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Lorber et al.

[11] **3,768,046**

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[54] **PRECISION DISTRIBUTED PARAMETER DELAY LINE**

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[52] **U.S. Cl.** .... **333/31 R,** 333/20, 333/70 T, 333/84 M, 328/56

[51] **Int. Cl.** **H03h 7/30,** H01p 3/08

[58] **Field of Search** .... 333/31 R, 70 T, 31 C, 333/84 R, 84 M; 328/56, 67, 66, 121, 151

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[57] **ABSTRACT**

A precision distributed parameter delay line for use in high speed circuitry requiring very precise nanosecond delay intervals. The delay line, in one preferred embodiment, comprises a section of coaxial cable transmission line having a central conductor and a coaxially aligned conductive sheath with the sheath preferably being insulated over its length. The section of coaxial cable tranmission line functions as a low impedance delay element of extremely small outer diameter whose length may be adjusted to provide delays of from tenths to hundreds of nanoseconds. The nature and size of the delay line is such as to make it extremely adaptable to being coiled so as to significantly reduce the amount of space which it occupies. A very short section of coaxial cable transmission line of similar design and impedance characteristics is coupled to the input and/or output ends of the coaxial cable transmission line section central conductor to improve the rise time and provide an extremely high delay to rise time ratio, low insertion loss, low characteristic impedance and is adaptable for use over a wide frequency bandwidth.

The delay line may also take the form of a printed circuit of the microstrip type transmission line comprised of an elongated, preferably undulating conductive strip separated from a conductive ground plane by a suitable dielectric with input and output terminals being located a spaced distance from the extremities of the undulating conductive member to provide the characteristics set forth hereinabove while taking advantage of microconductor techniques to further reduce the size and allow dual-in-line delay line packages. Both of the above embodiments may be modified accordingly to provide a tapped delay line having the desirable characteristics set forth herein.

16 Claims, 7 Drawing Figures

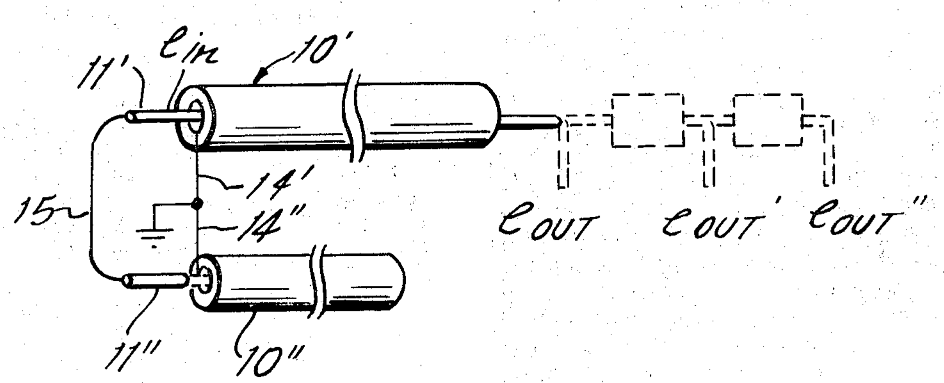


FIG. 1

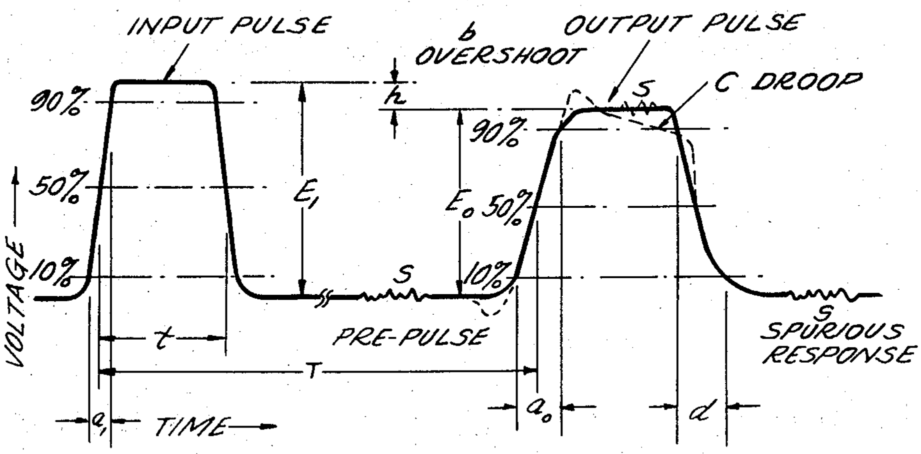


FIG. 2

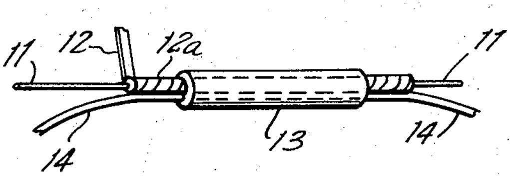


FIG. 4a

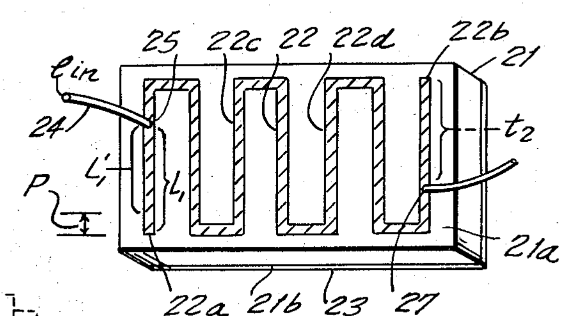


FIG. 3

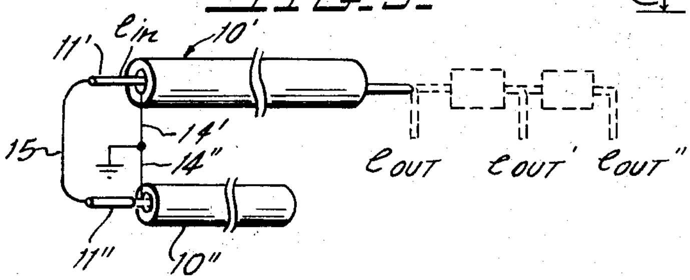


FIG. 4b

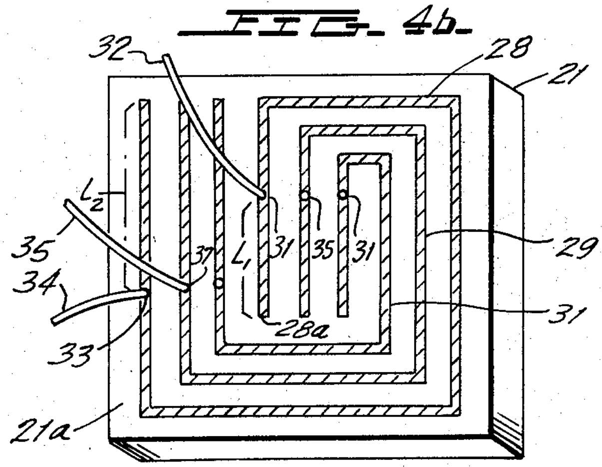


FIG. 5

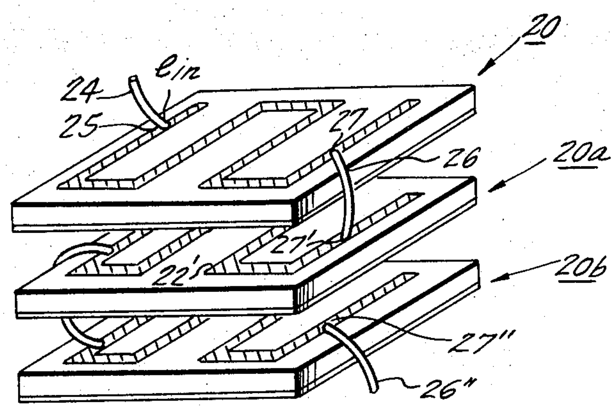
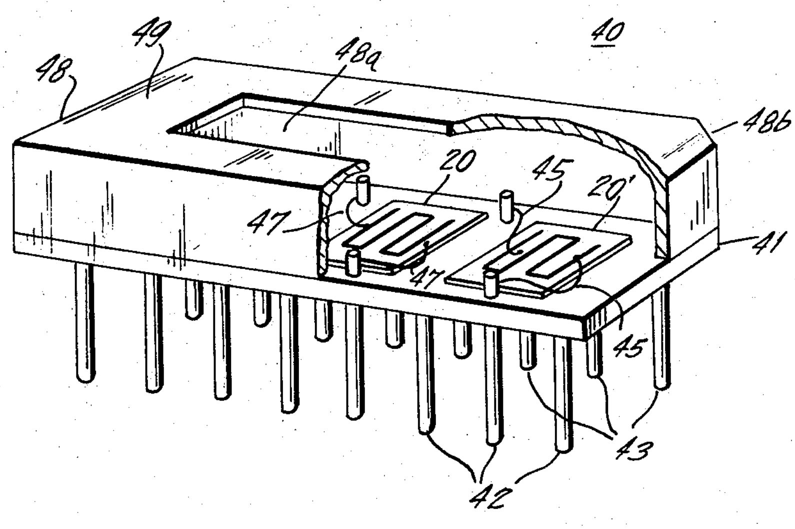

20
e_{in}
24
25
27
26
20a
27'
22's
20b
27''
26''

FIG. 6


49
48a
40
48
48b
20
45
20'
47
47
41
45
43
42

PRECISION DISTRIBUTED PARAMETER DELAY LINE

The present invention relates to delay lines and more particularly to a precision delay line structure utilizing an additional delay line section or sections to significantly improve rise time, reduce insertion losses and provide a delay line having a low impedance characteristic while at the same time providing precise delays in the nanosecond range.

BACKGROUND OF THE INVENTION

Delay lines are presently employed in a wide variety of applications. Some very important applications exist in the computer area wherein it is required to provide for simultaneous presence of a plurality of signals at the input to a gate, for example, whereby some of these signals may pass through logic chains of differing lengths, thereby requiring delay lines to equalize the delays of such signals to insure their presence when they are required. Other areas such as radar communications and sophisticated electronics applications also have need for delay lines which provide precise delay intervals in the nano second range.

Some of the major problems existing in connection with conventional delay line structures are the poor rise and fall times, the high impedance characteristics of the delay lines, the narrow bandwidths in which conventional delay lines may be employed and the high insertion losses which occur in conventional delay lines. One of the most significant problems in conventional delay lines resides in their poor delay to rise time ratio. One technique which has been employed in the prior art is the utilization of a series connected capacitor and resistor element connected between the central conductor of a coaxial cable transmission line and ground which is provided to improve the rise time characteristic of the delay line. However, this technique has led to a reduction in signal strength (i.e., increase in attenuation of the delayed output pulse) and to a change in the characteristic impedance of the delay line.

BRIEF DESCRIPTION OF THE INVENTION

The present invention is characterized by providing a distributed parameter delay line structure of small size so as to occupy a relatively small amount of space as compared with conventional delay lines and which is provided with a short delay line section coupled across the input and/or output terminals of the delay line which short section acts to significantly improve the delay to rise time ratio and which further reduces the insertion loss and does not affect the low impedance characteristic of the delay line while at the same time being adaptable for use over a wide bandwidth.

In one preferred embodiment of the present invention, the delay line is comprised of a first coaxial cable transmission line section of extremely small outer diameter and having a length selected to provide the appropriate nanosecond delay. A second section of coaxial cable transmission line of similar physical design and characteristics has its central conductor connected to the input terminal of the delay line. The conductive sheaths of both the second coaxial cable transmission line section and the delay line section are preferably grounded while the free end of the short second delay line section remains electrically isolated from the remainder of the circuit and functioning as a tuning element. It has been found that the resulting delay line structure provides an extremely fast rise time and hence a high delay to rise time ratio while at the same time providing low insertion loss, low input impedance and is adaptable for use over a wide bandwidth.

The amount of delay is obtained by selecting a coaxial cable transmission line delay line section of appropriate length and the delay line apparatus provides a very precise delay in the range from tenths to hundreds of nanoseconds with a precision of the order of ± one-half nanosecond.

A similar short coaxial type delay line section may be coupled across the output terminal of the delay line apparatus in a manner similar to that described hereinabove in connection with the short delay line section coupled across the input of the delay line to provide impedance matching between the output of the delay line and the input of an electrical circuit or other component connected thereto as well as improving rise time of the delayed signal.

Another preferred embodiment of the present invention employs microconductor techniques in which a conductive strip or coating preferably arranged in an undulating pattern is mounted upon an insulating substrate having a predetermined dielectric constant and being adapted to receive a ground plane upon its opposite surface so as to form a microstrip type delay line. The input and output connections of the delay line are spaced inwardly by predetermined distances from the extremities of the undulated conductive strip so as to provide effective short delay line sections functioning as a tuning element for improving the quality of the delay line output signal, as was described hereinabove as well as for providing excellent impedance matching between the output of the delay line apparatus and the input of associated circuitry. A distributed parameter delay line apparatus manufactured in accordance with the above techniques provides an extremely small and compact delay line structure which lends itself advantageously for use in a dual in line package. Delays of the order of tenths of hundreds of nanoseconds with the tolerance of the order of ± one-half nanosecond are obtained by etching or machining away the portion of the undulating conductive strip, with the amount etched or machined away being dependent upon the particular delay interval desired. The characteristic impedance of the delay line may be controlled over a wide range through appropriate selection of a dielectric material and further by controlling its thickness.

Both types of delay lines as described hereinabove may be appropriately modified to provide a tapped delay line structure.

OBJECTS OF THE INVENTION

It is therefore one primary object of the present invention to provide a novel delay line structure of extremely small size for providing delays of precise values within the nanosecond range.

Another object of the present invention is to provide a novel delay line apparatus of extremely small size for providing a precise delay interval within the nano second range and which incorporates an additional section or additional sections coupled to the input and output ends thereof for significantly improving the delay to rise time ratio without adversely affecting the characteristic impedance and other advantageous characteristics of the delay line structure.

Another object of the present invention is to provide delay lines having the characteristics as defined by the above objects in which the delay line structures is formed of coaxial cable transmission line sections of extremely small diameters.

Still another object of the present invention is to provide a novel tapped delay line structure having the characteristics as set forth in the objects recited hereinabove in which microconductor techniques are employed in the manufacture of the delay line structure.

Still another object of the present invention is to provide a novel tapped delay line structure having the characteristics as set forth in the objects recited hereinabove.

BRIEF DESCRIPTION OF THE FIGURES

The above as well as other objects of the present invention will become apparent when reading the accompanying description in conjunction with the drawings in which:

FIG. **1** is a waveform useful in describing the various embodiments of the present invention and its advantages over the prior art.

FIG. **2** is a perspective showing one preferred type of coaxial cable transmission line which may be advantageously employed in the apparatus of the present invention.

FIG. **3** is a schematic diagram showing one preferred embodiment of a delay line structure designed in accordance with the principles of the present invention.

FIGS. **4***a* and **4***b* are perspective views showing other preferred embodiments of the present invention.

FIG. **5** shows another embodiment of the present invention in which delay lines of the type shown in FIGS. **4***a* and **4***b* may be stacked to provide a delay line structure of a multiplicity of precise delay intervals and increase the delay time preferably within the nanosecond range.

FIG. **6** is a sectional view showing one delay line package which may be employed for encapsulating delay line structures of the type shown in FIGS. **4***a* – **5.**

DETAILED DESCRIPTION OF THE FIGURES

The waveform of FIG. **1** is useful in evaluating and clarifying an understanding of delay line structures and their attendant shortcomings.

As shown in FIG. **1,** the input pulse, which is a substantially square pulse of narrow pulse width t is typically measured at the 50 percent amplitude points.

The delay time T between the application of the input pulse at the input terminal of a delay line structure and the current of the output pulse at the output of the delay line structure is typically measured from the 50 percent amplitude point of the leading edge of the input pulse to the 50 percent amplitude point of the leading edge of the output pulse.

The input pulse rise time a_i is the time duration measured between the instant in which the leading edge of the input pulse reaches 10 percent of its maximum amplitude and the instant at which it reaches 90 percent of its maximum amplitude. The output pulse rise time a_0 is determined in a similar fashion. The dashed line portions of the waveform shown in FIG. **1** show common variations which typically occur in the output wave shape. The dotted line section b represents overshoot which is a continuation of the leading edge of the pulse typically caused by resonances within the delay elements. The dotted line portion c indicates a droop which may occur in the output pulse which is a sloping of the top of the pulse due to poor low frequency response.

Spurious response S which is also typically referred to as distortion or ripple, defines any irregularities in the signal output of the delay line due to various causes such as electrical pick up caused by high impedance coupling.

The delay-rise time ratio (T/a_n) is the ratio of the total delay to the delay rise time wherein a_n is defined as

$$a_n = \sqrt{(a_o)^2 - (a_i)^2}$$

This ratio is one measure of the quality of the delay line. The bandwidth characteristic of a delay line is determined by those frequencies which are capable of being passed by the delay line at a useful bandwidth (i.e., signals attenuated 3 db or less, for example). This is related to rise time approximately by

$$\text{bandwidth} \times \text{rise time} = 0.4$$

The temperature of a delay line is typically expressed as a percentage change in delay per change in degree C.

Delay lines may also be employed as phase shifting devices. A delay line will shift the phase of a sine wave an amount in degrees equal to 360 times the delay time × the frequency of the sine wave or

$$\theta = 360 \times T \times f$$

The significant characteristic of a delay line resides in its ability to provide an output pulse which appears at the output of a delay line a predetermined time interval after application of the input pulse at the input terminal of the delay line with the output pulse being as nearly exact in shape and pulse width to the input pulse as is practically possible. Conventional delay lines have been found to generate output pulses whose rise time, as defined hereinabove, and fall time (defined as the time interval between the instant at which the output pulse drops to 90 percent of its maximum amplitude, excluding overshoot) to the time instant at which it falls to 10 percent of its maximum amplitude, also excluding overshoot, with the rise and fall times of the output pulse being significantly increased as compared to the rise and fall times of the input pulse. Efforts to overcome such deficiencies have been undertaken in the prior art. One typical approach is to provide a series connected resistor and capacitor connected between the central conductor of a coaxial cable transmission line type delay line and ground potential in order to improve the rise and fall times of the output pulse. This technique, however, has led to a significant deviation in the characteristic impedance of the delay line which is defined as the impedance presented to an input pulse applied to the delay line.

The shortcomings of prior art delay line structures have led to the development of the present invention which overcomes the deficiencies of the prior art, including but not limited to the above mentioned deficiencies, as will be described more fully in connection with FIGS. **2–6** of this application.

Before entering into a description of the one preferred embodiment of the present invention, a description will first be given of a delay line structure of the type shown in FIG. 2 which is extremely advantageous for use in the preferred embodiment of FIG. 3.

The delay line 10 of FIG. 2 is comprised of a central conductor 11 of relatively small diameter typically of the order of 4 mils. An elongated strip 12 of insulation material is wrapped around conductor 11 as shown at 12*a* in a helical overlapping fashion. The insulation material is formed of a suitable dielectric such as, for example, polyesters, polyimides, polyamides, polyolefins or fluoronated hydrocarbons, to name just a few. The exterior surface of the elongated insulating strip 12 (i.e., the surface remote from the conductor 11) has a conductive coating deposited or otherwise formed thereon so as to form a conductive sheath substantially coaxially aligned with and surrounding the central conductor 11. The resulting structure is then encapsulated within an elongated insulating sleeve 13 extending over substantially the entire length of the coaxial cable structure. An elongated conductive member 14 is run parallel to the central conductor 11 and is in intimate contact with the shield 12. This conductive member is known as a drain wire and greatly facilitates electrical connection of the coaxial cable into an electrical or electronic circuit. The short sections of conductive wire 14,14 are usually of a greater diameter than central conductor 11 and are typically of the order of 8 mils. The overall diameter of coaxial cable 10 is typically of the order of 25 mils.

Coaxial cable transmission line of the type shown in FIG. 1, due to its small size and design, is capable of providing an input impedance of the order of 50 ohms. This size is substantially smaller than conventional coaxial cable transmission lines.

The coaxial cable transmission line 10 of FIG. 2 may be used to advantage in the preferred embodiment 20 as shown in FIG. 3 of the present application, which is comprised of a coaxial cable transmission line section 10' which may be of the design shown in FIG. 2 and which is provided with input and output terminals e_{in} and e_{out}, respectively. The delay time of coaxial cable transmission line 10' is controlled by its length. For example, in cases where a delay line of 15 nanoseconds is desired, coaxial cable transmission line 10' may have a length of the order of 10 feet. The delay to rise time ratio of the delay line structure of FIG. 3 is significantly improved through the employment of a second delay line section 10'' substantially identical in design and operating characteristics to the cable section 10'. The section 10'' is substantially shorter in length than the section 10', as will be described in greater detail hereinbelow and has its central conductor 11'' electrically connected to a central conductor 11' of coaxial cable section 10' by means of a separate conductor 15. The separate conductor may obviously be omitted and the extremities of conductors 11' and 11'' may be directly electrically connected such as, for example, either mechanical connection or a soldered connection. The short conductive strips 14' and 14'' of coaxial cable transmission line sections 10' and 10'', respectively, are electrically connected to one another and are preferably grounded.

As was described hereinabove, the length of section 10' is determinative of the desired delay time. The length of section 10'' is selected as to provide the optimum delay to rise time ratio and in applications for providing delay times of the nanosecond range is typically of a length in the range from 5 to 20 percent of the length in the range from 10'.

In applications where delay times of the order of hundreds of nanoseconds are required, it is preferred that the coaxial cable transmission line sections 10' may be tightly (or loosely) wound in a loop so as to reduce its overall size (i.e., the space which it occupies). Likewise, the shorter section 10'' may be wound within the same loop. It should be noted that the free end of section 10'' is not connected in electrical circuit and remains "floating." Nanosecond delay lines of the type shown in FIG. 3 have been found to provide delay to rise time ratios which are significantly improved as compared with conventional devices and techniques.

FIGS. 4*a* and 4*b* show additional preferred embodiments of the present invention which incorporate microconductor techniques. FIG. 4*a* shows a delay line structure 20 embodying the concepts described hereinabove and comprised of a sheet of dielectric material 21 having high dielectric strength and specific dielectric constant and preferably taken from the group of materials described hereinabove in connection with the embodiment of FIG. 3 and the coaxial cable transmission line structure of FIG. 2. The undulating conductive coating 22 is deposited upon one surface 21*a* of dielectric sheet 21. A conductive ground plane 23 is coated on the opposite surface 21*b* of dielectric sheet 21 so as to form a microstrip transmission line circuit element. The conductive strip 22 which is arranged in an undulating pattern cooperates with conductive ground plate 23 to form a delay line whose physical length may be adjusted to provide the appropriate nanosecond delay. The selection of the appropriate material for dielectric sheet 21 and its thickness determines the characteristic impedance of the delay line. Electrical coupling to the delay line is provided by a short conductive lead 24 which is electrically connected at a point 25 spaced inwardly from one extremity of conductive strip 22. Electrical connection may preferably be made by soldering short lead 24 to strip 22 at point 25.

Electrical connection from the output of the delay line device to the input of an associate circuit (not shown for purposes of simplicity) may be provided for through the use of a second short lead 26 which is electrically connected at a point 27 spaced inwardly from the opposite extremity of undulating conductive strip 22.

The physical distance between points 25 and 27 measured along the undulating conductive strip 22 determines the amount of delay which the delay line apparatus provides. Thus by moving points 25 and 27 either closer together or further apart, the delay time of the circuit is accordingly respectively decreased or increased.

The length L_1 of the undulating conductive surface measured between its extremity 22*a* and point 25 functions in the same manner as the short delay line section 10'' shown in FIG. 3 so as to significantly improve the rise time of the output pulse. Similarly, the length L_2 of the undulating conductive strip 22 measured between its extremity 22*b* and point 27 likewise functions to improve the rise and fall time of the output pulse as well as controlling its shape so as to be as nearly identical to the input pulse as is practically possible and further functions to provide good impedance matching between the output of the delay line device **20** and the input of an electrical circuit connected thereto.

Points **25** and **27** are located in accordance with the length of the desired delay time. The length L_1 (and/or L_2) of the short delay line section is then controlled by etching, machining away or otherwise removing that amount of conductive strip from the extremity as is required to optimize the rise and fall times of the output pulse. For example, let it be assumed that a desired delay dictates that the input and output leads be connected at points **25** and **27.** After so locating these points, the length of the short section of delay line coupled to the input terminal is then optimized. Let it be assumed that this length should be L_a'. In this case a portion P of the forward extremity of undulating conductive strip **27** would be removed. Obviously, a similar operation would be performed in optimizing the length L_2 of the short delay line section provided at the output (if such a section is either needed or desirable).

FIG. **4***b* shows an alternative embodiment to that of FIG. **4***a* wherein like elements are designated with like numerals. The major difference between the embodiments of FIGS. **4***a* and **4***b* reside in the fact that a different conductive pattern is provided on the upper surface **21***a* of dielectric sheet **21.** As shown in FIG. **4***b*, the single undulating conductive strip **22** is replaced by three separate strips **28, 29** and **30** deposited or otherwise formed upon surface **21***a*. This arrangement enables a delay line to be made without a ground plane member. However, it should be noted that FIG. **4***a* may be modified so as to divide the single undulating conductive strip into a plurality of shorter conductive strips of either similar or dissimilar length by machining away portions thereof such as, for example, at **22***c* and **22***d* so as to form three separate delay line sections which may be used either independently or joined as desired.

Returning to the embodiment of FIG. **4***b*, the conductive strips **28, 29** and **30** are arranged in a substantially spiralling fashion so as to provide conductive strips of substantially great length within a reduced surface area and/or volume as compared with arranging the conductive strips in straight line fashion and in a spaced parallel arrangement. Whereas the embodiment of FIG. **4***a* shows an undulating pattern and the embodiment of FIG. **4***b* shows a substantially spiralling pattern, it should be understood that any other pattern may be employed which is conducive to providing a conductive strip of desired length while providing a package of minimul surface area and/or volume.

Conductive strips **28** and **30** act as the ground return for strip **29.** Dielectric sheet **21** is used as a support structure. The input and output terminals of the individual strips are located therealong depending upon the particular delay time desired. For example, strips **28** and **30** may be provied with input points at **31** located a spaced distance inwardly from their inner extremities **28***a* and **30***a* and electrically connected to a short lead section **32** such as, for example, by soldering. Likewise, output points may, for example, be located at points **33** and electrically connected to a short conductor **34** which is likewise soldered or otherwise connected at point **33.** The remaining portions of lengths L_1 and L_2 function in the same manner as those sections L_1 (or L_1') and L_2 of FIG. **4***a* or the short section **10'** of FIG. **3** in the same manner as was described hereinabove. If desired, strips **28–30** may spiral along continuous curves.

FIG. **5** shows another preferred embodiment of the present invention wherein delay line devices **20, 20***a* and **20***b* of the type shown in FIG. **4***a* may be stacked so as to provide resultant time delay equal to the sum of the time delays provided by each individual delay line device. For example, a short conductor **24** may be electrically connected to conductor strip **22** at point **25** wherein point **25** may be selected as the input terminal of the delay line structure. The output end **27** of delay line structure **20** is then electrically connected to point **27'** of strip **22'** provided in delay line structure **20***a* by means of a short conductive section **26.** This pattern may be repeated whereby the opposite extremity of undulating conductive strip **22** is electrically connected to one extremity (not shown) of delay line device **20***b* with the ultimate output connection being provided by connecting a conductive strip **26'** to output point **27''** on delay line device **20***b*. Obviously, any number of delay line sections may be stacked in this manner to provide the necessary delay time.

FIG. **6** shows one manner in which delay line devices of the type shown, for example, in FIGS. **4***a* and 4b may be encapsulated and packaged as a dual in-line device. The prepackaging assembly **40** of FIG. **6** is comprised of a base member **41** having a plurality of input leads **42** and output leads **43** arranged along longitudinal sides of base member **41.** The leads **42** and **43** are imbedded within base member **41** and have a short section thereof protruding upwardly through base member **41** for electrical connection to delay line devices such as the delay line devices **20** and **20'** of FIG. **6.** The leads **42** and **43** also protrude downwardly from base member **41** for the purpose of providing electrical connections to peripheral circuitry (not shown for purposes of simplicity).

The bottom surfaces of the delay line devices are preferably secured to the top surface of base member **41** by means of a pressure sensitive adhesive or suitable contact cement. Electrical connections are provided between the leads **42** and **43** and their associated delay line devices. For example, delay line device **20'** is shown as being electrically connected to selected ones of the leads **42** and **43** by means of short conductors **44** and **45,** respectively. Similar electrical leads **46** and **47** are shown as being provided for electrical connection between selected ones of leads **42** and **43** and the delay line device **20.**

The package assembly **40** is further comprised of a hollow lid member **40** designed to be positioned upon the base member **41** in the manner shown. The mating edges of members **48** and **41** may be sealed to one another by a suitable contact cement. Alternatively, the mating edges may be joined by the application of a suitable solvent which causes fusion and joining therebetween.

Preferably, the individual delay line devices are encapsulated within a material which may be provided thereon by a dipping operation, for example. Preferably, this operation should be preceded by providing an electrical connection in the form of leads **44** and **45,** for example. As an alternative arrangement, the encapsulated delay line devices may also be joined to the top surface of base member **41** by application of an adhesive to their mating surfaces so as to fuse and join the delay line devices to the base member **41.**

The hollow interior region defined by the base member **41** and cover member **48** is preferably filled with a foamed plastic material which functions to cushion and protect the delay line devices mounted therein while at the same time assisting and maintaining the appropriate dielectric environment for the delay line devices. The foamed plastic material which may, for example, be a foamed polyolefin or polyurethane may be inserted after mounting of the cover member **48** by providing a slot **48***a* in the top surface of the cover member through which the foamed material may be introduced. After filling the entire interior space, any excess foam may be wiped off. The slot **48***a* provided in the upper surface of cover member **48** may be covered by a cover strip or sheet **49** which may, for example, be formed of a paper material having a pressure-sensitive surface so as to cover over slot **48***a* while at the same time providing indicia identifying the particular product and its delay values to facilitate identification and use thereof. The cover member **48** may be provided with a bevelled corner **48***b* which serves as a means for identifying which row of leads **42** and **43** represents the input and respectively the output leads of the delay line devices. In a similar fashion, a corner of the base member may be bevelled along the edge associated with the bevel **48***b* provided in cover member **48** so as to provide a neat compact package. The introduction of the foamed plastic material provides sufficient cushioning for the delay line devices housed therein so as to eliminate the need for separate mounting of the delay line devices if desired.

To prevent oxidation and/or corrosion of the ground plane and conductive strips they may be coated with gold, nickel or a solder plating. Likewise, the short conductive sections provided for electrical connection between and among the delay line devices and between and among peripheral circuitry may be selected of a material which is substantial corrosion or oxidation free, such as, for example, gold plated or nickel plated leads.

Any of the embodiments described hereinabove may be modified to provide a tapped delay line structure. For example, coaxial sections as shown by section **10'** in FIG. **3** may be joined end to end as shown by dotted line sections **10***a'* and **10***b'*, with an output lead e_{out}, e_{out}' and e_{out}'' being provided at the common terminal between each end to end connector. The delay at any such output is the sum of the delays of each section provided between e_{in} and the output terminal selected. A short coaxial section **10''** may be provided only at the first section **10'** as shown in FIG. **3** or a section similar to **10''** may be provided at each common connection between adjacent sections.

The embodiments of FIGS. **4–6** may be modified in a similar fashion to provide a tapped delay line structure.

It can be seen from the foregoing description that the present invention provides a novel delay line device which is extremely small in size, has an extremely low input impedance and provides delayed output signals having significantly improved rise and fall times as compared with conventional structures while at the same time providing precise delay time intervals in the nanosecond range with tolerances of the order of ± one-half nanosecond.

Although there has been described a preferred embodiment of this novel invention, many varitions and modifications will now be apparent to those skilled in the art. Therefore, this invention is to be limited, not by the specific disclosure herein, but only by the appending claims.

The embodiments of the invention in which an exclusive privilege or property is claimed are defined as follows:

1. A delay line device comprising input means for receiving an input pulse to be delayed;

coaxial cable transmission line means having a predetermined length;

said input means being coupled to said coaxial cable transmission line means a spaced distance from a first extremity of said coaxial cable transmission line means;

output means coupled to the opposite end of said coaxial cable transmission line means for coupling the delayed input signal to an external circuit;

the length of the delay interval being determined by the electrical length of said coaxial cable transmission line means measured between said point of connection with said input means and the opposite end of said coaxial cable transmission line means;

said first extremity being electrically isolated from the remainder of said delay line as well as any associated circuitry;

the portion of said coaxial cable transmission line means between said first extremity and said point of connection having an electrical length substantially shorter than the remainder of said coaxial cable transmission line means and being adapted to improve the rise time of the delayed input pulse appearing at said output means.

2. A delay line device comprising output means for receiving an output pulse to be delayed;

coaxial cable transmission line means having a predetermined length;

said output means being coupled to one end of said coaxial cable transmission line means;

said output means being coupled to said coaxial cable transmission line means a spaced distance inward from the opposite end thereof for coupling the delayed input signal to an external circuit;

the length of the delay interval being determined by the electrical length of said coaxial cable transmission line means measured between the point of connection with said output means and said one end of said coaxial cable transmission line means;

said opposite end being electrically isolated from the remainder of said delay line as well as any associated circuitry;

the portion of said coaxial cable transmission line means between said one end and said point of connection having an electrical length substantially shorter than the remainder of said coaxial cable transmission line means and being adapted to improve the rise time of the delayed input pulse appearing at said output means.

3. The delay line device of claim **1** wherein said coaxial cable transmission line means is comprised of a first coaxial cable transmission line including a central conductor;

dielectric means surrounding said central conductor and a conductive sheath surrounding said dielectric means and substantially coaxially aligned with said central conductor;

insulation means covering said conductive sheath.

4. The delay line device of claim **3** wherein the portion of said coaxial cable transmission line means between said first extremity and said point of connection is a second coaxial cable transmission line including a central conductor;

dielectrical means surrounding said central conductor, and a conductive sheath surrounding said dielectric means and substantially coaxially aligned with said central conductor;

insulation means covering said conductive sheath;

means electrically connecting adjacent ends of first and second coaxial cable transmission line central conductors;

means for grounding adjacent ends of the first and second coaxial cable conductive sheaths.

5. A delay line device comprising input means for receiving an input pulse to be delayed;

a transmission line means having a predetermined length;

said input means being coupled to said transmission line means a spaced distance from a first extremity of said transmission line means;

output means coupled to the opposite end of said transmission line means for coupling the delayed input signal to an external circuit;

the length of the delay interval being determined by the electrical length of said transmission line means measured between said point of connection with said input means and the opposite end of said transmission line means;

said first extremity being electrically isolated from the remainder of said delay line as well as any associated circuitry;

the portion of said transmission line means between said first extremity and said point of connection having an electrical length substantially shorter than the remainder of said transmission line means and being adapted to improve the rise time of the delayed input pulse appearing at said output means;

said transmission line means comprising:

a layer of dielectric material;

an elongated conductive strip being provided on one surface of said layer;

a conductive ground plane being provided on the opposite surface of said layer;

said point of connection being a spaced distance in from one extremity of said conductive strip.

6. The delay line device of claim **5** wherein said conductive strip is arranged in an undulating fashion on said layer.

7. The delay line of claim **5** wherein said delay line further comprises at least one additional conductive strip arranged on said one surface of said layer and being speced and electrically isolated from said first strip.

8. The delay line device of claim **5** wherein said conductive strips are arranged in an undulating fashion on said layer.

9. The delay line device of claim **5** further comprising a housing for said delay line device;

said housing comprising a base member having input and output leads each having a first end protruding into the interior of said housing and a second end protruding from the exterior of said housing;

means for electrically coupling the first ends of said leads respectively to the input and output means of said delay line device;

a cover member sealed to said base member for encapsulating said delay line device;

the interior region of said housing being filled with a foamed insulating material for rendering said delay line device shock proof and for maintaining the desired dielectric medium within said housing.

10. The delay line device of claim **9** wherein said foamed insulating material is taken from the group of materials comprising polyolefins and polyurethanes.

11. A delay line device comprising input means for receiving an input pulse to be delayed;

transmission line means having a predetermined length;

said input means being coupled to said transmission line means a spaced distance from a first extremity of said transmission line means;

output means coupled to the opposite end of said transmission line means for coupling the delayed input signal to an external circuit;

the length of the delay interval being determined by the electrical length of said transmission line means measured between said point of connection with said input means and the opposite end of said transmission line means;

said first extremity being electrically isolated from the remainder of said delay line as well as any associated circuitry;

the portion of said transmission line means between said first extremity and said point of connection having an electrical length substantially shorter than the remainder of said transmission line means and being adapted to improve the rise time of the delayed input pulse appearing at said input means;

said transmission line means being comprised of first, second and third spaced conductive strips

arranged in a spiral fashion on an insulating substrate;

the point of connection of the input means being a spaced distance inward from a first extremity of the second conductor.

12. A tapped delay line device for providing a plurality of selectable delays comprising:

a plurality of coaxial cable transmission line means;

input means for receiving an input pulse to be delayed;

said input means being coupled to one end of a first one of said coaxial cable transmission line means;

a plurality of output means for electrically connecting the second end of said first coaxial cable transmission line means and the remaining ones of said coaxial cable means in end to end fashion;

drain means comprising a short coaxial cable transmission line means having a first end electrically connected to the common junction between said input means and said one end of said first coaxial cable transmission line means and having a second end unterminated for improving the rise time of the delayed input pulse appearing at any one of said output means, the length of said drain means being shorter than any one of said plurality of coaxial cable transmission line means.

13. The delay line device of claim **12** wherein said plurality of coaxial cable transmission means and said drain means are each comprised of a first coaxial cable transmission line including a central conductor; dielectric means surrounding said central conductor and a conductive sheath surrounding said dielectric means and substantially coaxially aligned with said central conductor; insulating means covering said conductive sheath; said output means each being coupled between adjacent ends of the central conductors of associated coaxial cables.

14. The delay line device of claim **1** wherein said coaxial cable transmission means comprises:

a layer of dielectric material;

a plurality of elongated conductive strips being provided on one surface of said layer at spaced intervals;

said point of connection being a spaced distance in from the extremities of said conductive strips whereby the portion of said strip between said point of connection and the extremity thereof functions to enhance the rise time of the delayed signal.

15. The delay line device of claim **14** wherein one of said strips is a ground return.

16. The delay line device of claim **14** comprising three strips; the outer two strips serving as a ground return.

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