Nov. 4, 1958 W. C. BROWN 2,859,411

MODULATED TRAVELING-WAVE TUBE

Filed June 19, 1953 3 Sheets-Sheet 1

FIG. 1

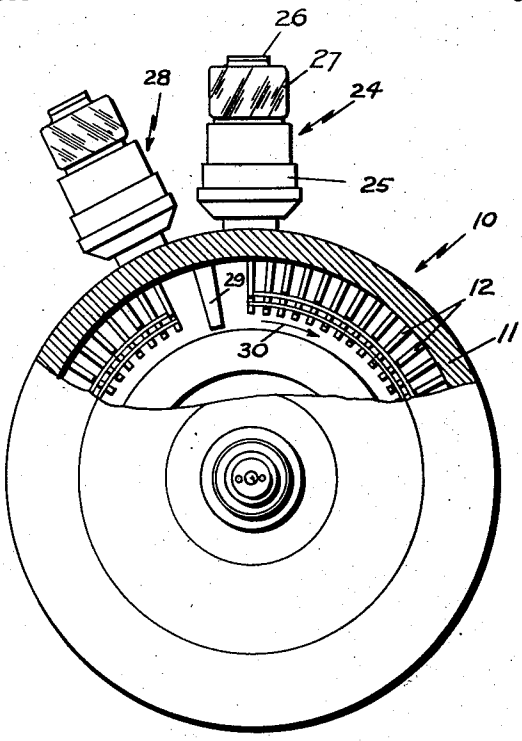
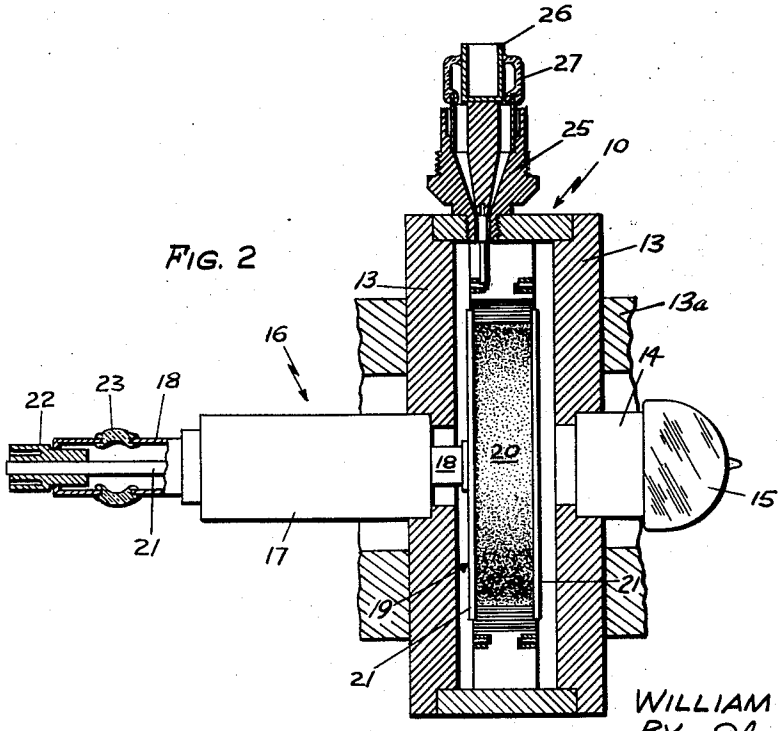


FIG. 2



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Filed June 19, 1953 3 Sheets-Sheet 2

FIG. 3

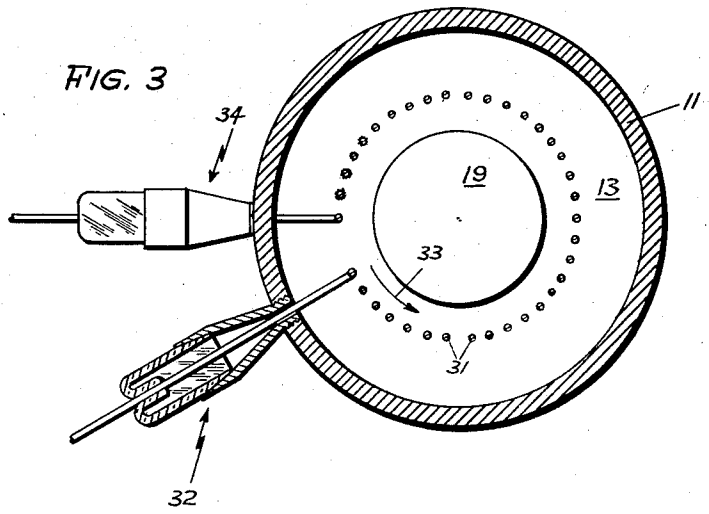
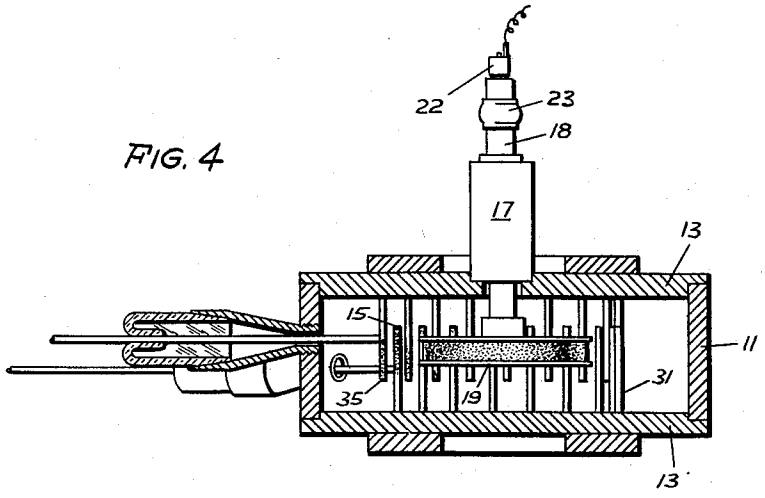


FIG. 4



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MODULATED TRAVELING-WAVE TUBE

Filed June 19, 1953 3 Sheets-Sheet 3

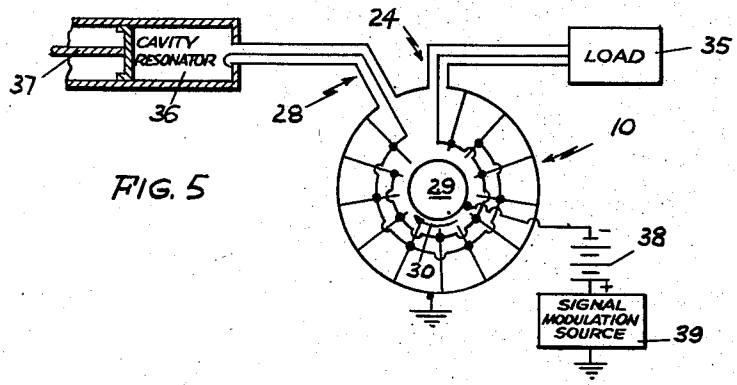


FIG. 5

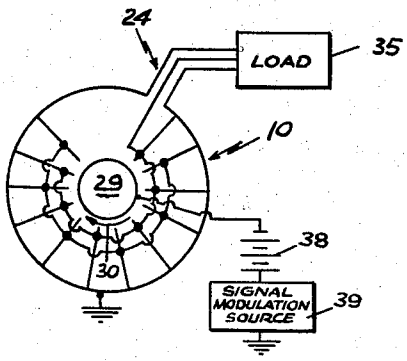


FIG. 6

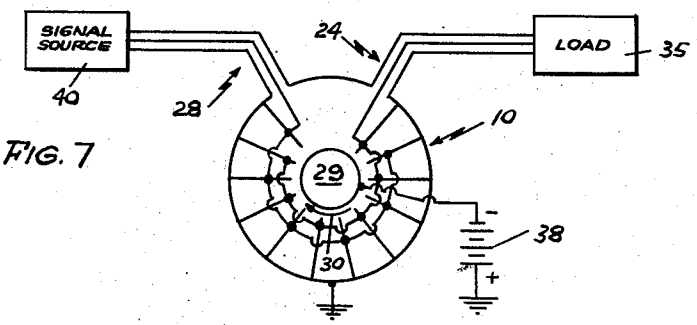


FIG. 7

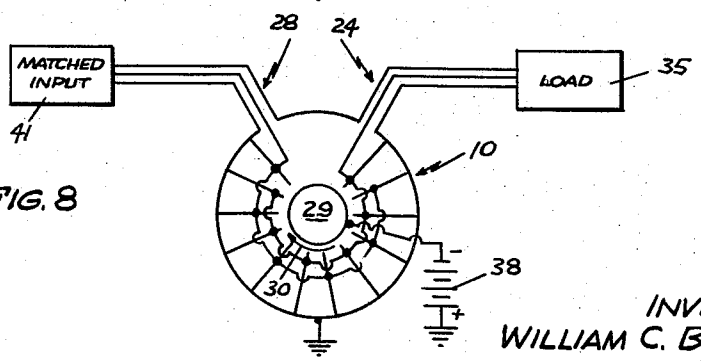


FIG. 8

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MODULATED TRAVELING-WAVE TUBE

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Application June 19, 1953, Serial No. 362,798

2 Claims. (Cl. 332—58)

This invention relates to electron discharge devices and more particularly to devices wherein interaction occurs between an electron steam and electric fields traveling along a transmission network adjacent the electron stream.

Certain networks when used in conjunction with an electron beam exhibit a characteristic such that within a particular range of frequencies a signal may be propagated along the network in a direction opposite to the beam but still interact with the beam because of an apparent phase velocity which is in the same direction as the electron beam and which is synchronous with it. It has been found that this characteristic exists in certain magnetron anode structures, such as the conventional strapped magnetron anode structure or the interdigital magnetron anode structure. This characteristic, for purposes of identification, will be termed the abnormal dispersion characteristic.

This invention discloses that the abnormal dispersion characteristic may be advantageously used in magnetron type structures to produce high efficiency stable oscillators which are substantially independent of their output loads. Briefly, this is accomplished by making the anode structure non-reentrant, for example, by omitting a number of anode elements and/or anode strapping at one point on the structure. The output coupling device is then coupled to the anode structure adjacent the end thereof away from which the electrons move along paths adjacent the anode structure. The electron stream interacts with the phase velocity portion of the wave which is traveling along the anode structure in the same direction and at substantially the same velocity as the electron stream, while the energy or group velocity of the wave is traveling in the opposite direction back along the anode structure from the regions of interaction to the output means. The cathode or electron source is spaced along adjacent an appreciable portion of the anode structure such that the electrons emitted therefrom in the presence of the magnetic field, conventionally associated with magnetron devices, will follow orbits substantially paralleling the face of the anode structure. In such a structure there will be a wide range of electron velocities present in the stream, and, therefore, signals over a wide range of signal velocities, which correspond to a relatively wide range of signal frequencies due to the variation or dispersion of signal velocity with respect to signal frequency along the networks generally associated with magnetron anode structures, may be amplified. This invention discloses that a wide range of frequencies will occur in the device if the end of the network opposite to the end coupled to the output load is terminated in an energy absorbing impedance matched structure, thereby producing a wide band noise generator.

This invention further discloses that a single frequency may be obtained at the output by terminating the end of the network opposite the output in a resonant load, such as a cavity resonator, said cavity resonator being tuned to substantially the desired output frequency.

This invention further discloses that the output amplitude of an external cavity-stabilized oscillator of this type may be amplitude modulated, with little or no variation in frequency, by varying the anode current to the device, this being obtained either by variation of the anode voltage, variation of the magnetic field, or simultaneous variation of both.

This invention further discloses that the device may be made to function as a signal-locked amplifier by substituting a signal source for the stabilizing cavity, said signal source being impedance matched to the anode structure. The output signal from the device will follow variations in frequency of the input signal, and, to a large degree, will follow variations in amplitude thereof.

This invention further discloses that the device may be made to operate as a stable single frequency oscillator, which may be frequency modulated, by removing the stabilizing cavity from the device and allowing the end of the anode structure opposite to the end coupled to the load to be impedance mismatched, for example, by simply leaving the anode structure disconnected from any load or impedance at this point. The frequency of the device is now determined by the phase of the reflected wave produced by the slight mismatch of the output load to the anode structure which is always present. Since variation of the anode voltage varies the average velocity of the electron stream, this variation may be used to vary the reflected phase of the wave, and, hence, vary the frequency output to the load. Such a device will have a relatively low amplitude modulation, and, if desired, this modulation may be still further reduced by applying a compensating modulation signal out of phase to the magnetic field.

Other and further objects and advantages of this invention will be apparent as the description thereof progresses, reference being had to the accompanying drawings, wherein:

Fig. 1 illustrates a partially transverse sectional view of a strapped magnetron structure embodying this invention;

Fig. 2 illustrates a longitudinal cross-sectional view of the device shown in Fig. 1;

Fig. 3 illustrates a transverse cross-sectional view of an interdigital magnetron structure embodying this invention;

Fig. 4 illustrates a longitudinal cross-sectional view of the device shown in Fig. 3;

Fig. 5 illustrates the schematic diagram of a circuit utilizing the devices of Figs. 1 and 2 or 3 and 4 for producing amplitude modulation;

Fig. 6 illustrates a schematic diagram of a circuit utilizing the devices of Figs. 1 and 2 or 3 and 4 for producing frequency modulation;

Fig. 7 illustrates a schematic diagram of a circuit utilizing the devices of Figs. 1 and 2 or 3 and 4 for producing signal amplification; and

Fig. 8 illustrates a schematic diagram of a circuit utilizing the devices of Figs. 1 and 2 or 3 and 4 for producing a wide band noise generator.

Referring now to Figs. 1 and 2, there is shown an anode structure **10** comprising an anode cylinder **11**. Extending radially inwardly from the inner surface of anode cylinder **11** are a plurality of anode members **12**. Anode members **12** are substantially rectangular planar members and are alternately connected adjacent their inner ends on their upper and lower edges by conductive strapping.

The ends of anode cylinder **11** are covered by end plates **13** hermetically sealed thereto. Attached to one end plate **13** is an exhaust tubulation **14** whose ends are sealed by a glass seal **15**. Extending through the other end plate **13** is a cathode support structure **16**, comprising an insulating support bushing **17**, sealed at one end

to a centrally located aperture in plate 13 and sealed at the other end to a metallic cylindrical member 18, which extends inwardly through the support bushing 17 and the aperture 13 and is rigidly attached to a cathode structure 19, positioned in the space defined by the inner ends of the anode members 12.

Cathode 19 comprises a cylindrical member 20 positioned coaxially with the anode cylinder 11 and somewhat smaller in diameter than the space defined by the inner ends of anode members 12. The outer surface of cylinder 20 is covered with electron-emissive material. The ends of cylinder 20 are covered by end shields 21, which are slightly greater in diameter than cylinder 20, and whose purpose is to deter movement of electrons in a direction axially to the anode and cathode cylinders. A heater coil, not shown, is positioned inside cylinder 20, one end thereof being connected to the cylinder 20 and the other end being connected to a leader rod 21 which extends through support cylinder 18 and is attached to an external terminal 22 which is sealed to the outer end of cylinder 18 by a ceramic seal 23. The structure thus far described is that conventionally used in magnetron anode structures, and it is to be clearly understood that the many different designs of cathode support and anode cavity design may be utilized in the practice of this invention.

At one point in the anode structure, the anode members 12 and their associated strapping have been omitted such that the anode structure comprises a continuous network of anode members and straps having two ends. Attached to one end of the network, for example, the beginning of the network illustrated in Fig. 1 moving in a clockwise direction, is a signal output structure 24, comprising a cylindrical outer conductor 25 threadedly attached and hermetically sealed to an aperture in anode cylinder 11. Positioned coaxially inside member 25 and spaced therefrom is a central conductor 26 hermetically sealed to outer conductor 25 by insulator seal 27. Central conductor 26 extends inside cylinder 11, spaced from conductor 25, and is attached to one of the straps alternately connecting anode members 12. Connected to the other end of the network made up of anode members 12 and their associated strapping is a signal coupling structure 28, identical with output coupling structure 24, and connected to one of the straps alternately connecting anode members 12 in the same manner as structure 24.

Extending inwardly from anode cylinder 11, in the space between the ends of the anode network, is an electrode 29 whose purpose is to prevent rotation of electrons around the cathode across the gap between the two ends of the anode network. The effect of the electrode 29 is to render the device operable over a somewhat wider range of frequencies than would be possible if electrode 29 were omitted. However, it is to be clearly understood that electrode 29 may be omitted, thereby allowing rotation of electrons around the cathode along the entire periphery thereof. Under these conditions, the device may be somewhat more limited in frequency range, but may be made somewhat more efficient. It is to be clearly understood that the electrode 29 could be in other forms, for example, it could extend outwardly from the cathode surface or could be insulated from the cathode and anode structures and have a control voltage superimposed thereon, which is either positive or negative with respect to the cathode potential to thereby control the degree of reentrancy of the electron stream.

With a suitable positive potential applied to the anode structure with respect to the cathode, a suitable heater current applied to the heater-coil to produce electron-emission from the cathode, and application of a suitable unidirectional magnetic field across the space between the cathode and anode substantially parallel to the axis of the device by means of a magnet 13*a*, electrons will circle the cathode with a motion substantially parallel to the face of the vane tips. If the electron stream is assumed to be rotating in a clockwise direction for the device shown in Fig. 1, as is indicated by the arrow 30, an output load may be coupled to the device through the output coupling structure 24, said output load being, for example, a radiating antenna, or other energy-absorbing load. A signal wave traveling along the anode structure, with a phase velocity in the same direction as the arrow 30 representing the direction of the electron stream, will interact with the electron stream producing an increase in the energy content of the signal. The energy content of the wave will travel in a direction opposite to the direction of the electron stream and will move toward the output structure 24 passing through to the load.

An explanation of the mechanism producing this backward wave phenomena, identified as the abnormal dispersion characteristic, is as follows. Consider two adjacent anode members which, together with the space therebetween, define a reactive impedance resonant at a frequency substantially equal to the π mode frequency. These anode members are connected to different straps, said straps being considered as the transmission line which is loaded by the impedances of the cavities defined by the anode members. Since the straps are the conductors of the transmission line, they are π radians out of phase with each other at any point along the network. For any frequency lying about the π mode frequency, that is, within the pass band of the anode network, a signal traveling along the straps will have a definite phase shift, depending on the phase velocity of the signal along the straps and the distance traveled along the straps. The signal appearing along the tips of the anode members will shift in phase by π radians, due to connection of adjacent anode members to different straps, and will also shift by the phase shift of the signal traveling along the straps. Since the π radian phase shift due to connection of the anode members to different straps may be achieved by either adding or subtracting π radians, and since the phase shift of a signal traveling along the straps is normally less than π radians between adjacent anode members, algebraic summation of the phase shift of a wave traveling along the straps and the normal π radian phase shift between adjacent anode members produces a resultant phase velocity, whose direction may be either in the same direction as that of the actual signal or group velocity signal component traveling along the network or away from it.

Referring now to Figs. 3 and 4, there is illustrated a further embodiment of the invention wherein the anode structure is of the interdigital type. As shown in Figs. 3 and 4, the anode cylinder 11 is closed by end plates 13. Extending in a direction parallel to the axis of the anode cylinder 11 from the end plates 13 are a series of anode fingers 31, which, as shown here, are simply straight rods. Adjacent anode fingers are connected to opposite end plates 13 and overlap each other for approximately half their length. Anode fingers 31 form the elements of a cylinder coaxial with anode cylinder 11. Positioned inside the space defined by anode fingers 31 is a cathode 19, which may be identical with that illustrated in Figs. 1 and 2, and may be supported in the same manner by means of elements 17, 18, 22 and 23.

A signal output coupling structure 32 is provided, connected to one of the anode fingers 31, which defines the beginning of the anode network made up of the anode fingers. For the device shown in Fig. 3, the electrons are assumed to rotate counterclockwise, as indicated by the arrow 33. Several anode fingers 31 are omitted in the space immediately clockwise from the point of connection of the output coupling 32 to the anode finger. Thus, the anode fingers form an anode network, having one end connected to the output coupling 32 and extending around the cathode structure 19. The anode network termi-

nates in a signal coupling structure **34** at the opposite end thereof from the structure **32**. Structure **34** may be similar to structure **32**, if so desired.

If it is desired to terminate the end of the anode network, to which coupling structure **34** is connected, in an impedance-matched signal-absorbing load, the structure **34** may be omitted, and the absorbing load may be coupled to the line in the form of lossy material coated on the anode fingers **31** on the opposite end of the anode network from that to which output coupling structure **32** is connected. This lossy material, illustrated, for example, at **35** is applied to the fingers **31** in progressively greater amounts as the end of the anode network is approduced, thereby producing an improved impedance match of the lossy material to the anode network. In some cases the signal coupling device **34** may still be desired with the use of varying amounts of lossy material coated on the anode members inside the device. The electrode **29** has been omitted from the space between the ends of the anode network in the device shown in Figs. 3 and 4. However, it is to be clearly understood that this electrode could be used, if so desired. The analysis of the abnormal dispersion characteristic of the anode structure, illustrated in Figs. 3 and 4, may be similar to that set forth in connection with Figs. 1 and 2, with the points of connection of adjacent anode fingers to opposite end plates **13** being considered the opposite conductors of the transmission line which introduces the additional π radian phase shift to the anode structure, which, when subtracted from the normal phase shift along the line, produces the abnormal dispersion characteristic.

Referring now to Fig. 5, there is illustrated a schematic diagram of a circuit which may be used with the device of Figs. 1 and 2 or 3 and 4 to produce frequencies very close to the responant frequency of the cavity resonator. If the Q of the cavity is high and it is coupled to the network properly, a very high degree of stabilization may result. The anode structure **10** of the device, which, as illustrated herein, is of the strapped anode type, has one end thereof coupled through an output coupling structure **24** to an energy-absorbing load **35**, such as a radiating antenna. The other end of the anode structure is connected through a signal coupling structure **28** to a cavity resonator **36** whose resonant frequency may be adjusted by means of a movable plunger **37**. The cathode **29** of the device is connected to the negative terminal of a voltage source, illustrated herein as a battery **38**. The positive terminal of battrey **38** is connected through a signal modulation source **39** to ground. The anode structure **10** of the device is connected to ground. The magnetic field is poled such that the electron stream moves clockwise. The resonant frequency of the cavity resonator **36** is adjusted to the desired carrier frequency of the device lying within the pass band of the anode network. Under these conditions the device will oscillate substantially at the resonant frequency of the cavity **36** and substantially independent of impedance variations of the load **35**. The group velocity component of the wave will move counter-clockwise along the anode network from the signal coupling structure **28** to the signal output coupling **24** and thence to the load **35**. Any signal reflections from the load **35** reflected back along the anode network will not be amplified by the device, but upon arriving at the cavity **36**, will again be reflected in a phase dependent upon the difference between the frequency of the signal and the resonant frequency of the cavity. In the steady state condition the total phase shift of the signal in its reflection from the output and its return to the output must be a multiple of 360 degrees. Because of the characteristic of very rapid change in phase of the reflection from the high Q cavity with any change in frequency, the resonant frequency of the cavity will dominate as a frequency determining element.

In the type of space charge flow occurring in this type of device, a wide range of electron velocity components are available in the stream and, hence, will interact with a wide range of signal phase velocities corresponding to a wide range of signal frequencies. Hence the cavity **36** may have its resonant frequency varied over a relatively wide range by moving of the plunger **37**, and the predominant oscillation frequency of the device will follow the resonant frequency of the cavity resonator **36**. Because the predominant frequency tends to degenerate or damp out all other frequencies, as is the case in a conventional oscillator, the device will be substantially noise free. Thus it may be seen that the device may be used in this manner as a simple cavity controlled oscillator without application of a modulation signal from the modulation source **39**.

Application of an alternating current voltage between the anode structure **10** and the cathode **29** from the signal modulation source **39** through the battery **38** will produce variations in the amount of anode current drawn by the device. Since increase of the anode current will result in increased R. F. energy in the network, a higher amplitude of signal will be fed to the load. Conversely, when the anode voltage is lowered, thereby lowering the anode current, the amplitude of the output signal decreases. Thus it may be seen that application of an alternating current signal between the anode and cathode will produce an amplitude modulation of the output microwave energy, and the envelope of the modulated output will conform with a relatively low degree of distortion to the modulating signal.

Referring now to Fig. 6, there is illustrated a schematic diagram utilizing a device of the types illustrated in Figs. 1 through 4 in a circuit for producing frequency modulation. The anode structure **10**, cathode **29**, battery **38**, modulation source **39**, output coupling **24** and load **35** are similar to those illustrated in Fig. 5. However, the signal coupling structure **28** and cavity resonator **36** have been omitted, and the end of the anode network to which the structure **28** was connected has been left unterminated, that is, open-circuited at the operating frequency of the device. Under these conditions, voltage reflected from the load **35** will upon traveling along the anode network, be reflected from the open circuit termination at the other end of the anode network and the device will oscillate at a frequency within the pass band of the anode network at which the reflections from the open termination will be in phase with the original waves. Since this oscillation frequency is governed by a reflected wave whose phase is dependent on the phase velocity of waves traveling along the anode network, and, since the predominant interaction will occur with the wave having in-phase reflections and a phase velocity substantially equal to, and in the same direction as, the largest percentage of electron velocities, variation of the anode voltage will vary the velocity of the largest percentage of electron velocities and hence vary the phase velocity, and, therefore, the frequency of the wave which will predominate. For this reason, application of an alternating current voltage between the anode **10** and cathode **29** through the battery **38** will produce frequency modulation of the output oscillation signal fed to the load **35**. The output signal will have relatively no noise and the modulation obtained in this manner may be on the order of ten megacycles or more for a normal oscillation frequency of 2000 to 3000 megacycles. If desired, the modulation frequency of the output of the device shown in Fig. 6 may be increased somewhat by applying small amounts of lossy material to the anode members adjacent the unterminated end of the anode network. However, the use of too much lossy material at this point will render the tube noisy.

Referring now to Fig. 7, there is shown a schematic diagram of a circuit embodying the device, as illustrated in Figs. 1 and 2 or 3 and 4, for producing a locked amplifier. The anode structure **10** and cathode **29** are similar to those shown in Figs. 5 and 6 and are connected to-

gether through a battery **38**, which maintains the cathode negative with respect to the anode by the desired operating voltage. The output coupling structure **24**, load **35**, and signal coupling structure **28** are similar to those illustrated in Fig. 5. However, a signal source **40** has been substituted for the cavity resonator **36**. The signal source **40** must lie within the pass band of the anode network, that is, it must have a frequency above the π mode frequency of the device. The signal source **40** may be of any desired type, such as an antenna, or a lower power device than that illustrated in Figs. 1 and 2 or 3 and 4, such as a klystron. The signal source **40** may be intelligence-modulated either in frequency or amplitude. The signal from source **40** travels along the anode network to the load **35** and is of sufficient strength to be the predominant signal applied to the line. Hence, the interaction between the electron stream and the wave traveling along the anode network will predominate at the frequency of the signal from the signal source and the device will consequently lock on this signal. The device will follow variations in the frequency of the signal from the source **40**, and, to a large degree, will follow variations in amplitude thereof. The systems of Figs. 5 and 7 will be most efficient, with the voltage of battery **38** adjusted such that the highest percentage of electron velocities in the stream have substantially the same velocity as the phase velocity of the desired signal frequency along the anode network. For this adjustment, locking may be produced by the lowest amplitude signal from the source **40**, and the device of Fig. 7 will follow the signal source over the widest range of frequencies and amplitudes.

Referring now to Fig. 8, there is illustrated a schematic diagram of a circuit utilizing the devices of Figs. 1 and 2 or 3 and 4 to produce wide-band, noise-modulated, microwave signals. The anode structure **10**, cathode **29**, output coupling structure **24**, signal coupling structure **28**, load **35**, and battery **38** are connected identically with those illustrated in Fig. 7. An impedance-matched signal-absorbing load is substituted for the signal source **40** such that group velocity waves traveling along the anode network from the load **35** in the matched input **41** will be completely absorbed thereby. The matched input **41** is preferably non-reactive, and, hence, will be matched to the characteristic impedance of the anode network over a wide range frequency. If desired, the signal-absorbing matched input may be in the form of lossy material applied to the anode members or strapping of the devices shown in Figs. 1 and 2 and the signal coupling structure **28** may be eliminated entirely. Tapering the amount of lossy material applied to the end of the anode network opposite that to which the load **35** is connected, such that the amount of lossy material applied to the anode members decreases with distance away from said end, will further improve the broad band characteristics of the impedance match. Since interaction will occur over a wide range of frequencies, all of these frequencies will occur at the output, and, since the signals are initiated by random applications of the electron stream, the amplitudes and frequencies of the output signals will be substantially non-coherent or in effect, noise. Such a circuit is useful for production of high power levels of microwave noise-modulated signals for jamming purposes.

This completes the description of the embodiments of the invention illustrated herein. However, many modifications thereof will be apparent to persons skilled in the art without departing from the spirit and scope of this invention. For example, other types of anode structures may be used besides those illustrated herein. The cathode structure need not necessarily be coated over its entire length, but may have areas which are not electron-emissive such as the areas immediately beneath the region between the ends of the anode network or adjacent the ends of the anode network. Indeed, if desired, the cathode may be coated on several successive areas along the surface thereof with the intermediate areas being non-emissive. Furthermore, any desired type of signal coupling structure may be used in place of that illustrated herein. For example, iris couplings or loop couplings could be substituted for the direct-coupling type of structure illustrated herein. In addition, the systems illustrated in Figs. 5 through 8 could all be pulse-modulated by pulsing the anode cathode voltage in a manner similar to that currently used with conventional pulsed magnetron oscillators. Accordingly, it is desired that this invention be not limited by the particular details of the invention described herein, except as defined by the appended claims.

What is claimed is:

1. A traveling wave electron discharge device system comprising a nonreentrant signal wave transmission network, a source of electrons, means for directing a reentrant stream of electrons along paths adjacent said network, a load output which absorbs the majority of the output power produced by said device coupled directly to one end of said network, and a frequency-determining structure directly terminating the other end of said network, said structure being resonant substantially at the desired operating frequency of said device.

2. A traveling wave electron discharge device system comprising a nonreentrant signal wave transmission network, a source of electrons, means for directing a reentrant stream of electrons along paths adjacent said network, a load output which absorbs the majority of the output signal power produced by said device coupled directly to one end of said network, and a frequency-determining structure directly terminating the other end of said network, said structure being resonant substantially at the desired operating frequency of said device, and means for varying the amplitude of the output signal to said load comprising means for varying the voltage between said network and said source.

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