May 31, 1960 D. REVERDIN 2,939,035

HELICAL DELAY LINES

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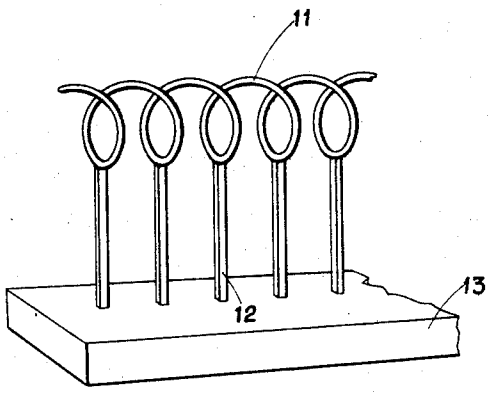


FIG. 1

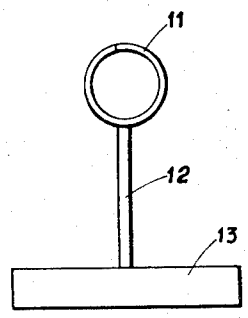


FIG. 2

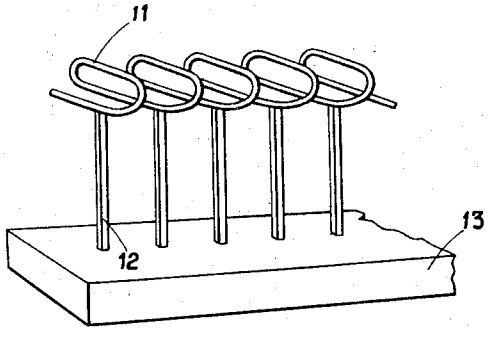


FIG. 4

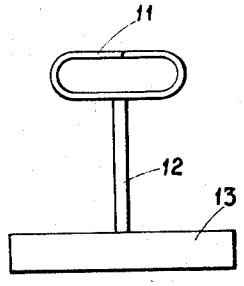


FIG. 5

Fig.3.

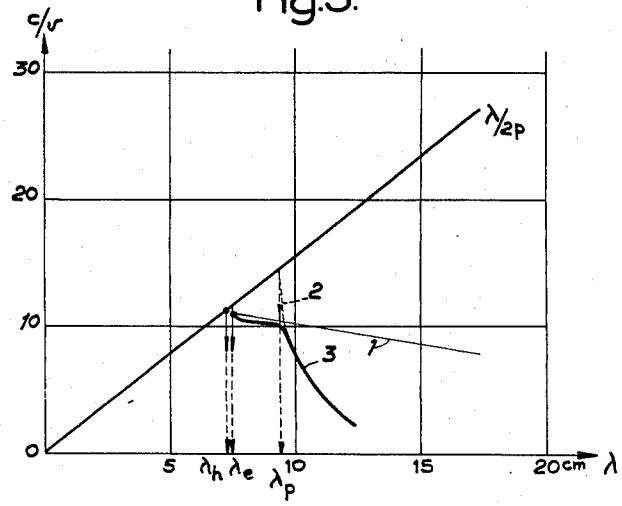


Fig.6.

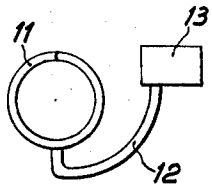


Fig.7.

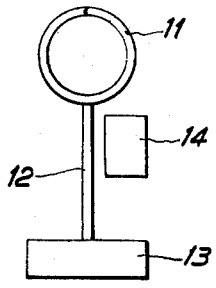
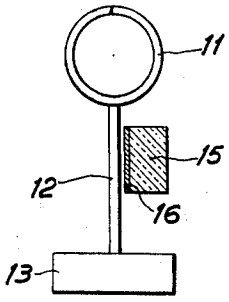


Fig.8.



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Fig.9.

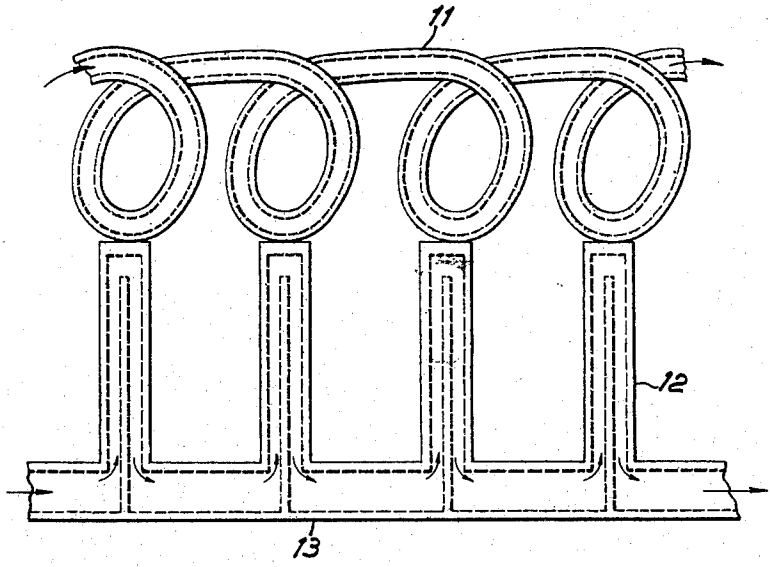
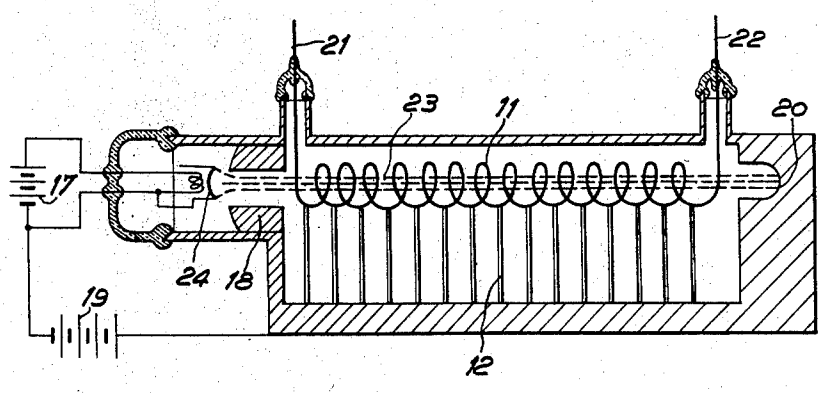


Fig.10.



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2,939,035

HELICAL DELAY LINES

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10 Claims. (Cl. 315—3.5)

The present invention relates to delay lines as used in traveling wave tubes, with or without crossed electric and magnetic fields in the electron and wave interaction space of the tube.

It is an object of the invention to provide an improved helical delay line, more particularly suitable for wide band traveling wave amplifiers.

The operation of a conventional traveling wave tube may be briefly outlined as follows: an electromagnetic wave travels along a delay line and comes into interaction with an electron beam projected in its immediate vicinity and with which it is in synchronism.

The purpose of the delay line is to reduce the velocity of the electromagnetic wave to a fraction of its value in free space, i.e. of the velocity of light, for instance to about a tenth thereof, at which it is in synchronism with the electron beam.

It is known that delay lines having a periodic structure consist of networks built up by setting end to end a certain number of identical elementary cells. The field distribution along a line with a periodic structure having a pitch p may be considered as resulting from the superposition of an infinite number of space harmonics having phase velocities respectively equal to:

$$v_k=\frac{\omega p}{\psi+2k\pi} \text{ with } k=0, \pm 1, \pm 2$$

where ψ is the phase shift between homologous points of two successive cells, assuming that the line is energized at one of such points.

The space harmonic in synchronism with the electron beam interacts with the latter.

It is usually desirable to work with the fundamental space component, since the latter carries most of the energy. In this case, k, in the formula giving the phase velocity v_k, has such a value that v_k is a maximum for a given value of ψ.

Further, in order that a traveling wave tube may operate as an amplifier, in the fundamental mode, the delay line must have a normal dispersion, or propagate a direct wave, for said mode. As is well known, the dispersion of a delay line is a characteristic consisting in that the respective phase velocities of the various space harmonic components of a traveling wave vary with frequency. This variation is due to the fact that the phase shift ψ between homologous points, separated by the pitch p, of two successive elementary cells of a delay line, varies with the frequency.

The dispersion curve is obtained by plotting the ratio

$$\frac{c}{v_g}$$

wave propagation velocity in free space to group velocity of the traveling wave, against the wavelength λ of the traveling wave. It is further known that in order that a traveling wave amplifier may operate with a wide passband, the delay line used must have a low dispersion.

The helix meets all the requirements so far laid down but has exhibited serious drawbacks in the prior art: it generally consists of a spiral conductor supported only at its two ends and cannot, under these conditions, dissipate much heat. This accumulated heat causes an expansion which alters the initial geometry and alignment of the helix and thus disturbs the correct operation of the tube.

The conductor forming the helix may be hollow and a coolant may be caused to circulate within the hollow conductor, but the latter tends to distort through its own weight.

Quartz rods are also employed for supporting the helix; these, however, are easily fouled in the tube and may become charged with electrons from the beam, thus also disturbing the operation.

According to the present invention, the above drawbacks are obviated by supporting the helix by an array of fins or an electrically conductive comb line to which it is rigidly connected.

The thermal energy originating in the helix is dissipated by the teeth of the supporting comb.

The invention takes thus advantage both of the rigidity and of the aptitude of a comb line readily to dissipate an appreciable amount of heat and also of certain properties, inherent to a helical delay line, especially insofar as the operation of a traveling wave amplifier is concerned.

The invention will be better understood from the following description with reference to the appended drawing in which:

Fig. 1 shows, in perspective, a delay line according to the invention;

Fig. 2 shows an end view of the helix of Fig. 1;

Fig. 3 shows various dispersion curves;

Fig. 4 shows, in perspective, a modification of the line according to the invention;

Figs. 5–9 show end views of various embodiments of the invention;

Fig. 10 shows a traveling wave amplifier equipped with a delay line according to the invention.

The same references have been used throughout all the figures to designate the helix, the teeth and the base of the combs respectively.

It may be seen in Fig. 1 that each turn of the helix **11** is rigidly attached to one fin or tooth of the array or comb, for instance by brazing. However, the whole structure may also be cut out from a solid block.

Fig. 2 shows one element of the delay line of Fig. 1.

Fig. 3 shows the dispersion curves **1**, **2** and **3** relative to the fundamental mode respectively of the helix alone, of the comb alone, in the presence of a back plate having a capacitive effect and of the comb and helix structure according to the invention. The dimensions of the structure considered in Fig. 3 are as follows:

	Mm.
Pitch of the helix and comb	3.2
Length of comb teeth	21.5
Outside diameter of the helix	12
Wire diameter of helix	1.5

The cut-off wavelength λ_h of the helix alone in the π mode, i.e. a mode for which $\psi=\pi$, is given by:

$$\lambda_h=2k_1\pi.d$$

where d is the mean diameter of the helix and k_1 a parameter depending on the ratio of the diameter of the wire constituting the helix to its pitch, the value of said parameter increasing from 1 to 1.1 when the ratio falls from infinity to 0.3.

The cut-off wavelength λ_e of the delay line according

to the invention, constituted by associating a helix and a comb the teeth of which have a uniform cross-section and a length l, is given for the π mode by the expression:

$$\lambda_e \simeq k_2(k_1 \pi d + 2l)$$

where k_2 is a coupling factor the value of which is approximately 1.2.

It is thus seen experimentally and is easily confirmed by calculation from the equation for the various dispersion curves that:

(1) λ_e is comprised between λ_h and λ_p, λ_p being the cut-off wavelength for the π mode of the comb alone, in the presence of a capacitive back-plate.

(2) λ_e is close to λ_h without, however, being identical therewith.

(3) The dispersion curve of the line according to the invention offers a portion of great interest located between the abscissae λ_e and λ_p.

(4) For operation on a wave length higher than λ_p, the delay line according to the invention is no longer of interest, since the influence of the comb is then dominant, the ultra-high frequency energy being propagated more and more along the comb at the expense of the helix.

The formulae giving the cut-off wave lengths for the π mode and the dispersion curve equations show the relation existing between the cut-off wave lengths and the various dimensions of the line.

Thus it will be possible to equate λ_e and λ_h if $\lambda_e - \lambda_h = 0$ or

$$\frac{1}{d} = \frac{\pi}{2} \cdot k_1 \left(\cdot \frac{2}{k_2} - 1 \right)$$

To obtain an amplifier with the widest possible passband, a maximum interval must be provided between λ_p and λ_h.

The most favorable compromise between conditions, which may be contradictory, will then be sought.

Figs. 4, 6, 7, 8 and 9 show, by way of non-limitative examples, various embodiments of the line according to the invention.

In Fig. 4 helix **11** is flattened out, while the helix of Figures 1 and 2 defined a cylindrical interaction space. Fig. 5 represents an element of Fig. 4.

Fig. 6 illustrates a preferred embodiment of the line according to the invention. Its overall dimensions have been reduced by curving fingers **12**. Effects which might complicate the interaction phenomenon of helix **11** and bar **13** of the comb need not be expected. The field prevailing outside the helix is weak and the field in the comb is concentrated between the fingers of the comb. This is all the more true when operating on a wavelength nearer to the cut-off wavelength of the structure.

Fig. 7 includes the same elements as are shown in Fig. 2. A metal strip, having a capacitive effect, is added, the cross-section of which is shown at **14**. This metal strip extends parallel to the comb fingers and forms a kind of back plate which artificially increases the electrical length of said fingers, thus varying the shape of the dispersion curve, by increasing its useful band and reducing its slope.

The position of this metal strip relatively to the comb fingers may be adjusted from outside the tube, for instance by means of a device of the type described in the copending patent application, Ser. No. 397,754, filed on December 11, 1953 in the name of O. Dohler and J. Nalot, now Patent No. 2,888,597, dated May 5, 1959, and assigned to the same assignee.

In Fig. 8, a strip 15 coated with an attenuating material **16** has been substituted for the metal strip **14**. Said coating attenuates the energy propagated along the comb. This attenuation may also be obtained by coating part or the whole of comb **12** with an attenuating material, for instance by means of a spray gun, without utilizing element **15**.

Thus the propagation within the helix may be modified by means of one of the devices shown in Figures 7 or 8, operating on the small quantity of high frequency energy traveling within the comb.

Finally, Fig. 9 shows some ways of improving the thermal dissipation of the line according to the invention. Thus, coolant fluid may be circulated in helix **11** constituted by a hollow conductor of adequate diameter or within base **13**, or within base **13** and teeth **12** of the comb.

As may be readily seen, the dissipation of thermal energy which originates within the helix is much increased, owing to the comb support and higher energy may be amplified in this way.

To complete the present description, the results of some accurate tests are given below:

The dispersion curve of the line according to the invention was plotted, the main dimensions of which were:

	Mm.
Pitch of the helix and comb	3.2
Length of the comb teeth	21.5
Outside diameter of helix	15
Wire diameter of helix	1.5

A dispersion curve was obtained, the slope of which was lower than 0.6 $cm.^{-1}$ in a band of 500 mc./s., around 2730 mc./s.

According to a modification, the number of turns in the helix, instead of being equal to the number of comb teeth, could be a multiple thereof, and the turns could be connected to the comb teeth, in pairs, or three together, etc. . . . Conversely, the number of comb teeth could be a multiple of the number of the turns, all the turns being connected to a tooth, although some teeth may not be connected to the turns.

A practical embodiment of tube using the delay lines according to the invention will now be described. Fig. 10 shows a conventional traveling wave amplifier with a helix shaped delay line **11**, supported by a comb **12**. The ultra-high frequency energy is supplied to the line **11** through an input **21** and collected at its output **22** after amplification by interaction with an electron beam **23**. Electron beam **23** is produced by a cathode **24** directly heated by a battery **17**. It is accelerated by an anode **18**, brought to a positive voltage by a battery **19**. A collector **20** is at the same potential as the delay line **11** and anode **18**. Cooling of the helix **11** through comb **12** takes place by conduction. It may also be effected by coolant circulation, and the delay line would in this case be of the type shown on Fig. 9.

Of course it is to be understod that neither the delay line according to the invention nor the use thereof must be limited to the examples given which are of merely illustrative character. For instance, it is obvious that the delay line described could be incorporated in tubes of types other than that shown in Fig. 10.

I claim:

1. Delay line for ultra-high frequency waves comprising: an elongated electrically conductive body; an array of electrically conductive parallel members each having a first and a second end; said members being attached to said elongated body by their respective first ends thus forming therewith a comb structure having teeth extending therefrom and a helical conductor having a given number of turns, at least some turns of said helical conductor being respectively strongly fixed directly to the second end of at least certain teeth of the comb structure.

2. Delay line as claimed in claim 1 wherein said helical conductor has the shape of a body of revolution.

3. Delay line as claimed in claim 1, wherein each turn of said helical conductor is strongly fixed to the second end of a different tooth of said comb structure.

4. Delay line as claimed in claim 1, further compris-

ing a movable metallic plate disposed parallel to the teeth of said comb structure.

5. Delay line as claimed in claim 1, which is at least partly hollow.

6. Delay line as claimed in claim 1, having passageways for circulating a cooling substance both within said comb structure and within said helical conductor.

7. A traveling wave amplifier tube having a vacuum-tight enclosure and, within said enclosure, an electron gun for projecting an electron beam, a collector electrode, an input and an output for the ultra-high frequency energy and a delay line, for delaying said ultra-high frequency, comprising: an elongated body electrically conductive; an array of electrically conductive parallel members, each having a first end and a second end; said members being attached to said elongated body by their respective first ends thus forming therewith a comb structure having teeth extending therefrom; and a helical conductor having a given number of turns, at least some turns of said helical conductor being respectively strongly fixed directly to the second end of at least certain teeth of the comb structure; said helical conductor having two ends, respectively connected to said input and output, and said elongated body

being integrally connected to said vacuum-tight enclosure.

8. Delay line as claimed in claim 1, further comprising a metallic plate disposed along one side of the teeth of said comb structure.

9. Delay line as claimed in claim 1, wherein said par-arallel members forming the teeth of said comb structure are straight rods.

10. Delay line as claimed in claim 1, wherein said parallel members forming the teeth of said comb structure are curved, whereby said helix is brought into proximity with said elongated body.

References Cited in the file of this patent

UNITED STATES PATENTS

2,636,948	Pierce	Apr. 28, 1953
2,706,366	Best	Apr. 19, 1955
2,768,322	Fletcher	Oct. 23, 1956
2,773,213	Dodds	Dec. 4, 1956
2,800,605	Marchese	July 23, 1957
2,853,642	Birdsall et al.	Sept. 23, 1958

FOREIGN PATENTS

1,053,362	France	Sept. 30, 1953