Theory of Operation of I/Q Demodulation

IQ-Demodulation

The operation of an IQ-demodulator can be explained by representing its RF input signal $s_{RF}(t)$ as a combination of two double sideband modulated quadrature carriers:

$$s_{RF}(t) = s_I(t) + s_Q(t) = I(t)\cos\omega_{RF}t - Q(t)\sin\omega_{RF}t. \quad (1)$$

As illustrated in Figure A, the in-phase component $I(t)$ and quadrature component $Q(t)$ are baseband signals that can be viewed as inputs to an ideal IQ-modulator generating $s_{RF}(t)$.

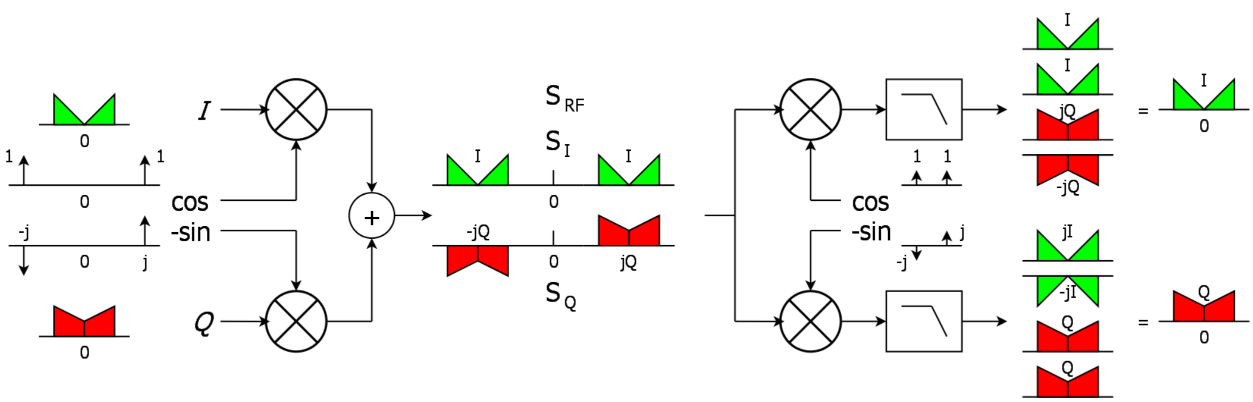

Figure A. Concept of IQ-modulation and IQ-demodulation.

An IQ-demodulator achieves perfect reconstruction of $I(t)$ and $Q(t)$ by exploiting the quadrature phase relation between $s_I(t)$ and $s_Q(t)$. The frequency-domain representation of a -90° phase shift corresponds to multiplication by the Hilbert transform:

$$H(j\omega) = -j\,\mathrm{sgn}(\omega).. \quad (2)$$

It converts a spectrum with even symmetry around $\omega=0$ to a spectrum with odd symmetry and vice versa. The spectra of $s_I(t)$ and $s_Q(t)$ therefore exhibit different symmetry; $s_I(t)$ has even symmetry, $s_Q(t)$ has odd symmetry. Downconversion of the even RF input component $s_I(t)$ with the even LO (cosine) retrieves $I(t)$, while $s_Q(t)$ with the odd LO (sine) retrieves $Q(t)$. Cross-combinations of even and odd yield zero.

An error φ on the quadrature relation between the LO outputs causes crosstalk between the I- and Q-channels. Using the I-phase channel as reference, an even component is introduced in the Q-channel LO:

$$\sin(\omega_{RF}t + \varphi) = \sin(\omega_{RF}t)\cos\varphi + \cos(\omega_{RF}t)\sin\varphi, \quad (3)$$

resulting in a contribution of *I(t)* to the Q-channel output $Q_{out}(t)$:

$$Q_{out}(t) = Q(t)\cos\varphi + I(t)\sin\varphi. \tag{4}$$

Image Cancellation Receiver

Another IQ-demodulator application is an image rejection/cancellation receiver with non-zero IF frequency, as shown in Figure B.

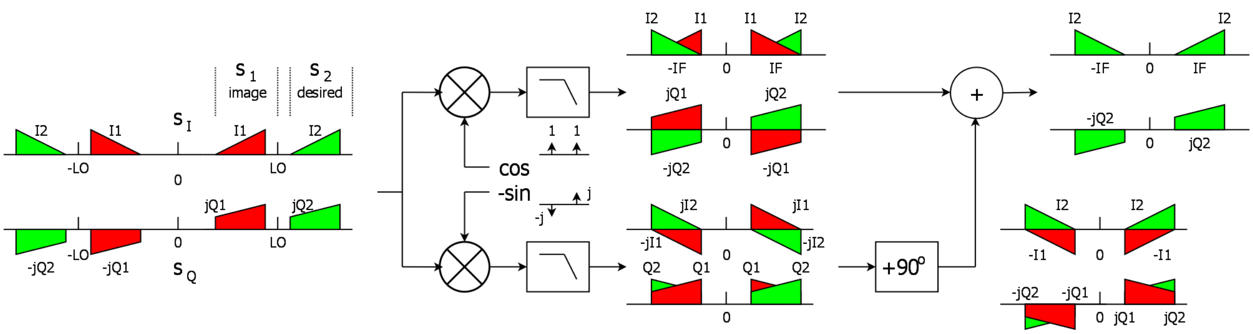

Figure B. Operation of the Hartley Image Rejection Receiver.

The I-channel preserves the symmetry in the RF input signal, while the Q-channel converts even components to odd and vice versa. The extra 90° phase shifter restores the original symmetry in the Q-channel, but with opposite sign for the signals $s_1(t)$ and $s_2(t)$; the phase of $s_2(t)$ is ahead of the LO since its center frequency is higher, while the phase of $s_1(t)$ lags behind. Addition to the I-channel reconstructs the downconverted signal $s_2(t)$; subtraction reconstructs $s_1(t)$.

The image rejection (IR) is degraded in the presence of a quadrature phase error φ or gain mismatch α between I- and Q-channels. The phase error introduces crosstalk between the channels, while gain mismatch results in imperfect cancellation by the adder:

$$IR = 10\log\left(\frac{1+\alpha^2+2\alpha\cos\varphi}{1+\alpha^2-2\alpha\cos\varphi}\right). \tag{5}$$

Figure C depicts the result for different gain and phase error combinations. Small gain errors have a larger impact than small phase errors.

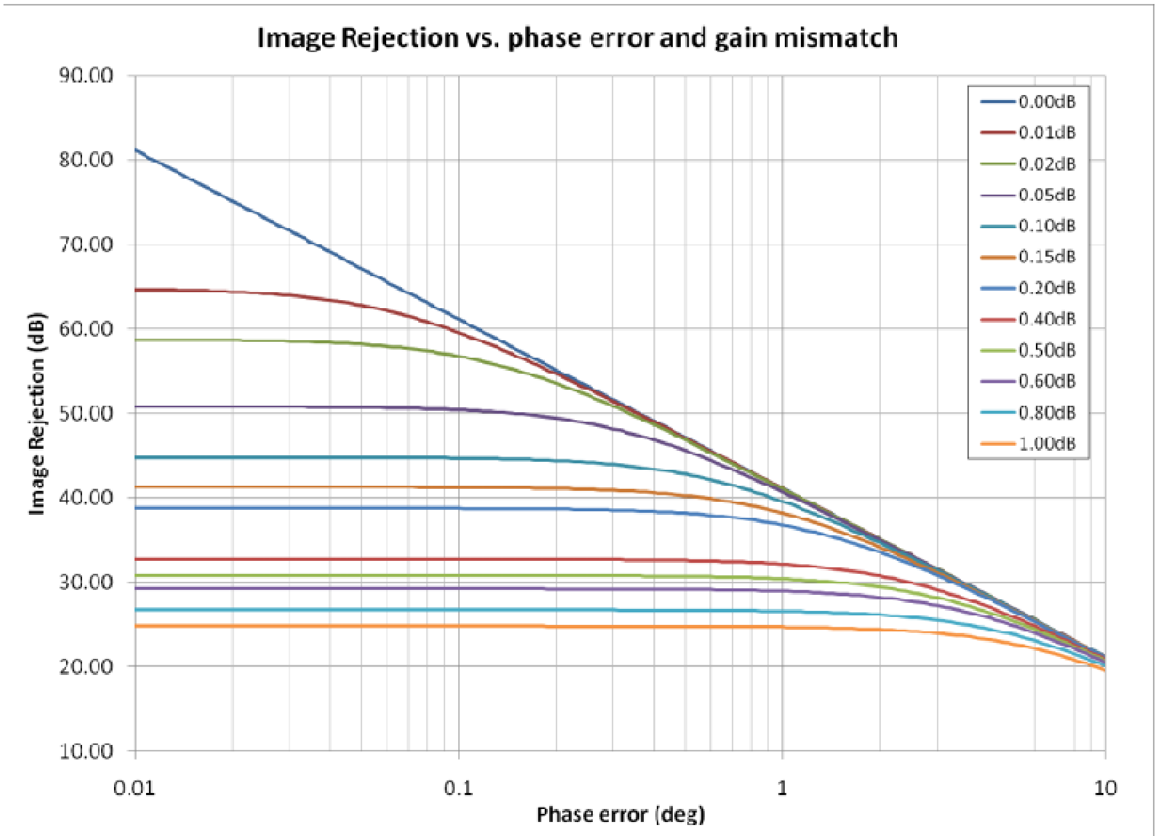

Figure C. Image rejection vs. phase error for different gain errors.