United States Patent [19]

Beurrier

[11] 3,731,237

[45] May 1, 1973

[54] BROADBAND TRANSFORMERS

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[73] Assignee: **Bell Telephone Laboratories, Incorporated,** Murray Hill, N.J.

[22] Filed: **Feb. 3, 1972**

[21] Appl. No.: **223,117**

[52] **U.S. Cl.** .....**333/24 R,** 333/24 C, 333/32

[51] **Int. Cl.** **H03h 7/38,** H03h 13/00

[58] **Field of Search** .....333/24, 24 C, 78, 333/77, 32, 28, 28 T; 336/69, 220

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Primary Examiner—Rudolph V. Rolinec
Assistant Examiner—Marvin Nussbaum
Attorney—R. J. Guenther et al.

[57] **ABSTRACT**

A high return loss is maintained over the passband of a broadband transformer by reducing parasitic interwinding capacitance. This is accomplished by locating the windings along physically separated regions of a common magnetic core. To compensate for any loss of magnetic coupling at the higher frequencies due to a decrease in core permeability, equal portions of the physically separated windings are connected in parallel.

4 Claims, 14 Drawing Figures

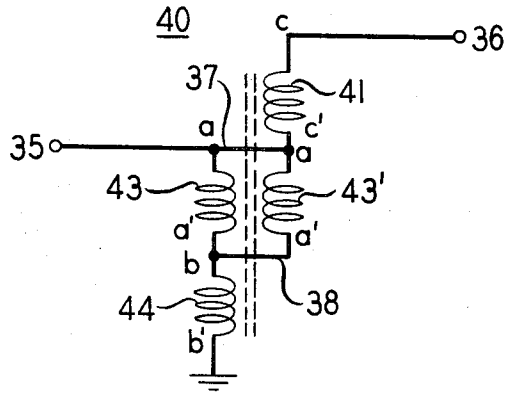


FIG. 1A

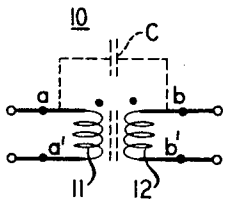


FIG. 1B

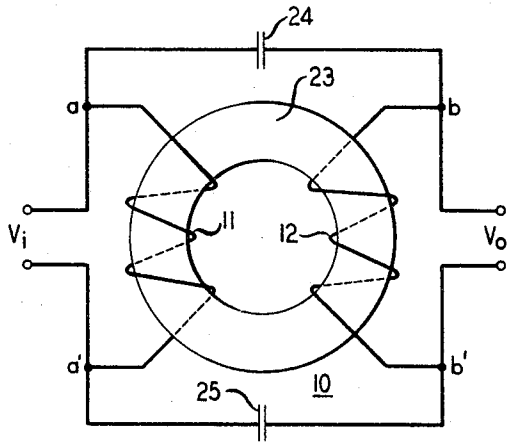


FIG. 1C

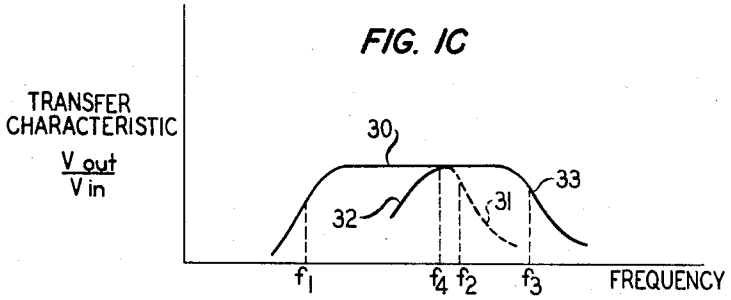


FIG. 2A

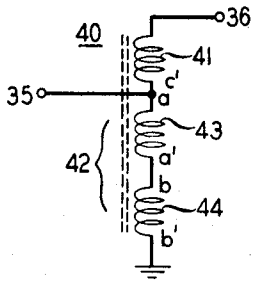


FIG. 2C

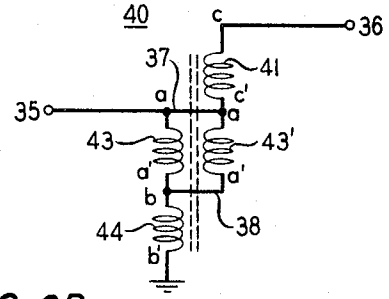


FIG. 2B

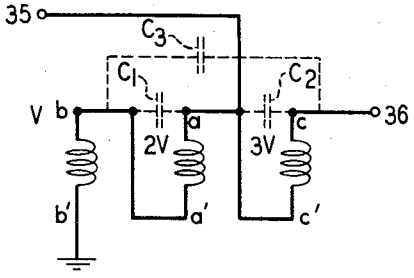


FIG. 2D

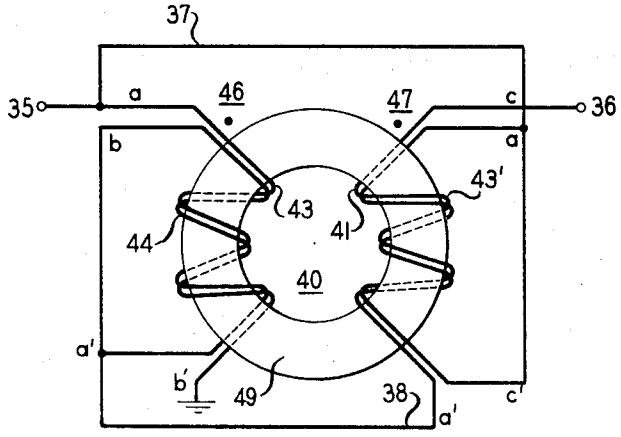


FIG. 3A

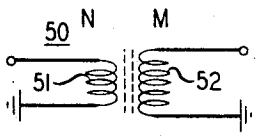


FIG. 3B

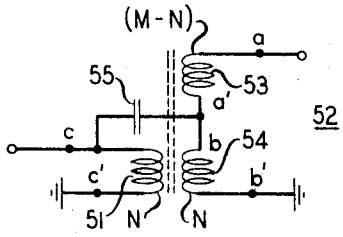


FIG. 3C

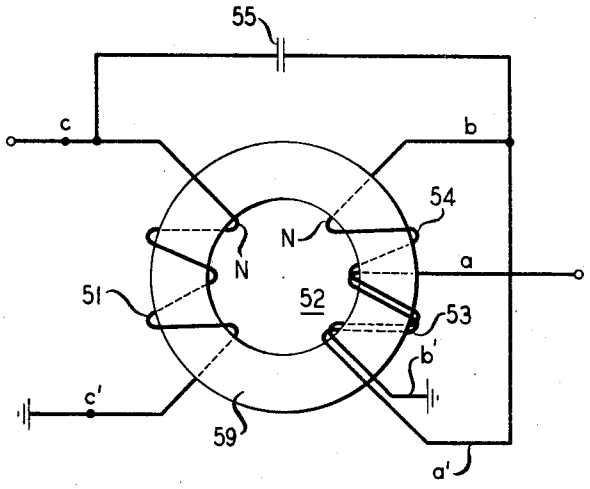


FIG. 4A

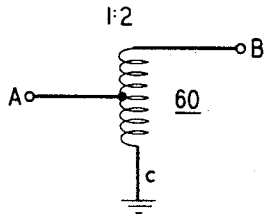


FIG. 4B

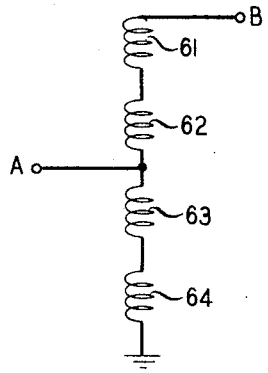


FIG. 4C

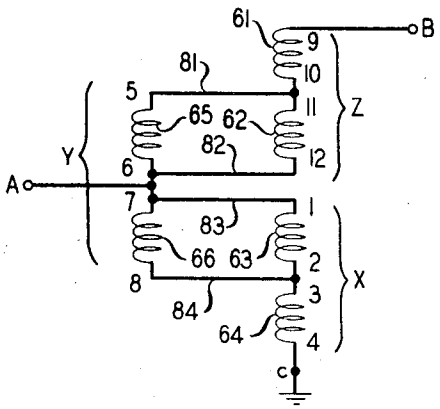
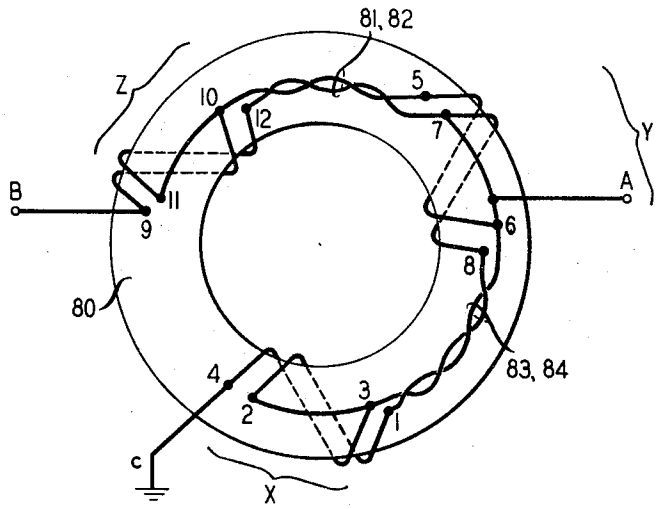


FIG. 4D



BROADBAND TRANSFORMERS

This application relates to broadband transformers.

BACKGROUND OF THE INVENTION

Two of the more important characteristics of a broadband transformer are its passband and its return loss, which defines the magnitude of the energy reflected by the transformer. Typically, the passband of a transformer is limited at the lower end of the band by the self-inductance of its windings, and at the higher end of the band by its parasitic interwinding capacitance and its leakage inductance. In an effort both to increase the self-inductance and to reduce the leakage inductance, it is customary to arrange the conductors in very close proximity, forming a multifilar winding, and to wind the conductors so arranged on a high permeability core. While this increases the self-inductance of the windings, thereby lowering the low frequency end of the passband, it also increases the parasitic interwinding capacitance, thus negating any improvement produced by lowering the leakage inductance. In particular, the increased capacitance converts the transformer to a complex reactive network which tends to lower the upper end of the passband, and to increase the return loss over the passband. Clearly, some means of obtaining a high self-inductance, and a lower leakage inductance without adversely affecting the high frequency characteristics of a transformer is required.

It is, accordingly, the broad object of the present invention to minimize the parasitic interwinding capacitance of transformers.

SUMMARY OF THE DISCLOSURE

A transformer, in accordance with the present invention, comprises a pair of physically separated windings, wound on a common magnetic core. To compensate for the loss of magnetic coupling at the higher frequencies, due to a decrease in core permeability, equal portions of the physically separated windings are connected in parallel.

In a first embodiment of a two-winding transformer, the two windings are capacitatively coupled together. In a second embodiment, comprising an autotransformer, the windings are conductively coupled together.

It is an advantage of the present invention that the parasitic interwinding capacitance of the transformer is decreased without adversely affecting its self-inductance or leakage inductance.

These and other objects and advantages, the nature of the present invention, and its various features, will appear more fully upon consideration of the various illustrative embodiments now to be described in detail in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A shows a schematic diagram of a two-winding transformer;

FIG. 1B shows the transformer of FIG. 1A constructed in accordance with the present invention;

FIG. 1C shows the transfer characteristics of a transformer in accordance with the present invention without and with the paralleling capacitors;

FIGS. 2A, 2B and 2C show schematic diagrams of an autotransformer;

FIG. 2D shows the autotransformer of FIG. 2C constructed in accordance with the present invention;

FIGS. 3A and 3B show schematic diagrams of a two-winding transformer having any arbitrary turns ratio N:M;

FIGS. 3C shows the transformer of FIG. 3B constructed in accordance with the present invention; and

FIGS. 4A, 4B, 4C and 4D show a transformer modified to include three separately wound bifilar windings.

DETAILED DESCRIPTION

Referring to the drawings, FIG. 1A shows, schematically, a simple 1:1 turns ratio transformer **10**, comprising a primary winding **11** and a secondary winding **12**. Typically, windings **11** and **12** are wound on a common magnetic core with a sufficient number of turns to provide the requisite impedance at the lowest frequency of interest.

To minimize the parasitic interwinding capacitance, C, shown in broken line, the windings of transformer **10** are physically separated from each other as illustrated in FIG. **1B**, wherein windings **11** and **12** are wound on opposite sides of a common magnetic core **23**. Since the two windings are no longer in close proximity, coupling between them is dependent upon the core material and tends to fall off at the higher frequencies as the permeability of the core material decreases with increasing frequency. In order to compensate for this, the two windings are connected in parallel by means of capacitors **24** and **25**, where capacitor **24** connects one end *a* of winding **11** to the corresponding end *b* of winding **12**, and capacitor **25** connects the other end *a'* of winding **11** to the other end *b'* of winding **12**. The magnitude of capacitors **24** and **25** are selected such that their impedance is very small relative to the load impedance across winding **12** at some specified frequency of interest. For example, the transfer characteristic, (i.e., the ratio of output voltage V_o to the input voltage V_i, as a function of frequency) for transformer **10** is typically as illustrated in FIG. **1C**. In the absence of capacitors **24** and **25**, the transformer passband, as given by curve **30**, extends between a lower frequency f_1 and a higher frequency f_2. The fall-off at the high end of the band, indicated by the dashed portion **31** of curve **30**, is a result of the loss of coupling due to the decrease in the permeability of core **23**.

The second curve **32** shows the added coupling provided by capacitors **24** and **25**. By suitably selecting their magnitudes, the coupling thus provided can be made significant at the frequency f_4 at which the magnetic coupling starts to decrease. This compensation extends the passband upward to frequency f_3, which is on the decreasing portion **33** of the net, overall transfer characteristic. The latter roll-off is due to the parasitic capacitance between turns of the respective windings, which effectively short-circuit the transformer windings, and to leakage inductance.

Thus, separating the transformer windings provides a simple and convenient means of reducing parasitic interwinding capacitance, while paralleling the two windings provides a means of compensating for any loss of coupling due to a decrease in core permeability. The

overall effect is to improve the return loss at the upper end of the transformer passband.

It will be recognized that in those cases where one end of each winding (i.e., a' and b') is connected to a common ground connection, only one capacitor (i.e., **24**) is required.

While the above discussion explains the principles of the invention, their application in connection with the particular embodiment described is not of great practical importance. Clearly, a prior art transformer, wherein the windings are wound closely together, has a significant parasitic interwinding capacitance. However, it will be noted that in a simple 1:1 turns ratio transformer the primary voltage $V_{a'a}$, and the secondary voltage $V_{b'b}$ are equal. Hence, the net interwinding voltage b_{ab} across the parasitic capacitance, C, is zero. Thus, while there is a significant parasitic capacitance produced by the transformer structure, the effect of this capacitance upon the operation of this particular transformer is not very great. On the other hand, there are other transformers, now to be considered, where the detrimental effect of winding-to-winding capacitance is quite noticeable.

FIG. **2A**, now to be described, shows a 2:3 autotransformer **40**, wherein one terminal **35** is a tap which divides the transformer winding into two portions, **42** and **41**, having a 2:1 turns ratio. In practice, winding **42** is further divided into two equal portions **43** and **44**, and then the three equal windings **41**, **43** and **44** are wound on a common magnetic core as a trifilar winding, connected as shown in FIG. **2B**. It will be noted that in this transformer, the voltages across the three windings are equal and additive such that a voltage v exists across the parasitic interwinding capacitances C_1 and C_2, and a voltage $2v$ exist across interwinding capacitance C_3. In order to extend the upper end of the return loss characteristic, in accordance with the present invention, the transformer illustrated in FIG. **2A** is first modified, as shown in FIG. **2C**, by the addition of a fourth winding **43'**, having the same number of turns as winding **43**. Winding **43'** is then conductively connected in parallel with winding **43** by means of conductors **37** and **38**. In all other respects, the transformers of FIGS. **2A** and **2C** are electrically the same. However, modified as shown, it is possible to divide the four windings into two groups **43–44**, and **41–43'**, which can then be physically separated, as shown in FIG. **2D**. Accordingly, a 2:3 turns ratio autotransformer, in accordance with the present invention, comprises a pair of two, physically separated bifilar windings **46** and **47**, wound on a common magnetic core **49**. Using the same identification numerals for the several windings as in FIGS. **2A** and **2C**, the first bifilar winding **46**, comprising one group of windings **43–44**, forms the equivalent of a primary winding the second bifilar winding, comprising the other group of windings **41–43'**, forms the equivalent of a secondary winding. As in the schematic diagram of FIG. **2C**, ends a and a' of winding **43** are connected, respectively, to ends a and a' of winding **43'** by means of conductors **37** and **38**. The common junction formed by ends a of windings **43** and **43'** is also connected to end c' of winding **41**, forming one terminal **35** of the transformer. The other end c of winding **41** is the other terminal **36** of transformer **40**. The common junction formed by ends a' of windings **43** and **43'** is connected to end b of winding **44**. End b' of said winding is the common terminal for the transformer input and output circuits. It will be noted that while this arrangement retains the interwinding capacitance between the two windings of each bifilar winding, it eliminates parasitic capacitance C_3 which coupled between the largest voltage differential $2v$ and, hence, was potentially the most harmful.

As an example of the improvement that can be realized by the transformer structure illustrated in FIG. **2C**, an autotransformer constructed in accordance with the prior art had a −30 db return loss characteristic which extended between 25 MHz and 100 MHz. By contrast, an autotransformer constructed in accordance with the present invention had a −30 db return loss which extended between 20 MHz and 140 MHz. (The downward extension of the lower end of the band from 25 to 20 MHz is not fully understood.)

FIGS. **3A**, **3B**, and **3C** show how the principles of the present invention can be extended to include transformers having any arbitrary turns ratio N:M. For example, FIG. **3A** shows, schematically, a transformer **50**, comprising windings **51** and **52**, having any arbitrary turns ratio of N:M. In FIG. **3B**, winding **52** is divided into two portions **53** and **54**, of which winding portion **54** has N turns and winding portion **53** has (M−N) turns. A capacitor **55**, connected between one end c of winding **51** and one end b of winding **54**, effectively connects these two windings in parallel at the higher end of the transformers passband in the manner explained in connection with FIG. **1C**.

The schematic of FIG. **3B** is implemented as illustrated in FIG. **3C**, which shows the two transformer windings **51** and **52** wound on a common magnetic core **59**, but physically separated from each other. Winding **52** can be a simple winding or advantageously, tighter coupling is obtained if at least a portion is wound as a bifilar winding. The latter arrangement is illustrated in FIG. **3C**. Assuming, for purposes of illustration, that $N > (M/2)$, the (M−N) turns of winding **53**, and (M−N) turns of winding **54** are bifilar wound. To complete the circuit, end a' of winding **53** is connected to end b of winding **54**. Capacitor **55**, connected between end c of winding **51** and the junction of ends b and a' of windings **53** and **54**, couple the N turns on winding **51** to an equal number of turns on winding **52**.

In this embodiment it was assumed that ends b' and c' of the transformer windings are both connected to a common junction. If they are not, a second capacitor is connected between these two ends, as illustrated in FIG. **1B**.

The above-described technique can be readily extended to form transformers having three or more physically separated windings, disposed along a common magnetic core. To illustrate, FIG. **4A** shows a 1:2 turns ratio autotransformer **60**. FIG. **4B** shows the transformer winding divided into four equal winding portions **61**, **62**, **63** and **64**. FIG. **4C** shows a further modification of the transformer wherein two additional windings **65** and **66**, equal to the winding portions **61** through **64**, are added and connected, respectively, in parallel with winding portions **62** and **63** by means of conductors **81**, **82**, **83** and **84**.

The windings are then grouped in three groups X, Y and Z, of which group X includes windings **63** and **64**,

group Y includes windings **65** and **66**, and group Z includes windings **61** and **62**. In accordance with the present invention, the three groups are then wound along physically separated regions of a common magnetic core **80**, as shown in FIG. **4D**. Identifying the winding ends with the numerals **1** through **12**, the windings are located and connected as shown therein. Since all the winding portions are equal, i.e., have the same number of turns, they are advantageously wound as bifilar windings. To reduce leakage inductance, the paralleling conductors **81** and **82**, and **83** and **84** are shown as twisted pairs.

SUMMARY

As explained hereinabove, the high return loss characteristic of a transformer can be improved at the higher frequencies by reducing the parasitic interwinding capacitance. This is done by physically separating the transformer windings. In a two-winding transformer, the primary and secondary windings are readily separated by winding them on different portions of a common magnetic core. To compensate for any decrease in core permeability, coupling capacitors or conductors couple a portion or all of the primary winding in parallel with an equal number of turns on the secondary winding.

In the case of an autotransformer, an additional winding is capacitively or conductively connected in parallel with all or a portion of the common portion of the autotransformer. The resulting "primary" and "secondary" windings thus formed are then physically separated and wound on a common magnetic core. The capacitive or conductive connection provides a compensating coupling for any decrease in core permeability at the higher frequencies.

Advantageously, the windings are divided so that they are wound as bifilar windings for more efficient coupling. However, this is not a necessary aspect of the present invention which is directed primarily to the feature of reducing parasitic interwinding capacitance, and to the feature of introducing other coupling means to compensate for any loss of magnetic coupling between the physically separated windings.

Thus, in all cases it is understood that the above-described arrangements are illustrative of but a small number of the many possible specific embodiments which can represent applications of the principles of the invention. Numerous and varied other arrangements can readily be devised in accordance with these principles by those skilled in the art without departing from the spirit and scope of the invention.

I claim:

1. A broadband transformer comprising:

a plurality of windings, including primary and secondary windings, wound on a common magnetic core;

characterized in that:

said primary and secondary windings are physically separated from each other to minimize parasitic interwinding capacitance;

said core has a decreasing permeability at the higher end of the frequency band of interest;

and in that at least a portion of a primary winding is connected in parallel with an equal portion of a secondary winding.

2. The transformer in accordance with claim **1** wherein said winding portions are conductively connected in parallel.

3. The transformer in accordance with claim **1** wherein there are two windings; and

wherein said winding portions are connected in parallel by means of a capacitor at one end and a conductor at the other end.

4. The transformer in accordance with claim **1** wherein said winding portions are connected in parallel by means of a pair of capacitors.

* * * * *

Disclaimer

3,731,237.—*Henry Richard Beurrier*, Chester Township, Morris County, N.J. BROADBAND TRANSFORMERS. Patent dated May 1, 1973. Disclaimer filed July 16, 1973, by the assignee, *Bell Telephone Laboratories, Incorporated.*

Hereby enters this disclaimer to claims 1–4 of said patent.

[*Official Gazette December 4, 1973.*]