Dec. 27, 1960 E. R. SCHMIDT ET AL 2,966,610

ELECTRON BEAM TUBE

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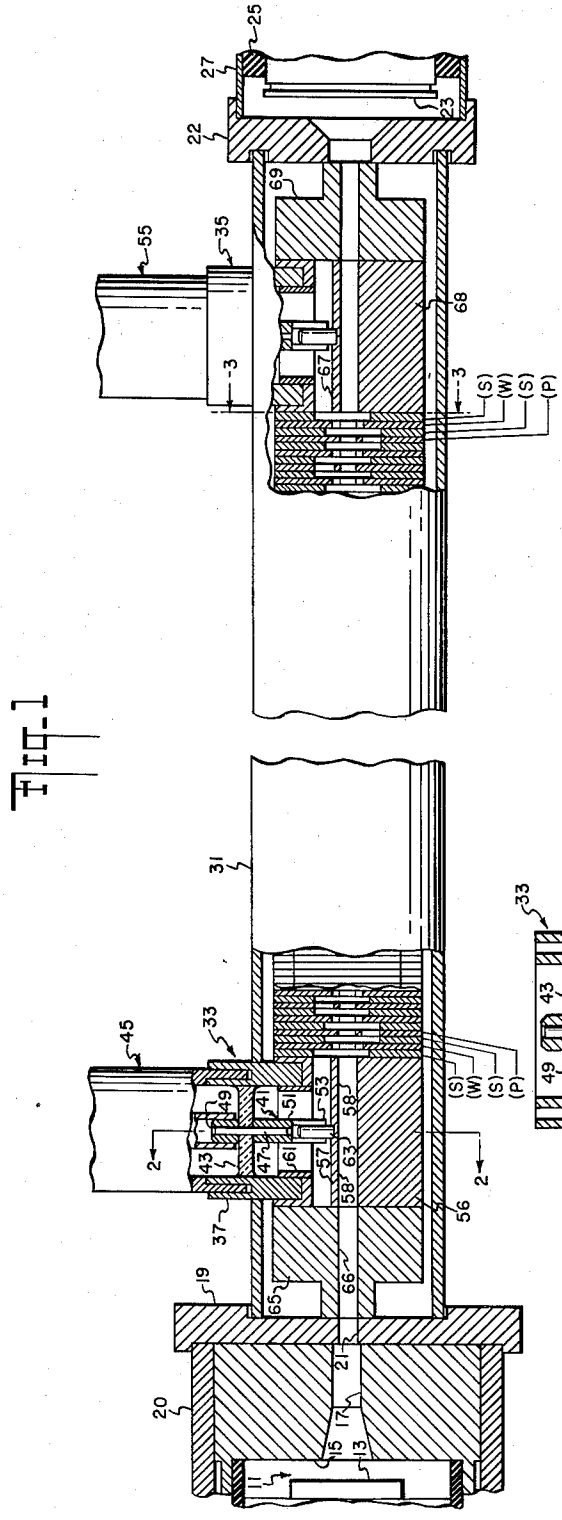


FIG. 1

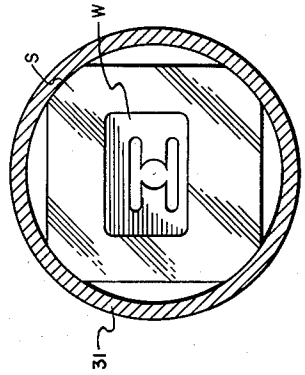


FIG. 3

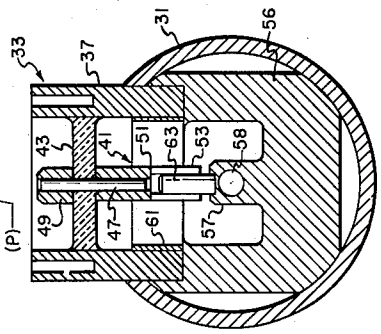


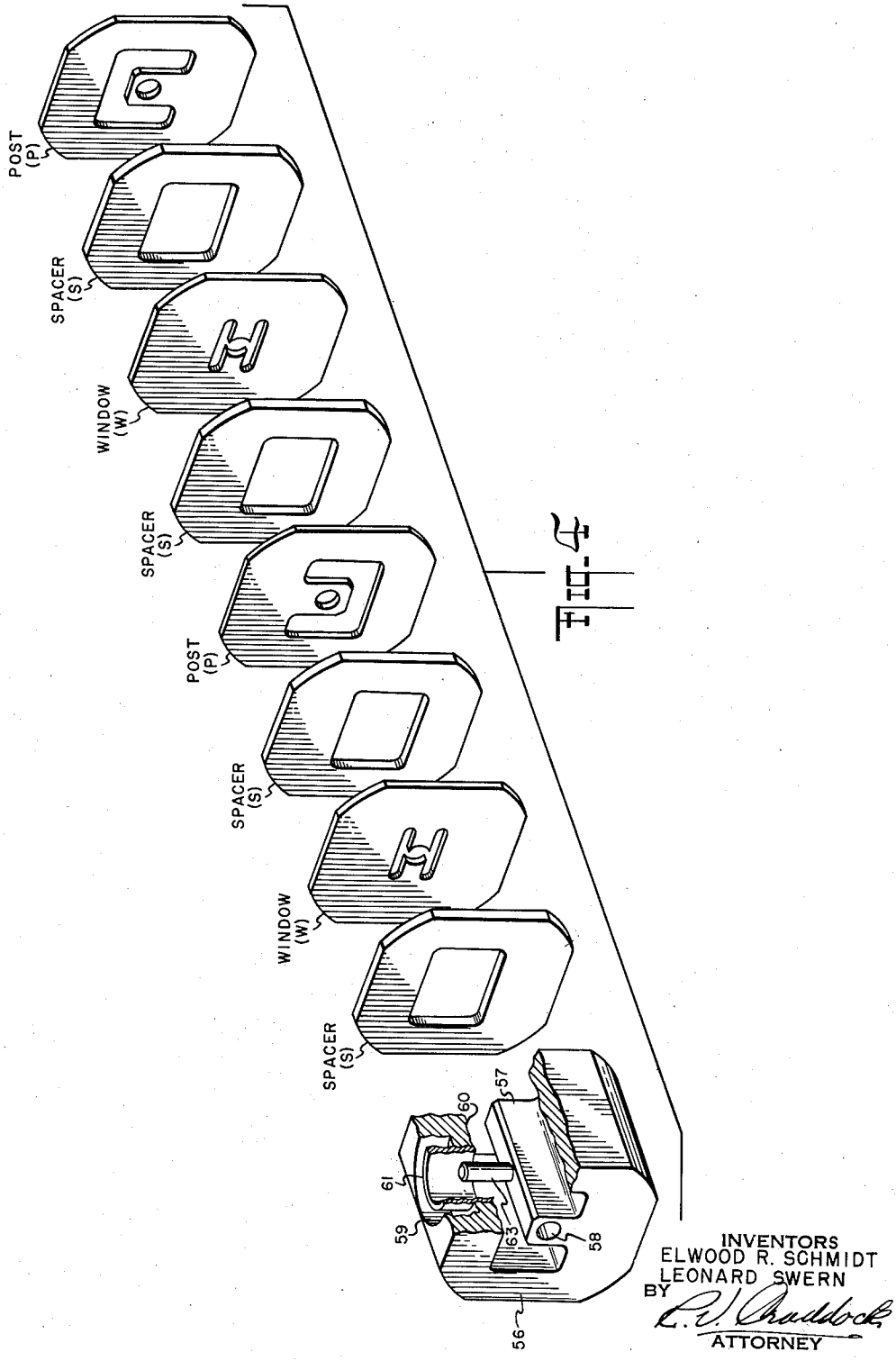
FIG. 2

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Filed Dec. 6, 1957 2 Sheets-Sheet 2



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United States Patent Office

2,966,610

Patented Dec. 27, 1960

2,966,610

ELECTRON BEAM TUBE

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Filed Dec. 6, 1957, Ser. No. 701,147

8 Claims. (Cl. 315—3.5)

The present invention relates to high frequency electron beam tubes of the type having a periodically loaded wave guide as a slow wave propagating structure. It is particularly concerned with improved apparatus for coupling the loaded wave guide of such a tube with external microwave transmission line devices.

Electron beam tubes such as travelling wave amplifiers, oscillators, or charged particle accelerators utilize slow electromagnetic wave energy propagating means along the axis of the tube for interaction with an electron stream directed along said axis. A periodically loaded wave guide structure is sometimes used as the wave energy propagating means. Such a structure is preferable to a helix, for example, since it is more rugged, is self-supporting and is capable of dissipating a large amount of heat. This is particularly desirable where the tube is designed for operation with high beam voltages.

Generally, the periodically loaded wave guide in a tube as aforedescribed has a higher impedance and carries energy in a different mode than input and output transmission lines to be coupled thereto. Thus, impedance and mode conversion means are required between the loaded wave guide and transmission lines.

It is an object of the present invention to provide a high frequency electron beam tube having a periodically loaded slow wave propagating structure and improved means for efficiently exchanging microwave energy between the periodically loaded structure and external transmission line devices.

It is another object of the invention to provide improved microwave energy transition coupling means for a tube whose slow wave propagating structure is of a type which includes a plurality of spaced conductive posts extending radially of the tube axis.

It is another object of the invention to provide such a tube which is of rugged mechanical construction, with all of the parts thereof near the beam being capable of dissipating a large amount of heat so that the tube can be operated with high beam voltages.

The foregoing and other objects and advantages of the invention are attained by the use of first and second ridge wave guide sections at opposite ends of the tube between respective ends of a periodically loaded slow wave propagating structure and first and second coaxial line coupling sections, respectively, extending at right angles with the axis of the tube. The periodically loaded structure is comprised of a plurality of spaced conductive post elements extending in directions radially of the tube axis in a common plane. The ridge wave guide sections extend along the axis of the tube, the electron beam passing through an aperture through the ridges of said sections. The ridges have the same general cross-sectional shape as the post elements, and lie in the plane of such elements. The inner conductors of the coaxial line coupling sections are connected to predetermined points along respective ridges. The aforementioned coupling sections and ridge wave guides provide suitable transition means for efficiently transferring microwave energy between the slow wave propagating structure and external transmission line devices.

Referring to the drawings,

Fig. 1 is a sectional view of a travelling wave tube in which the novel energy transition sections are incorporated in accordance with the present invention;

Fig. 2 is a cross-sectional view of the tube shown in Fig. 1, taken along the line 2—2;

Fig. 3 is a cross-sectional view of the tube shown in Fig. 1, taken along the line 3—3, and;

Fig. 4 is an exploded view of the elements forming the input ridge wave guide transition section and part of the periodically loaded wave guide propagating structure of the tube shown in Fig. 1.

Referring now to Fig. 1, the numeral 11 designates an electron gun comprised of a cathode, not shown, a focussing electrode 13 and an apertured anode 15. The gun 11 is of a conventional type for producing a solid electron beam of high current density. Such a beam is initially convergent from the gun cathode electron emitting surface to a minimum diameter at a predetermined point just beyond the end of an aperture 17 through a cylindrical piece of metal forming the anode. The first half of aperture 17 nearest the cathode is conically-shaped to prevent interception of the beam electrons as they converge to their minimum diameter region. The remaining half of aperture 17 has a constant diameter slightly larger than the diameter of the beam therewithin.

An apertured pole piece 19 of hightly magnetically permeable material such as iron abuts an end of the metallic piece forming the anode 15. One end of a tubular member 20, also of highly magnetically permeable material, is brazed to pole piece 19 and extends back around the electron gun 11 for shielding the gun from undesired magnetic fields. Member 20 also supports the anode 15 and other elements of the electron gun in coaxial relationship, and is vacuum sealed by suitable means at the end thereof, not shown.

The electron gun is designed so that the beam minimum diameter region occurs at a predetermined point within an aperture 21 through pole piece 19. The aperture 21 is coaxial with aperture 17, and preferably has a slightly smaller diameter than the adjacent end of aperture 17. A slightly smaller diameter is preferable since it affords a better magnetic flux pattern in the vicinity of aperture 21 for entrance of the beam thereinto.

The minimum diameter of the beam should occur at the effective entrance into the magnetic field within aperture 21 of pole piece 19, which field is established upon energization of an electromagnet or a permanent magnet, not shown. The magnetic field producing means would be connected between pole piece 19 and a further pole piece 22 at the output end of the tube. The magnetic flux produced thereby extends axially of the beam through the various parts of the tube between the pole pieces 19 and 22, and is provided for maintaining the diameter of the electron beam substantially constant between pole pieces 19 and 22. The details of such an electron gun and magnetic focussing system are more completely described in U.S. Patent 2,707,758, issued May 3, 1955, to C. C. Wang, for example.

The electron beam, after passing through pole piece 22 at the collector end of the tube, diverges and is collected by an electrode 23. The collector electrode 23 is coaxially supported by an annular insulating member 25. Member 25 is supported within a tubular metallic section 27 brazed at one of its ends to a recess in pole piece 22 for preserving a vacuum seal for the tube. Section 27 should be vacuum sealed at its other end by suitable means, not shown beyond the end of collector electrode 23 and member 25.

A further portion of the vacuum envelope for the tube consists of a cylindrical metallic member **31**. The ends of member **31** are brazed to the walls of suitable recesses provided in the opposing faces of pole pieces **19** and **22** for support of member **31** in coaxial relationship with the electron beam. The member **31** is also employed for coaxially supporting the periodically loaded wave guide and ridge wave guide transition sections of the tube, as well as input and output transmission line coupling sections **33** and **35**, respectively.

The coupling section **33** is comprised of a cylindrical metallic shell **37** having inner conductor means **41** coaxially supported within shell **37** by a dielectric insulating bead **43** of non-porous ceramic, for example, in vacuum sealed relationship with shell **37**. The shell **37** is supported at right angles with the axis of member **31** and extends through an aperture in the cylindrical wall of member **31** whereat it is brazed thereto.

The shell **37** has an annular recess at one end thereof for receiving and supporting an end of the outer conductor of an input coaxial line **45**. The inner cylindrical surface of shell has the same diameter as the inner diameter of the outer conductor of coaxial line **45**. Thus, when coaxial line **45** is in place, a substantially uninterrupted outer conducting surface is provided for microwave energy as it passes from the coaxial line **45** into the coupling section **33**.

The inner conductor means **41** of coupler **33** includes a metallic pin **47** passing through bead **43** in vacuum sealed relationship therewith. A cylindrical metallic sleeve **49** affixed to one end of pin **47** is received by a recessed end of the inner conductor of coaxial line **45** for providing a good electrical connection between the inner conductors of coupler **33** and coaxial line **45**. A further conductive sleeve **51** is provided at the other end of pin **47** in fixed engagement therewith. The sleeve **51** extends beyond the end of pin **47** and is slotted for providing a plurality of resilient contact fingers **53**.

The diameter of the pin **47** is chosen so that the characteristic impedance of the portion of coaxial line having bead **43** as a dielectric is the same as that of the coaxial line **45**, whose dielectric is air. The diameter of the sleeve **51** is chosen so that sleeve **51** and the inner surface of conductive member **37** forms a coaxial line of higher characteristic impedance than that of coaxial line **45**. The sleeve **51** is approximately one quarter of a coaxial line wavelength long at the mid-band frequency of operation. Thus, coupler **33** comprises a microwave transformer section of coaxial line between coaxial line **45** and an input ridge wave guide section to be described below. The elements of coupler **35** at the output end of the tube are identical with those of coupler **33**, and comprise a similar microwave transformer section between output coaxial line **55** and an output ridge wave guide section similar to the input ridge wave guide section.

The details of the input ridge wave guide section are more clearly apparent from Figs. 1, 2 and 4. As is illustrated, this wave guide is composed of a block **56** of conductive material having a suitable passage therethrough providing a rectangular ridge wave guide. The ridge of the wave guide is designated by numeral **57**, and is of rectangular cross section. The ridge wave guide should have a length of approximately one half wavelength (within the ridge wave guide) at the mid-band operating frequency, and a characteristic impedance intermediate that of coupling section **33** and that of the periodically loaded slow wave propagating structure. A circular aperture **58** of the same diameter as aperture **21** in pole piece **19** is provided through the ridge **57** for passage of the electron beam therethrough.

The block of metal **56** is suitably shaped at its corners for rigid support within the tubular member **31**, as shown in Fig. 2. The upper wall of the ridge wave guide is provided with a circular recess **59** as shown in Figs. 1 and 4 for receiving the outer conductive member **37** of the coupler **33**. A circular aperture **60** of smaller diameter than that of recess **59** extends from recess **59** into the interior of the ridge wave guide. A thin conductive sleeve **61** is brazed to aperture **60** and extends into recess **59** as illustrated in Fig. 2. The end of conductive member **37** fits tightly between member **61** and recess **59** for providing good electrical contact.

A conductive post **63** is affixed to the ridge **57** at an intermediate point therealong and protrudes upwardly into sleeve **61** as illustrated in Fig. 4. The spring fingers **53** of conductor **51** surround and tightly engage post **63** when the coupler **33** is in place as illustrated in Fig. 1. Thus, it can be seen that the inner conductor of the coaxial line **45** is electrically connected to the ridge **57** of the ridge wave guide by the inner conductor means **41** of coupler **33**.

A metallic block **65** fits within and is supported by the cylindrical member **31** between one end of the input ridge wave guide and the pole piece **19**. The block **65** includes an aperture **66** therethrough of the same diameter as aperture **58** and aligned therewith. The block **65** is brazed to the input end of the input ridge wave guide and provides a short circuited end wall for the ridge wave guide. The electrical distance from this end wall to the post **63** should be substantially one quarter of a ridge guide wavelength at the mid-band operating frequency for optimum coupling of microwave energy from coaxial line **45** and the ridge wave guide. The distance from post **63** to the end of the ridge wave guide nearest the slow wave propagating structure should be slightly less than one quarter of a ridge guide wavelength at the mid-band frequency for the device.

A block of metal **68**, machined similarly to block **56** and with the same dimensions provides an output ridge wave guide section similar to the input ridge wave guide. A further metallic block **69**, similar to block **65** is provided between the output pole piece **22** and the end of the output ridge wave guide for enhancing energy transfer to the output coaxial line **55**. The coupling section **35** between coaxial line **55** and the output ridge wave guide section is connected to this section in the same manner than coupler **33** is connected to the input ridge wave guide section.

The periodically loaded wave guide of the tube is composed of a plurality of apertured wafer-like conductive elements designated by the letters (S), (W) and (P). These elements are stacked in the order shown in Fig. 4 and soldered together for good electrical contact therebetween. The corners of each of the foregoing elements conform to the inner wall of envelope **31** for rigid support therein between the ends of the input and output ridge wave guide sections.

Each element (S) has a rectangular opening therethrough as is more clearly evident from Fig. 4. Such elements are referred to as spacers. The rectangular opening in each spacer has the same rectilinear dimensions as those of the interior of each ridge wave guide transition section.

Each element (W) has an I-shaped opening therethrough as indicated in Fig. 4. These elements are referred to as window elements. The central part of the opening in each of these elements conforms to a circle for passage of the electron beam therethrough, the openings in all of the (W) elements being coaxial with the electron beam.

Each element (P) has an opening therethrough which is of configuration similar to that of the interior of a ridge wave guide. The rectangular member protruding into the opening of each element (P) is a post of rectangular configuration, and includes a circular aperture for passage of the electron beam therethrough. The elements (P) are stacked so that the posts thereof lie in the plane of the ridges **57** and **67** of the input and output ridge wave guides, respectively. Adjacent posts are ori-

ented in 180 degree relationship relative to each other about the axis of the tube.

The first element of the loaded wave guide structure is a spacer element (S), which is soldered to an end of block **56** forming the input ridge wave guide section. The opening in this particular spacer should match the end opening of the input ridge wave guide. The next element is a window (W), the next being a spacer (S), the next being a post element (P). The element (P) nearest the input ridge wave guide has its post oriented in 180 degree relationship with the ridge **57** as is shown in Figs. 1 and 4. Succeeding post elements are oriented in 180 degree relationship as is also indicated in Figs. 1 and 4.

The last element of the loaded wave guide structure consists of a spacer element (S) soldered to an end of block **68** forming the output ridge wave guide section. The opening in this particular spacer element should match the end opening of the output ridge wave guide section. The post of the element (P) nearest the output ridge wave guide is oriented in 180 degree relationship with ridge **67** as is shown in Fig. 1.

The aforedescribed slow wave propagating device is known in the art as a Hines structure. It may be considered as a series of one quarter wavelength open circuited coaxial line resonators whose axes extend transverse the axis of the tube. The post of each element (P) forms the inner conductor of such a resonator, the walls of the elements (W) on opposite sides of each element (P) forming an outer conductor for each resonator. The I-shaped windows in the elements (W) couple the resonators together.

Each of the aforedescribed resonators should be resonant at the mid-band frequency of microwave energy to be supplied to the structure. The H-field (magnetic component) of microwave energy in each resonator is maximum at the base of each post of each element (P). Since the bases of adjacent posts of these elements are on opposite sides of the axis of the tube, coupling between the H-fields of the resonators is minimized.

The E-field (electrical component) of the microwave energy in each resonator is maximum at the free end of the post member of each (P) element. The E-field has an axial component suitable for interaction with the electron beam passing through the resonators. As is known in the art, there are a large number of space harmonic waves propagated along such a slow wave propagating structure at the design frequency thereof. In designing the structure for use in a travelling wave tube amplifier, the spacing between adjacent post members should be approximately three quarters of the first space harmonic wavelength at the resonant frequency of the resonators. The distance between adjacent post members is considered as a section of the slow wave propagating structure.

In operation of the device, electrons are emitted from the cathode of the electron gun and pass through the aperture in the input ridge wave guide section and through the slow wave propagating structure and the output ridge wave guide structure to the collector electrode **23**. The accelerating voltage is adjusted so that the electrons travel at approximately the same velocity as that of the aforementioned first space harmonic wave travelling along the slow wave propagating structure.

Input microwave energy is supplied to the tube by means of coaxial line **45**. This energy passes through the coupling section **33** and excites the input ridge wave guide of the device. Since the cross-sectional shape of the ridge of the input wave guide is approximately the same as the shape of the post members of the slow wave propagating structure, the electric and magnetic fields of the structure and the input ridge wave guide section will be similar for optimum transfer of microwave energy.

In general, an electron which enters into a section of the slow wave propagating structure, i.e., the space between adjacent posts, may see an accelerating field in the first half of a section while a deceleration field exists in the second half of the section. Since the space between post elements is approximately three-quarters of a wavelength of the first space harmonic wave and the beam is travelling at approximately the same velocity as this wave, the electron enters the second half of the aforementioned section when the field changes for further accelerating the electron. Thus, the net acceleration for such an electron is large. Conversely, an electron which enters a section when the field in the first half thereof is decelerating, would again be decelerated in second half of the section as it travels along the tube axis.

Thus, the beam electrons are caused to be bunched by the first space harmonic wave and give up energy thereto for increasing the amplitude of the wave. If the device is used as amplifier, suitable attenuating means, not shown, should be provided at an intermediate region along the slow wave propagating structure in order to prevent it from being set into oscillation.

The amplified microwave energy at the output end of the slow wave propagating structure is efficiently coupled into the output ridge wave guide section since the ridge of the output wave guide section is also of substantially the same cross-section as the post elements of the slow wave propagating structure. The microwave energy in this ridge wave guide section is coupled into the output coupler section **35**, and then to the output coaxial line **55**.

Generally, it is desirable that the input and output transmission lines **45** and **55** have a low characteristic impedance such as 50 ohms. A Hines slow wave propagating structure as aforedescribed generally has a considerably higher characteristic impedance. In one tube which was constructed for operation from 8.65 to 11 kilomegacycles, the Hines slow wave propagating structure had a characteristic impedance of 300 ohms.

The transition section comprising input coupler **33** and the input ridge wave guide section as well as the transition section comprising output coupler **35** and the output ridge wave guide section comprise means for providing a good impedance transformation between the slow wave propagating structure and the external coaxial lines. It was found for a tube whose slow wave propagating structure had a characteristic impedance of 300 ohms, with coaxial lines **45** and **55** each having an impedance of 50 ohms, that each of the couplers **33** and **35** could have an impedance of approximately 83 ohms. In such a tube each of the ridge wave guides had an impedance of approximately 195 ohms for satisfactory operation of the tube from 8.65 to 11 kilomegacycles.

If for some reason the post members of the elements (P) have a different cross-sectional shape from that of the ridge wave guide transition sections, the ridges of the wave guides could be tapered from the coaxial to ridge wave guide junction to a shape at the junction with the slow wave propagating structure which would be the same as that of the post members. Alternatively, the ridges between the coupling points and the slow wave propagating structure could be formed to provide a multiple step transformer from the coaxial to ridge wave guide junction to the ridge wave guide structure.

The aforedescribed tube is particularly advantageous over those of the prior art since it is mechanically strong and above to withstand shock and vibration. Furthermore, the tube is able to handle large electron beam powers without damaging the vacuum seal provided by the dielectric spacer members in the coupling sections **33** and **35**. This occurs since the large metal area of the ridge wave guides serve to keep the dielectric spacer members from becoming too hot.

While the invention has been described in its preferred embodiments, it is to be understood that the words which have been used are words of description rather than of limitation and that changes within the purview of the appended claims may be made without departing from

the true scope and spirit of the invention in its broader aspects.

What is claimed is:

1. A travelling wave tube, comprising means for producing and directing an electron stream along a predetermined axis, a periodically loaded slow wave propagating structure positioned along said axis for guiding electromagnetic energy for interaction with said electron stream, and a section of ridge wave guide extending along said axis in end to end coupled relationship with said slow wave propagating structure, said wave guide having a ridge containing an aperture therethrough along said axis for passage of said electron stream therethrough.

2. A travelling wave tube as set forth in claim 1, further including a tubular envelope within which said section of ridge wave guide and slow wave propagating structure are supported, means short circuiting an end of said ridge wave guide farthest from said slow wave propagating structure, and a coaxial transmission line coupling structure radially extending through said envelope and supported thereby, an inner conductor of said coupling structure being connected to an intermediate point along the ridge of said ridge wave guide between said short circuiting means and said slow wave propagating structure.

3. Electron beam tube apparatus comprising means for producing and directing an electron beam along a predetermined axis, a slow wave device disposed along said axis for carrying electromagnetic energy for interaction with said beam, said device having an electron beam passageway in alignment with said axis, a section of ridge wave guide extending along said axis in end to end coupled relationship with said slow wave device, the ridge of said wave guide being substantially aligned with the electron beam passageway of said slow wave device, and an aperture through said ridge for passage of said beam therethrough.

4. The combination as set forth in claim 3, wherein said slow wave device includes a plurality of conductive loading elements for reducing the axial velocity of electromagnetic energy carried by said slow wave device, each of said loading elements having an aperture therethrough in alignment with the aperture through the ridge of said wave guide, the projection of a cross section of the end of the ridge of said wave guide nearest said slow wave device being aligned with and substantially shaped like the projection of a section through one of said loading elements taken in a plane at right angles with the axis of said beam.

5. The combination as set forth in claim 4, wherein said slow wave device comprises a plurality of conductive sections having openings therein, said loading elements being disposed within the openings in one group of said sections, the size and configuration of the interior of said ridge wave guide in a cross sectional plane through said wave guide nearest said propagating structure being substantially the same as the size and configuration of the interiors of said one group of sections in cross sectional planes through said slow wave device.

6. The combination as set forth in claim 5, wherein succeeding ones of said loading elements extend across the axis of said beam from opposite sides of said conductive sections, the one of said loading elements nearest said ridge wave guide extending from a side of its conductive section that is opposite the side of said wave guide upon which the ridge thereof is supported.

7. Electron beam tube apparatus comprising means for producing and directing an electron beam along a predetermined axis, a slow wave device positioned along said axis for carrying electromagnetic energy for interaction with said electron beam, a section of ridge wave guide extending along said axis in end-to-end coupled relationship with said slow wave device, said ridge wave guide having an opening from one end to the other along said axis for passage of said beam therethrough, means for short circuiting the end of said section of ridge wave guide that is farthest from said slow wave device, an aperture through said short circuiting means for passage of said beam therethrough, and a section of coaxial transmission line having an inner conductor that extends transversely into the interior of said wave guide and is connected to a point along the ridge of said wave guide between said short circuiting means and said slow wave device.

8. Electron beam tube apparatus as set forth in claim 1, wherein said section of ridge wave guide is approximately one half wavelength long for electromagnetic energy carried by said wave guide at a mid-band operating frequency, the point of connection of the inner conductor of said coaxial transmission line to said ridge being substantially one quarter wavelength from said short circuiting means.

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