

[54] **LOW IMPEDANCE WIDEBAND STRIP
TRANSMISSION LINE TRANSFORMER**

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Related U.S. Application Data

- [63] Continuation of Ser. No. 677,690, Oct. 24,
1967, abandoned.
- [52] U.S. Cl.**333/84 M, 333/33, 333/97 R**
- [51] Int. Cl.**H01p 3/08, H01p 5/08**
- [58] Field of Search**333/84 M, 84, 33, 34, 35**

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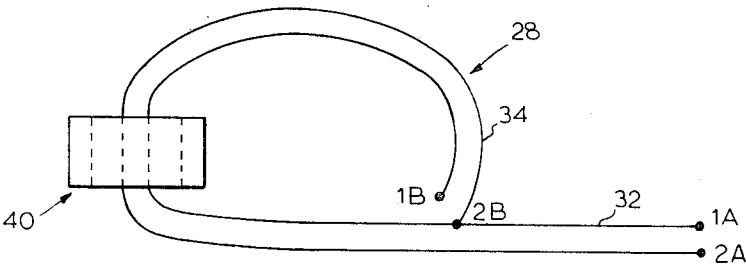
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[57] **ABSTRACT**

A low impedance wide band transformer comprised of
a strip transmission line wound on a ferrite core. The
strip line consists of a thin strip of flexible dielectric
material sandwiched between a pair of flat flexible
conductive layers. The dimensions of the line can be
selected to yield a very low characteristic impedance,
e.g., 1 ohm, so that the transformer can be used for
very low level impedance matching. Reduction of the
characteristic impedance extends the high frequency
operating range by minimizing core losses which occur
at high frequencies.

6 Claims, 7 Drawing Figures



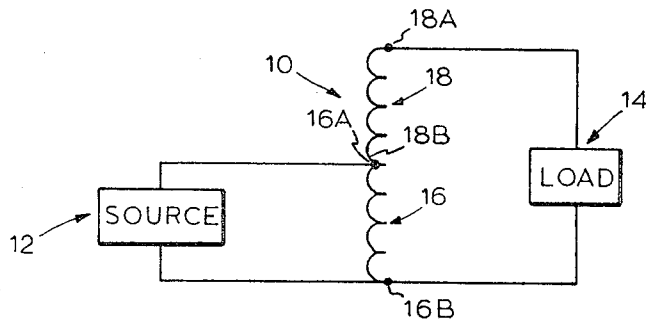


FIG. 1

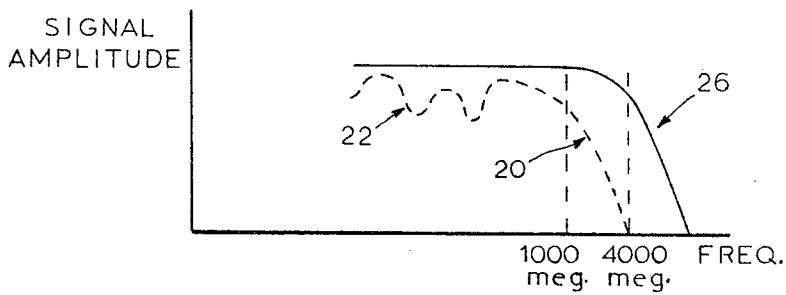


FIG. 2

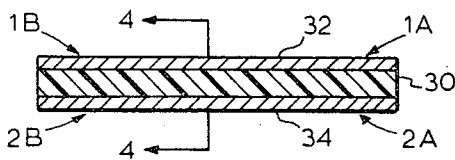


FIG. 3

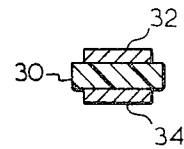


FIG. 4

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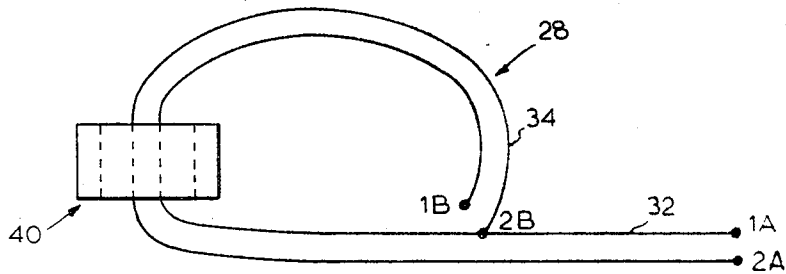


FIG. 5

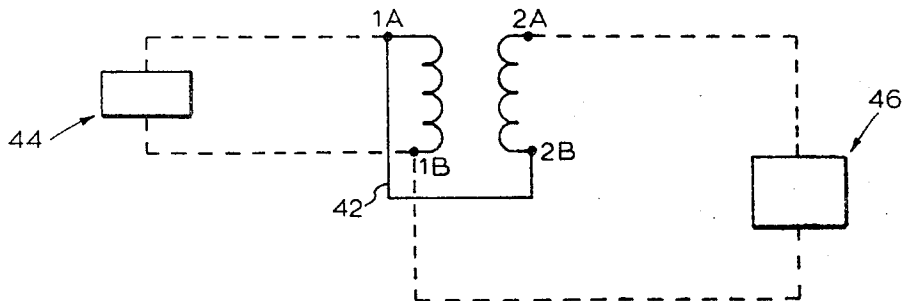


FIG. 6

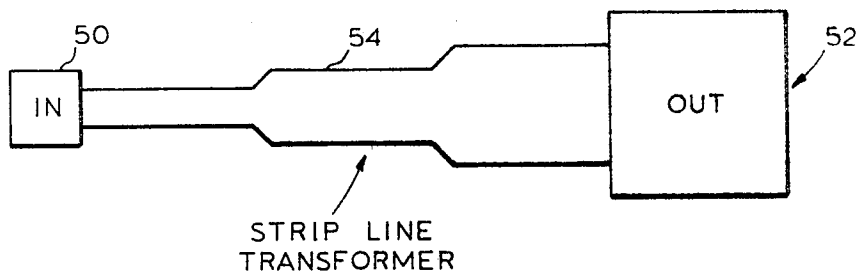


FIG. 7

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LOW IMPEDANCE WIDEBAND STRIP TRANSMISSION LINE TRANSFORMER

CROSS REFERENCE TO RELATED APPLICATION

This invention is a continuation of abandoned patent application Ser. No. 677,690, filed Oct. 24, 1967.

The invention herein described was made in the course of or under a contract or subcontract thereunder, with the Department of the Air Force, Rome Air Development Center.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to electrical signal transformers and more particularly to low impedance wide band transformers capable of operating to extremely high frequencies.

2. Description of the Prior Art

The prior art is replete with different transformer constructions intended to provide wide band coupling to very high frequencies, as for impedance matching purposes.

Some of these prior art transformer constructions enable operation over a wide frequency range extending to upper limits of a thousand megacycles by utilizing transmission line windings; e.g., see U.S. Pat. No. 3,037,175. Such transmission line transformers are based on the recognition that the earlier conventionally wound transformers were frequently limited by large interwinding capacitance which resonates at some relatively low frequency. The interwinding capacitance in transmission line transformers on the other hand forms part of the distributed transmission line system and does not limit the upper frequency response. However, in the transmission line transformers disclosed in the prior art, the upper frequency is limited by core losses and/or line length which become significant at frequency levels of about 1,000 megacycles.

More particularly, core losses become increasingly significant as the A.C. core resistance decreases inasmuch as the core resistance is effectively connected in parallel with the transmission line. Core resistance decreases as frequency increases. Thus for a transmission line having a certain characteristic impedance, there exists a certain frequency at which the parallel core resistance will fall to a level such that signal coupling to the transformer output will be down 3 db from maximum. This certain frequency will be referred to as the upper cutoff frequency or frequency limit. One of the objects of the present invention is to provide a transformer having a higher upper cutoff frequency than heretofore known transformers.

Typical prior art transmission line transformers utilize a twisted conductor pair which is wound about a ferrite core. This type of transmission line construction limits the characteristic impedance which can be realized to a level which is too high for efficient impedance matching to many modern low impedance transistor circuits. Thus it is an additional object of the present invention to provide a transformer construction which can be easily fabricated to realize lower characteristic impedances than are achievable by prior art construction.

SUMMARY

Briefly, in accordance with the present invention, a low impedance broad band transformer is provided comprised of a strip transmission line wound upon a ferrite core. The strip transmission line comprises a thin layer of flexible dielectric material sandwiched between a pair of flat flexible conductive layers.

The construction in accordance with the invention yields a lower inductance and higher capacitance than prior art twisted conductor pair transformers, thus resulting in a lower transmission line characteristic impedance. The provision of a lower characteristic impedance enables embodiments of the invention to be utilized in impedance matching applications in which the prior art transformers were unsuitable.

As a consequence of lowering the winding characteristic impedance, the transformer upper cutoff frequency is extended. This occurs because the decrease in core resistance with increasing frequency has less effect when the characteristic impedance is lower. In other words, a lower core resistance can be tolerated when the characteristic impedance is lower.

An important advantageous characteristic of embodiments of the invention results from the fact that strip transmission lines normally have much more uniform characteristics over a unit length than do twisted conductor pair transmission lines. The relative nonuniformity creates an undesirable ripple in the signal vs. frequency characteristic.

In contrast to the difficulties encountered in fabricating uniform twisted conductor pairs, uniformity presents no fabrication problem in the case of strip transmission lines. Flat conductors having a precise thickness can be easily bonded to opposite surfaces of a precisely dimensioned dielectric strip.

The greater uniformity achievable in strip transmission lines, as contrasted with twisted conductors, results in lower energy losses. This permits transformer embodiments of the present invention to be used in high power applications inasmuch as the power handling capability is a function of losses and the ability to dissipate heat.

In the use of a transmission line transformer for impedance matching, the characteristic impedance should be approximately equal to the geometric mean of the input and output impedances. The use of a strip transmission line facilitates the incorporation of smooth transitions to the input and output impedances, as for example, by tapering the conductor width.

THE NOVEL FEATURES

The novel features of the invention are set forth with particularity in the appended claims. The invention will best be understood from the following description when read in conjunction with the accompanying drawings, in which:

FIG. 1 is a schematic diagram illustrating the use of a transformer for coupling a source to a load;

FIG. 2 is a chart illustrating the bandpass characteristics of a prior art transformer and a transformer constructed in accordance with the present invention,

FIG. 3 is a sectional view of a strip transmission line;

FIG. 4 is a sectional view of a strip transmission line taken substantially along the plane 4—4 of FIG. 3;

FIG. 5 is a schematic illustration of a preferred embodiment of the present invention;

FIG. 6 is a schematic illustration of the electrical equivalent of the transformer of FIG. 5; and

FIG. 7 schematically illustrates the manner in which a transformer constructed in accordance with the invention can be efficiently connected between first and second external circuits.

Attention is now called to FIG. 1 which schematically illustrates a conventional auto transformer which can be used, for example, for coupling a first external circuit, e.g., source 12, to a second external circuit, e.g., load 14. As is well known, the auto transformer is comprised of at least first and second serially connected coils with one external circuit being connected across one coil and the other external circuit being connected across both coils. In the circuit of FIG. 1, the auto transformer 10 can be considered as being comprised of a first coil 16 connected in series with a second coil 18. The upper terminals of coils 16 and 18 are respectively designated at 16A and 18A. The lower terminals of coils 16 and 18 are respectively designated 16B and 18B. It can be noted that terminals 16A and 18B are connected in common with source 12 being connected between terminals 16A and 16B and with load 14 being connected between terminals 18A and 16B.

As is well known if the number of turns in the coils 16 and 18 are equal, the autotransformer 10 will provide an impedance transformation ratio of 4:1. It will, of course, be appreciated that the impedances of the source 12 and load 14 should be matched as closely as possible in order to achieve optimum energy transfer therebetween. Although in FIG. 1, the source 12 has been illustrated as being connected across coil 16 with load 14 being connected across coils 16 and 18, it will be understood that the source and load can be interchanged if an opposite transformation ratio, i.e., 1:4 is desired. As previously pointed out, continuing efforts have been made to extend the bandpass characteristic of coupling transformers and particularly to extend the upper cut-off frequency of the bandpass characteristic. In order to extend the upper cut-off frequency prior art transmission line transformers, such as are disclosed in U.S. Pat. No. 3,037,175, have been developed. These transformers employ twisted conductor transmission lines and provide a much higher cut-off frequency than transformers previously available in the art. However, the are still unsatisfactory for use in impedance matching applications for modern low impedance high frequency transistor circuits. Attention is called to FIG. 2 which illustrates in dotted line 20 a portion of the bandpass characteristic of a typical prior art transmission line transformer. It will be noted that the upper cut-off frequency i.e., 3 db down from maximum coupling, is approximately 1,000 megahertz. It will also be noted that the bandpass characteristic 20 displays a fair amount of ripple 22. This ripple is primarily introduced by nonuniformities in the dimensions of both the insulation on the pair of twisted conductors and the spacing between the conductors.

In contrast to the bandpass characteristic 20 exemplary of typical prior art twisted pair transmission line transformers, embodiments of the present invention yield the bandpass characteristic 26 illustrated in full

line in FIG. 2. It will be noted that the upper cutoff frequency has been extended to approximately 4,000 megacycles and that the characteristic is relatively flat throughout the bandpass region. In addition to extending the upper cut-off frequency and eliminating the ripple characteristic, embodiments of the present invention are useful for impedance matching applications to very low levels where the prior art transformers are unsuitable.

Briefly, embodiments of the present invention are comprised of stripline transmission lines which are formed to define one or more turns therein. More particularly a strip transmission line is illustrated in FIGS. 3 and 4. It is comprised of a flat flexible strip of dielectric material 30 formed, for example, of Teflon or epoxy glass. The strip 30 is relatively thin, having a thickness dimension as low as 0.001 inch. Flat flexible conductor strips 32 and 34 are adhered to opposite surfaces of the dielectric strip 30 as by bonding. The strips 32 and 34 can be formed of one-half or 1 ounce copper foil, for example. In order to prevent shorting between the conductor strips 32 and 34, the strip 30 is preferably made slightly wider than the strips 32 and 34 as shown in FIG. 4.

The construction of FIGS. 3 and 4 provides an excellent strip transmission line which can be fabricated to yield a very low characteristic impedance Z_0 inasmuch as the characteristic impedance is directly related to the magnitude of the inductance of the line and inversely related to the magnitude of the capacitance of the line. The flat closely spaced conductors 32 and 34 provide a relatively large opposed area to thereby yield a relatively high capacitance thus tending to reduce the characteristic impedance. The use of flat conductors 32 and 34 reduces the inductance as compared to twisted pair conductors, for example. Accordingly, as a consequence of the construction of the strip transmission line of FIGS. 3 and 4, the dimensions can be selected to yield a very low characteristic impedance Z_0 . The precise dimensions which should be selected to yield a desired impedance are expressed by the following equation:

$$Z_0 = \frac{377}{\sqrt{E_r}} \cdot \frac{h}{b} \cdot \frac{x}{F(x)}$$

where

E_r = dielectric constant

h = thickness of dielectric

b = width of the conductor

$x = (\pi b / 2h)$

$F(x) = 1 + x + Ln(1 + x)$

The strip transformer line of FIGS. 3 and 4 can be fabricated through the utilization of various techniques. One fabrication technique would be merely to cut a double clad circuit board material into strips. The copper conductors could be etched away to reduce their width dimension either before or after the board material is cut into strips.

In order to better appreciate the fabrication and operation of a transformer utilizing the stripline of FIGS. 3 and 4, the opposite ends of conductor 32 will be designated as terminals 1A and 1B respectively. The end of conductor 34 proximate to terminal 1A will be designated as terminal 2A and similarly the end proximate to terminal 1B will be designated as terminal 2B.

In order to form a transformer in accordance with the present invention, one or more turns are formed in a length of stripline. For example, FIG. 5 illustrates one turn formed in the stripline 28 with the second end 2B of conductor 34 being connected to the first end 1A of conductor 32. By so connecting conductors 32 and 34, one turn is formed from terminal 1A to terminal 1B and another turn is formed from terminal 2A to terminal 2B. In order to increase coupling between the turns, the stripline 28 extends through a ferrite core 40.

FIG. 6 represents the electrical equivalent of the structure schematically shown in FIG. 5, and accordingly illustrates one coil formed between terminals 1A and 1B and a second coil formed between terminals 2A and 2B. Bridging conductor 42 in FIG. 6 represents the connection between terminals 1A and 2B. In the use of the transformer represented in FIG. 6, a first external circuit such as a source 44 can be connected between terminals 1A 1B and a second external source or load 46 can be connected between terminals 2A and 1B. Reconsideration of FIG. 1 in the light of FIG. 6 will reveal that the circuit of FIG. 6 is electrically identical to the circuit of FIG. 1. In other words, the structure of FIG. 5 forms the auto transformer of FIG. 1 having an impedance transformation ratio of 4:1.

From the foregoing, it should be appreciated that the transmission line transformer structurally and schematically illustrated in FIGS. 3-5 yields a lower impedance characteristic than prior art transformers. The provision of a lower characteristic impedance not only permits embodiments of the present invention to be utilized in applications in which prior art transformers are unsuitable, but in addition extends the upper cut-off frequency of the transformer. More particularly the upper cut-off frequency in prior art transmission line transformers is limited by core losses (in ferrite core 40) which increase as frequency increases. Core losses increase with frequency because the A.C. resistance of the core decreases as frequency increases. Inasmuch as the core resistance effectively acts in parallel with the transmission line characteristic impedance, the lowering of the characteristic impedance has the effect of reducing the rate at which the core loss increases in response to a core resistance decrease. Thus, transformers constructed in accordance with the present invention having lower characteristic impedances can operate to higher frequencies before the core loss becomes significant.

Although the upper cut-off frequency has been discussed, the lower end of the bandpass characteristics has not yet been mentioned. Low frequency response can be extended by increasing inductance, as by increasing the number of turns or increasing the permeability of the core 40. It is pointed out, however, that the number of turns which can be utilized is limited because the total length of the transmission line should be less than one-quarter wave length at the upper cut-off frequency. As the transmission line approaches a quarter wave length, insertion losses increase rapidly. As an example, for an upper cut-off frequency of 3,000 megacycles, the transmission line length should be no more than about 2½ centimeters.

In order to achieve maximum power transfer between an input external circuit 50 (FIG. 7) and an output external circuit 52, the characteristic impedance Z_0 of the transmission line 54 of the trans-

former should be equal to the geometric mean of the input and output impedances. In order to provide a smooth transition from the input impedance to the characteristic impedance and from the characteristic impedance to the output impedance, the width of the conductors can be tapered as shown in FIG. 7 inasmuch as the impedance of the stripline material is a function of both its width and thickness. By incorporating smooth, rather than abrupt transitions, the voltage standing wave ratio on the line will be minimized.

From the foregoing, it should be appreciated that an improved transformer construction has been disclosed herein which yields a lower characteristic impedance than heretofore known devices and which is capable of defining a bandpass characteristic having a higher cut-off frequency than known prior art devices.

Although particular embodiments of the invention have been described and illustrated herein, it is recognized that modifications and variations may readily occur to those skilled in the art and consequently it is intended that the claims be interpreted to cover such modifications and equivalents.

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

1. A low impedance wideband auto transformer circuit providing a 4:1 impedance transformation ratio and having an extended upper cut-off frequency, comprising:
 - a strip transmission line comprised of first and second substantially flat flexible conductors respectively adhered to opposite surfaces of a substantially flat strip of dielectric material, the dimensions of said conductors and the dimensions and dielectric constant of said dielectric being chosen to provide a predetermined characteristic impedance for said transmission line,
 - a high permeability magnetic core through which said strip transmission line extends only once through said core with said first and second conductors respectively forming first and second coils inductively coupled to one another by said core, and with said first and second conductors being interconnected to one another so as to form an auto transformer providing a 4:1 impedance transformation ratio, the upper cut-off frequency of said circuit being sufficiently high so that losses occurring in said core are of sufficient significance to cause said upper cut-off frequency to be inversely dependent on the magnitude of said predetermined characteristic impedance,
 - a first external circuit defining a first impedance,
 - a second external circuit defining a second impedance, and
 - means connecting said first and second conductors and said first and second external circuits so as to provide auto transformer operation therebetween, said strip transmission line further having a construction so that each of said conductors has first ends disposed proximate to one another and second ends disposed proximate to one another, and said strip transmission line being shaped so that said first conductor first end is adjacent and in electrical contact with said second conductor on the core side thereof containing said second end so as to

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thereby form an auto transformer having a 4:1 impedance ratio, said predetermined characteristic impedance and said first and second impedances being chosen to optimize power transfer between said external circuits and also to provide a sufficiently low magnitude for said predetermined characteristic impedance so that the required upper cut-off frequency is obtained for said circuit despite the occurrence of the losses in said core.

2. The invention in accordance with claim 1, wherein said first external circuit is connected between said first conductor first end and said first conductor second end and said second external circuit is connected between said first conductor second end and said second conductor first end.

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3. The invention in accordance with claim 2, wherein said predetermined characteristic impedance has a magnitude substantially equal to the geometric mean of said first and second impedances.

4. The invention in accordance with claim 3, including substantially flat conductor portions of tapering width connecting said first and second conductors to said first and second external circuits.

5. The invention in accordance with claim 1, wherein the width of said strip of dielectric material is greater than the width of said first and second conductors.

6. The invention in accordance with claim 1, wherein said upper cut-off frequency is considerably greater than 1,000 megacycles.

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