Jan. 30, 1962 C. E. WELLMAN, JR 3,019,398

ELECTRICAL DELAY LINE

Filed Dec. 23, 1958

FIG.1.

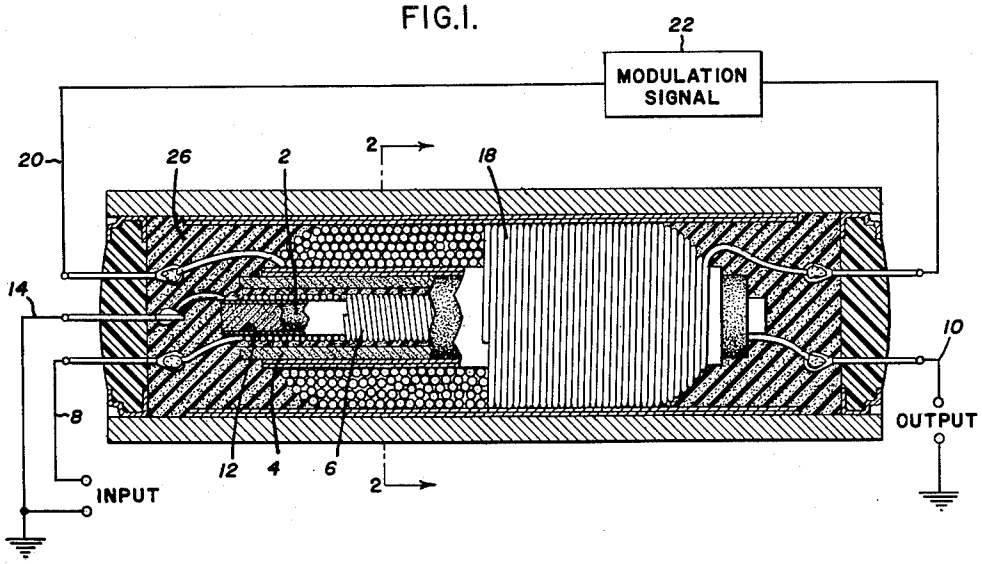


FIG.2.

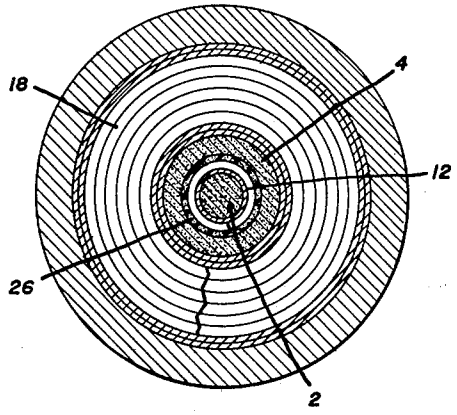
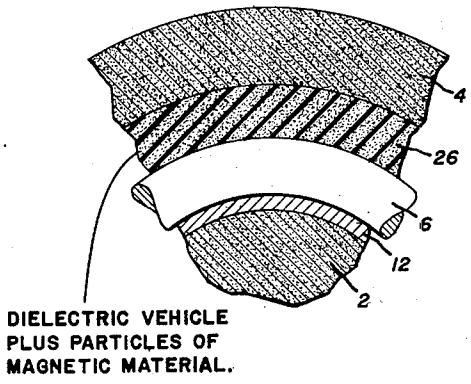


FIG.3.



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ELECTRICAL DELAY LINE

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The present invention relates to electrical delay lines of the type employing a signal winding disposed within an enclose of magnetic material.

A principal object of the invention is to facilitate assembly of the parts of a delay line and enable an increase in the dimensional tolerances of the various parts of delay line without adversely effecting the electrical properties of the delay line.

Another object is to provide an improved delay line having increased inductivity at high frequencies of the order of 30 to 40 megacycles per second and higher, and having maximum delay per unit physical length at such high frequencies.

These and other objects will be apparent from the following description taken in conjunction with the accompanying drawing wherein:

FIGURE 1 is a diagrammatic view partly, broken away in axial section, of a delay line constructed according to the present invention;

FIGURE 2 is an enlarged transverse sectional view of the structure of FIGURE 1 taken on the line 2—2 thereof.

FIGURE 3 is an enlarged fragmentary view of a portion of the structure shown in FIGURE 2.

Briefly, according to the present invention, the foregoing objects are achieved by providing within the magnetic enclosure a filling which occupies substantially all the spaces not otherwise occupied by the other parts of the delay line. The filling comprises a mixture of a material having dielectric properties for enhancing the capacitive coupling of the two conductive elements of the line and having lubricative properties facilitating assembly of the delay line part one within the other, and a finely divided magnetic material for optimizing the permeability of the region surrounding the inductive portion of the delay line.

FIGURE 1 shows a delay line constructed according to the present invention. The delay line shown includes a rod 2 which may be of non-conductive ferromagnetic material such as ferrite disposed within a tube 4 of non-conductive ferromagnetic material such as ferrite, the term "ferrite" being defined as a crystalline reaction product of iron oxide and one or more oxides of bivalent metal. The distributed inductance of the delay line is provided by a helical signal winding 6 to one end of which the signal to be delayed or modulated is adapted to be applied through a lead 8 and from the other end of which the delayed or modulated signal is recoverable through a lead 10. The signal winding is enclosed within the tube 4 and is preferably wound on the rod 2. The distributed capacitances of the delay line are provided by the plurality of capacitive couplings between the signal winding 6 and a ground plane 12 which consists of one or more conductors supported adjacent but in dielectrically spaced relation to the signal winding 6 and connected to an external lead 14. The ground plane conductors may consist for example of one or more strips or a single unified coating of conductive material extending along and supported preferably on the exterior surface of the rod 2.

As is well known in the art, the delay of the line per unit physical length is proportional to $\sqrt{LC}$ where L is the inductance per unit length and C is the capacitance per unit length of the line. Thus the delay of the line,

being proportional to the inductance L per unit length, may be changed by effecting a change in the effective inductance of winding 6 by varying the permeability of the tube 4 or the tube and rod 2. To enable varying the permeability of the tube 4 or tube and rod 2, means is provided for developing a magnetic field of variable intensity for saturating the tube or tube and rod to the desired degree. This means preferably takes the form of a magnetizing winding 18 disposed externally of the tube 4 and preferably wound on the exterior surface thereof and electrically insulated therefrom. The magnetizing winding is connected through lead 20 to any suitable source 22 of delay varying signals, which signals may be alternating or direct current or a combination of both.

In a delay line such as above-described the presence of high permeability material such as the tube 4 and rod 2 adjacent the signal winding contributes greatly to the prevention of decay in inductance of the line, particularly at the higher frequencies where the currents in the various turns of the signal winding 6 are not all in phase. This effect may be explained as follows: When the frequency of the signal applied to the winding 6 becomes high enough so that an appreciable phase difference occurs between the currents in the various turns of the winding 6, then the flux lines of the magnetic field produced by the winding 6 will not remain concentrated in the rod 2 as they do at lower frequencies. Instead the flux lines will form closed paths looping outside the rod 2 at intervals along the rod. The presence of the tube 4 outside the winding 6 provides a high permeability path for those portions of the flux lines outside the rod 2, thereby preventing the tendency to decay in inductance and resultant decrease in total delay of the line which would otherwise occur at the higher frequencies.

In accordance with the present invention optimum preservation of inductance at the higher frequenciee is provided while avoiding close fitting of the rod and tube about the winding 6, such as would require objectionably small dimensional tolerances on these elements. Moreover, dimensional tolerances of the several interfitting parts of the delay line can be increased to facilitate assembly and avoid parts rejections without adversely affecting electrical properties of the delay line. According to the present invention the spaces between the rod and tube, which would otherwise provide a low permeability air gap, are filled with a material 26 which serves as a lubricant to facilitate assembly of the parts, as a dielectric material to enhance the capacities coupling between the ground plane and signal winding, and as a ferromagnetic material to maximize the permeability of the region surrounding the signal winding. The dielectric constituent of the filling material may be any suitable material with good dielectric properties, preferably having as high a dielectric constant as possible, and preferably having lubricating properties. A low temperature coefficient of viscosity for the dielectric constituent of the filling is also desirable, particularly where operation over a wide temperature range is contemplated. The magnetic constituent of the filling material may be any finely comminuted magnetic material, such as ground ferrite, powdered iron, or the like. One satisfactory filling material is Dow Corning DC 4 silicone compound mixed with a zinc-nickel ferrite ground to a powder fine enough to pass through a 400 mesh per inch screen. Other dielectric constituents for the filling material may consist, for example, of various waxes as well as various dielectric synthetic materials, and the like. The dielectric constituent of the filling material, either before or after mixing with the finely divided magnetic material, may be coated on the interior surface of the tube 4 and the exterior surface of the rod 2 before the rod is placed inside of the tube to

lubricate the parts during insertion of the rod within the tube, thereby facilitating assembly. It will be evident that the dielectric material also provides a simple expeditious vehicle for carrying the finely divided magnetic material into intimate surrounding relation with the signal winding 6.

An electrical delay line constructed in the foregoing manner has several salient advantages in comparison with the prior art. First the presence of the dielectric material filling the space which would otherwise constitute an air gap between the signal winding 6 and ground plane 12 increases the average dielectric constant of the region between the signal winding and ground plane, thereby increasing the capacitance of the line and hence increasing its delay per unit length. Also the presence of the finally divided magnetic material in the region between the tube 4 and rod 2 increases the average permeability of the region surrounding the signal winding, thereby increasing the inductance of the delay line and clearly increasing its delay per unit length. Additionally it will be readily appreciated that the presence of the lubricant facilitates assembly of the parts during manufacture. Moreover the increase in the average permeability of the region surrounding the signal winding permits a widening of the dimensional tolerances of the parts, contributing further to ease of assembly of the line without incurring any penalty in decreased electrical performance.

It will be appreciated by those skilled in the art that the invention may be carried out in various ways and may take various forms and embodiments other than those illustrative embodiments heretofore described. It is to be understood that the scope of the invention is not limited by the details of the foregoing description, but will be defined in the following claims.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In a delay line including a rod of magnetic material disposed within a close fitting rigid tube of magnetic material, a signal winding disposed between the tube and the rod and a ground conductor capacitively coupled to the signal winding, means for increasing the inductance, capacitance and time delay of said delay line, said means comprising a filling between the rod and tube consisting of a lubricant mixed with particles of magnetic material, said filling further permitting ease of assembly of said rod within said tube.

2. In a delay line including a rod of magnetic material disposed within a close fitting rigid tube of magnetic material, a signal winding disposed between the tube and the rod and a ground conductor capacitively coupled to the signal winding, means for increasing the inductance, capacitance and time delay of said delay line, said means comprising a filling between the rod and tube consisting of a lubricant of dielectric material mixed with particles of magnetic material, said filling further permitting ease of assembly of said rod within said tube.

3. An electrical delay line including a ferrite rod disposed within a close fitting rigid ferrite tube, a signal winding comprising a plurality of turns of conductive material wound on the rod, a ground conductor supported on the rod and capacitively coupled to the signal winding, the space between the rod and tube being occupied by a filling consisting of a lubricant of dielectric material mixed with particles of ferrite, to increase the inductance, capacitance and time delay of said delay line.

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