Jan. 5, 1960 O. DOHLER ET AL 2,920,227

LADDER TYPE DELAY LINE

Filed May 19, 1953 6 Sheets-Sheet 1

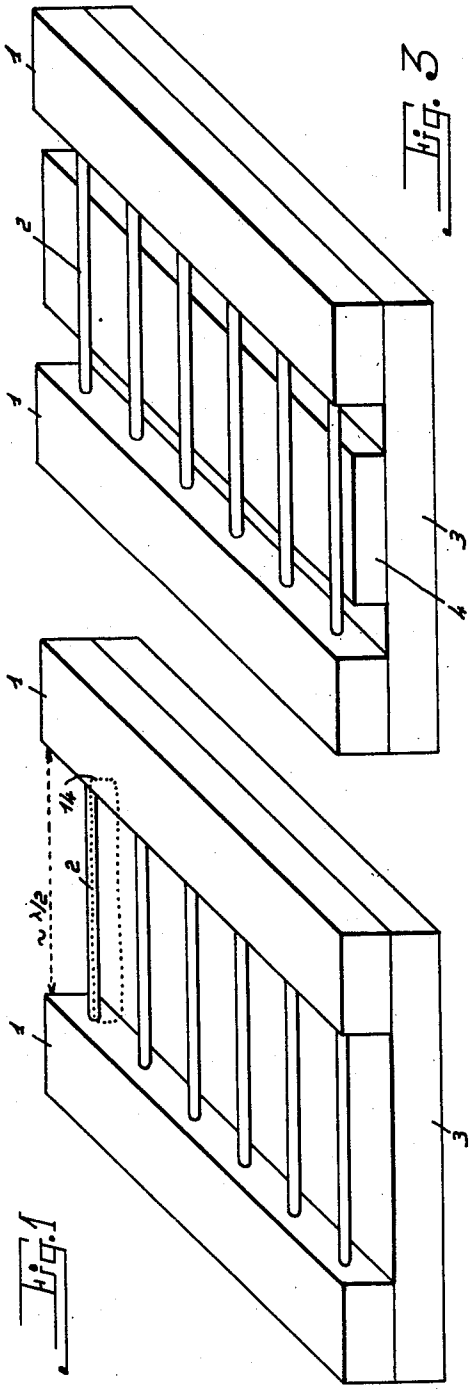


Fig. 1

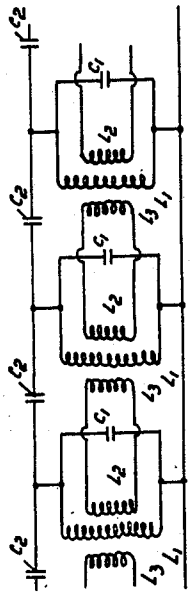


Fig. 2

Fig. 3

Jan. 5, 1960 O. DOHLER ET AL 2,920,227

LADDER TYPE DELAY LINE

Filed May 19, 1953 6 Sheets-Sheet 2

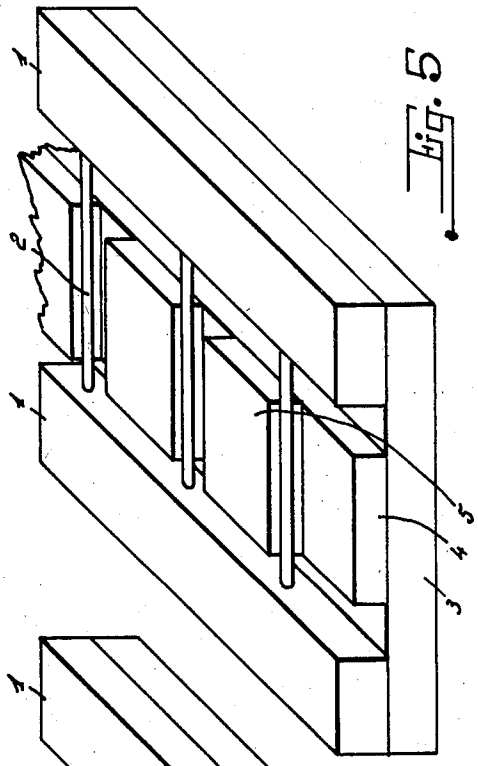


Fig. 5

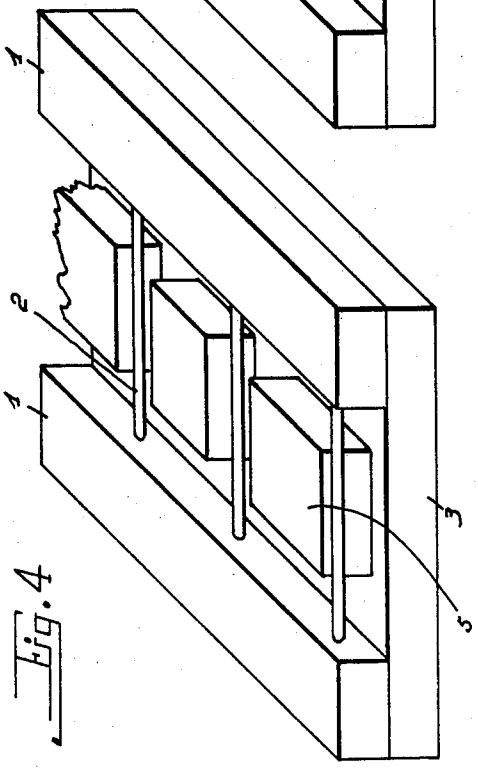


Fig. 4

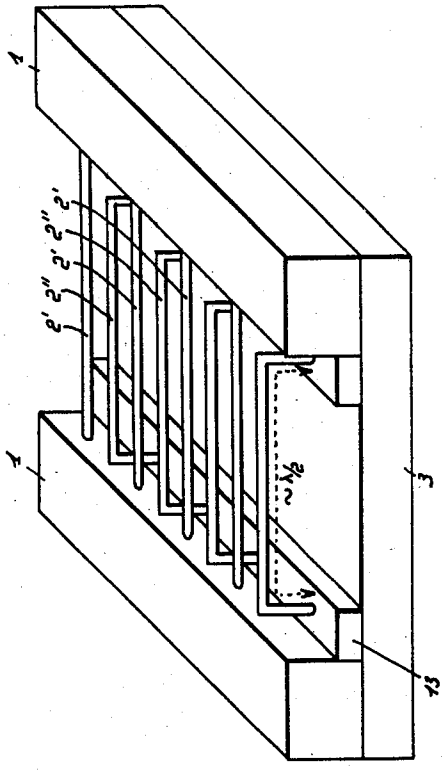


Fig. 7

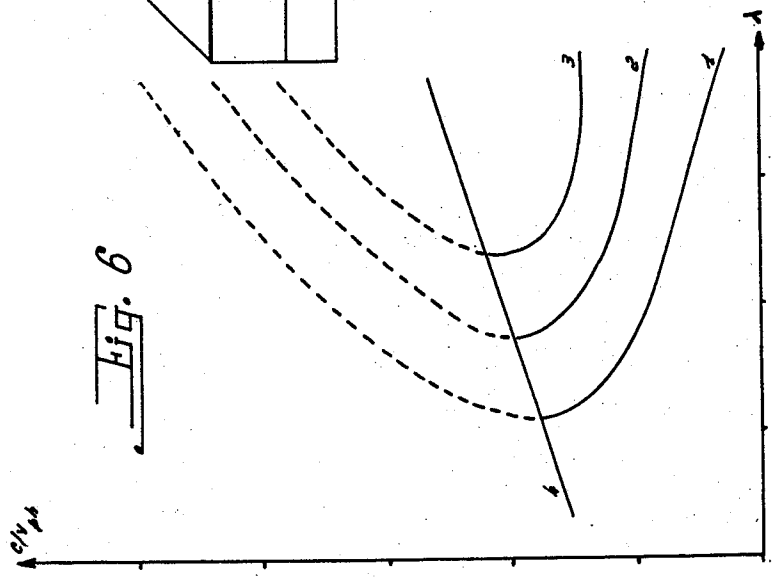


Fig. 6

LADDER TYPE DELAY LINE

Filed May 19, 1953 6 Sheets-Sheet 4

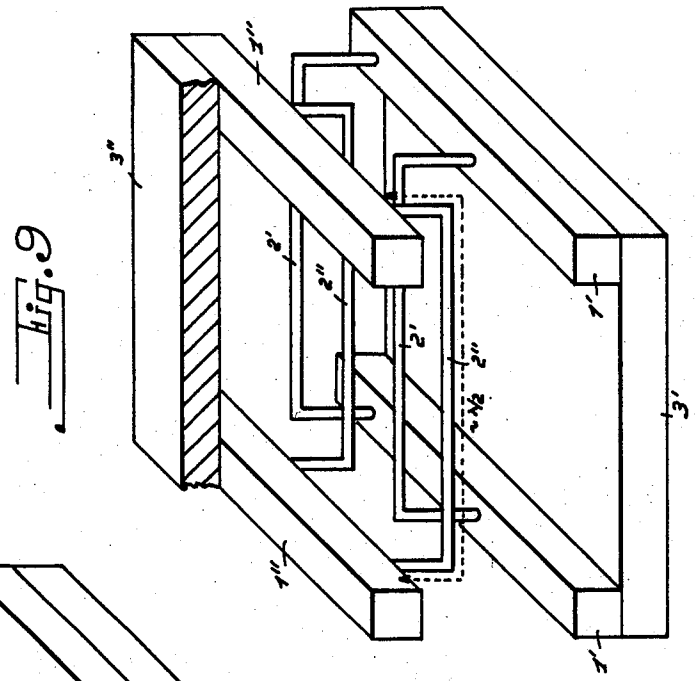


Fig. 9

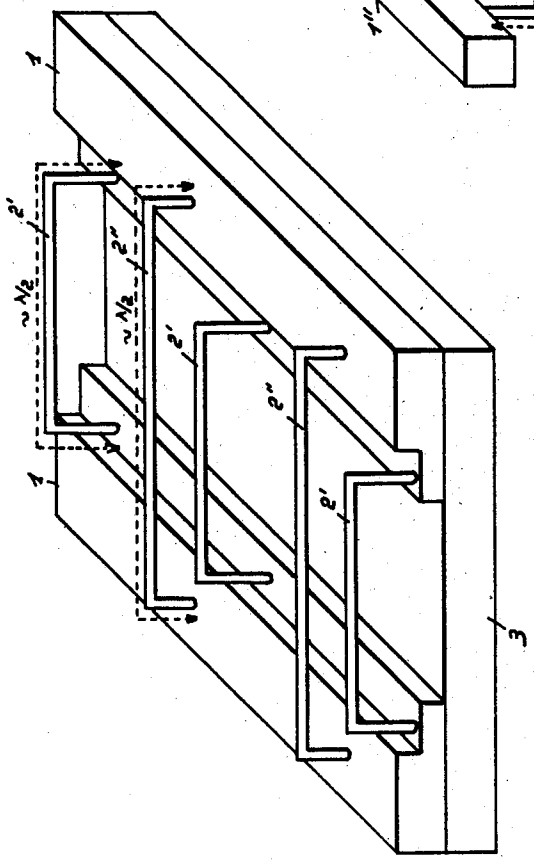


Fig. 8

Jan. 5, 1960 O. DOHLER ET AL 2,920,227

LADDER TYPE DELAY LINE

Filed May 19, 1953 6 Sheets-Sheet 5

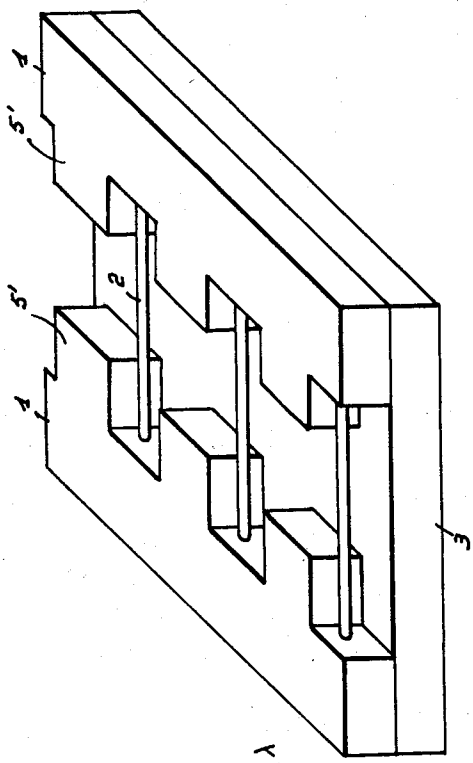


Fig. 11

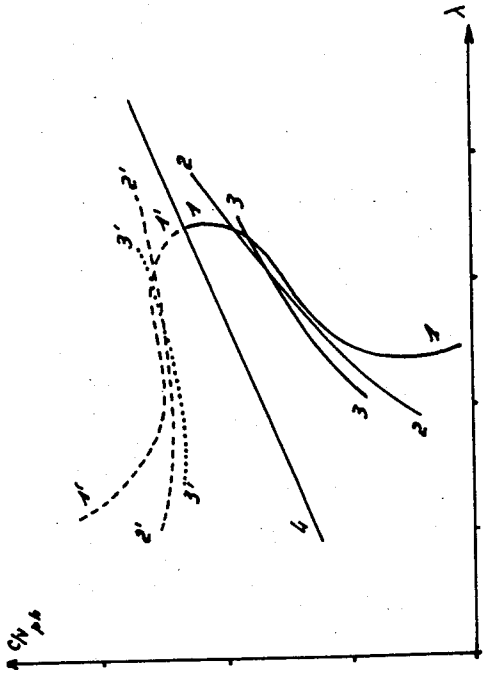


Fig. 10

Jan. 5, 1960 O. DOHLER ET AL 2,920,227

LADDER TYPE DELAY LINE

Filed May 19, 1953 6 Sheets-Sheet 6

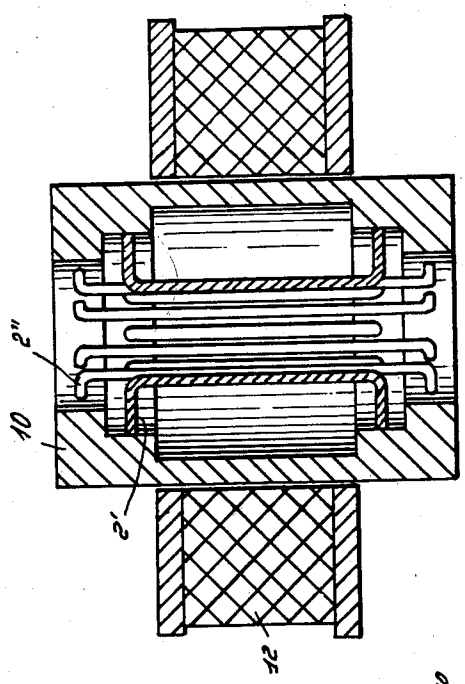


Fig. 13

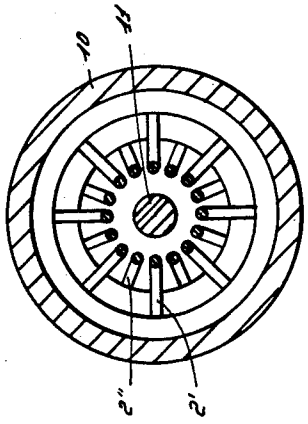


Fig. 14

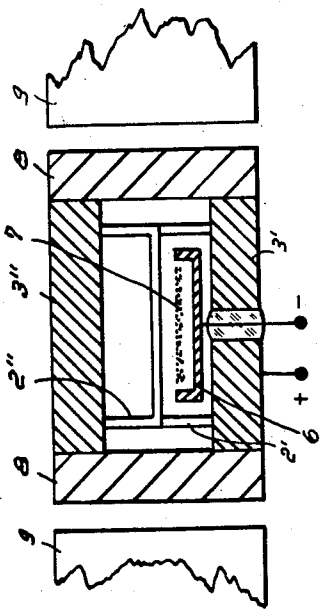


Fig. 12

United States Patent Office 2,920,227 Patented Jan. 5, 1960

2,920,227

LADDER TYPE DELAY LINE

Oscar Dohler and Bernard Epsztein, Paris, France, assignors to Compagnie Generale de Telegraphie Sans Fil, Paris, France

Application May 19, 1953, Serial No. 356,050

Claims priority, application France June 28, 1952

8 Claims. (Cl. 315—3.5)

The present invention relates to delay lines of the ladder type, more particularly for use in traveling wave tubes and magnetrons.

The present invention relates to a very particular type of delay line for use in electron discharge tubes operating by interaction between the energies contained respectively in the electron beam and in the field of an ultra high frequency wave propagated along the line, as for example in traveling wave tubes. This type of delay line is constructed in the form of a ladder comprising two parallel longitudinal lateral members and a series of parallel rungs extended between the two lateral members, and a metallic base plate upon which the lateral members are supported with the rungs spaced from the base plate. The length of the rungs is approximately equal to half the operating wave length, and from this point of view the ladder type delay line operates more efficiently than the other known types of delay line such as interdigital or baffle lines. The defect of these other types of line lies in the fact that the width of the line is only a quarter wave length or even less. Consequently, for equal length the ladder line may be used in a tube the electron beam of which is very much wider and the beam current of which is more intense, whereby the tube can supply a greater power. Furthermore, the coupling resistance between the wave and the beam is high with consequent favorable influence on the gain of the tube.

Delay lines of ladder type are already known, however, which have the disadavantage of opposed electrical and magnetic couplings as will be more fully explained hereinafter.

The present invention has for its purpose to improve the known delay lines of ladder type, the primary object being to increase the band width and permit propagation of energy within a wide band of frequencies independently of irregularities in the construction of the line. The principal feature of the present invention is the provision of means for tightening up the coupling between the individual circuits constituting the delay line.

The invention will be more readily understood from the ensuing description taken in conjunction with the accompanying drawing in which:

Figure 1 is a perspective view of a known delay line of ladder type;

Figure 2 is a diagrammatic representation of a chain of circuits constituting a delay line of the type shown in Figure 1;

Figures 3 to 5 illustrate three forms of the invention wherein means are provided for reducing the electrical coupling of a ladder type delay line;

Figure 6 is a graphic representation of the dispersion curves of the lines illustrated in Figures 3 to 5;

Figures 7 to 9 and 11 illustrate four embodiments of the invention comprising means for decreasing the magnetic coupling;

Figure 10 is a graphic representation of the dispersion curves of lines in accordance with Figures 7 to 9;

Figure 12 is a cross section through a crossed field traveling wave tube comprising a delay line in accordince with Figure 9; and

Figures 13 and 14 are respectively an axial section and a transverse cross section through a magnetron comprising a delay line in accordance with Figure 8 curved to circular shape.

Referring to Figure 1 the ladder type delay line of known construction comprises two longitudinal lateral members 1 and a series of rungs 2 spanning the space between the lateral members. The two lateral members are mounted on a metal base plate 3 and the length of the rungs 2 is approximately $\lambda/2$, λ being the operating wave length of the line.

Figure 2 illustrates how the delay line of Figure 1 may be assimilated to a chain of filter-type circuits having lumped constants. The dotted line 14 in Figure 1 comprising a rung 2 and the closed path along the walls of the lateral members 1 and across the base plate 3 may be considered the equivalent of an anti-resonant circuit comprising a coil L_1 and a capacitor C_1 tuned to $\lambda/2$. The distribution of potentials on each rung, as also in each half wave circuit, is such that the potential is zero at the extremities and maximum at the center. Consequently, in the central zone of the rung an electrical field of maximum value is coupled with the electrical fields of the neighboring rungs. This coupling between the electrical fields is the equivalent of the capacitor C_2 of Figure 2. Furthermore, a high frequency current circulates through each rung the distribution of which is such that it is high at the central zone of the rung and maximum at the extremities. This current generates a maximum magnetic field at the extremities of the rung which is coupled to the magnetic fields of the neighboring rungs. This magnetic coupling is the equivalent of an inductive coupling shown on Figure 2 as coils L_2 and L_3 between the coils L_1 of the successive circuits. Finally the diagrammatic showing of Figure 2 discloses a chain of anti-resonant circuits coupled electrically by the capacitors C_2 and magnetically by the induction circuits L_2, L_3.

It is known that in this type of chain the electrical and magnetic couplings are mutually opposed so that the resonant coupling is very weak. It is also known that a chain of weakly coupled circuits has a very narrow band width and that the circuits must be very closely tuned to the resonant frequency. This phenomenon is repeated in the ladder type delay line of Figure 1 where the dispersion, i.e. the variation of the delay factor as a function of the wave length, is very substantial, and where the slightest irregularity of mechanical structure involves discrepancies between the resonant frequencies of the individual circuits of the chain. The band width is in fact so narrow that this property of the ladder type delay line sometimes prevents it from propagating any electro-magnetic field whatsoever.

In Figure 3, where the same reference numerals designate the same elements as in Figure 1, the electrical coupling between the successive rungs is decreased by inserting a filler member 4 between the base plate 3 and the rungs 2. The filler member 4 extends longitudinally of the delay line or parallel to the locus of the rungs 2, the length of the member 4 being greater than either the space between adjacent rungs or the width of each rung has the effect of deforming the electrical field in the vicinity of the central zones of the rungs whereby a portion of the lines of force is deflected and redirected from each rung toward the filler member instead of toward the neighboring rung. Thus there is a smaller number of lines of force actively engaged in the electrical coupling.

In the embodiment according to Figure 4, baffles 5

are positioned in the spaces between the rungs 2, the width of the baffles being such as to extend over the central zones of the rungs. It will be readily understood in this embodiment the capacitor C_2 of Figure 2 is replaced by two capacitors connected in series, the result being well known in that it provides a reduced resultant capacity.

Figure 5 discloses a combination of the filler member 4 of Figure 3 and of the baffles 5 of Figure 4.

Decoupling by means of baffles in accordance with Figures 4 and 5 has the added advantage, in traveling wave tubes wherein it is well known that the beam gradually bends toward the anode as it progresses along the interaction space, that the baffles rather than the rungs are exposed to the stream of electrons. Thus the electrons are absorbed by massive elements which have a good heat dissipation. The upper surfaces of the baffles 5 which are exposed to the stream of electrons propagated in the interaction space along the delay line are parallel to the locus of the rungs longitudinally of the line as well as paralleling the rungs transversely of the line. The disposition of the flat electron beam along the delay line may be generally the same as that illustrated in Figure 12 with regard to the base plate 3'' and the transversely extending rungs thereon which are described hereinafter. The electron beam thus passes in interacting relationship with the rungs on the side thereof opposite the base plate 3.

The electrical decoupling in accordance with Figures 3 to 5 is increasingly effective in that order, Figure 5 being the most effective. Figure 6 is a graphic representation of the ratio between the speed of light c and the phase propagation velocity v_{ph} as a function of the wave length λ, from which it is possible to evaluate the dispersion. The curve 1 corresponds to the delay line of Figure 3 and the curves 2 and 3 to the delay line of Figure 5 wherein the baffles 5 are of different heights. The straight line 4 indicates the locus of the cut-off frequencies. The portions of the curves shown in full lines correspond to a propagation at the highest phase velocity among those which are feasible, and the portions shown in broken lines correspond to propagation with a phase velocity as close as possible to the maximum velocity of the preceding mode. It will be seen that the more effective is the electrical decoupling the weaker is the dispersion and consequently the wider will be the band.

Figures 7 to 9 illustrate the three embodiments of the invention wherein means are incorporated for decreasing the magnetic coupling, the charcteristic feature common to these three embodiments being that the rungs are divided into two groups occupying alternate odd and even positions, the rungs of at least one group being bent at right angles and the extremities thereof being implanted in the surface of a member separate from that in which the ends of the other group are implanted.

In Figure 7, the odd rungs 2' are conventional, whereas the even rungs 2'' are bent downwardly and their ends are implanted into the surface of elements 13 distinct from the surface of the lateral members 1 in which the ends of the rungs 2' are implanted.

In Figure 8, both groups of rungs are bent at right angles, one group having their ends implanted in the upper level of a stepped lateral member 1 and the other group in the lower level thereof, whereby the ends of the respective groups are implanted in two distinct surfaces. The width of one group between the bent portions thereof is different from the width of the rungs of the other group, but the overall length of each rung is equal to approximately $\lambda/2$.

In the embodiment shown in Figure 9, the rungs 2' and 2'' are bent over identically but in opposite directions, the lateral members 1 and the base plate 3 being duplicated as indicated respectively at 1', 1'', and at 3', 3''.

The magentic decoupling increase in effectiveness from Figures 7 to 9 in that order, and Figure 10 is a graphic representation similar to that of Figure 6 showing the dispersion curves 1, 2 and 3 corresponding respectively to the delay lines of Figures 7, 8 and 9. As in Figure 6 the straight line 4 indicates the locus of the cut-off frequencies, and the portions shown respectively in full, and in broken lines having the same significance as in Figure 6. It will be seen that the more effective the magnetic decoupling the weaker the dispersion, the slope of the curves being gradually reduced and becoming more regular.

There are, of course, many other possibilities of magnetic decoupling, for example as shown in Figure 11 where baffles 5' are inserted between the end portions of the rungs, this arrangement being similar with respect to magnetic coupling to what is shown for electrical coupling in Figure 4. In any event, not only in Figures 7 to 9 but also in Figure 11, decoupling is obtained by lengthening or complicating the path through which the current circulating on the surface of the metal mass short-circuiting the rungs would have to pass between the adjacent ends of two consecutive rungs.

The invention may be applied in practice to many types of electron discharge tubes operating on the principle of interaction between a beam and a wave. Delay lines according to the invention are more particularly intended, however, for use in traveling wave tubes wherein the interaction between the beam and the wave takes place within the range of crossed electrical and magnetic fields, these tubes operating as amplifiers in accordance with one mode of propagation wherein the phase velocity is of the same sign as the group velocity, or as oscillators in accordance with a mode of propagation wherein the two velocities have opposite signs. In Figure 6, the full line portions of the curves decrease when the wave length increases which indicates that the phase velocity has the same sign as the group velocity for the mode of propagation corresponding to those portions of the curves. The broken line portions increase on the contrary which corresponds to a phase velocity opposed to the group velocity. In Figure 10, on the contrary, the full line portions increase and the broken line portions decrease or are substantially horizontal. Consequently the delay lines of which the dispersion is indicated by the curves of Figures 6, i.e. electrically uncoupled delay lines, may be used in crossed field tubes operating as amplifiers in accordance with a mode of propagation the phase velocity of which is as high as possible, or as oscillators in accordance with a mode the phase velocity of which is lower than the highest possible velocity. The delay lines of which the dispersion is given by Figure 10, i.e. magnetically uncoupled delay lines, may be used in crossed field tubes operating as oscillators in accordance with a mode of propagation at maximum phase velocity, or as amplifiers in accordance with a mode of lower phase velocity.

Figure 12 illustrates by way of example a transverse section through a tube including a delay line in accordance with the present invention. The delay line is of the type illustrated in Figure 9, but it must be understood that any other one of the lines described herein could be substituted without departing from the scope of the invention. In addition to the rungs 2' and 2'' and the plates 3' and 3'' there are shown in Figure 12 the usual negative electrode 6, the electron beam 7 passing between the electrode 6 and the delay line, side walls 8 closing the tube, and magnetic poles 9.

The rectilinear shape of the tube shown in Figure 12 is in no way intended to limit the invention. On the contrary, the delay line may be bent to cylindrical shape for use in circular traveling wave tubes. Furthermore the property of low dispersion obtained with the delay lines according to the present invention renders them particularly suitable for use in magnetrons without the necessity

for using the connections known as straps which are inserted for artificially reducing the high dispersion of known anodes and for preventing the magnetron from jumping too easily from one frequency of oscillation to another. The delay lines according to the present invention, having a low dispersion and being comparable to a wide band circuit, already prevent these frequency jumps without the use of straps.

Figures 13 and 14 are respectively an axial section and a cross section through a magnetron using a delay line for example as in Figure 8 curved to circular shape, but it must be understood that any other line in accordance with the invention could be substituted. In these two figures, there are shown the rungs 2' and 2'', the lateral members 1 and base plate 3 being rolled to cylindrical shape. In the axis of the magnetron is positioned a cathode 11 and the magnetic field is produced by a coil 12.

What is claimed is:

1. A micro-wave delay line constructed and arranged for interaction with an electron beam propagated along said line in an adjacent interaction space, said delay line comprising at least one metal base plate, a pair of lateral members essentially parallel to said base plate and extending along the side edges thereof and a series of essentially parallel rungs extending between the two lateral members and of a length approximating one half the length of the wave to be delayed by the line, said lateral members being mounted so as to suspend said rungs in spaced relationship to said base plate on one side thereof between the plate and said interaction space, said line being electrically equivalent to a chain of coupled circuits including both electrical coupling and magnetic coupling, and conducting means comprising at least one conducting member secured to said base plate near the central portion of said rungs, whereby a part of the lines of force of micro-wave electromagnetic field is diverted to said member and said electrical coupling is reduced to a small value with respect to said magnetic coupling, said conducting member having a surface arranged to be exposed to said electron beam propagated along said line on the side of said rungs opposite said base plate, said surface extending parallel to said rungs transversely of said delay line, as well as extending generally parallel to the locus of said rungs longitudinally of said line.

2. A delay line as claimed in claim 1 wherein said conducting means comprises baffles extending between successive rungs, the transverse dimension of said baffles extending symmetrically on either side of the centers of said rungs.

3. A delay line as claimed in claim 1 wherein said lateral members extend in a straight line.

4. A delay line as claimed in claim 1 wherein each lateral member is curved to circular shape in a plane perpendicular to the longitudinal direction of said rungs.

5. In a travelling wave tube comprising an envelope, a delay line for micro-waves inside said envelope, said delay line being so constructed and arranged as to interact with an electron beam propagated along said line in an adjacent interaction space and comprising a metal base plate, at least one pair of lateral members extending longitudinally along the edges of said base plate, and a series of parallel rungs extending between said lateral members and connected thereto, the length of said rungs being substantially equal to one-half the length of the wave to be delayed by the line, said lateral members being mounted so as to suspend said rungs between said base plate and said interaction space in spaced relationship to a side of said base plate facing said interaction space, said line being electrically equivalent to a chain of coupled circuits including both electrical coupling and magnetic coupling, and conducting means comprising at least one conducting member secured to said base plate near the central portion of said rungs, whereby a part of the lines of force of micro-wave electromagnetic field is diverted to said member and said electrical coupling is reduced to a small value with respect to said magnetic coupling, said conducting member having a surface arranged to be exposed to said electron beam propagated along said line on the side of said rungs opposite said base plate, said surface extending parallel to said rungs transversely of said line as well as extending generally parallel to the locus of said rungs longitudinally of said line.

6. In a magnetron tube comprising an envelope, a delay line for micro-waves inside said envelope, said delay line being so constructed and arranged as to interact with an electron beam propagated along said line in an adjacent interaction space and comprising a metal base plate, at least one pair of lateral members extending longitudinally along the edges of said base plate, and a series of parallel rungs extending between said lateral members and connected thereto, the length of said rungs being substantially equal to one half the length of the wave to be delayed by the line, said lateral members being mounted so as to suspend said rungs between said base plate and said interaction space in spaced relationship to a side of said base plate facing said interaction space, said line being electrically equivalent to a chain of coupled circuits including both electrical coupling and magnetic coupling, and conducting means comprising at least one conducting member secured to said base plate near the central portion of said rungs, whereby a part of the lines of force of micro-wave electromagnetic field is diverted to said member and said electrical coupling is reduced to a small value with respect to said magnetic coupling, said conducting member having a surface arranged to be exposed to said electron beam propagated along said line on the side of said rungs opposite said base plate, said surface extending parallel to said rungs transversely of said line as well as extending generally parallel to the locus of said rungs longitudinally of said line.

7. A micro-wave delay line comprising at least one metal base plate, a pair of lateral members essentially parallel to said base plate and extending along the side edges thereof and a series of essentially parallel rungs extending between the two lateral members and of a length approximating one-half the length of the wave to be delayed by the line, said lateral members being mounted so as to suspend said rungs exterior to one side of said base plate, whereby a space is bounded by said base plate and said rungs, said line being electrically equivalent to a chain of coupled circuits including both electrical coupling and magnetic coupling, and conducting means comprising a conducting filler member secured to said base plate and extending in the space between said rungs and said base plate lengthwise of the delay line for a distance greater than the distance between adjacent rungs, said filler member having a surface parallel to the locus of said rungs near the central portion of said rungs, whereby a part of the lines of force of a micro-wave electromagnetic field is diverted to said member and said electrical coupling is reduced to a small value with respect to said magnetic coupling.

8. A micro-wave delay line comprising at least one metal base plate, a pair of lateral members essentially parallel to said base plate and extending along the side edges thereof and a series of essentially parallel rungs extending between the two lateral members and of a length approximating one-half the length of the wave to be delayed by the line, said lateral members being so mounted as to suspend said rungs exterior to one side of said base plate, whereby a space is bounded by said base plate and said rungs, said line being electrically equivalent to a chain of coupled circuits including both electrical coupling and magnetic coupling, and conducting means including a filler member extending in the space between said rungs and said base plate lengthwise of the delay line for a distance greater than the distance between adjacent rungs, said filler member being in a symmetrical position relative to the centers of said rungs, and baffles extending

between successive rungs and mounted on said filler member, the transverse dimension of said baffles extending symmetrically on either side of the centers of said rungs, whereby a part of the lines of force of a micro-wave electromagnetic field is diverted to said conducting means and said electrical coupling is reduced to a small value with respect to said magnetic coupling.

References Cited in the file of this patent

UNITED STATES PATENTS

2,511,407	Kleen et al.	June 13, 1950
2,527,477	Clapp	Oct. 24, 1950

2,565,387	McCarthy	Aug. 21, 1951
2,629,015	Reed	Feb. 17, 1953
2,643,353	Dewey	June 23, 1953
2,745,984	Hagelbarger et al.	May 15, 1956
2,768,322	Fletcher	Oct. 23, 1956
2,823,332	Fletcher	Feb. 11, 1958
2,827,589	Hines	Mar. 18, 1958

OTHER REFERENCES

Ragan, Microwave Transmission Circuits, published by McGraw-Hill, New York, in 1948, first edition, pages 358–359 (copy in scientific library).