Phase Shift as a Design Parameter in Impedance Matching Networks

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Engineers designing RF and microwave circuits do not often use phase shift as a parameter in the design of impedance matching networks. But in systems of combined amplifiers or antennas, the phase relationships among the various system components can be critical. When the application requires control of phase, impedance matching circuits can easily be designed for a specific phase shift in addition to impedance transformation.

In microwave engineering, we might use either lumped elements or transmission lines for matching. For this discussion, we will use L-C networks as examples. Since, as Terman [1] notes, a lumped element network is actually an artificial transmission line, this description is valid for all types of networks. Figure 1 clearly illustrates this analogy.

You may be familiar with the use of Q as a matching network design parameter. Phase shift is simply an alternate choice among initial parameters. Q and phase shift are related. In most practical networks, 90-degree phase shift corresponds to the lowest Q network that will accomplish the desired transformation. As the phase shift deviates from this 90 degree value, the Q of the network will be correspondingly higher.

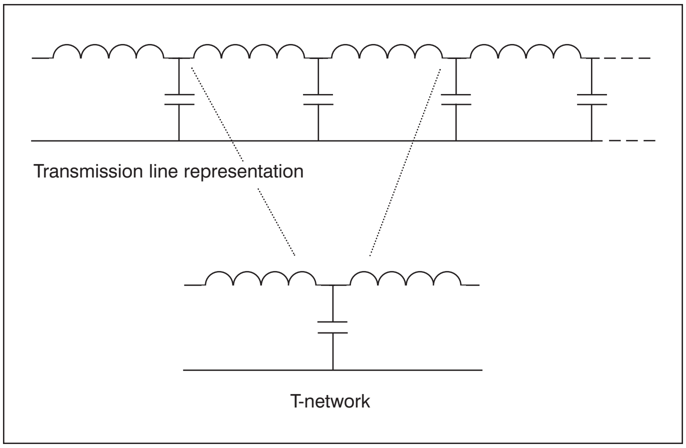
T-network design

This section uses data provided by Edison in the *NAB Engineering Handbook* [2]. The basic T-network configuration is shown in Figure 2. The three arms of the network are simply shown as reactances, which may be either inductive or capacitive, depending on the impedance transformation and the phase shift. The reactances are calculated using the following equations.

$$X_3 = \frac{\sqrt{R_1 R_2}}{\sin\beta}$$

$$X_2 = \frac{R_2}{\tan\beta} - X_3$$

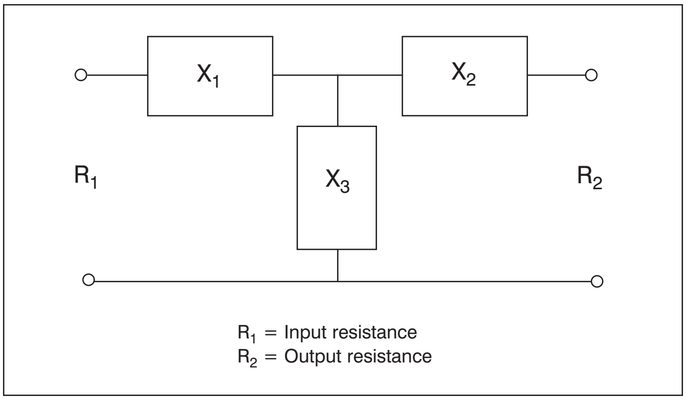
$$X_1 = \frac{R_1}{\tan\beta} - X_3$$



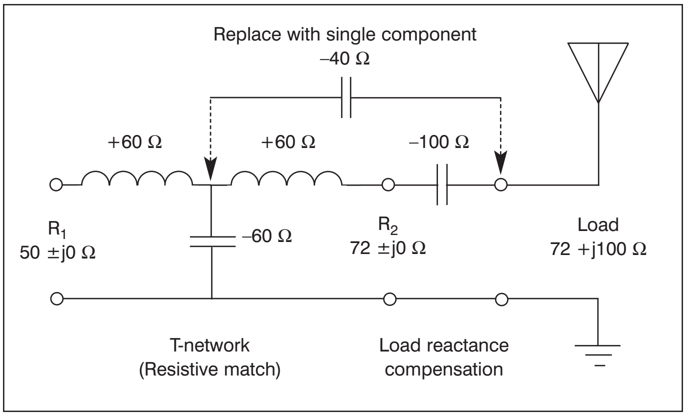
▲ **Figure 1. Matching networks can be described as artificial transmission lines. This is clearly illustrated using the familiar series-L, shunt-C equivalent circuit representation of a transmission line.**

It should be noted that Terman [1] provides these equations in a different form and includes the Pi-network design equations as well.

Although these equations are for purely resistive sources and loads, reactive impedances can also be accommodated. All that is required is placing an additional reactive component in the arm of the T-network that is in series with the associated load or source. This component has a reactance that is equal, but opposite in sign, to the reactance of the source or load. The compensating reactance and the network component reac-



▲ **Figure 2. The basic T-network configuration.**



▲ **Figure 3. Including load reactance into a network calculated using the resistive-only design equations.**

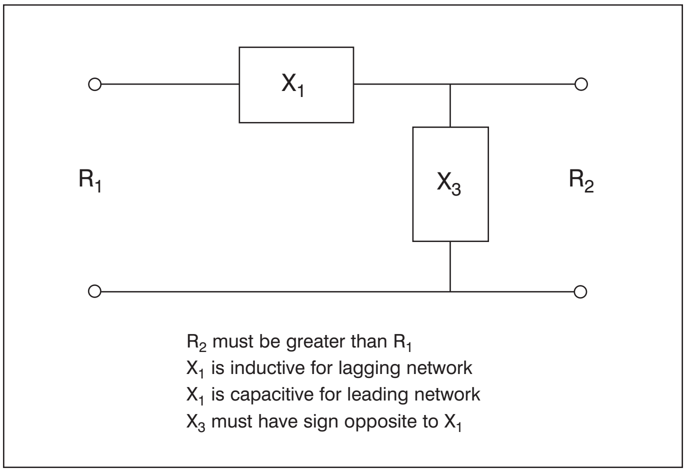
tance are then summed and replaced by a single component. Figure 3 illustrates this method in a typical antenna matching network.

This example will match a 50 ohm source to an antenna with an impedance of 72 +j100 ohms at its operating frequency. For this simple matching problem, we will select a phase shift of –90 degrees for lowest Q and maximum VSWR bandwidth. For the 50 ohm to 72 ohm resistive match, X_3 is computed as –60 ohms. X_1 and X_2 are both equal to $-X_3$, since the terms with tanβ in the denominator go to zero at $\beta = -90$ degrees. Thus, they are inductors with values of +60 ohms each.

On the load side of the network, we want to cancel the antenna's reactance using a series reactance of –100 ohms. The sum of the +60 ohm T-network output arm and the –100 ohm compensating reactance is –40 ohms, which means that the load arm of the network becomes a single capacitor.

L-network design

For simplicity, an L-network is sometimes chosen to reduce the component count. Although phase shift cannot be specified for an L-network, it can be calculated.



▲ **Figure 4. L-network configuration.**

The component values and the resulting phase shift are determined by the following equations. The basic circuit diagram is shown in Figure 4.

$$X_1 = \pm\sqrt{R_1 R_2 - R_1^2}$$

$$X_3 = \mp\frac{R_1 R_2}{X_1}$$

$$\beta = \cos^{-1}\sqrt{\frac{R_1}{R_2}}$$

Like the basic T-network design equations, those for the L-network assume purely resistive impedances. To accommodate complex reactances, there are two choices. The first is to add a component that is the negative of the reactance seen by the network (like the earlier description for T-network matching). The second choice is called the "phantom-T," where the T-network design equations are solved to cancel the reactance of the load with output leg of the network.

Let us use the earlier example of Figure 3. Instead of a T-network before the compensating reactance, we will use an L-network for the 50 to 72 ohms resistive match. Using the above equations, the input arm (X_1) is 33.17 ohms and the shunt arm (X_3) is –108.5 ohms. The phase shift of this L-network is –33.6 degrees. The result is a three-component network that resembles a T-network with the –100 ohm compensating reactance as the output arm.

For the phantom-T we need to design a T-network with an output arm of –100 ohms that will exactly cancel the reactive part of the load. X_2 is now a predetermined parameter instead of β. Rearranging the design equations with some trigonometry and algebra, we can determine that $\beta = -64.9$ degrees, $X_3 = -66.26$ ohms and $X_1 = 89.7$ ohms. The –100 ohm value we selected for X_2 exactly cancels the load reactance, eliminating a component at the output leg.

Summary

This note is a reminder that phase shift is a valid initial design parameter for T-networks, and that it can readily be determined for L- and phantom-T-networks. I hope that this review sheds new light on your understanding of matching network design.

References

1. Frederick Terman, *Electronic and Radio Engineering*, 4th edition, McGraw-Hill 1955.

2. Edward Edison, "AM Broadcast Antenna Systems," Chapter 2.4, Part II, *NAB Engineering Handbook*, National Association of Broadcasters, 1984 edition.