Sept. 26, 1961 R. W. PETER 3,002,123

TRAVELING WAVE TUBE STRUCTURE

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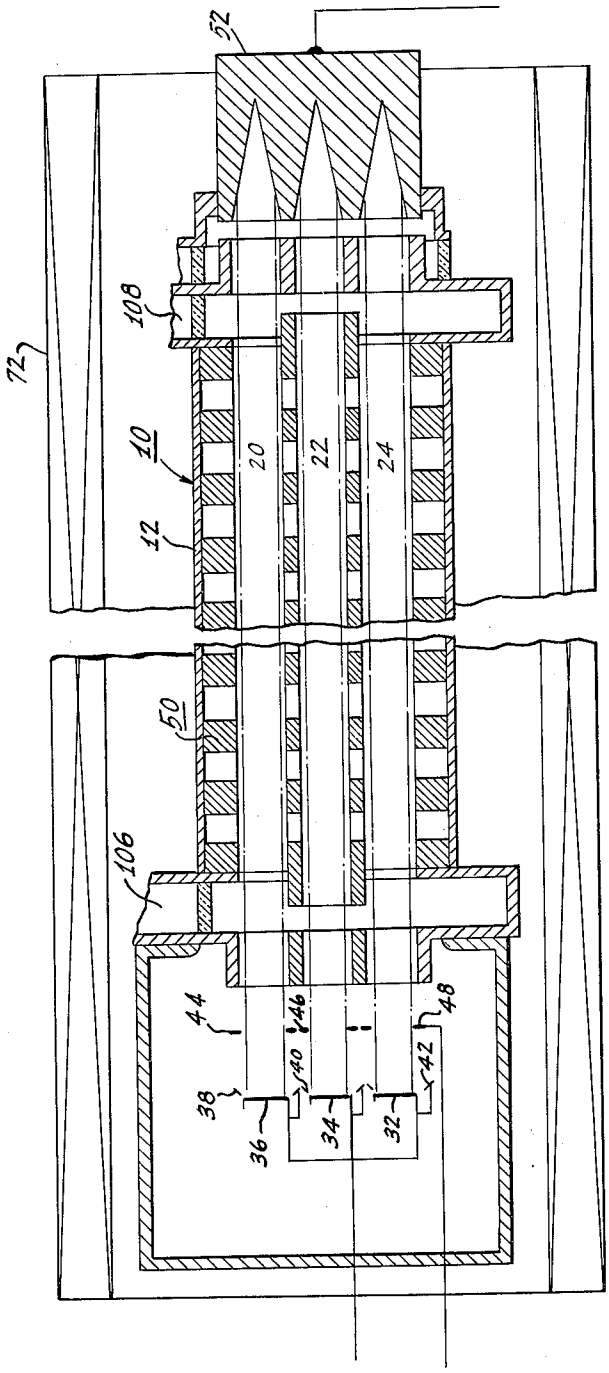


Fig. 1.

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Fig. 2.

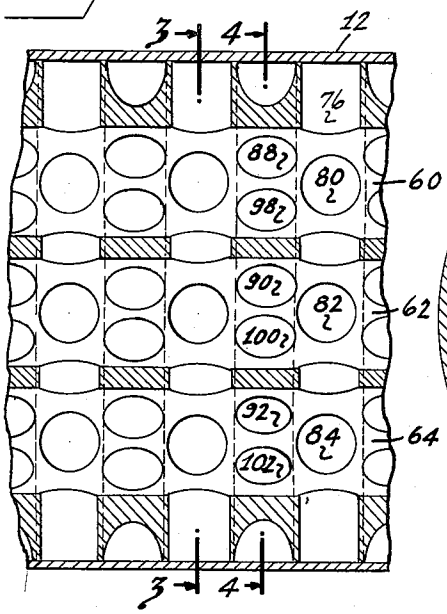
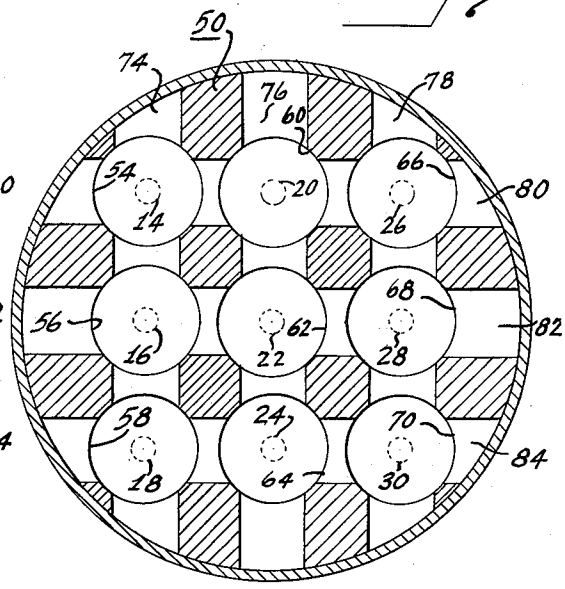


Fig. 3.



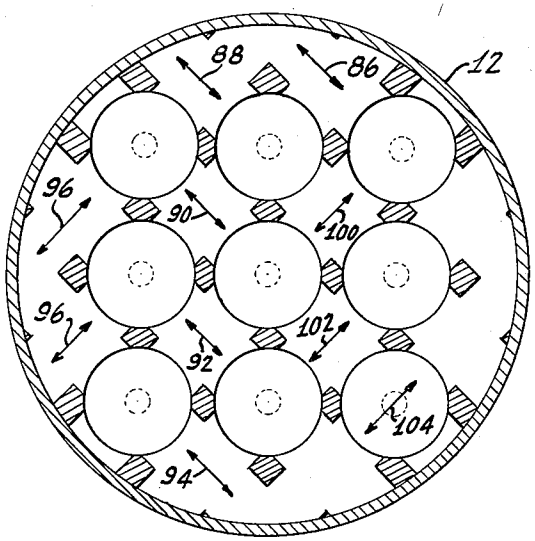


Fig. 4.

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TRAVELING WAVE TUBE STRUCTURE

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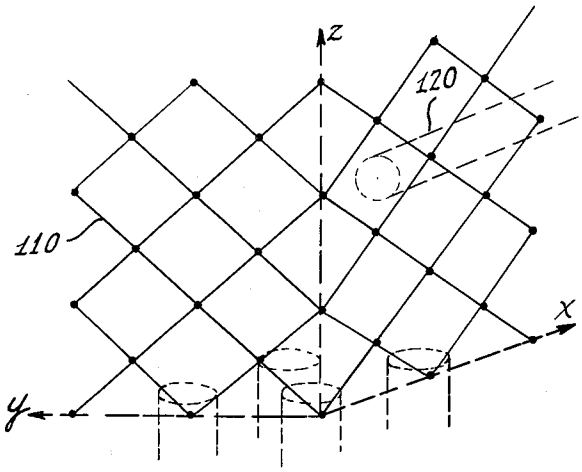
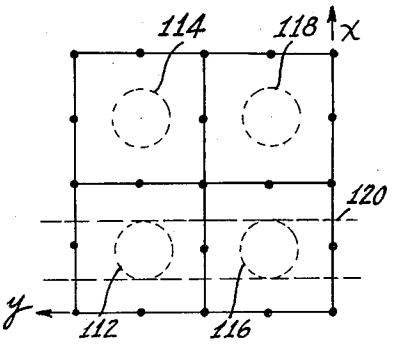


Fig. 5.

Fig. 6.



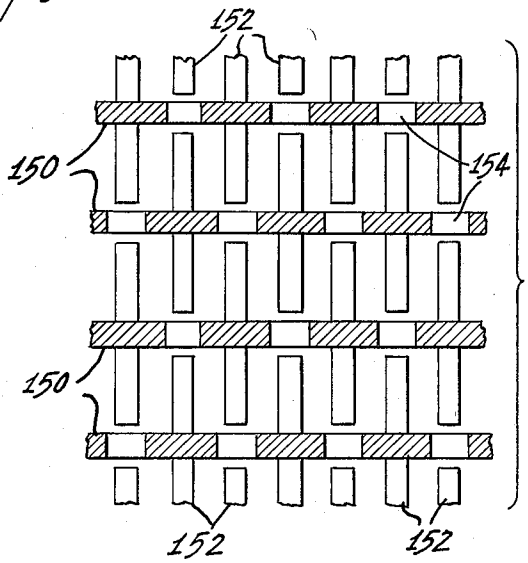


Fig. 10.

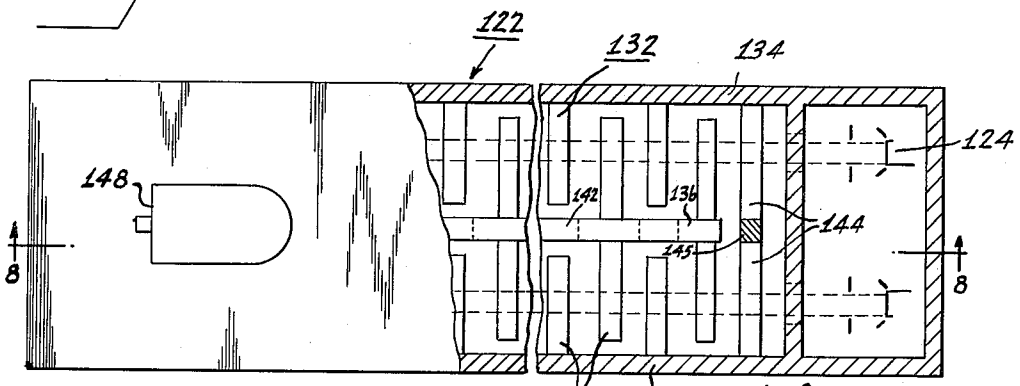
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TRAVELING WAVE TUBE STRUCTURE

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Fig. 7.



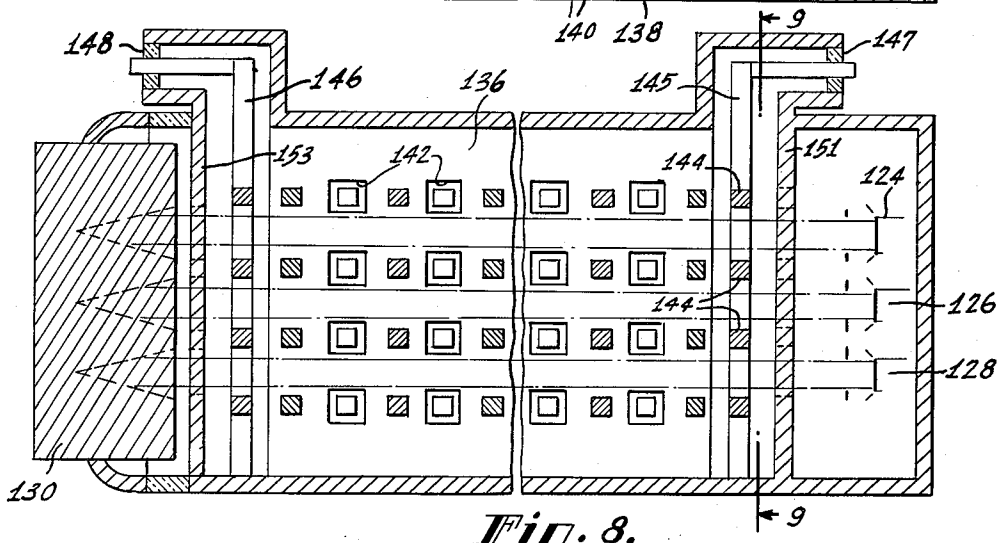


Fig. 8.

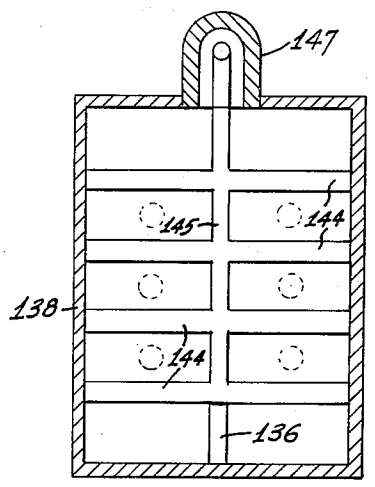


Fig. 9.

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United States Patent Office 3,002,123 Patented Sept. 26, 1961

3,002,123

TRAVELING WAVE TUBE STRUCTURE

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Filed Jan. 11, 1957, Ser. No. 633,604
3 Claims. (Cl. 315—3.6)

This invention relates to improvements in the art of traveling wave propagating structures and proves especially advantageous in traveling wave tubes. While not limited thereto, the invention is herein described as embodied in an improved delay line structure for such a tube.

In a traveling wave tube an electromagnetic signal wave is fed to one end of a suitable elongated, slow-wave propagating structure or delay line wherein the longitudinal velocity of the slow wave along the line is a fraction, say 1/13, of the velocity of light. An electron beam is projected along the line at a velocity approximately equal to the longitudinal wave velocity. Under such conditions the electron beam and the wave traveling on the delay line interact to cause the amplitude of the wave to increase exponentially; hence, an amplified signal is obtained at the output end of the tube. Actually, for maximum amplification the beam velocity should be slightly greater than the undisturbed longitudinal wave velocity of the delay line, that is, the wave velocity without the beam.

As is known, the power handling ability of a traveling wave tube is determined by the power carrying capacity of the delay line. When, for example, a conventional helix is used as the delay line of a traveling wave tube the helix diameter must be substantially smaller than ½ of the free space wavelength of the signal wave to be amplified. This requirement limits the maximum power that can be handled by the line, and also limits the maximum current of the electron beam projected adjacent to the line. The same limitations apply to previous delay lines of other types.

Accordingly, it is one of the objects of the invention to provide an improved traveling wave delay line structure which has a relatively high power carrying capacity.

Another object of the invention is the provision of an improved traveling wave tube having a relatively large current electron beam and a delay line having a relatively large power carrying capacity.

The foregoing and related objects are realized in accordance with the invention by the provision of a three-dimensional slow wave propagating structure having a phase velocity in any direction therethrough substantially less than the velocity of light in free space. The structure has a dimension in each of three co-ordinate directions at least equal to one-half wavelength at the lowest frequency in the operating frequency range, which preferably would be above 1000 megacycles.

The invention will now be described in greater detail in connection with the accompanying drawing wherein:

FIGURE 1 is a partially schematic, longitudinal sectional view of a traveling wave tube embodying a "swiss-cheese" like delay line according to the invention;

FIGURE 2 is an enlarged longitudinal sectional view of a portion of the tube illustrated in FIGURE 1;

FIGURE 3 is a transverse sectional view taken through line 3—3 of FIGURE 2;

FIGURE 4 is a transverse sectional view taken through line 4—4 of FIGURE 2;

FIGURE 5 illustrates schematically a portion of another delay line embodying the invention and exemplified in a zig-zag conductor delay line structure;

FIGURE 6 is a plan view of the delay line portion illustrated in FIGURE 5;

FIGURE 7 is a partially schematic plan view of a

portion of a traveling wave tube having an interdigital delay line structure according to another embodiment of the invention;

FIGURE 8 is a longitudinal sectional view taken through line 8—8 of FIGURE 7;

FIGURE 9 is a transverse sectional view taken through line 9—9 of FIGURE 8; and

FIGURE 10 is a sectional view of a portion of a traveling wave tube having an interdigital delay line structure and illustrating another aspect of the invention.

Referring now to the drawing in greater detail, there is shown in FIGURES 1 to 4 an elongated traveling wave tube 10 embodying an aspect of the invention. The traveling wave tube 10 includes a conductive envelope 12, which may be of a magnetically transparent material such as copper, and containing the various internal tube elements. A plurality of relatively dense beams of electrons 14, 16, 18, 20, 22, 24, 26, 28, and 30 (nine being used in the embodiment illustrated in FIGURES 1–4) are thermionically emitted from a number of cathodes 32, 34, and 36, one cathode for each beam. The cathodes 32, 34, and 36 are connected to a common lead and are each provided with a heater (not shown). Apertured focusing electrodes 38, 40, and 42 and apertured accelerating electrodes 44, 46, and 48 are provided, one for each cathode. Each of the focusing electrodes 38, 40, and 42 is connected to its cathode as indicated in FIGURE 1. Each accelerating electrode is supplied with a positive bias, with respect to its cathode, so that electrons from each of the cathodes are accelerated toward its accelerating electrode. The electrons of each beam pass through its accelerating electrode apertures and into a delay line structure 50, to be described, and drift toward a relatively high positively biased collector electrode 52.

According to the invention, there is provided a novel delay line structure 50 which has a relatively high power carrying capacity. This delay line 50, in the embodiment illustrated in FIGURES 1 to 4, has a generally "swiss-cheese" configuration and will be so referred to hereinafter. This swiss-cheese delay line 50 is a signal wave propagating structure comprised of an elongated block having aligned openings defining a three dimensional lattice of conducting walls defining intersecting passageways therethrough. In the embodiment illustrated each of the passageways has a circular cross section. The arrangement of passageways provides a structure in which the phase velocity of the delay line is reduced in any direction therethrough to a velocity substantially less than the velocity of light in free space. The delay line has a dimension in each of three co-ordinate directions at least equal to one half wavelength at the lowest operating frequency of the line, the frequency range being preferably above about 1000 megacycles. In the delay line 50 illustrated in the drawing, nine passageways 54, 56, 58, 60, 62, 64, 66, 68, and 70 are adapted to pass nine electron beams 14 to 30 longitudinally therethrough for interaction with a signal wave propagated along the line.

As illustrated in FIGURES 2 to 4, the reduced phase velocity of the delay line 50 is realized by virtue of the passageways therethrough. These passageways, in the delay line illustrated, comprise the nine longitudinally oriented passageways 54 to 70 and a number of longitudinally spaced sets of transversely oriented passageways. Each set of transversely oriented passageways is made up of a number of passageways in a common plane. The sets of transverse passageways consist of two different passageway orientations, with sets of one orientation alterating with sets of the other. The axis of each transverse passageway which passes through a longitudinal passageway passes through the axis of the longitudinal passageway.

The configuration of one set of transverse passageways is illustrated in FIGURE 3 and the configuration of transverse passageways of the other set is illustrated in FIGURE 4. The first of the two sets illustrated in FIGURES 2 and 3 is comprised of six passageways in two perpendicularly oriented arrays each made up of three passageways **74**, **76**, and **78**, and **80**, **82**, **84**, respectively. Each of the passageways in this first set passes through three of the longitudinally extending beam passageways. The second of the two sets, illustrated in FIGURES 2 and 4, is comprised of ten passageways in two perpendicularly oriented arrays each made up of five passageways **86**, **88**, **90**, **92**, and **94**, and **96**, **98**, **100**, **102**, and **104**, respectively, the direction of elongation of each passageway being indicated in FIGURE 4 by a double headed arrow. Four of the passageways (namely **86**, **94**, **96**, and **104**) in this second set each passes through only one of the longitudinally extending beam passageways, four pass through only two of the beam passageways, and two pass through three beam passageways. Adjacent sets have the direction of orientation of each of the passageways offset transversely 45° from the passageways in the adjacent set. The relatively massive nature of the delay line described provides a relatively large and efficient heat sink and allows the tube **10** to be operated at relatively high power levels.

While the swiss cheese delay line **50** has been described as embodied in a line having a given orientation and number of longitudinal and transverse passageways, it will be appreciated that a different orientation and number of longitudinal and transverse passageways may instead be used. Also, while the passageways have been described as being of circular cross section, some or all of the passageways may instead have cross sections of other shapes to provide different delay line characteristics or to accommodate differently shaped electron beams.

The delay line is made of a magnetically transparent material such as copper in order to allow magnetic flux from a focusing solenoid **72** around the tube **10** to penetrate the delay line and maintain the electron beams focused along their paths of travel.

In operation (FIGURES 1 to 4) a signal wave is fed into the tube through an input wave guide **106** where transverse and longitudinal signal wave components are excited in the delay line **50**. The longitudinal wave velocity along the line is reduced by the line to a small fraction of the velocity of light. The electric potentials on the tube electrodes are adjusted so that the electron beams are projected along the delay line at a velocity slightly greater than the undisturbed longitudinal wave velocity. Under such conditions, each of the electron beams and the wave components traveling longitudinally of the delay line interact to cause the amplitude of the wave to increase exponentially. Consequently, an amplified signal is obtained at the output end of the tube at the output wave guide **108**. Since the delay line of the invention allows the use of a large number of electron beams with a single delay line the tube is adapted to provide a relatively high power output. Actually, the power capabilities of the tube are determined by the heat conduction of the line in the transverse direction. Consequently, the delay line structure described provides a great advantage in terms of high power amplification in the microwave frequency range.

One practical way of constructing the swiss-cheese delay line **50** described is by taking a cylindrical block of copper and boring passageways therethrough as shown in FIGURES 2 to 4. After the passageways have been bored the cylindrical block is slid into a copper sleeve which is to form a part of the envelope **12**, for closing off the passageways thus providing a closed three-dimensional lattice of passageways.

While the swiss-cheese delay line described has been illustrated as having both longitudinal and transverse passageways for receiving electron beams therethrough and for reducing the phase velocity of the line to substantially less than the speed of light, it will be appreciated that additional passageways may be incorporated in the line to provide for water cooling of the line and thus increase its power handling capacity. However, such additional passageways have been omitted in the drawing for simplicity of illustration.

FIGURES 5 and 6 show, as another form of the invention, a delay line **110** having a zig-zag arrangement of wires connected together to form a three-dimensional lattice of intersecting passageways. As is the case in the swiss cheese delay line of FIGURES 1 to 4, the zig-zag delay line of FIGURES 5 and 6 have dimensions in each of three co-ordinate directions *x*, *y*, and *z* at least one half wave length of the lowest frequency of the frequency range of the tube. In the drawing, only the wires in two planes are illustrated, namely those in the planes *yz* and *xz*. The structure illustrated may, for example, be made of a number of flat zig-zag wires welded together at the apexes. The zig-zag delay line **110** is excited by signal wave and a plurality of electron beams **112**, **114**, **116**, and **118** are projected from suitably positioned electron guns (not shown) through the delay line. The interaction between the signal wave on the delay line **110** and the electron beams **112** to **118** is effected in substantially the same manner as that between the beams and delay line in the structures of FIGURES 1 to 4 to amplify the signal wave.

According to a feature of the invention, interaction may be provided in an electron tube between electron beams traveling in different directions in order to produce mixing or modulation. For example, another electron beam **120** may be projected from another suitably positioned electron gun (not shown) and through the zig-zag delay line **110** and through some of the other electron beams **112** and **116**. In such an event the beams having paths of travel in different directions interact with different space harmonic waves of the signal wave propagated along the line **110** to provide interaction simultaneously between each of the electron beams **112** to **120** and the relay line **110**.

In order to improve the power carrying capacity of the delay line **110**, the line may be electroplated to provide a relatively massive delay line structure defining a lattice of intersecting passageways.

As shown in FIGURES 7 to 9, a delay line according to the invention may take the form of an interdigital structure. In the traveling wave tube **122** of FIGURES 7 to 9 there is provided the usual electron guns **124**, **126**, and **128** at one end of the tube, a collecting electrode **130** at the other end of the tube, and an interdigital delay line **132** between the electron guns and the collecting electrode.

The interdigital delay line **132** here comprises three parallel, digitated wall-like delay line portions **134**, **136**, and **138**, the two outside portions **134** and **138** forming part of the envelope of the tube. Each of the wall-like portions **134**, **136**, and **138** have parallel, regularly spaced digits **140** extending transversely therefrom. The central wall delay line portion **136** has digits extending perpendicularly from both sides thereof and each of the other two portions **134** and **138** have digits extending perpendicularly only from the side of the portion facing the inside of the tube. The digits of the outside portions **134** and **138** are aligned with each other along axis perpendicular to the portions. The digits of the central portion **136** have their axes of transverse extension disposed intermediate adjacent longitudinally spaced digits of the outside delay line portions. The central portion **136** is provided with transversely extending passageways or apertures **142** at regions adjacent to the digits extending from the two outside portions so that adjacent digits of the two outside portions **134** and **136** can "see" each other through the apertures **142**. As illustrated in FIGURE 9, the end digits **144** of the two outside walls delay line portions extend into contact with each other and are connected to

each other at a position adjacent to the central portion **136** by means of a bus bar **145** and **146** at each end of the delay line **132**. The bus bars extend to the outside of the tube to provide, together with a portion of the tube envelope, the input **147** and output **148** of the tube. The longitudinal distances between each of the bus bars **145** and **146** and the end walls **151** and **153**, respectively, are chosen so that the impedance of the two conductor input and output lines **147** and **149** are each equal to the characteristic impedance of the delay line **132**.

In the arrangement described in FIGURES 7 to 9 adjacent walls are inductively and capacitively coupled to each other to provide a resultant interdigital structure having a phase velocity in any direction substantially less than the velocity of light in free space and with the delay line having a dimension in each of three co-ordinate directions at least equal to one-half wave-length at the lowest operating frequency of the tube.

The operation of the tube of FIGURES 7 to 9 is similar to that of the tube of FIGURES 1 to 4 but provides a physical structure which may be more easily constructed than the one of FIGURES 1 to 4.

When an interdigital delay line structure of the general type illustrated in FIGURES 7 to 9 is desired but with greater transverse dimensions than those of the delay line structure of these figures, more than three parallel, digitated wall-like delay line portions may be used. FIGURE 10 illustrates a delay line structure having four central wall-like delay line portions **150** each having digits **152** extending perpendicularly from both sides thereof and adapted to be used as part of a delay line structure made up of six parallel, wall-like delay line portions. Only the innermost extensions of the digits **152** of the two outside delay line portions are shown. As in the delay line of FIGURES 7 to 9, adjacent delay line portions have the axis of extension of their digits longitudinally spaced with respect to each other, with the inside wall-like portions having passageways or apertures **154** extending transversely therethrough adjacent to the digits of adjacent wall-like portions so that facing digits of alternate wall-like portions "see" each other through the apertures of the intermediate wall-like portion.

From the foregoing, it will be appreciated that the traveling wave structure of the invention provides an improved delay line which has relatively high power carrying capacity and lends itself for use in relatively high power, multi-beam traveling wave tubes.

What is claimed is:

1. A traveling wave tube comprising an evacuated envelope containing a signal wave propagating structure adapted to propagate slow waves therealong in each of three coordinate directions, and means for projecting a beam of electrons along a path through said structure and in interaction relation with waves propagated in one of said directions along said structure, said structure comprising conducting means defining a three dimensional lattice of intersecting passageways therethrough for reducing the phase velocity of said structure in any direction therethrough to a velocity substantially less than the velocity of light in free space, said conductive means comprising at least three parallel conductive plates each having a two-dimensional array of transverse conductive fingers interleaved with the fingers of an adjacent plate, the intermediate plate having apertures aligned with the fingers of the two adjacent plates, one of said passageways containing said path of said electron beam for interaction of said beam with a signal wave traveling along said structure.

2. A three-dimensional signal-wave propagating structure adapted to propagate slow waves therealong in each of three coordinate directions, comprising a three dimensional interdigital array of metallic digitaled conductors defining a three dimensional lattice of intersecting passageways therethrough for reducing the phase velocity of said structure in any direction therethrough to a velocity substantially less than the velocity of light in free space, said array of conductors comprising at least three parallel conductive plates each having a two-dimensional array of transverse conductive fingers interleaved with the fingers of an adjacent plate, the intermediate plate having apertures aligned with the fingers of the adjacent plates.

3. A traveling wave tube comprising an evacuated envelope containing a signal wave propagating structure adapted to propagate slow waves therealong in each of three coordinate directions comprising conducting means defining a three-dimensional lattice of intersecting passageways therethrough for reducing the phase velocity of said structure in any direction therethrough to a velocity substantially less than the velocity of light in free space, said conductive means comprising at least three parallel conductive plates each having a two-dimensional array of transverse conductive fingers interleaved with the fingers of an adjacent plate, the intermediate plate having apertures aligned with the fingers of the two adjacent plates and means for projecting a plurality of electron beams along parallel paths through a like plurality of said passageways in one of said directions, for interaction with a signal wave traveling along said structure in said one direction.

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