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TRAVELING-WAVE TUBE

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2 Sheets-Sheet 2

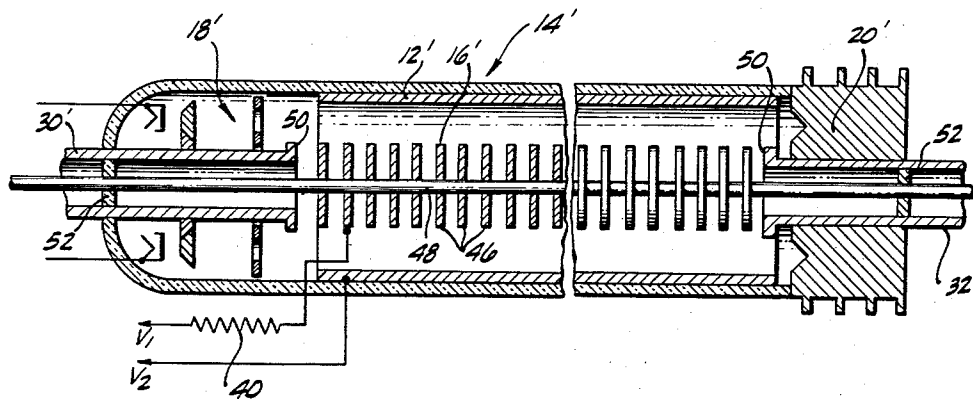


Fig. 3.

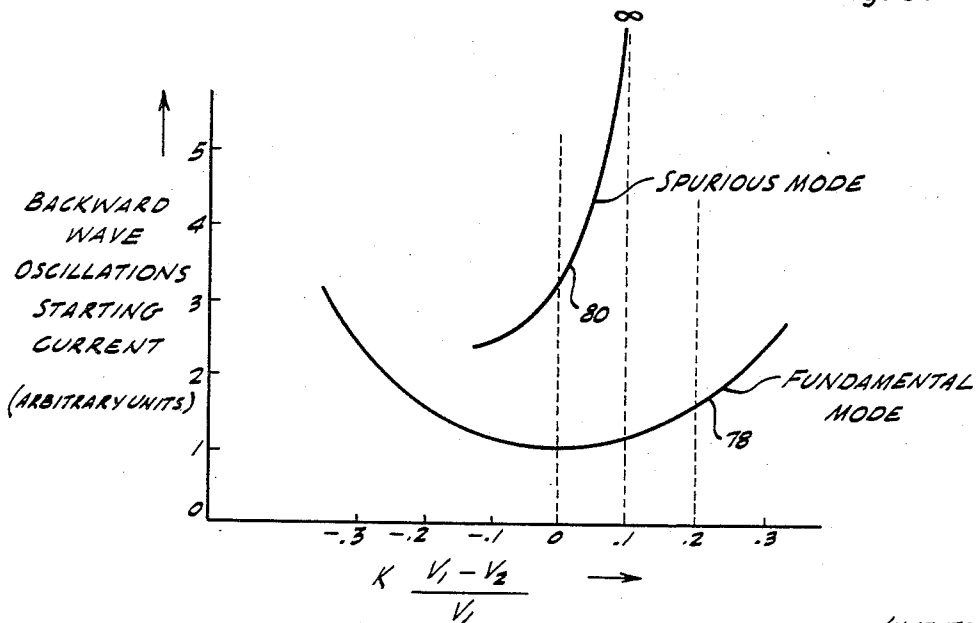


Fig. 4.

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1

2

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TRAVELING-WAVE TUBE

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2 Claims. (Cl. 315—3.5)

The present invention relates in general to traveling-wave tubes and more specifically to means for precluding spurious backward-wave oscillations in a traveling-wave tube.

Conventional traveling-wave tubes have found widespread use as microwave amplifiers because of their ability to provide useful gain over a broad bandwidth, especially when utilized as forward-wave amplifiers. Traveling-wave tubes generally comprise a slow-wave structure for propagating electromagnetic signal waves at a velocity considerably less than the velocity of light. An electron stream is then projected along the slow-wave structure in electromagnetic energy exchange relation with the traveling wave in a manner thus effectively to "push" or amplify the traveling waves.

When a traveling-wave tube is utilized as a backward wave amplifier or backward-wave oscillator, the tube is quite dispersive and is therefore a narrow-band device. That is, for a given velocity of electrons in the stream only a very narrow range of frequencies may be amplified in a backward wave, that is, a wave traveling in the direction opposite to that of the electron stream. In order that backward-wave oscillations may occur at a given frequency, a certain minimum starting current at a certain electron velocity is required.

It may be seen that when a traveling-wave tube is being utilized as a forward-wave amplifier, with the electrons in the stream traveling at a certain velocity, backward-wave oscillations may occur at the frequency determined by the dispersion characteristic for the tube as a backward-wave oscillator, provided there is a sufficient current of electrons at that certain velocity for the start-oscillation condition. Such backward-wave oscillations would be undesirable in a forward-wave amplifier.

Formerly, this backward-wave oscillation has been avoided in forward-wave amplifiers through the use of smaller helices or other circuits of low backward-wave impedance. Another method is disclosed and claimed in the copending application by Horace R. Johnson, et al., Serial No. 401,303, filed December 30, 1953, now Patent No. 2,809,321, dated October 8, 1957, entitled "Traveling-Wave Tube," and assigned to the assignee of the present application, which comprises using appropriate stop-bands for the purpose of rejecting the spurious backward-wave oscillations. The first method, viz., that of using a smaller helix, is limited to low-power tubes, since a smaller helix means a smaller inner passage or opening for the stream and hence limits the amount of total current in the electron beam. Also, special circuits can often not be utilized since they are usually quite dispersive and hence narrow-band devices. Dispersion is therefore also a problem with the latter method of utilizing stop-band circuits.

It is therefore an object of the present invention to provide a high-power traveling-wave tube which does not suffer the disadvantages of spurious backward-wave oscillations.

It is a further object to provide a backward-wave oscillator in which spurious modes of oscillation are prevented.

It is another object to provide such a traveling-wave tube without modifying the cold slow-wave structure, for example, its dispersion.

Briefly, these and other objects are achieved by providing a multi-velocity electron stream in a manner such that either fundamental mode backward-wave oscillation or highpower amplification may be produced, while at the same time having not enough stream electrons at a particular velocity to constitute the starting current required for spurious backward-wave oscillation frequencies. This velocity spread is produced by providing a steady electric field transverse to and across the electron beam. This may be done, for example, in a conventional helix type hollow beam traveling-wave tube by supporting a conducting rod along the axis of the traveling-wave tube inside of the hollow electron beam. This inner conductor is then maintained at a direct-current potential which is different from that of the surrounding helix. Various other means associated with other types of traveling-wave tubes for achieving a velocity distribution with such a transverse field are illustrated, discussed and explained in the following detailed description and drawings in which:

Fig. 1 is a sectional view of a traveling-wave tube constructed in accordance with the present invention;

Fig. 2 is a graph of the dispersion characteristic of the traveling-wave tube plotting velocity of electrons on the ordinate with microwave frequency on the abscissa; also shown is the beam current distribution versus velocity;

Fig. 3 is a sectional view of an alternative embodiment of the present invention; and

Fig. 4 is a plot of starting current on the ordinate versus velocity spread of the electron stream on the abscissa.

Referring with more particularity to the drawings for purposes of description and operation of the present invention, Fig. 1 illustrates an embodiment in which the transverse electric field across the electron stream is achieved in a radially symmetrical configuration. To this end a dielectric rod 10 with a conductive coating 12 is supported along the axis of a traveling-wave tube 14. The electrical potential of conductive coating 12 is maintained differently from and, in the case of a backward-wave device, more positive than that of a conductive helical slow-wave structure 16; in a forward-wave device the sense of the transverse field may be reversed. A hollow cylindrical electron beam produced by electron gun 18 is caused to pass through the cylindrical annular space between rod 10 and slow-wave structure 16, across which is maintained a steady direct-current potential. The electron stream is collected by a collector electrode 20 which is appropriately designed to effectively dissipate the kinetic energy of the stream electrons.

Electron gun 18 comprises an annular emitting cathode 22, a beam-forming electrode 24, a first accelerating electrode 26 and a second accelerating electrode 28. Each of the electrodes 26 and 28 have an appropriate center portion coplanarly supported with the outer electrode, as by grid wires or by a common supporting dielectric rod not shown, as is conventional in the art. Dielectric rod 10 is supported by and between the center portion of accelerating electrode 28 and collector electrode 20. A coaxial line 30 forms an input line if the tube is being operated as a forward-wave device, or may be used as an output line if operated as a backward-wave device, and is connected to the left-hand end of slow-wave structure 16, as may be coaxial line 32 to the right-hand end of slow-wave structure 16 which is an output line if the tube is a forward-wave device, or an input line if a backward-wave amplifier.

An axial magnetic field for focusing and constraining stream electrons is provided by an outer solenoid 34 energized by a battery 35. Appropriate taps on a source

of potential 36 are electrically connected to each of the various electrodes to provide operating voltages thereon. One such tap is labeled 38 and its position determines the relative potential, designated V_1 , of conductive coating 12 to which it is connected. This in turn determines the potential gradient between the conductive coating and slow-wave structure 16, the potential of which in this example is maintained at ground, designated as V_2 , through an isolating resistor 40. The potential of collector electrode 20 is maintained somewhat positive with respect to that of the conductive coating 12 or slow-wave structure 16 in order to minimize the deleterious effects of secondarily-emitted electrons therefrom.

The graph of Fig. 2 is provided for the purpose of depicting the dispersive characteristic of backward-wave oscillations associated with the traveling-wave tube of Fig. 1 when being operated as a forward-wave amplifier. Such backward-wave oscillations would be deemed spurious and undesirable when the tube is utilized as a forward-wave amplifier. The graph shows curve 43 plotting velocity of stream electrons versus the frequency of backward-wave traveling waves, the amplification of which would be effected by the indicated velocity of stream electrons in the forward direction.

The shaded area 42, limited by curve 41, independently represents the distribution of beam current electrons versus velocity which extend throughout the range of V_1 to V_2 , the potentials on conductive coating 12 and slow-wave structure 15, respectively. The distance on the distribution graph, indicated by the bracket 44, represents the starting current for backward-wave oscillations to be supported.

The diagram of Fig. 2 points out that while forward-wave amplification may be achieved by beam current electrons whose velocities are within the range from V_1 to V_2 , backward-wave oscillation is precluded because nowhere in this distribution are there sufficient electrons to constitute the required starting current for the associated frequency of backward-wave oscillations. Thus, there is provided a means for high-power amplification without backward-wave oscillation because a large magnitude of integrated stream current could be used without having sufficient electrons to constitute the starting current required for backward-wave oscillations.

Fig. 3 illustrates an embodiment of the present invention which may be considered the conjugate of the arrangement shown in Fig. 1 in that a slow-wave structure 16' lies along the axis of a traveling-wave tube 14', while a concentric tubular conductor 12' lies outside thereof with an annular cylindrical space in between through which may be projected a hollow beam of electrons generated by an electron gun 18'. The outer conductor 12' may be any nonmagnetic conductor or coating adaptable to achieve the function of providing a steady direct-current potential across the hollow electron beam. Slow-wave structure 16' is of a character well known in the art and is described for example in Patent No. 2,645,737, entitled "Traveling-Wave Tube," issued to L. M. Field on July 14, 1953. Conductive fins or discs 46 are substantially evenly spaced along an axial central conductor 48 which is functionally an extension of the inner conductor of coaxial feed lines 30' and 32'. The outer conductor of these feed lines is similarly extended into traveling-wave tube 14' with flared ends 50 which aid in achieving a suitable impedance match between coaxial line and slow-wave structure. Electro-magnetically transparent windows 52 permit the desired pressure differential between the evacuated interior of traveling-wave tube 14' and what might be, for example, atmospheric pressure outside thereof.

Referring now to the graph of Fig. 4, there is shown a plot of backward-wave oscillations starting current in arbitrary units versus velocity spread in the electron beam along the abscissa expressed as a ratio which is proportional to

$$\frac{V_1 - V_2}{V_1}$$

It has been found, when a backward-wave oscillator operating in its fundamental mode as represented by a position on curve 78 is provided with a transverse, time-constant or steady electric field across the electron beam, that the fundamental mode of oscillation is affected in a quite different way than are the higher order, spurious modes, the first and most troublesome of which is represented by the curve 80.

As may be seen from the graph of Fig. 4 which represents the operation of a backward-wave oscillator constructed substantially in accordance with Fig. 1 where V_1 is the voltage on the inner conducting rod and V_2 is the voltage on the helix, when V_1 is positive with respect to V_2 such that the tube is operating somewhat to the right of "0" of the abscissa, for example, near the point ".1," the starting current for the fundamental mode is increased relatively little from its value given by curve 78 at the point "0" where V_1 equals V_2 . On the other hand, it may be seen from curve 80 that the starting current for the spurious mode approaches infinity.

Typical empirical data follow below for a backward-wave oscillator constructed in accordance with Fig. 1 and operating near the point ".1" to the right of "0" in Fig. 4 where the inner conducting rod is constructed of ceramic coated with silver and is maintained at a potential positive with respect to the outer conducting helix. The electric field between the inner rod and the outer helix is approximately 1000 volts per inch; V_1 is of the order of 2000 volts positive with respect to the cathode; the beam current is in the range of 10 to 12 milliamperes; the frequency of operation is in the region of 3400 to 3500 megacycles; the axial constraining magnetic field is 1000 gauss; and the starting current for the spurious mode is infinity.

The inner conductive rod is readily placed sufficiently radially distant from the helix such as not to interfere with propagation therealong of microwaves, the fields of which are concentrated radially close to the helix. That such a transverse steady field gives rise to a velocity spread in the longitudinally traveling electrons may be seen by visualizing the resultant gradient across which the electron stream is spread. Those electrons radially nearer to the more positive cylinder will necessarily have more energy and hence be traveling faster than those in the more negative portions of the gradient. The transverse component of velocity given to the electrons by this field is a second order effect which actually aids in constraining the electrons against their tendency to defocus by repulsive space charge spreading effects.

There have thus been disclosed traveling-wave tubes which, when operated as forward-wave amplifiers or as backward-wave amplifiers or oscillators, may utilize a considerably increased magnitude of current in the electron stream without giving rise to undesired backward-wave oscillations. A valuable advantage in such traveling-wave tubes is that greater amplification and greater output signals may be achieved without interference from spurious backward waves and without the need for special attenuators and the like for absorbing undesired backward-wave oscillations causing insertion loss and cooling problems.

A further advantage of the present invention is that the claimed arrangement does not disturb the operation or characteristics of the cold circuit since, for example, in the case of Fig. 1 the inner conductive rod is in the region such that it does not interfere directly with waves propagated along the outer helix.

A still further advantage is that the inner conducting rod may be utilized to aid in the focusing of the electron stream along its length.

What is claimed is:

1. A backward-wave oscillator traveling-wave tube for generating signals in a predetermined, fundamental

5

mode of oscillation comprising: a conductive helix for the propagation of electromagnetic wave energy at a velocity substantially less than the velocity of light; an electron gun for producing a hollow stream of electrons projected contiguously within and in energy exchange relationship with said helix; output means coupled to the electron gun end of said helix; an elongated dielectric rod coated substantially over its length with a resistive layer and being disposed within said hollow electron stream coincident with the axis of said traveling-wave tube whereby said hollow electron stream flows between said elongated rod and said helix; means for providing a magnetic field substantially parallel to said axis for focusing said stream; and means for maintaining the resistive layer on said dielectric rod at a steady direct current potential which is positive with respect to said helix whereby a transverse direct current electric field is maintained between said helix and said rod across said hollow electron stream in a manner such that said hollow electron stream suffers a velocity spread in a manner to preclude spurious backward-wave oscillations in said backward-wave oscillator traveling-wave tube, said transverse direct current electric field being in the range of magnitude to not appreciably increase the magnitude of oscillation starting current for said fundamental mode.

2. A backward-wave oscillator traveling-wave tube for generating signals in a predetermined, fundamental mode of oscillation comprising: an electron gun; a helix for propagating high frequency electromagnetic energy at an axial velocity substantially less than that of light and having output means at its electron gun end and being maintained at a direct current potential of V_2 ; a coaxial, substantially coextensive dielectric rod having a resistive, nonpropagating layer on the outer surface

6

thereof and disposed within and radially spaced symmetrically from said helix and maintained at a direct current potential of V_1 where V_1 is positive with respect to V_2 to provide a radial potential gradient and an electric field of the order of 1000 volts per inch between said helix and said rod; means for providing a hollow electron stream projected coaxially along the length of the tube, electrons of said beam having a distribution of radial displacement between said helix and said rod in the direction of said gradient, those electrons passing nearer to said rod being in a region of higher potential and traveling at a higher velocity than those electrons nearer to said helix thereby providing a velocity spread in said electron stream in accordance with said voltage gradient, said velocity spread being of a magnitude to not appreciably increase the magnitude of required starting current for said fundamental mode but to make prohibitively large the starting current for a spurious mode of backward-wave oscillation; and means for providing a strong axial magnetic field for constraining said hollow electron stream to a substantially rectilinear flow along the length of said helix.

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