ELECTRONIC DESIGN

Back to Basics: Impedance Matching (Part 2)

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During impedance matching, a specific electronic load (R_L) is made to match a generator output impedance (R_g) for maximum power transfer. The need arises in virtually all electronic circuits, especially in RF circuit design.

L-Network Applications And Configurations

The primary applications of L-networks involve impedance matching in RF circuits, transmitters, and receivers. L-networks are useful in matching one amplifier output to the input of a following stage. Another use is matching an antenna impedance to a transmitter output or a receiver input. Any RF circuit application covering a narrow frequency range is a candidate for an L-network.

There are four basic versions of the L-network, with two low-pass versions and two high-pass versions *(Fig. 1)*. The low-pass versions are probably the most widely used since they attenuate harmonics, noise, and other undesired signals, as is usually necessary in RF designs. The key design criteria are the magnitudes and relative sizes of the driving generator output impedance and load impedance.

1. There are four basic L-network configurations. The network to be used depends on the relationship of the generator and load impedance values. Those in (a) and (b) are low-pass circuits, and those in (c) and (d) are high-pass versions.

The impedances that are being matched determine the Q of the circuit, which cannot be specified or controlled. If it is essential to control Q and bandwidth, a T or π-network is a better choice. These choices will be covered in a subsequent article.

While the L-network is very versatile, it may not fit every need. There are limits to the range of impedances that it can match. In some instances, the calculated values of inductance or capacitance may be too large or small to be practical for a given frequency range. This problem can sometimes be overcome by switching from a low-pass version to a high-pass version or vice versa.

Design Example #1

2. The RF source is a transistor amplifier with an output impedance of 10 Ω that is to be matched to 50-Ω output impedance load. The L-network with a parallel output capacitor is used.

Figure 2 shows the desired circuit. Assume an amplifier output (generator) impedance of 10 Ω at a frequency of 76 MHz. Calculate the needed inductor and capacitor values using the formulas given in *Figure 1a*:

$Q = \sqrt{[(R_L/R_g) - 1]}$

$Q = \sqrt{[(50/10) - 1]} = \sqrt{[(5) - 1]} = \sqrt{4} = 2$

$X_L = QR_g = 2(10) = 20\ \Omega$

$L = X_L/2\pi f$

$L = 20/[2(3.14)(76 \times 10^6)]$

$L = 42$ nH

$X_C = R_L/Q$

$X_C = 50/2 = 25\ \Omega$

$C = 1/2\pi f X_C$

$C = 1/[2(3.14)(76 \times 10^6)(25)]$

$C = 83.8$ pF

The bandwidth (BW) of the circuit is relatively wide given the low Q of 2:

$BW = f/Q = 76 \times 10^6/2 = 38 \times 10^6 = 38$ MHz

3. The equivalent circuit of the network in Figure 2 is a simple series RLC network where the reactances cancel and the source and load impedances match.

You can see how this matching network functions by converting the parallel combination of the 50-Ω resistive load and the 25-Ω capacitive reactance into its series equivalent *(Fig. 3)*:

$R_s = R_p/(Q^2 + 1)$

$R_s = 50/(2^2 + 1) = 10\ \Omega$

$X_s = X_p/\backslash\backslash[(Q^2 + 1)Q^2\backslash\backslash]$

$X_s = 25/(5/4) = 25/1.25 = 20\ \Omega$

Note how the series equivalent capacitive reactance equals and cancels the series inductive reactance. Also the series equivalent load of 10 Ω matches the generator resistance for maximum power transfer.

Parallel And Series Circuit Equivalents

Sometimes it's necessary to convert a series RC or RL circuit into an equivalent parallel RC or RL circuit or vice versa. Such conversions are useful in RLC circuit analysis and design *(Fig. 4)*.

R_s = series resistance

R_p = parallel resistance

X_s = series reactance

X_p = parallel reactance

The conversion formulas are:

$R_s = R_p/(Q^2 + 1)$

$X_s = X_p/\backslash\backslash[Q^2 + 1)Q^2\backslash\backslash]$

$R_p = R_s\ (Q^2 + 1)$

$X_p = X_s\ \backslash\backslash[(Q^2 +1)/Q^2\backslash\backslash]$

$Q = \sqrt{}\backslash\backslash[R_p/(R_s - 1)\backslash\backslash]$

$Q = X_L/R_s$

$Q = R_p/X_C$

If the Q is greater than 5, you can use the simplified approximations:

$R_p = Q^2R_s$

X = X

5. The RF source is a transmitter at 433 MHz with an output impedance of 50 Ω. The load is a loop antenna with an impedance of 5 Ω.

$Q = \sqrt{[(R_g/R_L) - 1]}$

$Q = \sqrt{[(50/5) - 1]} = \sqrt{[(10) - 1]} = \sqrt{9} = 3$

$X_L = QR_L = 3(5) = 15\ \Omega$

$L = X_L/2\pi f$

$L = 15/2(3.14)(433 \times 10^6)$

$L = 5.52$ nH

$X_C = R_g/Q$

$X_C = 50/3 = 16.17\ \Omega$

$C = 1/2\pi f X_C$

$C = 1/2(3.14)(433 \times 10^6)(16.67)$

$C = 22$ pF

In this example, the capacitor, inductor, and load resistance form a parallel resonant circuit *(Fig. 6)*.

equivalent resistance (R_R) of a parallel RLC circuit can be calculated by:

$R_R = L/CR$

or:

$R_R = R(Q^2 + 1)$

$R_R = L/CR = 5.52 \times 10^{-9}/(22 \times 10^{-12})(5) = 50.18\ \Omega$

$R_R = R(Q^2 + 1) = 5(3^2 + 1) = 50\ \Omega$

In both cases the parallel resonant load equivalent resistance is 50 Ω and equal to the generator resistance allowing maximum power transfer. Again, adjustments in these values should be made to include any load reactive component. The equivalent high-pass networks could also be used. One benefit is that the series capacitor can block dc if required.

A Modern Application

In radio communications, a common problem is matching a transmitter, receiver, or transceiver to a given antenna. Most transceivers are designed with a standard 50-Ω input or output impedance. Antenna impedances can vary widely from a few ohms to over a thousand ohms.

To meet the need to match a transceiver to an antenna, the modern antenna tuner has been developed. Manual versions with tunable capacitors and switched tapped inductors have been available for years. Today, modern antenna tuners are automated. When the transceiver is in the transmit mode, the tuner automatically adjusts to ensure the best impedance match possible for maximum power transfer.

Figure 7 shows a representative tuner. It is essentially an L-network that is adjusted automatically by switching different values of capacitance in or out and/or switching different taps on the inductor to vary the inductance. A microcontroller performs the switching according to some algorithm for impedance matching.

The criterion for determining a correct match is measuring the standing wave ratio (SWR) on the transmission line. The SWR is a measure of the forward and reflected power on a transmission line. If impedances are properly matched, there will be no reflected power and all generated power will be sent to the antenna. The most desirable SWR is 1:1 or 1. Anything higher indicates reflected power and a mismatch. For example, an SWR value of 2 indicates a reflected power of approximately 11%.

In *Figure 7*, a special SWR sensor circuit measures forward and reflected power and provides proportional dc values to the microcontroller. The microcontroller has internal analog-to-digital converters (ADCs) to provide binary values to the impedance-matching algorithm. Other inputs to the microcontroller are the frequency from a frequency counter circuit and the actual complex load impedance as measured by an impedance-measuring circuit.

One typical commercial automated antenna tuner, the MFJ Enterprises MFJ-928, has an operating frequency range of 1.8 to 30 MHz and can handle RF power up to 200 W. It has an SWR matching range of 8:1 for impedances less than 50 Ω and up to 32:1 for impedances greater than 50 Ω.

The total impedance-matching range is for loads in the 6- to 1600-Ω range. The range of capacitance is 0 to 3900 pF in 256 steps, and the range inductance is 0 to 24 µH in 256 steps. Note that the capacitance may be switched in before or after the inductor. This provides a total of 131,072 different L/C matching combinations.

Such automatic tuners are widely used in amateur radio and the military where

References

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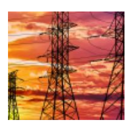
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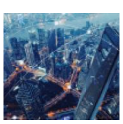
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