

April 25, 1939.

R. A. HEISING

2,156,088

MULTIELEMENT ELECTRON DISCHARGE APPARATUS AND SYSTEM

Filed Jan. 11, 1936

3 Sheets-Sheet 1

FIG. 1

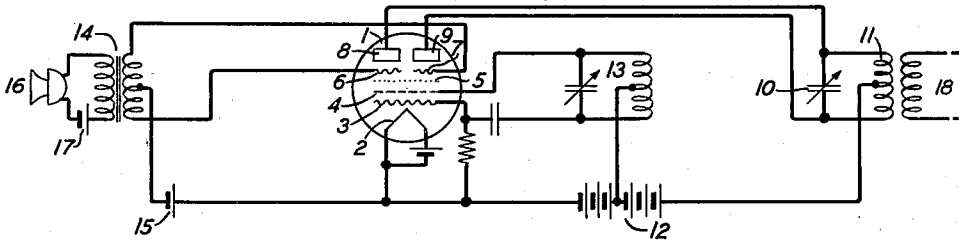


FIG. 2

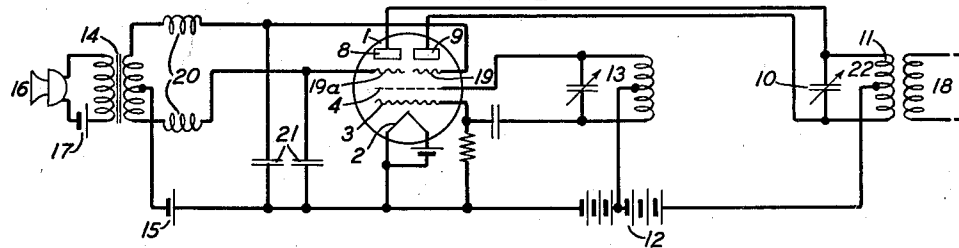


FIG. 3

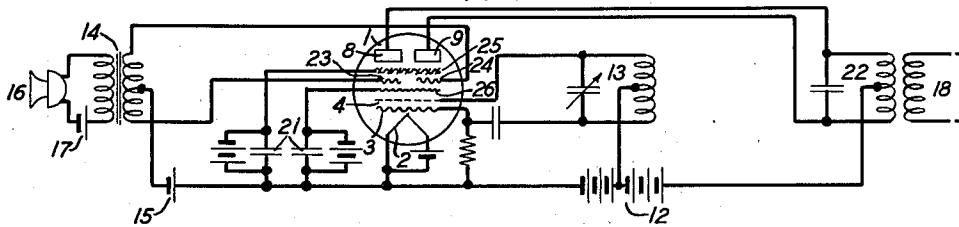


FIG. 4

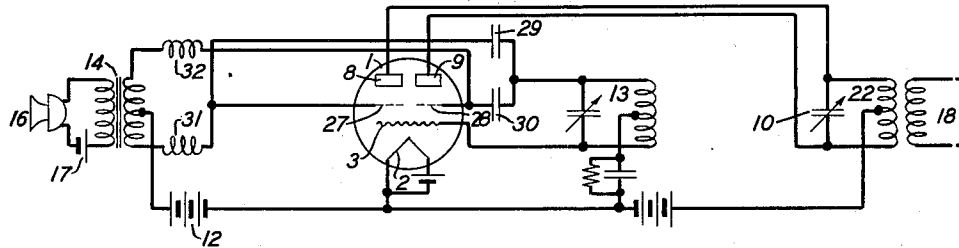
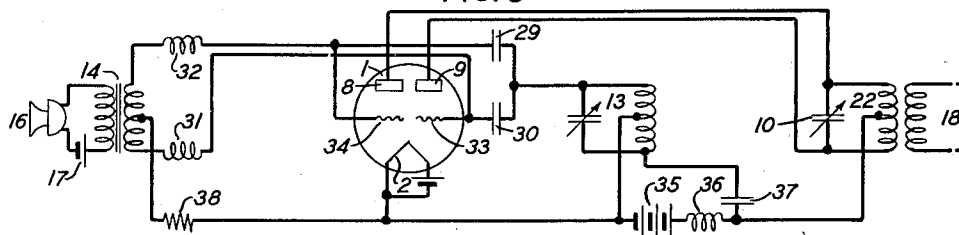


FIG. 5



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FIG. 6

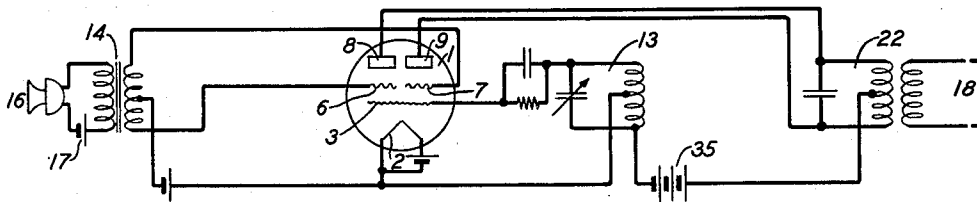


FIG. 7

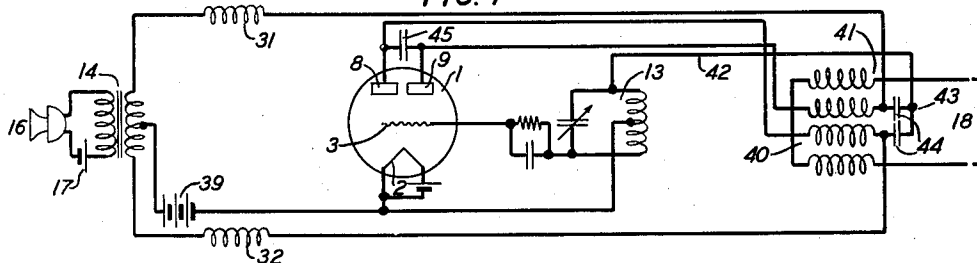


FIG. 8

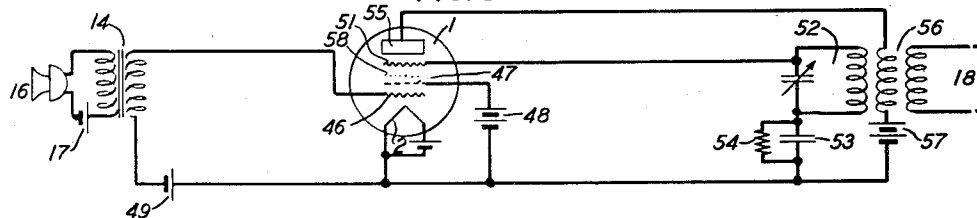


FIG. 9

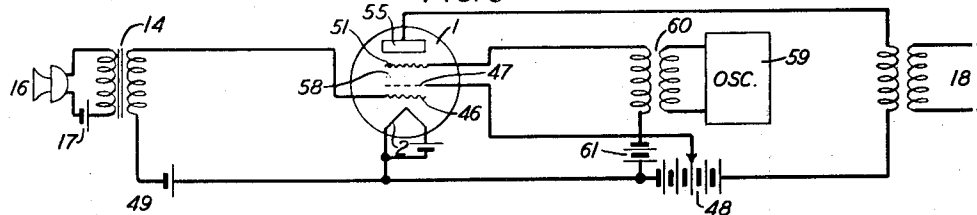
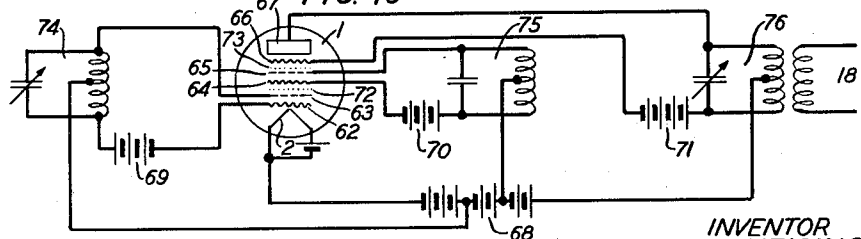


FIG. 10



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FIG. 11

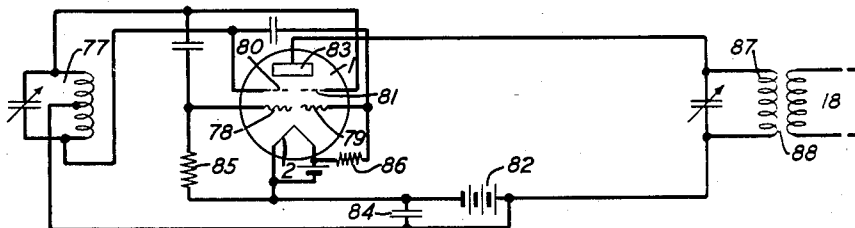


FIG. 12

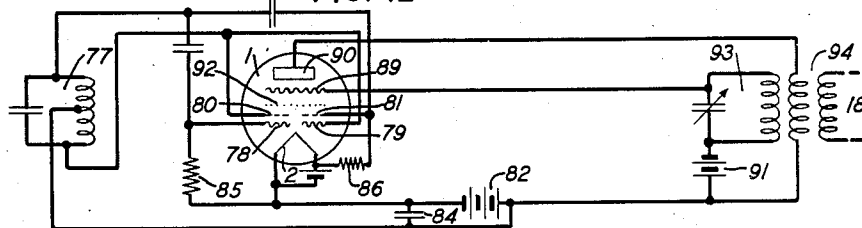


FIG. 13

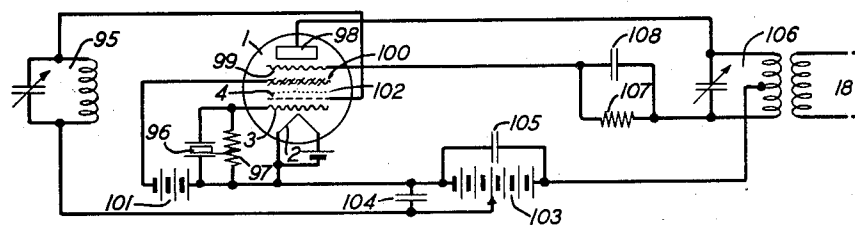
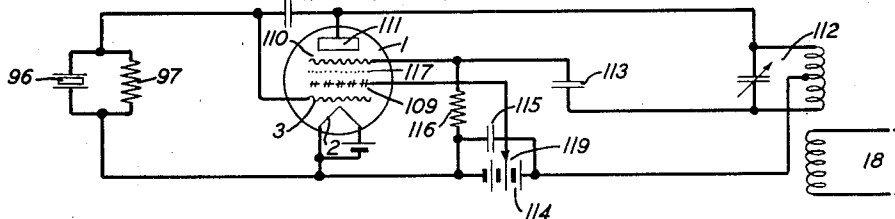


FIG. 14



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2,156,088

MULTIELEMENT ELECTRON DISCHARGE
APPARATUS AND SYSTEMRaymond A. Heising, Summit, N. J., assignor to
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Application January 11, 1936, Serial No. 58,653

17 Claims. (Cl. 179—171)

This invention relates to electron discharge systems and more particularly to circuits employing electron discharge devices to simultaneously perform a number of different functions.

5 The various functions for which electron discharge tubes have been used such as generation of oscillations, production of harmonics of the oscillations, modulation of oscillations in accordance with signal or control waves and
10 amplification of oscillations have generally been performed by individual discharge devices. This is for the reason that the requirements imposed upon the device and its associated circuits by one function are frequently unfavorable to the
15 performance of some other function. Moreover, it has been highly desirable to be able to secure independence in the control or adjustment of one of the functions so that each operation may be performed most efficiently and undisturbed by
20 adjustments required to establish the proper conditions for another operation.

The generation of oscillations and the modulation of the generated oscillations in accordance with message or control waves for carrier wave
25 transmission as is ordinarily required in carrier line transmitters or radio transmitters is an example of two frequently associated functions which present an opportunity for the use of multi-function tube circuits. Coupled frequently with
30 these two functions is that of suppressing any unmodulated carrier wave component so that only the side-bands produced by the modulating operation or the pure modulated wave may be transmitted. Corresponding situations occur
35 in carrier wave receiving systems and particularly in those of the heterodyne or superheterodyne types where it is frequently necessary to generate local oscillations and to combine them with incoming or received oscillations
40 in a device which does not permit tuning of either the primary receiving circuit or of the local oscillator frequency determining circuit to interfere with or react upon the other.

According to the invention an electron discharge device is provided with three electrodes
45 corresponding to the usual cathode, grid and anode and each electrode is so polarized and the external grid and anode circuits are so coupled as to cause oscillations to be generated. The anode
50 differs from that of the usual type in that it is of foraminate or screen type so that a portion of the electrons emitted from the cathode and impelled by the positive anode potential in the direction of the anode are not intercepted by the
55 anode but pass into the space beyond. Additional

systems of electrodes in the same envelope operate upon these electrons in the region beyond the oscillator anode to impose modulations or control characteristics upon the stream which the electrons constitute in addition to the pulsation which it already possesses by virtue of the oscillating potentials on the oscillator grid and anode. If one of the additional electrodes beyond the oscillator anode be given a normal negative polarization, its potential may be so predetermined
10 if desired as to retard the electrons which pass the anode and to reduce their velocity substantially to zero at some plane or region beyond the anode. Subsequent courses of these electrons depend upon the electrical environment of the zero
15 velocity plane or region, which has been called a virtual cathode for the reason that in their subsequent transit the electrons may be regarded as having been originally emitted at the locus of the virtual cathode.

The pulsating electron stream which passes beyond the transmitter oscillator anode may be directed toward a pair of additional electrodes each of which absorbs its portion of the electrons. By impressing modulating potentials between the anodes the relative portions of the
25 pulsating electron stream which they absorb may be varied in accordance with the modulating forces. Accordingly, an output or work circuit differentially connected to the additional anodes
30 will receive no energy as long as the modulating forces are zero but will receive pulsations of the oscillator frequency corresponding to the difference in the two anode streams during modulation. Since these modulated pulsations are free
35 from the normal unmodulated component the output wave will be of the well-known suppressed carrier type. A similar effect may be obtained if in lieu of applying the modulating electromotive forces between the additional anodes, it is applied
40 between a pair of additional grids so positioned that each lies in the path of the main electron stream from the virtual cathode to one of the additional anodes. The additional grids alternately accelerate and impede their individual
45 electron streams thus in effect switching the main stream to greater or less extent from one of the additional anodes to the other.

In the drawings:

Fig. 1 discloses a single tube circuit which serves as a combined oscillator and balanced
50 modulator; Fig. 2, a modification in which the modulating grids serve also as screens for the modulator anodes at high frequencies; Fig. 3, a modification of the circuit of Fig. 2 in which sep-
55

arate shielding is employed; Fig. 4, a simplified apparatus in which the two modulator grids serve as parallel connected anodes for the oscillator; Fig. 5, a further simplification which is the equivalent of two three-electrode tubes connected in parallel for oscillation and in push pull for modulation; Fig. 6, modification of the circuit of Fig. 4; Fig. 7, a plate modulation circuit; Fig. 8, a device in which a virtual cathode supplies a speech modulated electron stream for the space current path of an oscillator; Fig. 9, a signal modulated virtual cathode apparatus to supply the electron stream of a modulator; Fig. 10, harmonic generator circuit employing multiple electrode tubes; Figs. 11 and 12, two different harmonic generator circuits in which the primary or base frequency oscillator elements are arranged in push-pull fashion; Fig. 13, a circuit for producing harmonics from a crystal-controlled generator, and Fig. 14, a circuit of a crystal-controlled oscillator for supplying high power oscillations to a load circuit.

Referring to Fig. 1 an electron discharge device 1 of the highly evacuated type contains a thermionic cathode 2, an oscillator grid 3, and a foraminate oscillator anode 4. A virtual cathode 5 represented by a line of dots is established by negatively biased modulator grids 6 and 7 which tend to retard electrons from cathode 2 impelled through the meshes of anode 4. Modulator anodes 8 and 9 are respectively connected to the opposite terminals of a capacity element 10 which, together with an inductance 11 serving as the primary winding of a transformer, constitutes a tuned output circuit. A source 12 of space current is connected between the cathode 2 and a central point of inductance 11. Grid 3 and anode 4 are connected to the opposite terminals of a frequency-determining tuned circuit 13 the electrical midpoint of which is connected to a point in the space current source 12. Grid 3 is biased negatively by grid leak current and anode 4 is positively biased by the space current source 12. The elements 2, 3 and 4 with their associated tune circuit 13 and biasing sources constitute an oscillator of well-known type.

Grids 6 and 7 are connected to opposite terminals of the secondary winding of a voice frequency transformer 14 and are polarized to such a negative potential by source 15 that part of the electrons from cathode 2 passing through the oscillator anode 4 are substantially brought to a stop in the region of the virtual cathode 5. The modulator anodes 8 and 9 have such positive potential as to tend to draw the electrons from the virtual cathode. The grids 6 and 7 are alternately rendered positive and negative with respect to their own normal negative bias potential by sound signals incident upon microphone 16 in circuit with source 17 and the primary winding of transformer 14. When grid 6 is driven in a positive direction electrons move from the virtual cathode region to plate 8. On the reverse part of the signaling cycle grid 7 is driven in a positive direction and electrons move toward plate 9. When there is no signal electromotive force generated and grids 6 and 7 remain at the same potential the pulses of electrons passing to anodes 8 and 9 are equal and neutralize in their effect in the primary winding 11 and no oscillations are supplied to output circuit 18.

The circuit of Fig. 1 may also be used for detection purposes if instead of elements 16, 17 and audio frequency transformer a high frequency receiving circuit or antenna associated

with a radio frequency transformer is connected to grids 6 and 7. In that case the transformer of which inductance 11 forms the primary winding should be so designed as to effectively transmit the detected currents to output circuit 18.

Fig. 2 shows a circuit similar to that of Fig. 1 but without the virtual cathode feature and in which the modulating grids serve also as high frequency shields for the anodes. As like parts are similarly designated it will be understood that elements 2, 3, 4 and 13 constitute a high frequency oscillator the frequency of which is determined by tuned circuit 13. Anodes 8 and 9, capacity element 10, inductance 11 and anode source 12 correspond to the similar elements of Fig. 1. A microphone 16, current source 17 and balanced audio frequency transformer 14 serve to apply low frequency signal electromotive forces to the grids 19 and 19a. Audio frequency electromotive forces are impressed on each grid over a path extending from the cathode by way of the grid bias source to the midpoint of the secondary winding of transformer 14, through the appropriate portion of the secondary winding and the radio frequency choke coil 20 to the respective grid. The grid bias source is indicated in the drawings as having a polarity toward the grid which may be either positive or negative. In the usual case the grids 19 and 19a will be biased positively with respect to the cathode. However in the event that a high output power is desired the anode voltage will preferably be made high and in order to avoid a power loss in the grid circuit the polarity of the biasing source may be such as to render the grids negative. The grids may also be made negative to avoid power loss in the grid circuit in the case where only a medium or low anode potential is used and in this case the mesh of the grids will preferably be increased to reduce the decelerating effect of the grids upon the electrons. Whenever the grids are biased negatively there is a tendency to form a virtual cathode and the degree to which such a cathode is formed is a function of the magnitude of the negative grid bias potential utilized. Connecting the grids directly to the cathode are capacity elements 21 which serve to bring the grids to the cathode potential at high frequencies but which are of too small capacity to permit signal frequency electromotive forces to be shunted thereby. Choke coils 20 prevent the external circuit of grids 19 and 19a from entering into the high frequency operation in any way. The grids 19 and 19a are of the screen type and as such are designed to serve as shields for the anodes 8 and 9 so that direct interelectrode capacitance effects between anodes 8 and 9 and the remaining electrodes of the tube are substantially eliminated. Consequently, the tuned output circuit 22 will not react upon the oscillator to affect its frequency. As in the circuit of Fig. 1, signal electromotive forces on one-half cycle increase one electron stream, e. g., that to the anode 8 and decrease that to the other and on the reverse half cycle bring about an opposite result. As a result, anodes 8 and 9 receive pulsating electron streams, the instantaneous magnitudes of which, in the absence of signal electromotive forces in transformer 14, are alike so that the resultant or differential output current supplied to the load circuit under those circumstances is zero. When signal electromotive forces occur the resultant high frequency current supplied to the output circuit 18 is a pure modulated

wave, i. e., a modulated carrier wave devoid of any unmodulated component of the carrier frequency.

Fig. 3 shows a circuit that is similar to that of Fig. 2. In this circuit the modulating grids 23 and 24 serve solely for modulating purposes. To eliminate any interelectrode capacitance effect at the oscillation frequency, the discharge device is provided with two sets of screening grids 25 and 26 each of which is connected by a capacity element 21 constituting a low impedance path at the oscillation frequency to the cathode. The grid bias source in shunt to each capacity element 21 is indicated as impressing either positive or negative potential upon the respective grid. This feature has been explained in connection with the similar biasing source of Fig. 2. Screen grid 25 effectively isolates anodes 8 and 9 and output circuit 22 from the oscillator elements. Screen grid 26 which may be used together with grid 25 or as a substitute for it also serves to eliminate interelectrode capacity effects at high frequencies between the oscillator electrodes and the remaining elements of the discharge device.

In Fig. 4, the functions of the foraminant oscillator anode and the modulating grids are combined with a simplification of the structure involved. The oscillator comprises cathode 2, oscillator grid 3 and the two foraminant anodes 27 and 28 connected to the oscillation frequency-determining circuit 13 by parallel paths including blocking condensers 29 and 30 which permit high frequency oscillations to pass but prevent unidirectional space current sources from impressing potentials on the oscillator grid 3. The anodes 27 and 28 are connected to space current source 12 through choke coils 31 and 32 which suppress currents of the oscillation frequency but do not seriously impede voice frequency, or other low frequency modulating currents. Modulating electromotive forces are impressed from the secondary winding of transformer 14 through high frequency choke coils 31 and 32 upon electrodes 27 and 28 which, although connected in parallel as oscillator anodes, are connected in push-pull fashion to serve as modulator grids. The effective potentials of electrodes 27 and 28 are thus alternately increased and decreased in turn so that the one electron stream to anode 8 is increased as that to anode 9 is decreased and vice versa. Accordingly, load circuit 18 receives a signal modulated oscillation that is free from any unmodulated component of the carrier frequency.

Fig. 5 illustrates a further simplification in which the same anodes, control electrodes and cathode serve for both the oscillator and modulator. The cathode 2 is connected to the two oscillator grids 33 and 34 by parallel paths extending through capacity elements 29 and 30 which readily pass the oscillation frequency currents but are of high impedance for speech currents or other low frequency modulating currents. The anodes 8 and 9 are supplied with space current from space current source over a path extending through radio frequency choke coil 36 and the inductance of output circuit 22. Modulation electromotive forces are impressed from the secondary winding of transformer 14 in push-pull fashion on elements 33 and 34, serving as modulator grids, by way of paths through choke coils 31 and 32 which readily pass the low frequency signal currents. Large stopping capacity element 37 completes the high frequency oscillator anode path to a point in frequency-determining circuit 13 of opposite phase to that of the

grid connection. A grid leak path extends from the central point of the secondary winding of transformer 14 through high resistance element 38 to the cathode. The device, accordingly, operates as two parallel connected high frequency oscillators with their outputs differentially connected to the load circuit 18. Accordingly, the unmodulated carrier frequency component will be suppressed. However, whenever signals are incident upon microphone 16 one oscillator space circuit will prevail during the positive half wave of the signal and the other during the reverse half wave so that a pure modulated carrier wave will be supplied to load circuit 18.

In the circuit of Fig. 6, the oscillator and modulator have a pair of anodes in common but the oscillator has a single impedance control grid while the modulator has two grids arranged in push-pull fashion. The oscillator comprises the cathode 2, grid 3, anodes 8 and 9 connected in parallel and the frequency-determining circuit 13. The modulating input circuit is substantially identical with that of Fig. 1. The grid bias source for grids 6 and 7 may be so poled as to polarize the grids normally either positively or negatively with respect to the cathode as explained in connection with the grid bias source of Fig. 2.

The circuit of Fig. 7 differs from the previously described circuits in its use of plate circuit modulation. Cathode 2, grid 3, anodes 8 and 9, plate current source 39 and frequency-determining circuit 13 comprise the oscillation generator. The path connecting grid 3 to circuit 13 may include the usual grid leak resistance and condenser combination. The space current path of the oscillator anodes may be traced by way of cathode 2, space current source 39, the secondary winding of transformer 14 and the primary windings of the two output transformers 40 and 41 whose secondary windings are differentially connected to load circuit 18. In order to permit the anodes 8 and 9 to operate in parallel in generating high frequency oscillations, the oscillation frequency determining circuit 13 is connected by a lead 42 to the junction point 43 of two capacity elements 44 connected between the leads extending from the outer terminals of the secondary winding of transformer 14 to the anodes. The capacity elements 44 transmit the high frequency oscillations with very little impedance but are not of sufficient capacity to appreciably shunt the speech or modulation frequency currents impressed on its output circuit by the secondary winding of transformer 14. Accordingly, the potentials of anodes 8 and 9 alternately rise and fall in push-pull fashion in accordance with the modulating electromotive forces delivered by transformer 14. At the same time the anodes undergo high frequency variations or potential variations for which they are effectively tied together electrically with consequent simultaneous rise and fall of potential at the oscillation frequency. The oscillations delivered by anode 8 and those delivered by anode 9 are accordingly modulated in the manner of the well-known plate modulator circuit. During non-signaling intervals the anodes deliver equal amplitude unmodulated oscillations. The differential circuit connection of transformers 40 and 41 causes the unmodulated equal amplitude oscillation to annul each other's effect on load circuit 18 so that no unmodulated oscillations are transmitted thereto. Moreover, an instantaneous increase in oscillations delivered by one anode is accompanied by a simultaneous decrease in the oscillations delivered

ered by the other. The differential connection makes these two changes additive with respect to the output circuit 18. A capacity element 45 is connected directly between the anodes 8 and 9 to reduce to a minimum any high frequency oscillation difference of potential but is of insufficient capacity to permit a substantial diversion of modulation frequency currents.

Fig. 8 discloses a circuit for generation and modulation of high frequency oscillations by an electron discharge device in which the signaling electromotive force controls a virtual cathode for the high frequency carrier source. Referring to the drawings the device 1 includes the customary cathode 2, an impedance control electrode 46 and a foraminate anode 47. A source 48 of space current is connected between the anode 47 and cathode 2. Microphone or other signal generating element 16, source 17 and primary winding of transformer 14 are included in a circuit coupled by the transformer to the signal input control path connecting cathode 2 and grid 46 and which includes a grid biasing source 49. A grid 51 positioned beyond the anode 47 is connected to the cathode by a loop circuit 52 tuned to the carrier oscillation frequency and a grid leak path comprising capacity element 53 and high grid leak resistance 54. Oscillator anode 55 is connected to cathode 2 over a path including a winding of three-winding transformer 56 and space current source 57. A second winding of transformer 56 constitutes part of the oscillation circuit 52 so that the anode circuit and the circuit of grid 51 are coupled to generate sustained oscillations of a frequency substantially determined by the tuning of circuit 52. A third winding of transformer 56 is connected to the load circuit 18 and serves to couple that circuit to the oscillator output circuit. During the continuance of oscillations in loop circuit 52, the rectifying action of the grid leak circuit will cause grid 51 to be maintained at a negative potential. The entire circuit of Fig. 8 is preferably so designed and adjusted that the resulting normal negative bias potential on grid 51 is sufficient to retard electrons proceeding through the interstices of anode 47 beyond the anode and to set up a virtual cathode 58 which serves as the cathode for the oscillator. Since the number of electrons available at the virtual cathode 58 is controlled by the electromotive forces impressed upon control grid 46, the oscillations generated which will vary in accordance with the electron supply at 58 will, accordingly, be effectively modulated by the speech or other signal or control electromotive force applied to grid 46. As a result, carrier frequency oscillations will be supplied to load circuit 18 and whenever signal impulses are impressed over transformer 14, the carrier oscillations transmitted to circuit 18 will be modulated by the signal impulses.

Fig. 9 illustrates a modification of the circuit of Fig. 8 according to which the carrier oscillations are externally produced by a source 59 and are impressed on the input circuit of high frequency control grid 51 by a transformer 60. The circuit of grid 51 includes a negative bias source 61 to assist in production of a virtual cathode. In other respects the elements correspond generally to those of Fig. 8 and are similarly designated. The operation of this circuit will, it is believed, be apparent without further description.

A harmonic generator or frequency multiplication circuit is illustrated in Fig. 10 in which an electron discharge device includes in the sequence of their position, a cathode 2, control grid 62,

foraminate anode 63, second control grid 64, second foraminate anode 65, control grid 66 and main anode 67. A space current source 68 is connected between the cathode 2 and the anodes 63, 65 and 67. Grid 62 is suitably polarized by grid biasing source 69. Grids 64 and 66 are so negatively biased by sources 70 and 71 respectively, that virtual cathodes are produced at 72 and 73. Grid leak and stopping condensers may be utilized in the customary fashion instead of polarizing sources 69, 70 and 71. A tuned circuit 74 is associated with the paths connecting grid 62 and anode 63 to the cathode 2 in such fashion that these three electrodes and their associated circuits and biasing sources constitute a source of oscillations of a frequency f_1 corresponding to the natural frequency of circuit 74. In similar fashion a tuned circuit 75 is associated with grid 64 and anode 65 cooperating with virtual cathode 72 to constitute a source of oscillations of frequency $n f_1$ representing any desired multiple of the frequency f_1 and corresponding to the tuning of the circuit 75. A third circuit 76 tuned to the frequency $kn f_1$ representing any desired harmonic of the oscillations produced in circuit 75 is associated with the main anode 67, grid 66 and the virtual cathode 73 to produce oscillations of the frequency of circuit 76. It will be apparent, therefore, that oscillations of the frequency f_1 produced in circuit 74 give rise to a correspondingly pulsating source of electrons 72 so that circuit 75 operates to produce oscillations of a multiple frequency of those produced by circuit 74. In its turn circuit 75 and its associated electrodes set up at 73 a virtual source of electrons pulsating at the multiple frequency corresponding to the tuning of circuit 75. In like manner, still higher frequency oscillations are produced in the oscillator output circuit 76. Accordingly, the device as a whole comprises three oscillator stages, the first two of which each serve to provide a virtual source of electrons of an oscillating amplitude for the succeeding stage oscillator. Circuit 76 is coupled to the load circuit 18 to supply the desired harmonic frequency oscillations thereto.

Figs. 11 and 12 illustrate circuits for producing harmonics of a fundamental frequency in which the elements nearer the cathode are constructed and positioned to operate in push-pull fashion. In Fig. 11, for example, the cathode 2 is connected to tuned circuit 77 of frequency f_2 to which grids 78 and 79 are also connected at points differing 180° in phase. Foraminate anodes 80 and 81 are connected to these same points, anode 80 being connected at a point of opposite phase with respect to its cooperating grid 78 and anode 81 likewise being connected to a point of opposite phase with respect to its cooperating grid 79. Space current source 82 is connected between the cathode 2 and the foraminate anodes 80 and 81 and also between the cathode and the principal anode 83. A very large capacity condenser 84 in shunt to source 82 provides a by-pass therearound for oscillations. Grid leak circuits 85 and 86 serve to overcome the positive potential that would otherwise be impressed upon grids 78 and 79 by the source 82 and to cause the grids to be brought to the proper potential, with respect to the cathode. Ordinarily, although not necessarily, potentials of the two grids will be somewhat negative with respect to that of the cathode. A tuned output circuit 87, preferably tuned to a harmonic $n f_2$ of the frequency f_2 , is included in series in the path between the cathode and the main anode 83.

Fig. 12 comprises a primary oscillator including

cathode 2, tuned circuit 77, grids 78 and 79, foraminate anodes 80 and 81, space current source 82, by-pass capacity element 84 and grid leak paths 85 and 86 corresponding to the similar elements of Fig. 11. An additional grid 89 between the anodes 80 and 81 and the main anode 90 is biased negatively with respect to the cathode by means of source 91 so as to produce a virtual source 92 of electrons between the foraminate anodes and the grid 89. In the external circuit of the grid 89 is a tuned loop circuit 93 which is preferably tuned to multiple $n/3$ of the frequency of the primary oscillations. The circuit 93 is coupled to the external circuit of anode 90 to provide the necessary feed-back for production of the multiple frequency oscillation by a three-winding transformer 94, the third winding of which is included in series with the load circuit 18 to transfer harmonic frequency oscillations of the frequency $n/3$ thereto.

Fig. 13 illustrates a circuit for producing high power or harmonic oscillations from a crystal controlled circuit. The primary oscillator comprises an electron discharge device having a cathode 2, a control grid 3 and a foraminate anode 4. A loop 95 tuned to the frequency of oscillations to be produced is included in the anode circuit. The grid circuit includes piezoelectric element 96 of any well-known type shunted by leak resistance 97. The element 96 is designed and constructed in accordance with well-known piezoelectric technique to be resonant at substantially the desired oscillation frequency. Accordingly, the primary oscillator, as so far described, will produce oscillations, the frequency of which is substantially determined by the natural period of vibration of the piezoelectric device 96, in the circuit 95 tuned to approximately the same frequency in accordance with well-known practice. The electron discharge device also includes a main anode 98, a grid 99 cooperating therewith and a screen grid 100 interposed between the foraminate anode 4 and electrodes 98 and 99. Grid 100 is preferably polarized by a source 101 to such a potential as to produce or assist in producing a virtual source of electrons 102 in the region beyond anode 4. It will be understood however as indicated in the drawings and described in connection with Fig. 2, the grid bias source 101 may render grid 100 either normally positive or negative with respect to the cathode. A space current source 103 serves to positively polarize the main anode 98 as well as the foraminate anode 4. This source will be designed to impress an unusually large potential upon anode 98 when high power is desired. By-pass capacity elements 104 and 105 having negligible reactance at the oscillation frequencies involved are associated with the space current source 103 in the manner indicated in the drawings. A tuned loop 106 is connected with the main anode 98 and the grid 99 to regeneratively couple their respective circuits whereby the apparatus tends to produce oscillations of the resonance frequency of circuit 106. A grid leak resistance 107 and shunting grid leak condenser 108 in the circuit of grid 99 normally maintain the grid 99 at a negative potential during the occurrence of oscillations in circuit 106 in a manner well understood in the art. If it is desired to transmit oscillations of the fundamental frequency to the load circuit 18, the circuit 106 coupled thereto will be tuned to the frequency of the primary oscillator. If, however, it is desired to supply to the load circuit 18 harmonic oscillations of the primary oscillation

frequency, the circuit 106 will be tuned to the desired harmonic frequency. In that event the screen grid 100 may be omitted if it is desired to simplify the apparatus, although it is preferable to employ it.

Fig. 14 shows another circuit for an oscillator for producing high power oscillations employing the virtual cathode principle. As shown, the discharge device 1 includes a cathode 2, control grid 3, a positively polarized screen 109, an oscillator grid 110 and an oscillator anode 111. Connected between cathode 2 and grid 3 are piezoelectric element 96 and shunting leak resistance 97. A tuned loop 112 is connected between the grid 110 and anode 111, the connection to the grid passing by way of large capacity element 113. A path from the cathode 2 leads by way of space current source 114 and large by-pass condenser 115 to a central point in the inductance of the tuned loop 112. A grid leak resistance 116 connects grid 110 to cathode 2 thus permitting grid 110 to be normally negatively polarized by grid rectification action during continuance of oscillations in the circuit 112. The negative polarization of grid 110 is preferably sufficient so that in cooperation with the other elements it produces a virtual source of electrons at 117 in the region between the screen 109 and the grid 110. A coupling capacity element 118 of small capacity connects the piezoelectric device 96 to the oscillation circuit 112 to permit the reactance of the device 96 to control the frequency of the oscillations generated. It will be understood that in operation electrons are drawn to the positively polarized screen 109 which is in effect an auxiliary anode operating at a reduced anode voltage by virtue of the tap 119 which connects the external terminal of the element 109 to the space current source 114. The virtual cathode 117 accordingly provides electrons in pulsations of a frequency determined by the piezoelectric element 96. Accordingly, the virtual cathode 117 cooperating with the grid 110 and the anode 111 with the relatively high potential source 114 serves to produce oscillations of high power in the circuit 112. Circuit 112 is tuned in the usual manner to substantially the natural frequency vibration of piezoelectric element 96 and is coupled to load circuit 18 to supply high power oscillations thereto.

In the various figures of the drawings the load circuit 18 should be understood as representative of any suitable transmission path. For example, it may be a carrier wave transmission line or it may be a circuit leading to an antenna.

The principles of the invention are, in general, applicable to demodulators as well as to modulators. In general, therefore, the source of low frequency modulating signals may be replaced by a high frequency incoming transmission line or by a connection from a receiving antenna. It will be understood that in all such instances, it will be necessary to provide the incoming path with a suitable high frequency transformer and that it will be necessary to eliminate from that path impedance elements which would interfere with effective transmission of the incoming high frequency waves.

For the purpose of simplifying the drawings, unidirectional sources of space current and polarizing electromotive forces have been illustrated and the discharge devices have been disclosed as of the thermionic cathode type. It will, of course, be understood that any suitable source of rectified current may be employed in a well-

known manner for current supply purposes and that the discharge devices may be of the indirectly heated cathode type. It will, of course, also be understood that by-pass condensers are to be connected across any current or potential supply source where impedance through the source, or in lead wires to the source, are appreciable and that such current or potential supply sources are not restricted to the specific locations indicated, but may be shifted to other positions according to well-known practices in the art. It will also be understood that potential biases for grid electrodes may be either primary current sources or grid leak and stopping condenser combinations, or both, in all oscillator grid circuit paths wherever a grid bias or grid leak stopping condenser combination is shown.

What is claimed is:

1. Electron discharge apparatus including a cathode, an impedance control element and a screen form anode, means for polarizing the impedance control element and the anode to constitute a virtual source of electrons in the space beyond the anode, a pair of coplanar control grids, a pair of coplanar anodes, the pair of grids lying respectively in the paths of electrons passing from the virtual source to the pair of anodes and an output circuit connected to the coplanar anodes.
2. A modulation apparatus comprising an electron discharge device having three electrodes including a cathode and two foraminate electrodes, means for polarizing one of the foraminate electrodes to cause it to serve as an anode, external paths connecting each of the foraminate electrodes to the cathode, means for coupling the external paths to cause oscillations to be produced, a pair of coplanar modulating grids and a pair of coplanar anodes included within the device, means for impressing modulating electromotive forces in push-pull fashion between the coplanar grids, and a path connecting the coplanar anodes and including means for deriving modulated currents therefrom.
3. A modulating device comprising an electron discharge container, a cathode, an impedance control element and an anode therein constituting with their external circuits an oscillator, a second control electrode and two output electrodes in said container, an output circuit connected to the two output electrodes and a modulation control circuit connected to the second control electrode, and means whereby the output circuit in response to signal electromotive forces applied to the modulation control circuit may yield oscillations modulated in accordance with the signal electromotive forces and substantially free from an unmodulated carrier frequency component.
4. A modulator comprising an electron discharge device having cathode, grid and a pair of screen form anodes, means for impressing carrier frequency oscillations between the grid and cathode, a pair of main anodes in the space beyond the screen anodes, a modulating circuit connected between the screen anodes for impressing modulated electromotive forces therebetween and an output circuit connected between the cathode and the pair of main anodes for deriving modulated carrier frequency oscillation therefrom.
5. An electron discharge device having a cathode, a grid and a perforated anode, external coupled grid-cathode and anode-cathode circuits to produce oscillations and project electrons in pulsating fashion through the perforated anode, a

modulating means and a pair of anodes located in the path of the projected electrons, an external output circuit differentially connected between anodes of the pair and a source of modulating electromotive force connected to the modulating means whereby oscillations may be derived from the output circuit having frequencies of the sum and difference respectively of the frequency of the oscillations and the frequency of the modulating electromotive force free from unmodulated components of the oscillation frequency.

6. In combination, an electron discharge device having a cathode, a grid, an anode, external anode-cathode and grid-cathode circuits coupled to each other to cause the device to produce oscillations, the anode consisting of two separate foraminate parts to permit some of the electrons impelled theretoward to pass therethrough, output anodes positioned in the line of the electrons passing through the foraminate anodes, a low frequency modulating signal circuit connected in push-pull relation to the foraminate anodes and a load circuit differentially connected to the output anodes.

7. A system for producing modulated oscillations comprising an electron discharge device having a cathode, a grid and two coplanar anodes, a source of space current connected between the cathode and anodes, a resonant circuit connected to the cathode, the grid, and the anodes in such fashion as to constitute an oscillator in which the anodes operate in parallel with respect to the space current source, a source of modulating currents, means for connecting said source of modulating currents in push-pull relation to the two anodes, a load circuit, and means for connecting the two anodes in differential fashion to the load circuit whereby the oscillations delivered thereto are substantially free from an unmodulated component.

8. A system for transmitting modulated carrier waves comprising an electron discharge device having a cathode, a grid and a foraminate anode, a path including a polarizing source connecting the cathode and foraminate anode, a circuit connected between the grid and cathode and including means for impressing carrier frequency signal waves thereon, a pair of output anodes in position to receive electrons projected through the foraminate anode, a modulating grid in the path of the projected electrons, means for impressing audio frequency potentials upon the modulating grid with respect to the cathode, an output circuit connected differentially between the two output anodes and the cathode and a load circuit coupled thereto to receive signal modulated carrier frequency oscillations therefrom.

9. An electron discharge device comprising a cathode, a grid and a foraminate anode, an output anode lying in the path of electrons projected through the foraminate anode, means also lying in that path for producing a virtual cathode in the region between the foraminate anode and the output anode, a carrier frequency input circuit connecting the grid and the cathode, a path including a polarizing source connecting the foraminate anode and the cathode, means for controlling the impedance of the device between the virtual cathode and the output anode in accordance with audio frequency electromotive forces, a resonant loop circuit connected between the anode and the cathode, a work circuit associated with the resonant loop circuit, and means for preventing the output anode from impressing un-

modulated carrier frequency oscillations upon the resonant loop circuit.

10. In a modulating system, an electron discharge device including a cathode, an impedance control element and an anode, a path including the secondary winding of a carrier frequency transformer connecting the impedance control element to the cathode whereby carrier frequency potentials may be impressed upon the impedance control element with respect to the cathode connecting the impedance control element to the cathode, a path including polarizing means connecting the anode to the cathode, the electron discharge device also including a second control electrode and two coplanar output electrodes, an output circuit differentially connected to the two output electrodes and the cathode, and a modulation control circuit connected between the second control electrode and the cathode whereby the output circuit in response to modulation frequency electromotive forces applied to the second control element may yield modulated carrier frequency oscillations substantially free from an unmodulated carrier frequency component.

11. A system for producing modulated carrier oscillations comprising an electron discharge device having electron discharge electrodes and an impedance control element, external circuits connected to the electrodes and the element and so coupled as to cause the device to produce a stream of electrons having a periodic variation in its amplitude, a pair of output anodes symmetrically positioned with respect to the varying amplitude electron stream, means for differentially controlling the portions of the stream of electrons reaching each anode in accordance with signals, and an output circuit connected between the output anodes whereby modulated carrier frequency oscillations are delivered to the output circuit free from an unmodulated component.

12. A system for intermodulating two sets of different frequency oscillations, comprising an electron discharge device having electron discharge electrodes including a cathode and anode means to receive electrons therefrom, an impedance control element, external circuits connected to the electrodes and to the element and so coupled as to cause the device to produce a stream of electrons having a periodic variation in its amplitude corresponding to one set of the oscillations to be intermodulated, a second anode means positioned in the path of the varying amplitude electron stream and polarized positively to receive electrons therefrom, the anode means nearer the cathode being foraminant to permit passage therethrough of electrons to the other anode means, one of the anode means consisting of two separate parts positioned symmetrically with respect to the electron stream and between which the electron stream is divided, and means for controlling the impedance presented to the two parts of the stream in accordance with a set of oscillations of the other frequency.

13. A system for producing oscillations comprising an electric discharge device having a cathode, foraminant anode means, a second anode means in general alignment with the cathode and the foraminant means and more remote from the cathode than the foraminant means, a source of electromotive force connected in circuit between the cathode and the foraminant anode means to impel a beam of electrons from the cathode, impedance control means located in the space traversed by the electron beam, intercoupled external connections, including impedance control polar-

izing means, from said cathode to said impedance control means and said foraminant anode means whereby oscillations are produced, one of the anode means consisting of two separate parts symmetrically positioned with respect to the electron beam emanating from the cathode and between which that anode beam is divided, the other anode means encompassing substantially the entire beam, and a load circuit and a source of anode potential connected between the second anode means and the cathode.

14. An oscillation producing system comprising an electric discharge device having a cathode, a first anode means consisting of a pair of elements closely adjacent to but electrically insulated from each other and with their principal electron receiving surfaces lying generally in the same plane, the two elements being positioned symmetrically with respect to a line from the cathode perpendicular to said plane and serving when positively polarized to develop a pair of contiguous electron streams from the cathode, circuits including polarizing means connecting the pair of anode elements in push pull fashion to the cathode, impedance control means positioned adjacent each stream, a second anode means and a second impedance control means each encompassing an area through which both of the contiguous electron streams pass, one of said anode means being foraminant to permit passage of the electron streams to the other anode means, means for polarizing the second anode means with respect to the cathode, electrical connections to the cathode for one of the anode means and its associated impedance control means so coupled as to cause the production of oscillations, and means for applying an alternating electromotive force to the other impedance control means to modulate both the electron streams in accordance with the applied electromotive force.

15. A system for production and modification of electrical oscillations comprising an electric discharge device including a cathode, foraminant anode means, a grid, circuits connecting the cathode to the grid and anode means and including polarizing means whereby oscillations are produced, means for reducing the velocity of electrons which pass the foraminant anode means to constitute a virtual cathode, two cold electrodes beyond the virtual cathode in the path of the electrons which pass through the foraminant anode means, a closed tuned loop circuit comprising an inductance element and a capacity element having the two common terminals of the elements connected respectively to the two cold electrodes, a connection from a central point in one of the elements to the cathode, and an energy transmission circuit connected in energy transfer relation to the tuned loop circuit.

16. In an oscillation producing and modifying system, an electric discharge device comprising a cathode, anode means, impedance control means, connections including polarizing means from the anode means and the impedance control means to the cathode, a second anode means, a second impedance control means, connections including polarizing means from the second anode means and the second impedance control means to the cathode, one set of anode means and impedance control means being foraminant and the other lying in the path of the same electron stream from the cathode so that the electron emission from the cathode is controlled by both, the circuits connecting one set of anode means and impedance control means to the cathode

being intercoupled to constitute an oscillator, one anode means comprising two insulated anode elements equidistant from the cathode and symmetrically placed with respect to the total electron stream so as to divide the total electron stream into two streams, and means including the impedance control means associated therewith for controlling their respective streams with the same controlling electromotive force.

- 10 17. An oscillation producing and transmitting system comprising an electric discharge device having a cathode, a set of two foraminate cold electrodes lying at different distances from and in the same direction from the cathode and externally connected thereto, means for rendering
15 one of the electrodes positive with respect to the cathode to cause a stream of electrons to be impelled toward it from the cathode, means for setting up such an electric field in the region beyond the cold electrodes as to retard electrons
20 and constitute a virtual cathode, a second set

of two cold electrodes both lying in the zone of the electron stream and beyond the virtual cathode, means for positively polarizing at least one of the electrodes of the second set with respect to the cathode, external paths connecting the electrodes of the second set to the cathode and each including at least a portion of a closed loop tuned circuit electrically coupling the paths, and means controlled by the current in the external path from the cathode to one of the positively polarized electrodes for causing one of the other cold electrodes to present an impedance to the electron stream proceeding to said positively polarized electrode which varies at the frequency of the oscillations which it is desired to produce, whereby oscillations are produced and corresponding oscillations are supplied from the second set of cold electrodes to the closed loop tuned circuit.

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