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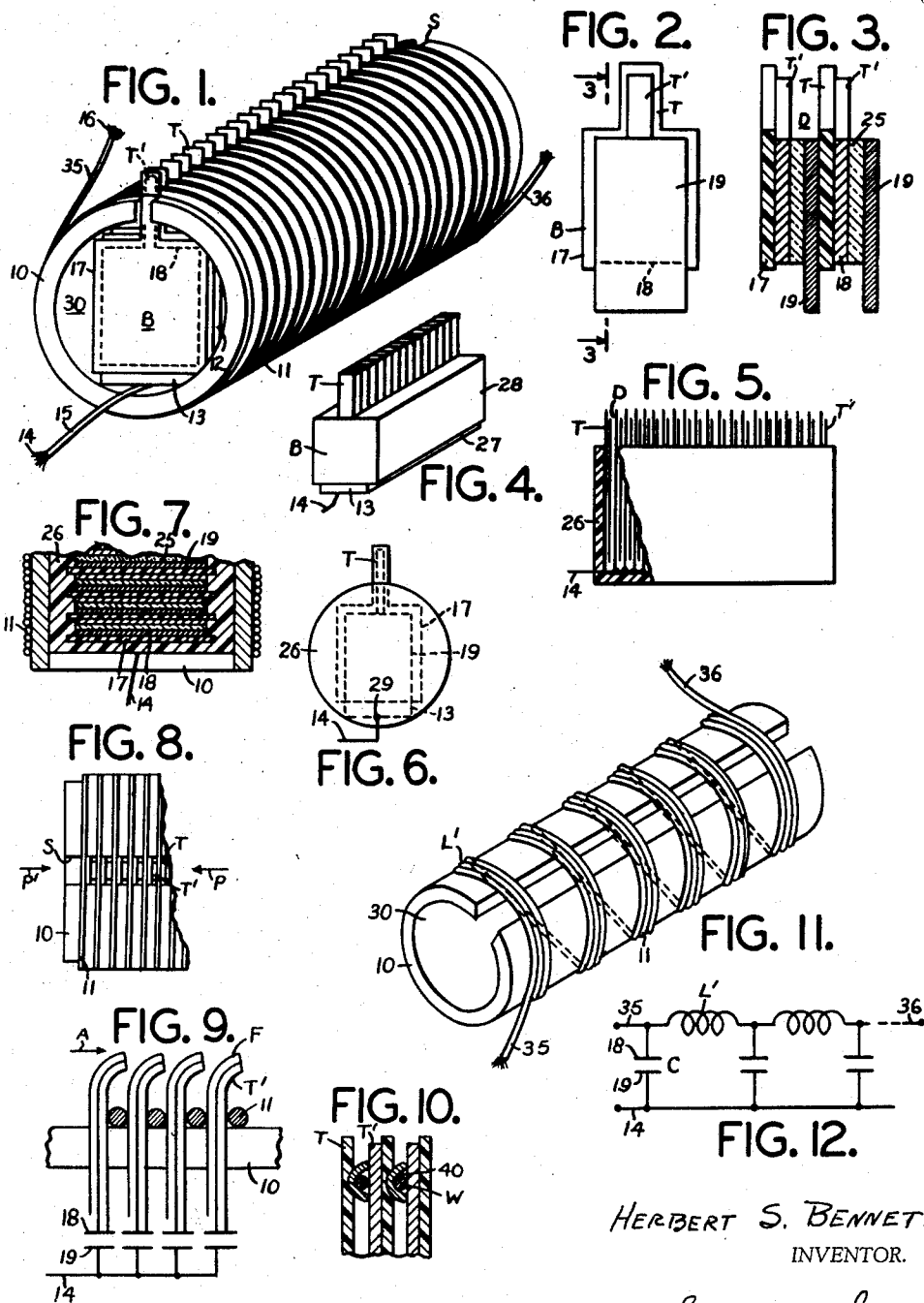
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3,081,439

ELECTROMAGNETIC DELAY LINES

Original Filed June 22, 1955

2 Sheets-Sheet 1



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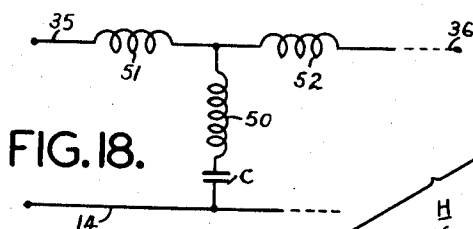
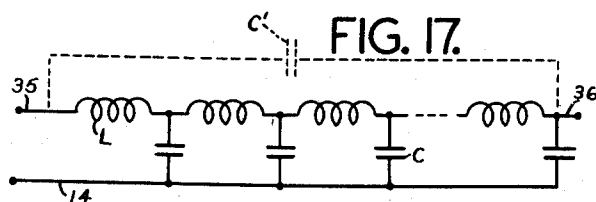
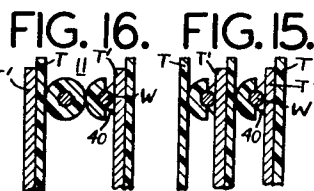
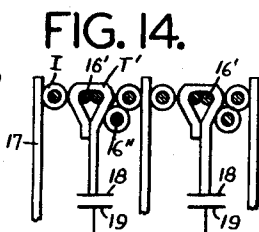
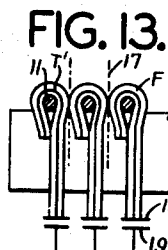


FIG. 19.

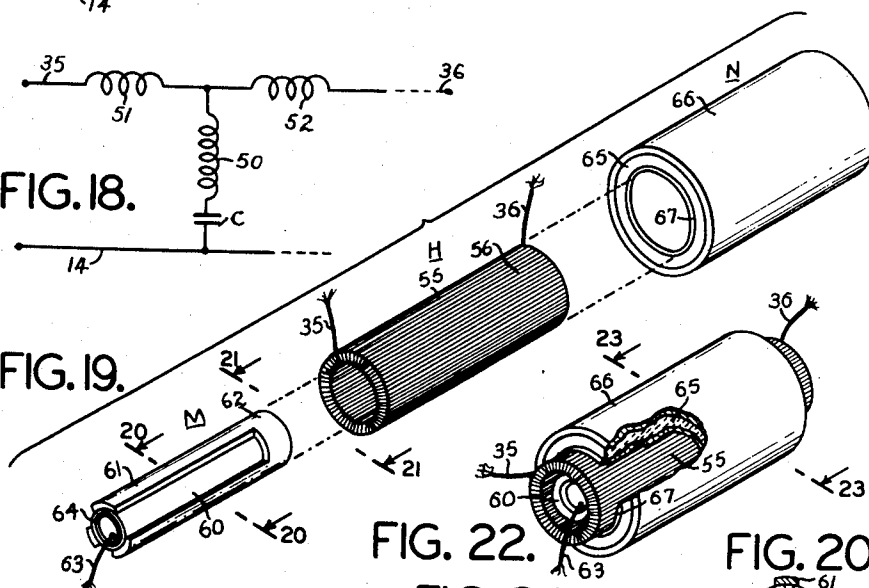


FIG. 22.

FIG. 24.

FIG. 20.

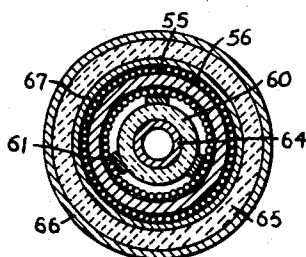


FIG. 23.

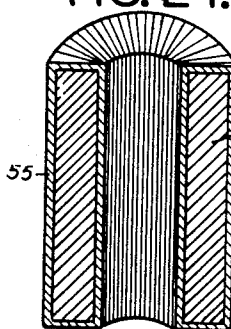


FIG. 21.



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ELECTROMAGNETIC DELAY LINES

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Original application June 22, 1955, Ser. No. 517,131, now Patent No. 2,892,162, dated June 23, 1959. Divided and this application June 19, 1959, Ser. No. 821,538
5 Claims. (Cl. 333—31)

This invention relates to the art of electromagnetic delay lines and particularly concerns delay lines of miniature size having delay characteristics of about 1.5 microseconds and usable in circuits operated at frequencies of about 10 megacycles per second. This application is a divisional patent application based on my pending patent application Serial No. 517,131 filed June 22, 1955.

The invention in one form is a delay line having distributed constants and in another form has both distributed and lumped constants generally identified herein as a semi-lumped constant delay line.

Heretofore satisfactory miniature delay lines operable in the vicinity of 10 megacycles per second providing delays of the order of 1.5 microseconds with good voltage responses have not been generally available in spite of an ever increasing need for such circuit members for use in high frequency assemblies of electronic equipment.

It is thus one object of the invention to provide a novel miniature delay line including a helical coil and a plurality of capacitors connected to the coil and disposed within it.

It is a further object to provide a novel miniature delay line with distributed constants.

It is a further object to provide a miniature delay line having a generally cylindrical form with a maximum diameter of about one-half inch and a length of not more than one and one-half inches, and providing a circuit time delay of approximately one and one-half microseconds at a circuit frequency of ten megacycles per second.

It is a further object to provide a miniature delay line having lumped and distributed constants.

It is a further object to provide a miniature electromagnetic delay line having distributed constants, and including a plurality of concentric tubular capacitors and a coil of rectangular cross section wound on a hollow core.

It is a further object to provide novel methods and techniques for manufacturing miniature delay lines having both lumped and distributed constants.

A delay line having lumped constants may be realized according to the invention by providing a slotted hollow cylindrical ferrite core on which a coil is wound to provide an inductance. A plurality of miniature capacitors with glass or mica dielectrics having capacitances of approximately 160 micromicrofarads are disposed within the hollow core. The capacitors have metal foil tabs projecting through the slot in the core and between individual windings or groups of windings of the coil. The capacitors are arranged in a stack which may include about a hundred capacitors in a block of about 1.4 inches in length. The tabs may be soldered to the respective turns of the coil, or the tabs and winding may be compressed to effect electrical contact between windings and capacitor plates. Each capacitor consists of a pair of foil plates secured to a suitable dielectric plate. The dielectric may be glass, mica, or other appropriate dielectric material. The capacitors may be separated by plastic films having a thickness of the order of one mil. The films may be of precast material such as polytetra-fluorethylene or other polyhaloethylene. A suitable plastic film for this purpose is provided by the Dupont Company of Wilmington, Delaware, under the name "Teflon." A film may also be provided by coating one side of each capacitor with a suitable dielectric material which hardens on drying.

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Such a coating may be formed with an acrylic lacquer. Whatever material is used as the separating film should have a high dielectric constant, at least 3.1 at one megacycle and at least 6 at 30 megacycles. The power factor should be not more than 0.05 and the film must have good resistance to water, alkali, acids, oils, greases, and chemical fumes. Resistance to high temperatures of the order of 500° F. is also desirable if the capacitors are to be soldered to the coil. The coil may be wound with enameled wire or a braided type of wire generally known as litz wire. A suitable coil may be wound with five strand, 44 gauge litz wire. The tabs of the capacitors may be curved around the coil windings or left uncoiled. The capacitors each have one foil plate grounded or rather connected to a common lead. They are thus arranged in parallel circuit in the delay line. If the tabs of the capacitors are curved around the coil windings, the total capacitance of the stack will be higher than if the tabs are not so curved even though a heavy pressure may be applied to compress the tabs and coil turns together. Besides the projecting tabs of those plates which contact the coil turns, the capacitors also have foil plates with projecting portions which are connected in common. These projecting foil portions are compressed together and may be covered with a conducting silver paint or may be soldered to connect all plates with good electrical contact to a common lead. The capacitor stack may be formed into an integral unit by casting into a cylindrical plastic resin block casing or by coating the stack with an air drying and hardening resin casing.

In accordance with the invention a distributed constant miniature delay line may be constructed by winding a toroidal coil on a hollow cylindrical ferrite core. Two cylindrical ceramic capacitors are disposed concentrically, one inside and one outside the ferrite core. The inner and outer capacitors may have barium titanate dielectric cores.

The invention will be better understood from the following description taken together with the drawing, wherein:

FIG. 1 is an oblique view of a delay line of semi-lumped constant type according to the invention.

FIG. 2 shows in elevation a capacitor stack.

FIG. 3 is a sectional view taken on lines 3—3 of FIG. 2.

FIG. 4 shows an oblique view of a capacitor assembly block.

FIG. 5 is a side elevational view partly in section of another capacitor assembly block.

FIG. 6 is an end view of the block of FIG. 5.

FIG. 7 is a plan central sectional view of a portion of a delay line including the capacitor block of FIGS. 4 and 5.

FIG. 8 is a top plan view of a delay line.

FIGS. 9, 10, 13, 14, 15 and 16 show ways of arranging capacitor tabs to contact coil turns.

FIG. 11 is an isometric view of a coil and core assembly.

FIGS. 12, 17, 18 show equivalent circuits for delay lines.

FIG. 19 is an exploded isometric view of components of a distributed constant type of delay line.

FIG. 20 is a sectional view taken on lines 20—20 of FIG. 19.

FIG. 21 is an end view of a tubular capacitor employed in the delay line of FIG. 19.

FIG. 22 is an isometric view of an assembled distributed constant delay line with a portion broken away to show internal features.

FIG. 23 is a sectional view taken on lines 23—23 of FIG. 22.

FIG. 24 is a longitudinal sectional view of a solenoid. In FIG. 1 is shown a semi-lumped constant delay line according to the invention. The delay line includes a core

10 which is a hollow cylinder having a longitudinal slot S. The core may be composed of ferrite material. A coil 11 of litz wire is wound on the core. A stack 12 of capacitors is disposed wholly inside the core. Projecting ends 13 of the negative or ground plates of the capacitors are connected by a wire 14. A portion of the wire has an enameled coating 15. The wire of the coil is insulated and consists of braided strands 16. The plastic insulator films 17 separate the individual capacitors. Each film separator is generally T-shaped with a rectangular body B and a tab T. The over-all size of the film separator is somewhat larger than that of the correspondingly shaped positive plate 18 of each capacitor and the tabs T project up through the slot S and above tabs T' of the positive foil plates 18.

In FIGS. 2 and 3 are shown the stacking arrangement of the capacitor. The negative plate 19 is shown uppermost in FIG. 2. Tab portion 13 extends below positive plate 18 and dielectric spacer member 25. The separators 17 are disposed between the positive plate 18 of one capacitor and the negative plate 19 of an adjacent capacitor. A space D exists between tab T of each separator and the tab T' of the positive plate of the next capacitor. One or more coil turns are lodged in this space D when the delay line is fully assembled. A separator film 17 is also placed at the beginning and end of each stack of capacitors. The width of tabs T should be just wide enough to enter slot S in the core. The slot may be about $\frac{1}{16}$ of an inch in width. Instead of litz wire, single conductor enamel insulated wire may be used. A coil wound with a solid conductor wire will have a Q somewhat lower than that of a coil wound with litz wire of substantially equal area.

The stack of capacitors may be assembled as shown in FIG. 4. A silver paint coating 27 covers the exposed tabs 13 of the negative plates and a suitable lacquer or varnish coating 28 covers the bodies of the capacitors. The tabs T and T' are left uncoated.

In FIGS. 5 and 6 are shown another capacitor stack assembly cast in a cylindrical resin block 26 with tabs T and T' exposed. The negative plates 19 are connected by the common wire 14 which may be soldered by joints 29 to the plate portions 13. The diameter of block 26 should be such that the stack will fit snugly in circular bore 30 of the core 10 as shown in FIG. 7.

In FIG. 8 is shown the tabs T and T' extending through slot S. One turn of winding 11 passes between each pair of tabs. When the tabs and winding are compressed by opposed forces P, P' directed along the slot, electrical contact is effected between tabs T' and the turns of the wire. In the region of the slot S it will be necessary to remove the insulating coating of the wire which can be done by any suitable solvent. In FIG. 8 the tabs T' are unsoldered.

In FIG. 9 is shown an arrangement similar to that of FIG. 8 for effecting electrical contact between the tabs T' of plates 18 and the turns of coil 11 by application of a force to bend the tabs in direction A. The tabs and foil plates are coated on one side with a film F of a suitable insulating lacquer. The total capacitance of the stack is rather low when contact is obtained only by applied pressure. In FIG. 10 the tabs T' are shown soldered to turn portions W of the coil by solder joints 40. The tabs and coil turns are also compressed so that the solder and wires will be pressed into the bodies of tabs T. This arrangement produces a higher coil Q than if the tabs and coil are not compressed. The reason for increase in Q may be explained by reference to FIGS. 15 and 17. FIG. 15 shows the tabs T and T' and coil turn portions W in an uncompressed state. FIG. 17 shows a constant K type of circuit constituted by a delay line in which each turn L of the coil is connected to a capacitor C. There is a distributed capacitance C' existing by reason of the extended form of the coil. When the assembly of FIG. 15 is compressed to the form of FIG. 10 the distributed capacitance decreases to increase the Q of the coil.

Either litz wire or solid copper wire may be used for the coil turns depending on the coil Q required. A No. 30 gauge enameled solid wire will generally produce the same delay time as five strand No. 44 gauge litz wires. The soldering of the wires and tabs requires microscopic soldering techniques, since the available width for the joint may be less than one sixteenth of an inch and the over-all length of the delay line including about a hundred stacked capacitors may be an inch to an inch and a half.

FIG. 11 shows a coil assembly in which winding 11 has a plurality of interconnected groups of turns L'. The coil 11 terminates at its ends in leads 35, 36. When a capacitor stack 12 is disposed in cavity 30, the circuit arrangement shown in FIG. 12 will be obtained. Capacitors C are connected between adjacent turns of adjoining coil groups L'. The negative plates 19 are connected in common to lead 14.

In FIG. 13 is shown one way of connecting tabs T' to coil 11. Each foil tab T' is bent around a turn of wire and the turns are pressed together. The wire may be a solid conductor or litz wire. Each turn of the winding contacts a tab T'. In FIG. 14 the tab T' engages two strands 16' of a five strand insulated litz wire. The tab is bent around strands from which insulation I has been removed. Plastic separating films 17 may be disposed between adjacent litz wires. In FIG. 13 one side of each positive plate 18 and its tab T' is coated with an insulating film F or the separating films 17 may be used between the several capacitors. The presence of insulated turns 16'' in the arrangement of FIG. 14 improves the resistance to short circuiting when the turns are strongly pressed together to effect complete contact between tabs T' and the strands 16'.

FIG. 15 shows another assembly scheme in which insulation is removed from one side of each insulated turn to expose the wire portion W. The turns are then strongly pressed together to effect electrical contact between the coil turns and tabs T'. The exposed wire portions and tabs should be soldered together by joints 40 to obtain optimum contact between the turns and tabs. In FIG. 16 two turns of the coil 11 are disposed between tabs T' and one portion W is soldered to the tab T'.

A typical miniature delay line constructed according to the invention in which the winding includes 100 close turns of five strand No. 44 gauge insulated litz wire on a ferrite core and 100 capacitors each having a value of 160 micro-microfarads, will be about 1.4 inches long and less than one half inch in diameter. It will have approximately the following parameters at 17 megacycles per second.

Inductance	-----	250 microhenries.
Delay	-----	1.8 microseconds.
Characteristic impedance	-----	125 ohms.

The ferrite composing core 10 may be powdered iron in a suitable binder or other magnetic diamagnetic, or paramagnetic material. The core may even be made of fiber instead of ferrite for certain applications. The coil winding 11 as indicated above may be litz wire or solid enameled wire. The capacitors may have copper, aluminum or brass foil plates with exposed portions silvered to facilitate soldering. The dielectrics between plates may be glass, mica (natural or artificial) or other suitable material. The separator films 17 may be made of a suitable cast film such as one of the polytetrahaloethylenes. The binder for forming a block of capacitors may be a cast resin such as an acrylic resin material. The number of turns for the coil winding may be increased or decreased as desired depending on the particular parameters of the delay line desired.

One important use of the semi-lumped constant type of delay line as disclosed herein is as a constant K type of low pass filter as shown in FIGS. 12 and 17. The delay line can also be constructed as an m-derived filter circuit as shown in FIG. 18 where inductors 51 and 52 are each equal in inductance value to one-half of that

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of inductor 50. Inductors 51, 52 are connected in series. Inductors 50 and capacitor C are connected between inductors 51, 52 and ground wire 14.

In FIG. 19 are shown the several tubular components of a miniature distributed constant type of delay line. A helical coil 55 of wire is wound lengthwise on the hollow cylindrical core 56 to form solenoid H. The core may be composed of ferrite material and provides a dielectric for the distributed capacitance of the delay line in addition to serving as a support for the coil. The coil may be wound with insulated copper litz wire. A suitable type has five strands 16 and is No. 44 gauge. A single layer winding is used having about forty-four turns between terminal leads 35, 36. The coil is rectangular in cross section as clearly shown in FIG. 24. The coil may be wound with insulated solid copper wire but at high frequencies copper losses due to skin effects and other causes become excessive so that the braided litz wire must be used to minimize these losses.

A hollow cylindrical core 60 which may be of vitreous barium titanate is provided as an inner cylindrical capacitor element M for the delay line. Core 60 has several conductive stripes 61 of powdered silver paint on the outer surface of core 60. The stripes extend lengthwise and are joined at one end by a circular ring 62. These stripes 61 are used but this number of stripes may be increased or decreased. A silver layer 64 is disposed on the inner surface of core 60. The lead wire 63 is soldered to the layer 64.

Another core 65 has inner and outer surfaces coated with silver layers 67 and 66 respectively deposited by electrolytic deposition, evaporation or other suitable method to form tubular capacitor N. Core 60 fits snugly in the solenoid H formed by coil 55 and core 56 and the solenoid H fits snugly in the tubular capacitor N.

FIG. 22 shows the completed assembly with members M, H, N one within the other. It is important that the several members make good contact with each other by a snug frictional fit. Member H is somewhat longer than members M and N as shown in FIG. 22. Some functions of inner member M are to increase the total capacitance of the delay line and to correct for Q changes, high frequency energy losses, and leakage inductance. These functions are performed to a greater or lesser degree depending on the orientation of member M with respect to the other members, by the mode of connection to the other members, and by the arrangement of stripes on member M. The stability of capacitance of the delay line will be improved if the layer 64 is electrolytically deposited to produce a stable, uniform thickness of silver in the core 60. The inner member M may also be adjusted to improve pulse response of the delay line copper may be used instead of silver for the various layers but silver is preferred to minimize reflections in the line. The equivalent circuits for the delay line depending on external circuit connections may be represented by the constant K circuit of FIG. 17 on the derived circuit of FIG. 18.

The foregoing is illustrative of preferred forms of this invention and it will be understood that these preferred forms may be modified and other forms may be pro-

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vided within the broad spirit of the invention and the broad scope of the claims.

What is claimed and desired to protect by Letters Patent of the United States is:

1. A delay line comprising a plurality of concentrically disposed hollow cylindrical cores nested within each other, a first one of said cores having a coil of insulated wire wound lengthwise thereon, the windings thereof extending along the inner and outer surfaces of said core and across its ends, a second one of said cores being a tubular capacitor having inner and outer surfaces thereof coated with a metal film, the film on the said inner surface being in close contact with the coil, and a third one of said cores having an inner surface coated with a metal film and an outer surface coated with a metal film in the form of interconnected metal stripes, said stripes being in close contact with the coil.

2. A delay line according to claim 1, wherein said first core is composed of ferrite material, and the second and third cores are composed of vitreous barium titanate.

3. A delay line according to claim 2, wherein said coil is composed of litz wire consisting of copper wire strands and the metal films are composed of silver.

4. A miniature electromagnetic delay line, comprising an inner hollow cylindrical core, an outer hollow cylindrical core, and an intermediate hollow cylindrical core, all of said cores being concentric with and nested within each other, the inner core having a conductive layer on its inner surface and a lead being connected to said conductive layer, a plurality of longitudinally extending spaced strips mounted on the outer surface of said inner core, a ring connecting said strips at one end thereof, said strips and ring being composed of conductive material, the intermediate core being wound with a coil of insulated wire extending longitudinally thereof, said wire coil extending along the inner and outer surfaces of said intermediate core and across its ends to define a substantially rectangular cross-section, said wire-wound intermediate core being mounted on said longitudinally extending strips, said outer core comprising a tubular capacitor having a conductive layer on its inner surface and a second conductive layer on its outer surface, and being mounted on said wire-wound intermediate core with said inner conductive surface in contact with said coil, and leaves connected to opposite ends of said coil.

5. A delay line in accordance with claim 4 wherein the intermediate core is composed of ferrite material and the inner and outer cores are composed of vitreous barium titanate, said strips, ring and conductive layers on the inner and outer cores being composed of metallic silver.

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