United States Patent

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[72] Inventors **Edwin S. Eichert**
Bryn Mawr;
William T. Storey, II, West Chester, both of, Pa.

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[73] Assignee **Technitrol, Inc.**
Philadelphia, Pa.

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[54] **DELAY LINE HAVING NON PLANAR GROUND PLANE, EACH LOOP BRACKETING TWO RUNS OF MEANDERING SIGNAL LINE**
9 Claims, 7 Drawing Figs.

[52] **U.S. Cl.** **333/31,** 333/6, 333/84, 333/96, 174/36
[51] **Int. Cl.** **H01p 5/12,** H01p 3/02, H01p 3/08
[50] **Field of Search** ..... 333/31, 84 (M), 84, 95 (A), 96, 24.1; 174/28, 29

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Primary Examiner—Herman Karl Saalbach
Assistant Examiner—Wm. H. Punter
Attorney—Yuter and Fields

ABSTRACT: An electrical component such as a delay line comprising a first signal conductor and a second signal conductor spatially displaced from and electrically cooperable with said first signal conductor. At least one of said first or second signal conductors extending through an enclosure of nonconductive material having nonplanar upper and lower surfaces to provide increased isolation between an input and an output signal.

A method of making the electrical component also is disclosed.

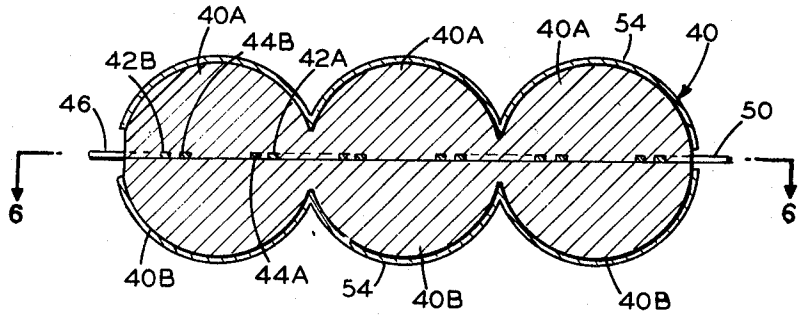


FIG. 1

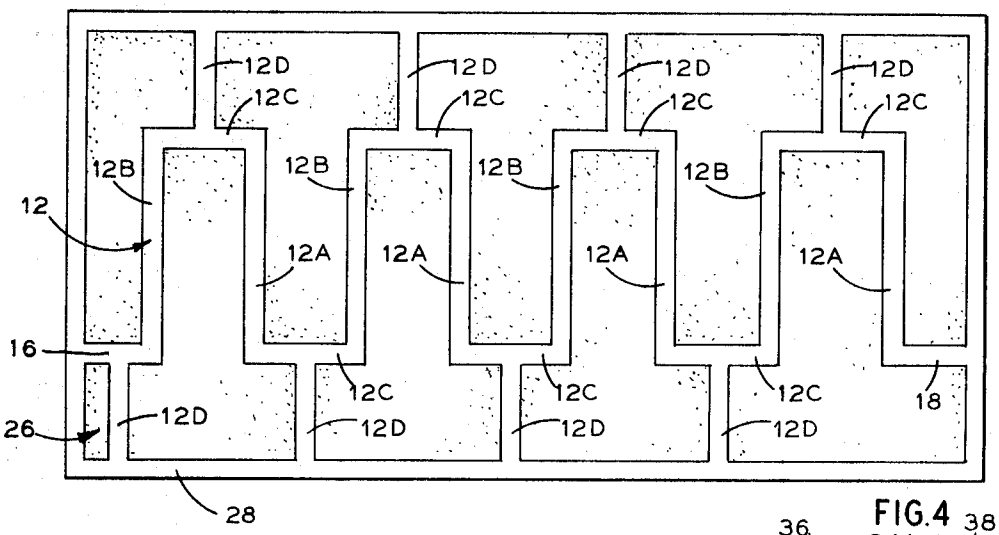


FIG. 2

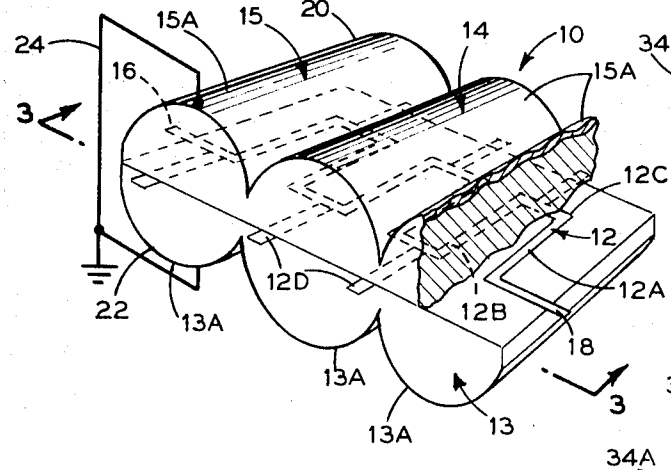


FIG. 4

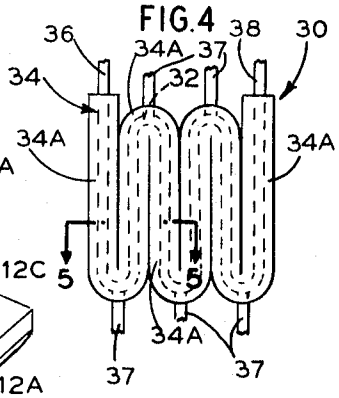
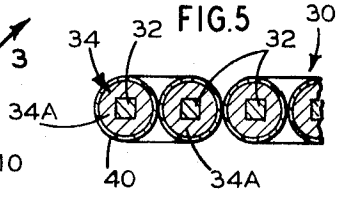


FIG. 5



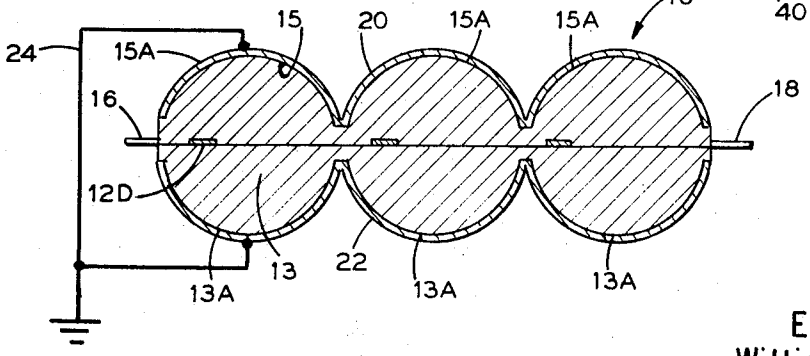


FIG. 3

INVENTORS
Edwin S. Eichert
William T. Storey, II
BY Yuter & Spiecens
ATTORNEYS

FIG.6

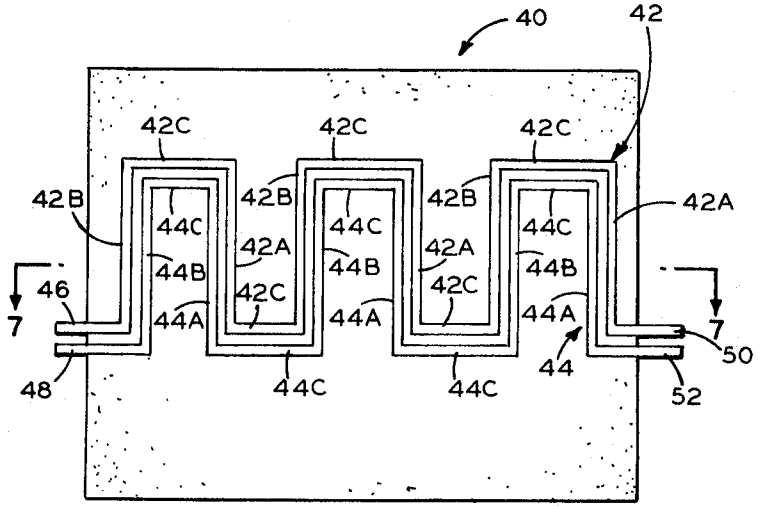
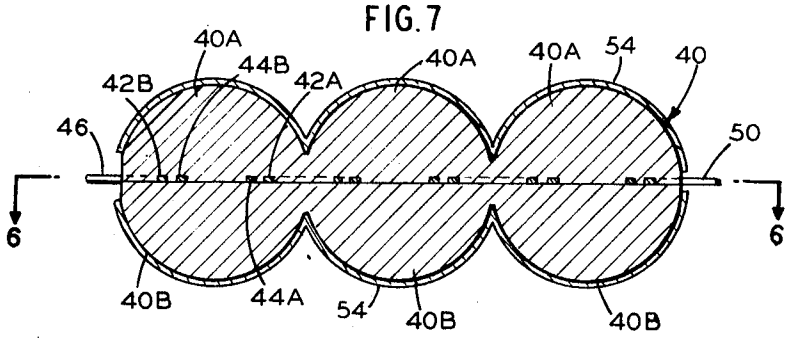

40
42
42C
42C
42C
42B
42B
42B
42A
44C
44C
44C
42A
44B
42A
44B
42C
42C
44B
46
44A
44A
44A
7
7
50
48
44C
44C
44
52

FIG.7


40A
44B
42A
40A
40A
54
40
42B
46
50
6
6
40B
44A
54
40B
40B

DELAY LINE HAVING NON PLANAR GROUND PLANE, EACH LOOP BRACKETING TWO RUNS OF MEANDERING SIGNAL LINE

This invention relates generally to an electrical component and to a method of making the same and, more particularly, pertains to an electrical component that may be used as a delay line that provides substantial isolation between input and output signals.

Presently, so-called lumped constant transmission lines or distributed constant coaxial lines are utilized as signal delay lines to delay the time of arrival of a signal at a particular point in a circuit. However, these devices inherently are bulky and are uneconomic in terms of both cost and space since many feet of coaxial cable, for example, are required to obtain delay magnitudes of the order of tenths of milliseconds. The present trend toward miniaturization of circuits has produced a need for corresponding miniaturized delay lines. While a number of such delay lines have been proposed, they have numerous disadvantages associated with their use. For example, such delay lines have been found to introduce considerable distortion, provide long rise times, and lack isolation between the input and output circuits.

Accordingly, an object of the present invention is to provide an improved delay line.

A more specific object of the present invention is to provide a miniaturized electrical component which may be used as a transmission line or a delay line.

Another object and feature of the present invention resides in the novel details of construction which provide a delay line of the type described having a high magnitude of isolation between the input and output circuits.

A further object is to provide an electrical component which is economic to fabricate and reliable in operation.

Accordingly, an electrical component constructed according to the present invention comprises signal conducting means for conducting an electric signal. An enclosure of nonconductive material surrounds at least a portion of the signal conducting means and is provided with an upper and a lower surface. At least one of the upper and lower surfaces comprises nonplanar portions juxtaposed across the length of the enclosure to provide the component with desired characteristics.

At present, many of the above-described miniature electrical components such as transmission or delay lines are made by laminating together the various elements comprising the particular line. However, this method is an expensive and time consuming operation.

Accordingly, another object of this invention is to provide an improved method for making an electrical component of the type described.

Thus, a method of making an electrical component in accordance with this aspect of the invention includes encapsulating a signal conductor within a block of nonconducting material having a dielectric constant substantially independent of frequency, low dielectric loss and a magnetic permeability greater than unity. The method further includes forming the block with upper and lower surfaces comprising nonplanar portions juxtaposed across its length.

Other features and advantages of the present invention will become more apparent from a consideration of the following detailed description when taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a top elevational view of a conducting plate having a signal conductor traced thereon, to an enlarged scale;

FIG. 2 is a perspective view with parts broken away, of an electrical component constructed according to the present invention;

FIG. 3 is a vertical sectional view taken along the line 3–3 of FIG. 2;

FIG. 4 is a top plan view of a modified embodiment of an electrical component constructed in accordance with the present invention;

FIG. 5 is a sectional view thereof taken along the line 5–5 of FIG. 4;

FIG. 6 is a sectional view of a further modified embodiment of an electrical component taken along the line 6–6 of FIG. 7; and

FIG. 7 is a sectional view of the embodiment of FIG. 6 taken along the line 7–7 thereof.

While the present invention has applicability both as a delay line or a transmission line, it will be described as a delay line. However, it is to be understood that this is by way of example only and not by way of limitation. That is, the electrical components and methods of making the same described hereinbelow apply to delay lines and/or transmission lines.

A delay line constructed in accordance with the present invention is designated generally by the reference numeral **10** in FIG. 2 and includes an electrical signal conductor **12** which extends through an enclosure or housing **14**. The housing **14**, which includes a lower section **13** and an upper section **15**, is fabricated from a nonconductive material which, in practice, has a high permeability-permittivity product which is substantially frequency independent (e.g., substantially less than a 5 percent change over a frequency range of from 1 megahertz to 1 gigahertz). Moreover, the material forming the housing **14** should have a low dielectric and magnetic loss over the noted range of frequencies. Thus, a ferrite material may be used for the housing since it exhibits such properties. Alternatively, another material which exhibits these properties is a plastic matrix in which is dispersed a magnetic material.

A suitable plastic would be one having the characteristics of a substantially frequency independent dielectric constant and a low dielectric loss. It has been found that plastics such as: Mylar, Polyethylene; Polystyrene, Rexalite 1422, Styrloy 22; and Vibron 140 satisfy the above criteria. In practice, a polytetrafluoroethylene plastic is ideally suitable for use. The magnetic material embedded in the plastic matrix can be either a ferromagnetic or a ferrimagnetic material. More specifically, powdered iron or powdered ferrite is preferred.

The signal conductor **12** is provided with an input arm or lead **16** which is adapted to be connected to appropriate input circuitry (not shown), and an output arm or lead **18**, which is adapted to be connected to appropriate output circuitry (not shown). Between the input and the output arms **16** and **18** the signal conductor **12** traces out a meandering path. More particularly, the signal conductor **12** is formed by a plurality of pairs of interdigit elements **12A** and **12B**, which are in adjacent and substantially parallel relationship and which are interconnected serially by respective serial elements **12C**. Additionally, the serial elements are connected with transversely extending arms or leads **12D** which extend beyond the side edges of the housing **14** to provide a plurality of taps which are spaced throughout the length of the delay line, to obtain corresponding different time delays. More specifically, the distance between any one of the taps **12D** and the input lead **16** is proportional to the delay time. Hence, by connecting the output circuit to respective ones of the taps **12D** different delay times may be had.

The lower surface of the lower section **13** and the upper surface of the upper section **15** comprise a plurality of convex portions **13A** and **15A**, respectively, juxtaposed across the lengths of the respective sections. As shown in FIG. 3, the portions **13A** and **15A** are in a one-to-one correspondence and respective portions are aligned with each other to provide sets of opposed convex portions. Additionally, in the embodiment shown, each set comprising opposed portions **13A**, **15A** is sized and positioned to bracket a different pair of interdigit elements. For example, the right-hand portions **13A**, **15A**, as taken in FIGS. 2 and 3, bracket the right-hand interdigit elements **12A** and **12B**, and the left-hand portions **13A**, **15A** bracket the left-hand elements **12A**, **12B**. The convexity of the upper and lower surfaces provide substantial isolation between the input and the output circuits connected to the delay line **10**. Moreover, the lengths of the interdigit elements and the spacing between the elements **12A**, **12B** comprising any pair which is bracketed by a set **13A**, **15A** of curved surfaces controls the coefficient of coupling between the elements and can be used to vary the properties of the delay line.

Alternatively, the convex portions and/or the interdigit elements 12A, 12B may be sized and positioned so that each set of convex portions 13A, 15A brackets more than two interdigit elements in accordance with the desired characteristics of the line.

The upper and lower surfaces of the respective upper and lower sections 15 and 13 are covered with respective upper and lower conductive layers 20 and 22 which conform to the curvature of these surfaces. The layers 20 and 22 may be connected together and to ground by a lead 24 to provide respective ground plane elements. On the other hand, the layers 20 and 22 may extend completely about the housing 14 so that they are electrically connected together without the need for an external wire. In this latter embodiment, appropriate provision is made so that the leads 16, 18 and 12D do not contact the layers 20, 22, in any conventional manner.

Signals applied between the input arm or lead 16 and one or both grounded layers 20, 22 travel along the signal conductor 12 and are transmitted as delayed signals across the output arm or lead 18 and ground or across any one of the respective transverse taps 12D and ground. The transmitted signals will be delayed a period of time related to the mechanical length of the signal conductor 12 between the arm 16 and the arm 18 or the selected tap 12D, and the electromagnetic properties such as the permeability and the permittivity of the region surrounding the conductor 12. Thus, greater delays per unit length are obtained from the meandering geometry of the signal conductor. In addition, increasing the product of the average permeability and average permittivity of the region surrounding the signal conductor 12 increases the delay per unit length.

A method for fabricating the delay line 10 includes tracing the signal conductor 12 on a conducting plate 26 (FIG. 1) which may be made of aluminum or copper or a similar metal. A marginal area 28 to which arms 12D extend is similarly traced on the conducting plate. The signal conductor 12 including the marginal area 28 then is removed from the remainder of the metal plate by etching or stamping or a similar procedure. The resulting conductor and attached marginal area 28 may be silvered on both surfaces to decrease the rise time of the resultant delay line.

A mold comprising two halves or sections is provided. The bottom surface of each section of the mold comprises convex portions juxtaposed across the length of the mold. Each section is filled with a potting compound comprising one of the above-noted plastics such as polytetrafluoroethylene in particulate form having the powdered magnetic material dispersed therein. Alternatively, the mold sections may be filled with a powdered ferrite material or any other material having the desired properties.

The conductor 12 having the marginal area 28 connected thereto is positioned on one of the mold sections so that the marginal area 28 forms a seal when the mold halves are closed. The mold is then closed. It is to be noted that the material from the top section of the mold fills the spaces between the elements comprising the signal conductor 12.

Heat is applied to the mold to melt the particular mixture or material used so that the material completely surrounds the conductor 12. The mold is allowed to cool so that the material solidifies about the conductor 12 to form the enclosure 14 through which the conductor extends. The resulting product then is removed from the mold and the marginal area 28 broken away to provide a conformally potted delay line having substantial isolation between input and output due to the curvature of the upper and lower surfaces.

The upper and lower surfaces of the enclosure or housing 14 are coated with a metal by spraying or any other conventional method to form the conductive layers 20 and 22.

Accordingly, an electrical component and a method of making the same has been disclosed which is simple to construct and economic to produce, and which provides substantial isolation between the input and output circuits.

It is to be understood that the present invention also includes a construction similar to that illustrated in FIGS. 1—3, but one in which each set of opposed curved portions 13A, 15A brackets a single interdigit element 12A or 12B. That is, the convex portions 13A, 15A are sized to encompass only one interdigit element. Thus, for a delay line of the type shown in FIG. 3 which includes six interdigit elements, six sets of opposed convex portions would be provided. However, it is obvious, for this latter construction that the properties of the delay line cannot be varied by changing the spacing between interdigit elements because they effectively are isolated from each other.

Moreover, it is emphasized that the convex surfaces shown are for illustrative purposes only and are not to be interpreted as a limitation of the present invention. That is, the invention contemplates an enclosure having nonplanar upper and lower surfaces. To put this another way, the distance of the surfaces from the plane of the conductor or lead 12, as measured along a normal to the plane, varies from a minimum to a maximum value for each interdigit element or elements bracketed by a respective set of nonplanar surfaces.

A modified embodiment of a delay line constructed according to the present invention and one in which each interdigit element is isolated from the adjacent elements is shown in FIGS. 4 and 5 and designated generally by the reference numeral 30. The delay line 30 includes a signal conductor 32 which traces out a meandering or sinuous path as shown. The conductor 32 is enclosed within an enclosure or housing 34 having the same meandering or sinuous shape as the conductor. The housing 34 is nonconductive, has a high permeability-permittivity product which is substantially frequency independent over the usable bandwidth, and has low dielectric and magnetic losses over the range of frequencies of use. Accordingly, the housing 34 may be fabricated from any of the materials noted above with respect to the housing 14. The ends of the conductor 33 extend beyond the housing 34 to provide respective input and output leads 36 and 38. Additionally, the conductor 32 is provided with a plurality of taps 37 similarly to the taps 12D of the conductor 12.

The housing 34 includes interconnected parallel sections 34A which surround the parallel interdigit elements of the conductor. Additionally, each section 34A and the interconnecting portions of the housing are substantially circular in cross section, as shown in FIG. 5, thereby to provide substantial isolation between adjacent elements of the conductor 32 and between the input and output leads. In other words, the top and bottom surfaces of the housing 34 are convex similarly to the housing 14.

Provided on the outer surface of the housing 34 is a metal coating 40 which functions as a ground plane element for the delay line.

The delay line 30 may be manufactured in the same manner as the delay line 10. More specifically, the conductor 32 is produced by tracing the conductor on a conductive sheet and removing the same from the sheet. If desired the conductor 32 may be coated with silver on one or both sides to reduce rise times. Mold sections having respective semicircular upper and lower surfaces are filled with a potting compound such as a ferrite material or any of the other materials noted, and the signal conductor 32 is placed on one section of the mold. The mold is then closed and heated. Thereafter, the mold is cooled and the delay line 30 is removed therefrom and coated with a conductive layer such as silver to provide a conformally molded delay line having substantial isolation between the input and output leads.

FIGS. 6 and 7 illustrate a balanced transmission or delay line construction wherein two spatially displaced conductor leads 42 and 44 extend through the enclosure or housing 40. More specifically, the balanced construction of FIGS. 6 and 7 includes the enclosure 40 of dielectric material. The composition of the enclosure 40 may comprise any of the materials specified above such as ferrite, or a plastic matrix of the type noted in which is dispersed a magnetic material.

The signal conductors or leads **42** and **44** are similar in construction to the signal conductor **12**. Accordingly, the conductors **42**, **44** respectively include: input arms **46**, **48**; output arms **50**, **52**; pairs of interdigit elements **42A**, **42B** and **44A**, **44B**; and serial interconnecting elements **42C**, **44C**. Moreover, the conductors **42**, **44** may be provided with transverse taps. As shown in FIG. **6**, corresponding elements of the leads or conductors **42** and **44** are in substantially adjacent parallel relationship.

Additionally, the upper and lower surfaces of the enclosure **40** comprise respective sets of nonplanar or convex portions **40A** and **40B** juxtaposed across the length of each enclosure. As shown in FIG. **7**, each set of portions **40A**, **40B** brackets a pair of interdigit elements **42A**, **44A** and **42B**, **44B** of the conductors **42** and **44**. However, as in the embodiment of FIG. **2**, more or less then a pair of interdigit elements may be bracketed by a set of nonplanar portions. Thus, the embodiment of FIGS. **6** and **7** provides a balanced line in which there is substantial isolation between a signal applied to inputs **46** and **48** and the signal taken from outputs **50** and **52**.

Additionally, although the device of FIGS. **6** and **7** is balanced, in many applications it may be desirable to contain the electric field produced by the signal carried by the leads within the enclosure **40** or to shield the leads from external electric fields. Accordingly, conductive layers **54** may be provided on the enclosure **40** to effect such shielding.

The balanced line embodiment of FIGS. **6** and **7** may be made by utilizing the method described above in conjunction with the device of FIGS. **2** and **3**. More specifically, the conductors **42** and **44** are traced on a conducting plate and are connected by a marginal area. The conductors and the marginal area are then separated from the remainder of the plate and may be silvered. Mold halves having nonplanar bottom walls are filled with the material comprising the enclosure **40** and the leads are placed over one mold half so that the marginal area forms a seal when the mold is closed. The mold halves are closed so that the dielectric material falls about and between the conductors. Heat is then applied to melt the material to form the balanced line.

After the mold has cooled the component is removed therefrom and the marginal area is separated from the extending portions of the signal conductors. If desired, the enclosure then may be coated with a metal for shielding purposes.

While preferred embodiments and methods of making the present invention have been shown and described herein it will be obvious that numerous omissions, changes and additions may be made in such embodiments and methods without departing from the spirit and scope of the invention.

What we claim is:

1. An electrical component comprising signal conducting means for conducting an electrical signal, an enclosure of nonconductive material surrounding at least a portion of said signal conducting means and having an upper and a lower surface, at least one of said upper and lower surfaces comprising a plurality of nonplanar portions juxtaposed across the length of said enclosure, said signal conducting means including a first signal conductor and a second signal conductor spacially displaced from said first signal conductor and electrically cooperable therewith, said first signal conductor being formed by a plurality of pairs of serially connected interdigit elements which are in adjacent and substantially parallel relationship, and at least one of said plurality of nonplanar portions brackets at least one of said plurality of pairs of interdigit elements.

2. An electrical component comprising signal conducting means for conducting an electric signal, an enclosure of nonconductive material surrounding at least a portion of said signal conducting means and having an upper and a lower surface, at least one of said upper and lower surfaces comprising a plurality of nonplanar portions juxtaposed across the length of said enclosure, said signal conducting means including a first signal conductor and a second signal conductor spacially displaced from said first signal conductor and electrically cooperable therewith, said first signal conductor being formed by a plurality of pairs of serially connected interdigit elements which are in adjacent and substantially parallel relationship, said plurality of nonplanar portions each comprising a convex section, each of said convex sections being sized to bracket a respective pair of said interdigit elements.

3. An electrical component comprising signal conducting means for conducting an electric signal; said signal conducting means including a first signal conductor and a second signal conductor spacially displaced from said first signal conductor and electrically cooperable therewith; an enclosure of nonconducting material surrounding at least a portion of said signal conducting means and having an upper and a lower surface; said material having a dielectric constant substantially independent of frequency, low dielectric loss and a magnetic permeability greater than unity; said upper and lower surfaces comprising a plurality of nonplanar portions juxtaposed across the length of said enclosure, said first signal conductor comprising a plurality of pairs of serially connected interdigit elements which are in adjacent and substantially parallel relationship, each one of said nonplanar portions of said upper surface being defined by indentations which are aligned with and spaced from indentations defining a respective nonplanar portion of said lower surface to provide a plurality of sets of aligned nonplanar portions, said sets and said interdigit elements being sized and positioned so that at least a pair of interdigit elements is received within each set of nonplaner portions.

4. An electrical component as in claim **3**, in which said second signal conductor comprises electrically conductive elements connected to said upper and lower surfaces and conforming to the shape of said nonplanar portions.

5. An electrical component as in claim **3**, and a plurality of taps on said first signal conductor extending beyond said enclosure and adapted to be connected to respective output circuits.

6. An electrical component as in claim **3**, in which said first signal conductor includes an upper and a lower surface, and a coating of silver material on said upper and lower surfaces of said first signal conductor.

7. An electrical component as in claim **3**, in which said nonplanar portions are convex in shape.

8. An electrical component as in claim **7**, in which said second signal conductor comprises a plurality of pairs of serially connected interdigit elements which are in adjacent and substantially parallel relationship, each one of said interdigit elements of said first signal conductor being positioned adjacent to a respective interdigit element of said second signal conductor, said first and second signal conductors and said sets of nonplanar portions being sized and positioned so that each set of convex portions bracket at least an interdigit element of said first signal conductor and an interdigit element of said second signal conductor.

9. An electrical component as in claim **8**, and electrically conductive elements connected to said upper and lower surfaces.