Chapter 3

Wideband 90° Phase Shifters

3.1 Introduction

The wideband 90° phase shifter is a critical building block in image-reject receivers, quadrature demodulators as described in the previous chapter, and many other applications where quadrature signal generation is required [1, 2, 3, 4, 5, 6]. The performance of the 90° phase shifter is directly linked to the image rejection performance of those receivers.

Mathematically, the 90° phase shifter is the Hilbert transformer [7], or a Hilbert filter. It is defined as a device in the form of a linear two-port whose output signal is a Hilbert transformation of the input signal. The strict definition of a Hilbert transformation is out of the scope of this book and can be found in many signal processing text books, for example in [8]. The transfer function of an ideal Hilbert transformer is given by:

\[
H(j\omega) = \begin{cases} 
-j & \text{for } \omega > 0 \\
0 & \text{for } \omega = 0 \\
j & \text{for } \omega < 0.
\end{cases}
\]  

(3.1)

The transfer function is illustrated in Figure 3.1. The magnitude \(|H(j\omega)| = 1\) for all \(\omega\) and the passband is infinite. The phase function is a step function: \(\varphi(\omega) = -(\pi/2)\text{sign}(\omega)\), where function \(\text{sign}(\omega)\) outputs the sign of \(\omega\). It shifts the phase of input signal by 90° from zero to infinite frequency.

Obviously, such an ideal Hilbert transformer is unrealisable in real world. Practical Hilbert transformers approximate the transfer function of (3.1) just
in a certain frequency band, which is called the care-band of the transformer in this chapter. The accuracy of 90° phase-shift and care-band bandwidth are two most important performance parameters of a Hilbert transformer.

The Hilbert transformers can be implemented as an analogue or digital device. The focus of this chapter is on the analogue implementations, which can be in continuous-time (CT) or discrete-time (DT) domain.

There are many ways to implement CT Hilbert transformers, for example, delay lines, distributed couplers, lumped LC couplers and RC/CR allpass networks. However, only those circuits that are suitable for monolithic integration will be discussed in this chapter. These circuits are the conventional passive and active RC networks as well as asymmetric polyphase RC/CR networks [9]. Tuning circuit for these CT circuits is usually required because their edge frequencies depend on the absolute values of R and C. Otherwise the bandwidth of care-band must be over-designed.

The DT Hilbert transformers can be approximated by finite impulse response (FIR) and infinite impulse response (IIR) filters. Both of them can be realized by discrete-time circuit techniques, like switched-capacitor (SC) technique. In general, DT Hilbert transformers have two advantages over CT transformers: (1) wide effective bandwidth can be easily obtained; (2) edge frequency can be well controlled so that no tuning is required. However, they find applications in different systems. For example, if the system is indeed a DT system, then DT transformers should be used. Otherwise anti-aliasing or smoothing filters are required and this may increase the cost.

In this chapter, a conventional two-phase SC circuit realization and several new proposed SC realizations, including a polyphase circuit, a pseudo N-path circuit and a reduced opamp gain and bandwidth sensitivity circuit. All these circuits offer better performance and reduced complexity then the two-phase