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TEE-NETWORK HAVING SINGLE CENTER-TAPPED HIGH-Q INDUCTOR IN ITS SERIES BRANCHES AND A LOW-Q INDUCTOR IN SHUNT

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FIG. 1

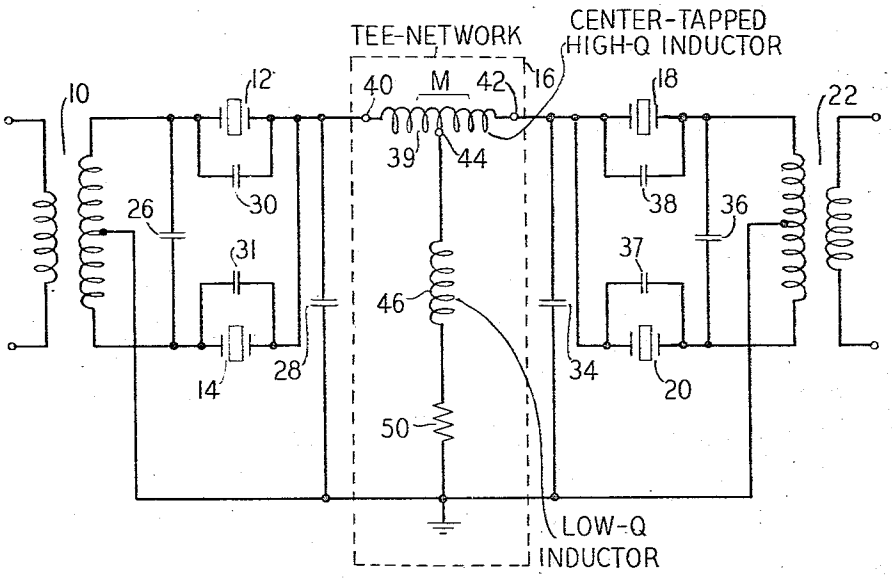
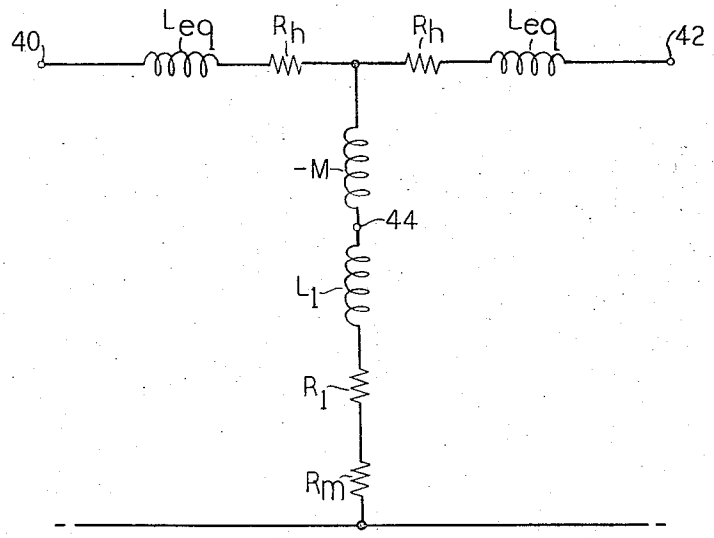


FIG. 2



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TEE-NETWORK HAVING SINGLE CENTER-TAPPED HIGH-Q INDUCTOR IN ITS SERIES BRANCHES AND A LOW-Q INDUCTOR IN SHUNT

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This invention relates to electrical transmission networks and more particularly to a tee-network useful in the construction of electrical filters employing piezoelectric crystals, as well as in other transmission applications.

Piezoelectric crystals are used extensively as components in electrical filters because they possess high frequency selectivity, they are relatively insensitive to ambient temperature changes, and they remain stable for long periods of time. For example, a lattice network in which the arms are composed of crystals is a common form of bandpass filter that exhibits low signal loss within its passband and high signal attenuation outside of its passband. In some applications, notably telephone transmission by carrier, the passband of a bandpass filter constructed solely of crystals is found to be too narrow to transmit a usable signal. To remedy this situation, it is a common practice to employ inductors in combination with the crystals to increase the passband of the filter. According to one technique, inductors are placed in series with at least one of the input terminals and at least one of the output terminals of a crystal configuration. When two or more of the resulting filters are cascaded, as is commonly done, two inductors are consequently connected together at the junction of the filter sections. In addition, a resistor is connected in shunt at the junction for impedance matching and amplitude equalization purposes. There results a tee-network comprising two inductors forming branches, hereafter called the series branches, connected in series between the crystals of successive filter sections and one resistor forming a branch, hereafter called the shunt branch, shunting filter sections.

A tee-network having inductors as series branches and a resistor as a shunt branch is of course utilized in many other applications to couple a source of electrical signals to a load. In these applications, as well as the case of the tee-network found in cascaded filter sections, high-Q inductors, i.e., inductors having a high ratio of inductive reactance-to-resistance, are usually specified as components for the series branches of the tee-network in order to minimize dissipation of power and transmission distortion. High-Q inductors are however bulky and expensive, and thus they contribute the size and cost of the coupling network.

It is therefore the object of this invention to reduce the cost and size of tee-networks having inductive series branches and a resistive shunt branch.

This object is realized by employing a single high-Q inductor having an intermediate tap dividing it into two portions which constitute the two series branches of the tee-network. Connected to the intermediate tap is one end of the shunt branch of the tee-network. As a result of this arrangement, a mutual inductance, part of which has an effect such that it can be considered to appear in series with the shunt branch, arises between the portions of the high-Q, series inductor .The invention calls for the shunt branch of the tee-network to include another inductor, the inductance of which is equal to the part of the mutual inductance that appears in series with the shunt branch. Consequently, the inductance of the shunt

inductor completely nullifies the effect of this part of the mutual inductance. The shunt inductor is permitted to have a lower Q than the series inductor because its internal resistance is utilizable as part or all of the resistance required in the shunt branch. Thus, two high-Q inductors in a tee-network are replaced, according to the invention, by one high-Q inductor having an intermediate tap and one low-Q inductor. A reduction in the cost and size of the tee-network ensues.

These and other features of the invention will become more apparent from consideration of the following detailed description taken in conjunction with the drawing in which:

FIG. 1 is a schematic circuit diagram of a tee-network arranged according to the invention and shown interconnecting the crystal portions of two filter sections; and

FIG. 2 is a schematic circuit diagram representing an equivalent circuit of the tee-network shown in FIG. 1.

In FIG. 1 an input transformer **10** having a center-tapped secondary winding is shown. The end terminals of the secondary of transformer **10** are connected to piezoelectric crystals **12** and **14**, respectively, and the center tap is connected to ground. Crystals **12** and **14** are interconnected by a tee-network **16**, embodying the principles of the invention and described in detail below, to piezoelectric crystals **18** and **20**, which are in turn connected to an output transformer **22** having a center-tapped primary whose center tap is also connected to ground. Two crystal filter sections are thus formed, each of which is the functional equivalent of a lattice crystal filter.

A capacitor **26** shunts the end terminals of the secondary of input transformer **10**, while a capacitor **28** is connected between the center tap of the secondary of input transformer **10** and the junction of crystals **12** and **14**. Similarly, a capacitor **36** shunts the end terminals of the primary of output transformer **22**, while a capacitor **34** is connected between the center tap of the primary of output transformer **22** and the junction of crystals **18** and **20**. Connected in parallel with crystals **12**, **14**, **18**, and **20** are respectively capacitors **30**, **31**, **37**, and **38**. As part of tee-network **16**, a center-tapped, high-Q inductor **39** is connected between the junction of crystals **12** and **14** and the junction of crystals **18** and **20**.

It is well known that use of inductors and capacitors in conjunction with crystals makes possible construction of filters that have impedance and attenuation-versus-frequency characteristics that differ greatly from a filter constructed solely of crystals. The values required of the capacitors and inductors, as well as those required in the equivalent circuit of the crystal units are determined by the impedance and attenuation characteristics of the filter.

It is generally desirable in network design that the Q of the inductive elements in the series branches of a tee-network be high so that the tee-network introduces little attenuation and distortion over the transmission band. According to the invention, the portions of high-Q inductor **39** between terminals **40** and **44** and between terminals **42** and **44** are used to form the two series branches of a tee-network. The shunt branch of the tee-network, including a low-Q inductor **46**, is connected between center-tap terminal **44** and ground by way of a resistor **50**.

Use of a single center-tapped inductor such as **39** instead of two inductors to form the series branches of a tee-network is accompanied by a mutual inductance. The effect of one part of the mutual inductance is such that it can be considered to appear in series with the series branches, i.e., it increases the effective inductance of the series arms, and the effect of the other part of the mutual inductance is such that it can be considered to appear in series with the shunt branch as a negative inductance.

The inductance of low-Q inductor 46 is selected to be equal to the part of the mutual inductance appearing in series with the shunt branch and, as a result, eliminates its effect.

An equivalent circuit of tee-network 16 which represents the effect of the mutual inductance is illustrated in FIG. 2. R_h represents the resistance of each portion of high-Q inductor 39, L_{eq} represents the equivalent or effective inductance of each series branch including part of the mutual inductance, M represents the part of the mutual inductance appearing in series with the shunt branch L_l represents the self-inductance of inductor 46, and R_l represents the internal resistance of inductor 46. In the equivalent circuit of FIG. 2, $L_{eq}=(l+k)L_h$ and $L_l=-M=-kL_h$, where L_h is the actual self-inductance of each portion of inductor 39 and k is the coupling coefficient between the two portions of inductor 39. In a typical embodiment k might be of the order of .9.

The value of the total resistance in the shunt branch of the tee-network is selected to effect an impedance match between the filter sections. Consequently, the resistance R_h associated with the portions of inductor 39 and the total resistance in the shunt branch of the tee-network form an all-pass, constant loss attenuator between filter sections.

As a rule, the resistance required in the shunt branch to bring about impedance match is substantial. Thus, the Q of inductor 46 is permitted to be low and its resistance can be utilized as part or all of the matching resistance required in the shunt branch. The remainder of the resistance in the shunt branch, if any is required, can be provided by resistor 50, having a resistance represented by R_m in FIG. 2. For example, it can be determined mathematically that if the Q of inductor 39 is 200, the bandwidth of the filter is 4 kilocycles, and the center frequency of the filter is 160 kilocycles, then inductor 46 is required to have a Q of approximately 8. In this case the arrangement of the invention permits use of one inductor with a Q of 200 and one inductor with a Q of 8, whereas the technique used heretofore employs two inductors with a Q of 200. Although high-Q inductor 39 has twice the inductance of one of the high-Q inductors used in the old technique, it is not significantly larger or more expensive than one of them.

The invention, although particularly useful in constructing crystal filters comprising two or more sections, is not limited to this application. In general, the invention is applicable to any circuit configuration that includes as part of it a tee-network requiring inductance in each of its series branches and resistance in its shunt branch. A bridged-tee network, a twin-tee network, an H-network, two tandemly connected pi-networks, or two tandemly connected lattice networks, among many others, are all circuit configurations including in part a tee-network in the construction of which the invention may be practiced.

What is claimed is:

1. A tee-network comprising a first inductor having two end terminals and an intermediate terminal and a second inductor having one terminal connected to said intermediate terminal of said first inductor, the portion of said first inductor between one of said end terminals and said intermediate terminal constituting one series branch of said tee-network, the section of said first inductor between the other of said end terminals and said intermediate terminal constituting the other series branch of said tee-network, and said second inductor constituting at least part of the shunt branch of said tee-network, said second inductor having a self-inductance equal to the mutual inductance between the portions of said first inductor appearing in series with said shunt branch.

2. In combination, a source having first and second output terminals, a load having first and second input terminals, and a tee-network interconnecting said source with said load comprising a first inductor having two end terminals and an intermediate terminal, one end terminal of said first inductor being connected to the first output terminal of said source and the other end terminal of said first inductor being connected to said first input terminal of said load, a circuit node, and a second inductor connected in series between the intermediate terminal of said first inductor and said circuit node, means connecting said circuit node to the second output terminal of said source and the second input terminal of said load, the self inductance of said second inductor being equal to the mutual inductance between the portions of said first inductor separated by said intermediate terminal appearing in series with said second inductor.

3. In combination, a first electric circuit having first and second output terminals, a second electric circuit having first and second input terminals, and a tee-network interconnecting said first circuit with said second circuit comprising a high-Q inductor having two end terminals and an intermediate terminal, one end terminal of said high-Q inductor being connected to the first output terminal of said first circuit and the other end terminal of said high-Q inductor being connected to said first input terminal of said second circuit, and a low-Q inductor having one terminal connected to the intermediate terminal of said high-Q inductor and having the other terminal connected to both the second output terminal of said first circuit and the second input terminal of said second circuit, the self inductance of said low-Q inductor being equal to the mutual inductance between the portions of said high-Q inductor separated by said intermediate terminal appearing in series with said low-Q inductor.

4. An electrical filter comprising an input transformer having a secondary winding with a center tap, a first circuit node, a piezoelectric crystal connected between each of the end terminals of the secondary winding of said input transformer and said first node, a second circuit node, an output transformer having a primary winding with a center tap connected to the center tap of the secondary winding of said input transformer, piezoelectric crystals connected between each of the end terminals of the primary winding of said output transformer and said second node, and a tee-network comprising a high-Q center-tapped inductor connected between said first node and said second node and a low-Q inductor connected between the center tap of said high-Q inductor and the center tap of the secondary winding of said input transformer, said second inductor and each half of said first inductor having resistance that forms a resistive tee-network connecting sections of said filter, the self inductance of said low-Q inductor being equal in magnitude to the mutual inductance between the two halves of said high-Q inductor appearing in series with said low-Q inductor, and the total resistance in the branch of said coupling network between said center tap of said high-Q inductor and said center taps of said transformers being of such value to cause a substantial impedance match between the sections of said filter connected by said resistive tee-network.

5. The combination of claim 2 in which the resistance of said second inductor is of such value that it and the resistance of said first inductor form an all-pass constant loss attenuator causing an effective impedance match between the parts of said combination that it connects.

No references cited.

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