June 5, 1962 E. C. DENCH ET AL 3,038,067

ELECTRICAL TUNING SYSTEMS WITH TRAVELING WAVE TUBE

Filed May 31, 1956 2 Sheets-Sheet 1

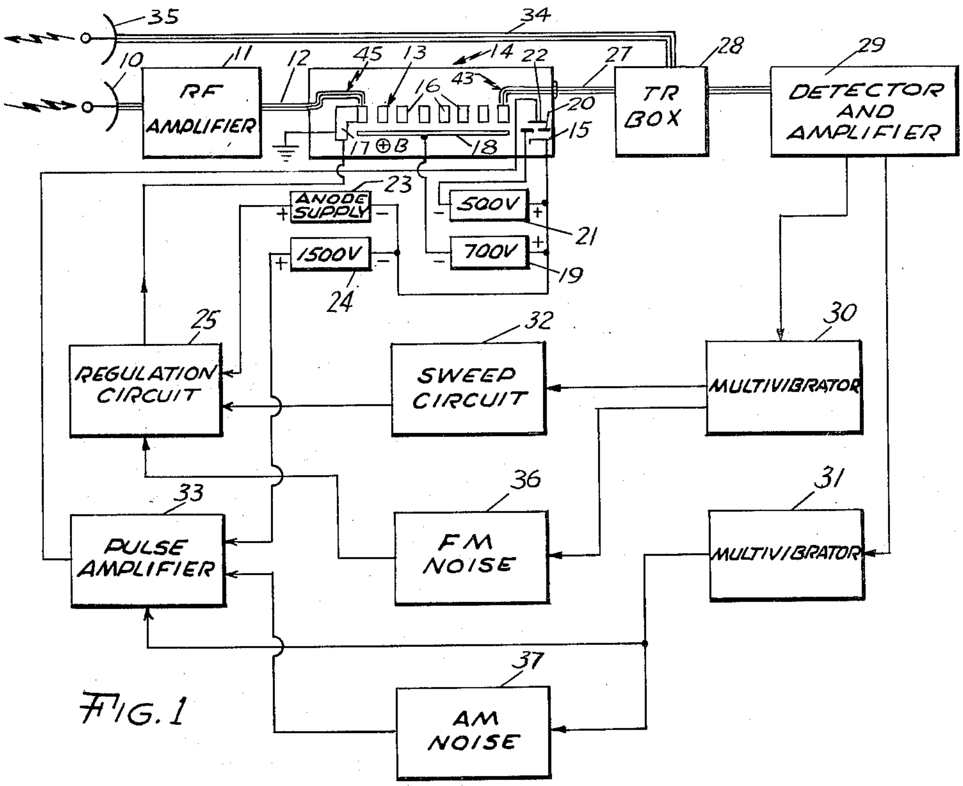

FIG. 1

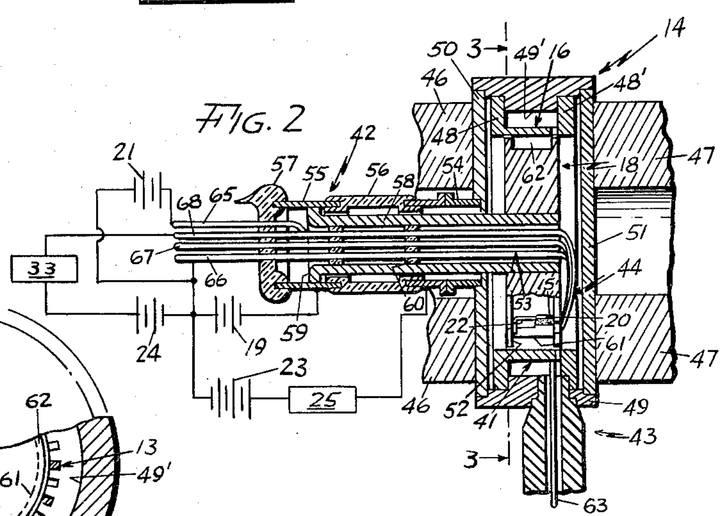

FIG. 2

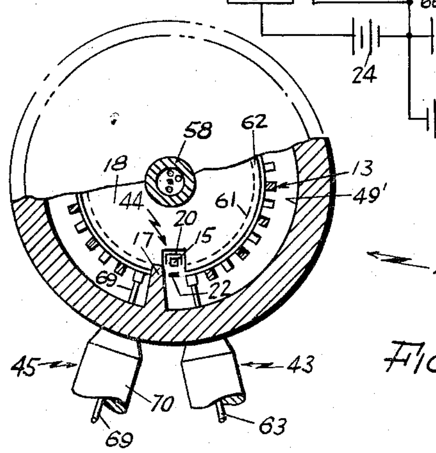

FIG. 3

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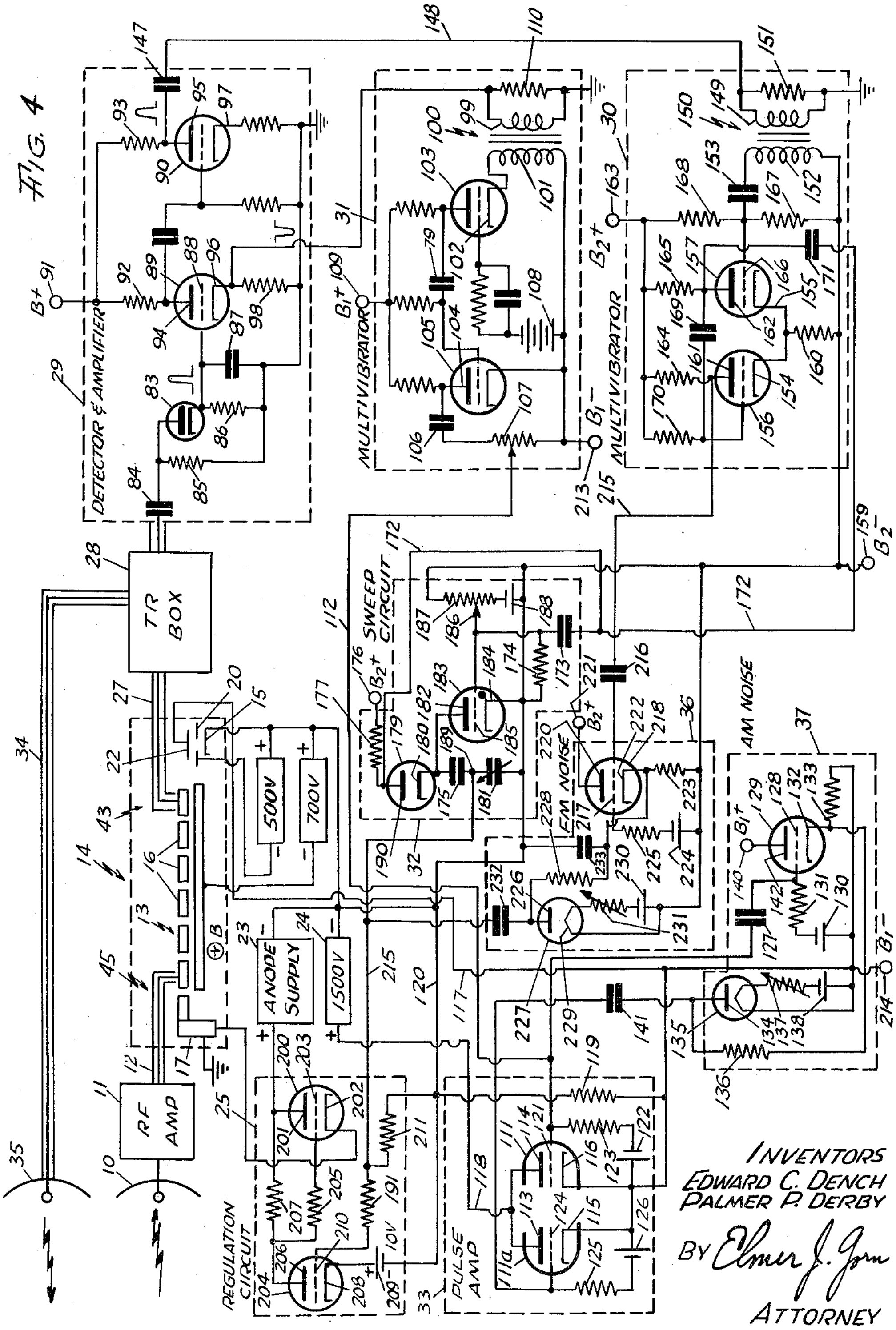

FIG. 4

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ELECTRICAL TUNING SYSTEMS WITH TRAVELING WAVE TUBE

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12 Claims. (Cl. 250—13)

This invention relates to a traveling wave electron discharge device of the backward wave type adapted to operate either as an amplifier of electromagnetic signals or as an oscillator to transmit response signals of a predetermined pattern upon reception of said electromagnetic signals, and more particularly, to a system for controlling the mode of operation of one or more of said backward wave electron discharge devices to receive and amplify said electromagnetic signals or to retransmit signal energy at substantially the same frequency as said received electromagnetic signals.

In traveling wave devices of the backward wave type in which electrons are projected in an extended stream in the vicinity of a wave propagating structure, oscillatory energy is produced by the interaction or transfer of energy from the electron stream to a backward wave which propagates along the wave propagating structure, commonly referred to as a signal transmission network, at a velocity substantially equal to that of the electron stream. As is known, the frequency of oscillations generated as a result of such interaction can be controlled by varying the velocity of the electron stream above or below a particular value substantially equal to the velocity of the backward wave, the oscillatory energy so generated being extracted from said signal transmission network by coupling means at one end thereof.

Also, as is generally known, a backward wave electron discharge device or tube commences oscillation when the electron beam current exceeds a critical value, which, for convenience, may be designated at I_0, while the device functions as a narrow band voltage-tunable backward wave amplifier when the beam current is adjusted below this value. Furthermore, it has been discovered that oscillations at a beam current above the value I_0 for a given voltage representing a particular beam velocity occur at substantially the frequency at which the device has peak amplification when the beam current is below the critical value I_0, the beam velocity being held substantially constant. The advantages of this particular operational characteristic in which the backward wave tube, when in a transmitting mode of operation, is capable of initiating oscillations at substantially the same frequency as when the tube is in the receiving mode of operation, is more readily appreciated when an attempt is made to utilize the device as a novel signal amplifier which is actuated by a received signal to generate response signals bearing a predetermined frequency relationship to the frequency of the received signals.

In accordance with the present invention, a backward wave tube is caused to sweep cyclically through a predetermined frequency band until an incoming signal is encountered and amplified in said tube. The output thus produced in said tube is then made effective to halt the sweeping of said tube to increase the beam current of the electron stream flowing adjacent the signal transmission network of said tube to a value substantially above the current required to sustain oscillation and to transmit a predetermined signal for a given length of time at substantially the same frequency as the received signal.

The invention further discloses a novel method of applying amplitude modulation or frequency modulation, which may be in the form of noise, to the appropriate electrodes of the backward wave oscillator tube. Amplitude modulation is also achieved concurrently with frequency modulation to produce a wideband noise modulated signal by simultaneously applying both frequency modulation and amplitude modulation to the oscillator tube.

Other objects and features of this invention will be understood more clearly and fully from the following detailed description of the invention with reference to the accompanying drawings wherein:

FIG. 1 is a schematic diagram of a traveling wave oscillator system according to the invention;

FIG. 2 is a detailed view of a portion of the anode assembly of a backward traveling wave oscillator tube employing a transverse magnetic field;

FIG. 3 is a section view taken along the line 3—3 of FIG. 2; and

FIG. 4 is a circuit diagram illustrating a preferred manner of practicing the invention.

Referring now to FIG. 1 showing the block diagram of the backward wave oscillator amplifier system, an antenna **10** is provided to couple recurring signal pulses, such as radio pulses, communication signals, radar signals, and the like to a radio frequency amplifier **11** and then by coaxial transmission line **12** to the end remote from the electron source of the signal transmission network **13** of backward wave tube **14**.

The traveling wave tube oscillator **14**, as shown, includes a grid **20**, an acceleration electrode **22** and a cathode **15** positioned at the other end of the signal transmission network **13** and provided with a heater, not shown. The purpose of the cathode **15** is to emit electrons which, under the influence of the proper electrostatic and magnetic fields produced in the space adjacent the signal transmission network, will move along paths adjacent a series of interdigital fingers **16** forming said network and, after amplifying any signal present in the network through interaction therewith, will impinge on collector electrode **17** or on the signal transmission network **13**, which serves as an anode. Signal transmission network **13** is maintained at the same potential as the collector electrode **17**, or at some other potentiall relative to the cathode. The structural details of the cathode **15**, collector electrode **17** and the remaining elements and electrical connections comprising the backward wave tube **14** will be described below. Extending adjacent interdigital fingers **16** and forming a space through which the electron beam travels, is an elongated electrode **18**, commonly referred to as a sole, which, in this embodiment, is maintained negative with respect to the cathode **15** by a 700 volt power supply **19**. In like manner, the grid or control electrode **20** is maintained negative with respect to the cathode by a 500 volt power source **21**.

Voltage tuning of the backward wave tube is accomplished by effectively changing the sole-to-anode voltage by control of the cathode-to-anode voltage by means of a regulation circuit **25**, the sole being maintained at a constant voltage reference with respect to the cathode. In like manner, the mode of operation of the backward wave tube is selected by raising or lowering the accelerator voltage with respect to the cathode by control of a 1500 volt power supply **24** by means of a pulse amplifier circuit **33**, which regulates the beam current above or below the aforementioned I_0 value in a manner which will be described in detail below. It should be noted that the beam current can also be controlled by providing circuits which control the potential on the grid **20** instead of accelerator electrode **22**. Thus, if a signal is injected by means of a coaxial line **12** into the backward wave oscillator, the anode current being reduced somewhat below the point of oscillation, the input signal will be amplified. The backward-wave interaction permits the tube 14 to act as a regenerative amplifier in which the frequency at which maximum gain occurs depends upon the anode-to-sole voltage and, as noted, is very close to the frequency at which the tube delivers an output when oscillating.

In like manner, the signal amplified in backward wave tube 14 is extracted by an output coupling device 43 and fed through a coaxial output line 27 to a conventional duplexer or TR box 28 and, thence, to a standard detector and amplifier circuit 29, the output of which is a detected high-frequency gate signal which is fed to a pair of multivibrators 30 and 31 in the form of positive and negative voltage pulses, respectively. An output of multivibrator 30, which is a conventional one-shot multivibrator, applies a negative gate pulse to terminate the operation of a sweep generator 32, thereby holding its sawtooth voltage output at a voltage level corresponding to the frequency of the an incoming signal in tube 14 during its operation as a voltage swept amplifier. Thus, the sawtooth voltage output from sweep generator 32 is fed to the voltage regulation circuit 25 which controls the value of the voltage applied from anode supply 23 to the anode 13 to cause frequency scanning of tube 14. When, during the scanning of a given frequency spectrum by said voltage tuning, an input signal is encountered, the aforementioned amplified signal output is present in the output coupling 43 of tube 14 and is used to stop the scanning voltage of sweep generator 32 at the precise value existing when the input signal occurred and, in this manner, the amplifier is locked to the input signal. Simultaneously, with the halting of the scanning voltage output of sweep generator 32, an output pulse is fed from multivibrator 31 to the pulse amplifier 33 to gate a positive voltage pulse of predetermined length from accelerator supply source 24 to acceleration anode 22, thereby to increase the beam current of amplifier tube 14 above the value I_0 and to initiate oscillation at substantially the same frequency as that at which the incoming input signal occurred. In this manner, multivibrator 31 determines the length of time oscillations are generated in tube 14. This oscillatory energy is fed to TR box 28, which operates in a conventional manner to feed the energy through an antenna coaxial line 34 to an antenna 35 which radiates the energy into space in the general direction of the incoming signals.

At the same time as oscillations are being generated in backward wave tube 14, multivibrator 30 feeds a gate pulse to FM noise generator 36, the output of which is used to frequency-modulate tube 14 by controlling the cathode-to-anode voltage by means of regulation circuit 25. The FM noise modulation could also be applied in other embodiments of this invention in the circuit of sole 18. In like manner, the output of multivibrator 31 is used to gate AM noise generator 37 to actively produce and apply AM noise to pulse amplifier 33 to initiate a noise-modulated output at the acceleration electrode 22. In other embodiments, it should be understood this AM noise signal could be applied in the circuit of control grid 20. It should be noted that a delay can be inserted between the time the device locks on the received signal and the time tube 14 is made to transmit, which, in particular communication applications, may be desirable. Additionally, the backward wave tube can be actuated to transmit a narrow band or a wide band noise-modulated signal, depending on whether amplitude modulation, frequency modulation or a combination of the two are applied to the tube.

Referring now to FIGS. 2 and 3, the construction details shown therein do not form a part of the invention and are not described in detail. They are, however, shown and described in detail in the copending application for "Electrical Systems," Serial No. 562,472, of Edward C. Dench and Albert D. La Rue, filed January 31, 1956. In FIGS. 2 and 3, a backward wave tube 14 is shown which comprises an anode assembly 41 which includes the energy propagating structure or signal transmission line including interdigital fingers 16, the elongated electrode or sole 18 which, as noted, is maintained negative with respect to the interdigital fingers forming anode delay line 13, a lead-in assembly 42 and an output coupling means 43. In addition, there is shown an electron gun mounting assembly 44 including the cathode 15 containing a heater, not shown, a control grid 20, an input coupling means 45 for the coaxial transmission line 12 of FIG. 1, and a transverse magnetic field-producing means 46—47, a portion of which is indicated in FIG. 2.

The interdigital fingers 16 comprising the signal transmission line include a plurality of members which extend from oppositely-disposed annular members 48, 48′, respectively. These members are secured by screws, not shown, to the shoulder portion of a cylindrical thermally-conductive ring 49—49′ to which is hermetically sealed a pair of oppositely-disposed cover plates 50 and 51.

The sole 18 consists of a cylindrical block of material, such as copper, having a centrally-located aperture 53 to permit connection of lead-in assembly 42 and to allow for passage of external circuit-connecting leads.

Referring more particularly to FIG. 2, the lead-in assembly 42 comprises an electrically-conductive cylindrical sleeve 54, which is inserted in an aperture in cover plate 50. Interconnecting metal sleeve 54 and outer metal sleeve 55 is a section of cylindrical glass tubing 56. The other end of sleeve 55 is provided with a glass seal 57 for sealing the tube 14 after evacuation. The assembly 42 is arranged perpendicularly to cover plate 50 of tube 14 and further includes an elongated electrically-conductive tubular supporting cylinder 58, which serves as a main support for sole 18 and is affixed at one end to the periphery of aperture 53 in sole 18. The outward end of cylinder 58 contains an outwardly flared portion 59, which is connected to the inner surface of outer metal sleeve 55. The necessary leads for the electron gun are fed through supporting cylinder 58 and are insulatedly supported therefrom by one or more glass beads 60. The interdigital fingers comprising the signal transmission line 13 are arranged concentrically with sole 18 and are separated from the circumferential wall 61 of the sole to form an interaction space 62 through which the stream of electrons generated in the tube passes. The interdigital delay line or signal transmission network 13 including interdigital fingers 16 may be terminated at one end by attenuation, which may be in the form of an energy dissipative material, such as iron, applied to the fingers. The coaxial output coupling means 43 is sealed in an opening of wall 49 of the anode and is impedance-matched to the interdigital delay line 13. The inner conductor 63 of coaxial output coupling means 43 is connected to a finger at or adjacent the end of the periodic anode delay line 13 adjacent the electron gun.

The backward wave tube 14 may be provided with a collector electrode 17, as shown in FIG. 3, for intercepting electrons after one traversal of the arcuate interaction space. This collector electrode may take the form of a projection from the back wall 49′ of the interdigital delay line 13. In some instances, however, the collector electrode may be omitted and the electron stream made reentrant. Furthermore, the sole 18 may be either primarily or secondarily electron-emissive.

Electron gun assembly 44 for the backward wave tube, shown in FIGS. 2 and 3, includes the grid 20, the cathode 15 with a heater inserted therein, not shown, and an acceleration electrode 22, as shown in FIG. 2. More particularly, the cathode 15 is shown, by way of example, as a rectangular body provided with a circular bore, not shown, in which the heater is inserted. The cathode body 15 has at least the surface facing the accelerating anode 22 coated with an electron-emissive material, such as a compound of barium. Cathode 15 is positioned within the wall 61 of sole 18. The cathode lead 66 is connected electrically to the cathode 15. One end of the heater, not shown, is connected to the inner wall of the cathode body, while the other end of the heater is attached to the heater lead 67, shown in FIG. 2.

The auxiliary electrode 22 which, in effect, is an accelerating anode serving to aid in the production of the desired electron beam trajectory, is insulatedly supported from flange portion 52 of sole 18. The auxiliary electrode lead 68 is attached to the auxiliary electrode 22.

A suitable electric field between anode and sole may be obtained by means of a voltage applied therebetween. The sole 18 may be negatively biased with respect to the cathode by means of the supply source 19 of voltage connected between the cathode lead 66 and tubular sleeve 58, by way of metal sleeve 55. The cathode may, in some applications, be at the same potential as the sole. The grid 20 may be maintained at negative potential with respect to the cathode by grid supply source 21 of voltage connected between cathode lead 66 and grid lead 65, only partially shown in FIG. 2. Similarly, the signal transmission network or anode delay line 13, as shown in FIG. 3, is maintained at a positive potential relative to the sole and cathode by means of anode supply source 23 of voltage connected between metal sleeve 54 and regulation 25, which is connected in turn to the anode transmission line 13 and cathode lead 66. As noted, the auxiliary or acceleration electrode 22 is pulsed at a positive potential relative to the cathode by means of supply source 24 of voltage connected in series with pulse amplifier 33 between leads 66 and 68.

A uniform magnetic field transverse to the direction of propagation of the electron beam is provided either by a permanent magnet or an electromagnet having cylindrical pole pieces 46 and 47 radially positioned on or adjacent the tube. Pole piece 46 is apertured to receive the lead-in assembly 42 and pole piece 47 is apertured to maintain symmetry of the magnetic field. The flux lines should be concentrated in the interaction space 62 between sole 18 and cylindrical transmission network 13. By proper adjustment of the magnitude and polarity of the magnetic and electric fields, the electron beam may be made to follow a circular path about interaction space 62 under the combined influence of these transversely disposed fields.

As noted, the radio frequency energy generated in the interaction space 62 traveling along signal transmission line 13 sets up a high frequency electromagnetic field which may be analyzed as a series of space harmonics, some of which travel in one direction (clockwise) along the anode structure, the others of which travel counterclockwise, and all of which travel with differing phase velocities. If the electron beam is synchronized with the proper space harmonic, interaction, of the beam and the space harmonic will result in the production of oscillations within the tube. The oscillations can be controlled by changing the electron beam current above or below the critical value I_0, thereby selecting the mode of operation of the tube, that is, of amplifications or oscillations. The energy travels through the aforementioned space toward the electron gun and is extracted at the gun end of the signal transmission line 13 by way of the coaxial output line 43.

Backward wave tube 14 further includes the input coupling assembly 45 comprising an inner conductor 69 and an outer conductor 70 coaxially arranged with respect to one another. The inner conductor 69, as shown in FIG. 3, is connected to one of the fingers 16 at or adjacent the end of the anode transmission line 13 electrically removed from the electron gun, while the outer conductor 70 may be attached to the cylindrical wall 49 of anode assembly 41. The input coupling means 45, as well as the output coupling means 43, need not be coaxial; for example, the energy may be coupled to or from signal transmission line 13 by means of a waveguide.

It should be understood that the delay line or signal transmission network 13 may not be of the interdigital type, but may be any suitable periodic delay structure such as a helix, disc-loaded waveguide, or the like. As noted, tuning of the backward wave oscillator may be accomplished by varying the voltage between the signal transmission line 13 and sole 18, as will be described in detail below. However, tuning of the backward wave tube 14, also, may be accomplished by varying the magnetic field strength, either by varying the position of the magnet pole pieces in the case of a permanent magnet or by varying the electric current in the case of an electromagnet having a coil surrounding the core. Variation of both the electric field and the magnetic field simultaneously, of course, is possible.

Referring now to FIG. 4, there is shown a circuit diagram of a preferred circuit embodiment of the system described generally in FIG. 1. In FIG. 4, where the elements are shown in FIG. 1, the same reference numbers are used. In FIG. 4, the radio signals which are to be amplified by backward wave tube 14 are brought from antenna 10 into a conventional type broad band radio frequency amplifier 11, which may be of the traveling wave type and tuned to the frequency band swept by tube 14. The output of radio frequency amplifier 11 is coupled by means of a coaxial line 12 to the input coupling assembly 45 of the traveling wave tube. With the tube 14 operating in the amplifying or regenerative mode by application of a proper value of accelerating anode voltage from anode supply 24 to maintain the anode current below the I_0 value required for oscillation, the amplified signal output of tube 14 is fed through output coupling means 43 and coaxial line 27 to a duplexer comprising a conventional TR box 28 operating to prevent radiation of the received signal by coaxial cable 34 into radiating antenna 35 and to feed the amplified signal to a conventional detector and amplifier circuit 29.

The detector and amplifier circuit 29 forming part of the signal receiving means may, for example, consist of a standard pulse-radar receiver, the output of which is a detected high-frequency signal. As shown, the conventional diode detector circuit includes a coupling capacitor 84 and a coupling resistor 85 providing a high input impedance circuit for the detector diode 83. The detector output signal appears across diode resistor 86 and capacitor 87 and is fed to the input grid 88 of a twin-triode amplifier including input triode tube 89 and output triode tube 90. The amplifier tubes are supplied with a positive voltage applied to terminal 91 and coupled through plate load resistors 92 and 93 to amplifier plates 94 and 95 and amplifier cathodes 96 and 97, respectively. A negative signal produced across cathode resistor 98 is fed to a primary winding 99 of acceleration anode isolation transformer 100, while the secondary winding 101 feeds pulse amplifier circuit multivibrator 31.

The basic plate-to-grid-coupled monostable multivibrator 31, generally referred to as a "flip-flop," is triggered by applying a negative trigger voltage to the cathode 102 of input tube 103 and produces, according to well-known multivibrator operation and, in particular, according to the value of timing capacitor 29, a rectangular positive output voltage of a predetermined duration at the plate 104 of multivibrator output tube 105. The predetermined duration of the rectangular output voltage which is coupled to capacitor 106 and level setting or coupling potentiometer 107 determines the length of time tube 14 is maintained in the oscillatory mode of operation upon the reception of an appropriate input signal. Multivibrator 31 is provided with a fixed bias source 108 and a separate source of plate voltage, which, for convenience, is designated B_1+. This voltage is applied to terminal 109 and isolated from the voltage applied to terminal 91 of the amplifier and detector. It should be noted that input transformer 100 is, preferably, insulated to withstand a voltage of approximately ten kilovolts. It should also be noted that primary winding 99 and impedance matching resistor 110 have one terminal thereof grounded, while the remainder of the multivibrator circuit including the secondary of isolation transformer **100** is pulsed upward by the acceleration anode supply **24** and the pulse amplifier tube **111**, in a manner which will be described in detail below.

The output of gating multivibrator **31** is applied by way of line **112** to the input of pulse amplifier circuit **33**. This circuit includes a pair of heavy duty triodes **111** and **111***a*, such as 2C53 type tubes having plates **113** and **114** and cathodes **115** and **116** coupled in parallel arrangement and operating as amplifier tubes for pulsing acceleration anode **22** of tube **14** by way of pulse line **117**. The plates **113** and **114** are connected to the 1500 volt supply via plate line **118**. The high voltage output pulse developed across cathode follower output resistor **119** is connected by way of negative voltage line **120** to the negative side of pulse amplifier supply **24** and anode supply **23**. In operation, a positive rectangular pulse is applied to grid **121** of tube **111** maintained negative and below cutoff with respect to cathode **116** by means of fixed bias supply **122** and bias resistor **123**. In like manner, grid **124** is biased negatively to slightly below cutoff by bias resistor **125** and fixed bias supply **126** connected from grid to cathode. This tube **111***a* is used, at appropriate time intervals, to apply to tube **14** an amplitude modulated noise pulse from AM noise source **37**. Thus, in response to an incoming or input signal, a positive rectangular voltage is applied to grid **121** of the pulse amplifier tube **111**, which conducts and applies a positive-going pulse to the acceleration anode **22** to initiate oscillation in tube **14** for a predetermined time interval. This positive pulse applied to grid **121** is also applied by way of coupling capacitor **127** to the grid **128** of a noise gate tube **129**, which is biased negatively by fixed bias source **130** and bias resistor **131**. Cathode **132** of the noise tube **129** applies a positive rectangular pulse produced across cathode resistor **133** to the plate **134** of noise tube **135** by way of noise loop resistor **136**. The amplitude modulated noise tube **135** may be a temperature-limited noise diode, the degree of noise being controlled by noise potentiometer **137** in series with noise filament supply **138**. Thus, noise is produced across the noise loop resistor **136** which may have a value of approximately 100,000 ohms. The plate **142** of the noise gate tube **129** is connected to a positive source of voltage applied to terminal **140**. The voltage source may, for convenience, be the same as that applied to positive terminal **109**. The noise output produced at the plate **134** of noise tube **135** is fed through coupling capacitor **141** to the grid **124** of pulse amplifier tube **111***a*, thereby to vary the conductivity of said tube in relation to the amplitude-modulated noise voltage present at its grid and, in turn, to apply an amplitude modulated noise voltage to acceleration electrode **22**. Thus far, the means for transmitting an amplitude modulated noise signal in response to an incoming signal have been described; the operation of the voltage-tuned frequency scanning and locking circuit will be described in detail below.

Referring again to FIG. 4, a positive voltage gate pulse is coupled from plate **95** of amplifier tube **90** and fed by way of coupling capacitor **147** and sweep gate line **148** to the primary winding **149** of sweep circuit isolation transformer **150**. Primary winding **149** of transformer **150** and impedance matching resistor **151** have one terminal thereof grounded. The transformer **150** is, preferably, insulated to withstand a voltage of approximately ten kilovolts. A positive gate pulse from secondary winding **152** is coupled to sweep circuit multivibrator tube **157** by coupling capacitor **153**. The cathodes of multivibrator tubes **156** and **157**, respectively, are connected through cathode resistor **160** to negative terminal **159**, which, for convenience, may be referred to as B_2-. Multivibrator tubes **156** and **157** have plates **161** and **162** connected to a separate source of positive potential at terminal **163**, referred to as B_2+, by means of plate resistors **164** and **165**, respectively. Thus, when multivibrator circuit **30**, and more particularly, grid **166** is fed with a positive trigger pulse applied to the junction of biasing resistors **167** and **168**, a negative rectangular output voltage is produced at the plate **162** of tube **157**, the duration of the output being determined in part by the value of timing condenser **169** and timing resistor **170**. The negative square wave output, taken from plate **162** of tube **157**, is connected through coupling capacitor **171** and sweep timing line **172** to differentiation capacitor **173** and differentiation resistor **174** in the input of sweep circuit **32**. The differentiated output of the negative square wave is used to determine the firing time of the sweep thyratron tube **183** at the end of the noise and oscillation period initiated by an incoming signal. This oscillation period is determined by the width of the multivibrator pulse.

Referring in particular to sweep generator circuit **32**, sweep charging capacitor **175** which, with capacitor **181**, determines the frequency band over which tube **14** is swept, is charged by means of a positive potential applied to terminal **176**, which, for convenience, may be the same B_2+ source that feeds terminal **163**. The voltage applied to terminal **176** is connected through resistor **177** to the plate **190** of charging diode **179**. The cathode **180** of the charging diode is connected to one side of charging capacitor **175** and then to sweep charging capacitor **181**. Capacitors **175** and **181** act as a voltage divider to set a sweep amplitude limit for the regulation circuit. The cathode of diode **179** also is connected to the plate **182** of thyratron discharge tube **183**, the cathode **184** of which is connected to the negative side of sweep capacitor **181**. In order for the discharge devices **179** and **183** to operate as a sawtooth generator, the condensers **175** and **181** must charge through the diode **179** and resistor **177**. The grid **185** of gaseous discharge tube **183** is connected to the tap **186** of a bias potentiometer **187**. One end of potentiometer **187** is connected to the negative terminal **159** and the other end thereof is connected to a source of negative potential **188**, which sets the firing point of gaseous discharge tube **183**.

The operation of sweep circuit **112** will now be described. Assume the gaseous discharge tube **183** has just fired. The condensers **175** and **181** discharge rapidly through the gaseous discharge tube **183** until the potential difference thereacross is sufficiently low to extinguish the discharge tube. When the discharge tube becomes extinguished, the grid **185** thereof regains control and prevents firing of the discharge tube. The condensers **181** and **175** begin to charge from the source of negative potential at terminal **159** to one side of the condenser **181**, through the common connection of condenser **181** and **175**, thence, from the other side of the condenser **175** through the diode **179** and resistor **177** to the source of positive potential at terminal **176**. As the potential across condensers **175** and **181** rises, the voltage at midpoint **189** of the condensers also rises, and this rising voltage is fed by line **215** to the regulation circuit **25** to control the frequency band through which tube **14** is swept. Since the charging current remains substantially constant, the potential difference between the cathode **184** and the grid **185** of the gaseous discharge tube **183** remains substantially constant. However, the potential difference between the plate **182** and the cathode **184** of the gaseous discharge device **183** increases as the charge developed across condensers **175** and **181** increases until a point is reached where the grid loses control as a result of ionization and the tube **183** fires. This again discharges the condensers **175** and **181**, thereby terminating the generation of one sawtooth waveform and initiating generation of the next. The variable charging condenser **181** sets the grid-cathode voltage of the tube **204** in regulation circuit **25** and determines the limits of the band of frequencies over which tube **14** sweeps. By adjusting the variable tap **186** of potentiometer **187**, the point at which the discharge tube **183** fires may be set, thereby adjusting the amplitude of the sweep. Thus, in the absence of a signal, condensers 175 and 181 are permitted to charge through diode 179 and charging resistor 177.

However, upon reception of an input signal, the negative square wave output in line 172 is differentiated to produce a negative-going spike corresponding to the initial drop in voltage followed by a positive spike corresponding to the trailing edge of the square wave. It is this positive spike which is fed to grid 185 of discharge tube 183, causing the discharge tube to conduct heavily and discharge condensers 175 and 181, thus terminating the generation of one sawtooth waveform and initiating generation of the next series of sweeps. Additionally, upon the presence of a signal during the charging time of condensers 175 and 181, a negative square wave from line 172 occurs early in the sweep cycle to cut off diode 179 by lowering the plate potential momentarily with respect to the cathode 180. Since the cathode 180 is made positive with respect to the diode plate 190, the diode will not conduct. Hence, condensers 175 and 181 can charge no further through the charging circuit. Under these conditions, the sawtooth generator is disabled, and the condensers 175 and 181 are held at the voltage level present when the signal occurred. Thus, it may be seen that the system automatically switches the backward wave tube from sweeping operation to locking operation upon the arrival of an input signal.

It should be noted that, in the presence of an input signal, the trailing edge of the differentiated negative square wave output of multivibrator tube 157 forms a positive trigger pulse which is applied to grid 185 of discharge tube 183 to discharge the sweep condensers at the completion of each noise period, and that the differentiated leading edge is ineffective to cut off discharge tube 183. However, as noted, upon the presence of an input signal during the sweeping period, the negative leading edge of the square wave from multivibrator circuit 30 is connected by way of line 172 to the plate 190 of diode 179, thereby cutting off the diode and disabling the sawtooth generator at a voltage level substantially corresponding to the frequency of the input signal.

The regulation circuit 25 controls the voltage applied from anode supply 23 to the anode 13 of tube 14. The regulation circuit includes regulator or control tube 200 having a plate 201 connected to the positive terminal of anode supply 23 and a cathode 202 connected to anode 13. The voltage from plate to cathode of tube 200 is controlled by the voltage produced at plate 206 of amplifier tube 204 and is applied through isolation resistor 205 to grid 203. Tube 200 is, preferably, a heavy duty regulator, such as a 2,000 T-type tube. The plate 206 of tube 204 is connected to a plate resistor 207 while the cathode 208 is connected to a fixed bias source 209 of approximately ten volts and also to grid resistor 211 of approximately ten megohms. The sweep voltage from capacitor 181 is applied across this resistor, which is of a large value to prevent discharge of the sweep capacitor 181 during the noise-oscillation period. When grid 210 of the control tube 204 receives a control voltage by the way of line 215 and isolation resistor 191, it conducts and lowers the voltage at its plate 206 and also, at grid 203 which, in turn, causes regulator tube 200 to conduct less heavily, thereby lowering the voltage applied to anode 17. In this manner, control tube 204 performs a sensitive control function in response to voltage changes applied to its grid from the midpoint 189 of charging capacitors 175 and 181. As shown, the lower plate of charging capacitor 181 is connected by way of negative lead 120 to the negative terminal of the bias source 209 to the negative terminal of anode supply 23 and accelerator power source 24, cathode 15, and, also, to terminal 159. In addition, negative terminals 213 and 214, B_1-, can be supplied by the same power source, and are isolated from negative terminal 159. It should also be noted that the voltage at terminal 159, and also at terminals 176 and 163, B_2+, moves up and down in value with respect to ground corresponding to the voltage swings produced by the anode regulation circuit 25 which controls the frequency of tube 14. It has been established for best operating efficiency, the sole-to-cathode voltage of tube 14 should be held to approximately 700 volts. When the cathode-to-ground voltage of tube 14 is changed, the operating frequency of the tube is also changed by a corresponding change in the sole-to-ground voltage. Accordingly, isolation transformers 100 and 150 are required to isolated the multivibrator and sweep circuits from ground potential during the aforementioned substantially wide voltage swings. Thus, in sweeping a given frequency range, a cathode voltage of approximately −2,000 to −5,000 volts with respect to ground is required, while the input voltage in response to the charging of capacitors 175 and 181 may vary only to the extent of five to ten volts at the grid 210 of control tube 204. Also, as noted, this control voltage is held substantially constant at a predetermined level when diode 179 is cut off in response to an incoming signal to amplifier 29, and, thus, in accordance with the invention, tube 14 is made to lock at the frequency of an input signal and its acceleration anode pulsed to initiate oscillations within the tube 14, thereby to transmit a response signal by way of coaxial cable 27 and the TR box 28 to radiating element 35.

Additionally, frequency modulated noise is accomplished by connecting the output of FM noise generator 36 to grid 210 of amplifier tube 204 in regulation circuit 25. A positive square wave produced at plate 161 of multivibrator tube 156 is connected by way of noise line 215 and coupling capacitor 216 to the grid 217 of noise gate tube 218. The latter tube is provided with a plate 220 connected to B_2+ terminal 221 which, for convenience, may be the same voltage source as that which supplies terminals 163 and 176. Cathode 222 is connected to resistor 223. A positive pulse is applied to grid 217 of cathode follower tube 218 to override the negative source of bias 224 applied to the grid 217 through bias resistor 225. Voltage produced across cathode folllower resistor 223 supplies voltage for the plate 226 of noise tube 227 through plate load resistor 228. Filament 229 is feed by voltage source 230 through variable control resistor 231 which is adjusted for a desired value of noise, these elements completing a noise loop through resistor 223, resistor 228 and the plate 226 of noise tube 227. The noise voltage produced across resistor 228 is coupled by way of coupling capacitor 232 to the grid of amplifier tube 204 through isolation resistor 191, thereby producing a wide band noise-modulated signal in tube 14.

It should be noted that by means of a negative lead coupling capacitor 233, only the noise produced across resistor 228 is applied to the grid 210 of tube 204, rather than a noise-modulated pulse as obtained from series-connected resistors 133 and 136 in the AM noise circuit 37. This arrangement prevents the pulsing of grid 210 of tube 204, thereby preventing any substantial frequency deviation of tube 14 from the input signal during the application of FM noise. Additionally, TR box 28 operates in the conventional manner to prevent radio frequency energy from entering the detector and amplifier circuit 29.

This completes the description of the modification of the invention disclosed herein. However, many variations thereof will be apparent to persons skilled in the art. For example, the invention is not limited to a system in which a single backward wave oscillator is voltage tuned over a wide range of frequencies by varying the electron beam velocity or by separate adjustment of the transverse magnetic field strength in those oscillator tubes employing a transverse magnetic field, but rather, the invention further contemplates the use of mechanical means for changing the geometry of the signal transmission network of one or more of said tubes to permit matching of the phase velocity of the backward wave with that of the electron beam velocity.

It further contemplates the use of conventional linear beam backward wave amplifier-oscillator tubes which do not require the use of a transverse magnetic field. Also, different sweeping circuits could be used to control the frequency of one or more oscillator tubes, such as tube **14**. Other types of noise sources could be used or eliminated in place of the particular arrangement shown here. 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. An electrical system for receiving and transmitting electromagnetic energy comprising a backward wave electron discharge device tunable through a predetermined frequency range and alternately adapted to receive and transmit electromagnetic energy in response to the magnitude of electron beam current in said device, means for cyclically varying the velocity of the electron beam to tune said device through said frequency range, means for halting tuning of said device upon reception of electromagnetic energy by said receiving means, and means responsive to said received electromagnetic energy to change the magnitude of the electron beam current to a value adapted to render said device oscillatory to produce an electromagnetic energy output at substantially the same frequency as said received energy.

2. An electrical system for receiving and transmitting electromagnetic energy comprising a backward wave electron discharge device voltage tunable through a predetermined frequency range and adapted to transmit electromagnetic energy during oscillation at substantially the same frequency at which maximum gain occurs when receiving said electromagnetic energy, means for continuously and cyclically varying the velocity of the electron beam in said device to tune said device through said frequency range, means for halting tuning of said device upon reception of electromagnetic energy by said receiving means, and means responsive to said received electromagnetic energy to change only the beam current in said device to render said device operable to produce an electromagnetic energy output.

3. An electrical system for receiving and transmitting electromagnetic energy comprising a transverse magnetic field backward wave electron discharge device voltage tunable through a predetermined frequency range depending upon the velocity of the electron beam in said device and having a mode for receiving and a mode for transmitting electromagnetic energy, means for continuously and cyclically varying the velocity of the electron beam in said device to provide tuning of said device through said frequency range, means for halting tuning of said device upon reception of electromagnetic energy by said receiving means, and means responsive to said received electromagnetic energy to change the beam current to a value adapted to produce an electromagnetic energy output at substantially the same frequency as said received energy.

4. An electrical system for receiving and transmitting electromagnetic energy comprising a backward wave voltage tunable electron discharge device tunable through a predetermined frequency range depending upon the velocity of the electron beam therein, said device having means inherent in said device for receiving electromagnetic energy and transmitting electromagnetic energy at substantially the same frequency to which said device is tuned when receiving said electromagnetic energy, means for continuously and cyclically varying the velocity of the electron beam to tune said device through said frequency range, and means for halting tuning of said device upon reception of electromagnetic energy by said receiving means, said voltage tunable device responsive to said received electromagnetic energy to vary the magnitude of the beam current in said device to render said device operable in an oscillatory mode to produce an electromagnetic energy output at substantially the same frequency as said received energy.

5. An electrical system for receiving and transmitting electromagnetic energy comprising a backward wave electron discharge device tunable through a predetermined frequency range in response to a change in velocity of the electron beam therein, said device having a mode for amplifying electromagnetic energy with maximum gain at substantially the same frequency as the mode for transmitting electromagnetic energy, means for continuously and cyclically varying the velocity of the electron beam in said device to tune said device in said amplifying mode through said frequency range, means for rendering the velocity of the electron beam substantially constant to halt the tuning of said device upon the amplification of electromagnetic energy entering said device means, responsive to said amplified electromagnetic energy to change the magnitude of beam current in said device to render said device operable in said transmitting mode to produce an electromagnetic energy output at substantially the same frequency as said amplified energy, and means for supplying said device with an amplitude modulating voltage to control the amplitude of said electromagnetic energy output.

6. An electrical system for receiving and transmitting electromagnetic energy comprising a backward wave electron discharge device tunable through a predetermined frequency range having a mode for receiving and a mode for transmitting electromagnetic energy in response to the magnitude of beam current in said device, means for cyclically varying the velocity of the electron beam in the device to sweep said device throughout a predetermined range in said receiving mode, thereby to sweep said device through said frequency range, means for halting sweeping of said device upon the reception of electromagnetic energy, means responsive to said received electromagnetic energy to adjust the beam of current of said device to a value required to render said device operable in said transmitting mode to produce an electromagnetic energy output, and separate means for varying the frequency of said electromagnetic energy output.

7. In combination, a plurality of traveling wave electron discharge devices one of which is adapted to operate as a backward traveling wave oscillator or an amplifier of electromagnetic energy depending upon the beam current magnitude in said device, output means coupled to each of said devices for extracting energy generated within said devices for applying a cyclical voltage to said backward traveling wave device, means for varying the frequency of said backward traveling wave device over a predetermined frequency range, means for stopping said frequency variation upon the reception of electromagnetic energy, means responsive to said received electromagnetic energy to adjust the beam current independently of the beam velocity to a value adapted to render said backward traveling wave device operable to produce an electromagnetic energy output at substantially the same frequency as said energy amplified by said devices, and means for supplying at least one of said devices with an amplitude modulating voltage to control the amplitude of said electromagnetic energy output.

8. In combination, a first traveling wave amplifier having an output and an input terminal, a second voltage tunable electron discharge device operating alternately as a backward wave amplifier oscillator in response to the beam current magnitude in said electron discharge device and having an output and an input terminal, means for connecting the output terminal of said first amplifier to the input terminal of said second amplifier, means for adjusting the voltage applied to said second amplifier to lock said second amplifier in frequency to that of said first amplifier in response to an external signal fed to

the input terminal of said first amplifier, and means for varying the velocity of the beam for cyclically sweeping said second amplifier over a predetermined frequency range.

9. An electrical system for receiving and transmitting electromagnetic energy comprising a backward wave electron discharge device adapted to operate alternately as an amplifier or an oscillator voltage tunable through a predetermined frequency range having an amplifying mode of operation and an oscillatory mode of operation depending upon the magnitude of beam current in said device, means for setting said device to the amplifying mode of oscillation by adjusting the magnitude of beam current to a predetermined value, means for varying the velocity of the beam to sweep said device through a predetermined band of frequencies in said amplifying mode, means for halting said frequency sweeping means upon the encountering of an electromagnetic signal, and means responsive to said electromagnetic signal to change the magnitude of the beam current from said predetermined value to shift said device to said oscillatory mode of operation, thereby to transmit electromagnetic energy at a predetermined frequency with respect to that of said electromagnetic signal.

10. A system for alternately providing signal amplification and oscillation in a voltage tunable backward wave electron discharge device adapted to operate at substantially the same frequency in an amplifying and an oscillatory mode of operation in response to the magnitude of beam current in said device including means for sweeping velocity of the beam through a predetermined velocity range thereby to sweep said device through a predetermined frequency range, means for stopping said sweeping of said device upon encountering an input signal, means for adjusting the beam current to operate said device in said amplifying mode, voltage regulating means responsive to said amplified input signal to operate said device at a beam current value adapted to provide a continuous wave oscillatory output, and means for modulating said continuous wave oscillatory output with a predetermined noise voltage.

11. A system for alternately providing signal amplification and oscillation in a voltage tunable backward wave electron discharge device adapted to operate at substantially the same frequency in an amplifying and an oscillatory mode of operation for a predetermined magnitude of beam current in said device including means for changing the velocity of said beam to sweep said device through a predetermined velocity range in said amplifying mode of operation, thereby to sweep said device through a predetermined frequency range, means for stopping said sweeping of said device upon encountering an input signal, means for holding the magnitude of said beam current at a predetermined value amplifying said input signal by said device in said amplifying mode, means for setting the magnitude of said beam current to a value adapted to generate a continuous wave oscillatory output from said device at substantially the frequency of said encountered signal, and means for modulating said signal output with a predetermined noise voltage.

12. In combination, a voltage tunable backward wave amplifier tube adapted to operate alternately as an oscillator or as an amplifier depending upon the magnitude of beam current in said tube, an input and an output terminal connected to said tube, means for adjusting the velocity of the beam for cyclically sweeping said amplifier over a predetermined frequency range, means for varying the magnitude of beam current in said amplifier tube to substantially amplify a signal encountered at said input terminal at a frequency to which said amplifying tube is tuned, means responsive to a signal encountered to initiate oscillations at said latter-recited frequency, and means for amplitude and frequency modulating said oscillations to provide a noise output voltage.

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