Sept. 10, 1957 C. L. CUCCIA 2,806,172

HIGH FREQUENCY COUPLING AND MODULATING APPARATUS

Filed March 19, 1951 3 Sheets-Sheet 1

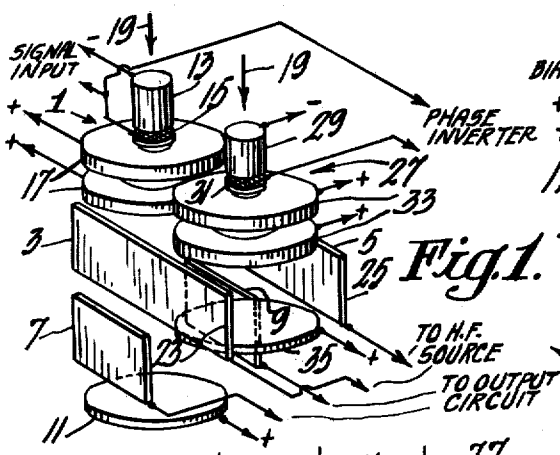


Fig. 1.

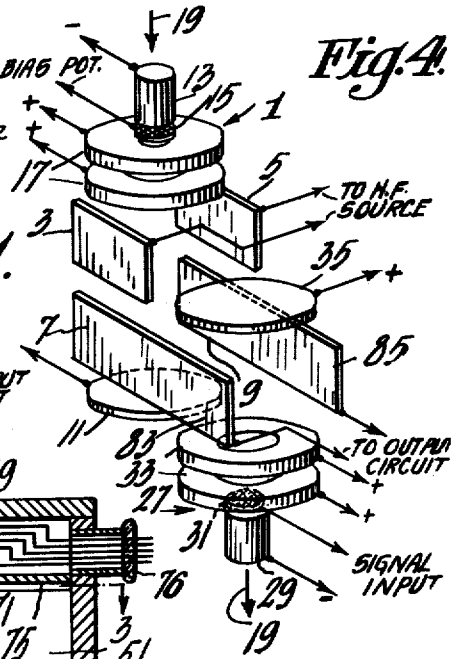


Fig. 4.

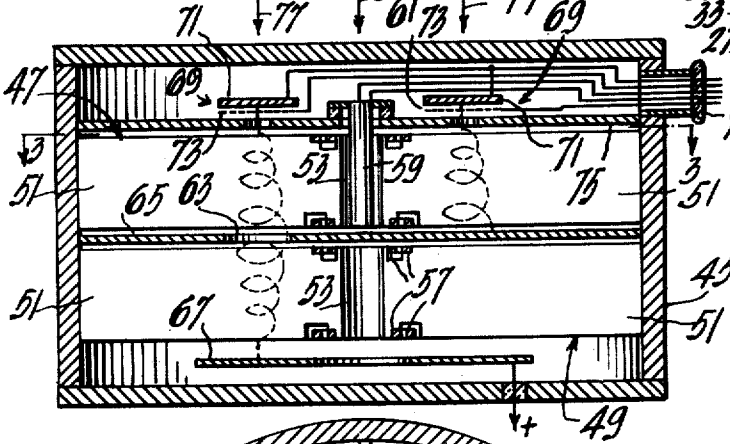


Fig. 2.

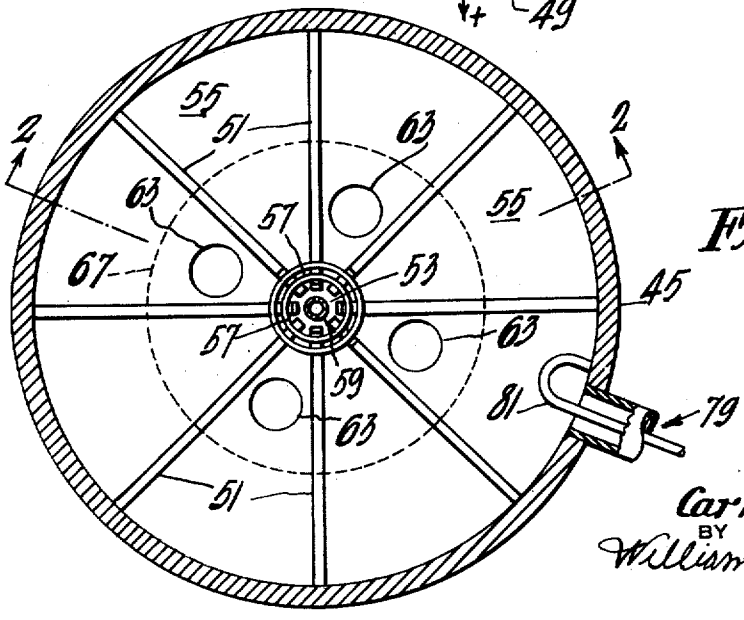


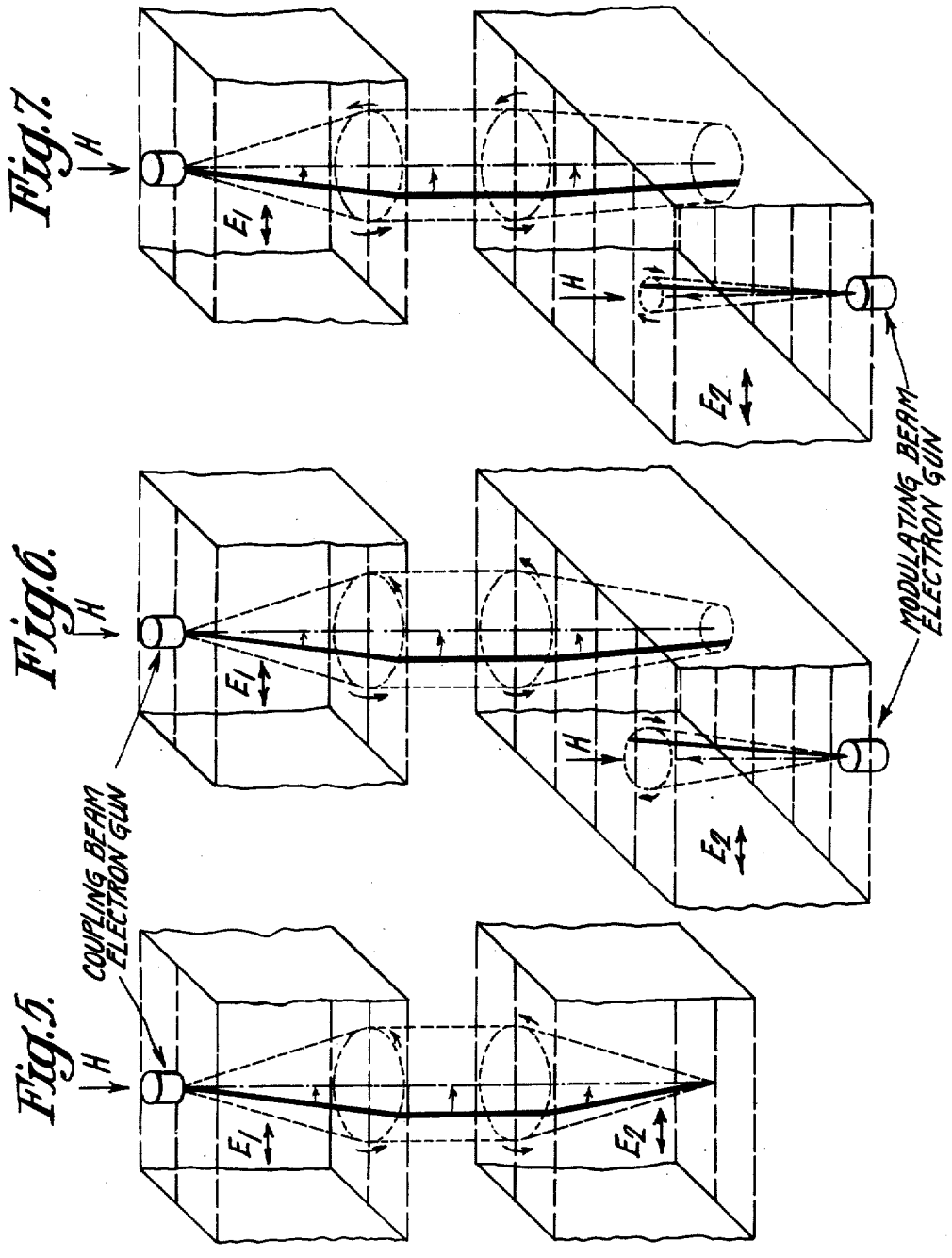
Fig. 3.

INVENTOR
Carmen L. Cuccia
BY
William A. Palesch
ATTORNEY

Sept. 10, 1957 C. L. CUCCIA 2,806,172

HIGH FREQUENCY COUPLING AND MODULATING APPARATUS

Filed March 19, 1951 3 Sheets-Sheet 2



INVENTOR
Carmen L. Cuccia
BY
William A. Galeski
ATTORNEY

Sept. 10, 1957 C. L. CUCCIA 2,806,172

HIGH FREQUENCY COUPLING AND MODULATING APPARATUS

Filed March 19, 1951 3 Sheets-Sheet 3

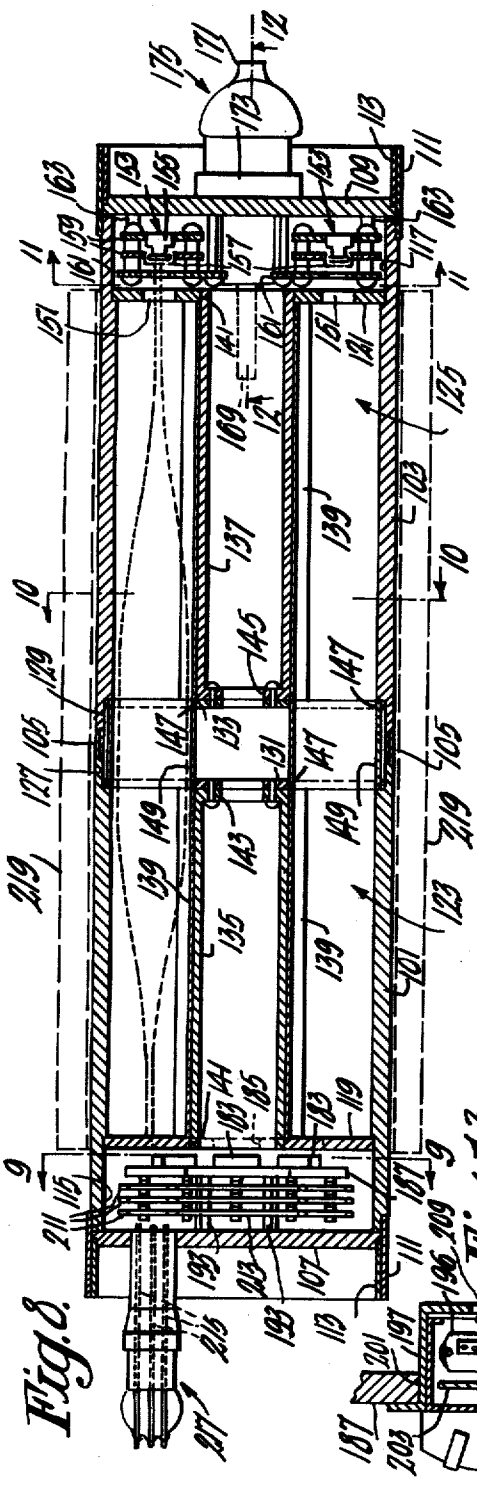


Fig. 8.

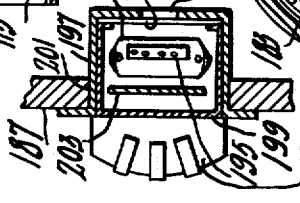


Fig. 13.

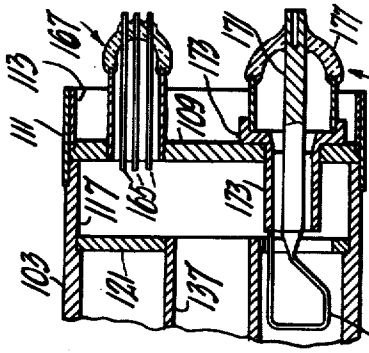


Fig. 12.

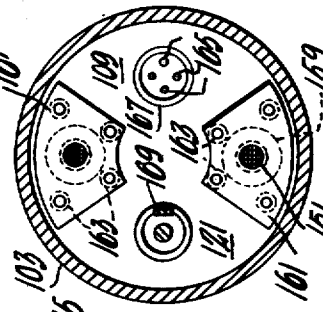


Fig. 11.

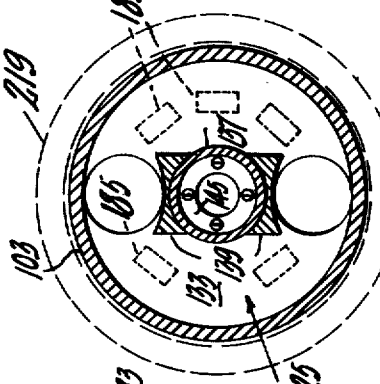


Fig. 10.

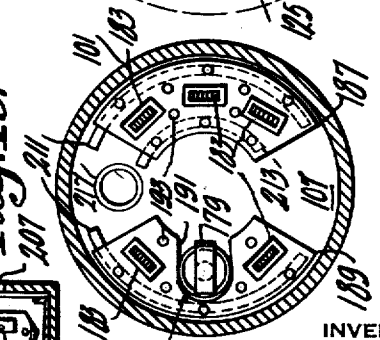


Fig. 9.

INVENTOR
Carmen L. Cuccio
BY
William A. Zalesak
ATTORNEY

United States Patent Office 2,806,172 Patented Sept. 10, 1957

2,806,172

HIGH FREQUENCY COUPLING AND MODULATING APPARATUS

Carmen L. Cuccia, Princeton, N. J., assignor to Radio Corporation of America, a corporation of Delaware

Application March 19, 1951, Serial No. 216,320

20 Claims. (Cl. 315—5.16)

This invention relates generally to high frequency coupling and modulating apparatus and more particularly to an electron tube utilizing a spiral beam for amplitude modulating high frequency energy supplied by a generator to a load circuit.

The invention constitutes an improvement over the coupling apparatus disclosed and claimed in my Patent No. 2,542,797, dated February 20, 1951. Said patent discloses an electron discharge device or electron tube having an electron gun arranged to project an electron beam through a high frequency electric field energized at the desired operating frequency, in a direction transverse to the field. A constant magnetic field is applied parallel to the initial path of the electron beam. As the electron beam passes through the transverse high frequency electric field, it absorbs high frequency energy therefrom, the magnetic field causing the individual electrons to traverse spiral paths having radii proportional to the energy absorbed from the electric field and having axial velocities proportional to the axial beam voltage. The spirally traveling electrons form an electron beam which revolves about the central axis and lies in the surface of a cone, since all of the electrons at any instant lie on the directrix of the cone and are similarly phased. The spiral or cone-directrix beam is projected between a pair of capacitive electrodes, or through a cavity resonator, coupled to a load circuit, whereby the beam delivers energy to the electrodes and to the load circuit which is tuned to the operating frequency. The spiral beam induces a high frequency voltage between the capacitive electrodes which establishes a high frequency electric field therebetween transverse to the beam path. As energy is abstracted from the spiral beam, the radii of the spirally-traveling electrons comprising the beam are reduced as a function of the energy abstracted and corresponding energy may be derived from the coupling electrodes. After delivering energy to the output coupling elements, the beam is collected by a positively-biased collector electrode.

By applying control or modulating signal potentials to a control grid forming a part of the electron gun, the intensity of the beam current may be varied as a function of the applied control potentials. As the beam current is varied, the effective coupling factor between the input and output circuits is correspondingly varied, thus providing amplitude modulation or coupling control of the output energy. Alternatively, the accelerating potentials applied to the electron beam may be varied by control potentials in order to vary the axial beam velocity and thus control the effective coupling between the input and output circuits. The input and output electric field elements comprise pairs of plane or arcuate electrodes, or cavity resonators which may include such electrodes. The electron gun preferably should be of the screen grid type including a control grid. Preferably, the input and output electric field elements should be shielded from each other.

An analysis of the operation of the above-described coupling and modulating apparatus was published in my paper entitled "The electron coupler—a developmental tube for amplitude modulation and power control at ultra-high frequencies," RCA Review, June 1949, pp. 270–303.

The principal object of the present invention is to provide improved means for modulating the amplitude of high frequency oscillations. More specifically, the object is to provide means for varying the amount of energy supplied by a high frequency generator to a load circuit while maintaining the load on the generator substantially constant.

Another object of the invention is to provide certain novel electron beam tubes particularly adapted for use as modulating devices.

In accordance with the invention, an electron coupler tube, such as the coupling devices disclosed in my Patent No. 2,542,797, is provided with one or more auxiliary beams in either the input or the output portion of the tube, parallel with the coupling beam or beams. When the auxiliary beam is projected transversely through the input electric field or cavity resonator, the auxiliary beam absorbs high frequency energy from the input electric field, and the coupling between the beam and the field is varied in phase opposition to the modulation signal applied to the tube, as by phase inversion means coupled between the control grids of the two electron guns where the signal is applied to control the coupling beam current, to maintain the input impedance of the tube susbtantially constant.

When the auxiliary beam is projected transversely through the output electric field or cavity resonator, the auxiliary beam absorbs energy from the output electric field, which is excited by the primary or coupling beam, without affecting the input electric field. The beam current of the coupling beam is maintained at a constant optimum value, to maintain a constant load on the driving generator, and the tube is modulated by varying the coupling between the auxiliary beam and the output electric field. In this manner, the amount of energy delivered by the tube to the output load can be varied from full load to substantially zero load, without varying the load on the generator.

The driving generator may be incorporated in the tube itself, as in Figures 12–14 of my Patent No. 2,542,797 where all of the beams are coupling beams, in the form of a magnetron constituting a part of the input structure of the tube.

The invention will be described in greater detail by reference to the accompanying drawings, in which

Fig. 1 is a schematic perspective diagram of a first embodiment of the invention wherein an electron coupler is provided with an auxiliary beam in the input system for stabilization purposes;

Fig. 2 is an axial sectional view taken along the line 2—2 of Fig. 3 of a multi-beam electron coupler including a multi-cavity magnetron input system, a multi-cavity magnetron anode output system, a plurality of coupling beams through both systems and a plurality of auxiliary beams through the input system only;

Fig. 3 is a transverse sectional view along the line 3—3 of Fig. 2;

Fig. 4 is a diagram similar to Fig. 1 of a second embodiment wherein an auxiliary beam is provided in the output system for modulation purposes;

Fig. 4 is a diagram similar to Fig. 1 of a second embodiment wherein an auxiliary beam is provided in the output system for modulation purposes;

Figs. 5, 6 and 7 are diagrams which will be used to explain the effects of various load conditions;

Fig. 8 is a longitudinal sectional view of a practical embodiment of the invention incorporating two coaxial

line type cavity resonators, two coupling beams and five auxiliary beams;

Figs. 9, 10 and 11 are transverse sectional views taken on line **9—9**, **10—10** and **11—11**, respectively, of Fig. 8;

Fig. 12 is a detail sectional view taken on line **12—12** of Fig. 8; and

Fig. 13 is an enlarged cross sectional view of one of the electron guns of Fig. 9.

Referring to Fig. 1 of the drawings, the invention is shown incorporated in an electron coupler tube such as that schematically shown in Fig. 2 of my Patent No. 2,542,797. As in said patent, an electron beam is projected, within an envelope not shown, by an electron gun **1**, through the space between a pair of input electrodes **3** and **5** and the space between a pair of output electrodes **7** and **9**, in succession, to a collector electrode **11**. As shown, the electron gun **1** may comprise a thermionic cathode **13**, a control grid **15** and one or more accelerating electrodes **17**.

In operation, suitable positive potentials with respect to the cathode **13** are applied to the accelerating electrode **17** to provide the desired beam velocity. The collector electrode **11** is also positively biased. The electron beam current is controlled by suitable control and bias potentials applied to the grid **15**. A magnetic field of constant direction and intensity is established in the direction of the arrows **19** by any suitable means, such as a permanent magnet or an electromagnet external to the tube. The input electrodes **3** and **5** are coupled to a source of high frequency voltage to establish a high frequency electric field across these electrodes transverse to the electron beam and the constant magnetic field. As the beam enters the transverse electric field each electron is deflected thereby. Since this deflection is transverse to the lines of force of the magnetic field the electrons are also deflected by the latter and are caused to spiral.

The magnetic field strength H is adjusted to make the cyclotron frequency

$$f_0=\frac{He}{2\pi m}$$

of the magnetic field equal to the frequency f of the high frequency source, where e and m are the charge and mass, respectively, of the electron. Under these conditions, the electrons spiral always in phase with the oscillations of the electric field, and hence, continuously absorb energy therefrom. The radius of the path of each electron at any instant is dependent upon the energy which has been absorbed by that electron from the electric field. Since all of the electrons have substantially the same initial electron energy and are similarly phased, they will be at any instant upon the directrix of a hollow cone, for parallel plate electrodes as shown. Hence, the beam is variously called a cone-directrix beam, a rotating-pencil beam, and a spiral beam (since the individual electrons follow spiral paths).

After the beam leaves the input electric field between electrodes **3** and **5**, still under the influence of the axial magnetic field, the electrons follow helical paths of constant radius. Entering the space between the output electrodes **7** and **9**, the beam revolves past these electrodes and induces high frequency voltages therebetween. When a suitable load is connected to electrodes **7** and **9**, high frequency energy at the frequency of the source **21** can be derived therefrom. As the electrons give up energy to the output electric field induced between the electrodes **7** and **9** their radii decrease, thus producing an inverted cone-directrix beam in this region. With a matched load the electrons can be caused to give up all of their rotational energy.

With a constant beam current the tube constitutes a coupling device for transferring high frequency energy from a source to a load. When the beam current is varied, as by a signal applied to the control grid **15**, the total number of available coupling electrons is varied, which varies the output to the load.

In accordance with the present invention, an auxiliary beam is projected through one of the electric field regions, for purposes of stabilization or modulation. The input electrodes **3** and **5** are extended as shown at **23** and **25**, to provide room for another beam. An auxiliary beam is projected, by a second electron gun **27**, similar to the first gun **1**, and including a cathode **29**, control grid **31**, and one or more accelerating electrodes **33**, between the extensions **23** and **25** to a collector electrode **35**.

In operation, the electrodes **29**, **31**, **33** and **35** are biased in the same manner as electrodes **13**, **15**, **17** and **11**, respectively, with the exception that separate leads are provided for the two control grids **15** and **31**. These two grid leads are connected to a phase inversion device or circuit, and the lead for the grid **15** of the coupling beam gun **1** is connected to the source of modulation signals. The phase inversion device causes the beam current of the auxiliary beam to vary inversely with the coupling beam current. Since each beam absorbs energy from the input electric field proportional to the beam current the impedance of the input system, and hence, the load on the generator or other apparatus constituting the source can be maintained substantially constant while varying the coupling beam current by a signal to vary the energy delivered by the tube output load circuit. Therefore, auxiliary beam serves as a stabilizing beam in the embodiment of the invention shown in Fig. 1.

Figs. 2 and 3 show the invention embodied in a multicavity electron coupler, such as that shown in Figs. 12–14 of my Patent No. 2,542,797. The tube comprises a metallic envelope **45** containing two vane-type multicavity magnetron anode structures **47** and **49** mounted within the envelope in end-to-end, aligned relation, as shown in Fig. 2. Each anode structure comprises a number, eight as shown, of flat metal vanes **51** extending radially from a central space **53** to the envelope **45**. The vanes **51** form, with the connecting portions of envelope **45**, cavity resonators **55** open toward the central space **53** and adapted to be excited to establish a high frequency electric field associated with the resonators and having electric field components extending between the vanes transverse to the tube axis and magnetic field components extending through the cavities parallel to the tube axis and linked together around the vanes in the end spaces. In the optimum, π-mode operation, the field components in the cavities at any instant alternate around the anode structures with adjacent cavities operating 180° out of phase. Alternate vanes **51** may be strapped together by strapping rings **57** to favor π-mode operation.

For use as an electron coupler tube, either of the anode structures could be driven from an external high frequency source as in Fig. 1. However, in Fig. 2 a cathode **59** is mounted coaxially within the central space **53** of the anode structure **47** to produce a magnetron oscillator within the tube envelope. In operation, a constant magnetic field, of suitable intensity for magnetron operation, is applied parallel to the cathode **59** as indicated by the arrow **61**, by any suitable means exterior to the envelope. The anode structure **47** is biased positively with respect to the cathode **59** to cause the magnetron to oscillate and establish the desired high frequency electric field in the anode cavities of the anode structure **47**.

An electron beam is projected through each of the cavities **55** of the anode structure **47**, in a direction parallel to the tube axis, and hence, transverse to the electric field component in each cavity, as schematically shown in Fig. 2. Half of the beams, preferably the alternate ones, pass through apertures **63** in a shield plate **65**, interposed between the anode structures **47** and **49**, and on through the aligned cavities of the anode structure **49** to a common collector **67**, to serve as coupling beams. The other half of the beams are collected by the plate **65**, and

hence, pass through only one of the anode structures, to serve as stabilizing beams. A separate electron gun **69** is provided for each beam, each gun including a cathode **71** and a control grid **73**. An apertured plate **75** serves as the accelerating grid for each gun and also as a shield between the guns and the high frequency field in the cavity structure **47**. The magnetron cathode **59** may be supported on the grid plate **75**, as shown in Fig. 2. The control grids of the coupling beams and the stabilizing beams are connected together in two separate groups. The leads for the cathode **59** and the beam guns may be brought out of the envelope **45** through a seal **76**.

In operation, a constant magnetic field is applied parallel to the coupling and stabilizing beams, as indicated by the arrows **77**, of strength H such that the magnetron frequency f is equal to $He/2\pi m$. The coupling and absorbing beams absorb energy from the electric field in the magnetron cavities and traverse spiral paths toward their respective collectors. The coupling beams pass through the cavities of the output anode structure **49** and induce a high frequency field therein. Energy is extracted from the output structure **49**, for example, by a transmission line **79** coupled into one of the cavities of the anode structure by a coupling loop **81**. As in Fig. 1, the load on the high frequency generator is stabilized by varying the beam currents of the coupling or modulating beams and the stabilizing beams 180° out of phase.

In the embodiment of the invention shown schematically in Fig. 4 an auxiliary beam is projected through the output system and is employed as a modulating beam. The structure is similar to that of Fig. 1 except that the output electrodes **7** and **9** are extended, as shown at **39** and **41**, instead of the input electrodes **3** and **5**, and the auxiliary beam is projected between these extensions. The auxiliary beam is shown as projected in a direction opposite to the coupling beam, but the direction is immaterial. Corresponding elements have the same numerals as in Fig. 1.

In operation, the bias potential of the control grid **15** of the coupling beam gun is adjusted to give the desired beam current and maintained constant. The control or modulating signal is applied to the control grid **31** of the auxiliary beam gun to vary the auxiliary beam current. Hence, the auxiliary beam is employed as a modulating beam for varying the energy delivered by the tube to the output load. The modulating beam is, in effect, a variable shunt load placed across the output load of the tube. When the modulation beam is biased off with no signal the shunt load resistance is infinite and has no effect on the amount of energy delivered to the output load. When the modulating beam current is sufficiently high that the shunt load resistance is low compared with the load resistance, the output to the load is reduced to substantially zero.

Figs. 5, 6 and 7 show diagrammatically the effect of providing a modulating beam in the output electric field system. Fig. 5 shows in dotted lines the envelope of the rotating coupling beam with a matched output load and no modulating beam present. The boundaries of the transverse electric fields E_1 and E_2 in the input and output regions are shown by horizontal dash lines. One instantaneous position of the rotating beam is shown by a heavy solid line. When the output load is matched to the coupling beam the transfer efficiency from generator to load is substantially 100 percent. As shown in Fig. 5, the coupling beam gives up all its rotational or spiral energy to the output field and spirals down to zero radius. For a matched load, the output load resistance, R_0, in ohms, is

$$R_0=8\frac{V}{I_0}\left(\frac{d}{l}\right)^2 \qquad (1)$$

where I_0 is the coupling beam current in amperes, V is the beam accelerating voltage in volts, l is the axial length of the electrodes defining the output electric field, and d is the distance between these electrodes. See Equation (18)p, page 278, of my RCA Review paper referred to above.

If the effective load resistance is changed from a matched load, the amount of energy given up by the coupling beam to the output electric field is changed, with a corresponding change in the coupling beam envelope. The effective load resistance may be changed by changing the output load resistance or by applying a shunt load R_1 across the output load resistance. When a shunt load is placed across the output load of an electron coupler modulation of the output power can be produced in the following way. If R_0 is the output load resistance which is matched to the electron beam to yield maximum output power, and R_1 is the shunt load resistance, the transfer efficiency of the electron coupler, in percent, is

$$\eta=\frac{4\alpha}{(1+\alpha)^2}\cdot 100 \qquad (2)$$

where

$$\alpha=\frac{R_1}{R_1+R_0}$$

Where a modulating electron beam is employed in the output electric field as the shunt load, as in the present invention, the mechanism of modulation may be described as follows. The shunt resistance, R_1, of the modulating beam is

$$R_1=8\frac{V}{I_1}\left(\frac{d}{l}\right)^2 \qquad (3)$$

where I_1 is the modulating beam current. When the shunt beam is biased off, R_1 is infinite and α is unity, and hence, the transfer efficiency η is 100 percent, and the beam power to the collector is zero. As the shunt load resistance R_1 is reduced, by increasing the modulating beam current from zero, the output electric field system experiences a mismatch between the coupling beam and the load presented to the beam. The transfer efficiency is reduced and power now goes to: (a) the coupling beam collector; (b) the shunt load; and (c) the output load. The envelope of the coupling beam in the output region changes from that shown in Fig. 5 to that shown in Fig. 6 or 7, for example. Fig. 6 shows approximately the case where the modulating beam current is such that the shunt resistance R_1 is equal to R_0. In this case the transfer efficiency is 88 percent, the power to the collector is 12 percent, the power to the output load is 44 percent, and the power to the shunt load is also 44 percent. Since the electric field is uniform over both the coupling and modulating beams, the rate of increase in spiral radius of the modulating beam is equal to the rate of decrease of the spiral radius of the coupling beam, and hence, the angles between each cone-directrix beam and the central beam axis are equal. Due to the reversal of phase between the driving beam and the driven beam, the modulating beam rotates in a direction opposite to the coupling beam, as indicated by the arrows in the drawing.

Fig. 7 shows the case where R_1 is small compared with R_0. Where R_1 is one-tenth of R_0 the transfer efficiency is 30 percent, the power to the collector is 70 percent, the power to the output load is 2.72 percent, and the power to the shunt load is 27.28 percent. When the modulating beam current is relatively high, the output electric field strength is low as indicated by the small maximum spiral radius of the modulating beam. The values given above for power to the output load show that the present invention provides means whereby the output power of an electron coupler can be varied between a maximum value and substantially zero, by varying the beam current of a modulating beam in the output electric field of the coupler between zero and a relatively high value. Thus, it is possible to obtain nearly 100 percent amplitude modulation of the power delivered by the electron coupler from a generator to a load.

Figs. 9–13, inclusive, illustrate the invention embodied

in an electron coupler tube having input and output cavity resonators of the coaxial line type. The tube envelope comprises a tubular outer wall, made in two sections **101** and **103** joined together at **105**, and two end discs **107** and **109** connected to the tubular sections **101** and **103** by sealing rings **111** and **113**. The outer ends of the sections **101** and **103** are internally recessed, at **115** and **117**, to receive two rings **119** and **121** which form the outer end walls of two coaxial line cavity resonators **123** and **125**. The inner ends of the sections **101** and **103** are internally recessed, at **127** and **129**, to receive two rings **131** and **133** which form the inner end walls of the cavity resonators. The inner walls of the coaxial line resonators **123** and **125** are formed by a pair of tubular members **135** and **137** each having a pair of concave pole face elements **139** mounted on opposite sides thereof, as shown in Figs. 8 and 10. The outer ends of the tubular members **135** and **137** are mounted with the apertures **141** of the rings **119** and **121**, while the inner ends are attached, by means of inturned flanges **143** and **145**, to the rings **131** and **133**.

The tube is designed for two coupling beams, hence, each of the rings **131** and **133** is provided with two apertures **147**, slightly larger than the maximum distance between the pole face elements **139** and the outer resonator wall. Two sleeves **149** are mounted within the apertures **147**, with the inner surface thereof substantially flush with the surfaces of the outer resonator wall and the pole face elements **139**, as shown in Fig. 8. The ring **121** is provided with two coupling beam apertures **151** aligned with the sleeves **149**. Two coupling beam gun structures **153** are mounted, one aligned with each of the apertures **151**, in the space between the ring **121** and the disc **109**. Each of the gun structures **153** comprises a cathode **155** and a grid **157** having supporting rings **159** which are mounted in insulated relation on a screen grid plate **161**. Each of the plates **161** is mounted on the disc **109** by four rods **163**. Potential leads (not shown) for the cathodes **155** and grids **157** are connected to terminals **165** extending through a seal **167**. The screen grid plate **161** may be insulated from the resonator structure, and a separate lead brought through the seal **167** to permit the application of a different potential to the screen grid plate, if desired. The two coupling beams are projected by the gun structures **153** through the two coaxial cavity resonators **123** and **125**, in succession, and are collected by the ring **119**.

The resonator **125**, which serves as the input resonator, is provided with exciting means in the form of a coupling loop **169** mounted in a plane passing through the longitudinal axis of the tube to link the circumferentially-extending magnetic field lines of the high frequency field within the coaxial-line type resonator. The loop **169** is connected across the inner and outer conductors **171** and **173** of a coaxial line coupling element **175** which is mounted in an aperture in the disc **109** and provided with a seal **177**. The output cavity resonator **123** is provided with an output coupling loop **179** and coaxial line coupling element **181**, similar to the loop **169** and coupling element **175**, as shown in Fig. 9.

Mounted within the space between the end disc **107** and the ring **119** are five modulating beam gun structures **183**, arranged on a circle in position to project five modulating beams through five apertures **185** in the ring **119** toward the solid portions of the ring **131**, as shown in Figs. 8–10. Three of the gun structures **183** are mounted on a ring segment **187**, and the other two are mounted on another ring segment **189** having a notch **191** to clear the output coupling loop **179**. The two ring segments **187** and **189** are supported on the disc **107** by rods **193**. As shown in Fig. 13, each of the gun structures **183** comprises a cathode **195** and a surrounding control grid **196** mounted within a pair of telescoped U-shaped members **197** and **199**. The outer U-shaped member **197** is flanged outwardly and mounted in an aperture **201** in the

ring segment **187** (or **189**). A plane reflector electrode **203** is disposed between the control grid **196** and the inner member **199**. The cathode **195**, control grid **196** and reflector **203** are insulatedly supported on mica plates **205** at the ends of the U-shaped member **199** in position to project a modulating beam through a beam aperture **207** in the member **197**. If desired, a screen grid **209** may be mounted across the aperture **207**. A plurality of arcuate terminal strips **211** and **213** are mounted in insulated relation on the rear side of the ring segments **187** and **189**, for convenience in making connections to the electrodes of the modulating beam guns. Connections, not shown, are made to terminals **215** extending through a seal **217** in the disc **107**.

In operation, the tube of Figs. 8–13 is mounted coaxially within a magnetic field coil **219**, to apply a constant magnetic field parallel to the coupling and modulating beams and of intensity H such that $He/2\pi m$ is equal to the resonant frequency f of the cavity resonators **123** and **125**. An accelerating voltage of suitable value is applied between the resonator structure and the cathodes of the coupling and modulating beam guns. A suitable bias potential is applied to either or both of the coupling beam control grids **157**. The input coupling **175** is coupled to a high frequency generator of frequency f. Control or modulation potentials are applied simultaneously to all of the control grids of the modulating beam control grids **196**, to vary the power delivered to the output load which is coupled to the output terminal **181**.

The power into a spiral beam in a cavity having uniform transverse electric field along the Z-axis (axis of beam travel) is

$$P_1=\frac{1}{16}\frac{I_0}{V}E^2\left(\frac{L}{2}\right)^2 \tag{4}$$

where I_0 is the beam current, V is the beam voltage, E is the peak value of the alternating transverse electric field and $L/2$ is the total axial distance through the cavity.

In the case of a coaxial cavity resonator, such as those employed in the embodiment of the invention shown in Figs. 8–13, the transverse electric field, e, varies sinusoidally along the Z-axis, i. e.

$$e(z,\omega_0 t)=E\sin\left(\frac{2\pi}{L}z\right)\epsilon^{j\omega_0 t} \tag{5}$$

where z is some axial distance equal to or between zero and $L/2$, $\omega_0=He/m$, t is the instantaneous time corresponding to the distance z. Let Equation 4 be written in the form

$$P=k_1\theta^2 \tag{6}$$

where

$$k_1=\frac{E^2}{16}\frac{I_0}{V}\left(\frac{L}{2\pi}\right)^2 \tag{7}$$

$$\theta=\frac{2\pi z}{L} \tag{8}$$

Then, according to the well-known Superposition Integral Theorem,

$$P=k_1\int_0^{\pi}(\pi-\theta)^2\cos\theta d\theta \tag{9}$$

where the length of the cavity resonator corresponds to the limit, π, used in the integral, and cos θ is the time derivative of the variation of transverse electric field along the Z-axis. Solving the integral, we obtain

$$P=\frac{2}{16\pi}\frac{I_0}{V}\left(\frac{L}{2}\right)^2E^2 \tag{10}$$

Equation 10 shows that, for equal field strengths, the power absorbed in a coaxial cavity resonator is $2/\pi$ times that absorbed in a cavity resonator with uniform transverse electric field.

The transverse deflection, x, experienced by a spiral beam traveling through a transverse alternating electric field, $E\,e^{j\omega_0 t}$, which is uniform along the Z-axis is described as follows:

$$x=2.36\frac{Ez}{V^{1/2}f_0} \tag{11}$$

where $f_0=He/2\pi m$. Considering a coaxial cavity, where the transverse electric field is a function of the axial distance of z, according to Equation 5, let

$$x=k_2\theta \tag{12}$$

where

$$k_2=\frac{2.36}{2\pi}\frac{EL}{V^{1/2}f_0} \tag{13}$$

It follows from the Superposition Integral Theorem that

$$x=k_2\int_0^{\varphi} z(\varphi-\theta)\cos\theta d\theta \tag{14}$$

where φ is some angle equal to or between zero and π. When $\varphi=\pi$, $z=L/2$. Carrying the formulation through, we obtain

$$x=\frac{2.36}{2\pi}\frac{E}{V^{1/2}f_0}\frac{L}{2}\left(1+\cos\frac{2\pi z}{L}\right) \tag{15}$$

Equation 15 indicates that, in the case of the coaxial resonators of Figs. 8–13, the envelopes of the spiral beams are cone-shaped as in Figs. 1–7, but instead, have a shape similar to that of a milk bottle. This shape is shown by dotted lines for the upper coupling beam in Fig. 8. The shape of the envelopes of the modulating beams, not shown in the plane of Fig. 8, is also similar to that of a milk bottle.

By employing a coaxial type of resonator structure, as shown in Figs. 8–13, a large number of modulating beams can be accommodated within the electric field space, with a correspondingly large total modulating beam current being made available for controlling the output power of the tube.

What is claimed is:

1. A high frequency coupling device including means for establishing a first high frequency electric field in a first direction, means for projecting a primary electron beam through said field in a direction transverse to said first direction, means for establishing a constant magnetic field substantially parallel with said beam, whereby the electrons of said beam absorb energy from said electric field and traverse spiral paths of increasing radii, means positioned to be traversed by said beam after passing, through said first electric field and adapted to be excited by said beam to establish a second high frequency electric field transverse to said beam, and means for projecting an auxiliary electron beam through only one of said electric fields in a direction substantially parallel with said first beam and said magnetic field.

2. A coupling device as in claim 1, wherein said first-named means comprises a pair of deflecting electrodes on opposite sides of the path of said primary electron beam, and said fourth-named means comprises a pair of inductive output electrodes on opposite sides of said path and spaced from said deflecting electrodes.

3. A coupling device according to claim 1, including means for controlling the coupling between said auxiliary beam and said one electric field.

4. A coupling device according to claim 1, wherein said auxiliary beam is projected through said first electric field only.

5. A coupling device according to claim 1, wherein said auxiliary beam is projected through said second electric field only, and further including means for coupling a load circuit to said fourth-named means, and means for varying the coupling between said auxiliary beam and said second electric field, to vary the energy delivered to said load circuit.

6. A high frequency electron tube including means for producing at least one primary electron beam along a predetermined path, means in said path for establishing a first high frequency electric field in a direction transverse to said path in a first region adjacent to said beam producing means, means in said path adapted to be adapted to be excited by said primary beam to establish a second high frequency electric field in a direction transverse to said path in a second region located beyond said first region, and means for producing at least one auxiliary electron beam along a path substantially parallel with said predetermined path and extending through only one of said electric field regions.

7. A tube according to claim 6, including means for controlling the coupling between said auxiliary beam and the electric field of said one region.

8. A tube according to claim 6, wherein the path of said auxiliary beam extends through said first electric field region only.

9. A tube according to claim 6, wherein the path of said auxiliary beam extends through said second electric field region only.

10. A high frequency electron tube including means for producing a plurality of spaced parallel primary electron beams, means in the path of said beams for establishing a first high frequency electric field in a direction transverse to said primary beams in a first region adjacent to said beam producing means, means in the path of said beams adapted to be excited by said primary beams to establish a second high frequency electric field in a direction transverse to said beams in a second region located beyond said first region, and means for producing a plurality of auxiliary electron beams substantially parallel with said primary beams and extending through only one of said electric field regions.

11. A tube according to claim 10, including means for simultaneously controlling the coupling between said auxiliary beams and the electric field of said one region.

12. A high frequency electron tube including a first cavity resonator structure adapted to be excited to establish a high frequency electric field therein, a second cavity resonator structure, means for projecting at least one primary electron beam through both of said resonator structures in succession in a direction transverse to said electric field, and means for projecting at least one auxiliary electron beam through only one of said resonator structures in a direction parallel to said primary electron beam.

13. An electron tube according to claim 12, including means for controlling the coupling between said auxiliary beam and said one resonator structure.

14. An electron tube according to claim 12, wherein said auxiliary beam is projected through said first resonator structure only.

15. An electron tube according to claim 12, wherein said auxiliary beam is projected through said second resonator structure only.

16. A high frequency electron tube including a first cavity resonator structure adapted to be excited to establish a high frequency electric field therein, a second cavity resonator structure, means for projecting a plurality of spaced parallel primary electron beams through both of said resonator structures in succession in a direction transverse to said electric field, and means for projecting a plurality of auxiliary electron beams in a direction substantially parallel with said primary beams and through only one of said resonator structures.

17. An electron tube according to claim 16, including means for simultaneously controlling the coupling between said auxiliary beams and said one resonator structure.

18. A high frequency electron tube comprising two multi-cavity resonator magnetron anode structures disposed in end-to-end, aligned relation, one of said anode structures being adapted to be excited to establish high

frequency electric fields in the cavity resonators of said one anode structure, means for projecting a plurality of coupling beams of electrons through some of the cavity resonators of both anode structures in succession in a direction transverse to said electric fields, with one beam in each cavity resonator, and means for projecting a plurality of auxiliary beams of electrons through others of the cavity resonators of said one anode structure only in a direction transverse to said electric fields, with one beam in each cavity resonator.

19. A high frequency electron tube comprising a first coaxial line cavity resonator having inner and outer electrodes and being adapted to be excited to establish a high frequency electric field having regions wherein the lines of force extend substantially parallel to each other between said electrodes, a second coaxial line cavity resonator similar to said first resonator disposed in end-to-end, aligned relation with said first resonator, means for projecting a plurality of spaced parallel primary electron beams through said regions of both of said resonators in

succession in a direction transverse to said electric field, and means for projecting a plurality of auxiliary electron beams in a direction substantially parallel with said primary beams and through only one of said resonators.

20. A coupling device as in claim 1, wherein said first-named means is provided with high frequency coupling means adapted to be coupled to a source of high frequency electrical energy, and said fourth-named means is provided with high frequency coupling means adapted to be coupled to an output load.

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