United States Patent

[11] 3,629,741

[72] Inventor **William L. Brune**
Winston-Salem, N.C.

[21] Appl. No. **828,851**
[22] Filed **May 29, 1969**
[45] Patented **Dec. 21, 1971**
[73] Assignee **Bell Telephone Laboratories, Incorporated**
Murray Hill, N.J.

[54] **TRANSFORMER WITH CONTROLLED LOW COUPLING**
4 Claims, 10 Drawing Figs.

[52] **U.S. Cl.** **333/78,** 336/155
[51] **Int. Cl.** **H03h 7/08**
[50] **Field of Search** 333/77, 78, 26; 336/200, 229, 120, 155; 334/12, 14; 325/383

[56] **References Cited**

UNITED STATES PATENTS

3,403,323	9/1968	Wanlass	323/56
3,287,670	11/1966	Schroeder	333/79
3,430,175	2/1969	Matsuoka	336/155
3,146,293	8/1964	Gibbon	323/56
3,227,973	1/1966	Gray	333/78
2,818,555	12/1957	Lo	340/174
2,938,180	5/1960	De Witz	333/79
2,838,737	6/1958	Duncan	336/120
2,631,193	3/1953	Roberts	333/78

FOREIGN PATENTS

1,117,998	5/1956	France	333/78

Primary Examiner—Herman Karl Saalbach
Assistant Examiner—C. Baraff
Attorneys—R. J. Guenther and William L. Keefauver

ABSTRACT: A transformer having controlled low coupling between its windings. The transformer comprises a unitary core of ferromagnetic material, such as ferrite or carbonyl iron, fabricated in one piece with first and second pairs of apertures formed therein. A primary winding is threaded through the first pair of apertures and a secondary winding is threaded through the second pair of apertures. The coupling between these windings is controlled by means including a portion of the unitary core which is located between the two pairs of apertures. This provides completely closed magnetic paths in the core material for all the magnetic flux produced by driving either the primary or secondary windings.

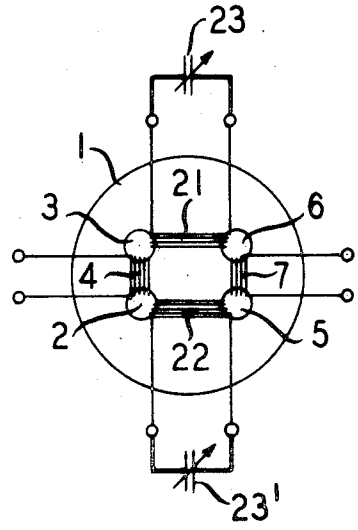


FIG. 2

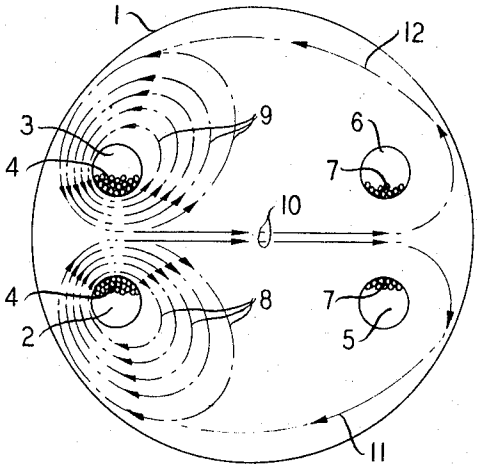


FIG. 1

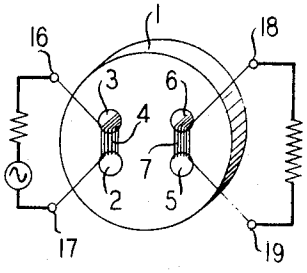


FIG. 4

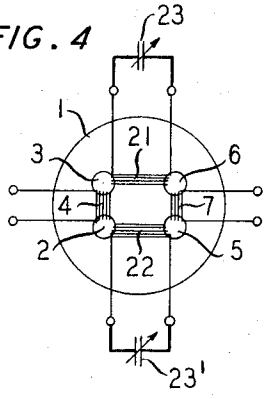


FIG. 3

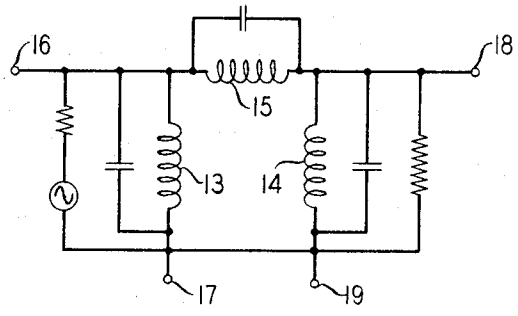


FIG. 5

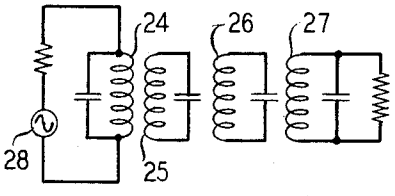
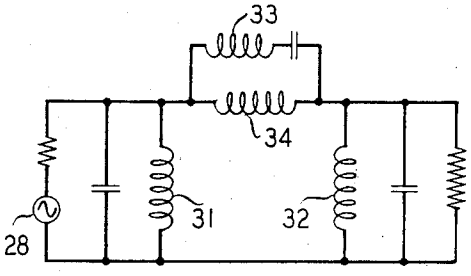


FIG. 6



INVENTOR
W. L. BRUNE
BY
B. F. Stoddard
ATTORNEY

FIG. 7

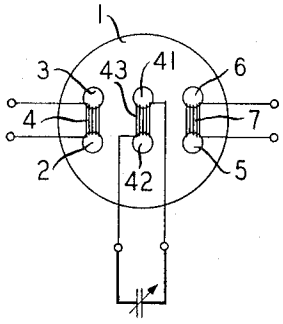


FIG. 8

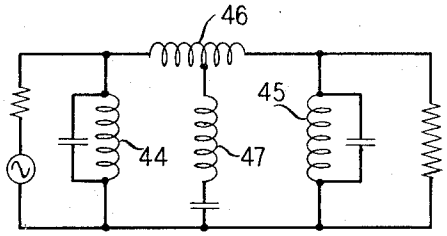


FIG. 9

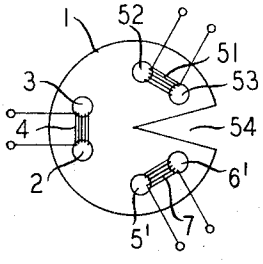
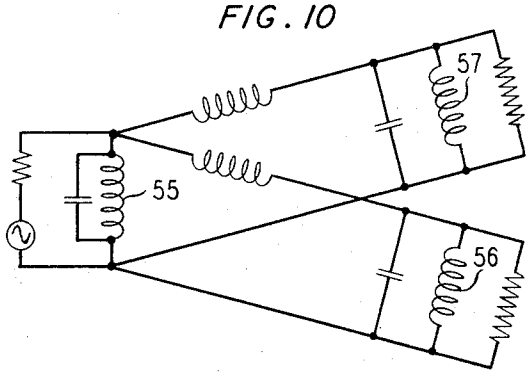


FIG. 10



TRANSFORMER WITH CONTROLLED LOW COUPLING

GOVERNMENT CONTRACT

The invention herein claimed was made in the course of, or under contract with The Department of the Army.

BACKGROUND OF THE INVENTION

This invention relates to transformers and, more particularly, to a transformer having controlled low coupling between its windings.

In the field of analog circuitry there has existed a need for a transformer with controlled low coupling which would function as a narrow band-pass filter. The need for such a device is particularly urgent in certain transmission circuits and delay line networks employed in radar and communication systems. In addition, it is desired that the shape of the device be such as to have a low or flat profile so that it can be incorporated as an appliqued part in integrated circuit assemblies.

SUMMARY OF THE INVENTION

The present invention is designed to provide a transformer construction having inherent controlled low coupling between its windings. The transformer is fabricated in one piece having a unitary core in the shape of a disk with first and second pairs of apertures formed therein. A primary winding is threaded through the first pair of apertures and a secondary winding is threaded through the second pair of apertures. By virtue of this construction, the coupling between these windings is controlled by means including a portion of the unitary core which is located between the two pairs of apertures. This is because the unitary core provides completely closed magnetic paths in the core material for all the magnetic flux produced by driving either the primary or secondary windings.

The core material is composed of magnetically soft material; that is, material that cannot be permanently magnetized. This is an important feature of the invention because, due to the low retentivity of the soft magnetic material, the core will return to its unmagnetized state when current is removed from the windings. Accordingly, the core is made of a suitable ferromagnetic material, such as ferrite or carbonyl iron. The low, flat profile of the disk renders it suitable for incorporation as an appliqued part in an integrated circuit assembly.

Another important feature of this invention is that the soft magnetic core provides at least two distinct and completely closed paths for magnetic flux to flow whenever either of the windings is energized. The magnetic flux therefore divides between the available paths in a manner that is controlled by the construction of the disk. It is this division of the flux between the paths that produces the desirable results obtained from using this invention.

The control of the division of the flux between the paths is achieved by the particular design of the core as is explained in more detail hereinafter. It is sufficient at this point to state that the coupling can be increased by positioning the pairs of holes closer together. The coupling can also be increased by increasing the spacing between the holes in each pair. Reduction in the degree of coupling can be accomplished by removing, such as by gouging, some of the magnetic material in that portion of the unitary core which is located between the two pairs of apertures.

It should be noted that, due to the variable control of the coupling, the device of this invention is basically a frequency selective device. In addition, since it is made of magnetic material having low retentivity, it constitutes a linear circuit element or component in that all of Kirchhoff's laws apply at any discrete frequency.

The invention is not restricted to a core having only two pairs of apertures therein because the number of apertures can be increased and can be variously disposed, as is described hereinafter, to constitute other useful frequency selective, linear circuit elements.

BRIEF DESCRIPTION OF THE DRAWING

The features of this invention are more fully discussed hereinafter in connection with the following detailed description of the drawing in which:

FIG. 1 is a perspective view of one embodiment of the invention showing a disk having primary and secondary windings threaded through respectively different pairs of holes formed therein;

FIG. 2 is a schematic plan view on an enlarged scale of the device shown in FIG. 1 and includes a representation of the magnetic flux paths therein;

FIG. 3 is a circuit diagram of a transmission network that is equivalent to the device shown in FIG. 1;

FIG. 4 is a plan view of a device somewhat similar to that shown in FIG. 1 but which has been modified to provide greater frequency selectivity;

FIG. 5 is a schematic diagram of the device shown in FIG. 4;

FIG. 6 shows a circuit which is equivalent to the device shown in FIG. 4;

FIG. 7 is a plan view of a device having three pairs of holes with windings threaded through them for functioning in the manner of a narrow band-pass filter;

FIG. 8 is a diagram of a circuit that is equivalent to the device shown in FIG. 7;

FIG. 9 is a plan view of a different device having windings threaded through three pairs of holes and having a wedge-shaped portion cut or removed from the core material; and

FIG. 10 is a diagram of a multiple path linear circuit which is equivalent to the device shown in FIG. 9 and which constitutes a separation filter.

DETAILED DESCRIPTION

In the exemplary embodiment of the invention that is shown in FIGS. 1 and 2, a transformer is represented as comprising a disk-shaped unitary core 1 having a first pair of holes 2 and 3 formed or drilled therein. The turns of a primary winding 4 are threaded through the first pair of holes 2 and 3. The core 1 is further provided with a second pair of holes 5 and 6 through which the turns of a secondary winding 7 are threaded. As was explained above, the low, flat profile of the disk 1 makes it suitable for use as an appliqued part in an integrated circuit assembly.

When an electric current is applied to one of the windings, such as the primary winding 4, a magnetic flux will be formed in the core 1 principally around the primary winding 4 as is illustrated by the arrows in the groups indicated by the reference numerals 8 and 9. Some of the flux will travel through the central portion of the core 1, as is shown by the group of arrows indicated by the reference numeral 10, and will induce an electric current in the secondary winding 7. This central core flux will travel around outer portions of the core 1 as is represented by the groups of arrows indicated by the reference numerals 11 and 12. All of these flux paths are closed in the magnetic material of which the core 1 is fabricated thereby keeping the stray flux field and undesired couplings to other circuit components at a minimum.

At this point, it should be stated that the unitary core 1 is fabricated in one piece from soft magnetic material of a suitable ferromagnetic type, such as ferrite or carbonyl iron. The term "soft magnetic material" is used to signify a material which has low retentivity and which cannot be permanently magnetized in contrast to a "hard magnetic material" which retains a remanent magnetization. Thus, when an electric current is applied to one of the windings, such as the primary winding 4, the core 1 will be temporarily magnetized. However, when the electric current is removed, the core 1 will return to its unmagnetized state. Accordingly, the device shown in FIGS. 1 and 2 constitutes a linear circuit element or component because all of Kirchhoff's laws will apply to it for any discrete frequency of the electric current in either of the windings 4 or 7.

Due to the manner in which this device is constructed, the coupling between the primary winding 4 and the secondary winding 7 is controlled by means including principally that portion of the unitary core 1 which is positioned, or interlocated, between the first pair of holes 2 and 3 and the second pair of holes 5 and 6. This controlled coupling is low because the magnetically soft material of the core 1 provides two separately distinct and completely closed magnetic paths so that only part of the magnetic flux that is produced by energizing either the primary winding 4 or the secondary winding 7 will flow to couple the other winding.

Since at least two distinct and completely closed paths are provided in the core 1 for the flow of the magnetic flux, the flux will therefore divide among the available paths in a manner that is controlled by the coupling construction of the core 1. This coupling can be increased by forming the second pair of holes 5 and 6 closer to the first pair of holes 2 and 3. The coupling can also be increased by widening the spacing between the holes 2 and 3 in the first pair and between the holes 5 and 6 in the second pair. Obviously, these two methods of varying the coupling must be performed before the device is fabricated. However, the coupling can be varied after the transformer has been fabricated by removing, such as by scraping or gouging, some of the magnetic material in the central portion of the core 1. This removal of the core material 1 reduces the thickness of this portion of the core 1 and thereby reduces the coupling between the primary winding 4 and the secondary winding 7.

As was stated above, it is this controlled division of the flux between the closed paths in the core 1 that produces the desirable results obtained from employing the device of this invention. Because of this adjustable control of the coupling provided by the core 1, the device is basically a frequency selective component.

In one embodiment of the form of the invention shown in FIGS. 1 and 2, the core 1 is constituted by a disk having a diameter of five-sixteenths of an inch and a thickness of one-sixteenth of an inch. Each of the holes 2, 3, 5, and 6 was drilled with a No. 60 drill. The spacing between the first pair of holes 2 and 3 and the second pair of holes 5 and 6 is 0.170 inch. A spacing of 0.075 inch is provided between the holes 2 and 3 and also between the holes 5 and 6. The primary winding 4 and the secondary winding 7 are each formed with thirteen turns of No. 36 copper wire. This construction provides a coupling of 2 percent.

The device shown in FIGS. 1 and 2 may be regarded as constituting a transmission network that is equivalent to a π configuration of inductances with associated parasitic capacitances, The equivalent network is shown in FIG. 3 wherein two shunt inductors 13 and 14 are bridged by a series inductor 15. The terminals 16 and 17 represent the ends of the primary winding 4, and the terminals 18 and 19 represent the ends of the secondary winding 7. In this circuit, the two shunt inductances 13 and 14 are constituted respectively by the primary winding 4 and the secondary winding 7. The series inductor 15 is produced by the coupling between the two windings 4 and 7 and this is provided by the core material 1. By thus using the single core 1 and the two windings 4 and 7 in the manner shown in FIGS. 1 and 2, the effect is that which might be produced by employing the three equivalent inductors 13, 14, and 15. In addition, it should be noted that the device shown in FIGS. 1 and 2 provides ground isolation between the windings 4 and 7.

The three inductor elements of the device shown in FIGS. 1 and 2 may be independently adjusted by changing the number of turns on the windings 4 and 7 and by changing the coupling through removal of some of the magnetic core material in the manner described above.

Since the equivalent series inductor effect produced by the core 1 is actually not a physical inductor, it is possible to place shields between the windings 4 and 7 and thereby reduce the stray capacity in the core 1 to a value which is appreciably less than that which can be obtained when using conventional inductors. Thus, for the same equivalent value of series inductor, the device shown in FIGS. 1 and 2 can be operated at higher frequencies than is possible when a physical inductor is used.

FIG. 4 illustrates the manner in which the device shown in FIGS. 1 and 2 may be modified to provide greater frequency selectivity. It can be seen in FIG. 4, that a third winding 21 is threaded through the holes 3 and 6 while a fourth winding 22 is threaded through the holes 2 and 5. Both of the windings 21 and 22 are of suitable electrically conductive wire.

FIG. 5 shows a circuit schematic of this device wherein the inductor 24 represents the primary winding 4, the inductor 25 represents the upper winding 21, the inductor 26 represents the lower winding 22, and the inductor 27 represents the secondary winding 7. If the primary winding 4 is driven from a source 28 and is tuned to a first frequency while the secondary winding 7 is also tuned to the first frequency, then the tuning of the upper and lower windings 21 and 22 to a second frequency will prevent the uncoupled flux at this second frequency from passing through these windings 21 and 22 if they are not loaded. The tuning of the windings can be accomplished in any suitable manner, such as by adjusting the variable capacitances 23 and 23'.

Thus, greater frequency selectivity can be achieved by using the device shown in FIG. 4 than can be obtained with the device shown in FIGS. 1 and 2. This is due to the fact that the tuning of the upper and lower windings 21 and 22 prevents the flux from passing through these windings at the tuned frequency thereby increasing the degree of coupling.

FIG. 6 represents a ladder circuit that is equivalent to the device illustrated in FIG. 4. In FIG. 6, the inductor 31 represents the primary winding 4, the inductor 32 represents the secondary winding 7, the inductor 33 represents the series combination of windings 21 and 22, and the inductor 34 represents the effect of the controlled coupling.

FIG. 7 shows a different embodiment of the invention in which a third pair of holes 41 and 42 are formed or drilled in the core 1 and an auxiliary winding 43 of electrically conductive wire is threaded therethrough. Normally, when the primary winding 4 is driven, there will be an output current at the secondary winding 7. However, if the auxiliary winding 43 is tuned to a particular frequency and is unloaded, this will restrict the coupling flux between the primary and secondary windings 4 and 7 at the frequency to which the auxiliary winding 43 is tuned. Thus, no current at this frequency will appear at the output of the secondary winding 7. Accordingly, it can be understood that the device shown in FIG. 7 functions in the manner of a narrow band-pass filter.

FIG. 8 shows a circuit which is equivalent to the device represented in FIG. 7. In FIG. 8, the inductor 44 represents the primary winding 4, the inductor 45 represents the secondary winding 7, the inductor 46 represents the coupling provided by the core 1 between the primary and secondary windings 4 and 7, and the inductor 47 represents the auxiliary winding 43.

The filtering function of the devices shown in FIGS. 4 and 7 can be combined with the function of a modulator by driving windings 21 and 22 in the device shown in FIG. 4 or winding 43 in the device shown in FIG. 7 as a control winding, such as by shorting it by means of a diode, thereby varying the coupling between the two other windings. This modification can function in the manner of a balanced modulator without the necessity of employing balanced diodes.

FIG. 9 illustrates the manner in which the device of this invention can be modified to function in the manner of a separation filter using multiple path linear circuits. In FIG. 9, the primary winding 4 remains in the same position as is shown in FIGS. 1 and 2 but the secondary winding 7 has been moved downward at an angle. A third winding 51 of electrically conductive wire is threaded through a third pair of holes 52 and 53. A wedge-shaped opening 54 is cut in the core 1 to provide a physical separation between the second pair of holes 5^1 and 6^1 and the third pair of holes 52 and 53 thereby preventing the

flow of flux between their windings 7 and 51. The tuning of the winding 7 to a first frequency and the tuning of the winding 51 to a second frequency will cause the device shown in FIG. 9 to function in the manner of a separation filter. Since each of the windings 4, 7, and 51 is separate and distinct, ground isolation is available if desired.

FIG. 10 shows a circuit which is equivalent to the device illustrated in FIG. 9. In FIG. 10, the inductor 55 represents the primary winding 4, the inductor 56 represents the secondary winding 7, and the inductor 57 represents the third winding 51. The inductor 58 represents the coupling which is provided by that portion of the core material 1 which is between the primary winding 4 and the third winding 51. Similarly, the inductor 59 represents the coupling which is provided by that portion of the core material 1 which is between the primary winding 4 and the secondary winding 7.

What is claimed is:

1. An inductive device comprising a transformer having primary and secondary windings with controlled low coupling between said windings and adapted for functioning in the equivalent manner of a transmission network having a π configuration of two shunt inductances bridged by a series inductance,

said device comprising a flat unitary core of magnetically soft material having means defining a plurality of holes therein,

a primary winding of electrically conductive wire threaded through a first pair of said holes,

a secondary winding of electrically conductive wire threaded through a second pair of said holes,

said primary and secondary windings being adapted for producing the effect of said two shunt inductances of said π configuration,

means for electrically energizing said primary winding for creating a magnetic flux in said core,

a first portion of said magnetic flux being adapted to flow in said core in the immediate area therein around said first pair of holes,

coupling means for providing at least one closed path between said primary and secondary windings for the flow therein of a second portion of said magnetic flux from said primary winding to said secondary winding,

said coupling means including an integral portion of said unitary core that is positioned between said first and second pairs of holes,

said integral core portion being so constructed and fabricated as to provide said controlled low coupling between said primary and secondary windings,

and said integral core portion being adapted for producing the effect of said series inductance of said π configuration.

said coupling means including a portion of said core that is positioned between said first and second pairs of holes,

and said core portion constituting said series inductance.

2. An inductive device having a substantial degree of frequency selectivity,

said device comprising a disk of magnetically soft material having means defining a plurality of holes therein,

a first winding of electrically conductive wire threaded through a first hole and a second hole,

a second winding of electrically conductive wire threaded through a third hole and a fourth hole,

means for tuning said first and second windings to a first frequency,

means for electrically energizing said first winding for creating a magnetic flux in said disk,

coupling means for electrically coupling said first winding to said second winding,

said coupling means comprising means for providing a closed path for the flow of said flux from said first winding to said second winding,

said last-mentioned means including a portion of said disk that is located between said four holes,

and instrumentalities for increasing the degree of said coupling,

said instrumentalities including a third winding of electrically conductive wire threaded through said first hole and said third hole,

a fourth winding of electrically conductive wire threaded through said second hole and said fourth hole,

and means for turning both said third and fourth windings to a second frequency.

3. An inductive device for functioning in the manner of a narrow band-pass filter,

said device comprising a flat core of magnetically soft material having means defining first and second pairs of holes therein,

a first winding of electrically conductive wire threaded through said first pair of holes,

a second winding of electrically conductive wire threaded through said second pair of holes,

means for electrically energizing said first winding for creating a magnetic flux in said core,

coupling means for electrically coupling said first winding to said second winding,

said coupling means comprising means for providing a closed path for the flow of said flux from said first winding to said second winding,

said last-mentioned means including a portion of said core that is located between said first and second pairs of holes,

and instrumentalities for blocking the flow of flux in said portion of said core for energy of a particular frequency,

said instrumentalities comprising means defining a third pair of holes in said core,

said third pair of holes being located in said portion of said core between said first and second pairs of holes,

a third winding of electrically conductive wire threaded through said third pair of holes,

and means for tuning said third winding to said particular frequency.

4. An inductive device for functioning in the manner of a separation filter,

said device comprising a disk of magnetically soft material having means defining three pairs of holes therein,

a first winding of electrically conductive wire threaded through a first pair of said holes,

a second winding of electrically conductive wire threaded through a second pair of said holes,

a third winding of electrically conductive wire threaded through a third pair of said holes,

means for electrically energizing said first winding for creating a magnetic flux in said disk,

first coupling means for providing a closed path for the flow of said flux from said first winding to said second winding,

said first coupling means including a first portion of said disk that is located between said first and second pairs of holes,

second coupling means for providing a closed path for the flow of said flux from said first winding to said third winding,

said second coupling means including a second portion of said disk that is located between said first and third pairs of holes,

means for tuning said second winding to a first frequency,

means for tuning said third winding to a second frequency,

and means for preventing the flow of said flux between said second and third windings,

said last-mentioned means including means defining a wedge-shaped opening formed in said disk between said second pair of holes and said third pair of holes.

* * * * *