United States Patent

Seidel

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[54] **IMPEDANCE-MATCHING NETWORK**

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[52] **U.S. Cl.** **333/32,** 333/24, 179/173

[51] **Int. Cl.** **H03b 7/38**

[58] **Field of Search** 179/173; 333/32, 24, 26, 33; 178/45; 324/95

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[57] **ABSTRACT**

This application describes an impedance-matching network comprising two transformers having turns ratios, 1:N and 1:M, where N and M are rational numbers. The first of these transformers senses the signal current flowing in the signal wavepath and induces a secondary current that is proportional thereto. The secondary current, thus induced, energizes the second transformer which injects into said wavepath a component of current that is proportional to the signal current by a factor equal to the product of the turns ratios of the two transformers. When at least one of the two transformers is a two-winding transformer, the effective turns ratio of this network is given by 1:1 ± 1/(NM), where the sign (±) is determined by the manner in which the transformers are connected. When two, single-winding transformers, such as autotransformers, are used, the effective turns ratio is given by 1: [(N−1)/N±1/MN].

6 Claims, 6 Drawing Figures

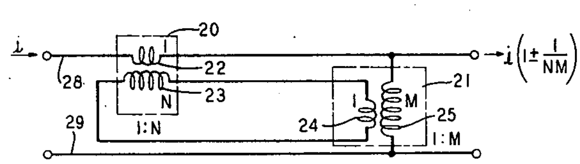

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FIG. 1

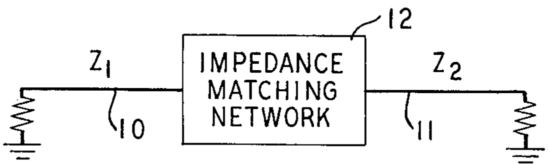


FIG. 2

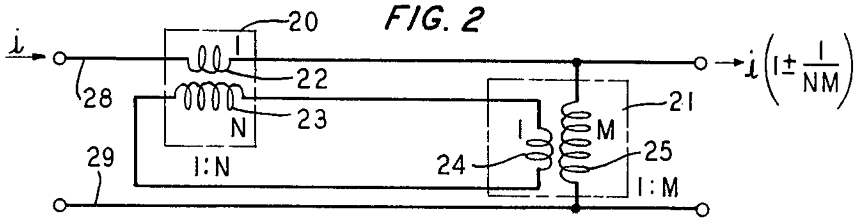


FIG. 3

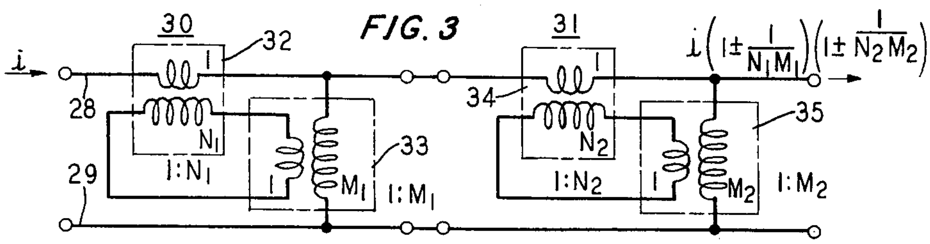


FIG. 4

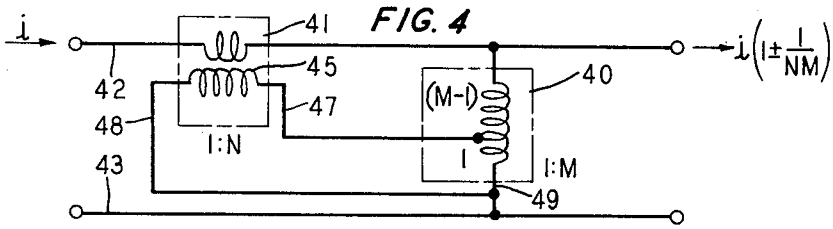


FIG. 5

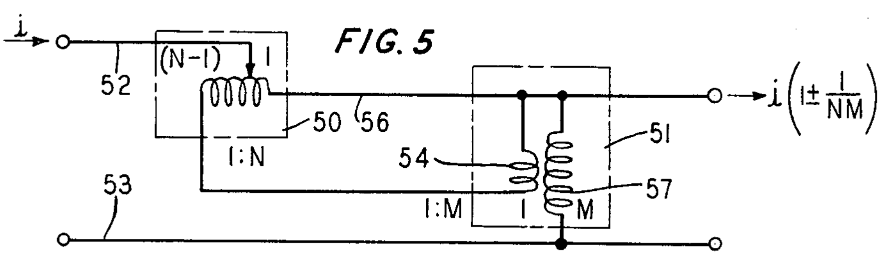
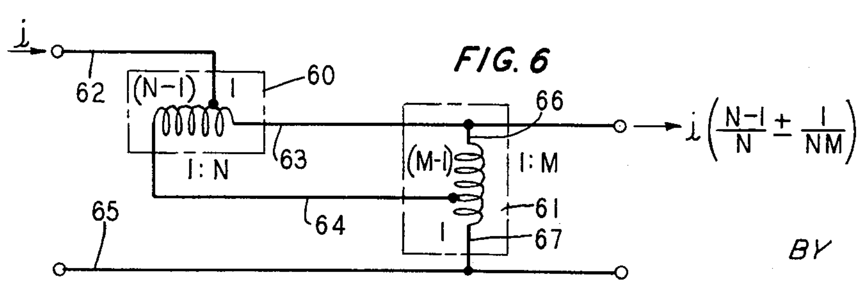


FIG. 6



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IMPEDANCE-MATCHING NETWORK

This invention relates to impedance-matching networks.

BACKGROUND OF THE INVENTION

One of the more common problems encountered in a communication system is how to connect portions of said system having different impedance levels. At the lower frequencies, this is conveniently done with transformers whose turns ratios are such as to provide the required impedance transformation. Using conventional transformers, however, the impedance transformations attainable are a direct function of the square of the transformer turns ratio. At the higher frequencies where the absolute number of turns that can be used is limited by parasitic effects to about five or less, the gradation in impedance levels that can be matched by conventional transformers is, as a result, very coarse. For example, it is virtually impossible to provide an acceptable impedance match between 50 ohms and 75 ohms by means of a single transformer when the number of turns that can be used in the primary and secondary of said transformer are thus limited.

It is, accordingly, the broad object of this invention to extend the range of impedance matches that can be obtained by means of transformers.

SUMMARY OF THE INVENTION

In accordance with the present invention, the range of impedance transformations that can be obtained by means of transformers is greatly extended by using two transformers having turns ratios of 1:N and 1:M. The first of these transformers senses the signal current flowing in the signal wavepath and induces a secondary current that is proportional thereto. The secondary current, thus induced, energizes the second transformer which injects into said wavepath a component of current that is proportional to the signal current by a factor equal to the product of the turns ratios of the two transformers. Designating the transformer turns ratios as 1:N and 1:M, respectively, the effective turns ratio of the two transformers, connected in the manner described, is of the form $1:A \pm 1/(NM)$, where A is a parameter which depends upon the type of transformers used, and the sign ($\pm$) is determined by the manner in which the transformer windings are connected.

In one embodiment of the invention to be described in greater detail hereinbelow, two, two-winding transformers are used. One winding of the first of said transformers is connected in series with the wavepath, while one winding of the second of said transformers is connected in shunt with the wavepath. The other windings of said transformers are connected in series with each other.

In alternate embodiments of the invention, one or the other of said transformers is a single-winding transformer. In all of these configurations $A = 1$, and the effective turns ratio is given by $1:1 \pm 1/MN$.

In an alternate embodiment of the invention, in which both transformers are single-windings transformers, $A = (N-1)/N$, and the effective turns ratio is given by $1: [(N-1)/N \pm 1/MN]$. As a result, it is an advantage of the present invention that very fine changes in the impedance transformation ratio can be realized by making relatively coarse changes in the turns ratios of either or both of said transformers or by cascading pairs of transformers connected in the manner described.

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 transmission system including two portions having unequal impedance levels coupled together by means of an impedance-matching network;

FIG. 2 shows a first embodiment of an impedance-matching network in accordance with the invention, using two, two-winding transformers;

FIG. 3 illustrates a cascade of two impedance-matching networks of the type shown in FIG. 2;

FIGS. 4 and 5 show second and third embodiments of the invention wherein one of the transformers is an autotransformer; and

FIG. 6 shows a fourth embodiment of the invention in which both transformers are autotransformers.

DETAILED DESCRIPTION

Referring to the drawings, FIG. 1 shows, in block diagram, an electrical transmission system comprising a first wavepath **10**, characterized by an impedance level Z_1, coupled by means of an impedance matching network **12**, to a second wavepath **11**, characterized by an impedance level Z_2. In general, the impedance matching network can be any one of the variety of such networks known in the art. In particular, the present invention relates to the use of transformers as impedance matching devices.

As is known, the impedances coupled to the two windings of a transformer are matched when the turns ratio of said windings, 1:N, is related to the impedance ratio, $Z_1:Z_2$, such that

$$(Z_1)/(Z_2) = (1/N)^2 \qquad 1.$$

In a simple iron-core transformer, the impedance transformations that can be realized are, as given by equation (1), simply equal to the square of the transformer turns ratio. When N is small, as it typically is at the higher frequencies, the gradation in impedance levels that can be realized by changing N is very coarse. Impedance-matching networks in accordance with the present invention permit much finer gradation in impedance matches. One such network, shown in FIG. 2, comprises two transformers **20** and **21** having turns ratios 1:N and 1:M, respectively. One winding **22** of transformer **20** is connected in series with the signal wavepath, while one winding **25** of transformer **21** is connected in shunt with the signal wavepath. The second windings **23** and **24** of transformers **20** and **21** are connected in series with each other. While shown floating, the series-connected windings **23** and **24** can be, alternatively, conductively connected to either of the signal wavepath conductors **28** or **29**.

In operation, the signal current i flowing in the signal wavepath flow through primary winding **22**, inducing a secondary current i/N in secondary winding **23**. This current, in turn, energizes primary winding **24** of transformer **21**, inducing a secondary current $i/(NM)$ in secondary winding **25**. Depending upon the manner in which the transformer windings are connected, the current in winding **25** is injected into the signal wavepath in phase or 180° out of phase with the signal current i, to produce a net output current $i \pm i/(NM)$. Since the turns ratio of a transformer is inversely proportional to the ratio of the input current to output current, the network shown in FIG. 2 has an effective turns ratio 1:T given by

$$\frac{1}{T} = \frac{i \pm \frac{i}{NM}}{i} = 1 \pm \frac{1}{NM} \cdot \qquad (2)$$

As an example, let us consider a 50:75 ohm matching transformer which requires a 1:1.225 turns ratio. Choosing $M = 3/2$ and $N = 3$, a transformer in accordance with the invention was built at VHF having a turns ratio of

$$1 + \frac{1}{\left(\frac{3}{2}\right) \cdot (3)} = 1.222.$$

This transformer provides a greater than 30 db return loss over the 0.5 to 20 MHz band for which it was designed.

It will be noted that the above-described transformer configuration has the effect of removing the restriction that only impedance transformation ratios that are proportional to the transformer turns ratio can be realized with iron-core transformers. This softening of the restrictions on the impedance ratios that can be matched by means of such transformers can be extended further by cascading networks, as illustrated in FIG. 3. In this arrangement, the first network **30**, comprising transformers **32** and **33**, produces the equivalent of a 1:1 ± $1/(N_1M)$ turns ratio. The second network **31**, comprising transformers **34** and **35**, produces the equivalent turns ratio 1:1 ± $1/(N_2M_2)$. Together, the cascaded pair produce an equivalent turns ratio given by

$$1:T = 1:\left(1 \pm \frac{1}{N_1M_1}\right)\left(1 \pm \frac{1}{N_2M_2}\right). \qquad (3)$$

More generally, the turns ratio for n cascaded sections is

$$1:T = 1:\prod_{j=1}^{n}\left(1 \pm \frac{1}{N_jM_j}\right). \qquad (4)$$

In the special case where $n = 2$, $N_1M_1 = N_2M_2$, and wherein we select the positive sign for one network and the negative sign for the other network, equation (4) reduces to

$$1:T = 1:1 - (1/NM)^2 . \qquad 5.$$

Since 1/NM can have values close to unity, extremely fine variations in the net effective turns ratio can be obtained by cascading such networks in the manner described.

FIG. **4** shows a second embodiment of the invention wherein one of the transformers is a single-winding transformer, such as an autotransformer. In this particular illustration, the series-connected, signal-sensing transformer **41** is a two-winding transformer and the shunt-connected transformer **40** is the autotransformer. As shown, one end **48** of secondary winding **45** of transformer **41** is connected to the lower end **49** of transformer **40** and to wavepath conductor **43**. The other end **47** of winding **45** is connected to a tap on transformer **40**.

In the embodiment of FIG. **5**, the series-connected, signal-sensing transformer **50** is a single-winding transformer and the shunt-connected transformer **51** is a two-winding transformer. One wavepath conductor **52** connects to a tap on transformer **50**. The latter is, in turn, connected in series with the primary winding **54** of transformer **51**. In addition, one end **56** of transformer **50** constitutes one of the output wavepath conductors to which secondary winding **57** of transformer **51** connects. The other end of winding **57** connects to the other wavepath conductor **53**.

FIG. **6** shows a fourth embodiment of the invention in which both transformers are single-winding transformers. As in FIG. **5**, one wavepath conductor **62** connects to a tap on the series-connected transformer **60**. One end **63** of transformer **60**, constituting one of the output wavepath conductors, connects to one end **66** of shunt-connected transformer **61**. The other end **67** of transformer **61** connects to the other wavepath conductor **65** while the other end **64** of transformer **60** connects to a tap on transformer **61**.

With the transformers connected in the manner indicated, the effective turns ratio 1:T is given by

$$1:T = 1:\left(\frac{N-1}{N} \pm \frac{1}{MN}\right). \qquad (6)$$

It will be noted that when two, single-winding transformers are used, the first term of the turns ratio is modified slightly from that given by equation (2).

It is apparent that depending upon the turns ratios and the nature of the transformers, many different specific embodiments of the invention can be devised. Thus, in all cases it is understood that the above-described arrangements are illustrative of only 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. In an electromagnetic wavepath, an impedance-matching network for coupling between two unequal impedances comprising:

a first transformer having a turns ratio 1:N and a second transformer having a turns ratio 1:M;

characterized in that:

said first transformer senses the current in said wavepath and, in response thereto, couples a first current into a winding of said second transformer, inducing a second current;

and in that said second current is injected into said wavepath, producing a net effective turns ratio 1:T for said network given by

$$1:T = 1(A \pm 1/(NM),$$

where A is a parameter which depends upon the type of transformers used,

and the sign (±) is determined by the manner in which said transformers are connected.

2. The network according to claim **1** wherein both transformers are two-winding transformers;

and wherein A = 1.

3. The network according to claim **2** wherein one winding of one transformer is connected in series with said wavepath;

one winding of the other of said transformers is in shunt with said wavepath;

and wherein the other windings of said transformers are connected in series with each other.

4. The combination according to claim **1** wherein one of said transformers is a two-winding transformer;

the other of said transformers is a single-winding transformer;

and wherein A = 1.

5. The network according to claim **1** wherein both transformers are single-winding transformers;

and wherein A = (N-1) /N.

6. In an electromagnetic wavepath, an impedance-matching network for coupling between two, unequal impedances comprising:

a plurality of n pairs of transformers having turns ratios $1:N_j$ and $1:M_j$, respectively, where N_j and M_j are rational numbers;

characterized in that:

each of said pairs of transformers is connected in accordance with claim **1** and cascaded along said wavepath to produce a net effective turns ratio 1:T given by

$$1:T = 1:\prod_{j=1}^{n}\left(A_j \pm \frac{1}{N_jM_j}\right).$$

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