Dec. 18, 1962 J. F. SKOWRON ETAL 3,069,588

TRAVELING WAVE TUBES

Filed Sept. 26, 1958

FIG. 1

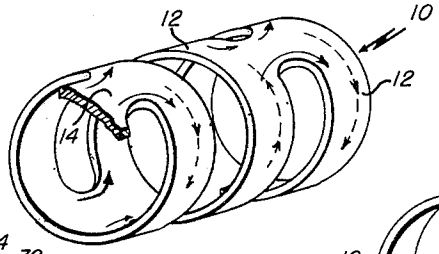


FIG. 3

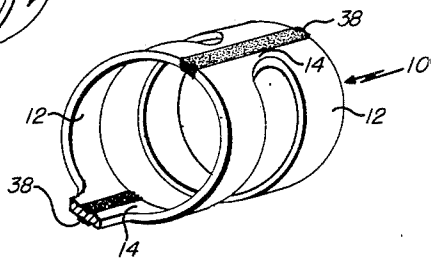
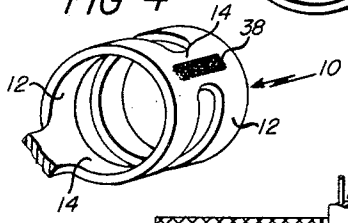


FIG 4



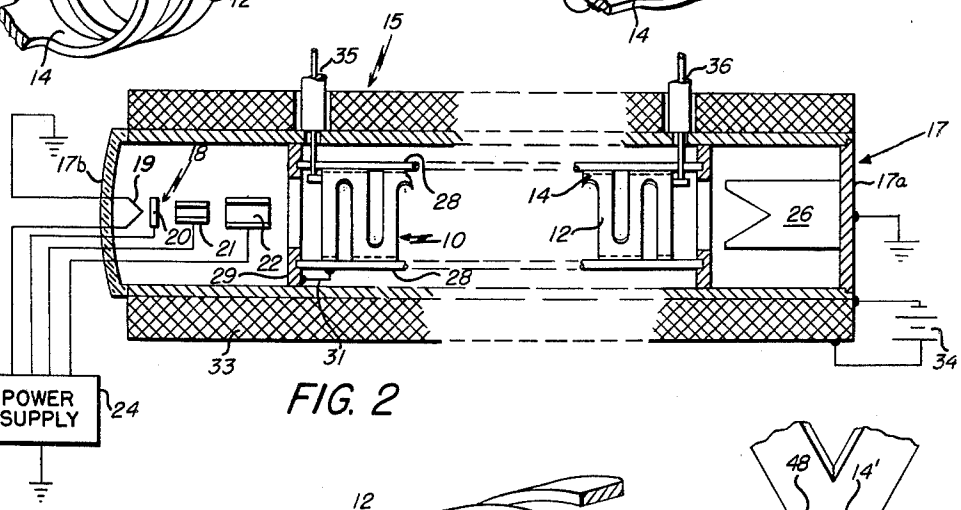
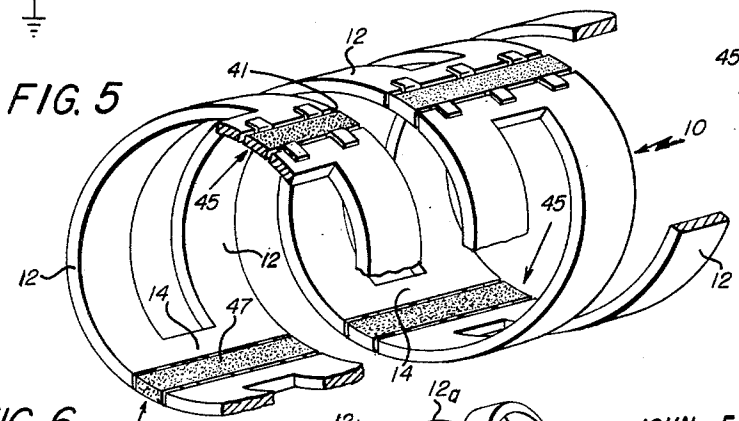


FIG. 2

FIG. 5



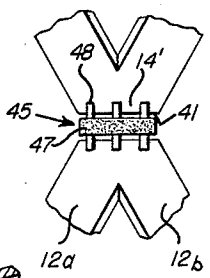


FIG. 8

FIG. 6

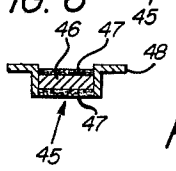
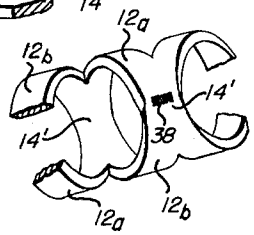


FIG. 7



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TRAVELING WAVE TUBES

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This invention relates to a traveling wave electron discharge device having a contra-wound helical slow wave propagating structure, or a modified form thereof, which is designed to suppress the undesirable ring mode of oscillation often prevalent in such devices.

Traveling wave amplifiers, particularly those capable of handling high power, sometimes utilize a contra-wound helix, or its approximate equivalent, a ring-bar delay structure, consisting of several rings, adjacent ones of which are joined together by a strip or bar. Delay structures of the contra-wound helix type are characterized by higher impedance in the forward wave fundamental and lower impedance in the space harmonics than for a single helix. Such delay structures, unfortunately, are characterized by a propagating mode in addition to the usual helix modes normally used for amplification. This undesirable mode, referred to as the ring mode, has a field pattern consisting of a phase shift of 360° around the circumference of the helix, that is, the circumference of the helix is equal to one wave length for the ring mode. This ring mode produces strong oscillations that prevent normal traveling wave tube amplification. This type of interference to amplification is especially prevalent in tubes operating at relatively high power and gain, where the beam current is large and the beam is located close to the helix in order to achieve maximum coupling between the helix and the beam. Since the phase velocity of the ring mode may be of the order of magnitude of the phase velocity of the normal amplifying mode, strong coupling may exist between the ring mode and the electron beam, and the ring mode, consequently, is readily excited.

The ring mode is derived theoretically from a helix having zero pitch angle, which is equivalent to a series of disconnected rings resonating at a natural frequency equal to the ratio of the velocity of light to the product of 2π and the radius of the rings. The physical orientation of the ring mode in such a case is determined by the source of excitation. In the practical ring-bar helix, however, the cross-over or bar fixes the orientation so that a definite relation exists between the fields around adjacent rings. The plane of symmetry of such a structure passes through the center lines of each of the bars. A first set of alternate bars is disposed colinearly while the other set of alternate bars is disposed colinearly and diametrically opposite the first set of bars. Consequently, high current points occur in the region of the bars and high voltage points at regions 90° displaced from the bars. Moreover, the directions of the ring mode currents is across the bar, as contrasted with the regular helix mode current, which is along the bar. If the bar is slotted in a longitudinal direction, the currents associated with the ring mode may be perturbed, without concurrently perturbing the currents associated with the usual helix mode. The disruption of the ring mode, however, does not eliminate the ring mode, but merely shifts its frequency, owing to the capacitance presented by the slots at the high frequency involved. The ring mode also occurs in the basic contra-wound helix delay structure and may be shifted, but not eliminated, by slotting, just as in the case of the ring-bar structure.

In accordance with one embodiment of the invention, a much more effective method of suppressing the undesired

ring mode involves placing resistors across the slots. Selective attenuation of the ring mode then occurs, whereby the Q of the ring mode may be reduced to the point where the ring mode cannot sustain itself in oscillation. The resistors have negligible effect upon the fundamental helix mode, since the currents associated therewith travel along the length of the bars on either side of the resistor-filled slots. The resistors do not absorb appreciable power from the fundamental amplifying mode, since little, if any, currents from this mode pass through the resistors. Resistors in this position do not absorb power from the ring mode because oscillation is prevented.

Also in accordance with the invention, ring mode suppression may be accomplished in a contra-wound helix or ring-bar structure which is not slotted. The resistance in such a case may be in the form of a strip or layer of resistive material whose thickness is greater than the skin depth for the frequency involved; this resistive material, in the case of the contra-wound helix, may be positioned in the region of the crossover region of the two helices, or, in the case of the ring-bar structure, may be deposited on one or more surfaces of the ring bar structure in the region of the bar. More specifically, the resistive material should be placed as close as possible to the plane of symmetry of the delay lines which, in the case of the contra-wound helix, passes through each of the crossover regions of the two helices, and, in the case of the ring-bar structure, passes through each of the bars of the structure at the center line of said bars.

The novel features of the invention, together with further objects and advantages thereof, will be more fully comprehended from the following description considered in connection with the accompanying drawing, wherein:

FIG. 1 is a pictorial view of a portion of a ring-bar type of slow wave propagating structure, illustrating the current distribution for the fundamental mode and the ring mode;

FIG. 2 is a cross-sectional view of a traveling wave tube incorporating a slow wave propagating structure according to the invention;

FIGS. 3 and 4 are pictorial views of a portion of a slow wave propagating structure which may be used in the tube of FIG. 2;

FIG. 5 is a pictorial view of a portion of another type of slow wave propagating structure which may be used in the tube of FIG. 2;

FIG. 6 is a detail view showing one of the resistive elements used in the slow wave propagating structure of FIG. 5;

FIG. 7 is a detail view of a portion of a contra-wound helix incorporating the principles of the invention; and

FIG. 8 is a detail view of a portion of a ring-bar structure incorporating the principles of the invention.

Referring to FIG. 1 of the drawing, a portion of a ring-bar slow wave propagating structure 10 is shown. Such a delay structure includes a plurality of rings 12, adjacent ones of which are interconnected by bars 14 alternately disposed at diametrically opposite points along the rings. The fundamental mode of propagation along delay structure 10 is characterized by a current which travels in a direction indicated by the solid arrows in FIG. 1. This current travels around a half of each ring, thence along the length of a bar, around half of the next ring, etc. This current splits into two paths, some traveling about one-half of a given ring and the remainder traveling about the other half of the ring. The current in the two paths meets at a bar and flows along the length of the bar in the same direction. The current associated with the ring mode of oscillation follows a path as indicated in FIG. 1 by the detached arrows. This current follows paths around the entire periphery of each

ring, with the direction of the current being reversed in alternate rings. It has been found that, even if the bars 14 of the structure 10 of FIG. 1 were slotted so as to provide a discontinuity in the ring mode current path, there would still be some R.F. circulating currents associated with the ring mode, owing, for example, to the capacity between the portions of the structure on opposite sides of the slot. The practical effect of introducing slots in this structure merely is to tune the ring mode to a higher frequency than that which would be obtained with the solid structure shown in FIG. 1.

Referring now to FIGS. 2 and 3, a traveling wave tube 15 is shown which includes a cylindrical evacuated envelope 17 which may consist of a major portion 17*a* made of an electrically-conductive material and one end portion 17*b* made of glass or similar electrically insulating material. An electron gun 18 is positioned within the envelope 17 adjacent one end of the traveling wave tube 15 and may be of a type commonly used in traveling wave tubes. The electron gun 18 shown in FIG. 2 includes a heater 19, a cathode 20 associated therewith, a cylindrical focussing electrode 21 and an accelerating electrode 22. The various electrodes of the electron gun 18 are connected to an appropriate power supply 24, whereby an electron beam is produced and directed along the longitudinal axis of the traveling wave tube toward a collector electrode 26 mounted within the tube envelope at or adjacent the end of the tube remote from the electron gun. The leads connecting the electron gun electrodes to the external power supply 24 may be brought out through the glass portion 17*b* of the tube envelope. The entire envelope 17, of course, may be made of metal and the power supply leads brought out through electrically insulating bushings in the end of the tube envelope adjacent the electron gun. The electron gun electrodes are supported by structural means which have been omitted from the drawing for the sake of simplicity and clarity. The velocity of the electron beam is dependent upon the potentials on the various electrodes of the electron gun.

The slow wave propagating structure 10 is supported along the longitudinal axis of the tube 15 between the electron gun 18 and the collector 26 by means of electrically insulating rods 28 which may be made, for example, of glass or ceramic. These rods, in turn, are supported from the tube envelope 17 by means of transverse discoidal members 29 having recesses into which the ends of rods 28 may be inserted. The delay structure 10 is maintained at a positive potential relative to the cathode 20 by means of a lead 31 connecting a porton of the delay structure 10 to the discoidal member 29, which member is electrically connected to the grounded envelope 17. It should be understood that the tube envelope 17 need not be at ground potential; it is necessary only that the slow wave structure 10 be maintained at the proper positive potential relative to the cathode.

Transverse motion of electrons is kept within reasonable grounds by means of the longitudinal magnetic field produced by the cylindrical coil 33 surrounding tube envelope 17 and energized by a unidirectional voltage source 34. Input energy may be supplied to the slow wave structure 10 by means of a coaxial means 35 whose inner conductor is attached to the slow wave structure 10 at or adjacent one end thereof. Output energy is removed from the tube 15 by means of a coaxial output coupling means 36 whose inner conductor is connected to the slow wave structure 10 at or adjacent the other end.

The details of the slow wave structure 10 of the tube 15 are shown in FIG. 3 and include a ring-bar circuit comprising a plurality of rings 12 and bars 14, each bar interconnecting two adjacent rings alternately at points along the rings which are displaced 180°. This structure is symmetrical about a plane passing diametrically through said structure and passing through the center lines of said base.

In order to suppress the undesired ring mode, resistive strips 38 are applied to the surfaces of the slow wave structure 10 of tube 15 adjacent the plane of symmetry of structure 10, in the manner indicated in FIG. 3. The thickness of the strips preferably is at least equal to the depth of current penetration, or skin depth, for the frequency of the ring mode oscillation. The skin depth δ to which the current density is $1/e$ of its value at the surface may be given by the equation

$$\delta = \sqrt{\frac{\rho\mu}{Kf}}$$

where

ρ is the resistivity of the material
μ is its permeability
f is the frequency involved, and
K is a constant.

If the thickness of the resistive strip 38 is too thin, its effectiveness in lowering the Q of the slow wave structure for the ring mode would be decreased, since some of the circulating currents would be able to travel beneath the resistive strip.

Each resistive element 38 is disposed adjacent the plane of symmetry of the slow wave structure 10 and, in addition to passing along a bar 14, may span two adjacent rings 12 in the region coextensive with the interconnecting bar. The resistive material making up each resistive element may be applied to both sides and ends of the corresponding portion of the slow wave structure, as illustrated in FIG. 3. In many cases, however, it is not essential that the strips 38 be in the form of continuous loops. Indeed, it is possible, particularly at low power levels, to damp out the ring mode with a strip which does not span two rings and which is of lesser length than that of a bar. This arrangement is shown in FIG. 4.

Although the resistive element 38 is shown in FIGS. 3 and 4 as a more or less elongated rectangular strip, the element need not be limited to this configuration. It has been found that the resistive element is more effective if positioned at or adjacent the plane of symmetry of the delay structure, since the current peaks in the desired mode occur at the plane of symmetry, that is at positions which are displaced 180° at or near the center line of the various bars 14. The resistive element may be skewed slightly with respect to the center line of each bar without causing substantial degradation of selective cancellation of the ring mode. As the resistive material is located farther from the plane of symmetry, more of the current in the main mode flows through the resistive material and the main mode becomes more damped. Even with somewhat increased damping of the main mode, however, selectivity against the undesired ring mode continues quite high over a considerable range of size of the resistive element. If the resistive material were to be located on the entire surface of each ring, however, the main mode obviously would be damped unduly. For this reason, a limit is placed on the amount of resistive material that can be used in practice. In most cases a resistive strip located within the confines of each bar is adequate for suppressing the ring mode oscillation. The amount of resistive material applied to the slow wave structure 10 is dependent upon the power level. As the tube power increases, more damping obviously will be required, that is, the size of the resistive element 38 would have to be increased. In some cases, the resistive material may extend over the entire bar and over a portion of the adjoining rings.

Another arrangement for damping out the ring mode of oscillation is indicated in FIGS. 5 and 6. The delay structure 10 of FIG. 5, which may be substituted in the tube of FIG. 2 for the delay structure shown in FIGS. 3 and 4, the bar 14 and the portions of two adjacent rings 12 in alignment with said bar are slotted. The slots 41 extend in a longitudinal direction, and, although indicated

in FIG. 5 as spanning two adjacent rings 12, the slots may, in certain cases, be of shorter length, depending upon the amount of damping necessary for the particular tube to suppress adequately ring mode oscillation. In each slot 41 a resistor assembly 45 is inserted. This assembly, for example, may include a ceramic body 46 coated on at least one of two opposed surfaces with a resistive material 47, such as carbon or powdered iron suspended in an electrically insulating binder. Two edges of the body 46 are metallized and have attached thereto one or more metal lugs 48 bent in such a manner as to permit one end thereof to be fixedly mounted, as by brazing, to delay structure 10. Either or both of the opposed surfaces may be coated with resistive material, depending upon the amount of damping required for the particular tube. Although the resistor assemblies 45 are shown at the same length as the corresponding slot 41, these resistor assemblies need not be of the same length as the slot in all applications. The size of the resistor assembly 45, like that of the resistive strips 38 in the delay structure 10 of FIGS. 3 and 4, is dictated by the characteristics of the particular tube, in the manner already pointed out.

Although the invention described in FIGS. 1 to 6 illustrates a modified contra-wound helix, namely, a ring-bar structure, the invention also is applicable to a contra-wound helix. A portion of a contra-wound helical delay structure 10 is shown in FIG. 7; this delay structure may replace the ring-bar structure shown in the tube 15 of FIG. 2. The delay structure 10 of FIG. 7 comprises a pair of oppositely wound helices 12*a* and 12*b* which are electrically connected at the cross-over region 14'. A resistive element 38, such as described in FIG. 4 is positioned in the region 14', as shown in FIG. 7, so as to selectively attenuate the ring mode without appreciably perturbing the normal mode. The crossover region 14' of FIG. 7 corresponds to the bar portion 14 of the ring-bar structure 10 of FIGS. 1 to 5. As in the case of the ring-bar structure 10, the resistive element 38 preferably is disposed in the vicinity of the plane of symmetry of the structure which passes through each of the cross-over regions 14' of the structure. The same considerations regarding the effect of departures of the resistive element from the plane of symmetry apply as in the case of the ring bar structure already referred to. The type of construction shown in FIGS. 5 and 6 may be incorporated into a slotted contra-wound helix 10, as shown in FIG. 8.

This invention is not limited to the particular details of construction, materials and processes described, as many equivalents will suggest themselves to those skilled in the art. For example, although the resistive elements 38 are shown as resistive films in the drawing, the resistive elements 38 may be thin solid members of resistive material, either affixed to the surface of the delay structure 10 or imbedded in recesses in the delay structure 10. Moreover, the delay structure 10 could be made of a resistive material in the region where the resistive elements 38 are shown in the drawing. Similarly, the resistive elements 45 need not be in the form of a resistive film coated on ceramic but may be thin solid members. 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. In combination, a traveling wave tube comprising a slow wave structure including a plurality of spaced rings and a bar interconnecting each adjacent pair of rings, each bar extending adjacent the plane of symmetry of said structure, said structure as above defined being subject to operation in an undesired mode of oscillation having associated therewith currents circulating about said rings, each of said bars and a portion of each ring aligned with said bar containing a slot, and resistive means inserted within each of said slots, said resistive means each comprising a ceramic block having two opposed surfaces metallized and connected between opposite edges of said slot, said ceramic block further having at least one remaining surface coated with a resistive material for introducing a resistance between opposite edges of said slot.

2. In combination, a traveling wave tube comprising a slow wave structure including a pair of oppositely wound helical conductors interconnected at crossover regions disposed adjacent the plane of symmetry of said structure, said structure as above defined being subject to operation in an undesired mode of oscillation having associated therewith currents circulating about said structure, a portion of said structure at said crossover region containing slots disposed substantially along said plane of symmetry of said structure, resistive means inserted within each of said slots, said resistive means each comprising a ceramic block having two opposed surfaces metallized and connected between opposite edges of said slotted structure, said ceramic block further having at least one remaining surface coated with a resistive material for introducing a resistance between opposite edges of said slotted structure.

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