Aug. 2, 1960 C. V. LITTON 2,947,906

DELAY LINE

Filed July 29, 1955

Fig. 1

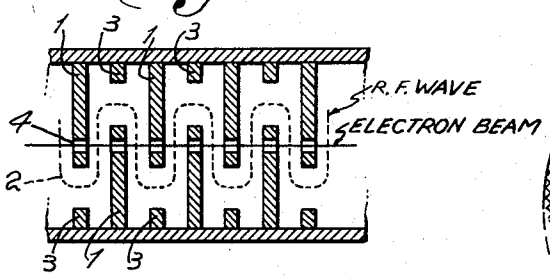


Fig. 3

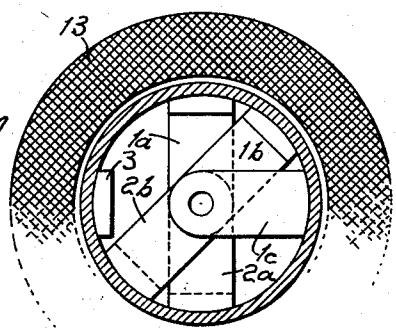


Fig. 2

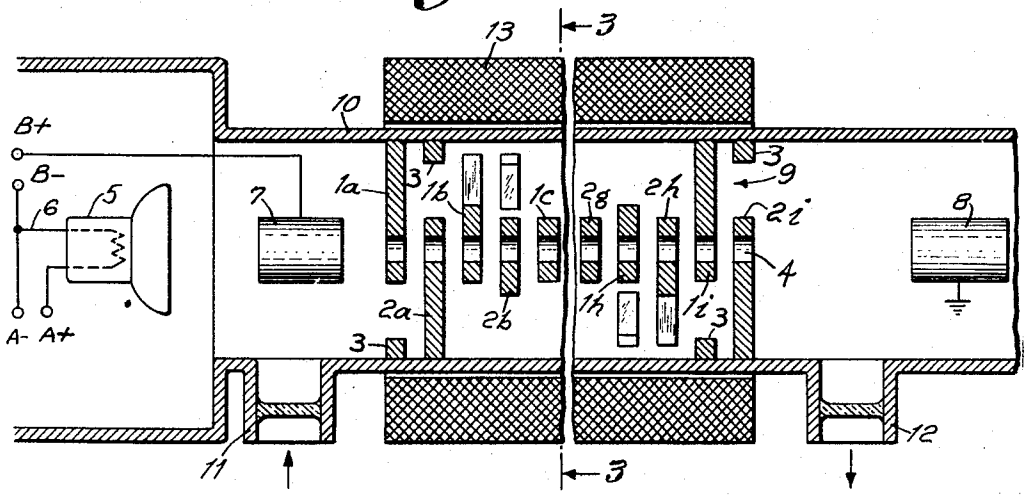
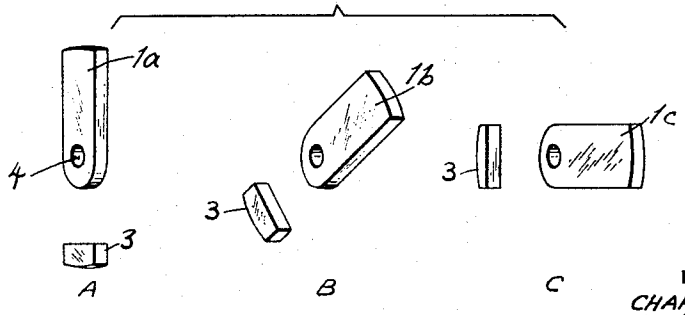


Fig. 4



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DELAY LINE

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6 Claims. (Cl. 315—3.5)

This invention relates to a delay line of the type employed in traveling wave tubes and more particularly, to a delay line which does not permit reflection of wave energy to enter the transmission end of the tube.

Traveling wave tubes have become well known to the art and comprise generally an electron gun for producing an electron stream, a delay line for delaying an electric wave, and a magnet for producing an axial magnetic field. The tube operates as an amplifier when there is interaction between the electron stream and the electric wave. It is known that the electric wave travels approximately at the speed of light, whereas the electrons travel at a much lower speed unless propelled by an extremely high voltage, which is impractical for most applications. Therefore, in order to retard the axial speed of the electric wave, a delay line of some type is provided within the envelope of the traveling wave tube. For example, the wave may be compelled to follow a helical path and therefore, its axial speed is reduced to an extent whereby the electron stream may be propelled to approximately the same velocity, using a more suitable voltage.

The width of the operating frequency band is determined substantially by the impedance matches at the input and the output ends of the delay line. However, it is extremely difficult to match impedances at both ends, over the complete band of usable frequencies, and therefore, reflections occur which tend to cause oscillations. To reduce the possibility of oscillations, it has been the practice to place attenuating material, at discrete points, within the tube. However, the attenuating material causes also, losses in the incident wave which reduces the gain of the amplifier.

Accordingly, it is an object of this invention to provide a unique type of delay line which eliminates substantially the reflected waves without attenuation of the incident waves.

It is a further object of this invention to provide a delay line which comprises in combination elements having a non-reciprocal rotational effect on the wave and elements having a reciprocal rotational effect on the waves; the elements being so arranged as to cancel the reflected waves with little attenuation of the incident waves.

It is a feature of this invention to provide ferrite elements in combination with helically arranged conductive members.

It is a further feature of this invention to utilize a gyrator type delay line is combination with a traveling wave tube.

In accordance with an aspect of the invention, there is provided in a traveling wave tube or wave guide, a delay line which comprises a plurality of helically arranged fingers serving to delay an electric wave and rotate reciprocally the electric field thereof. The delay line is characterized by providing a plurality of elements which have a non-reciprocal rotational effect and which are subjected to an axial magnetic field. The ferrite elements are positioned relative to the fingers so that the fingers are aligned with the electric vector of the wave traveling in one direction as the wave is rotated by the ferrite elements. However, for a reflected wave traveling in an opposite direction, the rotation produced by the ferrite elements is opposite to the rotation produced by the fingers and a point is reached where the electric vector produces no current flow in the fingers. At this point the tube would act as a simple waveguide, operating below cut-off, and therefore, unable to propagate the reflected wave.

The above-mentioned and other features and objects of this invention and the manner of attaining them will become more apparent by reference to the following description of an embodiment of the invention taken in conjunction with the accompanying drawings, wherein:

Fig. 1 is a cross-sectional view of a delay line used to illustrate the principles of the invention;

Fig. 2 is a schematical representation partly in cross-section of a travelling wave tube employing the delay line of the invention,

Fig. 3 is a view taken along lines 3—3 of Fig. 2; and

Fig. 4 is an exploded view of three fingers and ferrite elements constituting a portion of the delay line.

Although this invention is described in connection with a travelling wave tube, it is to be realized that the invention is broader and may be used in any device where it is desired to use a delay line in which reflections of the wave are unwanted.

Referring now to Fig. 1, there is shown a delay device which is similar in construction to the delay line of this invention, but for simplicity of explanation, the elements are shown linearly arranged rather than helically. The delay line comprises a plurality of inter-digital fingers **1** whereby the electric wave is caused to travel a path such as shown by the dotted line **2**. A focused electron beam is directed through axially aligned apertures **4** at one end of each of the fingers **1**. The tube operates on an amplifier when the wave is delayed to substantially the speed of the electrons in the beam so that there is interaction between the electron beam and the wave **2**. Mounted between each of the adjacent fingers and opposite the ends of the opposing fingers are ferrite elements **3**. An axial magnetic field is passed through the ferrites, whereby the ferrites develop the non-reciprocal property of rotating the electric vector of the wave.

As is well known, the ferrite is a microwave circuit element which is dependent on the Faraday rotation of a polarized wave. The ferrite does not follow the reciprocity theorem, so that a wave traveling in one direction through a ferrite is rotated in the same sense as a wave traveling in the opposite direction. Thus, if the electric vector of an incident wave is rotated 90° while traveling through a ferrite, the reflected wave is rotated another 90° in the same sense and the electric vector is turned 180° out of phase with the incident wave. The gyrator and isolator, are based on this phenomenon of the ferrite.

The invention is characterized by using the combination of elements which have a reciprocal rotational effect such as fingers **1** and elements which have a non-reciprocal rotational effect such as ferrites **3**. The invention is further characterized by positioning the fingers **1** with respect to the ferrite elements **3**, so that the fingers **1** are aligned with the electric vector of the wave as it is rotated by the ferrite elements **3**. Thus, for a wave traveling in one direction, the fingers **1** contribute substantially no rotational effect, whereas for the reflected wave, the fingers operate to rotate the electric vector in one sense opposite to the sense of rotation produced by the ferrites **3**. Because the ferrite elements **3** rotate the electric vector of the wave, the fingers **1**, to be aligned with the

electric vector as rotated by the ferrites, must be arranged in a helical path such as shown in Figs. 2 and 3.

It is known that a gyrator may cancel a reflected wave by rotating the vector of the wave sufficiently so that the gyrator acts as a rejection filter. The rejection may be a result of the geometry of the gyrator or the result of properly dimensioning and suitably placing lossy material in the gyrator.

In accordance with the invention, sufficient ferrite is included in the delay line, and the magnetic field adjusted, so that the reflected wave is rotated sufficiently, before the input end is reached, to produce no current flow in the fingers. Thus, propagation of the reflected energy fails because the wall of the tube acts as a simple wave guide, operating below cut off.

In Fig. 2, there is shown a traveling wave tube comprising a cathode **5**, heater **6**, accelerator anode **7**, collector anode **8** and a delay device **9**, with helically arranged interdigital fingers **1***a*—**1***i* and **2***a*—**2***i* and ferrite elements **3**. The fingers **1***a*—**1***i* define one helical path and the opposing fingers **2***a*—**2***i* define a second helical path. The two sets of fingers are interdigital and arranged that the apertures **4** are aligned along the axis of the tube. Fig. 4, for the purpose of clarifying the arrangement of the fingers and ferrites, shows three fingers **1***a*—**1***c* and the opposing ferrites **3**, defining one quadrant of a helical path. The heater **6**, cathode **5** and accelerator anode **7** constitute an electron gun assembly similar to that used in conventional cathode ray tubes. The delay line **9** and the collector anode **8** are contained within a cylindrical evacuated envelope **10** and may be supported by any suitable means.

An input wave guide **11** and an output wave guide **12** are coupled to opposite ends of the tube **10** adjacent the opposite extremities of the delay line **9**. A magnetic focusing coil **13**, is located along the tube **10** between the input and output of the wave guide. The action of the magnetic focussing lines in tube **10**, serve also to produce the Faraday rotation of the waves traversing this tube. The accelerator anode **7** is connected to a source of suitable positive potential B+, and the collector anode may be coupled to ground. The cathode is connected to a suitable negative potential source by way of the heater, and the heater is connected to a conventional A battery as shown.

The waves to be amplified are applied to the traveling wave tube via the input wave guide **11** and are taken from the tube via the output wave guide **12**.

The helically arranged fingers **1***a*—**1***i* and **2***a*—**2***i*, and the ferrite elements **3** are terminated adjacent the input and output wave guides.

The tube operates as an amplifier in the conventional manner. The beam of electrons is propelled along the axis of the tube and interacts with the wave traveling along the delay line.

It is to be realized that the fingers may be made of an energy absorbing material to absorb the reflected energy, or specific resistance elements may be placed within the tube. Further, the ferrite elements may be mounted integral with the fingers or with part of the fingers, without departing from the scope of the invention.

While I have described above the principles of my invention in connection with specific apparatus, it is to be clearly understood that this description is made only by way of example and not as a limitation of the scope of my invention as set forth in the objects thereof and in the accompanying claims.

What is claimed is:

1. In a traveling wave tube, a delay line capable of cancelling the reflected wave with substantially no attenuation of the forward wave, characterized by means having non-reciprocal rotational properties positioned to rotate the electric vector of the wave, means for generating an electron beam, said delay line being in coupled relationship with said electron beam. delay-producing means positioned along said delay line and relative to said non-reciprocal means in alignment with the rotation of the electric vector as the wave traveling in a forward direction is rotated, said delay-producing means having reciprocal electric vector rotating properties, whereby a reflected wave is rotated in opposite directions by said reciprocal and non-reciprocal means respectively, said reciprocal and non-reciprocal means being of sufficient axial length to rotate the electric vector of the reflected wave by at least 180° whereby further propagation of the reflected wave fails.

2. The delay line according to claim 1 wherein said non-reciprocal means comprises ferrites.

3. In a traveling wave tube, a delay line capable of cancelling the reflected wave with substantially no attenuation of the forward wave, comprising inter-digital conductive fingers extending radially within the tube and arranged helically along said tube, a plurality of ferrite elements mounted between each of said fingers, the fingers being arranged relative to said ferrite elements so as to be aligned with the electric vector of the wave as it is traveling in a forward direction, the reflected wave being rotated in opposite directions by said fingers and said ferrite elements respectively.

4. In a traveling wave tube, a delay line capable of cancelling the reflected wave with substantially no attenuation of the forward wave, characterized by means having non-reciprocal rotational properties positioned to rotate the electric vector of the wave, delay-producing means positioned relative to said non-reciprocal means so as to be aligned with the electric vector as the wave traveling in a forward direction is rotated, said delay-producing means having reciprocal electric vector rotating properties, whereby a reflected wave is rotated in opposite directions by both said reciprocal and non-reciprocal means respectively, said reciprocal and non-reciprocal means being of sufficient axial length to rotate the electric vector of the reflected wave to a point where further propagation of the reflected wave fails, said tube being cylindrical in form and said delay-producing means comprises interdigital fingers extending radially from the wall of said tube towards the axis thereof, the path of said fingers defining a helix.

5. In a traveling wave tube, a delay line capable of cancelling the reflected wave with substantially no attenuation of the forward wave, comprising fingers extending radially within the tube and arranged helically along said tube, a plurality of ferrite elements mounted between each of said fingers, the fingers being arranged relative to said ferrite elements so as to be aligned with the electric vector of the wave as it is traveling in a forward direction, the reflected wave being rotated in opposite directions by said fingers and said ferrite elements respectively.

6. The structure of claim 5, wherein said fingers have aligned apertures and means for focussing an electron beam and directing it through said apertures.

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