Dec. 29, 1970 H. SEIDEL 3,551,855

IMPEDANCE TRANSFORMER

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FIG. 1

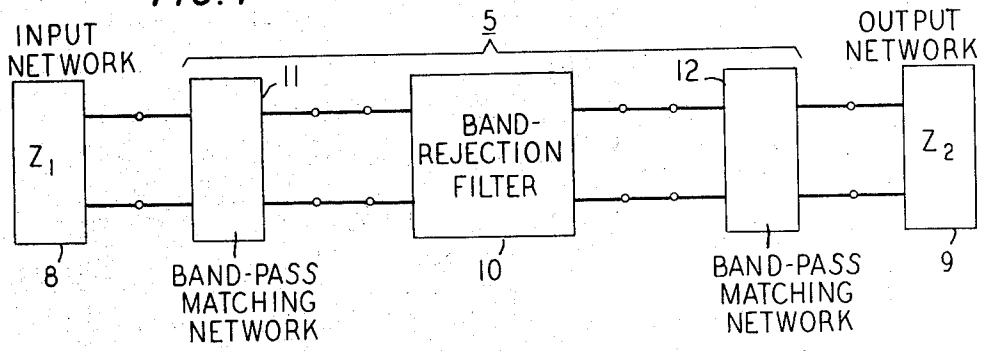


FIG. 2

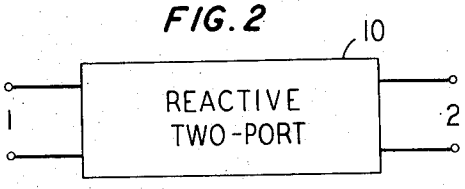


FIG. 3

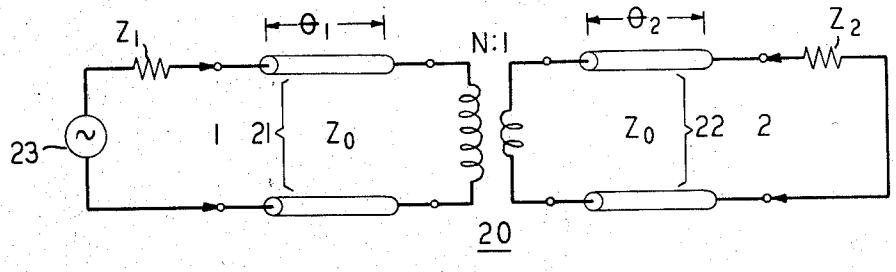
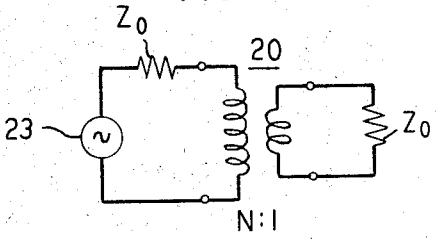


FIG. 4



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FIG. 5

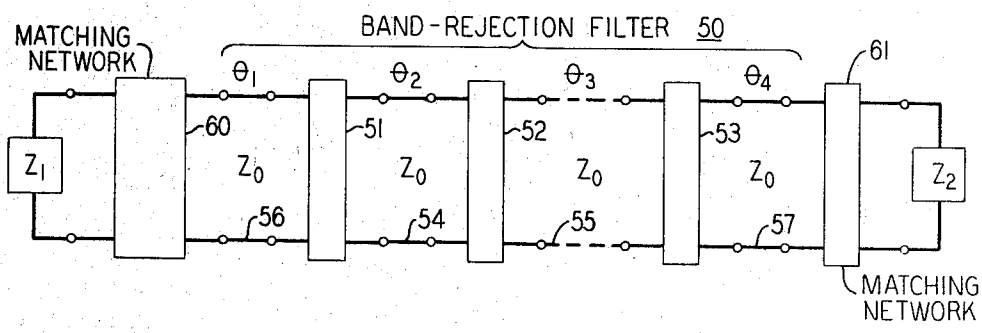


FIG. 6

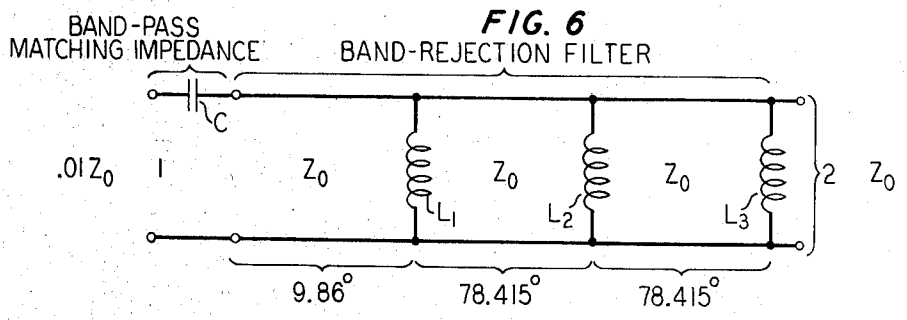


FIG. 7

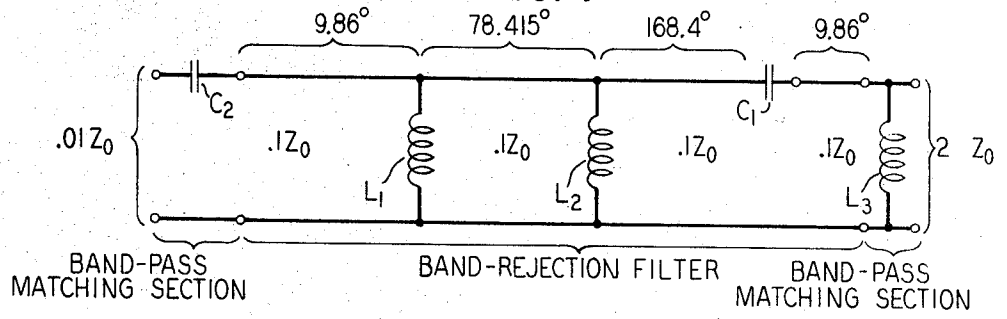
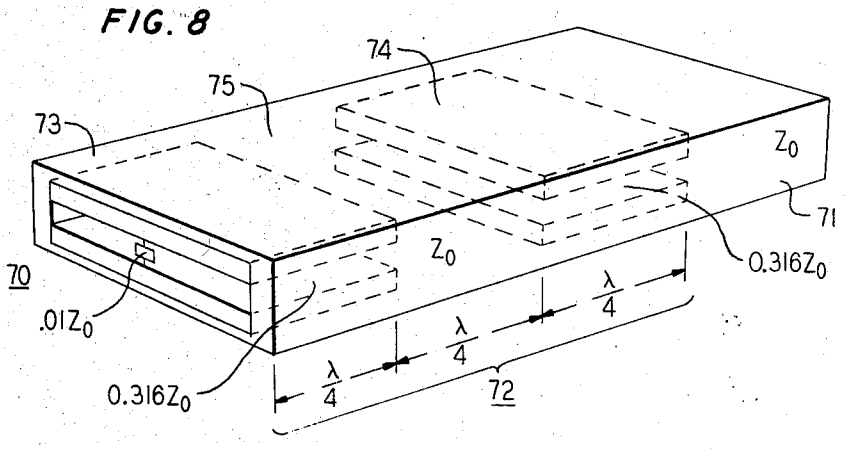


FIG. 8



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3,551,855

IMPEDANCE TRANSFORMER

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Int. Cl. H03h 7/38
U.S. Cl. 333—33 8 Claims

ABSTRACT OF THE DISCLOSURE

By applying the Weissfloch theorem, which states that any reactive two-port can be represented by an ideal transformer and lengths of transmission line, it is shown that a band-rejection filter can be employed as an impedance transformer. This makes it possible to achieve large impedance transformation ratios (i.e., 10^4) not heretofore realizable by conventional methods.

This invention relates to the use of band-rejection filters as impedance transformers.

BACKGROUND OF THE INVENTION

At the higher frequencies, high power transistors are made by paralleling a plurality of transistor chips within a single header. The difficulty with such an arrangement becomes painfully apparent when one attempts to couple energy from a network having an impedance of the order of 50 to 100 ohms into what proves to be an incredibly small impedance. Typically, such high power devices have input impedances of the order of milliohms, thus requiring impedance transformations of the order of 10^4.

The attempt to extend conventional techniques as a means of producing such large impedance transformations has proven to be impractical. A transmission line transformer made up of quarter-wave line sections must involve itself with sections of line having characteristic impedances of the order of fractions of an ohm and, ultimately, with a section of line having a characteristic impedance of the order of that of the termination. As is well known, transmission lines having such low characteristic impedances are exceedingly lossy. The same sort of difficulty is inherent in lumped element transformers.

SUMMARY OF THE INVENTION

The present invention is based upon the recognition that a band-rejection filter, comprising a plurality of two or more reactive discontinuities separated by lengths of transmission line of constant characteristic impedance, can be employed as an impedance transformer for coupling wave energy between exceedingly different impedance levels. Such a transformer is to be distinguished from the tapered, quarter-wave transformer mentioned hereinabove, wherein the characteristic impedance of successive quarter-wave sections changes monotonically.

The ability of a band-rejection filter to operate as an impedance transformer arises by virtue of the fact that, in general, any reactive two-port can be represented by an ideal transformer disposed between two lengths of transmission line. In particular, a band-rejection filter can be represented by an ideal transformer having a turns ratio N:1 that is a function of the insertion loss of the filter. Thus, in accordance with the present invention, the desired impedance transformation is realized by means of a band-rejection filter having the same insertion loss, over the frequency band of interest, as a similarly-terminated ideal transformer. The impedances introduced by the equivalent length of transmission line are incorporated into band-pass matching networks at either or both ends of the filter, effectively translating the reference planes of the terminations from the actual filter ports to the ports of the equivalent transformer.

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 an impedance transformation network in accordance with the invention;

FIG. 2, included for purposes of explanation, shows, in block diagram, a reactive two-port;

FIG. 3, included for purposes of explanation, shows the equivalent circuit of a reactive two-port;

FIG. 4, included for purposes of explanation, shows the equivalent circuit of FIG. 3 when match-terminated at both ports;

FIG. 5 shows the general configuration of an impedance transformer in accordance with the present invention; and

FIGS. 6, 7 and 8 show various specific illustrative embodiments of an impedance transformer in accordance with the invention.

DETAILED DESCRIPTION

Referring to the drawings, FIG. 1 shows an impedance transformation network **5** for coupling an input network **8**, at an impedance level Z_1, to an output network **9**, at an impedance level Z_2 that is very different than Z_1. More specifically, the impedance transformations contemplated by the invention are of the order of 10^2 and greater.

In accordance with the present invention, network **5** comprises a band-rejection filter **10** and a pair of band-pass matching networks **11** and **12**. As will be explained in greater detail hereinbelow, one or the other or both of the matching networks can be omitted. Two are shown in the interest of generality.

The operation of a band-rejection filter as an impedance matching network is based upon the theorem set forth by Albert Weissfloch in his paper entitled, "Transformation Theorem for Loss-Free Quadripoles; Application to Experimental Investigation of Decimetric and Centimetric Wave Circuits," published in the 1942 issue of Hochf. U Elekakus., 60, pp. 67–73, which states that any arbitrary, reactive two-port, shown in block diagram in FIG. 2, can be represented by an ideal transformer coupled to the two ports through lengths of transmission line. This equivalent circuit representation is shown in FIG. 3, wherein an ideal transformer **20**, having an N:1 turns ratio, is coupled to ports **1** and **2**, respectively, through the two lengths of transmission lines **21** and **22**. The characteristic impedance Z_0 of the transmission line segments is arbitrarily chosen and the Weissfloch equivalent circuit is a function of that choice. That is, the line lengths and the turns ratio of the transformer are defined by the characteristics of the two-port and the stipulated reference impedance level Z_0. As will be explained more fully hereinbelow, the reference impedance Z_0 is a useful parameter in the design of a filter for a particular impedance transformation.

In the special case where the network is match-terminated at both ports, respectively, by means of a load impedance $Z_2=Z_0$ connected at port **2**, and a signal source **23** having a source impedance $Z_1=Z_0$ at port **1**, the line lengths **21** and **22** can be ignored, and the equivalent circuit of FIG. 3 can be further simplified as in FIG. 4. In this simplified circuit, the source and load are effectively connected directly to the terminals of transformer **20**, with no intervening impedances.

If network **10** is a band-pass filter, and is match-terminated at both ends, in the manner described, all of the available energy derived from source **23** is coupled through the filter network to load Z_2. In terms of the equivalent circuit of FIG. 4, this would occur for $N=\pm 1$. That is, for a band-pass network, tranformer **20** in the equivalent circuit of FIG. 4 has a 1:1 turns ratio. If, on the other hand, network **10** is a band-rejection filter, a significant amount of the incident energy is reflected by the nework. Indeed, the network can be fully characterized by its coefficient of reflection k, or by its insertion loss L. In terms of the equivalent circuit of FIG. 4, the same insertion loss is produced by a similarly-terminated transformer having a turns ratio N given by

$$L=1+\frac{1}{4}\left(N-\frac{1}{N}\right)^2 \qquad (1)$$

If, on the other hand, instead of terminating port **2** of the band-rejection filter with a matched load, it is terminated with a load $Z_2<Z_0$, the mismatch produced by transformer **20** could be eliminated. In particular, by selecting Z_2 such that

$$N=\sqrt{\frac{Z_0}{Z_2}} \qquad (2)$$

the impedance mismatch is converted to an impedance match between the load and source. That is, a match would be produced if the load impedance could be effectively connected directly to the secondary terminals of equivalent transformer **20**. However, the complete equivalent circuit, shown in FIG. 3, includes the length of transmission line **22** which could only be ignored in the special case where $Z_2=Z_0$. This can no longer be done in the more general case where $Z_2 \neq Z_0$ since the equivalent impedance of the line can become a significant spurious reactance located between the transformer and the load impedance.

In order to elminate the effect of the length of transmission line **22**, it is noted that the coefficient of reflection at the terminals of a tranformer is real. That is, the coefficient of reflection is $k/0$. The coefficent of reflection at port **2**, on the other hand, is not real, but is, instead, given by $k/2\ \theta_2$ showing the presence of the length of line **22**. To eliminate the effect of the latter, a band-pass matching network, which incorporates the line length as one of its elements, is interposed between the filter and the load, as illustrated in FIG. 1. This network, by producing a real coefficient of reflection at the output port of the filter, in effect, translates the load from the actual filter terminals to the transformer terminals. It is as if the two ports of the ideal transformer in the band-rejection filter equivalent circuit were made directly available for connections. Since this transformer has been shown to have a turns ration N equal to

$$\sqrt{\frac{Z_0}{Z_2}}$$

the filter it represents simulates, over its band-rejection region, an impedance transformer of the same turns ratio.

In the more general case, both the input and the output networks can have impedances that are significantly different than the filter impedance. In this more general case, matching networks would be required at both the input and the output ends of the filter. Preferably, the reference impedance Z_0 of the filter is selected to be equal to one of these two impedances, thus eliminating the need for at least one of the matching networks and, thereby simplifying the circuit. Advantageously, the filter is so designed that the equivalent lengths of the two transmission lines **21** and **22** are sufficiently small that both can be neglected, thereby eliminating the need for a band-pass matching network at both ends of the filter.

In its most general form, a filter transformer in accordance with the present invention has a configuration

as shown in FIG. 5. Specifically, the band-rejection filter portion **50** comprises a plurality of reactances **51**, **52** and **53**, which can be either shunt or series elements, connected together by sections of transmission lines **54** and **55** of lengths θ_1 and θ_2, respectively. The characteristic impedance Z_0 of line sections **54** and **55** is a parameter of the filter and will vary with the specific application. As will be shown in the following examples, Z_0 can be equal to one or the other of the circuit impedances Z_1 or Z_2, or can be some value between Z_1 and Z_2.

The matching networks **60** and **61** are included, as required, to compensate for line sections **56** and **57** which can be part of the band-rejection filter. As will be shown, the band-rejection filter can be designed such that one or the other or both of the matching networks can be omitted.

EXAMPLES

Techniques and procedures for designing filters are well known in the art. Using the techniques developed in my paper entitled "Synthesis of a Class of Microwave Filters," (published in the April 1957 issue of the IRE Transactions on Microwave Theory and Techniques) for parameter χ in the region of 90 degrees, the 100:1 impedance transformer shown in FIG. 6 was designed. The filter, designed to couple between impedances $Z_1=Z_0$ and $Z_2=0.01Z_0$, comprises three shunt inductors L_1, L_2 and L_3, whose susceptances B, at the operating frequency, are given by

$$Z_0B_1=Z_0B_3=-5.56$$

and

$$Z_0B_2=-33.1$$

The inductors are spaced apart 78.415° by lengths of transmission line whose characteristic impedance Z_0 was selected to be equal to the higher of the two load impedances. As such, no band-pass matching network is required at the high impedance end of the filter. At the low impedance end, however, there is 9.86° of transmission line of characteristic impedance Z_0 between the filter and the low impedance port **1**. To compensate for this, a series capacitor C having a reactance $x/.01Z_0$ equal to 8.7 is added at the low impedance side of the filter to resonate the equivalent inductance of this length of line.

The use of a single capacitor to compensate the filter tends to narrow the transformer bandwidth to about 11 percent. If a broader bandwidth is desired, a multielement band-pass matching filter can be used.

FIG. 7 shows a second example of a filter transformer wherein the reactive discontinuities are connected by lengths of transmission line whose characteristics impedance has a value that is intermediate the impedances to be matched. In particular, a value of $0.1Z_0$, equal to the geometric mean between $.01Z_0$ and Z_0, has been selected. In this example the band-rejection filter comprises a 9.86° section of line; a shunt inductor L_1; a 78.415° length of line; a second shunt inductor L_2; a 168.4° length of line; a series capacitor C_1; and a final 9.86° length of line. The susceptance B and reactance X of the shunt inductors and series capacitor are

$$0.1Z_0B_1=-5.56$$

$$0.1Z_0B_2=-33.1$$

and

$$X_1/0.1Z_0=-5.56$$

Matching at the low impedance port **1** is achieved by means of a series capacitor C_2 having a reactance

$$X_2/0.01Z_0$$

equal to −0.87. At the high impedance end, matching is produced by a shunt inductor L_3 having a susceptance Z_0B_3 equal to 0.87.

This latter filter transformer, while it is somewhat more complicated than the embodiment of FIG. 5, has the advantage that the Q (0.87) of the matching sections is one-tenth the Q (8.7) of the matching section in the embodiment of FIG. 6 and, hence, the transformer is broader band.

In general, the implementation of a particular filter will depend upon the operating frequency. At the lower frequencies, lumped elements can be used, giving rise to filters of the type illustrated in FIGS. 6 and 7. At the higher frequencies, waveguide filters of the type illustrated in FIG. 8 can be employed. In this embodiment, a load **70** having an impedance $0.01Z_0$ is coupled to a waveguide **71** of characteristic impedance Z_0, by means of a filter **72** comprising two, reduced height, quarter-wave sections of lines **73** and **74** of characteristic impedance $0.316Z_0$, coupled together by a quarter-wave section of line **75** of characteristic impedance Z_0. It is a feature of this embodiment of the invention that no band-pass matching sections or required at either end of the filter transformer.

It should be noted that the three examples of filter transformer described above are merely illustrative of only a small number of the many possible specific embodiments which can represent applications of the principles of the invention. In general, there are as many possible embodiments of the invention as there are band-rejection filter designs having the prescribed injection loss over the frequency range of interest.

It should also be noted that while the invention has been described with reference to electromagnetic wave systems the principles of the invention are equally applicable to acoustic wave systems. Thus, 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. In combination:

a first circuit having an impedance Z_1;

a second circuit having an impedance Z_2 smaller than Z_1;

and an impedance transformer for coupling said circuits comprising:

a reactive two-port network comprising a plurality of reactive discontinuities connected by lengths of transmission line of constant characteristic impedance Z_0, and having an insertion loss over the frequency range of interest equal to

$$1+\tfrac{1}{4}(\sqrt{Z_1/Z_2}-\sqrt{Z_2/Z_1})^2$$

when terminated at both ends by an impedance Z_0.

2. The transformer according to claim **1** wherein $Z_0=Z_1$;

and including a band-pass matching network at the low impedance end of said network for producing a real coefficient of reflection at said low impedance end.

3. The transformer according to claim **1** wherein $Z_0=Z_2$;

and including a band-pass matching network at the high impedance end of said network for producing a real coefficient of reflection at said high impedance end.

4. The transformer according to claim **1** wherein $Z_2<Z_0<Z_1$;

and including a band-pass matching network at both ends of said network for producing a real coefficient of reflection at said both ends.

5. The transformer according to claim **4** wherein $Z_0=\sqrt{Z_1Z_2}$.

6. The transformer according to claim **1** wherein said reactive discontinuities comprise quarter-wave sections of transmission line having characteristic impedances intermediate Z_1 and Z_2;

and wherein the length of transmission line connecting adjacent discontinuities is a quarter-wave section of line of characteristic impedance Z_1.

7. The transformer according to claim **1** wherein said reactive discontinuities comprise quarter-wave sections of transmission line having characteristic impedances intermediate Z_1 and Z_2;

and wherein the length of transmission line connecting adjacent discontinuities is a quarter-wave section of line of characteristic impedance Z_2.

8. The transformer according to claim **1** wherein said reactive discontinuities comprise quarter-wave sections of transmission line having characteristic impedances intermediate Z_1 and Z_2;

and wherein the length of transmission line connecting adjacent discontinuities is a quarter-wave section of line whose characteristic impedance is intermediate Z_1 and Z_2.

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U.S. Cl. X.R.

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