

Sept. 27, 1949.

W. W. HANSEN ET AL

2,482,766

HIGH-FREQUENCY MODULATING SYSTEM

Filed Dec. 30, 1942

4 Sheets-Sheet 1

FIG. 1

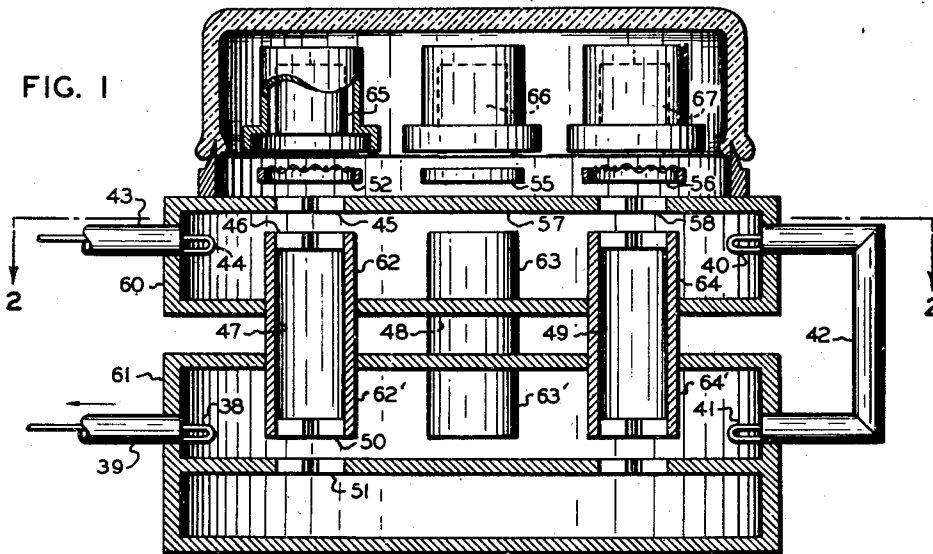


FIG. 4

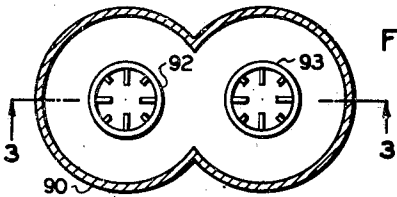


FIG. 2

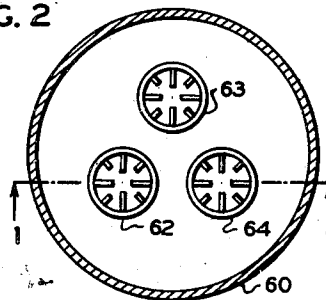
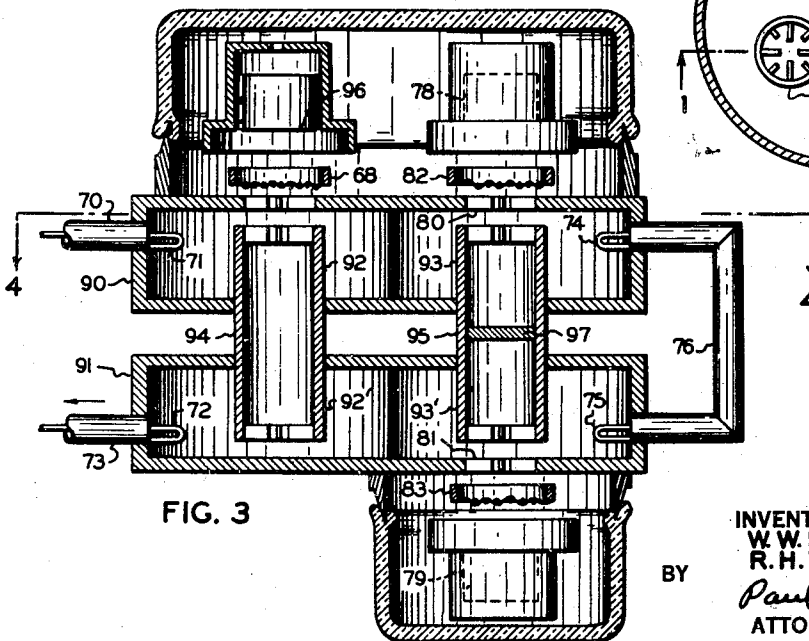


FIG. 3



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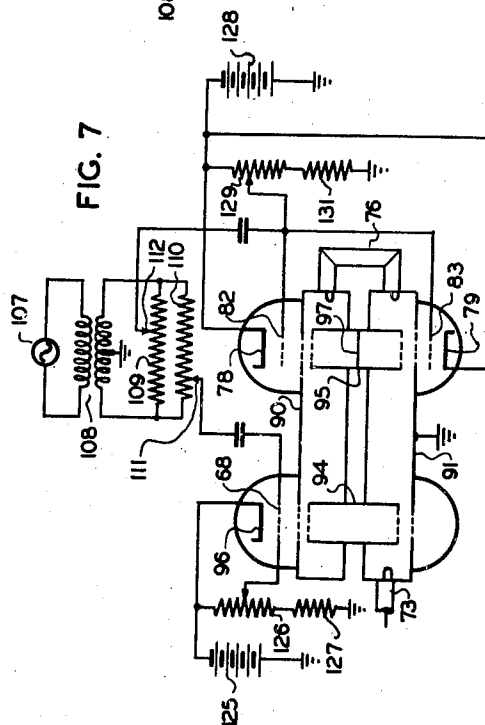
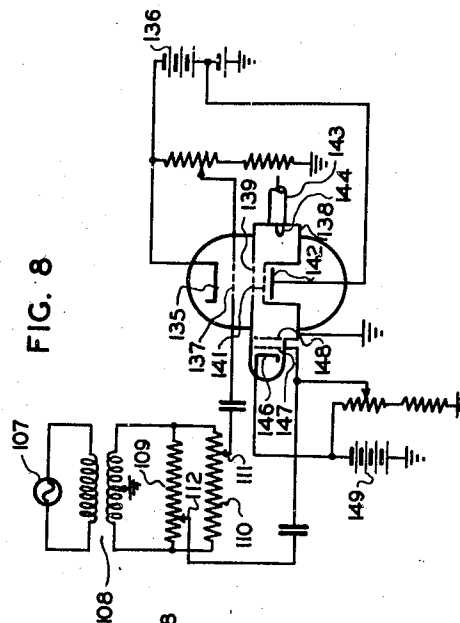
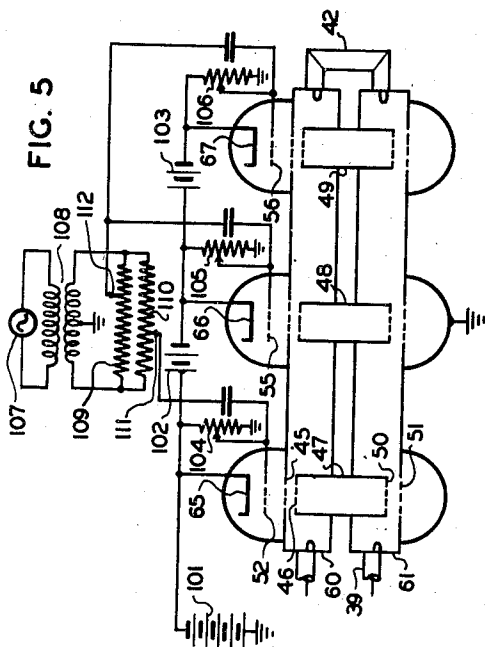
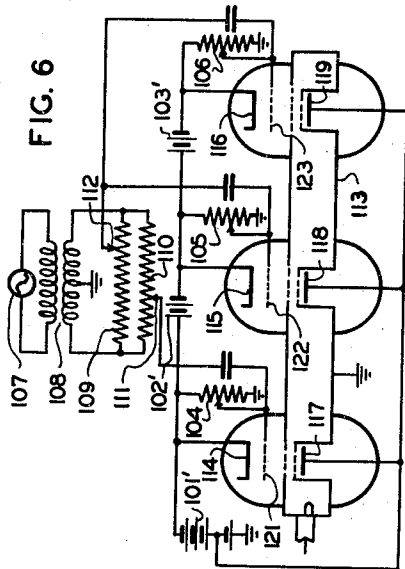
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FIG. 9

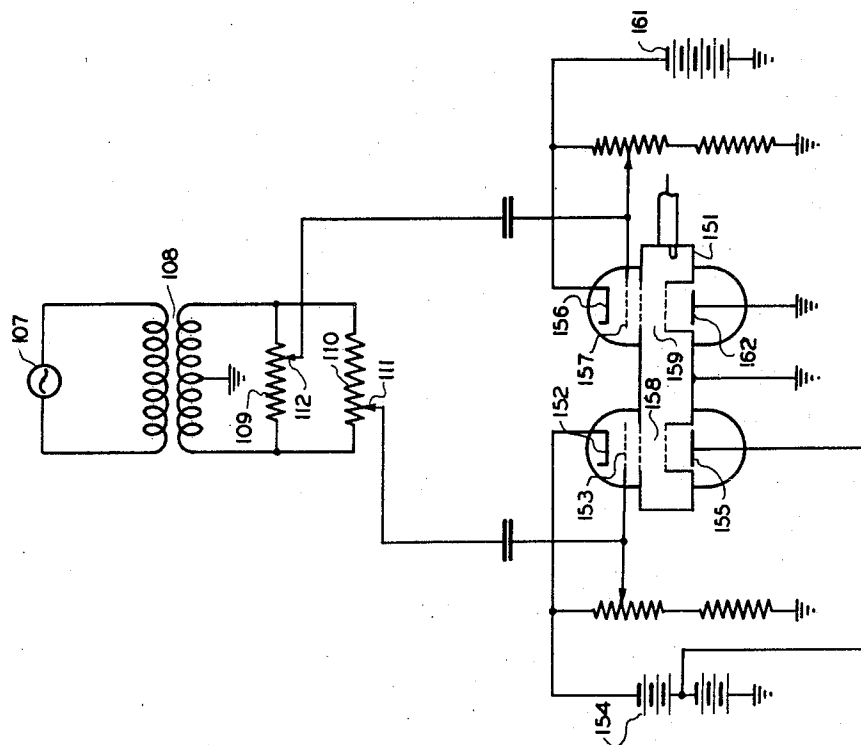
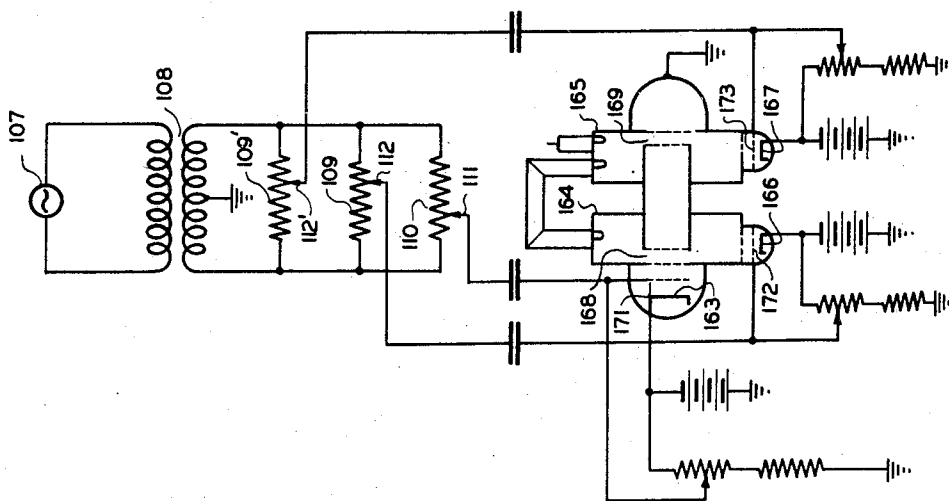


FIG. 10



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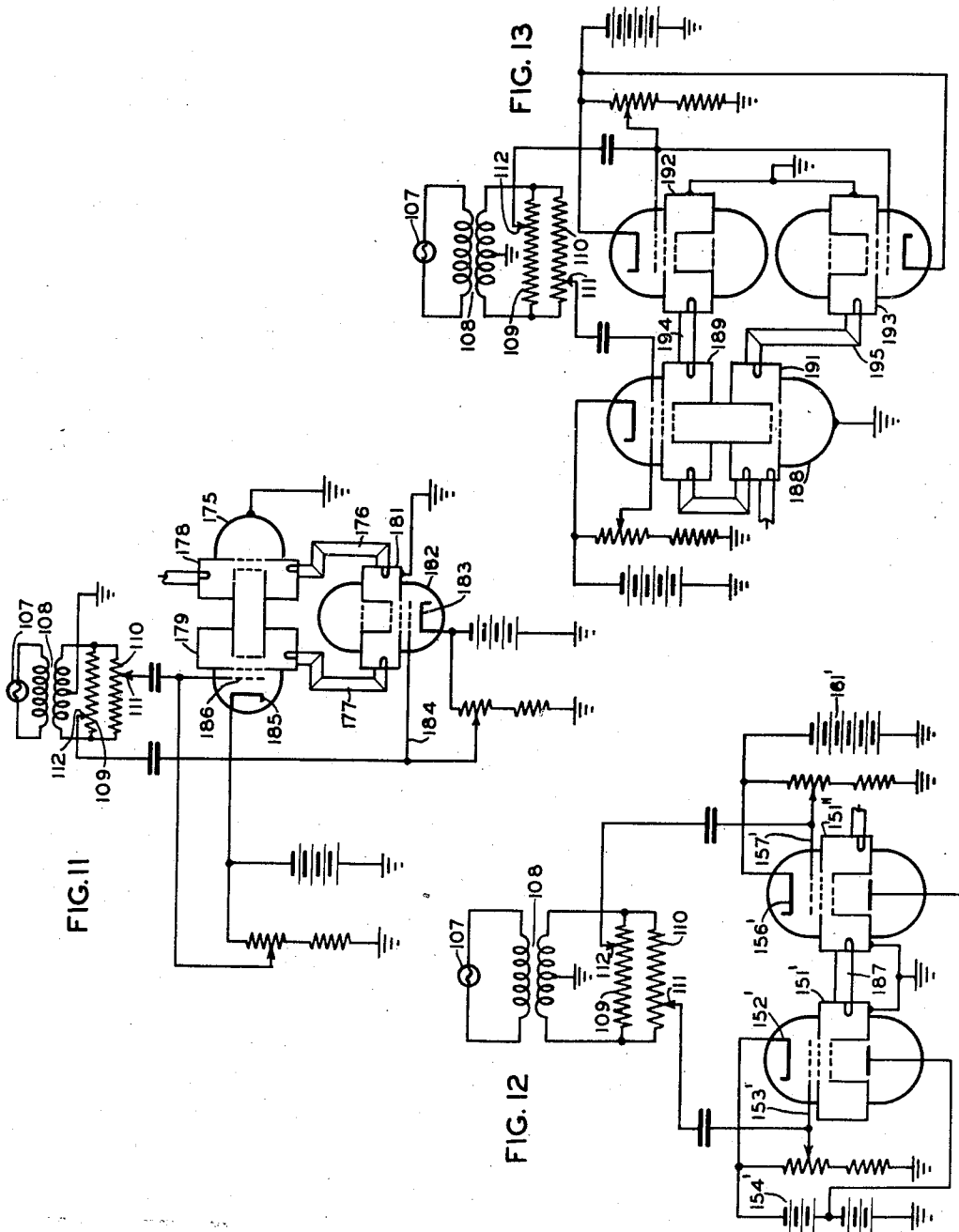
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HIGH-FREQUENCY MODULATING SYSTEM

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4 Sheets-Sheet 4



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UNITED STATES PATENT OFFICE

2,482,766

HIGH-FREQUENCY MODULATING SYSTEM

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Application December 30, 1942, Serial No. 470,678
In Great Britain July 1, 1942

34 Claims. (Cl. 332-17)

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This invention relates, generally, to the control of ultra high frequency electron beam velocity modulating tubes of the type disclosed in U. S. Patent No. 2,242,249, entitled "Electrical converter," issued May 20, 1941, in the names of Sigurd F. Varian and William W. Hansen, and, more specifically, to novel modulation means by which pure amplitude or frequency modulation can be obtained using such velocity modulation tubes.

This application is a continuation-in-part of copending application Serial No. 420,770, entitled "Electronic tuning control," filed November 28, 1941, and now U. S. Patent No. 2,439,387, issued April 13, 1948. Part of the subject matter of invention shown in this application is also shown and claimed in two copending divisional applications in the names of the same inventors, one of which is application Serial No. 584,660, entitled "High-frequency modulating system," filed March 24, 1945, and the other is application Serial No. 586,007, entitled "High-frequency modulating system," filed March 31, 1945.

As is shown in U. S. Patent No. 2,281,935, entitled "Modulation system," issued May 5, 1942, in the names of Russell H. Varian and William W. Hansen, electron beam velocity modulating tubes may have their carrier outputs modulated by signal frequencies. The most generally employed methods of modulation have been either to insert the signal voltage in series with the beam acceleration voltage or to supply the signal voltage to a fine wire mesh control grid interposed between the cathode and the entrance grid of the first resonator of the tube. If the action takes place in an oscillator tube, frequency as well as amplitude modulation will result.

One cause of frequency modulation depends on the well known fact that a space filled with electrons has a dielectric constant which differs from the dielectric constant of free space. A variation of the electron beam current by a signal voltage on the control grid alters the dielectric constant of the resonators through which the beam passes thus changing the effective tuning capacity and introducing a frequency change. A second source of frequency modulation lies in the change of phase between the driving voltage and the feedback voltage when the beam velocity is altered by a signal voltage in series with the beam acceleration voltage. The condition that oscillation occurs when the phase angle around the complete regenerative circuit is equal to some integral number times 2π radians indicates that any change in the transit time in the bunching

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space due to changes in acceleration voltage must be accompanied by a change in the phase angle between "buncher" and "catcher" resonators. This implies a frequency change accompanying the change in acceleration voltage. It is to be understood that frequency modulation will not occur in a modulated amplifier which is isolated from the oscillator by a buffer resonator. This procedure is, however, often undesirable since three more resonators are added which complicate the apparatus and greatly increase the tuning problem.

On the other hand, under some circumstances, due to the sharpness of the resonance curves of the resonators themselves, it is difficult to produce a pure frequency modulated carrier without simultaneous amplitude modulation.

It has been disclosed in above-mentioned Patent No. 2,281,935 that pure amplitude modulation or pure frequency modulation may be obtained by using combinations of acceleration voltage modulation and beam current modulation of the proper amount and in the correct phase relationship. This has the disadvantage, however, that acceleration voltage modulation requires a large signal amplitude and abstracts power from the signal source.

It is, therefore, the principal object of the present invention to provide means for obtaining, as desired, either amplitude or frequency modulation in ultra high frequency oscillators of the electron beam velocity modulating type without the simultaneous occurrence of the undesired form of modulation.

Another object is to provide means for obtaining pure amplitude or pure frequency modulation with moderate amplitude signals and negligible signal power consumption by impressing the signal upon the control grids of a plurality of electron beams coacting with coupled electromagnetic fields.

Still another object is to modify the modulation characteristics of an electron beam velocity modulating tube by altering the dielectric constant within one or more resonators of the device with one or more auxiliary electron beams.

A further object of the present invention lies in the provision in an ultra high frequency electron beam velocity modulating tube of an auxiliary electron beam or beams adapted to maintain the average electron density within common resonator or resonators substantially constant when the average electron density of the main electron beam is modulated by a signal voltage.

A still further object lies in the provision in

an ultra high frequency electron beam velocity modulating tube of an auxiliary beam or beams adapted to vary the average electron density within a common resonator or resonators at a signal frequency while the average electron density of the main electron beam remains substantially constant.

Yet another object is to provide means for obtaining frequency modulation without simultaneous amplitude modulation in an ultra high frequency electron beam velocity modulating device comprising means for creating and controlling a pair of auxiliary electron beams whose intensity is varied in accordance with a signal voltage while the electron groupings of the auxiliary beams are maintained in phase opposition with each other, thus substantially cancelling the effect of the auxiliary beams on the high frequency field but serving to vary the average electron density within a common resonator or resonators at the signal frequency.

Another object is to provide means in an ultra high frequency tube of the character described for selectively obtaining either pure amplitude modulation or pure frequency modulation by a simple operational adjustment.

Still another object is to provide means for producing amplitude modulation without simultaneous frequency modulation in an ultra high frequency electron beam velocity modulating device, comprising means for creating and controlling a pair of auxiliary electron beams whose intensity is varied in accordance with a signal voltage in predetermined phase relation with respect to the intensity variation of the main electron beam while the electron groupings of the auxiliary beams are maintained in phase opposition with each other, thus substantially cancelling the effect of the auxiliary beams on the high frequency field but serving to maintain the average electron density within a common resonator or resonators substantially constant.

Yet a further object is to provide, in an electron beam velocity modulating oscillator having a cavity resonator, means for controlling the average electron density within the resonator in accordance with a signal wave either to produce or to compensate for changes in the resonant frequency of the oscillator without imparting energy to the high frequency field therein comprising means for projecting an electron beam through the high frequency field of the resonator, and grid means for controlling the beam current, the beam being so directed as to be collected by the side of the resonator or other collector means without providing feedback coupling with the field.

Other objects and advantages will become apparent from the specification, taken in connection with the accompanying drawings wherein the invention is embodied in concrete form.

In the drawings,

Fig. 1 is a longitudinal section view of a novel multi-beam two resonator form of the modulator-oscillator of the present invention taken along cutting plane line 1—1 of Fig. 2.

Fig. 2 is a cross-section of the structure of Fig. 1 taken along the cutting plane line 2—2 of Fig. 1.

Fig. 3 is a longitudinal section of an alternative form of the modulator-oscillator of the present invention taken along cutting plane line 3—3 of Fig. 4.

Fig. 4 is a cross-section of the structure of Fig. 3 taken along the cutting plane line 4—4 of Fig. 3.

Fig. 5 is a schematic wiring diagram of the device illustrated in Fig. 1.

Fig. 6 is a schematic wiring diagram of a single resonator or reflex type of multi-beam modulator-oscillator.

Fig. 7 is a schematic wiring diagram of the device shown in Fig. 3.

Fig. 8 is a schematic wiring diagram of an alternative form of reflex type of multi-beam modulator-oscillator.

Fig. 9 is a schematic wiring diagram of a modification of the device shown in Fig. 6.

Fig. 10 is a schematic wiring diagram of an alternative form of two-resonator modulator-oscillator.

Fig. 11 is a schematic wiring diagram of an embodiment of the invention employing electronic tuning means in the feedback coupling between resonators of conventional two-resonator electron beam velocity modulating tube.

Fig. 12 is a schematic wiring diagram of a modification of the device shown in Fig. 9.

Fig. 13 is a schematic wiring diagram of a modification of the device shown in Fig. 7.

Similar characters of reference are used in all of the above figures to indicate corresponding parts.

It has been demonstrated mathematically and verified experimentally that the presence of free electrons within an electric field may either increase or decrease the dielectric constant of the space containing these charges from the unity value of a pure vacuum. For example, it is observed in the study of the ionosphere that the dielectric constant may be reduced to zero and even reversed in sign by the action of the electrons. The effect is mathematically very complex but it is a function, among others, of the electron density, the frequency of the electric field, and the transit time of the electrons passing through the field. In general, it may be said that if the electrons are projected in a low velocity beam and remain within the electric field for a duration long compared to a cycle of the field frequency, the dielectric constant is decreased by their presence. Contrarily, electrons projected through the electric field at a high velocity in a time short compared to a cycle of the field frequency cause an increase in the dielectric constant. The ionosphere exhibits the former effect while most electron velocity modulating devices exhibit the latter effect since electrons remain in the impressed electric fields for long and short durations, respectively. In the present invention both modes of operation are contemplated, and therefore, operating conditions stated for explanatory purposes are not to be considered in any way to limit the device to the exclusive employment of either high or low velocity electron beams.

Referring now to Fig. 1, there is shown a two-resonator velocity modulation tube of the type disclosed in copending application Serial No. 451,796, entitled "High-frequency tube structure," and filed July 21, 1942, in the name of William W. Hansen, in which a plurality of electron beams are projected through a plurality of reentrant poles containing grids and spaced symmetrically within the resonators. The multi-beam tubes described in the aforementioned application were utilized as frequency shifters or as balanced modulators, but in the present invention they are adapted to produce pure amplitude or pure frequency modulation of the ultra high frequency carrier.

The device illustrated in Fig. 1 is provided with a "buncher" resonator 60 and a "catcher" resonator 61 connected by three symmetrically spaced

drift tubes 47, 48 and 49. Drift tubes 47, 48 and 49 provide reentrant members 62, 63 and 64, respectively, in resonator 60 and similar members 62', 63, and 64' in resonator 61. Tube 47 is shielded by an exit grid 46 of resonator 60 and by an entrance grid 50 of resonator 61 to form a substantially field free space. Tubes 48 and 49 are of similar construction. Fig. 2 shows the placement of the drift tubes relative to the resonator 60. Resonator 60 has entrance grids 45, 57 and 58 placed opposite the reentrant members 62, 63 and 64, respectively, while resonator 61 has an exit grid 51 positioned opposite member 62' and similar grids opposite members 63' and 64'. Electron emissive cathodes 65, 66 and 67 are placed in line with entrance grids 45, 57 and 58, respectively, while control grids 52, 55 and 56, respectively, are interposed between these cathodes and their respective entrance grids. Supports for the cathode and grid structures are not shown for the sake of simplicity in the drawing since they are well known to the art. Coupling loop 41 in resonator 61 and loop 40 in resonator 60 are interconnected by coaxial line 42 to provide a feedback path between the resonators.

The operation of Fig. 1 may be more clearly understood with reference to Fig. 5. Electrons emitted from cathode 65 are accelerated by the voltage of a battery 101 placed between this cathode and entrance grid 45 and are projected through this grid. In the space between grids 45 and 46, the electrons are velocity modulated by an ultra high frequency electric field existing in the "buncher" resonator 60. The electrons pass through exit grid 46 down the drift tube 47 and arrive between grids 50 and 51 at a time when the velocity modulation has resulted in density modulation or grouping of the electrons. The arrivals of these bunches of electrons impart energy to an ultra high frequency electric field contained in the "catcher" resonator 61. A portion of the energy is fed back to resonator 60 by means of the coupling line 42, and thus the electromagnetic oscillations are maintained in a well known manner. The average intensity of the electron beam and therefore the amplitude of oscillation may be adjusted by potentiometer 104 supplying a bias voltage to the control grid 52.

Cathodes 66 and 67 provide electron beams which are also accelerated through resonator 60, drift tubes 48 and 49, respectively, and resonator 61. Voltage from a battery 101 in series with battery 101 is applied to cathode 66 while a potential from the series combination of a battery 103 and the batteries 101 and 102 is impressed on cathode 67. The difference between the acceleration voltages is such that the density groupings of these beams arrive at resonator 61 in phase opposition with each other, resulting in no contribution of energy to the high frequency field contained therein although these beams unavoidably remove some energy from resonator 60. Potentiometers 105 and 106 supply biasing voltages to grids 55 and 56, respectively, and are adjusted to maintain average electron currents from cathodes 66 and 67 preferably equal to each other and substantially one-half the intensity of the beam from cathode 65.

A signal source 107 is connected to the primary of an isolation transformer 108 whose secondary is center-tapped to ground and whose output terminals are loaded by potentiometers 109 and 110. Sliding contact 111 of potentiometer 110 is coupled through a blocking condenser to the grid 52 while a sliding contact 112 of the potentiometer

109 is connected by blocking condensers to grids 55 and 56.

Substantially pure amplitude modulation may be obtained from the device of Fig. 5 by adjusting the contact 112 to tap off modulation voltage for grids 55 and 56 approximately one-half the amplitude of and in reverse phase to the signal applied to grid 52. The average electron density of the three beams passing through resonators 60 and 61 is thus maintained substantially constant; consequently no frequency modulation due to the varying electrons density of the exciting beam from cathode 65 is produced. Since the amplitude of the high frequency field is essentially determined by the intensity of the exciting beam, the amplitude of the output wave supplied to coaxial line 39 is modulated substantially independently of the auxiliary beams. It is to be understood that the auxiliary beams from cathodes 66 and 67 need not be one-half the intensity of the exciting beam since the contact 112 may be empirically adjusted to obtain minimum frequency swing. While it is often desirable to employ low intensity auxiliary beams to avoid loading the resonators, it seems obvious that there are an unlimited number of adjustments of the intensity and degree of modulation of the auxiliary beams which will substantially neutralize the resonator detuning caused by the signal frequency variation of the exciting beam.

Substantially pure frequency modulation may also be obtained from the device of Fig. 5 by placing the tap 111 at the center of potentiometer 110 which corresponds to ground potential and impressing a full signal upon the control grids 55 and 56 of the auxiliary beams. Under these conditions, the resonant frequency of the oscillator is varied at the signal frequency without variation of the exciting beam intensity. In this manner, substantially no amplitude modulation is impressed upon the output wave. Predetermined amounts of amplitude and frequency modulation may, of course, be obtained by adjusting the signal voltages on grids 52, 55 and 56 to intermediate values.

The present invention may with equal ease be embodied in a form of single resonator modulator oscillator of the general type disclosed in U. S. Patent No. 2,250,511, entitled "Oscillator stabilization system," issued July 29, 1941, in the names of Russell H. Varian and William W. Hansen. Referring to Fig. 6, there is seen a reflex type of electron beam velocity modulating device that has a single resonator 113 which acts to both "bunch" and "catch" electron beams projected therethrough. Cathodes 114, 115 and 116 emit electron beams which are projected through the resonator 113 by accelerating voltages supplied from batteries 101', 102' and 103' connected in a manner similar to their unprimed counterparts in Fig. 5. Reflector plates 117, 118 and 119, maintained at an appropriate potential by a tap on the battery 101', are adapted to return the beams to resonator 113 after the velocity modulation of the electrons suffered by their initial passage through the resonator has resulted in density modulation of the beams. Because of the difference in acceleration potentials, the electron groupings of the beams from cathodes 115, 116 are in out of phase relation upon their second arrivals within the resonator 113, and therefore these beams contribute no energy to the ultra high frequency field contained therein. The beam from cathode 114 alone excites the resonator 113. Control grids

121, 122 and 123 are placed before the cathodes 114, 115 and 116, respectively, and it seems evident that signal voltages of proper magnitude and phase may be impressed upon these grids according to the teachings of Fig. 5 to obtain either pure amplitude modulation, pure frequency modulation, or calculable amounts of both types.

Referring now to Fig. 3 there is shown a type of two-resonator tube disclosed in above-mentioned copending application Serial No. 420,770 of which the present application is a continuation-in-part. As therein shown, the device comprises "buncher" and "catcher" resonators 90 and 91, respectively, containing reentrant members 92, 93 and 92', 93', respectively. The reentrant members 92 and 92' are formed by continuations of a drift tube 94 while members 93 and 93' are portions of a tube 95. The symmetrical placement of the tubes within the resonators is shown by the cross-section view of Fig. 4. A cathode 96 is placed in line with the drift tube 94 to enable an electron beam to be projected through the usual grid-shielded apertures in resonator 90 within which the beam is velocity modulated and thence supplied to resonator 91 which the beam excites in the conventional manner. Oscillation is sustained by positive feedback between resonators 91 and 90 consisting of a coaxial lead 76 attached to coupling loops 74 and 75 which couple to the fields of resonators 90 and 91, respectively. A coupling loop 72 and connected coaxial line 73 may be used to supply ultra high frequency power to utilization apparatus. A control grid 68 is interposed between cathode 96 and resonator 90, the conventional use of which as a modulation electrode gives rise to a mixture of amplitude and frequency modulation. The following means are provided to enable the modulation characteristics of the device to be altered at will.

Above resonator 90 is placed a cathode 78 before an entrance grid 80 lying opposite reentrant member 93. Likewise, below resonator 91 is placed a cathode 79 in front of an entrance grid 81 placed opposite reentrant member 93'. Positioned between cathode 78 and entrance grid 80 and between cathode 79 and entrance grid 81 are control grids 82 and 83, respectively. Tube 95 is divided by a transverse wall 97 which is adapted to collect and dissipate the energy of the electrons emitted by cathodes 78 and 79.

The operation of the device shown in Fig. 3 may be more clearly understood with reference to Fig. 7. A potential source 125, connected to the cathode 96, accelerates the exciting electron beam whose average intensity is adjusted by a variable bias voltage on the control grid 68 obtained from a potentiometer 126 in series with a grid load resistor 127 placed across the voltage source 125. Electron beams from cathodes 78 and 79 are likewise accelerated by a battery 128 across which is connected a potentiometer 129 in series with a grid load resistor 131. Control grids 82 and 83 are maintained at a desired bias voltage by the potentiometer 129. Since the electron beams from cathodes 78 and 79 do not couple with both resonators but are collected on wall 97 after only a single passage through a single resonator, they cannot contribute to the ultra high frequency field though they load the resonators slightly and alter their resonant frequency. Tap 111 on potentiometer 110 supplies the signal voltage to grid 68 while tap 112 on

potentiometer 109 supplies the signal voltage to grids 82 and 83.

Substantially pure amplitude or pure frequency modulation may be obtained from the device shown in Fig. 7. A signal wave may be readily impressed on the grids 82 and 83 with an amplitude and phase such that the electron beams from cathodes 78 and 79, respectively, alter the resonant frequency of resonators 90 and 91, respectively, in an opposite direction to the detuning of these resonators by the modulated exciting electron beam and to a substantially equal extent. If the velocities of the exciting and auxiliary beams are greatly different, like changes in beam intensities may have opposite effects on the dielectric constant of the resonators as mentioned above. Under these conditions the modulating and corrective signal waves are impressed on the control grids in like phase in order to cancel frequency modulation. Substantially pure frequency modulation, on the other hand, may be obtained by removing the signal wave from grid 68. If desired, either one of the auxiliary beams may be eliminated and the frequency control accomplished solely in one resonator.

Referring now to Fig. 8, there is seen a type of reflex electron beam velocity modulating tube of the type shown in U. S. Patent No. 2,250,511 but having a transverse electron control beam similar to that disclosed in above-mentioned copending application Serial No. 420,770. The device comprises an electron emissive cathode 135 from which an electron beam is accelerated by the potential from a battery 136 through a mesh control grid 137 and thence through a resonator 138 having entrance and exit grids 139 and 141, respectively. Behind exit grid 141 is mounted a reflector plate 142 supplied with a voltage from a tap on the battery 136. The electron beam is reflected back into the resonator 138 where it maintains an ultra high frequency field in the well known manner. A coaxial line 143 attached to a coupling loop 144 is adapted to remove energy from the resonator 138.

Attached to the side of resonator 138 is a means for producing an electron beam transverse to the electric field of the resonator. A cathode 146 of this device produces an electron beam which is accelerated through a mesh control grid 147 and through a grid 148 in the side wall of resonator 138 by a voltage supplied by a battery 149, so that the beam passes substantially at right angles to the electron beam from cathode 135 and between resonator grids 139, 141, preferably without impinging on these latter grids or the resonator walls. Loop 144 and line 143 are shown in the plane of the paper for convenience in drawing, but would preferably be located so that the beam from cathode 146 would not strike them. The modulation control grids 137 and 147 are connected to the taps 111 and 112, respectively, of the potentiometers 110 and 109, respectively.

In operation, the beam from cathode 146 contributes no energy to aid in maintaining the oscillating electromagnetic field within the resonator; in fact, it unavoidably extracts a small amount of energy. If the beam current intensity from cathode 135 is increased, there results an increase in the amplitude of oscillation of the electromagnetic field and a decrease in its frequency as a consequence of the tuning effect on the resonator. An increase in the beam current from cathode 146, however, produces a decrease

in output, due to its effect in loading the resonator, as well as a decrease or increase in output frequency dependent upon whether the control beam has a positive or negative effect on the dielectric constant of the resonator. Predetermined amounts of amplitude and frequency modulation may be obtained, therefore, by the amplitude and phase adjustment of the signal voltages on the control grids 137 and 147.

Fig. 9 illustrates an alternate form of the present invention wherein a reflex type of ultra high frequency oscillator has an auxiliary electron beam projected at preferably a low velocity parallel to the exciting electron beam. A resonator 151 of the device of Fig. 9 has a cross-section similar to that shown in Fig. 4. Cathode 152 provides an electron beam whose intensity is controlled by a grid 153 and which is accelerated by a battery 154 through entrance and exit grids 158 in the resonator 151. A reflector electrode 155 maintained at an appropriate voltage by a tap on the battery 154 returns the beam to the resonator 151 which is excited thereby in the usual manner. Cathode 156 emits electrons which are projected by the acceleration voltage of a battery 161 past control grid 157, and through a second pair of entrance and exit grids 159 in the resonator 151. The beam from cathode 156 is dissipated by a collector electrode 162 and therefore supplies no energy to the ultra high frequency field. Grids 153 and 157 are coupled to the signal source 107 by means of taps 111 and 112, respectively, of the potentiometers 110 and 109, respectively. The modulation characteristics of this device may be altered in a similar manner to the devices previously discussed.

Fig. 10 shows a form of the invention in which auxiliary electron beams are provided in a two-resonator device projecting substantially transversely of the electric fields in resonators. A cathode 163 emits an electron beam which is employed to excite resonators 164 and 165 in the well known manner. Cathodes 166 and 168 provide electron beams in resonators 164 and 165, respectively, which pass transversely between the grid structures 168 and 169, respectively, and thus contribute no energy to these resonators. Grids 171, 172, 173 are positioned before cathodes 163, 166, and 167, respectively, to control the intensities of the respective beams. Grids 171 and 172 are coupled to taps 111 and 112, respectively, of potentiometers 110 and 109, respectively, while grid 173 is supplied the signal wave from a tap 112' on a potentiometer 109' placed in parallel with the potentiometers 109 and 110. It seems evident that for any given set of beam velocities the signal waves on the control grids may be adjusted to obtain a minimum of undesired modulation of the generated ultra high frequency wave. Either of the auxiliary beams may be dispensed with if a reduction in the extent of frequency compensation or frequency modulation is immaterial.

Fig. 11 illustrates means for obtaining either pure amplitude or pure frequency modulation from a conventional two-resonator electron beam velocity modulating tube 175. Device 175 has feedback coupling means comprising coaxial lines 176 and 177 individually coupled to "catcher" and "buncher" resonators 178 and 179, respectively, of tube 175 and having common coupling with a resonator 181. Resonator 181 is a portion of an electronic tuning device 182 of the general type disclosed in above-mentioned application Serial No. 420,770. An electron beam

from a cathode 183 is projected through the resonator 182 for tuning purposes only. A control grid 184 placed before cathode 183 is adapted to control the beam intensity and thus the resonant frequency of the resonator 181. It seems evident that an ultra high frequency field will be set up in resonator 181 when tube 175 is excited by an electron beam from cathode 185. A control grid 186 may be employed to modulate the electron beam from cathode 185 with a signal from source 107 while the beam from cathode 183 may be likewise modulated by the same signal adjusted as desired in amplitude and phase with respect to the first-mentioned modulating voltage. An alteration of the resonant frequency of resonator 181 effects a change in the frequency of oscillation of the tube 175 dependent upon the coupling coefficients between resonator 181 and resonators 178 and 179 and the efficiencies of the resonators. The structure of Fig. 11 may thus be utilized in a manner similar to the previously discussed devices to produce any desired amount of either or both types of modulation. Resonator 181 is illustrated as reentrant, but it is to be understood that this resonator may have other forms. For example, resonator 181 may be a non-reentrant cylinder excited at its fundamental mode with the electric field parallel to the axis of symmetry. A high intensity low velocity electron beam may be projected across the cylinder perpendicular to the electric field for tuning purposes. This produces a high efficiency resonator from which the tuning electron beam abstracts little energy especially if the transit time across the resonator is large compared to the periodicity of the electromagnetic field.

Fig. 12 illustrates a modification of the device shown in Fig. 9 wherein the resonator 151 is separated into a driving resonator 151' and a tuning resonator 151'' coupled by a coaxial line 187. Resonator 151'', which may be similar to the resonators discussed with reference to Fig. 11, couples an impedance to resonator 151' in a manner analogous to simple coupled circuits. The operation of the device shown in Fig. 12 is similar to that of Fig. 9 and consequently needs no special explanation.

Fig. 13 illustrates a conventional two-resonator electron beam velocity modulating device 188 having a "buncher" resonator 189 and a "catcher" resonator 191 to which are coupled by coaxial lines 194 and 195 electronically tuned resonators 192 and 193, respectively. Resonators 192 and 193 have electron beams which may be modulated to vary the impedances coupled to resonators 189 and 191, respectively, thus altering the modulation characteristics of the device 188. If desired, one of the electronic tuning controls 192, 193 may be eliminated and all control effected with a single resonator.

It appears obvious that the teachings of the present invention may be extended to other types of electron beam velocity modulation devices that have radial shooting exciting beams, annular resonators, and similar structural modifications. The usual tuning arrangements may be employed with the illustrated embodiments of the present invention. Great latitude may be exercised in design of resonators, use of smoothing grids, employment of collector electrodes for mixer operation, and in similar engineering decisions.

As many changes could be made in the above construction and many apparently widely dif-

ferent embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A method of producing desired relative amounts of amplitude and frequency modulation simultaneously in an electron beam velocity modulating device ranging from substantially pure amplitude modulation to substantially pure frequency modulation, comprising the steps of projecting a plurality of electron beams through an electromagnetic field, at least one beam for maintaining the field and at least one beam for tuning purposes only, and varying the intensities of all said electron beams in accordance with the same signal waves with an amplitude and phase relationship correlated to the desired relative amounts of amplitude and frequency modulation of the electromagnetic field.

2. A method of producing desired relative amounts of amplitude and frequency modulation simultaneously in an electron beam velocity modulating device ranging from substantially pure amplitude modulation to substantially pure frequency modulation, comprising the steps of exciting an ultra high frequency electromagnetic field in said device by projecting an exciting electron beam therethrough, projecting an auxiliary electron beam solely for tuning purposes through at least a portion of the electromagnetic field created by said exciting electron beam, and modulating the intensities of both the electron beams in accordance with the same signal waves with an amplitude and phase relationship correlated to the desired relative amounts of amplitude and frequency modulation of the electromagnetic field.

3. A method of producing desired relative amounts of amplitude and frequency modulation simultaneously in an electron beam velocity modulating device ranging from substantially pure amplitude modulation to substantially pure frequency modulation, comprising the steps of producing an electromagnetic field by an electron beam, producing an auxiliary electron beam coupled to said field, and controlling said electron beams in accordance with signal waves having amplitude and phase relationships correlated to the desired relative amounts of amplitude and frequency modulation of said field.

4. A method of obtaining substantially pure modulation in an electron beam velocity modulating tube, comprising the steps of projecting an electron beam through said tube for exciting an oscillating field in the same, modulating the intensity of said beam in accordance with a signal, producing a second electron beam coupled to said field, and modulating said second beam to compensate for undesired modulation produced by said first beam.

5. A method of obtaining substantially pure amplitude modulation in an electron beam velocity modulating tube, comprising the steps of projecting an electron beam through the tube for exciting an oscillating field in the same, modulating the intensity of said beam in accordance with a signal, projecting a second beam through the field created by the exciting beam, and modulating the intensity of said beam in accordance with said same signal in a phase relation to said first-mentioned modulating process compensating for frequency modulation incurred by said modulating process.

6. A method of obtaining substantially pure amplitude modulation in an electron beam velocity modulating tube, comprising the steps of projecting an electron beam through said tube for exciting an oscillating field in the same, modulating the intensity of said beam in accordance with a signal, and maintaining the average electron density within said field constant to compensate for frequency modulation incurred by said first beam.

7. An electron beam velocity modulating device adapted to produce desired relative amounts of amplitude and frequency modulation comprising coupled resonator means, means for projecting an electron beam through at least one of said resonator means to excite electromagnetic oscillations within all said resonator means, means in said device for projecting an auxiliary electron beam through at least one of said resonator means to coact with said electromagnetic oscillations without imparting energy to said electromagnetic oscillations, and means for varying the intensities of the electron beams from said several projecting means in accordance with a signal wave, said last-mentioned means including a control electrode along the path of each of said beams and a source of signal wave coupled to all said control electrodes, said last-mentioned means being adapted to control the relative amplitudes and phases of said electron beam intensities in correlation with the desired relative amounts of amplitude and frequency modulation.

8. Means for simultaneously producing in an electron beam velocity modulating device desired relative amounts of amplitude and frequency modulation ranging from substantially pure amplitude modulation to substantially pure frequency modulation, comprising resonator means, means aligned therewith for projecting electrons through said resonator means to excite electromagnetic oscillations within the same, means for grouping said electrons at a predetermined frequency, auxiliary means also aligned therewith for projecting electrons to coact with the electromagnetic oscillations without imparting energy thereto, and means for varying the densities of the electrons from said several projecting means in accordance with a signal wave having a frequency substantially lower than said predetermined frequency, said last-mentioned means being adapted to control the relative amplitudes and phases of the electron densities in correlation with the desired relative amounts of amplitude and frequency modulation, and including respective control electrodes in the respective paths of said projected electrons, and a source of said signal wave coupled to said control electrodes.

9. Means for simultaneously producing in an electron beam velocity modulating device desired relative amounts of amplitude and frequency modulation ranging from substantially pure amplitude modulation to substantially pure frequency modulation, comprising resonator means, means aligned therewith for projecting an electron beam through said resonator means to excite an electromagnetic field within the same, means for grouping said electrons at a predetermined frequency, means aligned therewith for projecting an auxiliary electron beam through at least a portion of the electromagnetic field without imparting energy thereto, and means including a control electrode along the path of each of said beams and a source of signal wave coupled to said control electrodes, for varying the intensities of said electron beams in accordance with said

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signal wave having a frequency substantially lower than said predetermined frequency, said last-mentioned means being adapted to control the amplitude and phase relationship of said beam intensities in correlation with the desired relative amounts of amplitude and frequency modulation.

10. High frequency apparatus comprising a hollow cavity resonator having a plurality of electron-permeable portions, means for producing oscillations in said resonator comprising means aligned therewith for projecting a stream of electrons through one of said portions, means for grouping said electrons at a predetermined frequency, means for modulating said oscillations comprising means along the path thereof for controlling said stream in accordance with a modulation signal having a frequency substantially lower than said predetermined frequencies, and means for controlling the modulation of said oscillations comprising means aligned therewith for projecting a second stream of electrons through the other of said resonator portions, and means along the path thereof for controlling said second stream by said same signal.

11. Modulation control apparatus comprising resonator means, means for exciting oscillations within said resonator means including means aligned therewith for projecting an electron beam therethrough and means for grouping said electrons at a predetermined frequency, means for producing an auxiliary electron beam coupled to said oscillations, and means along the paths thereof for controlling said electron beams in accordance with signal waves to produce desired amounts of different types of modulation of said oscillations, said signal waves having a frequency substantially lower than said predetermined frequency.

12. Modulation control apparatus comprising means for producing an electromagnetic field including means for grouping electrons at a predetermined frequency and means for projecting said grouped electrons therethrough, means for producing an auxiliary electron beam coupled to said field, means along the path thereof for controlling said first electron beam in accordance with a modulation signal to produce modulation of said field, said modulation signal having a frequency substantially lower than said predetermined frequency, and means for modifying said modulation comprising means along the path thereof for controlling said auxiliary beam by said same modulation signal.

13. Modulation control apparatus comprising means for grouping electrons at a predetermined frequency, means for producing an oscillating electromagnetic field, means for producing modulation of the oscillations of said field in accordance with a modulation signal having a frequency substantially lower than said predetermined frequency, means for producing an electron beam coupled with said field, and means for modifying said modulation comprising means along the path thereof for controlling said beam.

14. An electron velocity modulating vacuum device for producing ultra high frequency oscillations comprising means for producing a primary electron beam, a buncher resonator, a catcher resonator, said primary beam producing means and said buncher resonator and said catcher resonator being located in axial consecution, means for modulating the intensity of said primary electron beam with a first signal, means in said device for projecting auxiliary elec-

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tron beams through said buncher and catcher resonators having respective electron groupings phase displaced to substantially cancel energy interchange of the auxiliary beams with the high frequency field, and means along the paths of said auxiliary beams for modulating the intensity of said auxiliary beams with said first signal in opposite phase to the modulation of said primary beam to maintain the average electron density in the resonators substantially constant.

15. An electron velocity modulating vacuum tube for producing ultra high frequency oscillations comprising a buncher resonator, a catcher resonator, means for projecting a primary electron beam successively through said buncher and catcher resonators, means in said tube for projecting through said resonators auxiliary electron beams having respective electron groupings mutually phase displaced to substantially cancel energy interchange of the auxiliary beams with the high frequency field within the catcher resonator, and means along the paths of said auxiliary beams for modulating the intensity of the auxiliary beams in accordance with a signal, thus varying the resonant frequency of the resonators at the signal frequency.

16. In an electron beam velocity modulating vacuum tube of the reflex type having a single resonator adapted to both bunch an electron beam projected therethrough and to catch the beam upon being subsequently reflected back thereto, thereby producing ultra high frequency oscillations, the combination comprising means aligned therewith for projecting auxiliary electron beams through the resonator having electron groupings phase displaced to cancel any substantial energy-interchange of the auxiliary beams with the high frequency field within the resonator, and means along the beam paths for varying the intensities of the auxiliary beams in accordance with an alternating signal thus altering the resonant frequency of the resonator at the signal frequency.

17. In an electron beam velocity modulating vacuum tube having a single resonator adapted to both velocity modulate an electron beam projected therethrough and to be electromagnetically excited by the same beam upon subsequent reflection of the latter in density modulated form back thereto, the combination comprising means along the path thereof modulating the intensity of said exciting electron beam with a signal, means aligned therewith for projecting auxiliary beams through the resonator having electron groupings phase displaced to substantially cancel energy-interchange of said auxiliary beams with the high frequency field within the resonator, and means along the beam paths for modulating the intensity of said auxiliary beams with said same signal to maintain the average electron density in the resonator substantially constant.

18. In an electron velocity modulating vacuum tube, buncher and catcher resonators, means intercoupling said buncher and catcher resonators to produce ultra high frequency oscillations, means in said tube for projecting an electron beam through said resonators, means for varying the intensity of said electron beam in accordance with a signal, means for projecting an auxiliary electron beam through one of the resonators, and means along the path of said auxiliary beam for varying the intensity of said auxiliary beam in accordance with said signal to maintain the average electron density in said one resonator substantially constant.

19. In an electron velocity modulating vacuum tube, buncher and catcher resonators coupled to produce ultra high frequency oscillations, means in said tube for projecting an electron beam through said resonators, means along the path of said beam for modulating the intensity of said beam with a signal, and means in said tube for maintaining the average electron density in said resonators substantially constant.

20. In an electron beam velocity modulating vacuum tube having a single resonator adapted to both velocity modulate an electron beam projected therethrough and to be electromagnetically excited by the same beam upon subsequent reflection of the latter in density modulated form back thereto, the combination comprising means along the path thereof for varying the intensity of said exciting electron beam in accordance with a signal, means aligned therewith for projecting an auxiliary electron beam through the resonator, and means along the path thereof for varying the intensity of said auxiliary electron beam in accordance with said same signal to maintain the average electron density in the resonator substantially constant.

21. Modulation control apparatus comprising means for producing an electromagnetic field, including a hollow cavity resonator, means aligned therewith for projecting an electron beam therethrough, and means along the path thereof for reversing said beam to reenter said resonator; means for producing an auxiliary electron beam coupled to said field, means along the path thereof for controlling said first electron beam in accordance with a modulation signal to produce modulation of said field, and means for modifying said modulation comprising means along the path thereof for controlling said auxiliary beam by said modulation signal.

22. High frequency apparatus comprising a hollow cavity resonator having a plurality of electron permeable portions, means for producing oscillations in said resonator comprising means aligned therewith for projecting a stream of electrons through one of said portions and for reversing said stream to reenter said resonator, means for modulating said oscillations comprising means along the path thereof for controlling said stream in accordance with a modulation signal, and means for controlling the modulation of said oscillations, comprising means aligned therewith for projecting a second stream of electrons through the other of said resonator portions, and means along the path thereof for controlling said second stream by said signal.

23. High frequency apparatus, comprising a velocity modulation device having means defining a pair of spaced electromagnetic field regions and means in said apparatus for projecting a first electron beam successively through said regions; and means for coupling said regions, including a cavity resonator coupled to each of said regions and means in said apparatus for controlling the resonant frequency of said cavity resonator, said frequency controlling means including means for projecting a second electron beam within said cavity resonator.

24. Apparatus as in claim 23, further comprising a source of modulation signal, and means coupled to the path of said second beam for controlling said second beam by said signal to produce modulation of said fields of said regions.

25. Apparatus as in claim 24, further comprising means coupled to the path of said first beam

for additionally controlling said first electron beam in response to said modulation signal.

26. High frequency apparatus comprising a velocity modulation electron discharge device having a cavity resonator, means for grouping electrons at a predetermined frequency, means for modulating the output of said device in accordance with a modulation signal, having a frequency substantially lower than said predetermined frequency, and means for controlling the modulation of said output, comprising a second cavity resonator coupled to said first resonator, means aligned therewith for projecting a beam of electrons through said second resonator, and means along the path thereof for controlling said beam by said signal.

27. High frequency apparatus comprising a pair of hollow cavity resonators, means adjacent one of said resonators for projecting an electron stream successively through said resonators to produce high frequency oscillations in the second resonator thereof, means along the path of said stream for controlling said stream by a modulation signal to produce modulation of said oscillations, and means in said apparatus for controlling the modulation of said oscillations, comprising a further cavity resonator coupled to one of said first named resonators, means coupled to said further cavity resonator for projecting a stream of electrons through said further resonator, and means coupled to the path of said latter stream for controlling said latter stream by said signal.

28. High frequency apparatus as in claim 27, wherein said further cavity resonator is coupled to both said first named resonators.

29. High frequency modulating apparatus comprising a pair of cavity resonators, means aligned therewith for projecting an electron stream successively in energy-exchanging relation with said resonators, and feedback means coupling said resonators, said feedback means including a third cavity resonator coupled to both of said pair of resonators, means adjacent said third resonator for projecting a second electron stream through said third resonator, and means coupled to the path of said second stream for controlling said second stream in accordance with modulating signals.

30. High frequency modulating apparatus comprising a high frequency oscillator having a cavity resonator and an output coupled to said resonator, and means in said apparatus for frequency modulating said output, comprising a second cavity resonator coupled to said first cavity resonator, means adjacent said second resonator for projecting an electron stream through said second resonator, and means along the path of said stream for controlling said stream by modulating signals.

31. High frequency modulating apparatus comprising a high frequency oscillator having a cavity resonator and an output coupled to said resonator, and means coupled to said oscillator for modulating said output, comprising a second cavity resonator coupled to said first resonator and means adjacent said second resonator for varying the tuning of said second resonator in accordance with a modulating signal.

32. High frequency apparatus comprising a cavity resonator, means in said apparatus for passing a fast stream of electrons through said resonator for producing oscillations therein, and means in said apparatus for projecting a relatively slow stream of electrons through said resonator for tuning control, and means adjacent the

paths of said streams controlling both said streams by a modulating signal.

33. High frequency modulating apparatus comprising means for producing modulated ultra high frequency oscillations, said oscillation producing means including a first cathode, a first modulating grid, a buncher resonator and a catcher resonator, all located in axial consecution; a further cavity resonator coupled both to said buncher resonator and said catcher resonator, said further cavity resonator having a second cathode and a second modulating grid, said first and second modulating grids being adapted to be connected to a modulating signal source, whereby predetermined relative amounts of amplitude and frequency modulation are obtained.

34. High frequency modulating apparatus comprising a velocity modulation tube having a first cathode, a buncher resonator and a catcher resonator; and means for producing predetermined relative amounts of amplitude and frequency modulation, said modulation producing means comprising a first modulating grid interposed between said first cathode and buncher resonator, a further cavity resonator coupled both to said buncher and catcher resonators, said further cavity resonator having a second cathode and a second modulating grid both aligned therewith,

said first and second modulating grids being adapted to be connected to the common modulation signal source.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,200,986	Fraenckel	May 14, 1940
2,259,690	Hansen et al.	Oct. 21, 1941
2,278,210	Morton	Mar. 31, 1942
2,283,895	Mouromtseff et al.	May 19, 1942
2,294,942	Varian et al.	Sept. 8, 1942
2,317,140	Gibson	Apr. 20, 1943
2,329,780	Zalesak	Sept. 21, 1943
2,338,237	Fremlin	Jan. 4, 1944
2,381,320	Tawney	Aug. 7, 1945
2,406,370	Hansen et al.	Aug. 27, 1946
2,407,667	Kircher	Sept. 17, 1946

FOREIGN PATENTS

Number	Country	Date
114,102	Australia	Oct. 22, 1941