Quadrature Modulation vs. Polar Modulation

Prof. Joon Ho Cho
Department of Electrical Engineering, POSTECH

- Review. We've seen that, under certain conditions, **a real bandpass signal** $x(t)$ is equivalent to **a complex baseband signal** called the complex envelope $x_l(t)$ in the sense that

$$x(t) = \mathrm{Re}\{x_l(t)e^{\mathrm{j}(2\pi f_c t+\theta)}\}.$$

- Preview. We will study how to generate a real bandpass signal. The key idea is to see $x_l(t)$ either in the Cartesian coordinate or in the polar coordinate.

- I-Q Modulator
  - First, let's see $x_l(t)$ in the Cartesian coordinate. Then,
  $$x_l(t) = \mathrm{Re}\{x_l(t)\} + \mathrm{Im}\{x_l(t)\} \triangleq x_c(t) + \mathrm{j}x_s(t),$$
  where $x_c(t)$ and $x_s(t)$ are the real and the imaginary parts of the complex envelope $x_l(t)$.
  - Thus, $x(t)$ can be generated by implementing
  $$x(t) = \mathrm{Re}\{x_l(t)e^{\mathrm{j}(2\pi f_c t+\theta)}\} = x_c(t)\cos(2\pi f_c t+\theta) - x_s(t)\sin(2\pi f_c t+\theta).$$
  - Fig.
  - This is called an I-Q modulator (I/Q modulator, IQ modulator), or a quadrature modulator.

– 4 major I/O ports of a commercial I-Q modulator block
  * an input port (IBB) that admits a real baseband signal $x_c(t)$,
  * an input port (QBB) that admits a real baseband signal $x_s(t)$,
  * an input port (LO) that admits a local oscillator signal $\cos(2\pi f_c t + \theta)$, and
  * an output port (VOUT) that outputs an RF signal $x(t)$.
– Fig.

– The above I-Q modulator consists of
  * a splitter,
  * a phase shifter,
  * two mixers, and
  * a combiner.

– Pro. Straightforward implementation. $\leftarrow$ Two almost identical paths for the in-phase and the quadrature signals.

– Pro. It can generate a wideband signal.

– Con. Two paths may experience different gain. $\rightarrow$ gain imbalance

– Con. It may be difficult to have perfectly synchronized $\cos(2\pi f_c t + \theta)$ and $\sin(2\pi f_c t + \theta)$ for a very high f_c. $\rightarrow$ phase imbalance.

- I-Q imbalance
  * gain imbalance
  * phase imbalance
- Fig.

- This problem can be mitigated if we allow multiple stages to up-convert the baseband signals.

- Polar Modulator
  - Second, let's see $x_l(t)$ in the polar coordinate. Then,

$$x_l(t) = |x_l(t)| e^{\mathrm{j}\measuredangle x_l(t)}.$$

where

$$|x_l(t)| \triangleq \sqrt{(x_c(t))^2 + (x_s(t))^2}$$

and

$$\measuredangle x_l(t) \triangleq \mathrm{atan2}(x_c(t), x_s(t))$$

are the magnitude and the phase angle of the complex envelope $x_l(t)$. Often, $|x_l(t)| = |x_+(t)|$ is called the envelope of $x(t)$.

  - Thus, $x(t)$ can be generated by implementing

$$x(t) = \mathrm{Re}\{x_l(t) e^{\mathrm{j}(2\pi f_c t + \theta)}\} = |x_l(t)| \cos(2\pi f_c t + \theta + \measuredangle x_l(t)).$$

– Fig.

– This is called a polar modulator.

– The above polar modulator consists of

  * an envelope detector,
  * a limiter,
  * a voltage controlled oscillator (VCO), and
  * a variable gain amplifier, but
  * no combiner.

- Pro. A major advantage of a polar modulator is that it allows the use of highly non-linear amplifier that becomes power efficient when envelope tracking (ET) approach is taken.

- Pro. Another advantage of a polar modulator is that it does not incur I-Q imbalance problem because of no use of a combiner.
- Con. It may not be easy to perfectly synchronize the amplitude modulation (AM) and the phase modulation (PM) signals.
- Con. It may not be easy to implement a VCO when the PM signal has a very large bandwidth.

- Note that
  * Ideally, any modulated signal can be generated by an I-Q modulator, because its complex envelope has a real and an imaginary part.
  * Ideally, any modulated signal can be generated by a polar modulator, because any modulated signal can be viewed as a combination of AM and PM.
  * However, a specific modulation scheme may be more suitable to a specific modulator.