May 6, 1969 D. C. BUCK 3,443,146

CONDUCTIVE ELEMENTS INTERCONNECTING ADJACENT MEMBERS OF THE DELAY STRUCTURE IN A TRAVELING WAVE TUBE

Filed Feb. 16, 1966

Sheet 1 of 2

FIG. 1.

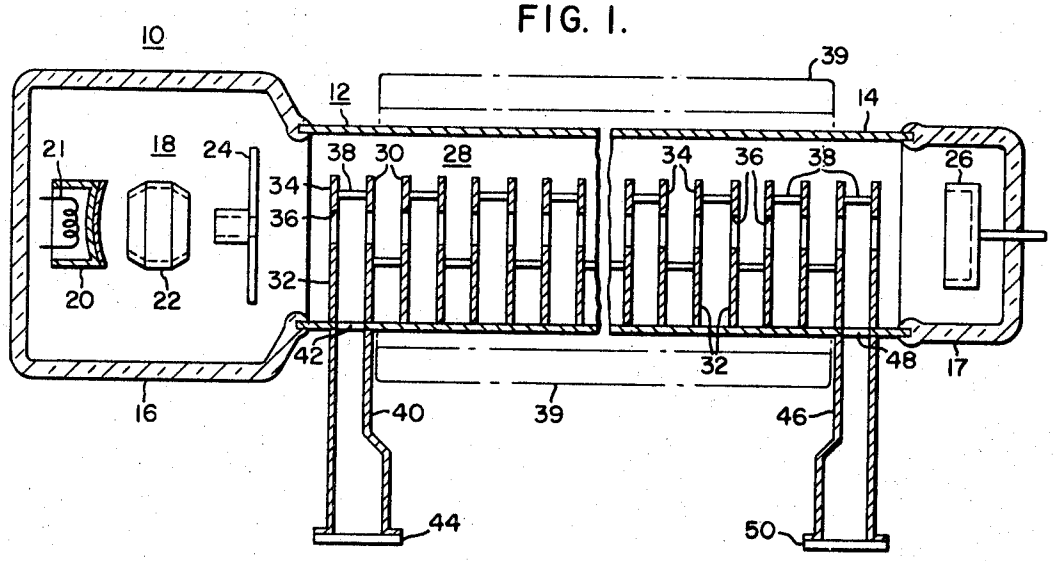


FIG. 2.

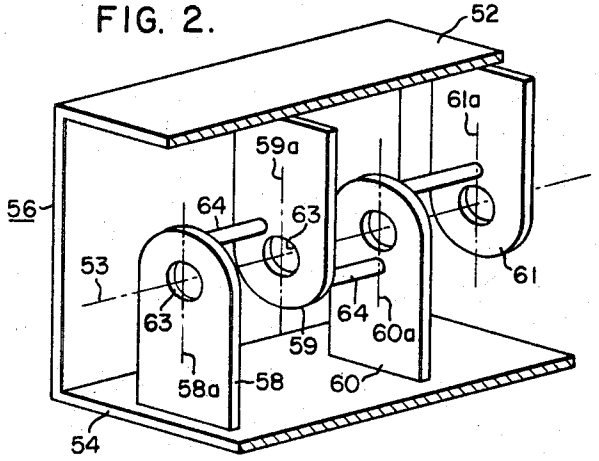
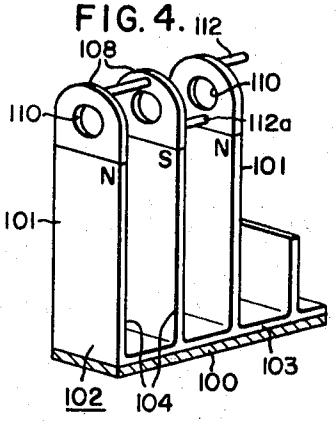


FIG. 4.



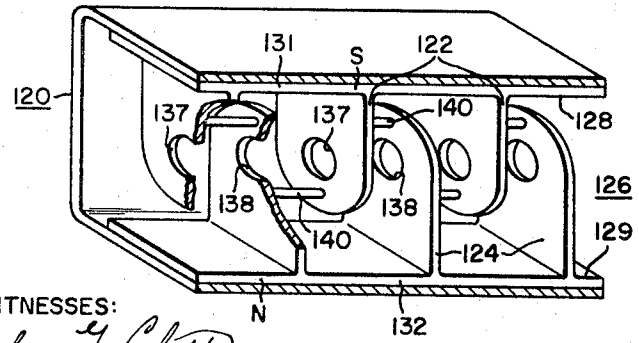


FIG. 5.

WITNESSES:

John L. Chopp

James F. Young

INVENTOR

Daniel C. Buck

BY R. Lewis Hoble

ATTORNEY

May 6, 1969 D. C. BUCK 3,443,146

CONDUCTIVE ELEMENTS INTERCONNECTING ADJACENT MEMBERS OF THE DELAY STRUCTURE IN A TRAVELING WAVE TUBE

Filed Feb. 16, 1966 Sheet 2 of 2

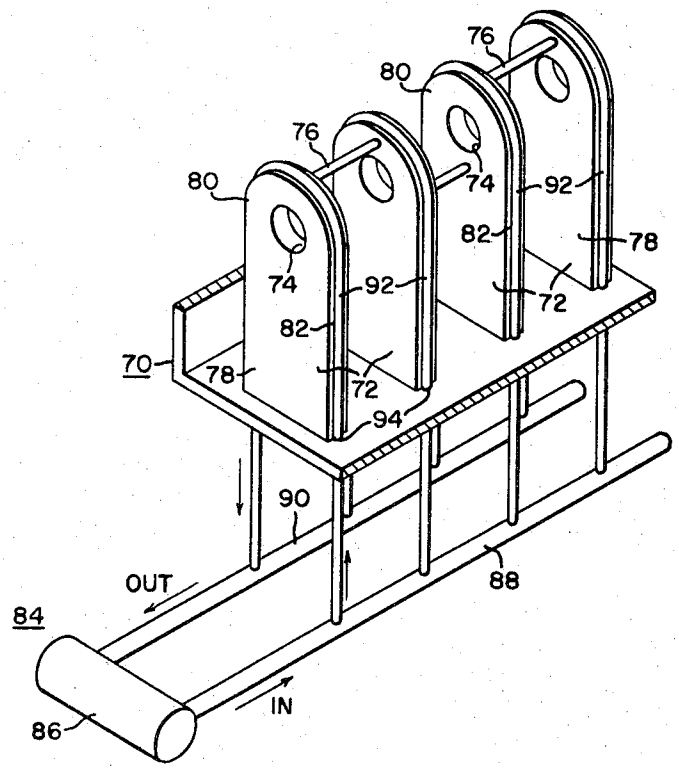


FIG. 3a.

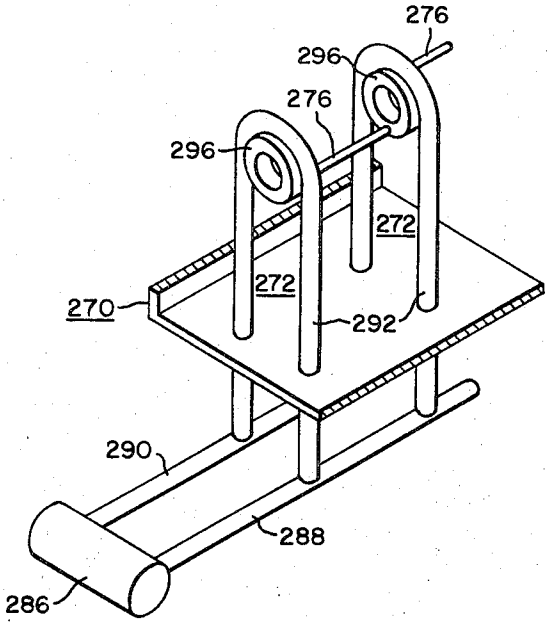


FIG. 3b.

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3,443,146

CONDUCTIVE ELEMENTS INTERCONNECTING ADJACENT MEMBERS OF THE DELAY STRUCTURE IN A TRAVELING WAVE TUBE

Daniel C. Buck, Horseheads, N.Y., assignor to Westinghouse Electric Corporation, Pittsburgh, Pa., a corporation of Pennsylvania

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U.S. Cl. 315—3.5 11 Claims

ABSTRACT OF THE DISCLOSURE

A traveling wave tube which includes a slow wave propagating structure having the electrical properties of a contra-wound helix, and a plurality of heat conductive members disposed between the slow wave propagating structure and a heat radiating surface to efficiently dissipate the heat.

The present invention relates generally to electron discharge devices, and more particularly to slow wave or delay line propagation structures for use in circuits or devices such as traveling wave tubes.

Traveling wave tubes generally include an elongated envelope with an electron beam producing means disposed in one end thereof for the production and projection of an electron beam through the envelope. A slow wave propagating structure coaxially mounted within the envelope functions to propagate electromagnetic energy along the length of the envelope in an interacting relation with the electron beam. An electron collector assembly is disposed at the opposite end of the envelope for receiving the electron beam. In operation, an electromagnetic wave is propagated along the slow wave propagating structure at a velocity substantially less than the velocity of light. The electron beam is projected through the slow wave propagating structure at approximately the same velocity as that of the electromagnetic wave. Mutual interaction between the electron beam and the electromagnetic wave effects a transfer of kinetic energy from the electron beam to the wave causing the electromagnetic wave to grow exponentially with distance, and thus to be amplified.

Typically, a slow wave structure comprises a helically shaped electrically conductive member upon which the traveling electromagnetic wave is established as described above. The helically shaped member provides an efficient performance for those tubes in which the electron beam has been accelerated to velocities corresponding to less than approximately 10 kv. or about 1/5 the velocity of light. As the operating voltage (and velocity) is increased, the pitch of the helical, propagation means must be increased in order that the velocity of the electron beam is approximately that of the electro magnetic wave propagated along the slow wave structure. Further, in order to handle a high power electron beam satisfactorily, it may be necessary to increase the radius of the slow wave helical structure. As a result of the increase of the radius and the pitch of the helical slow wave structure, the interaction impedance and ultimately the gain characteristic of the slow wave structure are decreased. Briefly, it may be understood that the interaction impedance K of the helix is generally described by the expression:

$$K=E^2/2\beta^2P$$

where E is the interaction field which is the longitudinal component of the electric field of the traveling wave, β is the phase constant of the wave and P is the total power.

The electromagnetic field associated with a slow wave structure can be represented by a series of spacial harmonics, whose wavelength as measured along the axis

of the slow wave propagation structure, are submultiples of the fundamental wavelength of the interaction field of the slow wave propagating structure. These subharmonic components travel at velocities slower than that of the fundamental wavelength, and if the velocity of the electron beam is selected to interact with the fundamental component, there will be no interaction with the higher space harmonics. However, power is associated with these subharmonic components. Thus, when operating in excess of 10 kv. with an increased radius and pitch of the helical slow wave propagating structure, it has been found that a larger fraction of the power is carried by the higher subharmonic components than for a low voltage structure with a smaller radius. This additional power carried by the higher space harmonic components represents a reduction in the impedance of the fundamental wavelength.

A further difficulty arising from the presence of certain of the space harmonics in the operation of the traveling wave tube embodying a single helix is the production of backward wave oscillations. These undesired oscillations are the result of an interaction between the electron beam and certain space harmonics of the electromagnetic wave whose energy are being propagated in a negative or opposite direction to that of the electron beam. These space harmonics still have a phase velocity in the forward direction, but the group velocity of these space harmonics is in the backward direction. Their forward phase velocity can be synchronized with the electron beam and thereby cause oscillation. The space harmonic components tend to be disposed in a region close to the slow wave propagating structure rather than on the axis of the slow wave structure. The n^{th} space harmonic phase constant β_n is given by the expression:

$$\beta_n=\beta_0L+2n\pi$$

where L is the axial pitch of the helix structure, and β_0 is the phase constant of the fundamental wave component. The strength of the axial electric associated with the n^{th} space harmonic decay at points away from the helix structure towards the beam axis in a transverse plane in accordance with the expression:

$$I_0(\beta_n r)$$

where r is the radial coordinate and I_0 is a modified Bessel function. The larger the value β_n, the faster the electric fields fall away from the wave circuit. Helices designed for progressively higher voltage beams exhibit progressively greater pitch to diameter ratios. The greater this ratio, the stronger is the strength of the first backward space harmonic. The initial conditions for backward oscillations then requires progressively smaller beam currents, thus limiting the practicality of such devices.

Thus, the reduction of the impedance of the fundamental wave component and the existence of backward wave oscillations make the use of a single helix structure extremely difficult when operating at high voltages i.e., in excess of 10 kv. However, it has been proposed that a slow wave propagating structure having two helixes which are oppositely wound and interposed will provide a mode of operation which possesses a high impedance in the fundamental component while providing a lower impedance in the first backward wave spacial harmonic than that of the single helix structure. Such a structure has been more fully described in the article by Chodorow and Chu, entitled "Cross-Wound Twin Helixes for Traveling Wave Tube," Journal of Applied Physics, vol. 26, pages 33–43, January 1955. It has also been shown that such a cross-wound structure has less velocity dispersion than the usual ring and bar structure which is in general present day use.

Further, the operation of high power traveling wave tubes has presented a problem of dissipating the heat generated by the slow wave propagating structure. In operating a wave propagating structure at high levels of power, the density of the electron beam becomes greater and tends to spread thereby striking the slow wave structure. Due to the bombardment of the dispersed electrons, the slow wave propagating structure is heated to a point where it or its surrounding components may be injured. In an article by Birdsall and Everhart, entitled "Modified Contra-Wound Helix Circuits for High-Power Traveling-Wave Tubes," IRE Transactions on Electron Devices, pp. 190 to 204, 1956, there is suggested a structure which partially alleviates the problem of heat dissipation from the slow wave structure. Typically, this structure includes a plurality of ring members interconnected by bars so as to form a contra-wound helix. Further, this slow wave structure is supported by a plurality of stubs which are disposed between the ring members and a supporting cylinder. Typically, the support stubs are in contact with only a small portion of the ring members and thereby only a limited amount of heat may be dissipated therefrom.

Further, most present day traveling wave tubes require the generation and projection of a long electron beam of high current density. The radial forces of space charge within these electron beams must be neutralized if the beam is to be confined over the distance in which the interaction with the slow wave propagating structure is to take place. Typically, the electron beam is focused and confined by immersing the electron beam in a uniform magnetic field. Such focusing fields can typically be obtained from either an electromagnet such as a solenoid or a permanent magnet. However, where such magnetic structures are combined with traveling wave tubes to produce a focusing effect on the electron beams, the resulting structures involve an inconvenient amount of weight and the solenoid structures require an additional power supply.

It is, therefore, an object of this invention to provide an improved electron discharge device.

A further object of this invention is to provide an improved slow wave propagating means for use in an electron discharge device.

Another object of this invention is to provide a new and improved slow wave propagating structure which may be suspended within an envelope of the electron discharge device in a secure fashion so as to efficiently dissipate heat from the slow wave propagating structure.

Still another object of this invention is to provide new and improved electron discharge devices in which there is supported a slow wave propagating structure having the electrical properties of a cross-wound helical structure in a manner so as to dissipate great quantities of heat without substantially decreasing the interaction impedance of the slow wave propagating structure.

It is a further object of this invention to provide a new and improved electron discharge device in which there is incorporated a dual purpose means for focusing the electron beam directed through the device and for supporting a slow wave structure in an interacting relationship with the electron beam so as to efficiently dissipate heat from the slow wave structure.

It is a still further object of this invention to provide an electron discharge device having therein a new and improved means for generating and focusing an electron beam in an interacting relationship with a slow wave propagating structure that avoids the use of a heavy, power consuming focusing structure.

Briefly, the present invention accomplishes the above-mentioned objects by providing an electron discharge device such as a traveling wave tube which includes a slow wave propagating structure having the electrical properties of a contra-wound helix, and a plurality of heat conductive members disposed between the slow wave propagating structure and a heat radiating surface to thereby efficiently dissipate the heat generated by the slow wave propagating structure. More specifically, a slow wave propagating structure is made up of a plurality of annular portions of members disposed in an interacting relationship about the electron beam and interconnected by conductive means so as to form the electrical equivalent of a contra-wound helical structure. Further, means disposed in essentially the same plane as the annular portions are interconnected in a heat transfer relationship between the annular members and the envelope of the electron discharge device.

In one specific embodiment of this invention, conduits are disposed about these heat conducting means and the annular members of the slow wave propagating structure to thereby more efficiently dissipate heat. In another embodiment of this invention, electron focusing means are incorporated within an electron discharge device and include a plurality of magnetic members disposed between the envelope and the slow wave propagating structure. More specifically, the magnetic members are disposed so that the polarity of the successive magnetic members alternate with each other so as to form a periodic focusing field.

These and other objects and advantages of the present invention will become more apparent when considered in view of the following detailed description and drawings, in which:

FIGURE 1 is an elevational view partially in section of a travling wave tube embodying the present invention;

FIG. 2 shows an alternate embodiment of the propagating structure of this invention which may be incorporated within the traveling wave tube of FIGURE 1;

FIGS. 3*a* and 3*b* show various embodiments of a slow wave propagating structure including a cooling system therefor which may be substituted in the traveling wave tube of FIG. 1;

FIG. 4 is a further embodiment of the slow wave propagating structure of this invention including periodic focusing means which may be incorporated in the electron discharge device of FIG. 1; and

FIG. 5 is a still further embodiment of the slow wave propagating structure of this invention including magnetic focusing means which may be incorporated within the device shown in FIG. 1.

Referring now to the drawings and in particular to FIG. 1, there is shown an electron discharge device **10** of the traveling wave type comprising an envelope **12** including a central, tubular portion **14** made of a suitable electrically conductive material such as a nonmagnetic stainless steel, and an enlarged portion **16** made of a suitable insulating material such as glass and which is sealed to the tubular portion **14** in a manner well known in the art. An electron gun, indicated generally by the reference character **18**, is disposed at one end of the envelope **12** within the enlarged portion **16**. The electron gun **18** comprises a thermionic, electron emissive cathode element **20**, a heater element **21** to energize the cathode element **20**, a focusing electrode **22**, and an accelerating electrode **24**. These elements are connected to suitable voltage sources, which have not been shown, and collectively act to generate and project a beam of electrons centrally along the axial length of the envelope **12** to the opposite end thereof. An electron collector **26** is provided within an end portion **17** at the opposite end of the envelope **12** and serves to collect the electron beam after it passes through the tubular portion **14**. In an illustrative embodiment of this invention, the end portion **17** may be made of a suitable electrically insulated material such as glass and is sealed to the tubular portion **14** in a manner well known in the art.

A slow wave propagating means or structure **28** is positioned intermediate of the electron gun **18** and the electron collector **26**. The propagating structure **28** functions to establish an electromagnetic wave along the

length of the tubular portion **14** in an interacting relationship with the electron beam. The propagating structure **28**, in accordance with teachings of this invention, includes a plurality of propagating elements **30** which are interconnected with each other by bars **38** so as to form a slow wave structure having the electrical properties of a contra-wound helical structure. More specifically, the propagating elements **30** are made of electrically conductive material such as 304 stainless steel, copper, or cupronickel and include a ring or annular portion **34** with an aperture **36** therein disposed in interacting relationship about the electron beam emitted by the electron gun **18**, and a stub portion **32** disposed between the ring portion **34** and the tubular portion **14** of the envelope **12**. Each of the stub portions **32** may extend radially from the ring portion **34** a distance equal to $n\lambda_0/4$ where n is any positive odd integer and λ_0 is the mid-frequency of the operating band of which the electron discharge device **10** is designed. An adjacent pair of stub portions **32** joined by a connecting **38** form a quarter wave, two conductor circuit with a characteristic impedance Z_0 determined by the geometry of the stubs, their proximity to one another, and their cross sections. The impedance taken at the connecting bar **38** due to the pair of stub portions and looking outward towards the envelope portion **14** is given approximately by the expression:

$$jZ_0 \tan \frac{2\pi l_{stub}}{\lambda_0}$$

where l stub is the length of the stub portion **32** from the connecting bar **38** to the envelope cylinder **14**, and λ_0 is the free space wavelength. If the geometry is adjusted to make the characteristic impedance Z_0 large compared to the impedance of the slow wave circuit itself, then the effect of the stub supporting means on the dispersion characteristics of the slow wave structure **28** will be small. As a result, a wave propagated along the slow wave structure **28** will substantially be unaffected in an electrical sense by the presence of the stub portions **32**.

In the illustrative embodiment of the slow wave structure of this invention as shown in FIG. 1, the slow wave structure **28** comprises a plurality of axially aligned, parallel ring portions **34** each of which is joined to successive ring portions by the interconnecting bars **38**. The bars **38** are electrically connected to the ring portion **34** at points spaced 180° apart and upon opposite sides of the ring portions **34**. The ratio of the length of the interconnecting bars **38** to the diameter of the ring portions **34** is determined by the velocity of the electron beam, and the length of the bars **38** is determined by both the electron beam velocity and the frequency of the electromagnetic wave being propagated upon the slow wave structure **28**. As shown in FIG. 1, the unitary propagating elements **30** are integral, relatively thin sheets of a metallic material which may be thought of as comprising a ring portion **34** and a stub portion **32**. The stub portion **32** is that part of the element **30** disposed between the conductive, tubular portion **14** and the interconnecting bar **38**. In other possible embodiments, as will be shown later, the portions may be made from separate elements. In accordance with the teachings of this invention, the portions **34** and **32** will abut each other along extensive portions thereof to thereby insure an efficient thermal relationship from the conductive portion of the stub portion. Further, the ring portion **34** and the stub portion **32** are disposed in the same plane which is substantially parallel to the planes of the other propagating elements and which is substantially perpendicular to the path of the electron beam emitted by the electron gun **18**.

Electromagentic energy is supplied to the propagating structure **28** by means of an input waveguide **40** which is positioned near the enlarged portion **16** in the manner as shown in FIG. 1. In particular, the input waveguide **40** is sealed about an opening **42** within the tubular portion **14** of the envelope **12**; further, the input waveguide **40** and the opening **42** are so aligned and so dimensioned so as to direct the electromagnetic energy between the first two propagating elements **30** which are nearest the electron gun **18**. Further, the vacuum is maintained within the envelope **12** by a window **44** which is made of a suitable dielectric material and which is disposed over and is sealed to the opening of the waveguide **40**. Similarly, an output waveguide **46** is provided near the end portion **17** for the removal of the electromagnetic energy from the slow wave propagating structure **28**. Typically, the output waveguide **46** is aligned with an opening **48** within the tubular portion **14** and is so dimensioned to receive electromagnetic energy from the last two propagating elements **30** which are disposed closest to the collector electrode **26**. Further, the vacuum within the envelope **12** is maintained by a window **50** which is disposed over and sealed to the opening within the waveguide **46**.

In order to prevent the electron beam from spreading to such an extent that it would be intercepted by the slow wave propagating structure **28** it is necessary to provide some form of focusing. In an illustrative embodiment shown in FIG. 1, focusing is provided by establishing a magnetic field axially along the envelope **12** by the use of a long solenoid **39** which surrounds the tubular portion **14** of the envelope **12** for substantially the entire length of the slow wave propagating structure **28**. To simplify the present drawing and description, the solenoid **39** is only schematically illustrated and the source of energization is not shown.

With reference now to FIG. 2, there is shown an alternative embodiment of the slow wave propagating structure which may be incorporated in the electron discharge device **10** which is shown in FIG. 1. The embodiment shown in FIG. 2 includes then an envelope having a rectangular portion **56** having a top wall **52** and a bottom wall **54** oppositely disposed. Further, a plurality of propagating elements **58** to **61** are disposed alternately from the top wall **52** and from the bottom wall **54**. Each of the propagating elements **58** to **61** has an aperture **63** therein which is so aligned that the centers of the apertures **63** lie upon the path designated by the numeral **53** along which the electron beam is directed. The propagating elements are interconnected as by a plurality of bars **64** so as to form the electrical equivalent of a contra-wound helical structure. Specifically, the propagating elements **58** and **60** are secured to the bottom wall **54** whereas the propagating elements **59** and **61** are secured to the top wall **52** of the envelope portion **56**. Further, the propagating element **59** has two interconnecting bars **64** electrically connected upon either side thereof and spaced 180° from each other about an aperture **63**. The interconnecting bars **64** connected to the propagating element **59** are in turn electrically connected to the propagating elements **58** and **60** disposed on alternate sides of the propagating element **59**. Each of the propagating elements **58**, **59**, **60** and **61** has a centerline, respectively, designated as **58***a*, **59***a*, **60***a* and **61***a* which intersect the line **53**. Further, the interconnecting bars are connected between adjacent propagating elements at points which lie upon the centerlines of the adjacent elements. Thus, a single plane, which passes through each of the centerlines of the propagating elements, would intersect each of the interconnecting bars **64** and the path **53**. By providing a slow wave structure with such a symmetry, it is believed that a greater bandwidth may be achieved.

It is noted that the interconnecting bars of the propagating elements **58** to **61** are spaced respectively from the top and bottom walls **52** and **54** by a distance equal to $n\lambda_0/4$ where n is any positive odd integer and λ_0 is the full space wavelength corresponding to the mid-frequency for which the device **10** is designed. By determining this distance, an open circuit will appear between adjacent propagating elements at the midfrequency. The particular advantages of the arrangement shown in FIG.

2 are: (1) a greater amount of heat may be dissipated from the slow wave structure and directed out through both the top and bottom walls of the envelope, and (2) the characteristic impedance Z_o of the transmission line formed by adjacent stubs is larger by virtue of the increased spacing between the stub portions. This means that the bandwidth over which the impedance of the stub circuit

$$\left(Z_o \tan \frac{2\pi_o}{\lambda_o}\right)$$

is greater than the slow wave structure impedance is increased proportionately to the value of Z_o.

Referring to FIG. 3*a*, a further embodiment of the slow wave structure of this invention is shown which may be incorporated in an electron discharge device as shown in FIG. 1. This embodiment includes an envelope having a tubular portion **70** upon which there is mounted a plurality of propagating elements **72** disposed in an essentially parallel relationship with each other. Each of the propagating elements **72** has an aperture **74** which is aligned with and disposed about the electron beam in an interacting relationship. Successive propagating elements **72** are interconnected as by bars **76** so as to form the electrical equivalent of a cross-wound helical structure. Further, the elements **72** include a ring portion **80** which is rigidly supported by an integral stub portion **78** upon the portion **70** of the envelope. The ring portion is spaced a distance of:

$$n\lambda_0/4$$

where n is any positive odd integer and λ_0 is the free space wavelength corresponding to the midfrequency of the operating band for which the device is designed. Thus, an open circuit does appear between successive ring portions of the propagating elements **72**. In the embodiment of FIG. 3*a*, additional means are provided to extract the heat generated within the propagating element **72** of the slow wave structure. In particular, there is shown a cooling system **84** including a pumping means **86**, which is connected through input and output conduits **88** and **90** to a plurality of U-shaped conduits **92** which are thermally disposed about each of the propagating elements **72**. Each of the U-shaped conduits **92** is interconnected between the input conduit **88** and the output conduit **90** to provide a flow of a cooling medium such as water about each of the propagating elements **72**. Further, the U-shaped conduits **92** are disposed in a sealed relationship through the openings **94** within the tubular portion **70** of the envelope and are disposed about the propagating elements **72** in a groove **82** which allows an increased thermal contact between the surface edge of the propagating element **72** and the conduit **92**. In operation, the pumping means would force the cooling medium out through the conduit **88** to be directed into each of the U-shaped conduits **92** and about the radiating element **72**. After absorbing heat from the propagating element **72**, the cooling medium is returned through the output conduit **90** to be recirculated by the pump means **86**.

Referring to FIG. 3*b*, an alternative embodiment of the slow wave structure of this invention is shown which has the capability of dissipating heat therefrom efficiently. More particularly, this embodiment includes an envelope having a portion **270** and a plurality of propagating elements **272** extending from the envelope portion **270** in a substantially parallel relation to each other. Each of the propagating elements **272** are formed essentially by a tube or conduit **292** for circulating a cooling medium and an annular member **296**. The tube **292** is of a U-shaped configuration with its leg portions extending through the envelope portion **270**. The annular member **296** are disposed within the bight of the U-shaped tubes **292** and so aligned with respect to each other that a beam of electrons may be directed therethrough. Successive propagating elements are interconnected by the electrically conductive bars **276** to form the electrical equivalent of a cross wound helical structure.

The annular member **296** and the bars **276** are spaced from the envelope portion **270** a distance of:

$$n\lambda_0/4$$

wherein n is any positive odd integer and λ_0 is the free space wavelength corresponding to the midfrequency of the operating band for which the device is designed. In the embodiment shown in FIG. 3*b*, the tubes **292** provide the means for supporting the annular members **296** and for dissipating the heat generated within the members **296**. The cooling system includes a pump **286** which forces a cooling medium through an input conduit **288** into the tubes **292** and from the tubes **292** through an output conduit **290**.

The characteristic impedance Z_o of the slow wave structure illustratively shown in FIG. 3*b* is very large. As a result, the bandwidth over which the impedance as presented by the supporting tubes, i.e.,

$$\left(Z_o \tan \frac{2\pi l}{\lambda_o}\right)$$

where l is the length of tubes is large as compared with the impedance of the slow wave circuit is larged.

Referring now to FIG. 4, there is shown a slow wave structure, which includes not only support means for the slow wave structure but also a periodic magnetic focusing system which is an integral part of the support means. As shown in FIG. 1, a solenoid **39** is normally needed to provide a confining or focusing effect upon the electron beam established by the electron gun **18**. However, such solenoids add appreciably to the weight of the electron discharge device **10** and in addition require an auxiliary power source. Therefore, the embodiment shown in FIG. **4** provides a focusing means which is incorporated within the envelope of the electron discharge device and which effects a considerable savings in weight and which also provides rigid support for the slow wave structure. There is shown in FIG. 4 a multipurpose assembly **102** having a base **103** from which extend in parallel relationship with each other a plurality of propagating elements **101**. The propagating elements include a ring portion **108** which is disposed in the same plane as a stub portion **104**. The ring portions **108** are interconnected as by bars **112** and **112***a* so as to form the electrical equivalent of a cross-wound helical structure. Further, the interconnecting bars **112***a*, which are disposed adjacent the base **103**, are spaced therefrom by a distance equal to:

$$n\lambda_0/4$$

where n is any positive odd integer and λ_0 is the free space wavelength corresponding to the midfrequency of the operating band for which this electron discharge device is designed. The particular contribution of this embodiment lies in the provision of a periodic permanent magnetic focusing system which is provided by making the stub portions **104** of a suitable magnetic material with a high coercive force such as Alnico V and magnetizing these portions so that successive stub portions **104** have opposite poles of magnetization. Further, the ring portions **108** are made of a suitable electrically conductive material such as core iron. The multipurpose assembly **102** is mounted upon a portion **100** of the envelope which may be made of a suitable ferrous material such as iron to provide an effective shielding to confine the magnetic flux established by the stub portions **104**. Thus, there has been shown a structure for establishing an alternating transverse magnetic field about the axis of the electron beam.

In an illustrative method of manufacture, the magnetic structure is shaped as the comb-like structure shown in FIG. 4. Next, the magnetic structure is secured to the en-

velope of the electron discharge device as by brazing. Then, the magnetic portions are magnetized in the cooling cycle of the final step of brazing; this is accomplished by placing the magnetic structure in a magnetic field and cooling the structure. Finally, the electron discharge device is exhausted and baked with the electron gun disposed at approximately 600° C., and the magnetic structure heated to temperatures not in excess of 450° C. At these temperatures the Alnico V material looses only about 5% of its strength, and further this heating step serves as a stabilizing treatment for the magnets. In addition, it is noted that the magnetic portion of the dual purpose assembly could be copper plated to reduce the microwave looses on the surface of the slow wave structure.

Referring now to FIG. 5, there is shown another embodiment of the slow wave structure of this invention which includes a periodic focusing system for confining the diameter of the electron beam and which is incorporated as an integral part of the support means. There is shown in FIG. 5 a slow wave structure **126** disposed within a tubular portion **120** of the envelope. The slow wave structure **126** includes first and second assemblies **128** and **129** each respectively having a plurality of propagating elements **122** and **124** and a base **131** and **132** from which extend in parallel relationship the propagating elements **122** and **124**. Apertures **137** and **138** are respectively placed in the propagating elements **122** and **124** and are so aligned with respect to each other to allow an electron beam to be projected therethrough in an interacting relationship with the propagating elements. As shown in FIG. 5, adjacent propagating elements are interconnected by bars **140** which are disposed alternately upon opposite sides of the apertures **137** and **138**. Further, the bars **140** are respectively spaced from the base of the assemblies a distance approximately equal to:

$$n\lambda_o/4$$

where n is any positive odd integer and λ_o is the free space wavelength corresponding to the midfrequency of the operating band for which this electron discharge device is designed. An important contribution of this embodiment lies in the provision of a periodic, magnetic focusing system by placing as in integral part of the propagating elements a magnetic means oriented in an appropriate direction as shown in FIG. 5. Illustratively, the propagating elements may be made of a magnetic material with a high coercive force, and the direction or orientation of the propagating elements is disposed in the same direction. In comparison with the embodiment shown in FIG. 4, this arrangement has a better symmetry of the magnetic field in the region of the electron beam. The magnetic structure in FIG. 5 is easier to orientate in that each propagating element is orientated in the same direction; further, the resultant electrical properties of this structure are inherently more broad band. The broad band characteristic of this structure is dependent upon the characteristic impedance Z_o of the parallel plane circuits formed by the adjacent elements. This may be understood by considering that the impedance as viewed by looking back from the apertures toward the base of the assemblies is:

$$Z_o \tan \frac{2\pi l}{\lambda_o}$$

where Z_o is the free space wavelength of the electromagnetic wave and Z_o is the characteristic impedance of the parallel plane circuit. Thus, the impedance in shunt of the structure of FIG. 5 is high over a given band and sufficiently high over a wide band. The shunt impedance must be greater than the impedance of the ring bar circuit so as not to load it down. Thus, this version of the structure as shown in FIG. 5 is superior to that of FIG. 4 since the characteristic impedance is greater due to the fact that the adjacent propagating elements are disposed further apart.

Since numerous changes may be made in the above described apparatus and different embodiments of the invention be made without departing from the spirit thereof, it is intended that all matter contained in the foregoing description or shown in the accompanying drawings, shall be interpreted as illustrative and not in a limiting sense.

I claim as my invention:

1. An electron discharge device comprising a tubular envelope, means for generating and projecting an electron beam, means for receiving said electron beam, a wave structure for propagating electromagnetic waves within a predetermined frequency band having a midfrequency corresponding to a free-space wavelength of λ_o, said wave structure disposed in an interacting relation with said electron beam and including a plurality of elements having an end thereof supported upon said envelope and the other end extending freely within said envelope, each of said elements having first and second portions disposed in substantially the same plane, said first portions comprising a magnetic material oriented to confine the diameter of said electron beam, said second portion having an aperture therein, said elements disposed so that said electron beam is directed along a path substantially perpendicular to said plane of said elements through said apertures, and electrically conductive means interconnecting adjacent elements at points oppositely disposed about said apertures, said second portion supported by said first portion from the supported end of said elements a distance substantially equal to $n\lambda_o/4$ where n is a positive odd integer.

2. An electron discharge device comprising a tubular envelope, means for generating and projecting an electron beam, means for receiving said electron beam, a wave structure for propagating electromagnetic waves within a predetermined frequency band having a midfrequency corresponding to a free-space wavelength of λ_o, said wave structures disposed in an interacting relation with said electron beam and including a plurality of elements having an end thereof supported upon said envelope and the other end extending freely within said envelope, each of said elements having first and second portions disposed in substantially the same plane, said second portion having an aperture therein, said elements disposed so that said electron beam is directed along a path substantially perpendicular to said plane of said elements through said apertures, and electrically conductive means interconnecting adjacent elements at points oppositely disposed about said apertures, said second portion supported by said first portion from the supported end of said elements a distance substantially equal to $n\lambda_o/4$ where n is a positive odd integer and conduit means for conducting a fluid coolant disposed in a heat transfer relation with said elements.

3. An electron discharge device as claimed in claim **2**, wherein each of said elements has a continuous periphery thereabout with a depression therein, said conduit means disposed within said depression to thereby achieve an efficient heat transfer therebetween.

4. An electron discharge device as claimed in claim **2**, further including means for pumping said fluid coolant, said conduit means including a plurality of tubes disposed upon the periphery of said elements and connected in a parallel relation to said means for pumping.

5. An electron discharge device as claimed in claim **2**, further including means for pumping said fluid coolant, each of said conduit means including a plurality of tubes of a U-shaped configuration with first and second leg portions, said pump means being connected with said conduit means so that a fluid coolant is pumped into said first leg portions and ejected through said second leg portions.

6. An electron discharge device as claimed in claim **2**, wherein said conduit means serves as said first portion to support said elements from said envelope, and said second portion includes an annular member through which

said beam of electrons is directed, said annular member disposed in a heat transfer relation with said conduit means.

7. An electron discharge device as claimed in claim 6, wherein said conduit means includes a plurality of U-shaped tubes having first and second leg portions for supporting said elements and a bight portion, said annular members disposed within said bight portions of said tubes.

8. An electron discharge device comprising a tubular envelope, means for generating and projecting an electron beam, means for receiving said electron beam, a wave structure for propagating electromagnetic waves within a predetermined frequency band having a midfrequency corresponding to a free-space wavelength of λ_0, said wave structures disposed in an interacting relation with said electron beam and including a plurality of elements having an end thereof supported upon said envelope and the other end extending freely within said envelope, each of said elements having first and second portions disposed in substantially the same plane, said second portion having an aperture therein, said elements disposed so that said electron beam is directed along a path substantially perpendicular to said plane of said elements through said apertures, and electrically conductive means interconnecting adjacent elements at points oppositely disposed about said apertures, said second portion supported by said first portion from the supported end of said elements a distance substantially equal to $n\lambda_0/4$ where n is a positive odd integer and magnetic means for confining the diameter of said electron beam, said magnetic means including a base and said plurality of elements extending from said base, said first portions of said elements comprising a magnetic material, said adjacent first portions being of opposite magnetic polarity.

9. An electron discharge device comprising a tubular envelope, means for generating and projecting an electron beam, means for receiving said electron beam, a wave structure for propagating electromagnetic waves within a predetermined frequency band having a midfrequency corresponding to a free-space wavelength of λ_0, said wave structures disposed in an interacting relation with said electron beam and including a plurality of elements having an end thereof supported upon said envelope and the other end extending freely within said envelope, each of said elements having first and second portions disposed in substantially the same plane, said second portions having an aperture therein, said elements disposed so that said electron beam is directed along a path substantially perpendicular to said plane of said elements through said apertures, and electrically conductive means interconnecting adjacent elements at points oppositely disposed about said apertures, said second portion supported by said first portion from the supported end of said elements a distance substantially equal to $n\lambda_0/4$ where n is a positive odd integer and a comb-like structure made of magnetic material and including a base and a plurality of said first portions extending therefrom, said adjacent first portions being magnetically oriented in opposite directions to thereby confine the diameter of said electron beam.

10. An electron discharge device comprising a tubular envelope, means for generating and projecting an electron beam, means for receiving said electron beam, a wave structure for propagating electromagnetic waves within a predetermined frequency band having a midfrequency corresponding to a free-space wavelength of λ_0, said wave structures disposed in an interacting relation with said electron beam and including a plurality of elements having an end thereof supported upon said envelope and the other end extending freely within said envelope, each of said elements having first and second portions disposed in substantially the same plane, said second portion having an aperture therein, said elements disposed so that said electron beam is directed along a path substantially perpendicular to said plane of said elements through said apertures, and electrically conductive means interconnecting adjacent elements at points oppositely disposed about said apertures, said second portion supported by said first portion from the supported end of said elements a distance substantially equal to $n\lambda_0/4$ where n is a positive odd integer and a first comb-like structure of magnetic material and including a base and a plurality of said first portions extending therefrom, and a second comb-like structure of magnetic material including a base and a plurality of said first portions extending therefrom, said first portions of said first assembly being interposed between the first portions of said second assembly, said adjacent first portions being magnetically oriented to be of opposite polarity to thereby confine the diameter of said electron beam.

11. An electron discharge device as claimed in claim 10, wherein said first portions of said first assembly are magnetically orientated in the same direction, and said first portions of said second magnetic assembly are magnetically orientated in the same direction.

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ELI LIEBERMAN, *Primary Examiner.*

SAXFIELD CHATMON, JR., *Assistant Examiner.*

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