United States Patent [19]

Giebeler

[11] **3,801,854**

[45] **Apr. 2, 1974**

[54] **MODULATOR CIRCUIT FOR HIGH POWER LINEAR BEAM TUBE**

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[73] Assignee: **Varian Associates,** Palo Alto, Calif.

[22] Filed: **Aug. 24, 1972**

[21] Appl. No.: **283,433**

[52] **U.S. Cl.** **315/5.29,** 315/5.38, 332/13, 332/58, 315/3.5

[51] **Int. Cl.** **H01j 25/12,** H01j 25/16

[58] **Field of Search** ..... 332/7, 13, 58; 315/3.5 X, 315/5.29, 5.38, 3.5

[56] **References Cited**

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[57] **ABSTRACT**

A high power linear beam tube; to be modulated, such as a high-power klystron, has its cathode directly connected with the depressed collector electrode of a modulator tetrode tube and its anode connected to the accelerating electrode of the tetrode modulator tube. The modulator tetrode tube includes a gridded convergent flow linear beam electron gun and a mirror image, substantially 100 percent depressed collector. The control grid is non-intercepting grid with and provides a voltage gain of 20 to 50 and a relatively high-power gain, as of 20 to 40 db. The electron gun includes a massive non-intercepting accelerating anode disposed between the control grid and the depressed collector. When the beam traverses the accelerating anode to the depressed collector, the collector is lowered toward cathode potential, causing an equivalent current to flow in the thermionic diode load. The beam perveance of the load tube is preferably substantially equal to the perveance of the electron gun of the tetrode modulator tube.

5 Claims, 5 Drawing Figures

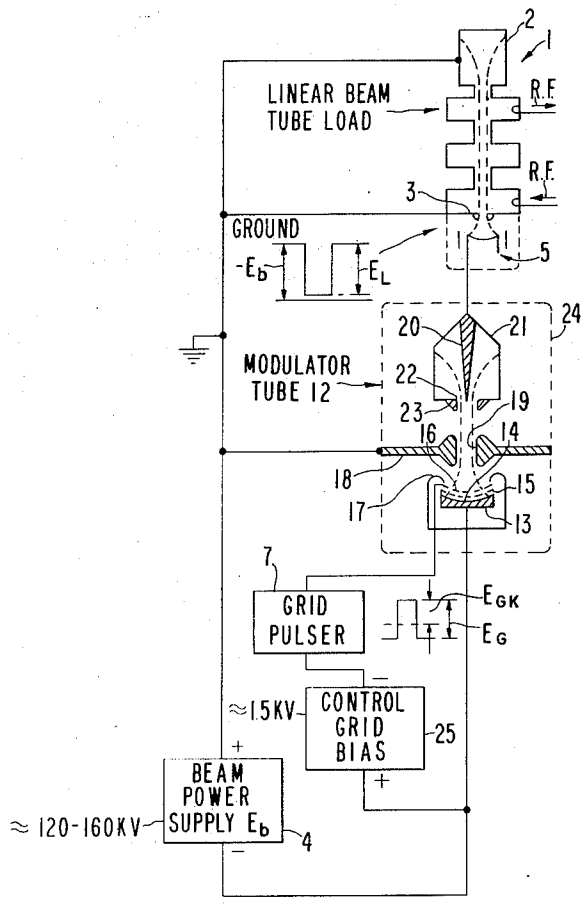


FIG. 1
PRIOR ART

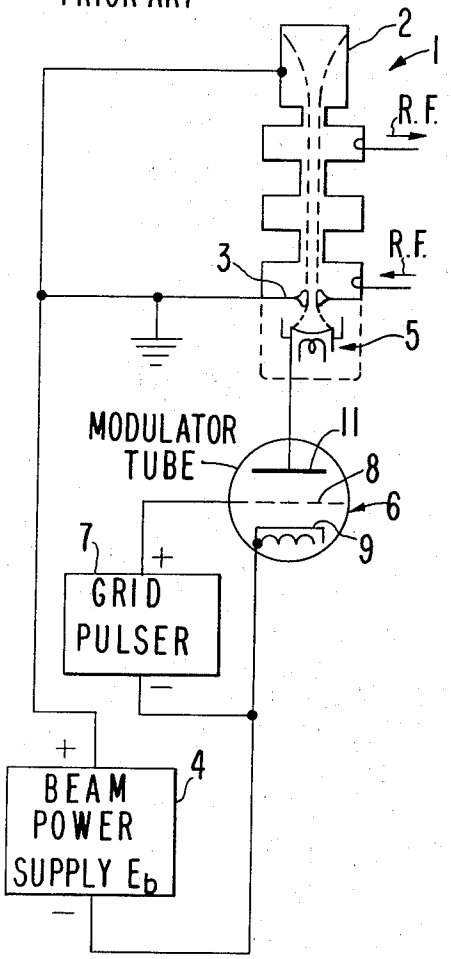


FIG. 2

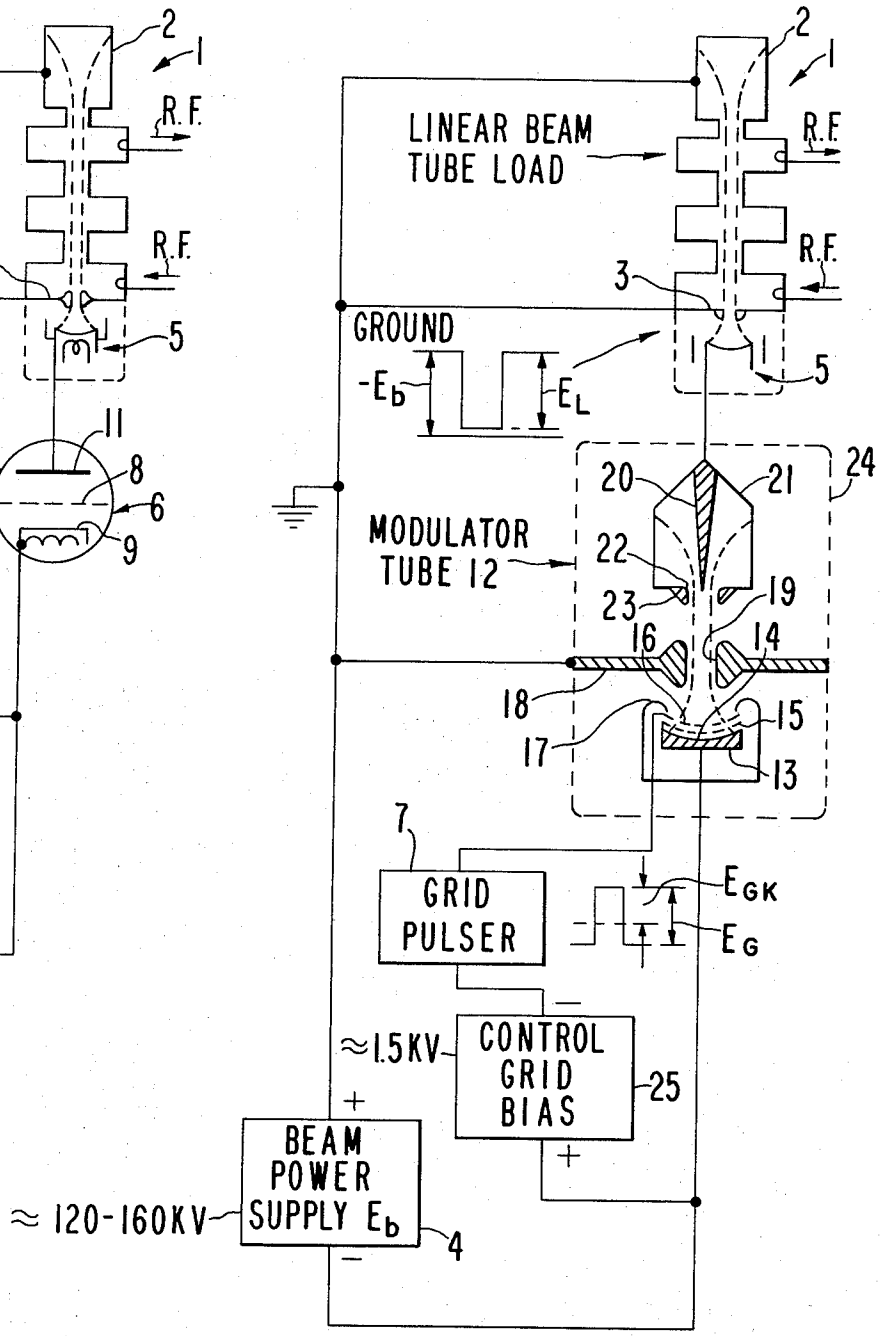


FIG. 3

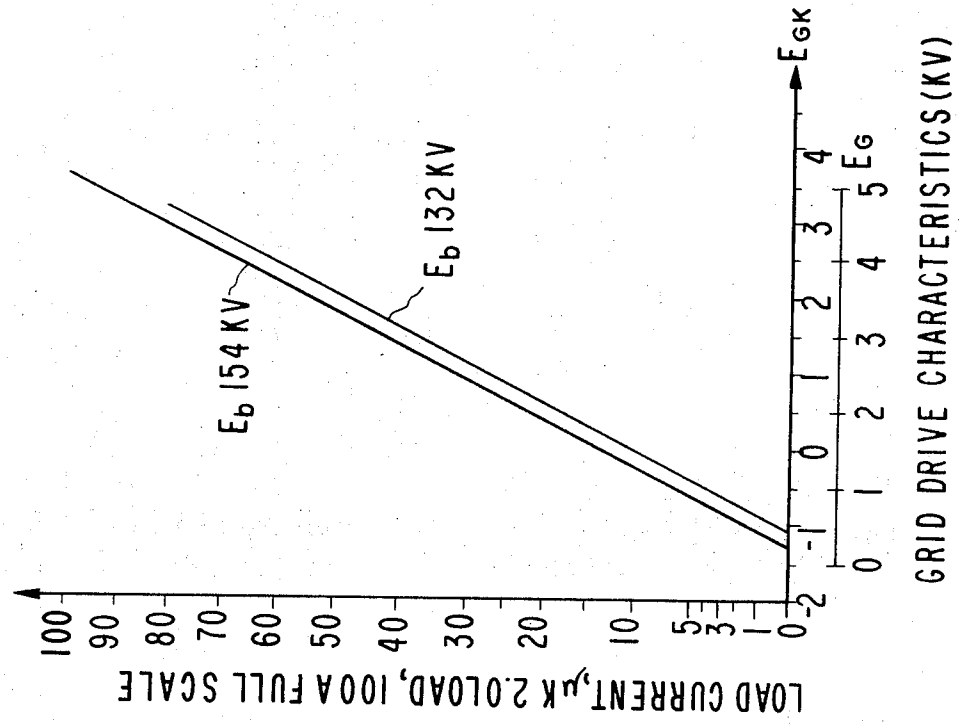


FIG. 4

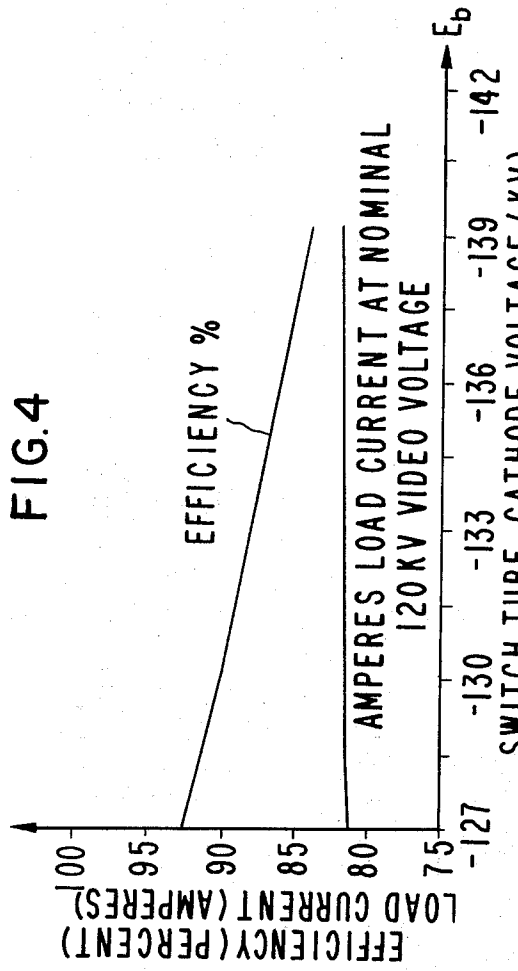
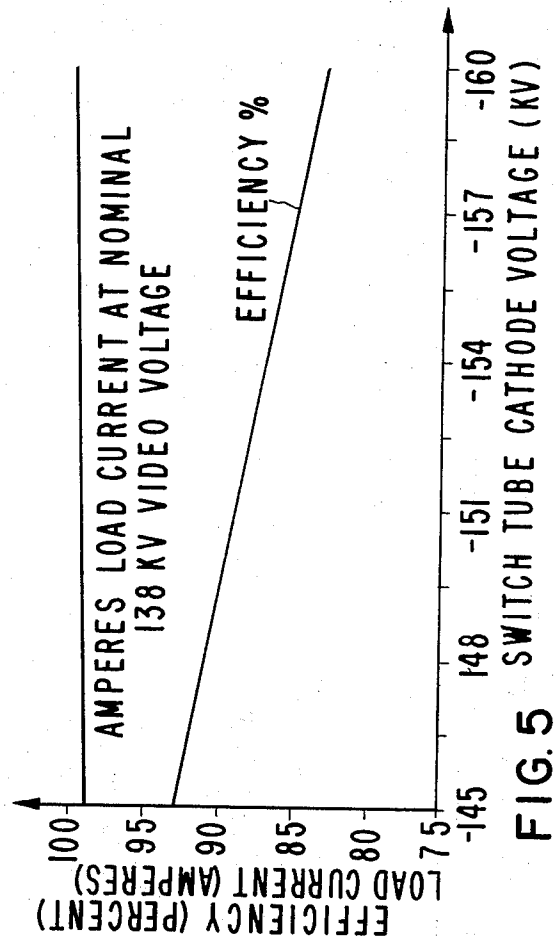


FIG. 5



MODULATOR CIRCUIT FOR HIGH POWER LINEAR BEAM TUBE

GOVERNMENT CONTRACT

The invention herein described was made in the course of or under a contract or sub-contract with the U.S. Department of the Air Force.

DESCRIPTION OF THE PRIOR ART

Heretofore, high-power in excess of thermionic diode loads, such as klystron amplifiers, traveling wave tubes and the like, have been pulse-modulated by means of a hard tube triode modulator series-connected such that the plate of the triode was connected to the thermionic cathode of the load and the cathode of the triode modulator was connected to the negative terminal of the beam power supply. The positive terminal of the beam power supply was connected to the anode of the load. The load was modulated by applying a pulse to the control grid of the triode modulator tube for turning on the modulator tube and causing the cathode of the load to be depressed to the potential of the negative terminal of the beam power supply through the conducting modulator tube.

The problem with a hard tube triode modulator, in the aforecited circuit, is that an arc in the triode modulator tends to pull the triode into a more conductive state, thereby increasing the current through the load. In addition, arcs within the triode tube tend to migrate to the grid because the grid is in a position of maximum gradient (normal coaxial triode configuration,) thereby tending to destroy the grid of the modulator tube.

Moreover, an arc in the load tube causes the triode modulator tube to be subjected to full beam voltage. Because the triode grid is positioned in a region of maximum gradient, an arc in the load tube tended to increase the probability of producing a corresponding arc in the modulator tube.

Another problem with the hard tube triode modulator is that it is relatively inefficient. The voltage drop across the modulator tube during its conducting intervals is approximately 20 percent of the voltage being switched. This is because the grid-to-place spacing has to be large to hold off the high grid-to-plate voltage. A large grid-to-plate spacing results in a relatively large voltage drop when the tube is conducting.

It is also known from the prior art that a high-power tetrode beam tube employing a depressed flytrap beam collector could be made to have high efficiency by shaping the equipotential surfaces at the mouth of the collector, when operating at depressed potential, to be approximately a mirror image of the equipotential surfaces at the thermionic cathode emitter in order to attain laminar electron flow of uniform current density as the beam expands into the collector. Such a high-power beam tube is disclosed and claimed in U.S. Pat. No. 3,453,482, issued July 1, 1969, and assigned to the same assignee as the present invention.

SUMMARY OF THE PRESENT INVENTION

The principal object of the present invention is the provision of an improved modulator circuit for high-power thermionic linear beam tube loads.

In one feature of the present invention, an improved modulator circuit is provided wherein a high-power tetrode of the type described in the abovecited U.S. Pat. No. 3,453,482 is connected in series with a beam power supply and the load to be modulated, such that the load is connected between the depressed collector and accelerating anode of the high-power tetrode, whereby a more reliable and efficient modulator circuit is obtained.

In another feature of the present invention, the drive potential supplied to the control grid of the tetrode modulator tube is adjusted such that the preveance of the electron gun of the modulator tube is adjusted to be approximately equal to the perveance of the electron gun of the load, whereby efficient modulator tube operation is obtained.

In another feature of the present invention, the thermionic load is a high-power linear beam tube having a beam microperveance within the range of 0.75 to 3.5 and the modulator tube has an electron gun microperveance falling within the same range.

Other features and advantages of the present invention will become apparent upon a perusal of the following specification taken in connection with the accompanying drawings wherein:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic circuit diagram, partly in block diagram form, of a prior art thermionic load modulator circuit,

FIG. 2 is a schematic circuit diagram, partly in block diagram, form, of a thermionic load modulator circuit incorporating features of the present invention,

FIG. 3 is a plot of load current in amps vs. grid drive in KV for two values of beam power supply voltage E_b and depicting the grid drive characteristics for the modulator circuit of FIG. 2,

FIG. 4 is a plot of load current in amperes and efficiency in percent vs. modulator tube cathode voltage E_b in KV depicting the efficiency of the modulator tube and the load at a nominal 120 kV load voltage E_L for the modulator circuit of FIG. 2, and

FIG. 5 is a plot similar to that of FIG. 4 depicting modulator tube efficiency and load current at a nominal 138 kv load voltage E_L for the modulator circuit of FIG. 2.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. 1, there is shown a prior art hard tube triode modulator circuit for modulating a thermionic linear beam tube load 1, such as a high-power klystron amplifier. The load 1 includes a beam collector 2 and a non-intercepting accelerating electrode or anode 3 operating at ground potential which is also the positive terminal of a beam power supply 4 supplying a beam voltage E_b, as of −120 to −160 KV.

A thermionic cathode emitter 5 of the load 1 is connected to the negative terminal of the beam power supply 4 via the plate-to-cathode circuit of a hard tube triode modulator tube 6. A grid pulser 7 pulses the grid 8 of the triode modulator tube 6 positive with respect to its thermionic cathode 9 for turning on the modulator tube 6 and causing the plate 11 and the modulator 6 to be dropped to substantially the negative potential of the beam power supply, thereby depressing the potential on the cathode 5 of load 1 to turn on the beam in load 1.

The modulator tube 6 is typically of the coaxial geometrical configuration wherein the thermionic cathode emitter 9 comprises a series of longitudinally directed filaments centrally disposed of the tube 6 and which includes the outer cylindrical plate 11 tube 6. A cylindrical cage-shaped grid structure 8 is closely spaced to the thermionic emitter 9 for controlling the current to the cylindrical plate 11.

The problem with this sort of modulator tube is that the electron beam is collected on the plate 11 in a region of relatively high electric field such that ions by bombardment of the plate can backstream to the control grid 8, which is also disposed in a region of relatively high gradient, to initiate an arc between the control grid 8 and the plate 11. An arc tends to turn the tube on harder such that more current is drawn by the modulator tube and excessive current may be drawn by load 1.

In addition, because the grid-to-plate spacing has to be high to hold off the high plate-to-grid voltage, the voltage drop through the tube, when conducting, is relatively high, resulting in a relatively low efficiency for the modulator tube. A typical efficiency is approximately 80 percent, there being a 20 percent voltage drop between the grid and plate of the modulator tube.

Moreover, the grid drive power, due to the relatively large beam interception on the grid, is relatively high. For example, to pulse modulate 10 megawatts peak output power, the peak grid drive power, due to grid interception, is approximately 40 kW. Thus, the grid pulser 7 must be capable of supplying a relatively high peak power to the grid circuit of the modulator tube.

Another disadvantage of the hard tube modulator circuit of FIG. 1 is that when an arc occurs in the load tube, excessive voltage appears across the grid-to-plate circuit of the modulator tube which may initiate an arc in the modulator tube. Thus the modulator tube is not protected from shorts in the load tube.

Referring now to FIG. 2, there is shown a modulator circuit for modulating a high-oower thermionic linear beam tube load 1 and incorporating features of the present invention. More particularly, the circuit of FIG. 2 is similar to that of FIG. 1 except that the triode hard tube modulator 6 has been replaced, in the circuit of FIG. 2, with a high efficiency tetrode switch tube of the type disclosed and claimed in the aforecited U.S. Pat. No. 3,453,482. The disclosure of U.S. Pat. No. 3,453,482 is hereby expressly incorporated by reference for a detailed description of the tetrode modulator tube 12.

Briefly, the modulator tube 12 includes a thermionic cathode emitter 13, preferably of the oexide coated type, having a spherically concave cathode emitting surface 14, preferably dimpled to form a multiplicity of individual concave lesser cathode emitters in the manner as disclosed and claimed in U.S. Pat. No. 3,558,967, issued Jan. 26, 1971, and assigned to the same assignee as the present invention.

A shadow grid 15 is disposed overlaying the emitting surface 14 of the thermionic cathode emitter 13. The apertures in the shadow grid 14 are aligned with the spherically concave lesser cathode emitting surfaces. The shadow grid 15 is operated at essentially the same potential as the thermionic cathoce emitter 13 for suppression of emission from the cathode in the undimpled region of the cathode shadowed by the grid 15.

A spherically concave control grid 16 is disposed overlaying the shadow grid 15 with the apertures of the control grid being aligned in registration with the apertures in the shadow grid 15. The control grid 16 is spaced from the cathode emitting surface 14 by relatively short distance, as of 0.039 inch, to define a multiplicity of Pierce guns when a positive potential, relative to the cathode, is applied to the control grid 16. The control grid 16 is supported in electrically insulative relation relative to the thermionic cathode, as by an insulator mounted to a surrounding focus electrode 17 operating at cathode potential.

A relatively massive centrally apertured accelerating electrode 18, as of copper, forms the anode of the composite electron gun comprising anode 18 and cathode 13. The composite electron gun is preferably of the Pierce design for laminar convergent electron flow from the thermionic cathode emitter surface 14 through a central aperture 19 in the accelerating electrode 18 to a depressed beam collector structure 21 at the terminal end of the beam path. The diameter of the accelerating aperture 19 in the accelerating electrode 18 is preferably substantially smaller than the cross-sectional dimension of the beam as it leaves the emitting surface 14 such that there is a laminar convergent electron flow through the aperture 19 in the accelerating electrode 18. Also the length of the passageway 19 through the accelerating electrode 18 is preferably longer than its transverse dimensions such that the cathode emitter 13 is shielded from the electric fields of the depressed collector 21.

The collector 21 is of the flytrap type wherein the collector cavity includes a constricted mouth portion 22 forming the entrance passageway into the collector cavity 21. A focus electrode structure 23 is provided at the lip of the beam entrance aperture 22 which cooperates with the mutually opposed surfaces of the accelerating electrode 18 such that a series of dish-shaped equipotential surfaces are formed in the region between the accelerating anode 18 and the mouth 22 of the beam collector 21 which is substantially a mirror image of the similar equipotentials formed between the concave emitting surface 14 of the thermionic cathode emitter 13 and the mutually opposed surfaces of the accelerating anode 18.

In addition, a tapered conductive probe 20 is preferably provided coaxially within the collector cavity 21 and terminating at a point substantially in the plane of the mouth 22 to further aid in obtaining laminar electron flow of uniform current density across the beam as it enters the mouth 22 of the depressed collector 21. The probe is disclosed and claimed in my copending U.S. application Ser. No. 283,431, filed Aug. 24, 1972 and; assigned to the same assignee of the present invention.

Thus, in this manner, substantially laminar flow for the electron stream is obtained from the cathode emitter 13 through the accelerating anode 18 and into the beam collector 21 to minimize reflection of electrons back to the accelerating electrode 18 when the potential of the beam collector 21 has been depressed to nominally the potential of the thermionic cathode emitter 13, as is obtained when the modulator tube 12 has been turned on and is conducting maximum current

through the load **1.** The modulator tube **12** includes an evacuated envelope **24.**

The modulator tube **12** is normally biased to an off (non-conducting) state via a d.c. negative potential, as of 1.5 kV, supplied to the control grid from a control grid bias supply **25** connected between the negative terminal of the beam power supply **4** and the control grid **16.** The grid pulser **7** is series connected with the control grid bias supply **25** and the control grid **16** for supplying a positive grid pulse E_G, as of 1 to 5 kV, to the control grid **16.** The positive grid pulse of voltage E_G is superimposed upon the d.c. negative control grid bias, as of 1.5 kV, such that the effective positive control grid voltage E_{GK} is the difference between the d.c. negative control grid bias and the positive grid pulse E_G.

In operation the pulse input grid voltate E_{GK} is adjusted such that electron gun perveance of the modulator tube **12** is approximately equal to or slightly less than the beam perveance of the gun of load **1.** When this is achieved, maximum efficiency for the modulator tube **12** is obtained because the magnitude of the voltage on the beam collector is slightly less than the magnitude of the beam supply voltage.

An advantage of this tetrode modulator circuit when used with a thermionic linear beam tube load is that the operating characteristics, such as efficiency, are constant over a wide range of power levels, provided appropriate adjustment of beam voltage and grid drive is made.

The constant efficiency is the result of the fact that the load impedance presented by a given perveance load is the optimum impedance for the tetrode modulator tube due to electron optics considerations which are optimum at a geven beam perveance. The degree of collector depression of the modulator tube **12** which is allowable without reflecting electrons to the accelerating electrode determines the modulator tube voltage drop and, therefore, the efficiency of the modulator. The μ of the grid **16** is generally in the range of 20 – 200 with a power gain of 20 to 40 db.

Referring now to FIGS. **3–5** there is shown the typical operating curves for a typical modulator circuit of FIG. **2.** At a load voltage E_L of approximately 120 kV FIG. **4** and a load current of 82 amps, the efficiency of the modulator circuit varies from 93 percent to 84 percent as a function of the power supply voltage E_b. FIG. **5** shows a plot of dynamic impedance and efficiency for an operating condition of 100 amps load current at 138 kV load voltage E_L with a beam voltage E_b on the modulator tube **12** of between 145 and 160 kV.

One advantage of the series modulator tube is a relatively high dynamic impedance which results in a video voltage E_L which is relatively independent of fluctuations in supply voltage E_b.

Another advantage of the modulator circuit of FIG. **2** is that the load tube **1** is protected from damage in the event of an internal arc in either the load tube **1** or the modulator tube **12** since the load tube **1** is isolated from the d.c. power supply **4** by the massive accelerating anode **18** of the modulator tube **12,** which is operated at ground potential. The maximum arc current in the load tube **1** is limited to the current drawn through the modulator tube **12.**

The rise time of the load voltage E_L follows closely the rise time of the grid drive voltage E_G since the only capacity to be charged is the capacity to ground of the modulator tube collector **21** (30 pf), the electron gun of the thermionic load **1** (30 pf), and the filament transformer (not shown) which can be as low as 30 pf. This total capacity of 90 pf can be charged by the beam current in 100 nanoseconds.

The recommended beam voltage E_b is 110 percent of the video output level E_L since this allows ± 5 percent variation of beam voltage E_b for ripple regulation and drop with a reasonable efficiency and a minimum dissipation.

Another advantage of the modulator circuit of FIG. **2** is that the efficiency is relatively independent of the power level at which the load **1** is supplied. For example, if it is desired to operate the load **1** at a lower power level, the beam voltage E_b of the power supply **4** is lowered and the grid drive voltage levels are readjusted such that the electron gun perveance of modulator tube **12** is approximately equal to that of load **1** being modulated.

Another advantage of the tetrode modulator circuit of the present invention is that the massive accelerating electrode **18** operating at ground potential serves as an excellent r.f. shield for shielding the control grid **16** from the collector **21,** thereby eliminating the degradation in gain called Miller effect experienced with prior art triode modulators. In addition, the tetrode may be installed in such a manner to shield the grid pulse modulator **7** from the output video voltage.

Although the description, thus far, has described the load **1** as a microwave linear beam tube, such as a klystron or a traveling wave tube, it is also useful for modulating the power output of other types of thermionic loads which have diode-like electrical characteristics, such as magnetrons, electron guns for exciting plasma discharges in high-power laser tubes, and other types of electron guns. There does not appear to be a theoretical limit to the peak or average power output that may be modulated by the modulator circuit of FIG. **2,** since the modulator tube **12** may be merely physically scaled to larger or smaller dimensions to accommodate a wide range of power levels.

While the above description contains many specificities, these should not be construed as limitations upon the scope of the invention, but merely as an exemplification of the preferred embodiments thereof. The intended scope of the invention is indicated by the following claims and their legal equivalents.

What is claimed is:

1. A high power modulator circuit, comprising:

high power beam tube means having a thermionic cathode and an anode spaced therefrom to define an operable electron gun for generating an electric beam which is to be modulated;

modulator tube means having a thermionic cathode, a centrally apertured, substantially non-intercepting accelerating anode spaced from said cathode for drawing electrons through said accelerating aperture for forming a high power electron beam, collector means for collecting said electron beam, said collector means operating at a depressed potential with respect to said anode, and a substantially non-intercepting control grid interposed between said anode and said cathode for controlling said electron beam;

power supply means for supplying direct current power to said beam tube means and said modulator tube means;

said modulator tube means being series-connected with the beam circuits of said beam tube means and said power supply means, the positive terminal of said power supply means being connected to said anode of said modulator tube means, and said thermionic cathode of said beam tube means being directly connected electrically to said depressed-potential collector means of said modulator tube means, whereby said beam tube means forms the load of said modulator tube means; and

means for pulsing said control grid of said modulator tube means positive with respect to said cathode thereof for modulating the beam current of said modulator tube and hence the beam current of said beam tube means.

2. The apparatus of claim **1** including control grid bias means connected for supplying a direct current bias potential to said control grid of said modulator tube, said bias potential being sufficiently negative relative to the potential of said thermionic cathode of said modulator tube such that in the presence of a turn-on pulse of predetermined positive potential applied to said control grid relative to said thermionic cathode of said modulator tube means, the perveance of the electron gun of said modulator tube means will be substantially equal to the perveance of the electron gun of said beam tube means.

3. The apparatus of claim **1** wherein said thermionic cathode of said modulator tube means has a concave emitting surface facing said central aperture in said accelerating anode of said modulator tube means, said central aperture of said accelerating anode being unobstructed and of substantially less cross-sectional area than said concave emitting surface of said cathode emitter, and wherein said collector means includes a cavity having a constricted beam entrance mouth portion facing said central aperture of said accelerating anode for passage of the beam into said collector means while restricting the backstreaming of secondary electrons from said collector cavity back toward said accelerating anode, and wherein the portions of said collector means facing said accelerating anode are shaped relative to the shape of the opposed surfaces of said accelerating anode to provide a series of generally concave equipotentials in the space between said accelerating-anode and said collector means, which series of equipotentials are generally a mirror image of a similar series of equipotentials in the space between said cathode and said accelerating anode when said tube is conducting maximum rated beam current into said beam tube means.

4. The apparatus of claim **2** wherein said beam tube means comprises a high frequency linear beam tube including said thermionic cathode, a non-intercepting centrally apertured anode spaced from said thermionic cathode for forming and projecting a beam of electrons over an elongated beam path, a beam collector structure at the terminal end of said beam path for collecting said beam, and a high frequency electrical circuit disposed along the beam path intermediate said anode and said collector in electromagnetic wave energy exchanging relation with said beam.

5. The apparatus of claim **2** wherein the electron gun of said beam tube means has a microperveance falling within the range of 0.75 to 3.5

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