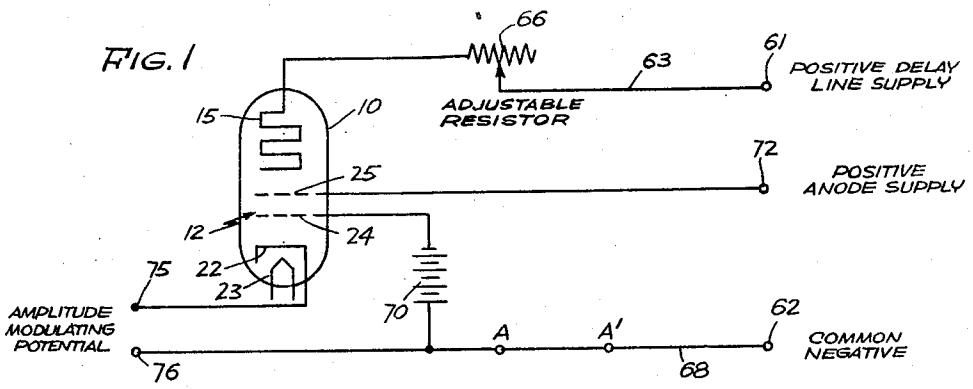
Dec. 8, 1959 R. HARPER 2,916,655

TRAVELING WAVE TUBES

Filed May 31, 1957

FIG. 1



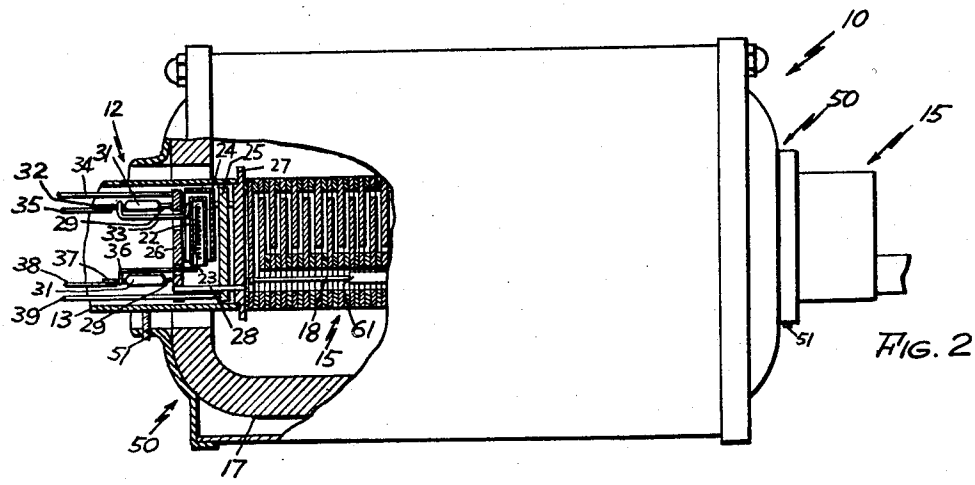


FIG. 2

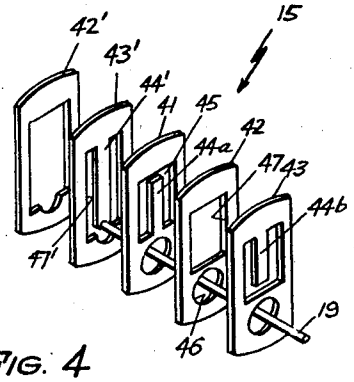


FIG. 4

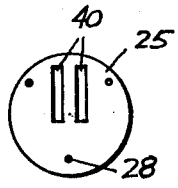


FIG. 3

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2,916,655

TRAVELING WAVE TUBES

Robert Harper, Waltham, Mass., assignor to Raytheon Company, a corporation of Delaware

Application May 31, 1957, Serial No. 662,755

12 Claims. (Cl. 315—3.5)

This invention concerns a traveling wave electron discharge device, and more particularly, to means for eliminating substantially frequency pushing in a traveling wave oscillator.

Before describing the invention, a brief description of traveling wave tube operation will be given. Traveling wave oscillators are known in which the electrons in an extended beam are caused to interact with the electromagnetic field of a wave propagating along the path adjacent the periodic slow-wave energy-propagating structure, which may be an interdigital delay structure. The electromagnetic field along such a structure may be considered to consist of a number of superimposed traveling waves or space harmonics. These harmonics traveling with different phase velocities, some of which are characterized in that the phase velocity is in the same direction as the energy or group velocity; such harmonics are referred to as forward waves. Other harmonics, on the other hand, are characterized by a negative phase velocity, that is, a phase velocity in a direction opposite to the energy or group velocity; these waves are referred to as negative space harmonics or backward waves. If, for example, the electron beam is propagated in the direction of one of these backward waves at a velocity substantially equal to the phase velocity of the backward waves, interaction will occur between the electron beam and the traveling wave and the energy will be transferred to the electromagnetic field; the energy given to the backward wave will be transferred along the periodic structure toward the beam source. If the electron beam exceeds a critical value at which oscillations can begin, and when the electron beam velocity is in substantial synchronism with the velocity of one of the space harmonics, such as a backward wave, oscillations may be generated in the tube. These oscillations will propagate along the periodic structure and may be extracted at one end thereof by means of an output coupling means such as a coaxial line whose inner conductor is attached to the periodic structure adjacent one end.

In one type of traveling wave tube, sometimes referred to as the "O"-type, the electron beam is permitted to pass through the interaction space adjacent the periodic slow-wave propagating structure and may be collected at the end thereof remote from the electron source by a collector electrode maintained at a potential positive relative to the electron source. The electron beam is prevented from moving laterally within the tube by a longitudinal focusing magnetic field. In another type of traveling wave tube, sometimes designated as the "M"-type tube, the electrons are permitted to move through unidirectional electric and magnetic fields which are transverse to one another and to the mean path of the electron beam.

In prior operation of traveling wave oscillator tubes, the power output can be changed by varying the potential of the electron gun control grid to effect a change in beam current. Such changes in power output are accompanied by undesirable changes in operating frequency. For example, as the control grid is made less negative so that the beam current, and hence the power output, is increased, the frequency of oscillation decreases; this is the well-known frequency-pushing effect. The frequency of oscillation of a traveling wave oscillator is at least partially dependent upon the velocity of the electron beam in the interaction space adjacent the slow wave propagating network structure, or delay line, which, in turn, has been found to be a function of the potential of the delay line relative to the cathode or other negative electrode. In other words, as the voltage between the delay line and the cathode increases, the frequency of oscillation increases, other factors remaining unchanged. Since this voltage essentially is unaffected by changes in the grid-to-cathode modulating potential, frequency pushing is observed with the grid amplitude modulation of the prior art. It is evident from the above remarks that if the voltage between the delay line and the cathode were increased (tending to cause an increase in frequency) at the same time that the power output or beam current is increased (tending to cause a decrease in frequency) the frequency shift attendant upon changes in power output may be compensated for in whole or in part.

In accordance with the invention, the voltage between the delay network and the cathode is varied concomitant with, and in the same direction as, the beam current and power output. This is accomplished by varying the potential of the cathode relative to all other electrodes of the traveling wave oscillator to amplitude-modulate the oscillator. As the cathode potential becomes more positive, the power output decreases, tending to cause the frequency of oscillation to increase in accordance with the well-known pushing effect above described. However, since a shift of the cathode potential in the positive direction decreases the potential difference between the positive delay network and the cathode, there is a tendency for the frequency of oscillation to decrease, whereby all or part of the undesired frequency shift can be cancelled out. By proper design, the control grid characteristic of the electron gun and the frequency versus delay line potential characteristic of the traveling wave tube may be adjusted to provide substantially exact compensation for undesired frequency pushing. The control grid characteristic may be altered, for example, by varying the electrode spacing of the gun elements.

By placing a variable resistor in series with the delay network, a further refinement is possible which permits compensation to be made for slight variations in individual tubes. The tube could be designed so that, when used in the circuit of the invention, the undesired frequency pushing is overcompensated for, that is, so that the frequency actually increases slightly with an increase in beam current (power output). As the beam current increases, the voltage drop across the resistor increases and the voltage available between the delay line and the cathode will decrease by a corresponding amount. In other words, the alteration of the voltage drop across the resistor as the beam current changes produces a change in delay line voltage which would produce a frequency shift opposing the frequency shift caused by the effect of change in the cathode potential on the delay line voltage. The amount of compensation when the frequency pushing is overcompensated for thereby can be reduced until the pushing effect is eliminated substantially. The compensating resistor may be placed either in the cathode end or the delay line end of the delay line voltage supply.

For a better understanding of the invention, together with further objects thereof, reference is made to the following description taken in conjunction with the accompanying drawing wherein:

Fig. 1 is a circuit diagram including a traveling wave oscillator in accordance with the invention;

Fig. 2 is a view, partly in section, illustrating a typical traveling wave oscillator used in the circuit of Fig. 1;

Fig. 3 is a plan view of the accelerating anode used in the gun assembly of Fig. 2; and

Fig. 4 is an exploded view of a portion of the interdigital delay line of the tube of Fig. 2.

Referring to the drawing, a traveling wave tube **10** is shown which includes an electron gun assembly **12** mounted within a cylindrical housing **13**, a slow wave propagating network structure, or delay line **15**, a focusing magnet **17**, and a coaxial output assembly **18**. The electron gun assembly **12** comprises a cathode **22** including therein a heater coil **23**, a grid **24**, an accelerating anode **25**, and mounting plates **26** and **27**, the latter of which is secured to one end of housing **13**. The elements **22** to **25** of the electron gun are insulatedly mounted in spaced relationship by means of ceramic support rods **28** which pass through mounting plates **26** and **27** and element **25**. A ceramic-to-metal seal may be made at the points of insertion of the support rods **28** into the accelerating anode **25** and the mounting plates **26** and **27**. The grid **24** is supported from mounting plate **26** by means of one or more wires **29** spot welded to the grid and extending through mounting plate **26**. A glass bead **31** is attached to one end of wires **29**, while wires **32** and **37** are secured to the glass beads **31**, as shown in Fig. 2. The cathode **22** is supported from mounting plate **26** by means of a support wire **33** spot welded to the cathode and passing through a central aperture in mounting plate **26**; this support wire **33** for the cathode is attached to wire **32**. Grid lead **34** is secured directly to the mounting plate **26**, while a cathode lead **35** is connected to wire **32**. A heater wire **36** interconnects one end of heater **23** and wire **37**; a heater lead **38** is attached to this wire **37**. The other end of the heater **23** may be connected directly to the cathode. The accelerating anode **25** is mounted on support rods **28** in spaced relationship with the grid **24**, and a lead **39** is connected to the accelerating anode **25**. The housing **13** is maintained at the same potential as the interdigital network **15** and an appropriate source of high voltage, not shown, is connected between the network **15** and cathode **22**. Likewise, appropriate sources of potential, not shown, for the other elements of the electron gun are necessarily provided. The leads **34, 35, 38 and 39** extend through a seal, not shown, mounted at the end of housing **13** remote from mounting plate **27**. The grid **24**, accelerating anode **25**, and mounting plate **27** contain two parallel slits **40** through which electrons from the cathode may pass. A plan view of the accelerating anode **25** containing slits **40** is shown in Fig. 3. By means of these slits, and by means of appropriate accelerating voltage between the accelerating anode **25** and the cathode **22**, a pair of substantially flat beams is directed into the interaction space **45** of the interdigital delay network **15** adjacent the edges of the fingers **44*a*** and **44*b***.

The axial focusing field for the electron beam is provided by the magnet assembly **17** which is mounted about the interdigital delay structure **15** by means of a ring plate assembly **50** positioned at each end of the tube. Set screws **51** passing through a portion of each assembly **50** and seating against electron gun housing **13** and the interdigital delay network **15**, respectively, maintain the axial magnetic field-producing means **17** in the desired relationship relative to the interdigital delay network **15**.

As shown in Fig. 2, the interdigital delay network **15** may be attached at one end to mounting plate **27** which, in turn, is affixed to housing **13**. As shown in Fig. 4, the interdigital network may be made up of several laminations. The major portion of the interdigital line **15** includes a plurality of sets of three laminations **41, 42** and **43**, each containing a circular aperture **46** near one end whose boundary serves as a portion of

the outer conductor of the coaxial output coupling means **18** when the laminations have been stacked together and assembled, as by brazing. Each lamination includes a generally rectangular opening **47**. Laminations **41** include an elongated electrically-conductive finger **44*a*** which extends from one edge of opening **47** almost to the opposite edge thereof. Laminations **43** likewise include an electrically-conductive finger **44*b*** which extends from the edge of opening **47** opposite that of lamination **41** to a point adjacent, but not contacting, the opposite edge of said opening. The elements or fingers **44*a*** of laminations **41**, when assembled, are positioned in spaced relationship with adjacent fingers **44*b*** of laminations **43** by means of spacer laminations **42** which do not contain any fingers. The end finger **44'** of lamination **43'** is slightly longer in order to permit connection to be made directly to the inner conductor **19** of coaxial output assembly **18**. The opening **47'** in lamination **43'**, unlike the openings **47** in the other laminations, is continuous with the circular aperture forming the boundary of the outer conductor of that portion of the coaxial output means **18** disposed within the interdigital network. Spacer **42'** is similar to that of spacer lamination **42**, except that it contains an enlarged opening like that in lamination **43'**, which may be provided at the end of the interdigital network **15** in order to allow room for sufficient movement of the matching finger **44'**. The invention is not restricted to coaxial output coupling assemblies; the use of waveguide coupling means, for example, is possible.

Alternatively, the interdigital delay network **15** may consist of two interleaved solid assemblies, such as indicated in Figs. 1 and 3 of a copending application of Robert McCowan Unger, Serial No. 580,609, filed April 25, 1956, now Patent No. 2,837,684. The invention, of course, is not limited to traveling wave tubes using interdigital delay networks; for example, the delay network may be in the form of a helix.

Although the traveling wave oscillator described in the drawing is the "O"-type, this invention may be applied also to the "M"-type tube which is described in an application by Edward C. Dench, Serial No. 391,628, filed November 12, 1953.

A source of delay line voltage for traveling wave tube **10**, preferably a well-regulated voltage, is available at the terminals **61** and **62**. The positive terminal **61** is connected by way of a positive supply lead **63** to the delay line **15** through an adjustable resistor **66**. As pointed out earlier, the use of the adjustable resistor **66** is optional, and compensation for frequency pushing may be achieved without inserting the resistor in series with tube **10**. The negative terminal **62** of the delay line voltage supply serves as the reference potential of the system and may be grounded. The adjustable resistor **66**, of course, may be inserted in the negative supply lead **68** between the points A and A'.

The control electrode **24** of the electron gun portion **12** of tube **10** is biased negatively with respect to the common or negative supply lead **68** by means of a fixed grid biasing voltage as from a battery **70**. The anode or accelerating electrode **25** of the electron gun **12** is connected to the positive terminal **72** of a regulated power supply separate from the delay line voltage supply.

The amplitude modulating potential is applied to terminals **75** and **76** which are connected, respectively, to the cathode **22** of the electron gun **12** and to the common negative terminal **62** of the delay line supply by way of negative supply lead **68**.

The operation of the circuit without the compensating resistor **66** will now be explained. As the amplitude modulating potential becomes increasingly negative, the beam current in the traveling wave tube increases and the power output thereof is correspondingly increased. Similarly, the power output will decrease as the potential of the cathode with respect to the negative terminal **62** be-

comes less negative. The frequency of either an "M"-type or "O"-type traveling wave oscillator tends to decrease with increasing beam current or power output. As the beam current increases in the tube, owing to a negative-going shift of the amplitude modulating potential applied to the cathode (relative to the negative terminal of the delay line supply), this pushing effect tends to decrease the frequency of oscillation. However, a shift of the cathode potential in the negative direction also results in an increase in the potential difference between delay line and cathode. Since frequency of operation of a traveling wave oscillator is dependent upon the delay line voltage and increases with increasing delay line voltage, the frequency tends to increase as the result of the increasing potential difference accompanying the negative-going shift in the amplitude modulating potential applied to the cathode. In other words, the effect of pushing is offset by the effect of increasing delay line-to-cathode voltage. By analogy, it can be shown that a positive-going change in cathode potential will be accompanied by a decrease in the potential difference between delay line and cathode, thereby tending to increase frequency.

When the variable resistor **66** is inserted in either of the lines **63** or **68**, the tube **10** may be designed so that the undesired frequency pushing is slightly overcompensated for (frequency increases slightly with increasing beam current). As the beam current increases, the voltage drop across resistor **66** increases, whereupon the delay line voltage between delay line **15** and cathode **22** decreases. This increased voltage drop across resistor **66**, owing to increased beam current and the resultant decrease in delay line voltage, tends to cause a decrease in frequency opposing the tendency for frequency to increase as the result of the effect of increasing cathode potential on the delay line voltage. A decreasing beam current will result in an increase in available delay line voltage, tending to cause an increase in frequency, which opposes the tendency for a decrease in frequency resulting from the effect of decreasing cathode potential on delay line voltage. By means of the resistor **66**, therefore, the amount of compensation obtainable when the frequency pushing is overcompensated for can be reduced so that frequency pushing is no longer consequential.

This invention is not limited to the particular details of construction, materials and processes described, as many equivalents will suggest themselves to those skilled in the art. It is accordingly desired that the appended claims be given a broad interpretation commensurate with the scope of the invention within the art.

What is claimed is:

1. In combination, a traveling wave electron discharge device comprising a periodic slow wave transmission network structure for transmitting electromagnetic wave energy, said network structure producing in a path adjacent thereto radio-frequency fields of the electromagnetic wave energy being transmitted, an electron gun including an electron source, a beam intensity control electrode, means including said electron gun for directing said electrons in a beam adjacent said path at a velocity substantially equal to that of said wave fields for energy-exchanging interaction with said wave fields, unidirectional energy supply means including first and second terminals across which a regulated supply voltage is maintained, and amplitude modulating means for varying the potential of said cathode relative to the potential of said control electrode and also relative to the potential of said second terminal for effecting amplitude modulation of said device.

2. In combination, a traveling wave electron discharge device comprising a periodic slow wave transmission network structure for transmitting electromagnetic wave energy, said network structure producing in a path adjacent thereto radio-frequency fields of the electromagnetic wave energy being transmitted, an electron gun including an electron source and a beam intensity control electrode, means including said electron gun for directing said electrons in a beam adjacent said path at a velocity substantially equal to that of said wave fields for energy-exchanging interaction with said wave fields, output coupling means coupled to the end of said network structure away from which said electrons are being directed, unidirectional supply means including first and second terminals across which a supply voltage is maintained, and amplitude modulating means for varying the potential of said cathode relative to the potential of said control electrode and also relative to the potential of said second terminal for effecting amplitude modulation of said device.

3. In combination, a traveling wave electron discharge device comprising a periodic slow wave transmission network structure for transmitting electromagnetic wave energy, said network structure producing in a path adjacent thereto radio-frequency fields of the electromagnetic wave energy being transmitted, an electron gun including an electron source and a beam intensity control electrode, means including said electron gun for directing said electrons in a beam adjacent said path at a velocity substantially equal to that of said wave fields for energy-exchanging interaction with said wave fields, unidirectional energy supply means including first and second terminals across which a supply voltage is maintained, said first terminal being positive relative to said second terminal, said first terminal further being coupled to said network structure, and modulating means for varying the potential of said cathode relative to the potential of said control electrode and also relative to the potential of said second terminal for effecting amplitude modulation of said device, an adjustable resistor in series with said supply means for varying the effective voltage between said electron source and said network structure to compensate for the effect on frequency of changes in the voltage between said electron source and said network structure achieved by said modulating means.

4. In combination, a traveling wave electron discharge device comprising a periodic slow wave transmission network structure for transmitting electromagnetic wave energy, said network structure producing in a path adjacent thereto radio-frequency fields of the electromagnetic wave energy being transmitted, an electron gun including an electron source and a beam intensity control electrode, means including said electron gun for directing said electrons in a beam adjacent said path at a velocity substantially equal to that of said wave fields for energy-exchanging interaction with said wave fields, first and second terminals across which a unidirectional supply voltage is maintained, said first terminal being coupled to said network structure, means for applying a fixed biasing voltage between said control electrode and said second terminal, and modulating means for amplitude modulating said electron discharge device in response to a modulating potential applied between said electron source and said control electrode, said modulating potential further being applied between said electron source and said second terminal.

5. In combination, a traveling wave electron discharge device comprising a periodic slow wave transmission network structure for transmitting electromagnetic wave energy, said network structure producing in a path adjacent thereto radio-frequency fields of the electromagnetic wave energy being transmitted, an electron gun including an electron source and a beam intensity control electrode, means including said electron gun for directing said electrons in a beam adjacent said path at a velocity substantially equal to that of said wave fields for energy-exchanging interaction with said wave fields, said means for directing including means for producing a magnetic field in the vicinity of said path, first and second terminals across which a unidirectional supply voltage is maintained, said first terminal being positive with respect to said second terminal, said first terminal being coupled to said network structure, means for applying a fixed bias-

ing voltage between said control electrode and said second terminal, and modulating means for amplitude modulating said electron discharge device in response to a modulating potential applied between said electron source and said control electrode, said modulating potential further being applied between said electron source and said second terminal.

6. In combination, a traveling wave electron discharge device comprising a periodic slow wave transmission network structure for transmitting electromagnetic wave energy, said network structure producing in a path adjacent thereto radio-frequency fields of the electromagnetic wave energy being transmitted, an electron gun including an electron source and a beam intensity controlled electrode, means including said electron gun for directing said electrons in a beam adjacent said path at a velocity substantially equal to that of said wave fields for energy-exchanging interaction with said wave fields, said means for directing including means for producing a magnetic field substantially normal to said path, first and second terminals across which a unidirectional supply voltage is maintained, said first terminal being coupled only to said network structure, means for applying a fixed biasing voltage between said control electrode and said second terminal, and modulating means for amplitude modulating said electron discharge device in response to a modulating potential applied between said electron source and said control electrode, said modulating potential further being applied between said electron source and said second terminal.

7. In combination, a traveling wave electron discharge device comprising a periodic slow wave transmission network structure for transmitting electromagnetic wave energy, said network structure producing in a path adjacent thereto radio-frequency fields of the electromagnetic wave energy being transmitted, an electron gun including an electron source and a beam intensity control electrode, means including said electron gun for directing said electrons in a beam adjacent said path at a velocity substantially equal to that of said wave fields for energy-exchanging interaction with said wave fields, said means for directing including means for producing a magnetic field substantially parallel to said path, first and second terminals across which a unidirectional supply voltage is maintained, said first terminal being coupled only to said network structure, means for applying a fixed biasing voltage between said control electrode and said second terminal, and modulating means for amplitude modulating said electron discharge device in response to a modulating potential applied between said electron source and said control electrode, said modulating potential further being applied between said electron source and said second terminal.

8. In combination, a traveling wave electron discharge device comprising a periodic slow wave transmission network structure for transmitting electromagnetic wave energy, said network structure producing in a path adjacent thereto radio-frequency fields of the electromagnetic wave energy being transmitted, an electron gun including an electron source, and a beam intensity control electrode, means including said electron gun for directing said electrons in a beam adjacent said path at a velocity substantially equal to that of said wave fields for energy-exchanging interaction with said wave fields, first and second terminals across which a unidirectional supply voltage is maintained, said first terminal being coupled only to said network structure, and modulating means for amplitude modulating said electron discharge device in response to a modulating potential applied between said electron source and said control electrode, said modulating potential further being applied between said electron source and said second terminal.

9. In combination, a traveling wave electron discharge device comprising a periodic slow wave transmission network structure for transmitting electromagnetic wave energy, said network structure producing in a path adjacent thereto radio-frequency fields of the electromagnetic wave energy being transmitted, unidirectional supply means for maintaining said network structure at a fixed potential relative to a predetermined reference potential, an electron gun including an electron source and a beam intensity control electrode, means including said electron gun for directing said electrons in a beam adjacent said path at a velocity substantially equal to that of said wave fields for energy-exchanging interaction with said wave fields, said unidirectional energy supply means including first and second terminals across which a regulated voltage is maintained, said first terminal being coupled only to said network structure, and modulating means for amplitude modulating said electron discharge device in response to a modulating potential applied between said electron source and said control electrode, said modulating potential further being applied between said electron source and said second terminal, and an adjustable resistor in series with said supply means for varying the effective voltage between said electron source and said network structure to compensate for the effect on frequency of changes in the voltage between said electron source and said network structure achieved by said modulating means.

10. In combination, a traveling wave electron discharge device comprising a periodic slow wave transmission network structure for transmitting electromagnetic wave energy, said network structure producing in a path adjacent thereto radio-frequency fields of the electromagnetic wave energy being transmitted, unidirectional supply means for maintaining said network structure at a fixed potential relative to a predetermined reference potential, an electron gun including an electron source and a beam intensity control electrode, means including said electron gun for directing said electrons in a beam adjacent said path at a velocity substantially equal to that of said wave fields for energy-exchanging interaction with said wave fields, said unidirectional energy supply means including first and second terminals across which a regulated voltage is maintained, said first terminal being coupled only to said network structure, means for applying a fixed biasing voltage between said control electrode and said second terminal, and modulating means for amplitude modulating said electron discharge device in response to a modulating potential applied between said electron source and said control electrode, said modulating potential further being applied between said electron source and said second terminal, and an adjustable resistor in series with said supply means for varying the effective voltage between said electron source and said network structure to compensate for the effect on frequency of changes in the voltage between said electron source and said network structure achieved by said modulating means.

11. In combination, a traveling wave electron discharge device comprising a periodic slow wave transmission network structure for transmitting electromagnetic wave energy, said network structure producing in a path adjacent thereto radio-frequency fields of the electromagnetic wave energy being transmitted, an electron gun including an electron source, a beam intensity control electrode, means including said electron gun for directing said electrons in a beam adjacent said path at a velocity substantially equal to that of said wave fields for energy-exchanging interaction with said wave fields, unidirectional energy supply means including first and second supply lines across which a unidirectional voltage is maintained, first and second terminals for connection to a source of amplitude-modulating voltage, said first supply line being connected to said slow wave network structure, said electron source being connected to said first terminal and said second terminal being connected directly to said second supply line.

12. In combination, a traveling wave electron dis-

charge device comprising a periodic slow wave transmission network structure for transmitting electromagnetic wave energy, said network structure producing in a path adjacent thereto radio-frequency fields of the electromagnetic wave energy being transmitted, an electron gun including an electron source, a beam intensity control electrode, means including said electron gun for directing said electrons in a beam adjacent said path at a velocity substantially equal to that of said wave fields for energy-exchanging interaction with said wave fields, unidirectional energy supply means including first and second supply lines across which a unidirectional voltage is maintained, first and second terminals for connection to a source of amplitude-modulating voltage, said first supply line being connected to said slow wave network structure, said electron source being connected to said first terminal and said second terminal being connected directly to said second supply line, said control electrode

being connected to said second terminal and to said second supply line.

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