 93 and the consequent phase shift of carrier wave current in the anode 101, as discussed previously, may be corrected in several ways. For example, ferromagnetic material may be utilized as described in connection with Figure 1 to produce a desired amount of flux saturation in order to correct such non-linearity. Alternatively the amplifier including the device 102 may be arranged so that its gain is reduced in proper amount in response to increasing instantaneous signal voltage in order to produce a similar flattening of the tops of half cycles of the signal voltage. It is apparent that the "flattening" process is actually compression of the dynamic range of the modulating signal.

Frequency modulated carrier wave voltages appearing across the tuned circuit 130, 131 are impressed between the control electrode 105 and

the grounded cathode 151 of device 106 through a coupling condenser 152. A suitable grid leak resistance 153 is connected between the control electrode 105 and cathode 151 and is arranged with such resistance in relation to the intensity of the carrier wave as to produce a bias potential on control electrode 105 sufficiently large to cause device 106 to operate in suitable manner for frequency multiplication. The anode 107 of device 106 is connected through a tuned circuit including an inductance 154 and a condenser 155, in parallel relation, and then through a decoupling resistance 156 to the positive terminal of source 118, a point between resistance 156 and the tuned circuit 154, 155 being by-passed to ground for carrier frequency currents through a by-passing condenser 157. The tuned circuit 154, 155 is resonant at a suitable multiple of the frequency of the carrier wave impressed on control electrode 105 so that the device 106 operates efficiently as a frequency multiplier.

Such higher frequency carrier wave voltages appearing across the tuned circuit 154, 155 are impressed through a coupling condenser 158 between the control electrode 108 and the grounded cathode 159 of the power amplifier 109. A suitable grid leak resistance 160 is connected between the control electrode 108 and cathode 159 and is sufficiently large to provide bias potential therebetween so that device 109 operates efficiently as a power amplifier. For example, the bias potential between control electrode 108 and cathode 159 may be sufficient to cause what is known as "class C" operation in which discharge current in the device 109 is prevented at all times except during short intervals in alternate half cycles of the carrier wave. The screen electrode 161 of the device 109 is by-passed for currents of carrier frequency to ground through a by-passing condenser 162 and is connected to the positive terminal of a source 163 of potential of which the negative terminal is grounded. The anode 110 of the device 109 is connected through a tuned circuit including an inductance 164 and a condenser 165 in parallel relation to the screen electrode 161. The inductance coil 164 is electromagnetically coupled with an inductance 166 to the ends of which are connected the radiating element or elements 111, suitably arranged to radiate properly at the frequency of a carrier wave from device 109 to which the tuned circuit 164, 165 is resonant.

The operation of the phase splitting network 96 is as follows: control element 97 is excited in phase through resistance 126 with carrier wave voltage at the upper terminal of coil 120. A lagging current flows between the terminals of coil 120 through inductance 122 and resistance 123 and produces a voltage through condenser 127 on control element 98 which lags by 120° the carrier voltage on control element 97. It is the function of condenser 127 to resonate at carrier frequency with the inductance in the remainder of the circuit between control element 98 and ground so that the impedance of that entire circuit appears resistive, as does the impedance of the circuit between control element 97 and ground. Similarly, a leading current flows between the terminals of coil 120 through condenser 124 and resistance 125 and a leading voltage is impressed through inductance 129 on control element 99, that voltage leading the voltage on control element 97 by 120°. The inductance 129 resonates at carrier frequency with capacity in the remainder of the circuit between control element 99 and ground so that

that whole circuit appears resistive at the control element 99 at carrier frequency.

This phase splitting network 96 is arranged in this fashion so that, when loads are applied to its output terminals, as by the flow of charging current in the control elements 97, 98 and 99, the symmetrical three phase distribution of its three phase voltage output is not disturbed. Without the special measures taken in the network 96 to prevent such loading effects, the equally phased output voltage of the network would be seriously disturbed, even if loads taken from the network were symmetrical, and these resulting asymmetries in the multiphase voltage output of the network 96 might become so large as to reverse phase rotation which would obviously cause the system to become inoperative. By providing the network 96 with its special characteristics to insure the impression of voltages equally displaced in phase on control elements 97, 98 and 99, any asymmetry in those voltages which might be introduced by loading caused by current flow in the control elements is entirely avoided.

While, in the circuit arrangement of Figure 16, the first focusing anode 137 is provided with a suitable positive bias potential with respect to cathode 104, it can be made to operate properly if it is maintained at cathode potential. For that purpose it may be connected directly with cathode 104 outside of the envelope of device 93, or preferably inside of that envelope.

The discharge device 93, as described for example in Figure 1, does not produce a sinusoidal current flow in the anodes 100 and 101. While special forms of the discharge device may be constructed to produce sinusoidal current variations in those anodes, good output for the discharge device can be obtained without that expedient. In fact, the device 93, where its output current is not sinusoidal, can be used as a frequency multiplier by the simple expedient of making the tuned circuit 130, 131 resonant at a frequency which is a multiple of the frequency of the carrier wave impressed on the network 96. For example, the usual type of wave form of the output current of device 93 has a substantial third harmonic content.

It should be emphasized that the coil 103 in connection with this special discharge device 93 simultaneously performs at least two functions which have heretofore necessarily been performed by entirely separate devices. The coil 103 with the discharge device 93 modulates the phase of a carrier wave in accordance with signal potentials from discharge device 102 and simultaneously, by virtue of the fact that it is an inductance, produces proportionately less phase modulating magnetic flux in response to signal voltages of high frequency than of low frequency, so that the type of phase modulation of the carrier wave which is produced is in fact frequency modulation, the frequency shifts of the carrier wave being substantially linearly proportional to instantaneous signal potential at any signal frequency.

It should also be kept clearly in mind that, as explained before, to operate in this fashion the coil 103 must be supplied with signal voltage which is at all times linearly proportional to instantaneous signal voltage produced by microphone 92. In order to assure this, the power amplifier including discharge device 102 must have an output circuit which, measured at the coil 103, has as low an impedance as possible. A satisfactorily low impedance amplifier can be provided by mak-

ing resistance 149 relatively small and by utilizing as a discharge device 102 a device of the type termed a "power amplifier" in which relatively large space current may flow and in which the control electrode 145 is usually of relatively large mesh spaced at relatively large distance from the cathode 146. Provided resistance 149 be made sufficiently small, the output impedance of the amplifier can be made as low as desired so long as the device 102 is capable of generating the necessary signal potential across the small resistance 149.

Good operation of the system results if the output impedance of the amplifier including device 102 and resistance 149 is substantially resistive and equal to the impedance of coil 103 at a frequency near the lowest frequency within the band of frequencies of the signals to be transmitted. If the internal anode resistance of the device 102 is large with respect to the magnitude of resistance 149, the resistance 149 and coil 103 may be made to have substantially equal impedances at the lowest signal frequency to be transmitted and satisfactory results may be obtained.

If the output resistance of the amplifier including device 102 and resistance 149 is substantially equal to the impedance of coil 103 at a frequency substantially higher than the lowest signal frequency to be transmitted, there is less frequency shift of the carrier wave in response to the same instantaneous signal potential at frequencies below that frequency of equality than at higher frequencies. Transmission of frequency modulated carrier waves is commonly carried out with what is termed "pre-emphasis," in which the frequency shift of the carrier wave is intentionally made to be greater in response to instantaneous signal potential at high signal frequencies than at low, for the purpose of reducing the effect of undesired noise and static voltages in the system. In view of the similarity of such pre-emphasis with the effect obtained in the present system when the amplifier output resistance is equal to the reactance of coil 103 at a frequency higher than the lowest signal frequency to be transmitted, that effect is herein termed pre-emphasis. The general statement may be made that, where such pre-emphasis is desired, the impedance of the signal amplifier including device 102 and resistance 149 should be substantially resistive and equal to the impedance of coil 103 at a frequency within the band of frequencies of the signal from the signal amplifier so that, above that frequency of equality, current in the coil 103 is substantially inversely proportional to signal frequency with a constant signal intensity and lags the signal voltage, while at frequencies below that frequency of equality current in the coil 103 is substantially independent of signal frequency and is substantially in phase with signal voltage from the signal amplifier. Under those conditions the signal amplifier and the coil 103 should be so arranged that the frequency of equality is at least three times as great as that frequency at which with substantially all the frequency modulation of the carrier wave for which the transmitter is designed, the non-linearity between flux produced by current in the coil 103 and the phase shift which results in the carrier wave in the output circuit of device 93 becomes greater than the non-linearity for which the transmitter is to be designed.

In Figure 17 a transmitter circuit is illustrated which is especially useful for the transmission of

carrier waves frequency modulated in accordance with high fidelity, audio signals such as are transmitted for broadcast purposes. Although, in general, this type of transmitter includes elements analagous to those described in connection with Figure 16, each of these elements differs in certain respects in order to obtain the results desired of a high fidelity broadcast transmitter of the frequency modulation type.

The oscillation generator includes a frequency determining device 167 connected between the anode 168 and the control electrode 169 of a pentode type electron discharge device 170. A resistance 171 is connected between the control electrode 169 and the grounded cathode 172 for the passage of grid current therebetween to provide a suitable operating bias potential. The anode 168 is connected through a tuned circuit including an inductance 173 and a condenser 174, in parallel relation, and then through a resistance 175 to the positive terminal of a source 176 of operating potential, the negative terminal of which is grounded. The screen electrode 177 is also connected through resistance 178 to the positive terminal of source 176 and is connected to ground through a by-passing condenser 178.

This oscillation generator operates by reason of voltage feedback from anode 168 to control electrode 169 through the piezo electric device 167, the tuned circuit 173, 174 being resonant at a resonant frequency of the device 167. It is convenient to make the oscillator including device 170 operate at a relatively low frequency, for example, in the order of one-half megacycle or less, because at such frequencies quartz crystals can be constructed and arranged in such oscillators to provide extremely high frequency stability under changing conditions encountered in the use of the apparatus.

A carrier wave generated by the oscillator is impressed on the device 179, which is one of the special forms of electron discharge device heretofore described and which has its anodes 180 and 181 especially arranged for operation in push-pull relation. To this end, the inductance 173 is magnetically coupled with an inductance 182 whose center tap is by-passed to ground through a by-passing condenser 183. Carrier wave voltages induced in coil 182 are in balanced relation with respect to ground and are transferred through a simple form of phase splitting network to three control elements 184, 185 and 186. Control element 184 is connected directly with the upper terminal of coil 182. A resistance 187 and a condenser 188 are connected serially between the terminals of coil 182 and a second condenser 189, and second resistance 190 are also connected serially between the terminals of coil 182, resistance 187 and condenser 189 being connected to the same terminal. Control element 185 is connected to a point between condenser 189 and resistance 190, and control element 186 is connected to a point between resistance 187 and condenser 188.

Leading current flows between the terminals of coil 182 through resistance 187 and condenser 188, and by adjusting relatively to each other the reactance of condenser 188 and the resistance 187 this leading current can be caused to produce a voltage drop across the resistance 187 such that the voltage on control electrode 186 lags the voltage on control electrode 184 by one-third of a cycle or 120°. That is, at the frequency of the carrier wave in question the reactance 187 should be greater than the reactance

of condenser 188 by a multiplying factor equal to the square root of 3. Current flowing between the terminals of coil 182 through condenser 188 and resistance 190 is also leading in larger amount than current through resistance 187, and the resistance 190 and the reactance of condenser 189 should be adjusted so that the voltage on control electrode 185 leads the voltage on control electrode 184 by one-third cycle or 120° . This will be the case if the reactance of condenser 189 at the carrier frequency in question is greater than resistance 190 by a multiplying factor equal to the square root of 3.

The control electrodes 184, 185 and 186 are maintained at a suitable positive potential with respect to the grounded cathode 191 of device 179 by means of a connection between the center tap of coil 182 to a point between resistances 192 and 193 of a potential divider including resistances 194, 192, 193, 195 and 196 connected serially in named order from ground to the positive terminal of source 176.

Because these control elements 184, 185 and 186 are maintained at a positive potential with respect to cathode 191, they inevitably have space current from cathode 191 flowing through them, and consequently impose some load on the phase splitting network 187, 188, 189 and 190. Such load imposed on that network tends to cause the otherwise accurately evenly phased three-phase voltages produced by the network to be changed in phase with respect to one another with the consequence that the moving electrostatic field may be somewhat distorted. This distortion can be compensated in several ways although in practical arrangements it is usually necessary only to make the impedances of the elements in the phase splitting network sufficiently low that the undesired phase change caused by loading is within tolerable limits, but not so low as to reduce undesirably the driving voltage available from the oscillator including device 170. If it be desired the physical positioning of the control elements 184, 185 and 186 may be made slightly asymmetrical in an amount just sufficient to compensate for the asymmetry of the three-phase voltage produced by the network so that a uniformly moving electrostatic field is produced. Alternatively, the impedances of the elements of the network may be adjusted under load to produce a substantially symmetrical three-phase voltage, and if it be necessary to obtain the desired symmetry the phase shifting network such as that illustrated in Figure 16 may be utilized.

The first focusing anode 197 of the device 179 is connected to a point between resistances 192 and 194 of the potential divider and is by-passed to ground for currents of carrier frequency through a by-passing condenser 198. As explained previously, the anode 197 may be connected to cathode 191 if it is properly constructed for good focusing at the cathode potential. The second focusing anode 199 is connected to a point between resistances 193 and 195 and is by-passed to ground for currents of carrier frequency through a by-passing condenser 200. The output electrodes 180 and 181 of the device 179 are connected to the opposite terminals of a tuned circuit including an inductance 201 and a condenser 202 in parallel relation, the center tap of the inductance 201 being connected to a point between resistances 195 and 196 and being by-passed to ground for currents of carrier frequency through a by-passing condenser 203.

As explained previously in connected with the discharge device 93 of Figure 16, the discharge device 179 operates to move a uniform velocity electron density wave across the anode path, thereby producing a carrier wave potential across the tuned circuit 201, 202, which is resonant at the frequency of the carrier wave generated by the oscillator 170 or at a multiple thereof.

Modulating signals produced by a microphone 204 are amplified through a suitable program amplifier 205, of which the output circuit has three terminals including a grounded center terminal and two other terminals between which a voltage balanced with respect to ground exists. These two balanced voltage terminals of the amplifier 205 are connected respectively through filter resistances 206 and 207 to the control electrodes 208 and 209 of a pair of power amplifier discharge devices 210 and 211 connected in balanced relation. A filter condenser 212 and resistance 213 are connected serially between the control electrodes 208 and 209 and, together with the filter resistances 206 and 207, alter the frequency response of the signal amplifying system in a desired manner by reducing in an amount determined by the relative impedances of the filter elements the high frequency components of the signal. The cathodes 214 and 215 of the devices 210 and 211 are connected together through a balancing resistance 216, whose center tap is connected through a biasing resistance 217 to ground. The screen electrodes 218 of the devices 210 and 211 are connected to the positive terminal of the source 176 and the two anodes 219 and 220 are connected together through a magnetic flux producing coil 221 which is arranged with respect to the device 179 to produce magnetic flux varying in accordance with some function of signal potential in the space between cathode 191 and the output electrodes 180 and 181, in a fashion similar to the operation of coil 103 with device 93 of Figure 16. A resistance 222, an inductance 223, and a resistance 224 are connected serially in the named order between the anodes 219 and 220, and the center tap of inductance 223 is connected with the positive terminal of source 176.

Although the devices 210 and 211 are of the type termed power amplifiers, by reason of the fact that they have screen electrodes 218 the internal anode resistance is relatively high and consequently the resistances 222 and 224 are made small for reasons set forth in connection with resistance 149 of Figure 16. Similar considerations apply to the relation between the magnitudes of resistances 222 and 224 and the inductance of coil 221 as were set forth with respect to resistance 149 and coil 103.

The inclusion of coil 223 in series with resistances 222 and 224 provides pre-emphasis in that the inductance of coil 223 is related to resistances 222 and 224 so that the impedance of those elements taken together increases at a predetermined rate as signal frequency increases above a frequency at which the reactance of coil 223 is equal to the combined resistance of resistances 222 and 224. The frequency at which this equality exists is generally in the upper portion of the band of frequencies of the signal to be transmitted, and above that frequency an amount of pre-emphasis exists which is determined by the relation between the inductance of coil 223 and resistances 222 and 224. That is, the larger the inductance of coil 223 the more rapidly signal voltage between anodes 219 and 220 increases with

a constant input signal voltage of increasing frequency.

The system so described produces across the tuned circuit 201, 202 a carrier wave whose frequency is modulated in accordance with the instantaneous intensity of signal potential regardless of signal frequency except for the pre-emphasis described.

This frequency modulated carrier wave voltage across coil 201 appears across an inductance coil 225 with which it is magnetically coupled, and a condenser 226 is connected in shunt with coil 225 to form a tuned circuit resonant at the same frequency as circuit 201, 202. Voltage across the tuned circuit 225, 226 is amplified and its frequency is multiplied a suitable amount in a frequency multiplier 227. The frequency multiplication may be in the order of one hundred or more times in order to obtain the desired amount of carrier wave frequency shift in response to signal potentials, which frequency shift for broadcast purposes is desirably several times greater than the highest frequency in the signal to be transmitted.

The output terminals of the frequency multiplier 227 are connected respectively with the control electrode 228 and the negative terminal of a source 229 of suitable biasing potential for the control electrode 228 of a high power electron discharge amplifier 230, the cathode 231 of which is grounded and is connected to the positive terminal of source 229. The anode 232 of device 230 is connected to one terminal of a tuned circuit including an inductance 233 and a condenser 234 in parallel relation, and the other terminal of the tuned circuit is connected to the positive terminal of source 235 of high potential suitable for the operation of the high power amplifier 230. The screen electrode 236 of the device 230 is connected to a tapped potential point of the source 235 to maintain the screen electrode 236 at a suitable positive potential with respect to cathode 231, the negative terminal of source 235 being grounded. A by-passing condenser 237 is connected between screen electrode 236 and cathode 231.

The tuned circuit 233, 234 is resonant at the frequency of the carrier wave impressed on control electrode 228 by frequency multiplier 227 and the inductance 233 is magnetically coupled with an inductance 238 which is connected with the radiating system 239 arranged to radiate the high power frequency modulated carrier wave from the device 230.

Although the transmitter of Figure 17 is described as having the frequency multiplier 227 arranged to multiply the frequency of the carrier wave, whose frequency is modulated by device 179, by one hundred or more times, this is not to be understood as meaning that this transmitter has any such large number of discharge devices as are necessary in present day frequency modulation transmitters of the phase modulation type. In such transmitters where the maximum phase shift attainable is less than one-half cycle and is not usually more than one-quarter cycle, a much greater amount of frequency multiplication is necessary since in the present system a phase shift of as much as four cycles or more may be readily attained with high linearity. The advantage given by such greater available initial phase shift does not lie only in a substantial reduction in number of discharge devices necessary in the frequency multiplier 227, since it is actually of greater importance that, with such a much

greater phase shift a large reduction in noise potentials and other undesired voltages is obtained, while retaining the advantage of quartz crystal control of the carrier wave center frequency and at the same time attaining to a high degree proportionality between instantaneous signal potential and frequency shift of the carrier wave.

With moderately careful construction of the device 179 and with the provision of adequately filtered power supplies the system produces a frequency modulated carrier wave which is substantially unmodulated in amplitude.

In the transmitter illustrated in Figure 16 several alternative ways of maintaining this linearity were described. In the transmitter of Figure 17 magnetic saturation is not utilized as in Figure 16 and it is instead preferred to arrange the balanced amplifiers 210 and 211 to cause signal voltage appearing across coil 221 to increase at a rate less than proportional to the increase of instantaneous signal potential on control electrodes 208 and 209. This is readily accomplished in such a balanced amplifier by impressing suitable bias potential on the control electrodes 208 and 209 so that, upon an instantaneous increase in signal potential upon either of the control electrodes 208 or 209 the increase in voltage across coil 221 is somewhat less than proportional by reason of the fact that such power amplifier devices have an initially curved grid voltage plate current characteristic. By adjustment of the tap on resistance 216 this characteristic of the devices 210 and 211 can be nicely adjusted to be symmetrical with reference to zero signal voltage and with reference to zero current in coil 221.

While particular embodiments of the present invention have been shown and described, it will be obvious to those skilled in the art that changes and modifications may be made without departing from this invention in its broader aspects, and, therefore, the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of this invention.

I claim:

1. In a timing modulation system, a carrier wave source, a signal source, means for producing a magnetic flux in response to a signal from said signal source, and means for shifting the phase of a carrier wave from said carrier wave source in response to said flux, said phase shifting means having the property of shifting the phase of said carrier wave more than proportionately to the instantaneous intensity of said flux, said flux producing means being arranged to produce flux whose intensity increases less than proportionately to increasing intensity of said signal whereby the linearity is increased between the phase shift of said carrier wave and the instantaneous intensity of said signal.

2. In a timing modulation system, a carrier wave source, a signal source, means for producing a magnetic flux in response to a signal from said signal source, and means for shifting the phase of a carrier wave from said carrier wave source in response to said flux, said phase shifting means having the property of shifting the phase of said carrier wave more than proportionately to the instantaneous intensity of said flux, said flux producing means including ferromagnetic material subject to flux saturation whereby the intensity of said flux in the presence of such saturation increases less than proportionately to increasing intensity of said signal and

the phase shift of said carrier wave is more nearly linear with respect to the instantaneous intensity of said signal.

3. In a timing modulation system, a carrier wave source, a signal source, means for producing a magnetic flux in response to a signal from said signal source, and means for shifting the phase of a carrier wave from said carrier wave source in response to said flux, said phase shifting means having the property of shifting the phase of said carrier wave more than proportionately to the instantaneous intensity of said flux, said flux producing means including a pair of multielectrode electron discharge devices arranged in push pull amplifying relation and supplied with such electrode potentials as to flatten the tops of the waves of said signals before said signals produce said flux, such flattening being sufficient to compensate substantially for said property.

4. In a timing modulation system, an electrode, a carrier wave source, a signal source, means responsive to a carrier wave from said carrier wave source for causing an electron density wave to progress recurrently at substantially uniform velocity past said electrode, means responsive to a signal from said signal source for producing a varying magnetic flux in the region through which said electron density wave passes and with such orientation with respect to said wave as to alter said wave by changing the velocity of its passage past said electrode, and means for deriving a phase modulated carrier wave from said electrode in response to the passage of said altered wave past said electrode, said flux producing means including an inductive coil upon which said signal is impressed from said signal source, and said signal source having low impedance whereby signal current in said coil decreases with increasing frequency and the phase modulation of said carrier wave is effectively frequency modulation.

5. In a frequency modulation system, a carrier wave source, a signal source having low impedance, an electrode, means responsive to a carrier wave from said carrier wave source for causing an electron density wave to progress recurrently at substantially uniform velocity across said electrode, an inductance coil, means for impressing a signal from said signal source on said coil whereby signal current in said coil is reduced as signal frequency increases, means for directing magnetic flux produced by signal current in said coil into the region traversed by said electron density wave with such orientation with respect to said wave as to alter said wave by changing the velocity of passage of the wave across the electrode, and means for deriving a wave voltage from said electrode in response to the passage of the altered wave across said electrode whereby said wave voltage derived from said electrode is modulated in frequency, the instantaneous frequency of said wave voltage being substantially proportional to instantaneous signal amplitude regardless of signal frequency.

6. In a frequency modulation system, a carrier wave source, a signal source having low impedance, an electrode, means responsive to a carrier wave from said carrier wave source to cause an electron density wave to pass recurrently at substantially uniform velocity past said electrode, an inductance coil, means for impressing a signal from said signal source on said coil whereby signal current in said coil is reduced as signal frequency increases, means for directing magnetic flux produced by signal current in said coil into the region traversed by said electron density wave

with such orientation with respect to said wave as to alter said wave by changing the velocity of passage of said wave across said electrode, and means for deriving a wave voltage from said electrode in response to the passage of the altered wave across said electrode whereby said wave voltage derived from said electrode is modulated in frequency, the low impedance of said signal source being substantially resistive and equal to the impedance of said coil at a frequency within the band of frequencies of the signal from said signal source whereby, above such frequency, current in said coil is substantially inversely proportional to signal frequency with a constant signal intensity and lags signal voltage but below such frequency current in said coil is substantially independent of signal frequency and is substantially in phase with signal voltage, said signal source and coil being so constructed that such frequency is at least three times as great as that frequency at which, with substantially all the frequency modulation of said wave voltage for which said system is designed, the nonlinearity between said flux and the phase shift in said wave voltage on said electrode produced by said flux becomes greater than that for which said system is designed.

7. In a frequency modulation system, a carrier wave source, a signal source having low impedance, an electrode, means responsive to a carrier wave from said carrier wave source to cause an electron density wave to pass recurrently at substantially uniform velocity across said electrode, an inductance coil, means for impressing a signal from said signal source on said coil whereby signal current in said coil is reduced as signal frequency increases, means for directing magnetic flux produced by signal current in said coil into the region traversed by said electron density wave with such orientation with respect to said wave as to alter said wave by changing the velocity of passage of said wave across said electrode, and means for deriving a wave voltage from said electrode in response to the passage of the altered wave across said electrode whereby said wave voltage derived from said electrode is modulated in frequency, said signal source including a high impedance signal voltage source and an element of smaller impedance in shunt to said voltage source, said element being constructed to have impedance increasing at a predetermined rate as signal frequency increases above a predetermined frequency in the band of frequencies of said signal, whereby a predetermined preemphasis in said frequency modulated wave voltage is produced.

8. In a timing modulation system, a carrier wave source, a signal source, means for shifting the phase of a carrier wave from said carrier wave source in response to the instantaneous intensity of a signal from said signal source, said means having the property of shifting the phase of said carrier wave in non-linear relation to the instantaneous intensity of said signal, and means for distorting said signal between said signal source and said phase shifting means in such sense as to compensate to a substantial extent for said non-linear relation, said distorting means comprising an electron discharge device arranged to transfer signals between said signal source and said phase shifting means and adjusted to have a non-linear relation between signal input to said device and current output thereof, and a load for said device having substantially smaller imped-

ance than the internal impedance of said device, signal voltage being developed across said load and impressed on said phase shifting means.

9. In a timing modulation system, a carrier wave source, a signal source, means for shifting the phase of a carrier wave from said carrier wave source in response to the instantaneous intensity of a signal from said signal source, said means having the property of shifting the phase of said carrier wave more than proportionately to the instantaneous intensity of said signal, and means for distorting said signal between said signal source and said phase shifting means in such sense as to compensate to a substantial extent for said property, said distorting means comprising an electron discharge device arranged to transfer signals between said signal source and said phase shifting means, and a load for said device having substantially smaller impedance than the internal impedance of said device, said device and load being adjusted to produce decreasing amplification of said signal in response to increasing instantaneous signal intensity, distorted signal voltage being developed across said load and impressed on said phase shifting means.

10. In a timing modulation system, a single phase carrier wave source, a signal source, means for deriving a polyphase carrier wave from said single phase carrier wave source, means responsive to said polyphase carrier wave and to a signal from said signal source for producing a carrier wave whose phase is shifted in accordance with the instantaneous intensity of said signal, said wave deriving means comprising a network energized by said single phase carrier wave source and having at least three output terminals with internal impedance therebetween substantially equal to each other, said network being constructed to produce voltages on said terminals whose vector sum is equal to zero with symmetrical loads connected to said terminals.

11. In a timing modulation system, a single phase carrier wave source, a signal source, means for deriving a polyphase carrier wave from said single phase carrier wave source, means responsive to said polyphase carrier wave and to a signal from said signal source for producing a carrier wave whose phase is shifted in accordance with the instantaneous intensity of said signal, said wave deriving means comprising a network energized by said single phase carrier wave source and having at least three output terminals with internal impedance therebetween substantially equal to each other, said network including means to produce a carrier wave voltage balanced with respect to ground from said carrier wave source, a first inductance and a first resistance serially connected across said balanced voltage producing means, a first condenser and a second resistance serially connected across said balanced means, three output terminals, a third resistance connected between one of said output terminals and one terminal of said balanced means, a second condenser connected between a second output terminal and a point between said first inductance and first resistance, and a second inductance connected between a third output terminal and a point between said first condenser and second resistance.

12. In a timing modulation system, a single phase carrier wave source, a signal source, means for deriving a polyphase carrier wave from said single phase carrier wave source, means responsive to said polyphase carrier wave and to a signal from said signal source for producing a carrier

wave whose phase is shifted in accordance with the instantaneous intensity of said signal, said wave deriving means comprising a network energized by said single phase carrier wave source and having at least three output terminals with internal impedance therebetween substantially equal to each other, said network including means to produce a carrier wave voltage balanced with respect to ground from said carrier wave source, a first inductance and a first resistance serially connected across said balanced voltage producing means, a first condenser and a second resistance serially connected across said balanced means, a third resistance connected between one of said output terminals and one terminal of said balanced means, a second condenser connected between a second output terminal and a point between said first inductance and first resistance, and a second inductance connected between a third output terminal and a point between said first condenser and second resistance, said first inductance and first condenser being connected to the same terminal of said balanced means, said third resistance being connected to such same terminal, said first and second resistances being equal and one third greater than said third resistance, the reactances of said first inductance and first condenser at the frequency of a carrier wave from said carrier wave source being equal to each other and $\sqrt{3}$ times as great as said first resistance, and the reactances of said second inductance and second condenser at such carrier wave frequency being equal and $\frac{1}{4}\sqrt{3}$ times as great as said first resistance, whereby the impedance of said network measured between any two of said output terminals is resistive at such carrier frequency and is equal to three fourths of said first resistance.

13. In combination in a frequency modulation system, a carrier wave source, a signal source, an electron discharge device including a source of electrons and an electrode, means responsive to a carrier wave from said carrier wave source to cause an electron density wave to pass recurrently at substantially uniform velocity across said electrode, means responsive to a signal from said signal source for producing a magnetic flux in the region through which said electron density wave passes, said flux having such orientation with respect to said wave as to alter said wave by changing the velocity of passage of said wave across said electrode, said magnetic flux producing means including an inductance coil connected with said signal source and a ferromagnetic flux director associated with said coil, the amount of change of velocity of passage of said electron density wave across said electrode tending to be more than proportional to the instantaneous amplitude of such signal from said signal source impressed on said coil, said ferromagnetic flux director being saturable within the range of amplitude of said signal whereby the amount of such change in velocity is more nearly proportional to the instantaneous amplitude of signals from said signal source, the resistance of said coil being small relative to the inductive reactance thereof whereby the current produced in said coil is substantially inversely proportional to the frequency of the signal impressed on said coil, and means for deriving a wave voltage from said electrode in response to the passage of said altered wave across said electrode, whereby, by reason of the inverse relationship between the flux produced by said coil and the frequency of the signal impressed on said coil, the wave volt-

age derived from said electrode is modulated in frequency, the instantaneous frequency of said wave voltage being substantially proportional to instantaneous signal amplitude regardless of signal frequency.

14. In combination in a timing modulation system, a source of polyphase carrier waves, a source of a signal of varying amplitude, an electron discharge device including a cylindrical cathode, means for focussing electron flow from said cathode into radial substantially coplanar paths surrounding said cathode, whereby an electron disc is formed, means responsive to said polyphase carrier waves for producing a peripheral electron density wave in said disc by deflecting electrons in said disc in directions normal to the surface of said disc and for causing said wave to progress around said cathode at a common angular velocity, said means comprising a plurality of control elements adjacent said disc around said cathode excited in progressive phase relation by said polyphase carrier waves, and an electrode external to said wave producing and rotating means lying in the path of the electrons in said wave and traversed by said wave, means responsive to said signal of varying amplitude for producing a magnetic flux of correspondingly varying density in the region through which said disc of electrons passes, said flux being so oriented as to alter said wave by changing the velocity of the passage of said electron density wave across said electrode, and means for deriving a timing modulated wave voltage from said electrode in response to the passage of said altered electron density wave across said electrode.

15. In combination in a timing modulation system, a source of polyphase carrier wave voltages, a source of a signal of varying amplitude, an electron discharge device including an electron source, means for focussing electron flow from said source into radial, substantially coplanar paths surrounding said source whereby an electron disc is formed, means responsive to said polyphase carrier wave voltages for producing a peripheral electron density wave in said disc by deflecting electrons in said disc along respective radii of said disc in directions normal to said disc, and for causing said electron density wave to progress about said electron source at a substantially constant angular velocity, an electrode disposed in the path of electrons in said disc and traversed by said electron density wave, means for altering said electron density wave by changing the velocity of its passage across said electrode in response to instantaneous amplitude variations in said signal, and means for deriving a timing modulated carrier wave from said electrode in response to the passage of said altered electron density wave across said electrode.

16. In a frequency modulation system, a polyphase carrier wave source, a signal source having low impedance, an electron discharge device including an electron source, means for confining electrons from said source to substantially radial, coplanar flow from said source whereby an electron disc is formed, means responsive to said polyphase carrier waves for producing a peripheral electron density wave in said disc by deflecting electrons in said disc along respective radii of said disc in directions normal to said disc, and for causing said electron density wave to progress about said electron source at substantially constant angular velocity, an electrode disposed in the path of electrons in said disc and

traversed by said electron density wave, an inductance coil, means for impressing a signal from said signal source on said coil whereby signal current in said coil is reduced as the frequency of said signal is increased, means for directing magnetic flux produced by signal current in said coil into the region traversed by said electron density wave with such orientation with respect to said disc as to alter said wave by changing the velocity of passage of the electron density wave across said electrode, and means for deriving a wave voltage from said electrode in response to the passage of the altered electron density wave across said electrode, whereby said wave voltage derived from said electrode is modulated in frequency, the sum of the resistance component of said signal source impedance and the resistance of said coil being equal to the reactance of said coil at a frequency equal to substantially three times the signal frequency at which phase shift distortion exceeds a predetermined limit.

17. In a frequency modulation system, a polyphase carrier wave source, a signal source having low impedance, an electron discharge device including an electron source, means for confining electrons from said source to substantially radial, coplanar flow from said source whereby an electron disc is formed, means responsive to polyphase carrier waves from said source for producing a peripheral electron density wave in said disc by deflecting electrons in said disc along respective radii of said disc in directions normal to said disc, and for causing said electron density wave to progress about said electron source at substantially constant angular velocity, an electrode disposed in the path of electrons in said disc and traversed by said electron density wave, an inductance coil, means for impressing a signal from said signal source on said coil whereby signal current in said coil is reduced as signal frequency is increased, means for directing magnetic flux produced by signal current in said coil into the region traversed by said wave with such orientation with respect to said beam as to alter said wave by changing the velocity of passage of the electron density wave across said electrode, and means for deriving a wave voltage from said electrode in response to the passage of the altered electron density wave across said electrode whereby said wave voltage derived from said electrode is modulated in frequency, the instantaneous frequency of said wave voltage being substantially proportional to instantaneous signal amplitude regardless of signal frequency.

18. In combination in a timing modulation system, a source of carrier wave voltage, a source of intelligence signal voltage of varying amplitude, an electron discharge device including a source of electrons, an electrode in proximity to said source of electrons, and means responsive to said carrier wave voltage for causing an electron density wave to progress recurrently at substantially uniform velocity across said electrode, means responsive to said signal voltage for producing a varying magnetic flux in the region through which such wave passes of such orientation with respect to said wave as to alter said wave by changing the velocity of its passage across said electrode, and means for deriving a timing modulated carrier wave from said electrode in response to the passage of the altered electron density wave across said electrode.

19. In combination in a timing modulation system, a source of carrier wave voltage, a source of

signal voltage of varying amplitude, an electron discharge device including a source of electrons, an electrode in proximity to said electron source, and means responsive to said carrier wave voltage for producing an electron density wave and causing such wave to progress recurrently at substantially uniform velocity across said electrode, means responsive to said signal voltage for producing a varying magnetic flux in the region through which such wave passes of such orientation with respect to said wave as to alter said wave by changing the velocity of its passage across said electrode, the amount of such change being more than proportional to the amplitude of said signal voltage by reason of the variation in the angle of impingement of electrons upon said electrode as the velocity of said wave is changed, said flux producing means including a flux generating element connected to have impressed thereon said signal voltage and a ferromagnetic flux directing element mounted to establish in the region through which said wave passes a magnetic field of such orientation as to change the velocity of said wave in response to said signal voltage, said flux directing element being dimensioned to produce such an amount of saturation as to offset substantially the non-linearity introduced by the disproportionality of the amount of change in velocity of the wave to flux density, such flux density being proportional to said signal voltage, and means for deriving a timing modulated carrier wave from said electrode in response to the passage of said altered wave across said electrode.

20. In combination in a timing modulation system, a source of carrier wave voltage, a source of signal voltage of varying amplitude, an electron discharge device including a source of electrons, a plurality of interconnected electrodes circumferentially spaced around said electron source, means responsive to said carrier wave voltage for producing an electron density wave and for moving said wave recurrently at substantially uniform velocity across said electrodes, said electron density wave having a wavelength integrally related to the length of the path of said electrodes, magnetic means responsive to a signal voltage from said signal source for changing the velocity of said electron density wave in its passage across said electrodes, and means for deriving from said interconnected electrodes a carrier wave timing modulated in accordance with said signal voltage.

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