

Quadrature Networks

We have had many conversations and received questions about I/Q circuits. Many of those conversations involve the means of obtaining the 0°/90° phase shifts needed in the signal path and local oscillator. Here is a summary of the most common methods for such circuits. The number of options may surprise engineers who are unfamiliar with quadrature circuits.

Delay lines—When the frequency is high enough that a 1/4-wavelength line is a practical length, a power divider with a simple delay line following one output can provide the necessary phase difference.

Transmission line structures—At even higher frequencies, it may be practical to use one of the ring topologies that were developed many years ago for radar and other microwave applications. These can be implemented in microstrip, stripline or coaxial cable.

LC/RC/RL networks—A narrowband quadrature network can be as simple as a few passive components (see Figure 1). Stable system impedances are required, and if they are not purely resistive, some empirical adjustment (tweaking) of the component values will be needed to maintain accurate phase shift and equal amplitudes at the desired center frequency.

All-pass networks—Op amp based all-pass networks are a good option for low frequency IF or base-band quadrature networks. Multiple poles can be cascaded to get the desired bandwidth.

Coupled-L quadrature networks—A common quadrature network uses a dual inductor with strong mutual coupling, plus capacitors connected at the ends to make a ring-type network. This topology provides good performance over a moderate bandwidth.

Polyphase networks—A four-leg RC network can provide wide bandwidth quadrature outputs. The absolute phase shift from input to output will vary over frequency, but the relative phase difference at the output remains constant over the design bandwidth. A four-section network (Figure 2) can cover a decade of bandwidth with less than 0.2° phase error—with ideal components and ignoring temperature coefficients. In practice, a carefully constructed circuit will provide perhaps twice that variation (0.4°).

The greatest advantage of polyphase networks is that the accuracy depends mainly on the components in each section being matched to one another, not to an absolute value of resistance or capacitance. The disadvantages of these networks are their obvious complexity and the fact that they are lossy.

Divide-by-2 or -4 digital circuits—For local oscilla-

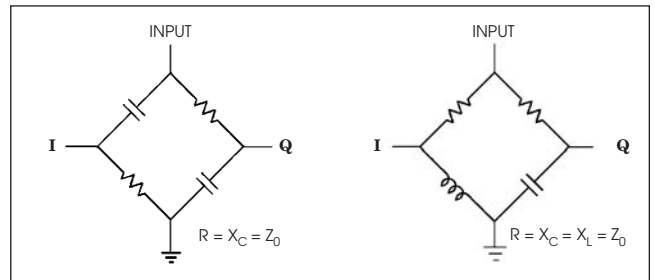


Figure 1 · RC (left) and RC/RL (right) networks providing the desired phase shifted outputs.

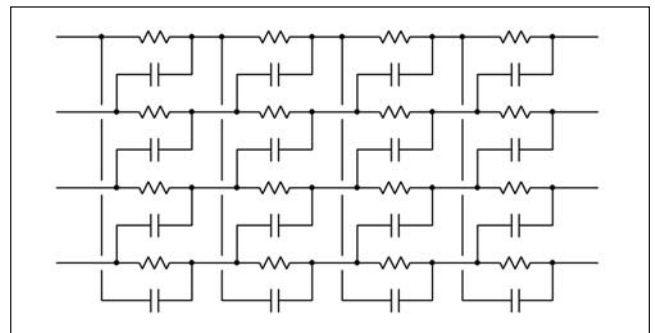


Figure 2 · Polyphase networks are attractive choices for wideband quadrature networks.

tors, it is often practical to use an oscillator at 2× or 4× the LO frequency and use a divider to obtain quadrature square waves. The speed of the logic family determines the upper limit of frequency where this method is practical.

Synchronized synthesizers—Precision tracking of quadrature signals can be obtained using synchronized phase locked loops or direct digital synthesizers with a common clock. Although a complex solution, the performance may warrant the additional cost, design time and board space.

DSP-based Hilbert Transform—This method is used more often than most of us realize. In modern wireless devices, considerable DSP power is available for modulation, demodulation, encoding and decoding, and other signal processing functions. The time-domain Hilbert Transform can provide highly accurate quadrature signal paths as part of the signal processing functionality.

A good starting reference is *Experimental Methods in RF Design* by Hayward, Campbell and Larkin, particularly Chapter 9. (American Radio Relay League, www.arrl.org, 2003, ISBN 0-87259-879-9.)