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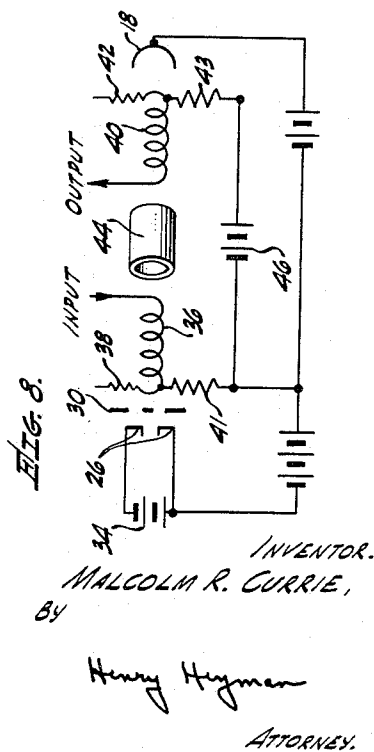
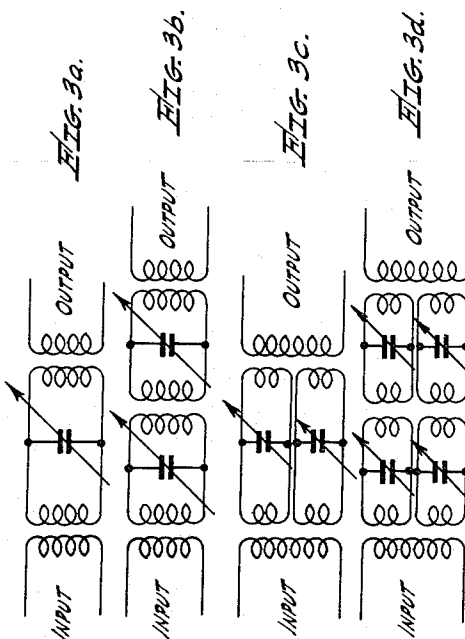
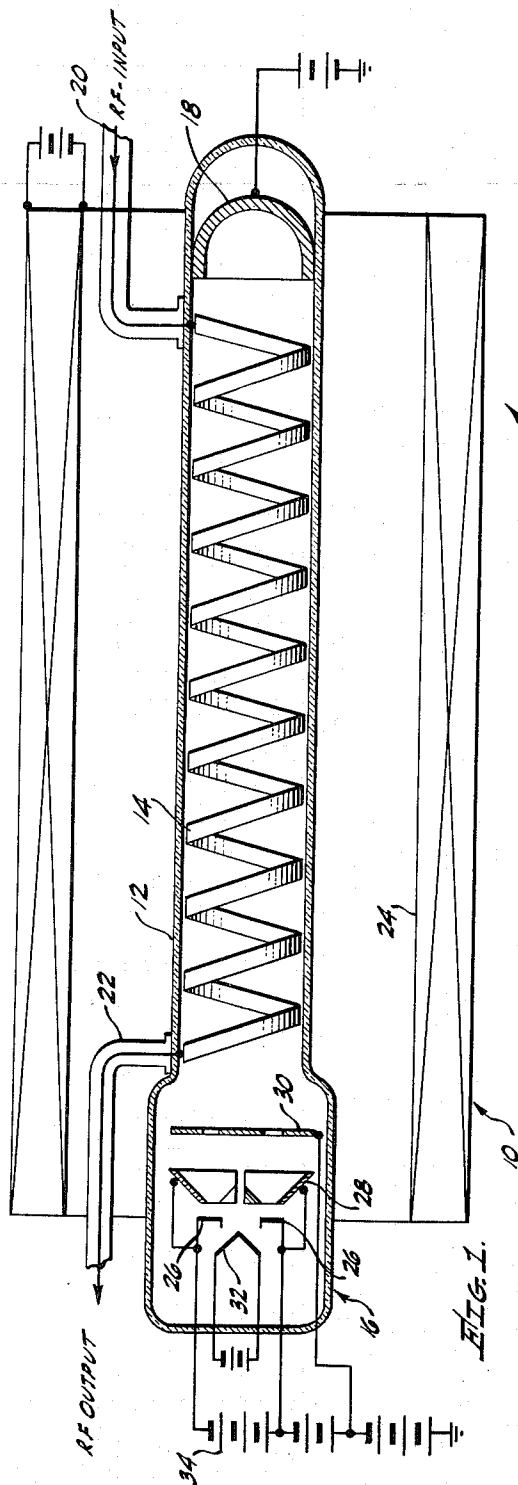
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2,911,558

BROAD-BAND BACKWARD-WAVE AMPLIFIER

Filed Nov. 1, 1955

2 Sheets-Sheet 1



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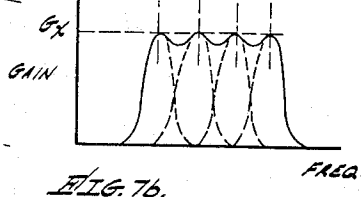
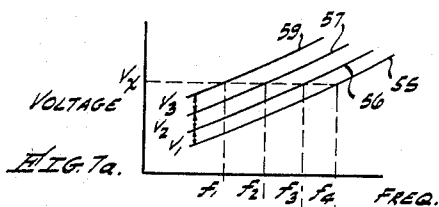
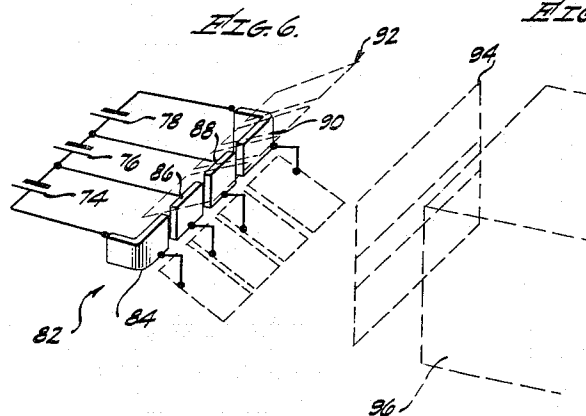
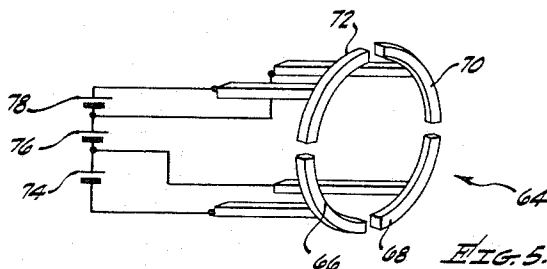
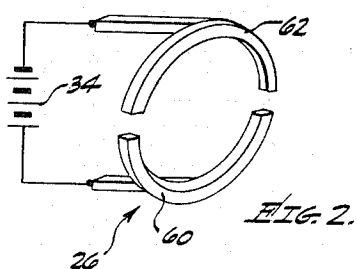
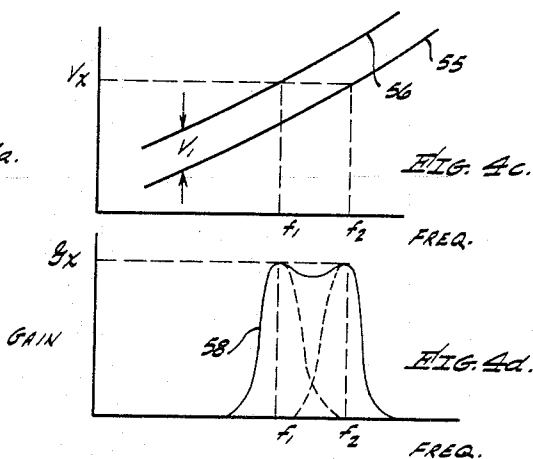
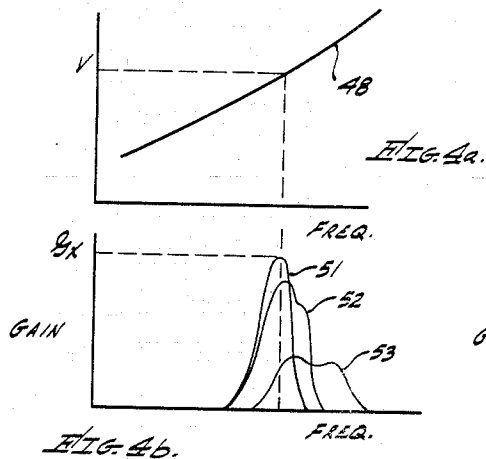
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BROAD-BAND BACKWARD-WAVE AMPLIFIER

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2 Sheets-Sheet 2



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## BROAD-BAND BACKWARD-WAVE AMPLIFIER

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4 Claims. (Cl. 315-3.6)

This invention relates generally to traveling-wave tubes and more particularly to an improved dispersive or backward-wave amplifier having a broad-band frequency response.

In a traveling-wave tube a slow-wave structure such as a helix is capable of propagating electromagnetic traveling waves in several different modes. One of these modes represents the fundamental wave which has a phase and group velocity in the forward direction. In a traveling-wave tube adapted to amplify this forward wave an electron stream is directed along the slow-wave structure at a velocity slightly greater than the phase velocity of the traveling wave to effect an interchange of energy from the electron stream to the wave to cause amplification of the wave. The frequency response of such an amplifier is quite broad. However, when it is desired to amplify a backward wave, that is, a wave representing a mode of propagation whose phase velocity is in a direction opposite to that of the fundamental mode, and the same as that of the electron stream, the frequency response is very narrow. This is due to the fact that for a given voltage or velocity of the electron stream there is only a very narrow band of frequencies in the wave traveling in the direction of the electron stream which the electron stream can electromagnetically "push," that is, which it can amplify or deliver energy to.

Heretofore broadening the frequency band of a backward wave amplifier was accomplished by providing two or more helices having different direct-current (D.C.) voltages which results in a stagger-tuned effect. Consequently, although the frequency response is indeed broadened, the gain-bandwidth product is not increased by an appreciable amount.

It is therefore an object of the present invention to provide a dispersive broad-band traveling-wave amplifier which does not suffer the disadvantages of stagger-tuned systems.

It is another object to provide, in a broad-band backward wave amplifier, a multi-velocity electron beam.

It is a further object to provide such a multi-velocity electron stream by means of a number of discrete cathodes, each being supplied with separate D.C. voltages.

In a conventional backward-wave amplifier the beam has the shape of a hollow cylinder projected along the interior of a slow-wave structure such as a helix. In accordance with one embodiment of this invention the cathode of the amplifier is ring shaped, the ring being severed into two or more discrete segments, each segment being electrically insulated from the others. A potential difference is applied between adjacent segments so that the electrons emitted from the various segments traverse the helix with different velocities dependent upon the potential difference between a particular segment of the cathode structure and the accelerating anode.

Another embodiment of the present invention includes a sheet beam forming cathode as used in traveling-wave tube amplifiers of the type called traveling-wave magnets. The sheet beam of electrons of rectangular cross-

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section is projected between a conductive plate and a slow-wave structure. The overall cathode shape in such a traveling-wave tube is an elongated rectangle disposed with its rectangular emissive surface perpendicular to the desired beam path. In accordance with the present invention the emissive strip is divided into two or more segments electrically insulated from each other and having a potential difference applied across the gap.

The novel features which are believed to be characteristic of the invention both as to its organization and method of operation, together with further objects and advantages thereof, will be better understood from the following description considered in connection with the accompanying drawings in which several embodiments of the invention are illustrated by way of example. It is to be expressly understood, however, that the drawings are for the purpose of illustration and description only and are not intended as a definition of the limits of the invention.

In the drawings:

Fig. 1 is a schematic view, partly in section, of a single helix backward-wave amplifier tube utilizing a cathode structure in accordance with this invention.

Fig. 2 is an enlarged perspective view of the cathode structure of the tube of Fig. 1.

Fig. 3a is a schematic diagram of a circuit which is analogous to a prior art single-helix tube.

Fig. 3b is a schematic diagram of a circuit which is analogous to a prior art double-helix tube.

Fig. 3c is a schematic diagram of a circuit which is analogous to the tube of Fig. 1.

Fig. 3d is a schematic diagram of a circuit which is analogous to a double-helix traveling-wave tube utilizing a cathode structure in accordance with the present invention.

Fig. 4a is a graph showing the dispersive characteristic of a conventional single-helix backward-wave amplifier tube.

Fig. 4b is a graph of the band-pass characteristic of a conventional double-helix backward-wave amplifier tube.

Fig. 4c is a graph illustrating the dispersive characteristics of the tube of Fig. 1.

Fig. 4d is a graph of the bandwidth associated with the tube of Fig. 1.

Figs. 5 and 6 illustrate additional embodiments of the cathode structure suitable for use in the tube of this invention.

Fig. 7a is a graph of the dispersion characteristic of backward-wave amplifiers utilizing the cathode structures of Figs. 5 or 6.

Fig. 7b is a graph of the bandwidth characteristic associated with a tube embodying a cathode of Figs. 5 or 6.

Fig. 8 is a schematic view of a double-helix backward-wave amplifier utilizing the cathode structure of Fig. 2.

Referring now to the drawings and particularly to Fig. 1, there is shown a backward-wave amplifier traveling-wave tube 10 having an evacuated envelope 12, which may be of glass, enclosing and supporting a slow-wave structure or helix 14, an electron gun 16, and a collector electrode 18. The collector 18 is disposed at the end of the glass envelope 12 opposite electron gun 16 and adapted to collect the electron beam and dissipate its kinetic energy. An input transmission line 20 is coupled in a conventional manner to the collector end of slow-wave structure 14, and an output line 22 is coupled to the emitter end of helix 14. A solenoid 24 surrounds the traveling wave tube and is adapted to constrain, confine and focus the electron beam along and within the conductive helix 14.

Electron gun 16 in accordance with the invention, comprises an annular, segmented cathode structure 26, corresponding segmented focusing electrode 28, accelerating

anode 30 and a filament heater 32. Respective segments of cathode structure 26 are electrically connected to segments of focusing electrode 28. A potential source 34 is connected between the two segments of cathode structure 26. Other suitable voltage sources are shown schematically in Fig. 1.

Fig. 2 illustrates in more detail the structure of cathode 26. Two segments 60 and 62 are separated and electrically insulated from each other, and voltage source 34 is connected between the two segments. The gap between segments 60 and 62 may also be filled with any suitable dielectric such as quartz. Cathode structure 26 is utilized to provide an electron beam having electrons of two discretely separate velocities, the electrons traversing the length of the helix of the traveling-wave tube. The difference in the two velocities is directly related to the magnitude of voltage source 34.

The single-tuned type of circuit of Fig. 3a is electrically analogous to a prior art single-helix, single-cathode backward-wave amplifier. There is as shown one tuning parameter and hence only a simple, single peak band-pass characteristic.

Fig. 3b illustrates, also by analogy, a prior art double-helix single-cathode backward-wave amplifier. Here there are two tuning parameters which may be set at slightly different frequencies to provide a stagger-tuned type of band-pass characteristic having two adjacent peaks.

Curve 48 of Fig. 4a where accelerating voltage or electron velocity is plotted on the ordinate and frequency of the traveling wave on the abscissa, demonstrates the dispersive characteristic of a single-helix, or non-stagger-tuned double-helix backward-wave amplifier of the prior art.

The graph of Fig. 4b plots tube gain on the ordinate and frequency on the abscissa. This graph demonstrates the decreasing gain when it is attempted to increase the bandwidth of a cascaded or double-helix backward-wave amplifier of the prior art, as analogized by the circuit of Fig. 3b, by stagger-tuning.

Curve 51 of Fig. 4b is the gain-frequency response without double tuning. Curves 52 and 53 demonstrate the effect of increased stagger tuning. Their effects are well known in the art.

The graph of Fig. 4c which plots electron velocity on the ordinate and frequency on the abscissa shows the dispersive curve of a single-helix backward-wave amplifier as illustrated in Fig. 1 which utilizes the cathode structure of the present invention. Curves 55 and 56 are separated vertically by a distance represented as  $V_1$ , equivalent to the magnitude of voltage source 34 schematically indicated in Fig. 1. The voltage on the ordinate represented by  $V_x$  is the potential on helix 14 of Fig. 1 with respect to a reference point and corresponds to frequencies  $f_1$  and  $f_2$  as derived from the points of curves 55 and 56 representing the voltage  $V_x$ .

Fig. 4d shows a graph which plots the gain versus frequency or band-pass characteristic of the tube of Fig. 1. Fig. 7a demonstrates the broadening of the pass band which is achieved by superposition of the effects of the two dispersive curves of the graph of Fig. 4c. It may be seen that the magnitude of the gain remains substantially constant between  $f_1$  and  $f_2$  thus increasing substantially the gain-bandwidth product.

Fig. 5 illustrates a different embodiment of the cathode structure suitable for use in a backward-wave tube in accordance with this invention. A segmented, annular cathode structure 64 may be used in the traveling-wave tube of Fig. 1. Annular structure 64 may be divided into four substantially equal segments 66, 68, 70 and 72. Again each segment is electrically insulated from the others, and a potential is applied between each pair of segments. For that purpose a voltage source 74 is connected between segments 66, 68, a voltage source 76 is

connected between segments 68, 78, and a voltage source 70 is connected between segments 70, 72.

A sheet beam forming cathode is illustrated in Fig. 6. A rectangular cathode 82 may be utilized for forming a sheet beam of electrons for use in a traveling-wave magnetron tube. Rectangular cathode 82 may be divided along its length into four segments 84, 86, 88, and 90. Voltage source 74 is here connected between segments 84, 86, voltage source 76 is connected between segments 86, 88, and voltage source 78 is connected between segments 88, 90. A focusing electrode shown schematically in dotted lines at 92, is provided for forming the emitted electrons into a sheet beam. Focusing electrode 92 is segmented to correspond with the segmentation of cathode 82 and respective segments of electrode 92 are electrically connected to segments of cathode 82. An accelerating anode 94, also shown in dotted lines, is provided for accelerating the electron sheet beam toward a magnetron slow-wave structure indicated schematically by dotted lines at 96.

The graphs of Figs. 7a and 7b illustrate, respectively, the dispersive characteristics and the band-pass characteristic obtained when cathode structures according to Figs. 5 or 6 are utilized in a backward-wave tube. The graph of Fig. 7a, which plots electron velocity or accelerating voltage along the ordinate and microwave frequency along the abscissa, illustrates the dispersion characteristics for such a backward-wave traveling-wave tube. In Fig. 7a, four curves 55, 56, 57, and 59 are respectively separated vertically by voltages  $V_1$  equivalent to the magnitude of voltage source 74,  $V_2$  which is equivalent to the magnitude of voltage source 76, and  $V_3$  which is equivalent to the magnitude of voltage source 78. The point on the ordinate indicated at  $V_x$  represents the D.C. voltage on a single-helix, for example helix 14 of Fig. 1. A horizontal line corresponding to this voltage,  $V_x$ , intersects four points on the curves 55, 56, 57, 59 thus determining four respective frequencies  $f_1, f_2, f_3, f_4$  of microwave energy which may be amplified by backward-wave amplification.

The graph of Fig. 7b which is associated with graph of Fig. 7a and which has the same abscissa while plotting gain on its ordinate illustrates the resultant very broad band-pass characteristic of the backward-wave amplifier utilizing cathode structure 64 of Fig. 5 or cathode structure 82 of Fig. 6.

The present invention provides a method of increasing bandwidth of all types of backward-wave or other dispersive amplifiers without appreciable sacrifice in gain; that is, the gain-bandwidth product of these amplifiers may be considerably increased according to the invention.

There are at present two classes of backward-wave amplifiers, the simple single-helix amplifier represented by the circuit of Fig. 3a and the cascaded, two-helix backward-wave amplifier demonstrated by analogy by the circuit of Fig. 3b. The bandwidth of a prior art single-helix amplifier is determined by the electromagnetic coupling between the helix and the electron beam and by the length of the helix in electronic wavelengths. Therefore once a design is fixed, the bandwidth at a given gain is also essentially fixed, and this bandwidth is too small for many desirable applications. It is extremely desirable therefore to increase the gain-bandwidth product of the single-helix backward-wave amplifier beyond the maximum value obtainable with prior art devices.

The gain-bandwidth product of a conventional cascaded backward-wave amplifier is somewhat greater than that of a conventional single-helix backward wave amplifier and may further be slightly increased by stagger-tuning the input helix and output helix. This may be done either by applying a D.C. potential difference between the cascaded helices, or by using helices having the same dispersion curve in free space, or alternatively by loading them differently with dielectric, or by designing each helix

to have a slightly different dispersion curve. The cascaded backward-wave amplifier may be compared to the series double-tuned circuit shown in Fig. 3b. When a single cathode is used and the helices are stagger-tuned, the gain bandwidth product can be increased slightly at first but after this initial small increase the overall gain drops very rapidly as the circuits are de-tuned, that is, the primary effect as shown by the graph of Fig. 4b is to increase bandwidth but at the expense of gain.

In accordance with the present invention two or more electron beams having slightly different velocities are employed in the same backward-wave amplifier tube. This is feasible and practical because the operation of backward-wave amplifiers is not primarily limited by current, that is, they are essentially low-current devices. It is therefore possible to design such a tube so that the design gain is obtained with a beam of one-half or one-fourth of the cross-sectional area available for the total beam within the helix. The remainder of the available cross-sectional area may then be used in accordance with this invention to provide another beam of electrons having a different velocity by utilizing two cathodes having applied thereto slightly different potentials.

As an example of the operation of such a backward-wave tube in accordance with the present invention consider the graphs of Figs. 4c, 4d, which will be used in describing the operation of a backward wave amplifier as shown in Fig. 1. The single helix 14 of backward wave amplifier 10 is supplied with a D.C. voltage of  $V_x$  with respect to a reference voltage. Separate segments of the cathode, two in this example, are supplied with a potential difference represented by  $V_1$ , the vertical distance between dispersion curves 55 and 56. The electrons passing through helix 14 then have two velocities corresponding to two bands of frequencies of microwave energy respectively centered about  $f_1$  and  $f_2$  which may be amplified as backward waves. Then as shown on the graph of Fig. 4b the pass band is essentially at the maximum gain value shown at  $G_x$  on the ordinate across the entire band between frequencies  $f_1$  and  $f_2$ .

The same multi-velocity electron beam producing cathode structures may be used with a cascaded two-helix backward-wave amplifier. Such an embodiment of the invention is illustrated in Fig. 8. In this example the advantages are even greater, because the input and output helices may be stagger-tuned in addition to the use of two or more beams at different velocities thus making it possible to increase bandwidth even further. Referring to schematic Fig. 8 cathode structure 26 is shown in a tube utilizing two helices 36 and 40 disposed in cascade along the multi-velocity electron stream. Accelerating anode 30 is again shown. The input helix 36 contiguously surrounds the first portion of the electron stream and is terminated in a conventional manner by resistance 38 which may be a dissipative load of the type in which a lossy material is sprayed onto the end of the helix. The output helix 40 is disposed in axial alignment with helix 36 adjacent the collector end of the traveling-wave tube and is likewise terminated in a conventional manner by a resistive load 42. A drift tube 44 separates and isolates helix 36 from helix 40. A voltage source 46 is connected through appropriate isolating resistors 41 and 43 between the two helices to provide a D.C. potential difference for stagger-tuning them in a manner so that electrons which traverse helix 36 with a given velocity will be accelerated to a different velocity when they traverse helix 40. Potential source 34 again is shown applied across the gap between the two segments of cathode structure 26. Collector 18 and other sources of potentials shown schematically complete the schematic presentation of the cascaded backward-wave amplifier. The schematic circuit shown in Fig. 3d is electrically analogous to the traveling-wave tube illustrated in Fig. 8. The circuit consists of two serially disposed pair of tuned circuits arranged in parallel thus

providing four tuning parameters. The fact that four tuning parameters are provided does not, however, complicate tuning, because there is no reciprocity or interdependence between parameters.

There has thus been disclosed an improved backward-wave amplifier with a greatly increased gain-bandwidth product. Several embodiments of the invention have been set forth by way of example.

What is claimed is:

1. A broadband dispersive traveling-wave amplifier tube adapted for propagating electromagnetic waves therethrough along a slow-wave structure and for effecting an interchange of energy between beams of electrons and the electromagnetic waves, said tube comprising: an electron emitter adapted to emit separate electron beams such that each beam contains substantially equal numbers of electrons, the electrons of each beam having a discretely different velocity within a predetermined velocity range, with a magnitude of current at each velocity which is less than sufficient to cause undesired oscillations, whereby due to the dispersive characteristic of the tube the bandwidth of the tube is determined by said predetermined electron velocity range without causing instability in the operation of said tube as an amplifier; an electron collector; means for projecting the electrons of each of said beams along a path between said emitter and collector; and a slow-wave structure disposed along and enclosing a portion of said path in energy exchange relation with said electron beams said slow-wave structure comprising a plurality of cascaded helices each maintained at a different direct current potential with respect to said emitter, the combination of said separate electron beams and said plurality of helices providing at least four substantially independent tuning parameters whereby the gain bandwidth product of said amplifier tube has a relatively large magnitude.

2. In a broadband dispersive traveling-wave tube having a cascaded helices type of dispersive slow-wave structure the separate helices of which being maintained at different direct-current potentials with respect to a predetermined reference potential, an electron gun for emitting a multivelocity stream of electrons, said electron gun comprising: an emissive conductive surface and a voltage source, said conductive surface being divided into at least two mutually insulated segments, one of said segments being maintained at said reference potential, portions of said voltage source being connected between pairs of said segments, whereby electrons are emitted at discretely different velocities in accordance with the difference in potential between said segments of said emissive surface with a magnitude of current at each velocity which is less than the start oscillation current for undesired oscillations so that the gain bandwidth product of said dispersive traveling-wave amplifier tube may be increased without causing instability in the operation of said tube as an amplifier.

3. A broadband dispersive traveling-wave tube comprising: a slow-wave structure comprising a plurality of cascaded helices, individual ones of which being maintained at different direct-current potentials with respect to the others; a collector electrode; an electron gun of the character adapted to emit a multivelocity stream of electrons toward said slow-wave structure, said electron gun comprising: electron accelerating means adapted to be maintained at a predetermined accelerating potential, electron focusing means, a voltage source, a segmented cathode, individual segments of said cathode being coupled to said voltage source so that different segments are at discretely different potentials with respect to said accelerating potential, whereby electrons in the multivelocity stream have different velocities determined by said voltage source, with a magnitude of current at each velocity which is less than sufficient to cause undesired oscillation thereby providing in the dispersive tube a broad frequency band of operation determined by said

voltage source without causing instability in the operation of said tube as an amplifier.

4. A broadband backward-wave amplifier tube comprising: an electron emitter, an electron collector, said emitter and collector being spaced apart, said emitter including a cathode adapted to emit electrons at two different velocities, with a magnitude of current at each velocity which is less than sufficient to cause undesired oscillation, whereby due to the dispersive characteristic of the tube, the bandwidth of said tube is broadened; means for projecting said electrons along a path between said emitter and collector; two helical slow-wave structures disposed in cascade along and enclosing a portion of said path, said slow-wave structures being electrically insulated from each other; and a source of potential applied between said slow-wave structures whereby the bandwidth of said backward wave amplifier is further broadened by stagger tuning with at least four substantial-

ly independent tuning parameters without causing instability in the operation of said backward-wave tube as an amplifier.

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UNITED STATES PATENT OFFICE  
CERTIFICATE OF CORRECTION

Patent No. 2,911,558

November 3, 1959

Malcolm Roderick Currie

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

Column 4, line 1, for the numeral "78" read -- 70 --;  
line 2, for the reference numeral "70", first occurrence, read  
-- 78 --.

Signed and sealed this 23rd day of August 1960.

(SEAL)  
Attest:

KARL H. AXLINE  
Attesting Officer

ROBERT C. WATSON  
Commissioner of Patents

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