Chapter 3

3. DIGITAL COMPENSATION METHODS FOR ANALOG I/Q MODULATOR ERRORS

The block diagram of the I/Q modulator and correction network is shown in Figure 3-1. The I/Q modulator has phase imbalance, gain imbalance and DC-offset errors. With a careful layout design, the errors can be minimized, but they can never be completely nulled. The phase imbalance is caused mainly by the local oscillator and phase shifter, which does not produce exactly 90 degrees of phase shift between the two channels. The gain imbalance is caused mainly by the mixers, which are not exactly balanced. The sideband suppression is a function of both the gain and phase imbalance (see Figure 1-2). The carrier suppression is a function of the DC offset between the in-phase (I) signal and the quadrature (Q) signal. This offset can be compensated by altering the DC offset of the input signals.

The effects of the modulator errors on the constellation are shown in Figure 3-2, Figure 3-3 and Figure 3-4. The phase imbalance results in rotation of the axes in the I/Q coordinates as shown in Figure 3-2. The gain imbalance results in distortion of the signal and transforms the circular constellation in the I/Q coordinates to elliptical ones, as shown in Figure 3-3. The DC-offset shifts all sample points the same amount in the same direction, as shown in Figure 3-4. Together these imbalances cause the bit-error rate of the connection to increase. In [Cav93], a more detailed discussion about analog IQ modulator errors and their effects on the communications can be found.

The effects of the analog I/Q modulator errors are modelled using matrix notation. The quadrature modulator (QM) output of Figure 3-1, when the nonidealities are taken into account, can be written as [Fau91]

\[ v_q(t) = MV_m(t) + Ma, \]  

(3.1)

where
\[
M = \begin{pmatrix}
\alpha \cos\left(\frac{\phi}{2}\right) & \beta \sin\left(\frac{\phi}{2}\right) \\
\alpha \sin\left(\frac{\phi}{2}\right) & \beta \cos\left(\frac{\phi}{2}\right)
\end{pmatrix}
\]  \quad (3.2)

\[
a = \begin{pmatrix} a_1 \\ a_2 \end{pmatrix},
\]  \quad (3.3)

where \(\alpha\) and \(\beta\) are gains of the \(I\) and \(Q\) channels, \(V_m(t)\) is the quadrature input, and \(\phi\) is the phase split between the channels. \(a_1\) and \(a_2\) are the dc offsets of the channels. The time invariant signals are expressed as the length of two vectors composed of the in-phase and quadrature phase parts of the signals. The representation in (3.2) is called a symmetric form of the error; (3.4) is the same error presented in asymmetric form. The symmetric model [Cav93] differs from the symmetric model presented in [Fau91] in that the phase imbalance is attributed completely to the Q channel. In this case

\[
M = \begin{pmatrix}
\alpha & \beta \sin(\phi) \\
0 & \beta \cos(\phi)
\end{pmatrix}
\]  \quad (3.4)

To compensate the errors, correction terms should be added so that errors presented in (3.1), (3.2) and (3.3) are null. The corrected output for the quadrature modulator compensator (QMC) output should be (if the QMC is in series with the QM)

\[
v_c(t) = C v_d(t) + b = G \Phi v_d(t) + b,
\]  \quad (3.5)

where \(v_c(t)\) is the compensator input, and

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**Figure 3-1. Quadrature modulator and correction network.**