Jan. 10, 1961 E. J. NALOS 2,967,968

ELECTRON DISCHARGE DEVICE

Filed June 24, 1957 2 Sheets-Sheet 1

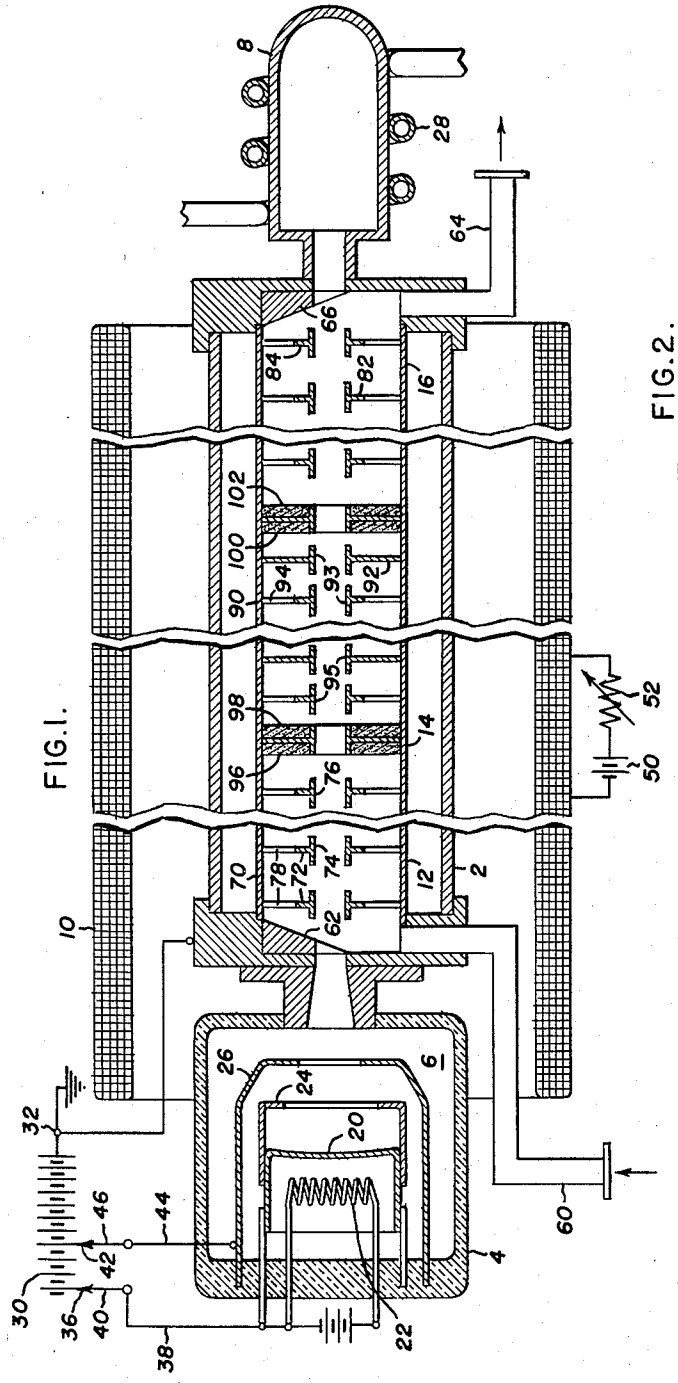


FIG. 1.

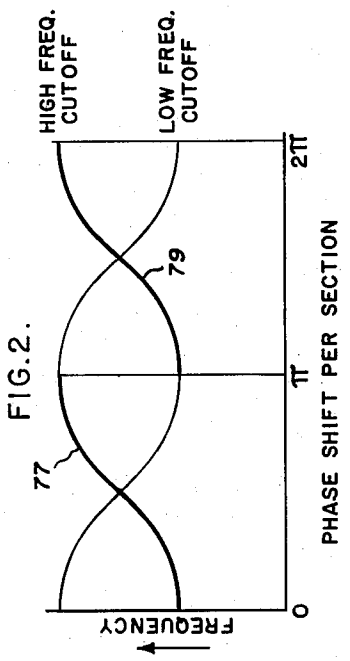


FIG. 2.

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FIG.3.

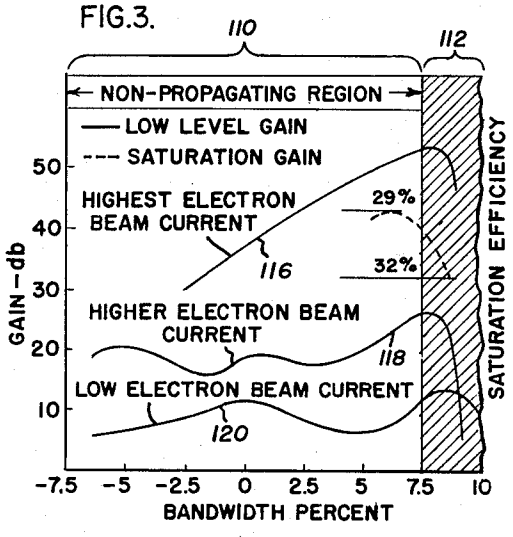


FIG.4.

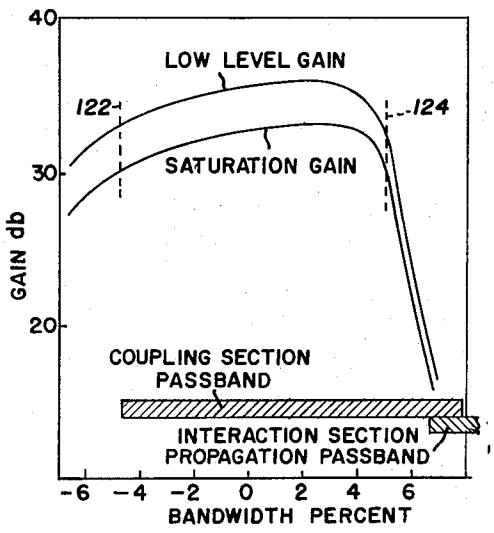
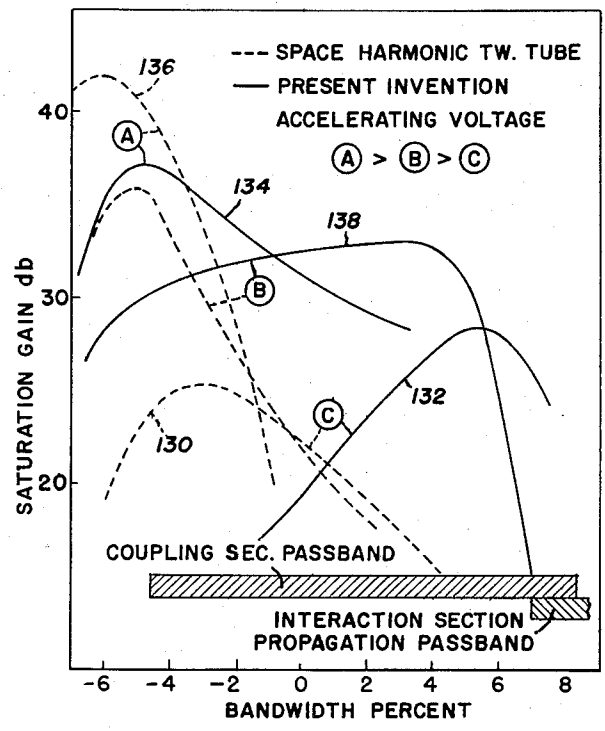


FIG.5.



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United States Patent Office 2,967,968 Patented Jan. 10, 1961

2,967,968

ELECTRON DISCHARGE DEVICE

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Filed June 24, 1957, Ser. No. 667,414

11 Claims. (Cl. 315—3.5)

This invention relates to electron discharge devices, and more particularly to improvements in electromagnetic wave amplifying electron discharge devices of the type employing energy exchanging interaction between an electron beam and a waveguiding structure disposed adjacent to the path of the beam.

One type of electron discharge device employing such interaction between an electron beam and a waveguiding structure is generally referred to as a traveling wave tube. Relatively low power traveling wave tubes are known in which the waveguiding structure consists of a helix along the axis of which a wave is propagated at a reduced velocity within the range of practically obtainable electron beam velocities, and in which the interaction of a coaxial electron beam and the reduced velocity wave, or slow-wave, propagated by the helix produces signal amplification. A principal advantage of such a traveling wave tube is the wide frequency range, or bandwidth, over which amplification may be obtained.

At relatively high power levels, however, because of its limited ability to dissipate the heat generated by the requisite electron beam currents, difficulty in focusing as physical size is reduced in accordance with wavelength, and reduction in its effective interaction impedance.

At high power levels or frequencies, slow wave propagating structures or circuits of the filter type, such as for example, a loaded wave guide or a linear array of coupled resonant cavities, have been found to be more practical. One disadvantage of the filter type slow wave circuit, however, is that high gain traveling wave operation with it is obtained only at a considerable sacrifice in the width of the frequency band across which the slow wave propagation necessary for traveling wave tube amplification occurs. Thus prior art wave amplifying devices of the traveling wave tube type capable of high gain operation at high power or frequency levels have generally been considerably limited in bandwidth.

Accordingly, it is a principal object of the present invention to provide an electron discharge device of the signal amplifying type employing interaction between an electron beam and a waveguiding structure and having an increased bandwith in comparison with prior art devices at high gain and high power or frequency levels.

Another object is to provide such an electron discharge device whose gain versus frequency characteristic may be readily tailored to any desired form.

Another object is to provide such an electron discharge device capable of providing a high and substantially uniform gain over a wide bandwidth and at high power or frequency levels.

Another object is to provide a mechanically relatively simple and sturdy broadband high power amplifier of reasonable efficiency and good gain.

These and other objects of the invention will be apparent from the following description, and the scope of the invention will be defined in the appended claims.

Briefly, the present invention arises from the discovery that high gain broadband electromagnetic wave amplification can be obtained from the reaction of an electron beam and a normally slow-wave propagating waveguiding or interaction structure in the frequency range which lies immediately below the pass band for slow wave propagation of the interaction structure.

For a more complete description of the invention reference is made to the accompanying drawings, wherein:

Figure 1 is an axial sectional, partially broken away view of one form of an electron discharge device constructed in accordance with the present invention;

Figure 2 is a graph showing certain relevant properties of loaded waveguide circuits;

Figure 3 is a graph of certain of the operating characteristics of a portion of the structure shown in Figure 1;

Figure 4 is a graph of certain operating characteristics of a discharge device constructed according to the invention; and

Figure 5 is a graph showing certain additional characteristics of a discharge device constructed according to the invention.

Referring now to the drawing, Fig. 1 shows one form of electron discharge device constructed in accordance with the present invention. The discharge device includes an evacuated elongated conducting envelope 2 having at one end a dielectric bulb 4 containing an electron gun 6 for producing an electron beam, and having at its other end a collecting electrode 8 electrically connected to the envelope for intercepting the beam. Focusing of the electron beam axially of the envelope is provided by a solenoid 10. The principal electromagnetic wave signal-handling portions of the device are arrayed along the path of the electron beam in coaxial relation therewith, and comprise, in order from the electron gun 6 toward the collector 8, and input coupling section 12, an interaction section 14, and an output coupling section 16, all of which will be described in detail hereinafter.

The electron gun shown includes a cathode 20, heater 22, a centrally apertured focus electrode 24 electrically connected to the cathode, and a centrally apertured accelerating electrode 26. Collector 8 may be cooled, if desired, by a suitable coolant in coil 28.

Unidirectional operating potentials may be supplied continuously or intermittantly to the various electrodes of the device from any suitable power supply, such as that shown schematically at 30. Power supply 30 includes a grounded point 32 to which the envelope 2 is connected by conductor 34, a point 36 negative with respect to ground to which cathode is connected by conductor 38 and adjustable tap 40, and a point 42 positive with respect to point 36 to which the accelerating electrode 26 is connected by conductor 44 and adjustable tap 46. A suitable power supply 50 provides the necessary focusing current to solenoid 10 through adjustable resistor 52.

Input signals are supplied to the discharge device through a suitable feed, here shown as a hollow pipe waveguide 60 terminating at input coupling section 12 and impedance matched thereto for broadband operation by any suitable means such as tapered member 62. Output signals are removed from the output coupling section 16 of the discharge device through a waveguide 64 impedance matched by any suitable means such as tapered member 66.

The purpose of the input coupling section 12 is to modulate the density of the electron beam with the input signals within the frequency range for which amplification is desired. The input coupling section may be of any suitable type sufficiently broadband to accommodate signals throughout the frequency range desired, and may be for example a heavily loaded single cavity or a resonant multi-cavity section of a propagating slow wave

circuit designed to provide output over a frequency range just below the wave-propagating region of the interaction circuit. As an additional alternative and by way of illustration, input coupling section **12** is shown as a slow wave circuit of the filter type, consisting of a linear array of cavity resonators formed by a conducting cylinder **70** coaxial with the electron beam and containing regularly spaced transverse partitions **72**. The partitions are centrally apertured as at **74** to pass the electron beam, are formed with coaxial reentrant portions **76** rimming their central apertures, and have diametrically spaced axially aligned openings **78** adjacent their peripheries which provide inductive coupling of the resonators.

The input coupling section **12** shown is designed to serve as a slow wave propagating circuit exibiting conventional traveling wave tube interaction in the frequency range for which amplification is desired, i.e. below the slow wave propagating frequency band of the interaction circuit **14**.

Coupling section **12** can be of the fundamental forward wave type, i.e. exhibiting a phase constant which varies in substantially direct proportion with frequency throughout the frequency range desired and in the range of phase shift per section from zero to π radians as shown in Fig. 2, heavy line portion of curve **77**; or coupling section **12** can be of the fundamental backward wave type, i.e. operating on a spatial harmonic forward wave and exhibiting a phase constant which varies in substantially direct proportion with frequency throughout the frequency range desired and in the range of phase shift per section from π to 2π radians, as shown in Fig. 2, heavy line portion of curve **79**. As is known to those skilled in the art, the frequency passband of coupling section **12** is determined by the transverse dimensions of cylinder **70** and the size of the coupling openings **78**. The length of the input coupling section is not critical, but preferably should be sufficient to build up a growing wave of sufficient amplitude for effective density modulation of the electron beam.

Output coupling section **16** likewise may be of any desired type of bandwidth sufficient to accommodate signals throughout the frequency range desired and capable of recovering the amplified signal from the density modulated electron beam. Output coupling section is shsown by way of illustration as similar in all respects to input coupling section **12**, and consists of a linear array of cavity resonators formed by a conducting cylinder **80** coaxial with the electron beam, and containing regularly spaced centrally apertured reentrant partitions **82**, slotted as at **84** for inductive coupling. The length of the output section, which in one discharge device constructed was eight resonator sections, is not critical, but preferably should be sufficient to obtain enough gain therein to give good overall efficiency.

Coaxially situated between the input and output coupling sections is the interaction section **14**. The interaction section or circuit is a waveguiding structure the purpose of which is to amplify the alternating current signal associated with the density modulated electron beam arriving from the input coupling section **12**. The present invention is based on the discovery that such amplification takes place with reasonable efficiency and good gain over a broad bandwidth when the interaction circuit is designed so that the frequency band through which it will propagate slow waves lies immediately above the frequency range for which signal amplification is desired, or conversely, so that the frequency range in which wave amplification is desired is immediately below the propagation passband of the interaction circuit.

The interaction section may be either of the fundamental forward wave type of the fundamental backward wave type. However, for high gain an interaction section of the fundamental backward wave type is preferred. This may be explained as follows. For high gain it is preferable to react the electron beam from electron gun **6** with a component of the eletcric field of tthe interaction section **14** having a phase velocity such that the impedance of the interaction section is high. It can be shown mathematically that one such component of the electric field associated with the interaction section is the first spatially harmonic component, having a phase shift per resonator section of nearly π radians near the low frequency cut off of the interaction section passband. Accordingly the electron beam velocity is preferably adjusted to a value such that strong interaction occurs between the beam and the phase spatial harmonic component of the electric field associated with the interaction section. As may be apparent from Fig. 3 and as is known to those skilled in the art, an interaction circuit having a phase shift per resonator section of approximately π radians near its low frequency cut off, and in which the phase shift per resonator section varies as required for broadband operation, in substantially direct proportion with frequency throughout the range of π to 2π radians per resonator section, is one having a fundamental field component whose phase velocity and group velocity are of opposite sign i.e. a fundamental backward wave circuit. Alternatively a fundamental forward wave circuit could be used, but for the desired broadband operation its impedance would be reduced, and hence its gain would be reduced. Accordingly, to accommodate the above-mentioned preference that the optimum gain the electron beam should react with a component of the electric field of the interaction section having a phase velocity such that the impedance of the interaction section is high, the interaction section **14** should preferably be of the fundamental backward wave type.

The interaction section shown is a waveguiding structure in the form of a slow-wave circuit of the filter type, consisting of a linear array of coupled cavity resonators formed by a conducting cylinder **90** coaxial with the electron beam and containing spaced transverse partitions **92** having central apertures **93** rimmed with reentrant portions **95**. To provide inductive coupling between resonator sections, partitions **92** have diametrically spaced slots **94**, the slots in successive partitions being preferably rotatively displaced 90°. While the electron beam accelerating voltage as determined by the cathode potential of point **36** relative to ground is not critical, as previously pointed out the voltage at point **36** is preferably adjusted to give an electron beam velocity such that strong interaction occurs between the beam and the first spatial harmonic component of the electric field associated with the interaction section.

At the ends of the interaction section **14** and at the adjacent ends of the coupling sections are attenuators **96, 98, 100, 102**, the purpose of which is to provide an impedance matching termination for each coupling section and to prevent oscillations of the interaction circuit in its own slow wave propagating pass band. The attenuators may be of any desired type, but to minimize the axial length required each attenuator preferably consists of a transversely disposed centrally apertured disc of carbonized ceramic, providing a high loss material of small axial dimension. Attenuators of this type are described more fully and claimed in the copending patent application of Kurt E. Zublin and Robert A. Craig, S.N. 632,841, filed January 7, 1957, and commonly assigned herewith. Attenuators **96, 98** are separated by and are situated on opposite sides of the left hand end partition **92** of the interaction section **14**, attenuator **96** serving to provide a matching termination for the input coupling section **12**, while attenuator **98** prevents oscillations in the interaction circuit. Attenuators **100, 102** are likewise separated by and situated on opposite sides of the right hand end partition **92** of the interaction section **14**, attenuator **100** serving to prevent oscillations in the interaction circuit and attenuator **102** matching the output coupling section **16**.

Certain of the operating characteristics of the interac-

tion section 14 alone as an electromagnetic wave amplifier are illustrated in Fig. 3, which is a graph of gain and saturation efficiency vs. frequency in percent bandwidth for low level and saturation beam currents in one embodiment tested. The region 110 represents the non-propagating region of the interaction section, while region 112 represents its slow-wave propagation pass band. As will be apparent from Fig. 3 at 114 saturation efficiency in the vicinity of 30% is obtained at frequencies slightly below the low frequency cut-off of the slow wave propagation pass band of the interaction circuit. Saturation gain at point 114 is in excess of 40 decibels. Gain increases with frequency, coming to a peak at a frequency, points 116, 118, 120, close to the low-frequency edge or cut-off of the propagation pass band. This latter feature is extremely desirable, since the variation of gain with frequency of loaded waveguide slow wave circuits is characteristically of the opposite slope, i.e. gain decreases with frequency. Hence a non-propagating interaction circuit 14 in series with one or more loaded waveguide slow wave circuits can be made to mutually compensate and thereby provide a gain-frequency characteristic of greatly improved flatness in comparison with devices of the prior art. Thus, for maximum flatness of gain-frequency characteristic in a discharge device such as shown in Fig. 1, the propagation passband of interaction section 14 should preferably be chosen so that its low frequency edge or cut-off occurs near the high frequency cut-off of the propagating passband of the coupling sections 12, 16 with a small degree of overlap to allow for the decreased gain of the coupling sections near their high frequency cut-offs.

The flat gain-versus-frequency characteristic possible with a device such as shown in Fig. 1 is best illustrated in Fig. 4, which illustrates the variation of gain with frequency for a typical electron beam accelerating voltage, at low level and saturation beam currents of one embodiment tested. As will be apparent from Fig. 4 between frequency limits 122, 124, the gain is flat within 3 db over a frequency range of substantially 10% bandwidth.

Another important advantage of the invention is illustrated in Fig. 5, which shows the variation of saturation gain with frequency of a discharge device constructed according to the invention, for various values of electron beam accelerating voltage. Also plotted in Fig. 5 for comparison is the gain characteristic of a conventional traveling wave tube composed entirely of a slow wave propagating circuit of the same overall length as the interaction and coupling sections of Fig. 1. Fig. 5 shows that at the lower voltages, curves 130 and 132, where the traveling wave sections have little gain, the overall gain characteristic of the device of the present invention is determined primarily by the interaction section, peaking toward the high frequency end of the band as shown by curve 132, whereas the gain of the conventional traveling wave tube falls off with frequency as shown by curve 130. At the higher voltages, curves 134 and 136, the overall gain characteristic of the device of the present invention is determined primarily by the traveling wave propagating coupling sections. This results, as shown in curve 134, in peak gain toward the low frequency end of the operating frequency range, similar to the characteristic of the conventional traveling wave tube, shown by curve 136. At intermediate voltages, however, as shown by curve 138, the gain characteristics of propagating and non-propagation sections mutually compensate, and thereby provide the characteristic previously noted, of very flat gain variation over a wide frequency band. Thus it may be seen that merely by varying the electron beam accelerating voltage at point 36, the gain variation with frequency of a discharge device constructed according to the invention may be tailored to have any desired characteristic or to peak at any desired frequency in the operating range.

The reason for the growth of the electron beam density modulation, i.e. amplification of the signal wave associated therewith, in the interaction section 14 at frequencies below its slow wave propagation passband is not fully understood. However, it is believed to result at least in part from a phenomenon heretofore recognized as providing amplification limited to a very narrow bandwidth of the order of 1 or 2%, and known to those skilled in the art as inductive wall amplification. For a fuller discussion of this phenomenon, reference may be had to the article, "Waves in an Electron Stream with General Admittance Walls," by C. K. Birdsall and J. R. Whinnery, Journal of Applied Physics, vol. 24, No. 3, March 1953.

Thus it may be seen that a wave amplifying device constructed according to the present invention is capable of providing operation at relatively high power or frequency levels with substantially broadened bandwidth and greatly improved flatness of gain vs. frequency in comparison with prior art devices of the traveling wave tube type. Moreover, the gain variation with frequency may be tailored to have any desired characteristic or to peak at any desired frequency in the operating range merely by varying the electron beam accelerating voltage. In addition, since with the arrangements shown the input and output circuits are mutually well isolated, good stability and freedom from spurious oscillations is obtained even with variable load, with a minimum of attenuation required.

It will be appreciated by those skilled in the art that the invention may be carried out in various ways and may take various forms and embodiments other than those illustrative embodiments heretofore described. It is to be understood that the scope of the invention is not limited by the details of the foregoing description, but will be defined in the following claims.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. A device for amplifying electromagnetic waves in a selected frequency band comprising means for generating an electron beam having a predetermined path, means for modulating the density of the electron beam in accordance with an applied wave to be amplified, a loaded filter type waveguiding structure having a plurality of sections disposed adjacent said electron beam path and in interacting relation with the density modulated electron beam, said waveguiding structure being loaded to provide a phase shift near π radians per section in the selected frequency band and having a wave propagation passband at least a portion of which is at a higher frequency than said selected frequency band, and means associated with the waveguiding structure and responsive to interaction of the density modulated electron beam with said waveguiding structure for deriving an amplified version of the applied wave.

2. A device for amplifying electromagnetic waves in a selected frequency band comprising means for generating an electron beam having a predetermined path, means for modulating the density of the electron beam in accordance with an applied wave to be amplified, an interaction structure disposed in adjacent coaxial relation with said electron beam path and in energy coupling relation with the density modulated electron beam, said interaction structure comprising a periodically loaded filter type waveguide slow-wave circuit for propagating a component of electric field in the direction of flow of said electron beam at a velocity substantially less than free space electromagnetic wave velocity, said interaction structure having a periodicity which produces a phase shift of near π radians per period at a selected frequency to be enhanced in said selected frequency band and a slow-wave propagation pass band at least a portion of which lies in a frequency range above said selected frequency band, and means associated with the interaction structure and responsive to interaction of the density

modulated electron beam with said interaction structure for deriving an amplified version of the applied wave.

3. A device for amplifying electrical waves in a selected frequency band comprising a waveguiding structure capable of propagating electrical waves at a velocity substantially less than their velocity in free space in a frequency band centered at a frequency higher than said selected band and a low frequency cut off near the high frequency cut off of the selected frequency band, means for producing an electron beam having a path adjacent to said waveguiding structure, input signal coupling means for density modulating said electron beam with a signal in said selected frequency band as it approaches said waveguiding structure, and output signal coupling means adjacent the path of said electron beam as it departs from said waveguiding structure for recovering an amplified signal from said electron beam.

4. A device for amplifying electrical waves in a selected frequency band comprising a sectioned loaded waveguide structure capable of propagating electrical waves at a velocity substantially less than their velocity in free space and in a frequency band centered at a frequency higher than the selected band, said sections of said waveguiding structure being selected to produce a phase shift of near π radians per section within the selected frequency band, means for producing an electron beam having a path adjacent to said waveguiding structure, input coupling means for density modulating said electron beam with a signal in the selected frequency band as it approaches said waveguiding structure, and output coupling means adjacent the path of said electron beam as it departs from said waveguiding structure for recovering an amplified signal from said electron beam.

5. A device for amplifying electromagnetic waves in a selected frequency band comprising means for generating an electron beam having a predetermined path, a first waveguiding structure disposed adjacent said electron beam path and in interacting relation with said beam, said first waveguiding structure comprising a slow wave circuit having a propagation passband at least a portion of which lies at a frequency above said selected frequency range and producing gain below its propagating passband and within said selected frequency range which gain increases with frequency in said selected frequency range, means for modulating the density of said electron beam in accordance with an applied wave to be amplified, a second waveguiding structure disposed adjacent said electron beam path in series relation with said first waveguiding structure and in interacting relation with said electron beam said second waveguiding structure comprising a slow wave circuit having a slow wave propagation passband in said selected frequency range and having a gain which decreases with frequency in said selected frequency range, whereby the overall gain vs. frequency characteristic of said device is a combination of the opposing gain vs. frequency characteristics of said first and second waveguiding structures, and means associated with one of said waveguiding structures and responsive to interaction of the density modulated electron beam therewith for deriving an amplified version of the applied wave.

6. A device for amplifying electromagnetic waves in a selected frequency band comprising means for generating an electron beam having a predetermined path, first, second and third slow wave circuits disposed adjacent said electron beam path and in interacting relation with said beam, said first and third slow wave circuits having slow wave propagation passbands in said selected frequency range and having a gain which decreases with frequency in said selected frequency range, said second slow wave circuit having a propagation passband at least a portion of which lies in a frequency band above said selected frequency range, said second slow wave circuit having a gain in the selected frequency range below the low frequency edge of its propagation passband and which increases with frequency toward the said configuration which produces a low frequency edge of its propagation passband, means for introducing an applied wave to be amplified into said first slow wave circuit to modulate the density of said electron beam in accordance therewith and means for deriving an amplified version of the applied wave from the third slow wave circuit, whereby the overall gain vs. frequency characteristic of said device is a combination of the individual gain vs. frequency characteristics of said first, second and third slow wave circuits.

7. A device for amplifying electrical waves in a selected frequency band comprising a waveguiding structure capable of propagating electrical waves with a velocity substantially less than the free space velocity in a propagation band having an effective low-frequency cutoff near the upper frequency of said selected band, means for producing an electron beam having a path adjacent to said wave guiding structure, input signal coupling means for density modulating said electron beam with a signal in said selected frequency band as it approaches said waveguiding structure, output signal coupling means adjacent the path of said electron beam as it departs from said waveguiding structure for recovering an amplified signal from said electron beam, and electromagnetic wave attenuating means associated with said waveguiding structure for preventing propagation of waves therein in the propagation band thereof.

8. A device for amplifying electrical waves in a selected frequency band comprising a waveguiding structure capable of propagating electrical waves with a velocity substantially less than their free space velocity in a propagation band having an effective low-frequency cutoff near the upper frequency end of said selected band, means for producing an electron beam having a path adjacent to said wave guiding structure, means for density modulating said electron beam with a signal in said selected frequency band as it approaches said waveguiding structure, means adjacent the path of said electron beam as it departs from said waveguiding structure for recovering an amplified signal from said electron beam, and means for adjusting the velocity of said electron beam to synchronize said beam in energy transferring interacting relation with a selected component of the electric field associated with said waveguiding structure.

9. A device for amplifying electrical waves in a selected frequency band comprising a waveguiding structure capable of propagating electrical waves with a velocity substantially less than their free space velocity in a propagation band having an effective low-frequency cutoff near the upper frequency of said selected band, means for producing an electron beam having a path adjacent to said wave guiding structure, means for density modulating said electron beam with a signal in said selected frequency band as it approaches said waveguiding structure, means adjacent the path of said electron beam as it departs from said waveguiding structure for recovering an amplified signal from said electron beam, means for adjusting the velocity of said electron beam to synchronize said beam in energy transferring interacting relation with a selected component of the electric field associated with said waveguiding structure, and means for suppressing amplification of undesired traveling waves in said waveguiding structure.

10. A device for amplifying signals in a desired frequency range comprising means for generating an electron beam having a selected path, means for collecting the beam, input signal coupling means for density modulating said electron beam and comprising a loaded-waveguide slow wave structure including a hollow pipe waveguide containing a plurality of spaced transverse centrally apertured plates having a slow wave propagation passband in said desired frequency range, said input signal coupling means being disposed between the beam direct-

ing means and beam collecting means with the central apertures in said plates arranged to pass said beam coaxially therethrough, output coupling means for recovering an amplified signal from the density modulation of said electron beam comprising a loaded-waveguide slow wave structure having a slow wave propagation passband in said desired frequency range, said output coupling means being disposed coaxially adjacent the electron beam path between the collector and input coupling means, and a wave amplifying interaction circuit adjacent said electron beam path between said input and output coupling means comprising a waveguiding structure having a slow wave propagation passband at least a portion of which lies at a frequency higher than said desired frequency range and a low frequency cut off near the high frequency cut off of the desired frequency range.

11. A device for amplifying signals in a desired frequency range comprising means for generating an electron beam, means for directing the beam along a selected linear path, means for collecting the beam, input signal coupling means for density modulating said electron beam and comprising a loaded-waveguide type slow wave structure including a hollow pipe waveguide containing a plurality of spaced transverse centrally apertured plates, said input signal coupling means being disposed between the beam directing means and beam collecting means with the central apertures in said plates arranged to pass said beam coaxially therethrough, output coupling means for recovering an amplified signal from the density modulation of said electron beam comprising a loaded-waveguide type slow wave structure including a hollow pipe waveguide containing spaced centrally apertured transverse plates, said output coupling means being disposed coaxially adjacent the electron beam path between the collector and input coupling means, said input and output coupling means having a slow wave propagation pass band in the desired frequency range, and a wave amplifying interaction circuit disposed adjacent the path of said electron beam between said input coupling means and said output coupling means, said interaction circuit comprising a loaded-waveguide type slow wave structure having a slow wave propagation passband centered at a frequency higher than said desired frequency range, and including a hollow pipe waveguide containing a plurality of spaced centrally apertured plates arranged in coaxial relation with said electron beam thereby defining a series of sections, said plates being spaced apart to produce a phase shift near π radians per section at a frequency within said desired frequency range.

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UNITED STATES PATENT OFFICE

CERTIFICATION OF CORRECTION

Patent No. 2,967,968 January 10, 1961

Ervin J. Nalos

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 7, line 74, before "gain" insert -- configuration which produces a --; column 8, lines 1 and 2, strike out "configuration which produces a".

Signed and sealed this 27th day of June 1961.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

DAVID L. LADD
Commissioner of Patents