United States Patent [19]

Seidel

[11] **3,883,829**

[45] **May 13, 1975**

[54] **TRANSFORMER WITH ADJUSTABLE TURNS RATIO**

[75] Inventor: **Harold Seidel**, Warren, N.J.

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

[22] Filed: **May 22, 1974**

[21] Appl. No.: **472,116**

[52] **U.S. Cl.** **333/11**; 323/48

[51] **Int. Cl.** **H03h 7/00**; G05f 3/04

[58] **Field of Search** 333/10, 11, 32; 323/48, 323/49, 56; 336/170, 180, 182

[56] **References Cited**

UNITED STATES PATENTS

1,916,007	6/1933	Mallett	323/48
2,608,681	8/1952	Stevens	323/48
3,675,164	7/1972	Seidel	333/32

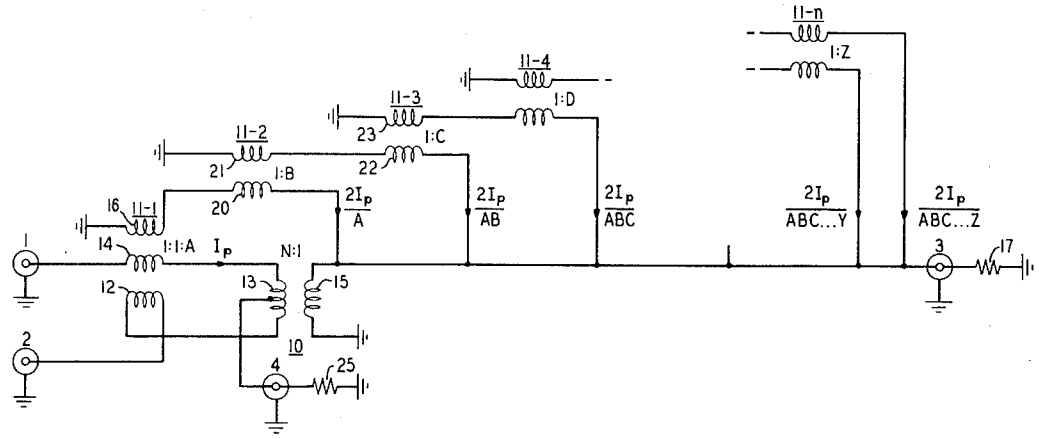
Primary Examiner—Paul L. Gensler

Attorney, Agent, or Firm—S. Sherman

[57] **ABSTRACT**

The effective turns ratio of a transformer is modified by sampling the transformer primary current and injecting at least one vernier current proportional thereto into the secondary circuit of said transformer. The sampling is done by at least one vernier transformer which is arranged to respond to asymmetric mode excitation but to be transparent to symmetric mode currents.

4 Claims, 2 Drawing Figures



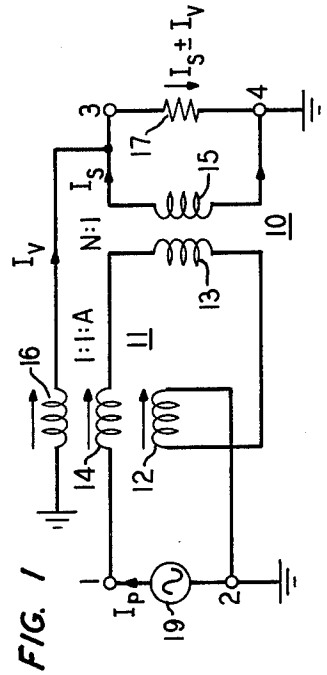

I_V
$I_S \pm I_V$
I_S
I_P
N:1
1:1:A
11
10
13
14
12
15
16
17
19
1
2
3
4

FIG. 1

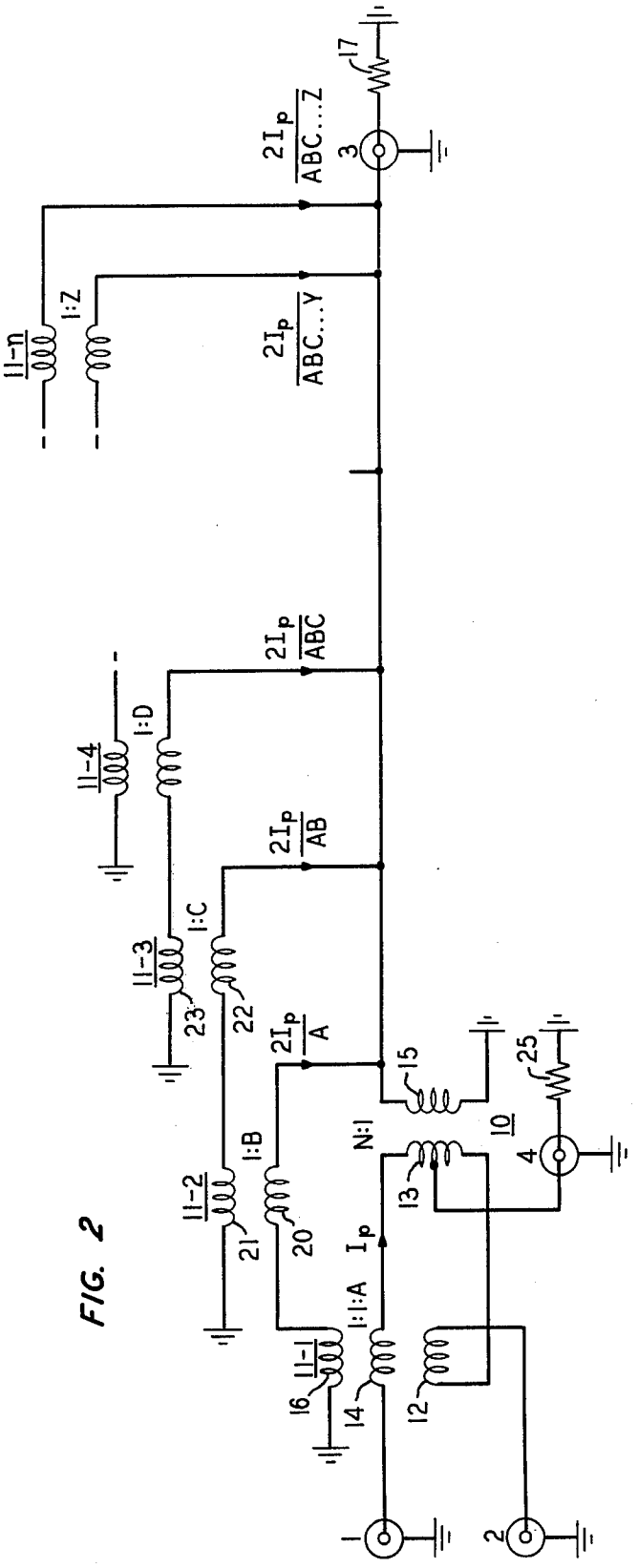

$2I_P$ / ABC...Z
$2I_P$ / ABC...Y
$2I_P$ / ABC
$2I_P$ / AB
$2I_P$ / A
11-n
1:Z
11-4
1:D
11-3
1:C
11-2
1:B
11-1
1:1:A
N:1
I_P
10
11
12
13
14
15
16
17
20
21
22
23
25
1
2
3
4

FIG. 2

TRANSFORMER WITH ADJUSTABLE TURNS RATIO

This invention relates to transformer circuits having adjustable effective turns ratios.

BACKGROUND OF THE INVENTION

In my copending application Ser. No. 466,213 filed May 2, 1974, there is described a technique for synthesizing in-phase hybrid couplers. Among the components of such couplers are transformers whose turns ratios cannot always be expressed as the ratio of two integers. At the lower frequencies one might approximate the desired turns ratio by using large numbers of turns. However, at the higher frequencies, where parasitic effects are important, this cannot be conveniently done. Since it is highly desirable that the turns ratios of the transformers used in these in-phase couplers be accurate, their fabrication can be a problem.

It is, accordingly, the broad object of the present invention to produce any arbitrary effective turns ratio by means of two or more transformers having simple turns ratios, each of which is expressible as a rational number.

SUMMARY OF THE INVENTION

A transformer network in accordance with the present invention, comprises a principle transformer having a primary-to-secondary turns ratio N:1, and at least one three-winding vernier transformer whose first, second and third windings are in the ratio of 1:1:A. One or more additional vernier, two-winding transformers having turns ratios 1:B, 1:C . . . 1:Z can be added if required; where N:1, 1:1:A, 1:B, 1:C . . . 1:Z are any conveniently realizable turns ratios. The most convenient are, of course, those wherein N, A, B, C . . . Z are rational numbers.

In operation, the vernier transformers sample the current I_p in the primary winding of the principle transformer and inject additional currents into the secondary circuit of the principle transformer which either add constructively or destructively to produce a net secondary current I given by

$$I = I_p \left(N \pm \frac{2}{A} \pm \frac{2}{AB} \ldots \pm \frac{2}{AB \ldots Z} \right).$$

The effective turns ratio of the principle transformer is then

$$N_{eff}:1 = \frac{I}{I_p}:1 = \left(N \pm \frac{2}{A} \pm \frac{2}{AB} \ldots \pm \frac{2}{AB \ldots Z} \right):1.$$

In the above-identified copending application the transformers in question are used to form hybrid couplers having symmetric and antisymmetric ports. It is an advantage of the present invention that the vernier action is responsive only to the antisymmetric mode of excitation and is transparent to symmetric mode excitation.

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. **1** shows a transformer circuit in accordance with the present invention comprising a principle transformer and one vernier transformer; and

FIG. **2** shows a transformer circuit comprising a principle transformer and a plurality of vernier transformers.

DETAILED DESCRIPTION

Referring to the drawings, FIG. **1** shows a transformer circuit in accordance with the present invention comprising a principle transformer **10** and one vernier transformer **11.** The former is a two-winding transformer having an N:1 primary-to-secondary turns ratio. The vernier transformer is a three-winding transformer having a first-to-second-to-third winding turns ratio of 1:1:A, where N:1 and 1:1:A are any conveniently realizable turns ratios.

The two transformers are arranged such that the vernier transformer windings **12** and **14,** and primary winding **13** are connected in series. Specifically, one end of the first winding **12** of vernier transformer **11** is connected to one end of primary winding **13,** and one end of the second winding **14** of vernier transformer **11** is connected to the other end of primary winding **13.** The other ends of windings **12** and **14** constitute a pair of external terminals **1–2** of the total transformer circuit of which pair terminal **2** is shown grounded.

In addition, windings **12** and **14** are arranged such that the magnetic fields produced in transformer **11** by a current flowing through the series-connected windings add constructively. This is indicated schematically in FIG. **1** by the cross-connection of winding **12.**

The two ends of secondary winding **15** of transformer **10** constitute the second pair of terminals **3–4** of the transformer circuit of which terminal **4** is shown grounded. A load resistor **17** is shown connected between terminals **3** and **4.**

The third vernier transformer winding **16** is connected across secondary winding **15,** i.e., between terminals **3** and ground.

In operation, a signal source **19** connected between terminals **1** and **2** produces a current I_p in the primary winding **13** of transformer **10** which induces a secondary current $I_s = I_p N$ in secondary winding **15.** In addition, current I_p, flowing through windings **12** and **14** of the vernier transformer, induces a current $I_v = 2I/A$ in winding **16.** This current is injected into the secondary circuit of transformer **10** and adds either constructively or destructively with current I_s, depending upon the sense of winding **16.** The total secondary current I flowing into resistor **17** is, therefore,

$$I = I_s \pm I_v \tag{1}$$

$$I = I_p (N \pm 2/A) \tag{2}$$

The net effective turns ratio of the transformer circuit is then given by

$$\frac{I}{I_p}:1 = N_{eff}:1 = (N \pm 2/A):1 \tag{3}$$

Thus, the effective turns ratio of the total transformer circuit differs from the actual turns ratio N:1 of the principle transformer by an amount determined by the turns ratio of the vernier transformer and the phase of the vernier current.

If the desired turns ratio cannot be realized by means of a single vernier transformer, the transformer circuit illustrated in FIG. **1** can be modified by the addition of one or more additional vernier transformers as shown in FIG. **2.**

Using the same identification numerals to identify common components in the two circuits, the embodiment of FIG. **2** comprises a principle, two-winding transformer **10** having an N:1 turns ratio, and a plurality of vernier transformers **11-1, 11-2 . . . 11-n**. The first of the vernier transformers **11-1,** corresponding to vernier transformer **11** in FIG. **1,** is a three-winding transformer whose windings **12, 14** and **16** are in the ratio of 1:1:A. The other vernier transformers **11-2, 11-3 . . .** 11-n are two-winding transformers whose turns are in the ratios of 1:B, 1:C . . . 1:Z, respectively, where N:1, 1:1:A, 1:B, 1:C . . . 1:Z are any conveniently realizable turns ratios.

Windings **12** and **14** of transformer **11-1** are connected in series with the primary winding of transformer **10** as explained hereinabove. Similarly, winding **16** is connected so as to inject the current $2I_p/A$ induced therein into the secondary circuit of transformer **10.** However, in the embodiment of FIG. **2** this connection is made through a winding **20** of the second vernier transformer **11-2,** thus generating a second vernier current $2I_p/AB$ in winding **21** of transformer **11-2.** This second vernier current is also coupled into the secondary circuit of the principle transformer. If, however, there is a third vernier transformer, as there is in FIG. **2,** this current is coupled through a winding **22** of the next vernier transformer **11-3.** This, in turn, serves to generate a third vernier current $2I_p/ABC$ in winding **23** of transformer **11-3,** which current is similarly coupled into the secondary circuit of transformer **10** through a winding of the next vernier transformer, if any. Thus, more generally, each vernier current in the embodiment of FIG. **2** is coupled into the secondary circuit of the principle transformer through a winding of the next vernier transformer, if any.

The total secondary current I is the algebraic sum of these currents, and is given by

$$I = I_p \left(N \pm \frac{2}{A} \pm \frac{2}{AB} \pm \frac{2}{ABC} \ldots \pm \frac{2}{ABC \ldots Z}\right). \quad (4)$$

The effective turns ratio of the transformer is then

$$N_{eff}{:}1 = \left(N \pm \frac{2}{A} \pm \frac{2}{AB} \pm \frac{2}{ABC} \ldots \pm \frac{2}{ABC \ldots Z}\right){:}1. \quad (5)$$

EXAMPLE

Assume: A desired N_{eff}:1= $\sqrt{3}$:1≈1.732:1; an actual turns ratio N:1=2:1; and two vernier transformers. From equation (5) we have for N_{eff}

$$N_{eff} = 1.732 = 2.000 \pm \frac{2}{A} \pm \frac{2}{AB},$$

or

$$-0.268 = \pm \frac{2}{A} \pm \frac{2}{AB}.$$

Since we have one equation and two variables, A and B, we further assume a value for one of the variables. In this case we assume A=8, and that the vernier currents add destructively. This gives

$$-0.268 = -0.25 \pm \frac{.25}{B},$$

or

$$B = 14$$

Substituting for A, B and N in equation (2) we obtain that N_{eff} = 1.7325.

Thus, by using two vernier transformers and a principle transformer having conveniently realizable simple turns ratios of 1:8, 1:14 and 2:1, a transformer circuit having an irrational turns ratio $\sqrt{3}$:1 has been realized to within a small fraction of a percent.

To employ the principles of the present invention in connection with the in-phase hybrid couplers described in my above-identified copending application, a fourth terminal **4** is provided at a center-tap along primary winding **13** of transformer **10.** Each of the terminals **1,** 2, 3 and **4,** taken with respect to a common junction, i.e., ground, is then a separate port of the resulting in-phase coupler. One of the advantages of the present invention now becomes readily apparent. In the above discussion, it was assumed that transformer **10** was excited in an asymmetric mode, resulting in a current I_p which flowed into port **1** and out of port **2.** If, in addition, transformer **10** is symmetrically excited by the application of in-phase signals to ports **1** and **2,** in-phase currents will flow into transformer ports **1** and **2** and out through port **4.** However, the magnetic fields induced in transformer **11-1** by these symmetric mode currents will add destructively, resulting in no net magnetic field and, hence, no component of induced current in winding **16** of transformer **11-1.** Thus, the above-described network of vernier transformers is responsive only to asymmetric mode currents and is transparent to symmetric mode currents.

If, for any reason, it is inconvenient to construct any of the vernier transformers as a single, two-winding transformer because the turns ratio is too large, the necessary turns ratio can be realized by using a tandem arrangement of two transformers. For example, in the illustrative example given above, the second vernier transformer had a turns ratio of 1:14. In this case the same turns ratio can be obtained using two transformers having turns ratios of 1:7 and 1:2 for a net turns ratio of 1:14.

Thus, in all cases it is understood that the above-described arrangements are illustrative of 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.

What is claimed is:

1. A transformer circuit comprising:

a two-winding principle transformer having an actual primary winding-to-secondary winding turns ratio of N:1;

and at least one three-winding vernier transformer whose first, second, and third windings are in the ratio of 1:1:A;

one end of said first winding being connected to one end of the primary winding of said principle transformer;

one end of said second winding being connected to the other end of said primary winding;

said first and second windings being further arranged so that the magnetic fields produced thereby by a common current flowing through said first, second and primary windings add constructively;

and means for connecting the third winding of said vernier transformer across the secondary winding of said principle transformer;

said transformer circuit having an effective turns ratio N_{eff}:1 between the other ends of said first and second windings and said secondary winding of ($N \pm 2/A$):1.

2. The arrangement according to claim **1** wherein said transformer circuit is an in-phase hybrid coupler having two pairs of conjugated ports in which:

one end of said secondary winding is a common junction;

the other end of said secondary winding and a center-tap along said primary winding, taken with respect to said common junction, constitute one pair of conjugate ports;

and in which the other ends of said first and second winding, taken with respect to said common junction, constitute a second pair of conjugate ports.

3. The arrangement according to claim **1** including at least one additional vernier transformer having a net first winding-to-second winding turns ratio of 1:B;

wherein said third winding of said three-winding vernier transformer and said first winding of said one additional vernier transformer are connected in series across the secondary winding of said principle transformer;

and including means for connecting the second winding of said additional vernier transformer across said secondary winding.

4. A transformer circuit comprising:

a two-winding principle transformer having a primary-to-secondary winding turns ratio of N:1;

a plurality of (n+1) vernier transformers including one three-winding transformer whose first, second and third windings are in the ratio of 1:1:A, and n two-winding vernier transformers whose first and second windings are in the ratios of 1:B, 1:C . . . 1:Z, respectively;

the first and second windings of said three-winding vernier transformer being connected in series with the opposite ends, respectively, of the primary winding of said principle transformer such that the magnetic fields produced by a common current flowing through said first and second series-connected windings add constructively;

the third winding of said three-winding transformer and the second winding of each of $n-1$ of said n two-winding vernier transformers being connected in series with a first winding of a different two-winding vernier transformer to form a total of n series-connected vernier windings;

each of said n series-connected vernier windings, and the second winding of said n^{th} two-winding vernier transformer being connected across the secondary winding of said principle transformer.

* * * * *