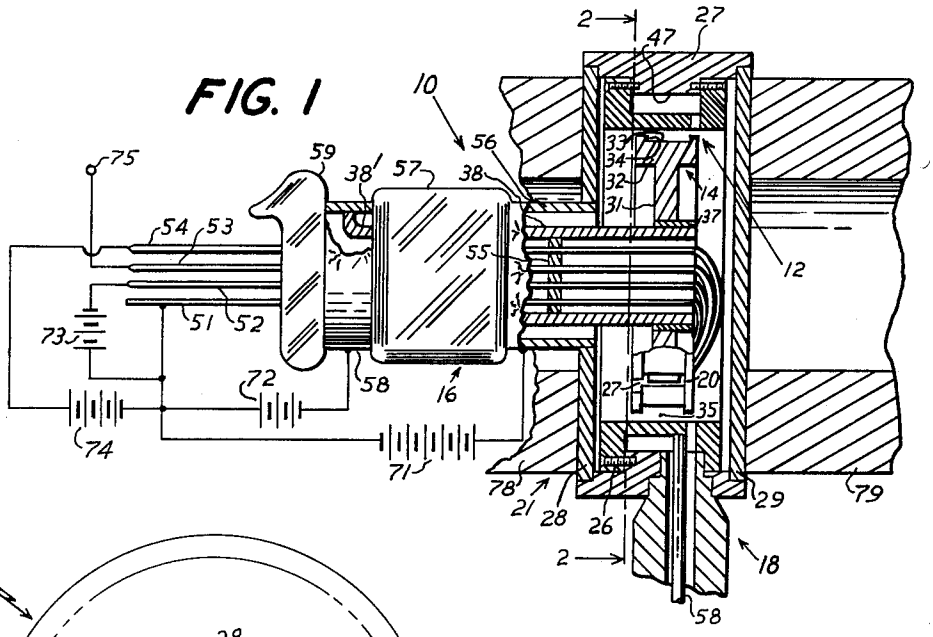
July 24, 1962 E. C. DENCH 3,046,443

TRAVELING WAVE TUBES

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FIG. 1



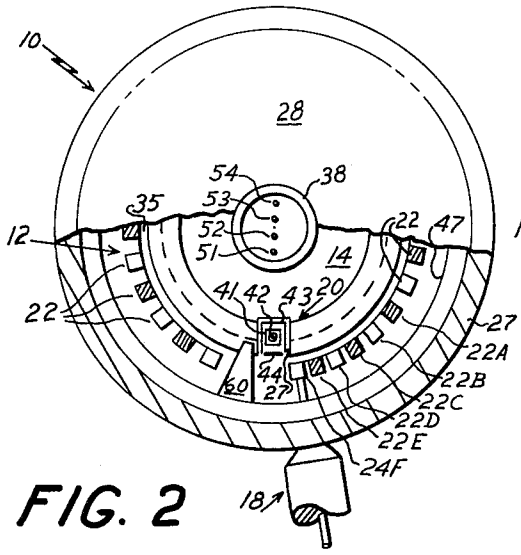


FIG. 2

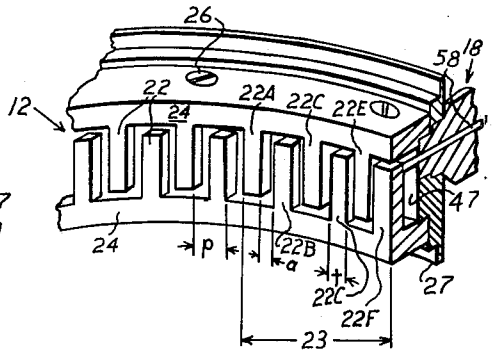


FIG. 3

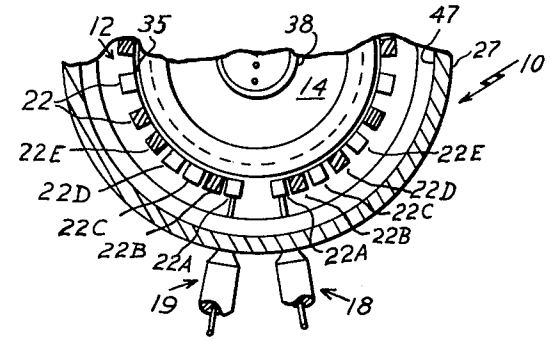


FIG. 4

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TRAVELING WAVE TUBES

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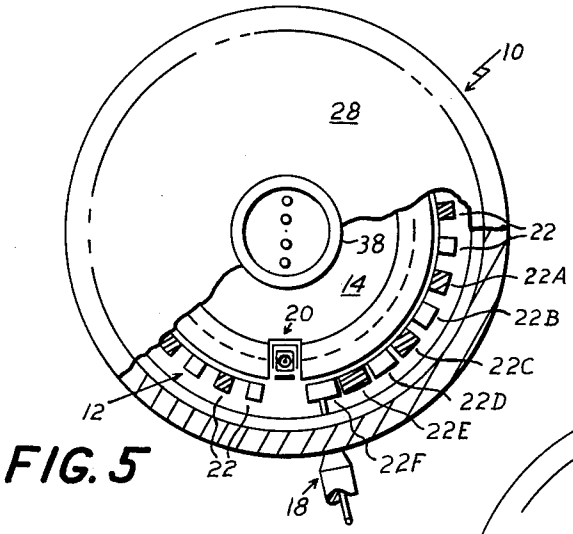


FIG. 5

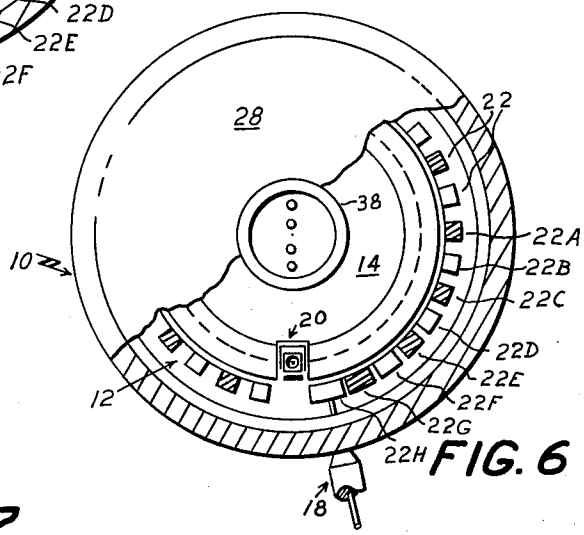


FIG. 6

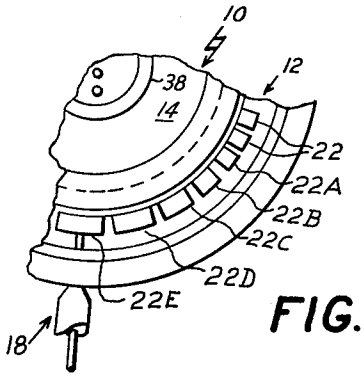


FIG. 7

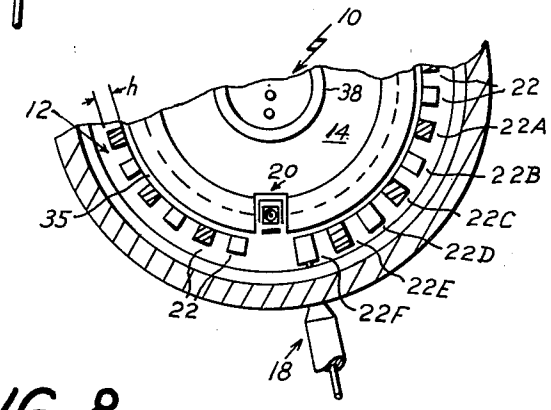


FIG. 8

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3,046,443

TRAVELING WAVE TUBES

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10 Claims. (Cl. 315—39.3)

This invention relates to a traveling wave electron discharge device in which certain parameters of the slow wave propagating structure thereof are progressively varied so as to provide an impedance match between the slow wave structure and an external coupling means.

Traveling wave tubes which depend upon interaction between an electron beam and high frequency fields of wave energy propagating along a slow wave structure or delay line are well known. In these tubes, energy may be transferred from the electron beam to the high frequency field when the electron beam velocity is substantially synchronized with the phase velocity of the high frequency field. A signal introduced into one end of such a delay line may be amplified, or the tube under certain conditions may be made to oscillate by virtue of this energy exchange.

One of the problems involved in traveling wave tubes designed for operation at relatively low frequencies is that of matching the impedance of the slow wave structure or delay line with the impedance of an input or output coupling means. For example, the impedance of an interdigital delay line may be of the order of 150 ohms, while that of a coaxial input or output coupling means is of the order of 50 ohms. If the delay line configuration along its entire length is unchanged, it is necessary, in order to obtain the desired impedance match, to use a transition means, such as a quarter wave transformer, positioned external to the delay line between the end of the delay line and the coaxial coupling means. Since the length of a quarter wave transformer is inversely proportional to frequency, such a transition means becomes unduly large at frequencies in the range of about 500 to 1500 megacycles, or lower. For example, at 500 megacycles, a quarter wave length is 15 centimeters; consequently, the length of the external coupling means, exclusive of the coaxial line, would be approximately six inches. The length of the coaxial conductor required for coupling energy into or from the delay line at such frequencies becomes excessive, particularly in applications requiring a minimum of space for equipment.

In accordance with this invention, the impedance of the traveling wave tube delay line is matched to that of the external coupling means by progressively altering certain parameters of the interdigital delay line. The impedance of an interdigital delay line increases as the space between adjacent edges of adjacent fingers increases and decreases with decreased separation between fingers. This finger separation may be accomplished in two ways. Firstly, the pitch, that is the distance between corresponding points on two adjacent fingers, may be held constant while the finger thickness is altered. Secondly, the finger thickness may be maintained constant while the pitch is varied. Both methods of varying the finger separation, of course, may be employed in the same traveling wave tube.

The impedance of the interdigital delay line also increases as the height of the fingers decreases, and vice versa. The finger height is the dimension of the finger measured from the tip to the edge adjacent the back wall of the delay line. This last method of varying impedance may be used together with any one of the two alternative methods previously mentioned.

If the delay line impedance is greater than that of the external coupling means, the transition region of delay line between the major portion of the delay line and the external coupling means would be characterized by gradually decreasing finger separation (accomplished either by gradually decreasing the finger thickness or by gradually decreasing the pitch), or by gradually increasing the height of the fingers, as the coupling means is approached. In those instances wherein the delay line impedance is lower than that of the external coupling means, the direction of variation of the parameters mentioned above obviously would be reversed.

If the traveling wave tube is an oscillator, only one coupling means, namely, the output coupling means and one transition region, would be required; if, on the other hand, the traveling wave tube is an amplifier, an input and output coupling means, as well as a transition region, at or near both ends of the delay structure, would be employed.

The type of coupling means is immaterial to the invention; for example, a coaxial line or a waveguide may be used to couple energy into or out of the traveling wave tube.

Other objects and features of this invention will be understood more fully from the following detailed description of the invention with reference to the accompanying drawings wherein:

FIG. 1 is a longitudinal cross-sectional view, partly in elevation, of a traveling wave oscillator which may incorporate a delay line according to the invention;

FIG. 2 is a sectional view, partly in elevation, taken along line 2—2 of FIG. 1;

FIG. 3 is a detail view of a portion of the delay line of the traveling wave oscillator of FIGS. 1 and 2;

FIG. 4 is a fragmentary sectional view of a traveling wave amplifier using the type of delay line construction indicated in FIGS. 2 and 3;

FIG. 5 is a sectional view, partly in elevation, of a traveling wave tube showing another type of delay line construction in accordance with the invention;

FIG. 6 is a sectional view, partly in elevation, of a traveling wave tube illustrating one combination of the types of delay line construction shown in FIGS. 2 and 5;

FIG. 7 is a fragmentary sectional view of a traveling wave tube illustrating another combination of the types of delay line construction shown in FIGS. 2 and 5; and

FIG. 8 is a sectional view of a traveling wave tube illustrating still another type of delay line construction in accordance with the invention.

Referring now to FIGS. 1 to 3, a traveling wave tube **10**, herein shown as an oscillator, comprises a periodic slow wave energy propagating structure or delay line **12**, an elongated electrode **14**, referred to as a sole, a lead-in assembly **16**, an output coupling means **18**, an electron gun assembly **20**, and a magnetic field-producing means **21**, a portion of which is illustrated in FIG. 1. The circular delay line **12** includes several interdigital fingers or elements **22** which extend from oppositely disposed annular members **24**. The latter may be secured, as by screws **26**, to the shoulder portion of a cylindrical electrically-conductive ring **27**. The remainder of the slow wave structure **12** includes a pair of oppositely disposed cover plates **28** and **29** hermetically sealed to ring **27**.

The sole **14**, which is arranged concentric with the delay line **12**, and which is normally maintained negative with respect to the delay line, consists essentially of a cylindrical block of electrically-conductive material which includes a web portion **31** bounded by an outer section **32** whose periphery consists of an active surface **33** and side members **34**. The purpose of the side members **34** is to confine the electron beam within the interaction space **35** between the active surface **33** of sole **14** and the interdigital delay line **12**. A tubular metallic insert **37** is brazed into position against the inner periphery of a centrally disposed aperture in the web portion **31** of sole **14**. One end of a hollow supporting member **38** is located

within the insert **37** and is fixedly attached thereto. Supporting member **38**, in addition to providing support for the sole **14**, forms a portion of lead-in assembly **16** and allows for passage of external circuit connecting leads in a manner to be described subsequently.

Sole **14** contains a slot **27** for accommodating the electron gun assembly **20**. Since the invention does not involve details of the electron gun, the latter is shown schematically in the drawing. The construction and manner of mounting of the electron gun **20** may be as shown in a copending application of Roy A. Paananen, Serial No. 717,897, filed February 27, 1958, now Patent No. 2,914,-700. The electron gun assembly **20** includes a cathode **41**, a heater **42**, a grid **43** which may be used for control of beam current (as for amplitude modulation, in the case of an oscillator) and an accelerating electrode **44**. The cathode **41** may be in the form of a rectangular prism provided with a circular bore in which a folded heater wire **42** is inserted; the heater may be connected at one end to the inner wall of the cathode. Electrical energy from appropriate sources is supplied to the cathode **41**, heater **42**, grid **43**, and accelerating electrode **44** by way of respective lead-in wires **51**, **52**, **53**, and **54**, which are brought out from the tube envelope through the lead-in assembly **16**.

Lead-in assembly **16** includes an electrically-conductive sleeve **56** attached to the inner periphery of cover plate **29**, as indicated in FIG. 1. A section of cylindrical glass tubing **57** interconnects sleeve **56** and a second electrically-conductive sleeve **58**. The other end of sleeve **58** is provided with a glass seal **59** for sealing the traveling wave tube **10** after evacuation. One end of the sole-supporting member **38** contains an outwardly flared portion **38'** which is connected to the inner surface of sleeve **58**. The leads **51**, **52**, **53**, and **54** are mounted in electrically insulated relation with supporting member **38** and form one another by one or more glass beads **55**.

The coaxial output coupling means **18** is sealed in an opening of ring **27** of delay line **12** and is impedance-matched to the delay line, in a manner to be described later. The inner conductor **58** of the output coupling means **18** is connected to a finger of delay line **12** at or near the end of the delay line adjacent electron gun **20**.

Traveling wave tube **10** may be provided with a collector electrode **60** for intercepting electrons after one traversal of the circular interaction space **35**. This collector electrode may be in the form of a projection from the back wall **47** of delay line **12** or may be a dependent structure maintained at an electrical potential of about the same order of magnitude as that of the delay line. In some instances, however, the collector electrode may be omitted and the electron stream made reentrant. This type of construction is shown in FIGS. 5, 6, and 8.

The necessary electric field between the slow wave structure **12** and sole **14** may be obtained by means of a unidirectional voltage applied therebetween; such a voltage may be supplied by batteries **71** and **72**. The sole **14** may be biased negatively relative to the cathode **41** by means of the source **72** connected between cathode lead **51** and sole supporting member **38** by way of sleeve **58**. The cathode **41** may, however, in some instances be at the same potential as the sole, in which case the source **72** would be omitted. Similarly, the delay line **12** may be maintained at a potential positive relative to both sole **14** and cathode **41** by means of the source **71** of unidirectional voltage connected between the cathode and sleeve **56**, which sleeve is connected, in turn, to delay line **12**. The heater voltage is obtained by means of a source **73** of voltage connected to leads **51** and **52**. The accelerating electrode **44** may be maintained at a potential positive relative to the cathode **41** by means of a source **74** of unidirectional voltage connected between leads **51** and **54**. The control grid lead **53** may be connected by way of terminal **75** to an appropriate energy source for controlling the magnitude of the electron beam current in the traveling wave tube.

A uniform magnetic field transverse to the direction of propagation of an electron beam is provided by a permanent magnet or electromagnet having cylindrical pole pieces **78** and **79** radially positioned on or adjacent the anode cover plates **28** and **29**, respectively. Pole piece **78** is apertured to receive lead-in assembly **16**, and pole piece **79** is apertured to maintain symmetry of the magnetic field. The magnetic flux should be concentrated in the interaction space **35** between the sole **14** and the delay line **12** and are generally transverse to the electric field lines between the sole **14** and delay line **12**. By proper adjustment of the magnitude and polarity of the magnet and electric fields thus established, the electron beam may be caused to move along a more or less circular path in the interaction space **35** under the combined influence of these transversely disposed fields.

As shown clearly in FIGS. 2 and 3, a major portion of the interdigital delay line **12** according to the invention is of uniform configuration wherein the space between adjacent fingers **22**, as well as the height and thickness of the fingers, is uniform. The fingers in this major portion of uniform configuration are indicated simply by the reference numeral **22**, in contrast with the fingers in the transition region **23**, now to be described, which are referred to by the reference numeral **22** with a letter. The transition region **23** of delay line **12** of FIGS. 2 and 3 comprises fingers **22A . . . 22E** wherein the separation between fingers, that is, the dimension "*a*" in FIG. 3, or the pitch "*p*" between corresponding points on adjacent fingers, is gradually decreased as the output coupling means **18** is approached, while the thickness "*t*" of the fingers is maintained constant. In this manner, the impedance of the delay line in the transition region progressively decreases as the distance from the output coupling means decreases.

The same type of delay line construction is shown in FIG. 4, except that the device of FIG. 4, being an amplifier, has an output coupling means **18** at one end of the delay line **12** and an input coupling means **19** at the other end of the delay line. For this reason, both ends of the delay line have transition regions including fingers **22A . . . 22E**.

It will be noted that the tube of FIG. 4, in addition to differing from the tube of FIG. 2 in that it is an amplifier rather than an oscillator, further differs in that the negative electrode **14** of the tube of FIG. 4 may serve as a continuous cathode and the localized electron gun **20** of FIG. 2 is omitted. The continuous cathode of the tube of FIG. 4 may be used with the oscillator of FIG. 2 or the localized electron gun **20** of FIG. 2 may be used with the amplifier of FIG. 3. In other words, the type of electron beam source used is not a part of the invention and does not depend upon the type of delay line transition region employed. It should also be noted that the collector electrode **60** of FIG. 2 may be used with a continuous cathode of the type shown in FIG. 4 when a non-reentrant electron beam is desired.

Although there are six fingers shown in the transition region of the device of FIGS. 2 and 3, and five fingers illustrated in the transition region of the device shown in FIG. 4, the number of such fingers is not limited to any particular number but depends upon the various parameters of the tube and of the external coupling means, such as the relative impedance of the uniform portion of the delay line **12** and the coupling means, the size of the fingers of the delay line, which may be dictated, to some extent, by the power capability of the tube, etc. Moreover, the taper of the interdigital delay line **12** in the devices of FIGS. 2 to 4, as well as those of FIGS. 5 to 7, may be linear, exponential, or any other configuration which permits the characteristic impedance of the delay line to change gradually along the transition region as the external coupling means is approached.

FIG. 5 illustrates another type of transition region **23** whereby the characteristic impedance of the delay line

may be progressively varied. Here, as in the delay lines of FIGS. 2 to 4, the fingers 22A . . . 22E in the transition regions are constructed so that the finger separation, and consequently, the impedance of the transition region of the delay line 12, progressively decreases as the external coupling means is approached. In contrast with the delay lines of FIGS. 2 and 4, the decrease in finger separation in FIG. 5 is obtained by maintaining the pitch constant while varying the finger thickness. If the impedance of the output coupling means were greater than that of the delay line, the finger thickness would be made to decrease in the direction of the output coupling means; in other words, the impedance of the transition region would increase in the direction of the output coupling means. The type of transition described in FIG. 5, may, like that previously referred to, be incorporated in an amplifier as well as in an oscillator; in such a case, a transition region would be located at both ends of the delay line 12, in the manner shown in FIG. 4.

In FIG. 6, the transition region of the delay line 12 incorporates one possible combination of the two types of progressive variation in finger separation previously described. The portion of the transition region including fingers 22A, 22B, and 22C is characterized by variable pitch and constant finger thickness, as in the device of fingers 2 and 3, while the portion of the transition region including fingers 22D . . . 22H is characterized by constant pitch and variable finger thickness, as in the device shown in finger 5. The configuration of the transition region of the delay line in FIG. 6 illustrates only one of many possible combinations of the two methods of achieving variable finger separation already described. For example, the fingers 22A . . . 22C may be of constant pitch and variable finger thickness and the fingers 22D . . . 22H may be of constant finger thickness and variable pitch. Furthermore, there could be more than one group of fingers of each type of construction in the transition region of the delay line. The arrangement shown in FIG. 6 is equally applicable to a traveling wave amplifier.

Another possible combination of the two types of progressive variation in the transition region previously described is illustrated in FIG. 7. The portion of the transition region including fingers 22A . . . 22E is characterized by a simultaneous variation of finger thickness and pitch, the pitch being measured with reference to the center lines of the fingers. As shown in FIG. 7, the spacing between center lines of the fingers 22A . . . 22E progressively increases as the external coupling means 18 is approached and, concurrently, the thickness of the fingers 22A . . . 22E progressively increases as the output coupling means 18 is approached. The center line-to-center line spacing and thickness may be progressively decreased as the output coupling means 18 is approached in cases where the characteristic impedance of the delay line 12 is less than that of the coupling means. The arrangement of the transition region shown in FIG. 7 is applicable to amplifiers, as well as to oscillators.

In FIG. 8, a traveling wave tube is shown wherein the delay line transition region between the uniform portion of the delay line and the coaxial output coupling means includes fingers 22A . . . 22F whose height *"h"* is increased progressively as the output coupling means 18 is approached. In this manner, the impedance of the transition region of the delay line 12 decreases as the output coupling means is approached. If the impedance of the delay line should be less than that of the output coupling means, however, the height of the fingers 22A . . . 22F would decrease progressively rather than increase in the direction of the output coupling means. The configuration of the transition region of the delay line 12 of FIG. 8 may be used at both ends of the delay line in the event that the tube of FIG. 8 is a traveling wave amplifier.

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. 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 periodic interdigital slow wave energy propagating structure having a plurality of interdigital fingers and constructed to produce along a path adjacent thereto fields of electromagnetic wave energy being transmitted, means for directing a beam of electrons along said path in energy-exchanging relation with said wave fields, and external energy coupling means coupled to said structure, said structure including a major region and a transition region disposed between said major region and said external energy coupling means, the dimensions of the fingers transverse to said path in said transition region being progressively varied, said energy coupling means being coupled directly to one of said fingers.

2. A traveling wave oscillator comprising a periodic interdigital slow wave energy propagating structure having a plurality of interdigital fingers and constructed to produce along a path adjacent thereto fields of electromagnetic wave energy being transmitted, means for directing a beam of electrons along said path in energy-exchanging relation with said wave fields, and external energy output coupling means coupled to said structure adjacent the end thereof away from which electrons move along said path, said structure including a major region and a transition region disposed between said major region and said external energy coupling means, the dimensions of the fingers transverse to said path in said transition region being progressively varied, said energy coupling means being coupled directly to one of said fingers.

3. In combination, a periodic interdigital slow wave energy propagating structure having a plurality of interdigital fingers and constructed to produce along a path adjacent thereto fields of electromagnetic wave energy being transmitted, means for directing a beam of electrons along said path in energy-exchanging relation with said wave fields, an external energy coupling means coupled to said structure, said structure including a major region and a transition region disposed between said major region and said external energy coupling means, the pitch of said transition region being constant and the height of the fingers in said transition region being progressively varied, said energy coupling means being coupled directly to one of said fingers.

4. In combination, a periodic interdigital slow wave energy propagating structure having a plurality of interdigital fingers and constructed to produce along a path adjacent thereto fields of electromagnetic wave energy being transmitted, means for directing a beam of electrons along said path in energy-exchanging relation with said wave fields, and external energy coupling means coupled to said structure, said structure including a major region and a transition region disposed between said major region and said external energy coupling means, the thickness of the fingers in said transition region being maintained constant and the pitch and height of the fingers in said transition region being progressively varied, said energy coupling means being coupled directly to one of said fingers.

5. In combination, a periodic interdigital slow wave energy propagating structure having a plurality of interdigital fingers and constructed to produce along a path adjacent thereto fields of electromagnetic wave energy being transmitted, means for directing a beam of electrons along said path in energy-exchanging relation with said wave fields, and external energy coupling means coupled to said structure, said structure including a major region and a transistion region disposed between said major region and said external energy coupling means, the height and the distance between adjacent edges of adjacent fingers in said transition region being progressively

varied, said energy coupling means being coupled directly to one of said fingers.

6. In combination, a periodic interdigital slow wave energy propagating structure having a plurality of interdigital fingers and constructed to produce along a path adjacent thereto fields of electromagnetic wave energy being transmitted, means for directing a beam of electrons along said path in energy-exchanging relation with said wave fields, and external energy coupling means coupled to said structure, said structure including a major region and a transition region disposed between said major region and said external energy coupling means, the distance between center lines of said fingers in said transition region and the height of said fingers in said transition region being simultaneously and progressively varied, said energy coupling means being coupled directly to one of said fingers.

7. In combination, a periodic interdigital slow wave energy propagating structure having a plurality of interdigital fingers and constructed to produce along a path adjacent thereto fields of electromagnetic wave energy being transmitted, means for directing a beam of electrons along said path in energy-exchanging relation with said wave fields, and external energy coupling means coupled to said structure, said structure including a major region and a transition region disposed between said major region and said external energy coupling means, said transition region including at least one portion wherein the thickness of said fingers is maintained constant and the pitch of said fingers is progessively varied, said transition region including at least one other portion wherein the pitch and height of said fingers is held constant and the height of said fingers is progressively varied, said energy coupling means bieng coupled directly to one of said fingers.

8. In combination, a periodic interdigital slow wave energy propagating structure having a plurality of interdigital fingers and constructed to produce along a path adjacent thereto fields of electromagnetic wave energy being transmitted, means for directing a beam of electrons along said path in energy-exchanging relation with said wave fields, and external energy coupling means coupled to said structure, said structure including a major region and a transition region disposed between said major region and said external energy coupling means, the height of the fingers in said transition region being progressively varied.

9. In combination, a periodic interdigital slow wave energy propagating structure having a plurality of interdigital fingers and constructed to produce along a path adjacent thereto fields of electromagnetic wave energy being transmitted, means for directing a beam of electrons along said path in energy-exchanging relation with said wave fields, external energy coupling means coupled to said structure, said structure including a major region, and means for matching the characteristic impedance of said major region to the characteristic impedance of said energy coupling means, said means for matching including a transition region disposed between said major region and said energy coupling means in which the dimensions of said fingers transverse to said paths are progressively varied so that the characteristic impedance of said transition region progressively varies from a value substantially equal to that of said major region to a value substantially equal to that of said coupling means as said coupling means is approached, said energy coupling means being coupled directly to one of said fingers.

10. In combination, a periodic interdigital slow wave energy propagating structure having a plurality of interdigital fingers and constructed to produce along a path adjacent thereto fields of electromagnetic wave energy being transmitted, means for directing a beam of electrons along said path in energy-exchanging relation with said wave fields, external energy coupling means coupled to said structure, said structure including a major region, and means for matching the characteristic impedance of said major region to the characteristic impedance of said energy coupling means, said means for matching including a transition region disposed between said major region and said energy coupling means, said transition region having a portion wherein the pitch of the fingers included therein is constant and the height and thickness thereof is progressively varied, said transition region further having a portion wherein the thickness of the fingers included therein is maintained constant and the pitch thereof is progressively varied, said energy coupling means being coupled directly to one of said fingers.

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