April 2, 1963 R. C. HERGENROTHER 3,083,443

WAVE RETARDATION LINES HAVING PERIODIC TAPERING PITCH

Filed Oct. 30, 1958

FIG. 1

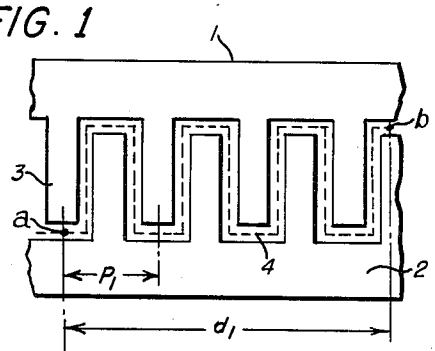
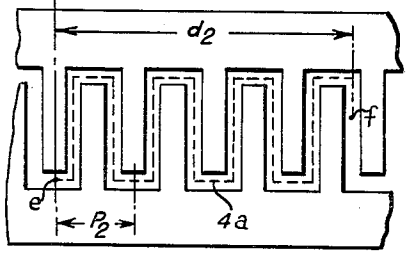



FIG. 2



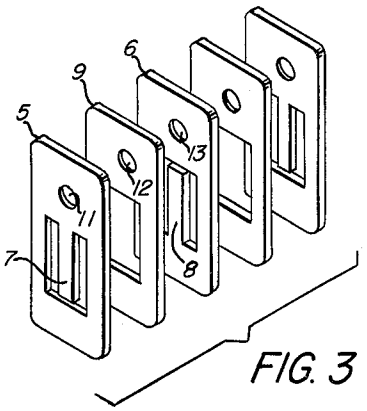




FIG. 3

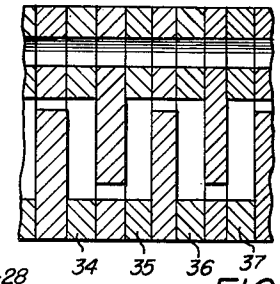



FIG. 4

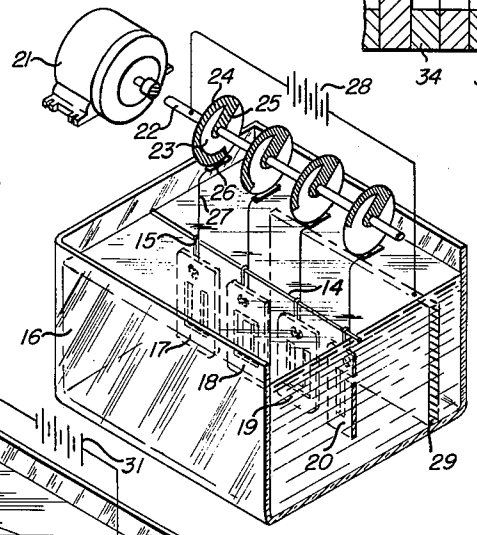



FIG. 5

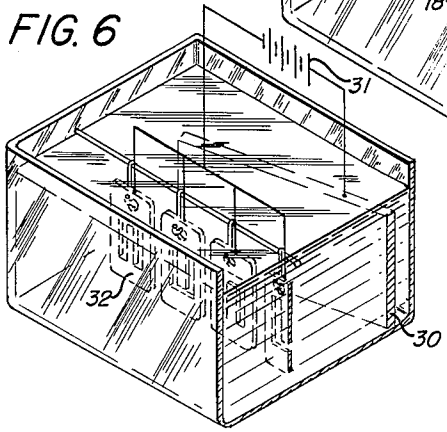



FIG. 6

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3,083,443

# WAVE RETARDATION LINES HAVING PERIODIC TAPERING PITCH

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2 Claims. (Cl. 29—155.5)

This invention relates to electromagnetic wave retardation structures, commonly known as delay lines, and more particularly pertains to a method for manufacturing a laminated delay line of the periodic type in which the pitch of the line progressively decreases. Delay lines having a periodic structure are employed in beam traveling wave electron tubes, such tubes being characterized by the exchange of energy between a beam of high velocity charged particles and an electromagnetic wave propagating along the delay line.

For a general description and discussion of the development of the beam traveling wave tube, reference is made to Proceedings of the I.R.E. of March 1956, p. 333 et seq., "The O Type Carcinotron Tube" by P. Palluel and A. K. Goldberger. A traveling wave tube utilizes an electron gun which generates an electron beam, the beam being directed through a long evacuated tube until it impinges upon a collector electrode which absorbs the beam. Within the tube and adjacent the path of the electron beam, there is situated a delay line for guiding and retarding the propagation of an electromagnetic wave. The electromagnetic wave travels on the delay line at a speed approaching the speed of light but due to the folded configuration of the delay line, the velocity of the wave in relation to the longitudinal axis of the tube is determined by the pitch of the delay line and is a fraction of the speed of light. The electron gun and collector electrode potentials are arranged so that the average axial velocity of the electron beam is equal to or somewhat greater than the axial wave velocity. Interaction of the electron beam and the high frequency field associated with the electromagnetic wave on the delay produces an exchange of energy. The greater the electron current density and the longer the delay line, the greater is the exchange of energy. In transit through the tube, the elcetron beam becomes bunched in certain potential regions of the traveling wave and this bunching effect results in a general retardation of electrons in the beam, the average electron velocity being reduced, and the diminution of energy represented by this decreased velocity being imparted to the electromagnetic wave. Physically, this retardation or general lowering of the average electron velocity is a consequence of the transfer of energy from the beam to the traveling electromagnetic wave. If electrons in the region of coupling with the electromagnetic wave travel at an axial velocity somewhat less than the axial velocity of the electromagnetic wave, then this bunching effect, which tends to synchronize the axial flow of electrons with the desirable potential regions of the traveling wave, results in a general increase of average electron velocity. This velocity increase which represents an increase in overall beam energy level is effected by extracting energy from the traveling wave and is obviously undesirable where the purpose is to transfer energy from the beam to the wave. To prevent this undesirable effect, the traveling wave must be progressively slowed as the electrons deliver their energy to the wave so that the retarded electrons remain in synchronism with the wave. The traveling wave can be progressively delayed by providing a periodic delay line having its pitch tapering from one end of the line toward the other, and this invention is directed toward a method for manufacturing such a delay line.



The invention resides in a method for manufacturing a periodically tapering delay line constructed from laminates. The laminates are punched from sheet stock having a uniform thickness and the stampings are then attached to a holder. A set of laminates for a section of the delay line would be attached to a holder and inserted in an electroplating bath. The plating process is performed in a manner such that the thickness of plate deposited on the laminates tapers uniformly over the complete set. The laminates are then held in the holder until final assembly when they are removed in succession by the operator in order to prevent the laminates from becoming mixed during the final assembly. The assembled laminates are then placed in an oven containing an atmosphere of hydrogen and heated until the assembly is bonded into an integral delay line section.

The method of manufacture and its advantages will be better understood by a perusal of the following description when considered in conjunction with the accompanying drawings wherein:

FIGS. 1 and 2 illustrate periodic interdigital delay lines;

FIG. 3 illustrates laminates employed in the construction of a laminated interdigital delay line;

FIG. 4 illustrates a segment of an assembled laminated delay line; and

FIGS. 5 and 6 illustrate apparatus for electroplating the laminates which are subsequently assembled to form an interdigital delay line.

The method of manufacture relates in general to delay lines which can be constructed from laminates. For purposes of discussion, however, the description will be limited to interdigital delay lines of the type shown in FIG. 1 and the generality of the method may be deduced from the description herein. The delay line shown in FIG. 1 may be viewed as comprising two combs **1** and **2** having their fingers or teeth **3** interleaved and fixed in relation to one another. The pitch $P_1$ of the line is defined as the distance between corresponding points on adjacent fingers projecting from the same comb. Electromagnetic wave energy is considered to propagate in the space bounded by the two combs. Assuming a constant velocity of propagation in that space it may be seen that by gradually decreasing the pitch of the line, the propagation path of the electromagnetic wave energy will be lengthened thereby causing the wave to be slowed down as it progresses along the delay line. The effect of reducing the pitch on the velocity of wave propagation can be more fully appreciated by comparing FIG. 1 with FIG. 2 which shows a section of an interdigital delay line equal in length to the delay line of FIG. 1 but having a smaller pitch P2 and, hence, more fingers. An electromagnetic wave propagating from the point *a* to the point *b* in FIG. 1 is constrained to follow the path indicated by the broken line **4** and will traverse that path in a time *t*. An electromagnetic wave starting from the point *e* in FIG. 2 will travel an equal distance in the time *t* along the broken line path *4a* and will therefore reach the point *f* at the expiration of time *t*. Whereas in FIG. 1 the electromagnetic wave has moved a distance $d_1$ along the delay line in the time *t*, the electromagnetic wave in FIG. 2 has in the same time moved a lesser distance $d_2$ along the delay line because of its smaller pitch. It is clear, therefore, that a decrease in pitch of the delay line causes the wave to progress longitudinally along the line at a slower speed.

FIG. 3 illustrates three types of stampings or laminates which are employed to form an interdigital delay line. The laminates **5** and **6** are characterized by dependent fingers **7** and **8** which protrude in opposite directions. The laminate **9** is a spacer element which is interposed between

the laminates 5 and 6 and therefore determines the spacing between fingers 7 and 8. By assembling the laminates in the sequence shown in FIG. 3, a delay line of any desired length may be formed. When the laminates are assembled the apertures 11, 12 and 13 therein are aligned and form a conduit through which a co-axial line center conductor may be inserted to form an output coupling. A unitary delay line is made of a large number of thin laminates brazed together to form an integrated laminar structure. The laminates shown in FIG. 3 are punched from sheets of copper or an alloy of copper. The metal employed in the stampings should be ductile, free of oxygen, and have high electrical conductivity. A variety of copper known as OFHC copper has been employed with satisfactory results. Laminates 5 and 6 are usually stamped from sheet stock of the same uniform thickness whereas the spacer 9 is stamped from sheet stock having a gage equal to the desired spacing between adjacent fingers. It should be understood that a conventional interdigital delay line may have 100 or more fingers and that delay lines having 200 fingers are not uncommon. The number of fingers in a delay line does not impose any limitation upon the method of manufacture described herein, as will be appreciated from a complete reading of this description. The dies for making the stampings are very accurately constructed and are hardened so that large numbers of stampings may be struck from thin sheets of copper while maintaining high dimensional precision. The stampings or laminates, after being formed by the dies, are cleaned, for example, by anodic pickling, to render their surfaces free from grease and other contaminants. As a precaution, the laminates should not be handled with bare hands until after firing in a brazing furnace because the skin secretes oils and inorganic salts which interfere with the formation of a good bond. The stresses set up in the copper stampings by the die-stamping operation are relieved by annealing the copper while concurrently applying a uniform pressure to prevent curling or bending of the stamping. The annealing operation is preferably performed in a reducing atmosphere to remove any oxides which may have formed on the stampings.

Assuming the requisite number of laminates of each type have been stamped from sheet copper, cleaned, and annealed, laminates of the type having dependent fingers are then arranged along a rod so that a laminate having a downwardly protruding finger alternates with a laminate having an upwardly protruding finger. The number of laminates spaced along the rod depends upon the number of fingers which it is desired to incorporate in the complete delay line or a delay line section. That is, a delay line may be constructed in laminar sections which are subsequently bonded together to form the complete delay line or, if the delay line is of moderate length, the complete laminated delay line may be fabricated as a unit. The total length of the complete delay line will govern the procedure best suited to the individual case. The rod 14 is fabricated of an insulative material and has attached to it a number of holders or clamps 15 from which the laminates are suspended. The rod and the suspended laminates are then placed in a copper plating bath and the laminates are electroplated by applying an electric potential between the laminates and a suitable oppositely polarized electrode. In order that the thickness of copper plate deposited on the laminates shall progressively decrease from one end of the rod to the other, two methods of arrangement are here described which achieve the desired results. The first method is illustrated in FIG. 5 which shows a tank 16 containing a copper plating solution in which are immersed the laminates 17, 18, 19, 20 suspended from the insulative rod 14 by suitable holders. A constant speed motor 21 is provided which drives a shaft 22 carrying a number of discs which rotate with the shaft. To the peripheral surface of each disc, the disc 23 for example, there is secured a conductive strip 24 and a radial conductive lead 25 provides an electrical



path from the strip to the metallic shaft. A brush 26 is positioned to bear on the periphery of disc 23 and an electrical connection 27 is provided between brush 26 and the laminate 17. In a similar manner, each of the other laminates in the bath is electrically connected to a brush bearing on the surface of a different disc. The conductive strips (exemplified by the strip 24) secured to the discs are of unequal lengths and are arranged so that the longest strip is secured to the disc 23 at one end of the shaft and each successive disc carries a strip of smaller length. A source of electrical current, here indicated by the battery 28, is connected between shaft 22 and an electrode 29 immersed in the tank. As shaft 22 turns slowly through a complete revolution, the duration of current flow between each laminate and the electrode 29 is determined by the length of the conductive strip in the periphery of its associated disc. The duration of current flow, in turn, determines the thickness of copper plate deposited on the laminate. Thus, in FIG. 5, the laminate 17 will have the thickest copper plate and each successive laminate will have a thinner copper plate.

The second arrangement for insuring that the copper plate deposited on the laminates shall progressively decrease from one end of the rod to the other is illustrated in FIG. 6. In this latter arrangement the laminates, suspended from a rod in the manner previously described, are immersed in a copper electro-plating bath. The electrode 30 is disposed at an angle to the suspended laminates and an electric potential is impressed for a predetermined length of time between the laminates and the electrode 30 by a source, here illustrated as a battery 31. The flow of current between each of the immersed laminates and the electrode is directly related to the spacing between those members and hence, the thickness of copper plate deposited on a laminate varies inversely with the distance between it and the electrode 30. That is, the larger the current, the more copper is deposited on a laminate. Thus, for the same period of current flow, the greatest thickness of plate will be deposited on laminate 32 with each consecutive laminate having a plating of lesser thickness. When the desired thicknesses of plate have been deposited, the current is turned off and the rod with its suspended laminates are removed from the bath.

Regardless of the process used to plate the laminates, the laminates are retained on the rod 14 until the final assembly stage is reached. Indiscriminate mixing of the plated laminates must be avoided. This can be more fully appreciated when it is realized that the difference in thickness between adjacent laminates may be of the order of one one hundred thousandth (1/100,000) of an inch. At the final assembly stage, the laminates are assembled on a fixture having a means for precisely aligning the dependent fingers. In the process of assembly, the plated laminates are successively removed from the rod beginning at one end and the laminates having dependent fingers are alternated with a spacer so that the laminated stack consists of laminates such as 5 and 6 in FIG. 3 and interleaved spacers such as the spacer 9. The assembled stack of laminates is placed in a rigid frame and placed in a brazing furnace where the laminated stack is subjected to compressive pressure while the temperature is raised to brazing heat.

A suitable brazing procedure is known in which the spacers, i.e., those laminates not having a dependent finger, are plated with a coat of silver having a thickness of the order of .0002". The laminates are assembled in the manner previously indicated, the stacked laminates are placed in a steel frame having 3/5 the expansion of copper, and the assembly is then placed in a brazing furnace. Upon heating the furnace to brazing temperature, i.e. the temperature at which the silver-copper eutectic melts, high intensity pressures are induced in the laminated stack because of the difference in the rates of thermal expansion between the copper laminates and the steel

frame. The laminated stack is subsequently slowly cooled so that the copper is again annealed. This procedure has proved to be highly successful in the formation of a vacuum tight bond without an accompanying excess of silver solder. For a fuller description of this brazing method, reference may be made to copending application Serial No. 627,453, filed December 10, 1956, now Patent No. 2,882,587.

FIG. 4 shows a cross-sectional view through a segment of an assembled delay line. It will be observed that the thickness of the fingers gradually diminishes as one progresses from the left end toward the right. The change in thickness has been greatly exaggerated in the drawings since in an actual delay line the difference in thickness is not readily detected by the unaided eye. It will also be noted that the spacers **34**, **35**, **36**, **37** are of the same thickness so that the spacing between fingers is maintained uniform throughout the delay line. However, where it is desired to change the impedance along the delay line in a gradual manner, the spacers **34**, **35**, **36** and **37** may be plated in the same manner as the laminates having fingers so that the spacing between fingers is not uniform but tapers from one end of the line to the other.

While the invention has been described with reference to copper laminates, the method here disclosed is applicable to many copper alloys and to other metals such as nickel and related alloys such as Monel. This invention, therefore, is not limited to the particular details of construction or materials described. It is accordingly desired that the appended claims be given an interpretation commensurate with the scope of the invention.

What I claim is:

1. A method of constructing a laminar delay line comprising the steps of forming metal spaces, punching metallic laminates having dependent digits from sheet stock having a uniform thickness, suspending said laminates from a holder in the order in which said laminates are to be assembled, immersing said laminates in an electroplating bath, causing each of said laminates to be plated for a different length of time determined by its position upon said holder, removing said holder and its suspended laminates from said bath, consecutively removing said laminates starting at one end of said holder, alternately stacking spacers and said laminates, and bonding the stack into an integral unit.

2. A method of constructing a laminar delay line comprising the steps of forming metal spacers, striking laminates having dependent digits from sheet metal of uniform thickness, arranging said laminates upon a holder in the order in which said laminates are to be assembled, immersing said laminates in an electroplating bath having an electrode diverging from said holder, concurrently connecting said laminates in parallel to a source of electric current whereby each of said laminates are coated with a metallic plate whose thickness is determined by the distance between the laminate and said electrode, removing said holder and the attached laminates from said bath, alternately stacking said spacers and laminates upon a jig which aligns said dependent digits, and simultaneously applying pressure and heat to the stacked assemblage to form an integral structure.

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