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Improving the Bandwidth of Simple Matching Networks

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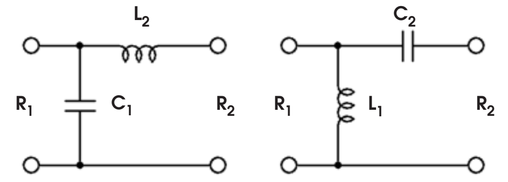
This tutorial describes methods for broadbanding matching networks using cascaded sections and compensating reactance

Impedance matching is probably the most engineering task in RF/microwave design. This tutorial is intended to demonstrate the first steps from simple two- and three-element networks that are designed for a specific center frequency, to larger networks that provide an acceptable match over a wider bandwidth. These wider bandwidth networks are important for modern communications systems that have operating bandwidths that are much wider than older technologies using FM and BPSK modulation. Even at narrower bandwidths, many digital modulation formats require flat amplitude and linear phase response, which can be achieved by using wideband matching networks, which have much smaller variation over a signal's occupied bandwidth.



$$\omega C_1 = Q/R_1 \qquad \omega L_1 = R_1/Q$$
$$\omega L_2 = Q \cdot R_2 \qquad \omega C_2 = 1/(Q \cdot R_2)$$
$$Q = \sqrt{R_1/R_2 - 1}$$
$$R_1 > R_2$$

Figure 1 · The two basic L-network topologies and their design equations.

Classic L, T and Pi Matching Networks

The simplest impedance transformation network is the L-network, which requires just two reactive components. Like a filter, the L-network can have a highpass or lowpass frequency response characteristic. Even if the particular response is unimportant, it means that two topologies are available—which is important when matching reactive loads, as we will see later.

Figure 1 shows the two L-network configurations and their design equations for resistive sources and loads. Note that Q is determined by the ratio of the impedances to be matched and cannot be chosen by the designer. Thus, L-networks are low-Q for small impedance transformations and high-Q for large impedance transformations. Also note that the equation for Q requires the shunt reactance to be located adjacent to the higher impedance.

Two L-network sections can be connected back-to-back, as shown in Figure 2. The intermediate impedance at the center of the network is virtual (no actual load is present) and is selected by the user, usually to achieve a particular value of Q. Back-to-back connection requires this virtual impedance to be either

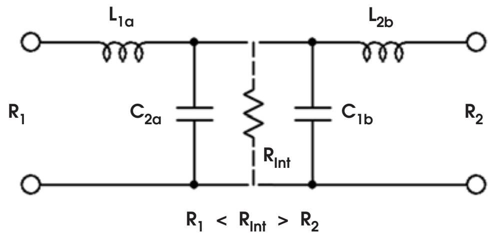


Figure 2 · Back-to-back L-networks with a user-selected intermediate impedance.

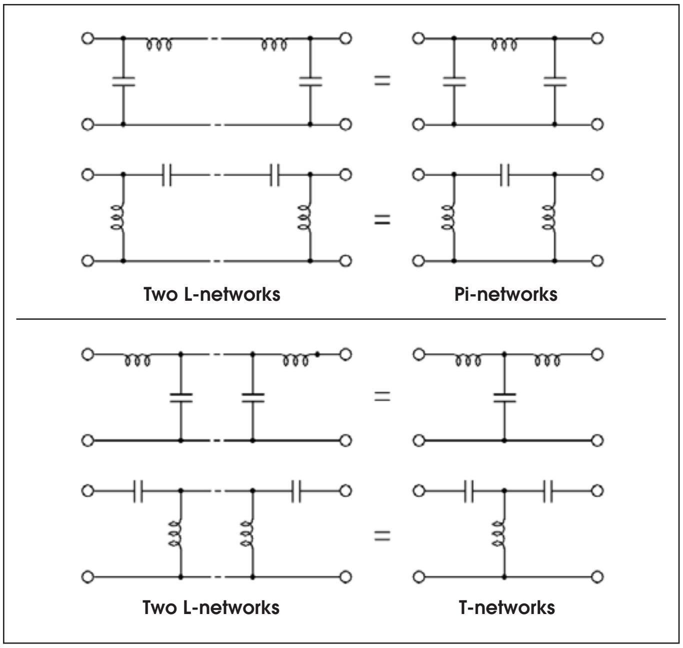


Figure 3 · T- and Pi-networks combine the center components of back-to-back L-networks. Additional topologies are illustrated in Ref. (1).

higher (as shown in Fig. 2) or lower than both the source and load impedance.

The center components of Figure 2 can be combined into a single component, with the result being the T-network. When the intermediate impedance is lower than the source and load, the result of combining the center components is the Pi-network. Figure 3 shows some of the ways that two L-networks can create T- and Pi-networks [1]. The choice among these topologies is determined by such factors as DC continuity and highpass, lowpass or bandpass frequency response. Practical component values are a major consideration in some cases, especially at high power levels.

Broadbanding with Cascaded L-Networks

Although T- and Pi-networks represent great flexibility in design parameter choices, they have narrower frequency response than a simple L-network. If wider bandwidth is the primary objective, L-networks can be cascaded in series rather than back-to-back, such as the 850 MHz 5-ohm to 50-ohm network shown in Figure 4 [2].

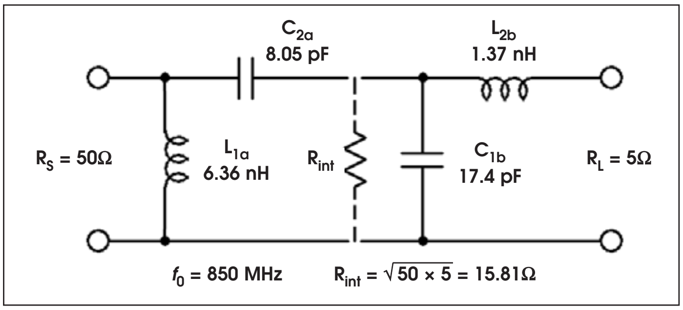


Figure 4 · Cascaded L-network example, with each section having a lower *Q* for improved bandwidth.

With cascaded sections, the lowest *Q* (and widest bandwidth) is achieved when the intermediate impedance is the geometric mean of the source and load impedances. For example, with source and load impedances of 5 and 50 ohms, a single L-network would have a *Q* of 3. When two sections are cascaded with $\sqrt{(50 \times 5)}$, or 15.81 ohms, as the intermediate impedance, each section has a *Q* of 1.47. With ideal, lossless components, the lower *Q* results in more than 3 times greater bandwidth near the center frequency (between the 0.1 dB points) [2].

Figure 5 is a plot of the impedance at the 50-ohm port for the cascaded network of Figure 4, compared to a single lowpass L-network. It is easy to see that the impedance deviation of the cascaded networks is far less than the single L-network section over this 35% bandwidth range.

Wider bandwidths and flatter impedance curves can be achieved by cascading more sections with the additional intermediate impedances creating smaller impedance ratios, and correspondingly lower *Q* for each section.

Incorporating Reactances

The above discussion was for resistive loads, but most practical applications involve loads that include reactance. The usual design procedure is to cancel the load reactance, then match the remaining resistive component to the system impedance. Figure 6 shows the two ways that reactance can be cancelled: (a) an equal but opposite sign reactance in series, and (b) a parallel reactance that resonates with the load reactance. A 5 –j5 ohm load is shown in this example.

The manner in which the reactance of the load is

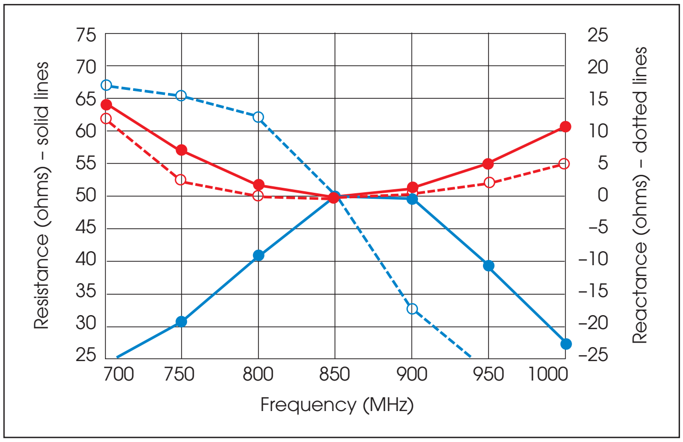
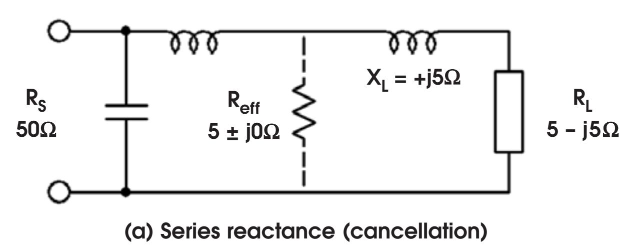
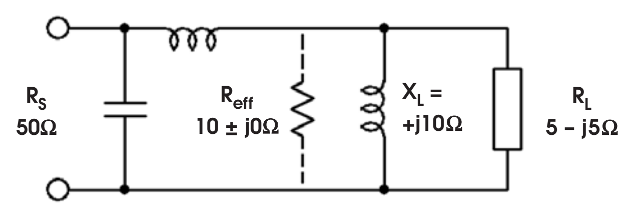


Figure 5 · Impedance at the 50 ohm port of a 5- to 50-ohm matching network: Example of Fig. 4 (red); Single section lowpass L-network (blue).



(a) Series reactance (cancellation)



(b) Parallel reactance (resonating)

Figure 6 · Two methods for cancelling the load reactance, combined with matching the resulting non-reactive impedance to a 50-ohm system.

incorporated into the matching network affects bandwidth. The finished network can save a component by combining the series cancelling reactance with the adjacent matching component, but the resonating solution has a wider bandwidth.

In Fig. 6(a), note that the effective load is 5 ohms for the series cancelling method, but is 10 ohms for the resonating inductor method of Fig. 6(b). This reduces the magnitude of the impedance transformation by the L-network, which was previously shown to result in a wider matching bandwidth. While this circuit has significant variation in impedance away from the center frequency, this has a much smaller effect on bandwidth than the increased effective load impedance.

The results for this example, using a center frequency of 850 MHz, is shown in Figure 7, which is a comparison of the impedances at the source port for the two options of Fig. 6. The smaller impedance deviation for the resonating solution of Fig. 6(b) is clearly illustrated.

Some Additional Considerations

This tutorial has presented some of the “first steps” in the path from narrowband to broadband matching. There are many additional techniques that are involved in further bandwidth improvement, as well as for implementing matching networks with practical component values. Below are a few notes on some of those techniques, along with notes on other issues that arise practical matching network design.

Transmission line equivalents—All designs using lumped elements may use transmission line elements, as well. The choice depends on the physical construction method, frequency of operation and, in some cases, is used to replace components with non-optimum values.

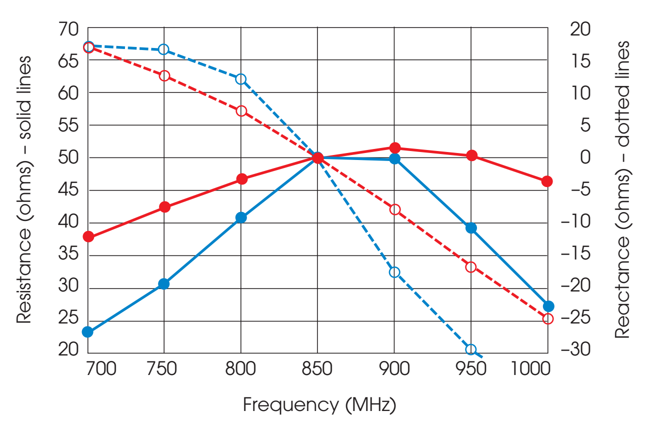


Figure 7 · Impedance at R_S port for the two matching options of Fig. 6(a) (blue) and Fig. 6(b) (red), implemented at f_0 = 850 MHz.

Trading loss for bandwidth—Often, a very low resistance or high reactance load, such as the gate of some power FET devices, can be more easily matched for wide bandwidth by adding a series resistance to raise the effective impedance. When the additional loss can be tolerated, this technique can greatly simplify broadband matching network design.

Non-standard impedances—Many matching tasks involve interfacing between devices or circuits that are both higher or lower than the typical 50-ohm system impedance. Unless there is a need to test individual modules, or to separate the modules for isolation, matching the actual impedances will result in the simplest or easiest to implement network.

Practical component values—With several options for matching topologies, the choice between them will often be based on the component values. The considerations include loss (e.g., large inductors with relatively low *Q*), impractical component values, and high currents or voltages at the various points in the network.

Reactance of the load—The magnitude of the load reactance and the slope of reactance change across the desired band must be accommodated in any broadband matching network design. This will affect the choice of topology and complexity of the network.

References

1. Chris Bowick, et al, *RF Circuit Design*, 2nd ed., Newnes imprint, Elsevier 2008, Chapter 4.

2. Les Besser, Rowan Gilmore, *Practical RF Circuit Design for Modern Wireless Systems*, Artech House 2003, Chapter 5.

3. Andrei Grebennikov, *RF and Microwave Power Amplifier Design*, McGraw-Hill 2005, Chapters 4 and 8.