Jan. 20, 1959 C. L. CUCCIA 2,870,368

ELECTRON BEAM TUBES

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Fig. 6.

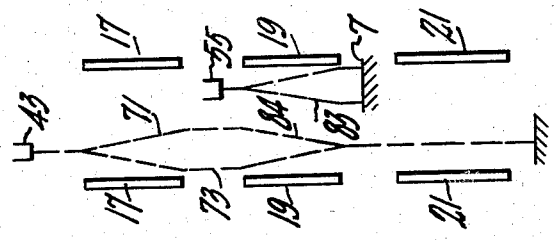


Fig. 5.

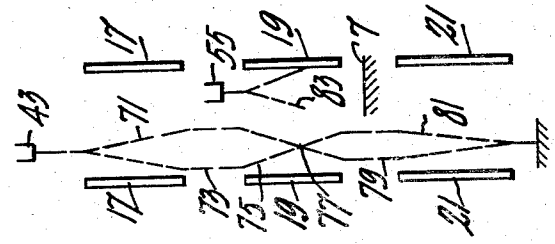


Fig. 4.

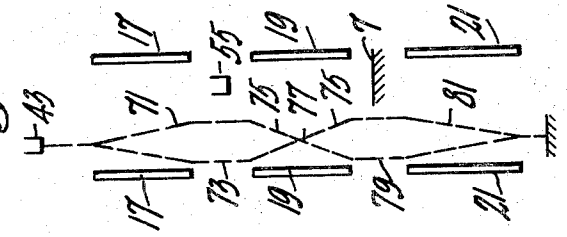


Fig. 3.

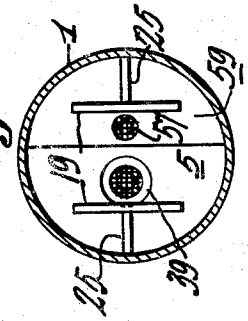


Fig. 2.

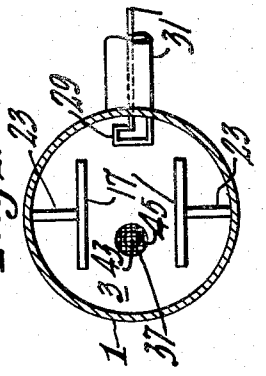
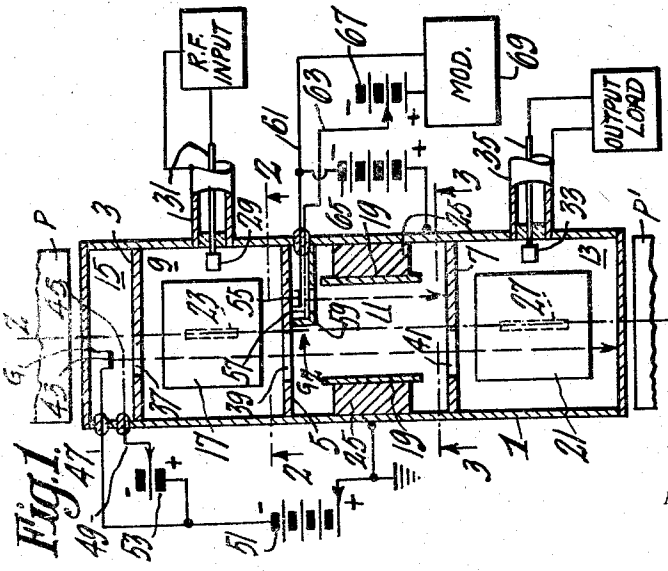


Fig. 1.



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Fig. 10.

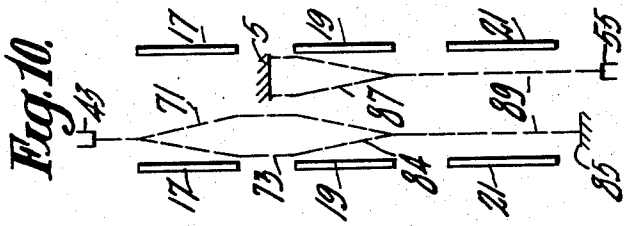


Fig. 9.

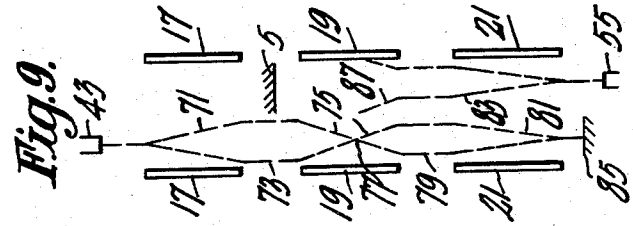


Fig. 8.

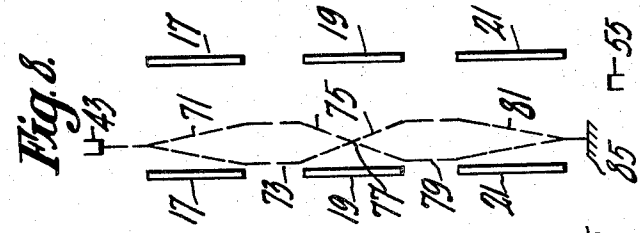
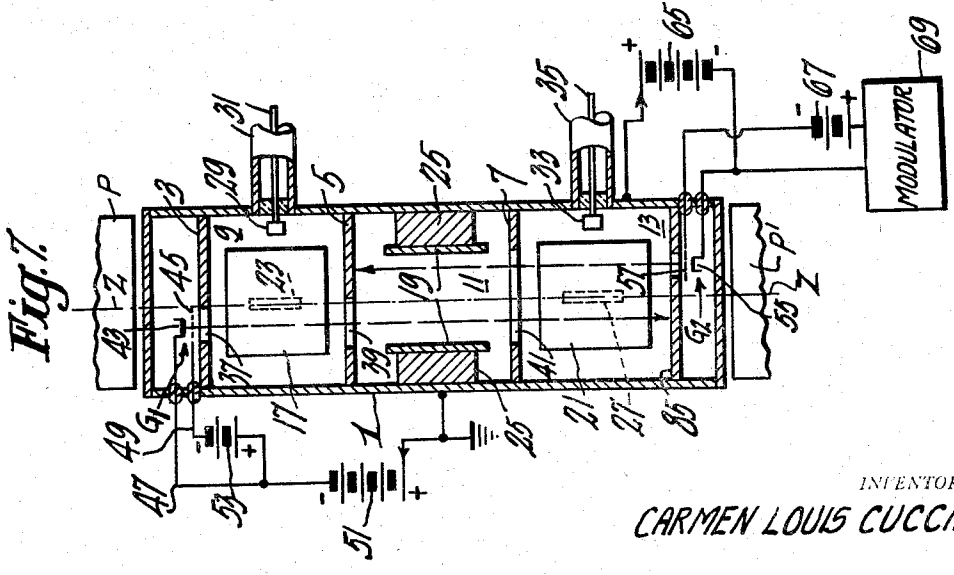


Fig. 7.



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ELECTRON BEAM TUBES

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Fig. 14.

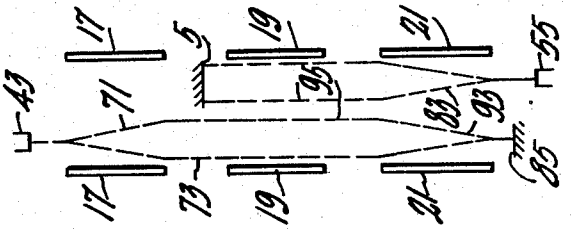


Fig. 13.

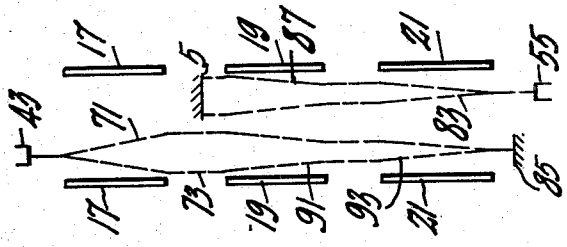


Fig. 12.

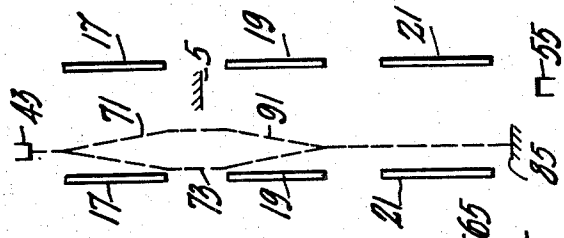
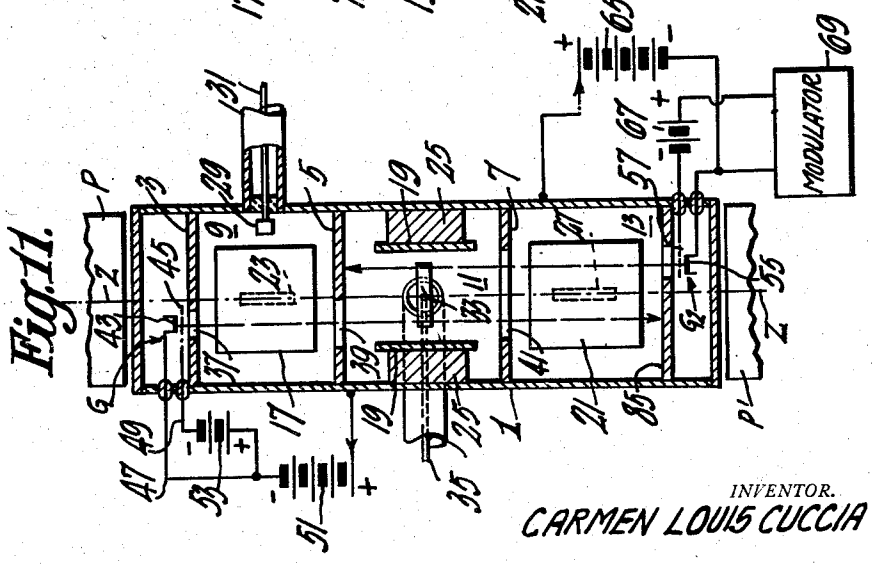


Fig. 11.



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ELECTRON BEAM TUBES

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Fig.18.

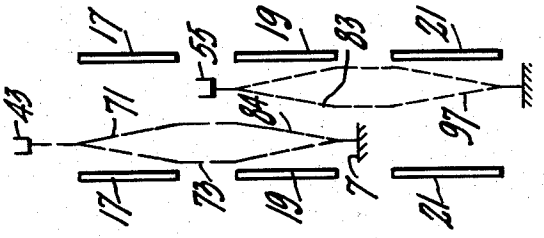


Fig.17.

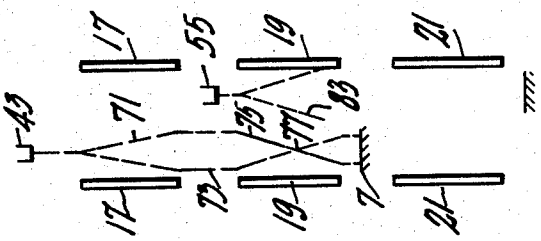


Fig.16.

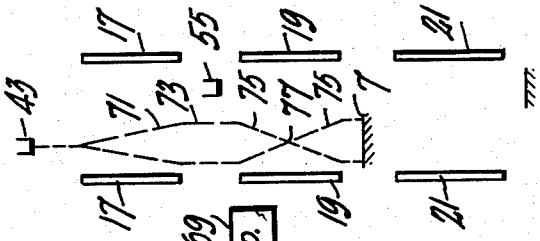
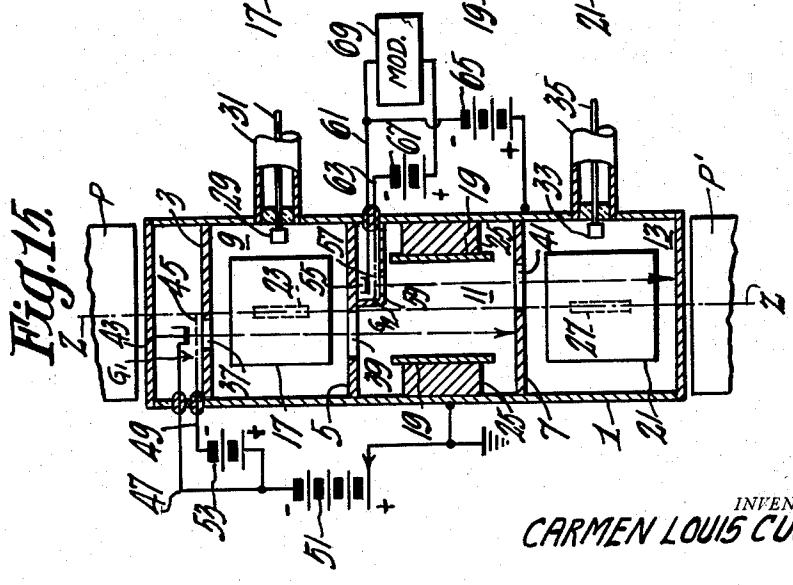


Fig.15.



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United States Patent Office 2,870,368 Patented Jan. 20, 1959

2,870,368

ELECTRON BEAM TUBES

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

Application July 14, 1953, Serial No. 367,941

17 Claims. (Cl. 315—5.49)

The present invention relates to electron beam tubes and circuits therefor, and particularly to beam tubes of the electron coupler type used for modulating devices.

In an electron coupler tube, as described in C. L. Cuccia, Patent No. 2,542,797, assigned to Radio Corporation of America, an electron beam is projected along a path extending in succession through an input region upon which is impressed a radio frequency electric field transverse to the beam path and an output region to which the beam gives up energy by inducing a second transverse radio frequency field. Each of the two regions includes a pair of opposed field-defining electrodes located on opposite sides of the beam path and coupled to a resonant circuit, which may be either an external circuit or some form of cavity resonator forming part of the tube structure itself. The input and output circuit are adapted to be coupled to a radio frequency source and a useful load, respectively. The beam is subjected to a constant axial magnetic field. The magnetic field strength H is adjusted to a value such that the angular cyclotron frequency

$$\omega_0=\frac{He}{m}$$

of an electron in said field is equal to ω, where e and m are the charge and mass, respectively, of an electron, and ω is the angular frequency of the radio frequency field set up in the input region. Under these conditions, as the beam passes through the input region the electrons are caused by the crossed electric and magnetic fields to move in spiral paths of increasing radii about the original beam axis, absorbing energy from the input region and the radio frequency source coupled thereto. Since they have the same angular and axial velocities, all the spirally traveling electrons in the beam lie at any instant on the linear directrix of a cone, and the envelope of the rotating or revolving beam is a cone. Hence, the beam is sometimes termed a "cone-directrix" or "rotating pencil" beam. In the output region the rotating beam gives up spiral energy to the region and coupled load by inducing radio frequency voltages on the field defining plates and thereby setting up a transverse radio frequency field in that region. As spiral energy is abstracted from the beam the radii of the electron paths are progressively reduced, and hence, the envelope of the beam in the output region is an inverted cone. The electron coupler tube may be used as a modulator by coupling an unmodulated carrier signal to the input region and modulating the beam current or the transit time by a modulating signal thus producing a modulated carrier signal in the output load, as disclosed in said Cuccia patent. On the other hand, an amplitude modulated signal coupled to the input region will be faithfully reproduced in the output of the device.

In a copending application of C. L. Cuccia, Serial No. 216,320, filed March 19, 1951, now U. S. Patent No. 2,806,172, granted September 10, 1957, assigned to the Radio Corporation of America, several two-region electron coupler tubes are disclosed in which a coupling beam

is passed through the input and output regions and an auxiliary beam is passed through one of these regions, for stabilizing or modulating purposes. When the auxiliary beam is passed through the output region the output of the device can be modulated by varying the auxiliary beam current. However, this arrangement has the disadvantage that it requires relatively high values of beam current, as compared to the coupling beam current, to produce amplitude modulation in the neighborhood of 100 percent. The principles of auxiliary beam modulation of the electron coupler are also described in a paper by C. L. Cuccia on pages 72–99, inclusive, RCA Review, vol. XIV, March 1953.

The principal object of the present invention is to provide electron coupler tubes capable of producing high depths of modulation with modulating beam currents of the order of the coupling beam currents.

A distinguishing feature of the invention is the use of an electron coupler tube having three interaction regions, instead of two as in previous coupler tubes. In the embodiments illustrated, three cavity resonators are arranged in line, end-to-end. One end cavity is an input cavity with coupling means for connection to an input radio frequency generator to establish a transverse electric field in the cavity. An electron gun at the end of the tube projects a coupling beam through the input cavity and at least the middle cavity. In some embodiments, the other end cavity is the output cavity while in one the output is taken from the middle cavity. In each embodiment a modulating beam is projected through one or two of the cavities other than the input cavity for amplitude modulating the output power of the tube.

In the accompanying drawing:

Fig. 1 is a longitudinal sectional view, partly schematic, of one embodiment of an electron coupler tube incorporating the present invention;

Figs. 2 and 3 are transverse sectional views taken on lines 2—2 and 3—3, respectively of Fig. 1;

Figs. 4, 5 and 6 are sketches referred to in the explanation of the operation of the tube of Figs. 1–3.

Fig. 7 is a view similar to Fig. 1 of a second embodiment of the invention;

Figs. 8, 9 and 10 are sketches relating to the operation of the tube of Fig. 7;

Fig. 11 is a view similar to Fig. 1 of a third embodiment;

Figs. 12, 13 and 14 are sketches relating to the operation of the tube of Fig. 11;

Fig. 15 is a view similar to Fig. 1 of a fourth embodiment; and

Figs. 16, 17 and 18 are sketches relating to the operation of the tube of Fig. 15.

Referring first to Figs. 1–3, there is shown an electron beam tube having an elongated metal envelope 1. The interior of the envelope 1 is divided by three transverse metal partitions 3, 5 and 7 into three cavities 9, 11 and 13, and an electron gun compartment 15. Three pairs of opposed pole faces 17, 19 and 21 are mounted in the three cavities 9, 11 and 13 by extensions 23, 25 and 27, respectively, to provide a transverse electric field region between the opposed pole faces in each cavity. Each pair of pole faces together with the surrounding wall of the envelope and the adjacent partitions form a coaxial line cavity resonator of the type shown in Figs. 5 and 15 to 18 of Cuccia Patent No. 2,542,797. The pole faces may be in the form of flat plates, as shown, or may be accurate in cross-section transverse to the longitudinal central axis Z—Z as shown in said patent. Cavity 9, the one nearest the gun compartment 15, is provided with means, which may be a coupling loop 29 and coaxial transmission line 31, adapted to be coupled to an external radio frequency source, for exciting an electromagnetic

field within the resonator and thereby establishing a radio frequency electric field between the pole faces in that cavity, which serves as the input cavity of the tube. The output cavity which is the third cavity **13** in the embodiment of Figs. 1–6, is provided with means, such as coupling loop **33** and transmission line **35**, for extracting radio frequency energy therefrom. The second cavity **11**, which has no radio frequency input or output means, serves as a part of the electronic modulating means of the present invention, in a manner to be described. Each pair of pole faces, **17**—**19**—**21**, constitutes an electrode structure adapted to be energized to establish a radio frequency electric field extending between the pole faces which serve as field-defining electrodes.

The three partitions **3**, **5** and **7** are provided with apertures **37**, **39** and **41**, respectively, at one side of the central axis and aligned with a first electron gun G_1 mounted by suitable means in the compartment **15**. The gun G_1 comprises a cathode **43**, a control grid **45** and an accelerating electrode which, as shown, is the apertured partition **3**. The cathode **43** and grid **45** are provided with leads **47** and **49**, sealed through the envelope in insulated relation, for connection to direct current voltage sources. As shown the cathode **43** is maintained at a low negative potential relative to the cavity structure and ground by a battery **51**, and the grid **45** is given a suitable bias potential by a battery **53**.

The gun G_1 is arranged as described to project a coupling electron beam through the cavities **9**, **11** and **13**, for transferring electrical energy from the input cavity **9** to the output cavity **13**. An axial magnetic field of constant field strength

$$H=\frac{m}{e}\omega_0 \qquad (1)$$

where m and e are the electronic mass and charge, respectively, and ω_0 is the angular frequency of the input radio frequency source used to excite the tube, is established along the axis of the tube, parallel to the beam path, by suitable means such as magnets having pole pieces P and P'.

A second electron gun G_2 is mounted by suitable means in one end of the second or middle cavity **11**, on the opposite side of the central axis from the coupling beam, to project a modulating electron beam through that cavity only, between the pole faces **19**. Gun G_2 comprises a cathode **55**, a control grid **57** and an accelerating electrode **59** in the form of an apertured plate. Cathode **55** and grid **57** are provided with insulated leads **61** and **63** through the envelope wall for connection to direct current and modulation voltage sources. As shown, the cathode **55** is maintained at a low negative potential relative to the cavity structure by a battery **65** The grid and cathode are connected by a grid-biasing battery **67** and a modulator **69** in series, so that the beam current of the modulating beam can be varied between zero and any desired value by varying the grid potential.

The operation of the embodiment of the invention shown in Figs. 1–3 as a modulator will now be described. When the electrodes of the coupling beam gun G_1 are energized and no energy is introduced into cavity **9**, the electrons in the coupling beam travel in substantially straight lines through the three cavities and are collected on the end wall of the cavity **13**, as shown by the dashed line in Fig. 1. When a source of radio frequency energy of frequency $\omega_0=He/m$ is coupled to input cavity **9**, the electrons in the coupling beam are deflected by the transverse electric and axial magnetic fields and caused to execute spiral paths of constantly increasing radii around the initial beam axis, and thereby form a revolving cone-directrix beam in the electric field region of the input cavity **9**, as described above in connection with the basic electron coupler of Cuccia Patent No. 2,542,797.

The conical envelope of this beam is shown at **71** in Figs. 4–6. In the space between the first and second regions, where there is no transverse electric field, the electrons traverse helical paths of constant radii, as shown by the cylindrical envelope **73** in Figs. 4–6. Thus the coupling beam enters the second cavity **11** with the spiral energy obtained from cavity **9**, represented by the radius of the envelope **73**.

When the modulating beam is biased off, the second cavity **11** is completely unloaded and the coupling beam in passing through that cavity will experience a phase reversal, as indicated by the double-conical envelope **75**, with a convergence or cross-over point **77** half way across the pole faces **19**. The reason for this is that each electron as it enters the region between the pole faces **19** induces smaller and smaller increments of voltage across these pole faces, 180° out of phase with the voltage applied to input pole faces **17** of cavity **9**, until all of its spiral energy has been absorbed, at the cross-over point. Beyond the cross-over point each electron reabsorbs energy from the pole faces **19**, in phase with the voltage thereon, until the radius of spiral is the same as that of envelope **73** to satisfy the condition that there be no net interchange of energy between the beam and the unloaded cavity **11**. In the space between the second and third regions, the coupling beam has a cylindrical envelope **79**, like envelope **73** between the first and second regions. Hence, under the conditions assumed the beam enters the third or output region with the same amount of spiral energy that it absorbed from the input region but of opposite phase. When the effective resistance R of the output load, expressed as the transformed resistance presented across the pole faces **21**, has the value defined by:

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

where V is the beam accelerating voltage in volts, I_0 is the electron beam current in amperes, L is the length of the pole faces **21** and d is the distance between them, both in centimeters, the beam will converge in the output region as shown at **81** so that the radius of revolution of the electrons is zero as they leave the region between the pole faces **21**. Equation 2 corresponds to Equation 15 of Cuccia Patent No. 2,542,797. If the resistance R of the output load were infinite the beam would have a phase-reversal with a cross-over point in the middle of the output region, as in the second region. Therefore, Fig. 4 shows the condition, with zero modulating beam current, of 100% transfer of energy from the input source to the output load, that is, maximum power output from the device.

When the modulating beam is turned on, as shown in Fig. 5, that beam will absorb energy from the second cavity and hence, from the coupling beam. The envelope of the cone-directrix modulating beam is shown at **38**. This loading of the second cavity causes the cross-over point **77** of the coupling beam to be shifted toward the exit of the second field region, so that the difference between the spiral energy of the coupling beam prior to cross-over and the spiral energy thereof after cross-over is equal to the energy absorbed by the modulating beam. Thus, less spiral energy is transferred to the output cavity and load by the coupling beam.

As the modulating beam current is increased until it equals the coupling beam current, the modulating beam will absorb all of the rotational or spiral energy of the coupling beam, the latter converging as a cone-directrix beam in the second region to zero radius at the exit thereof, as shown at **84** in Fig. 6. Where the field geometries for the two beams are not the same this condition will be met when the resistance presented by the modulating beam will match that of the coupling beam. Hence, no rotational energy is transferred to the output cavity and load, which is the case of zero power output from the

device. The energy of the modulating beam is dissipated in the partition 7 in the form of heat.

Therefore, it is apparent that, as the modulating beam current is varied between zero and a value equal to that which will cause a resistance match to the coupling beam, the power output of the device is varied from maximum to zero, which represents 100% amplitude modulation of energy transferred from the input source to the output load.

In each of the electric field regions the slope of the cone directrix is determined by the strength of the electric field within that region, or vice-versa. Hence, where there are two beams in the same region, as in the second region in Figs. 5 and 6, the cones of the two beams will have the same slope, as shown. One result of this is that the modulating beam will graze the pole face **19** for small beam currents and high electric field strengths, as shown in Fig. 5.

Figs. 7, 11 and 15 show modifications of the modulator tube of Figs. 1–3. The tube elements which are the same as in Fig. 1 have been similarly numbered in these modifications and will not be described in detail again.

In the embodiment of the invention shown in Fig. 7, the coupling beam is projected from gun G_1 through the cavities **9**, **11** and **13**, in succession, as in Fig. 1, the input radio frequency source is coupled into cavity **9**, and energy is extracted from cavity **13**, as in Fig. 1. However, the modulating beam is projected by electron gun G_2 in the opposite direction, through the output cavity **13** and the middle cavity **11**, instead of the middle cavity only. Gun G_1 is mounted by suitable means in a compartment formed by the envelope **1** and an apertured partition **85** which serves as the collector for the coupling beam and as the accelerating electrode of the modulating gun. The aperture **41** in the partition **7** is large enough to pass the modulating beam into the middle cavity **11**.

In the operation of the embodiment of Fig. 7, when the modulating beam is off the coupling beam absorbs energy from the first cavity **9**, goes through a phase reversal in cavity **11** and gives up maximum power to the third or output cavity **13**, exactly as in Fig. 4. When the modulating beam is turned on, as shown in Fig. 9, it will absorb some of the rotational energy from the coupling beam in the output cavity to form a directrix beam **83**, thus reducing the power taken by the output load. Upon entering the middle cavity the modulating beam will expand as shown at **87** and load the cavity, thereby causing the cross-over point **77** of the coupling beam to shift toward the output cavity, resulting in reduced power transferred to the output cavity. The modulating beam will also add a component of energy 180 degrees out of phase with the coupling beam in the middle cavity, as a result of the energy it absorbed from the output cavity, which will shift the crossover point still further, thereby further reducing the output power. The modulating beam will braze, as shown in Fig. 9. When the modulating beam matches the coupling beam, as shown in Fig. 10, the modulating beam will absorb all of the rotational energy of the coupling beam in the middle cavity, so that there will be no rotational energy left in the coupling beam for transfer to the output cavity and output load. As a result there will be no energy for the modulating beam to transfer to the middle cavity so that both beam paths will be straight in the output cavity **12**, as shown at **89** in Fig. 10.

In the embodiment shown in Fig. 11 all of the structure is the same as in Fig. 7 except for the output loop **33** and line **35**, which are coupled to the middle cavity **11**, instead of the third cavity **13**. In operation, with the modulating beam turned off, as shown in Fig. 12, the tube operates as a simple two-cavity electron coupler. If the output load is matched to the output cavity when the modulating beam is not on, the coupling or input cavity to form a cone-directrix beam and then give up all of its energy in the second or output cavity as shown at **91**, thus transferring maximum power from the radio frequency source to the output load. The beam will then pass through the third cavity **13** with only the direct-current energy due to the beam accelerating voltage.

When the modulating beam is turned on slightly (with low current) it will pass through the third cavity and into the second or output cavity where it will cause a mismatch between the directrix coupling beam and its effective load. At the instant it is turned on, however, the modulating beam has no rotational energy as it passes through the third cavity, and as it enters the second cavity the initial effect is as if the electron gun G_2 were located there. The general power transfer efficiency of the coupling beam to the output load, which is defined by

$$n=\frac{4R/R_0}{(1+R/R_0)^2}\times 100 \qquad (3)$$

will be reduced, due to the insertion of the modulating beam, resulting in some rotating beam power remaining in the coupling beam as it enters and passes through the third cavity, as shown at **93**. This power is absorbed by the modulating beam in the third cavity. The directrix of the modulating beam will be 180 degrees out of phase with the directrix of the coupling beam. When the modulating beam enters the middle cavity its out-of-phase rotational energy will serve to further reduce the amount of power extracted from the coupling beam by the output load.

As the modulating beam current is increased, more and more rotational energy enters the third cavity to be returned by the modulating beam to the second cavity, 180 degrees out of phase, until, when the beams are matched both beams will form cylinder-directrix beams **95** and no energy will reach the output load.

The embodiment shown in Fig. 15 is essentially a pair of two-cavity electron couplers in series, with the output cavity **11** of the input electron coupler **9—11** acting as the input cavity of the output electron coupler **11—13**. The structure is identical with that of Fig. 1 except for the partition **7** which in Fig. 15 has its aperture **39** positioned so that the partition will intercept the coupling beam from gun G_1 and allow the modulating beam from gun G_2 to enter the third cavity **13**.

In operation, with the modulating beam turned off, as in Fig. 16, the coupling beam absorbs energy from the input cavity **9** forming a cone-directrix beam **71**. Since there is no load on the middle cavity the coupling beam goes through with a phase-reversal **75** and a cross-over point **77** in the middle of the electric field region, as in Figs. 4 and 8. All of the coupling beam energy is dissipated in the partition **7**, and no power is delivered to the output cavity and load. When the modulating beam is turned on, as shown in Fig. 17, the beam absorbs energy from the middle cavity to form a cone-directrix beam, and the load presented by this beam causes the cross-over point of the coupling beam to move toward the far end of the middle cavity, as in Figs. 5 and 9. The energy absorbed by the modulating beam is equal to the difference between that represented by the coupling beam before cross-over and that after cross-over. As long as the modulating beam grazes the pole face **19** as shown the modulating beam cannot reach the output cavity, and hence, no power will be delivered to the load. When the modulating beam current is equal to the coupling beam current, the modulating beam will absorb all of the rotational energy of the coupling beam, which will converge at the end of the pole faces **19**, as in Fig. 6. Moreover, as the modulating beam approaches a match with the coupling beam, the electric field and the slope of the beam envelope cones in the middle cavity are reduced enough to permit the modulating beam to enter the output cavity **13** as shown at **97** (instead of grazing the pole face **19**) and deliver full power output to the output load. An advantage of this modification is that for a very small variation in modulating beam current the

power output of the tube can be switched from zero to full value. The rate at which the power will go from zero to full value will depend on the cavity design and the beam thickness, and the design is chosen to suit various usage requirements.

What is claimed is:

1. An electron beam tube including three electrode structures, each adapted to be energized to establish a radio frequency electric field transverse to a predetermined axis of the tube, means for projecting a first beam of electrons parallel to said axis and through the field of at least one but not more than two of said electrode structures, means for projecting a second beam of electrons parallel to said axis and through the fields of at least two of said electrode structures including an electrode structure traversed by said first beam and one not traversed by said first beam, and means for establishing a constant magnetic field through all of said structures parallel to said axis.

2. An electron beam tube as in claim 1, wherein said first beam is projected through only one of said electrode structures.

3. An electron beam tube as in claim 1, wherein said first beam is projected through two of said electrode structures.

4. An electron beam tube as in claim 3, wherein said second beam is projected through all three electrode structures.

5. An electron beam tube as in claim 3, wherein said second beam is projected through only two of said electrode structures.

6. An electron beam tube as in claim 1, wherein each of said electrode structures comprises a pair of spaced field-defining electrodes parallel to and on opposite sides of said axis.

7. An electron beam tube including three electrode structures, each adapted to be energized to establish a radio-frequency electric field transverse to a predetermined axis of the tube, means for projecting a first beam of electrons parallel to said axis and through at least one but not more than two of said electrode structures, means for projecting a second beam of electrons parallel to said axis and through at least two of said electrode structures including an electrode structure traversed by said first beam and one not traversed by said first beam, means for establishing a constant magnetic field through all of said electrode structures parallel to said axis, the electrode structure traversed by said second beam only being provided with coupling means adapted to be coupled to a radio-frequency source, and one of the other electrode structures being provided with coupling means adapted to be coupled to an output load.

8. An electron beam tube as in claim 7, further including means for varying the beam current of said first beam, to vary the amplitude of the power delivered to said load.

9. The combination of the electron beam tube of claim 7 with a radio frequency source having an angular frequency equal to

$$\frac{He}{m}$$

where H is the strength of said magnetic field, and e and m are the charge and mass, respectively, of an electron.

10. An electron beam tube including first, second and third electrode structures arranged in a row along a predetermined axis of the tube, each structure being adapted to be energized to establish a radio frequency electric field transverse to said axis, means for projecting a first beam of electrons parallel to said axis and through the fields of at least said first and second electrode structures in the order named, means for projecting a second beam of electrons parallel to said axis and through at least one of said second and third electrode structures only, and means for establishing a constant magnetic field through all of said electrode structures parallel to said axis.

11. An electron beam tube as in claim 10, wherein said first electrode structure is provided with coupling means adapted to be coupled to a radio-frequency source, and one of the other electrode structures is provided with coupling means adapted to be coupled to an output load.

12. An electron beam tube as in claim 11, wherein the third electrode structure is the one provided with output coupling means.

13. An electron beam tube as in claim 12, wherein said first beam is projected through all three electrode structures and said second beam is projected through said second electrode structure only.

14. An electron beam tube as in claim 12, wherein said first beam is projected through all three electrode structures and said second beam is projected through said third and second electrode structures, in that order.

15. An electron beam tube as in claim 12, wherein said first beam is projected through said first and second electrode structures only and said second beam is projected through said second and third electrode structures only.

16. An electron beam tube as in claim 11, wherein said second electrode structure is the one provided with output coupling means.

17. An electron beam tube including three cavity resonator structures, each adapted to be excited to establish a radio frequency electric field therein transverse to a predetermined axis of the tube, means for projecting a first beam of electrons parallel to said axis and through at least one but not more than two of said cavity resonator structures, means for projecting a second beam of electrons parallel to said axis and through at least two of said cavity resonator structures including a resonator not traversed by said first beam, and means for establishing a constant magnetic field through said cavity resonator structures parallel to said axis.

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