Lecture 9
Analog and Digital I/Q Modulation

Analog I/Q Modulation

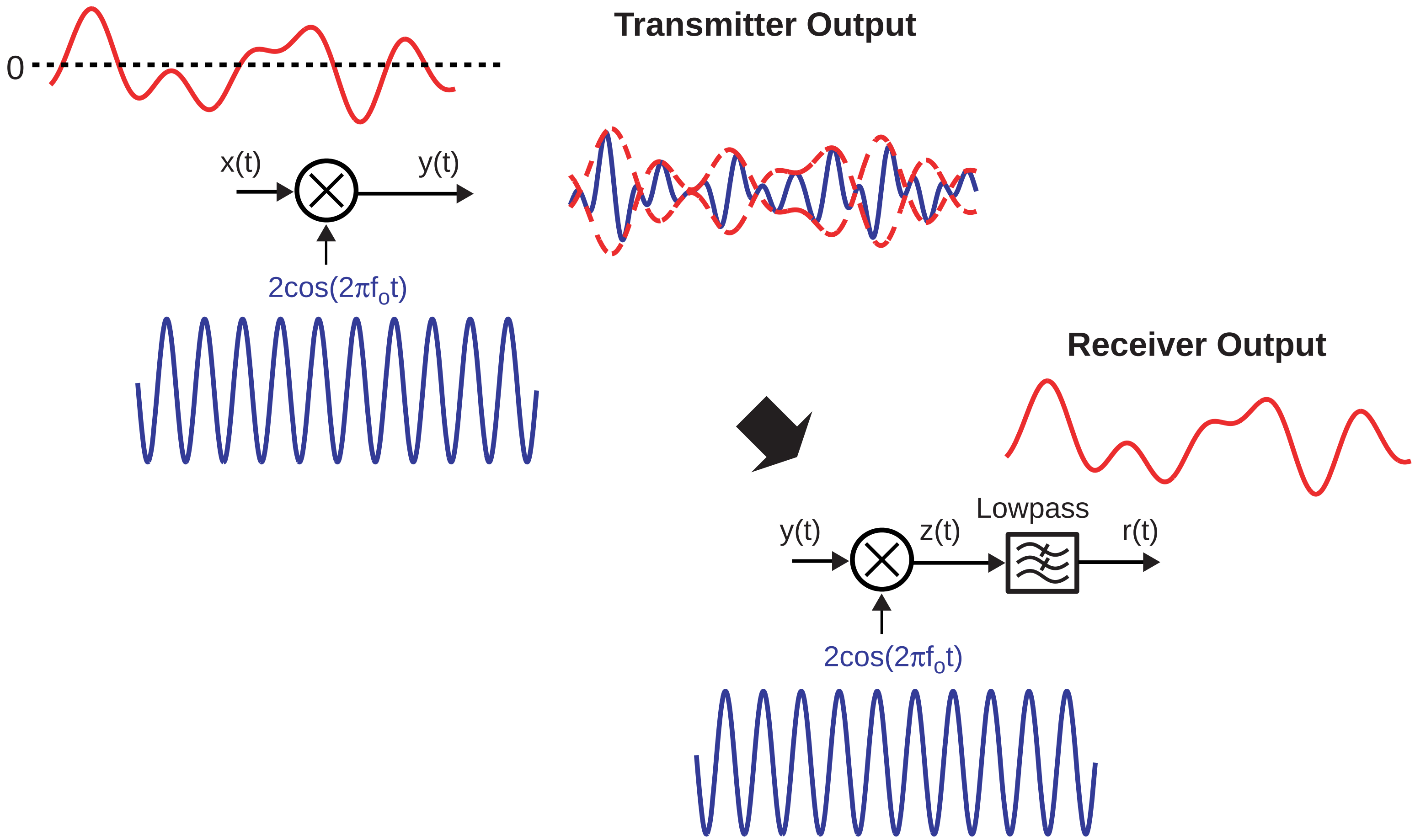
- Time Domain View
- Polar View
- Frequency Domain View

Digital I/Q Modulation

- Phase Shift Keying
- Constellations

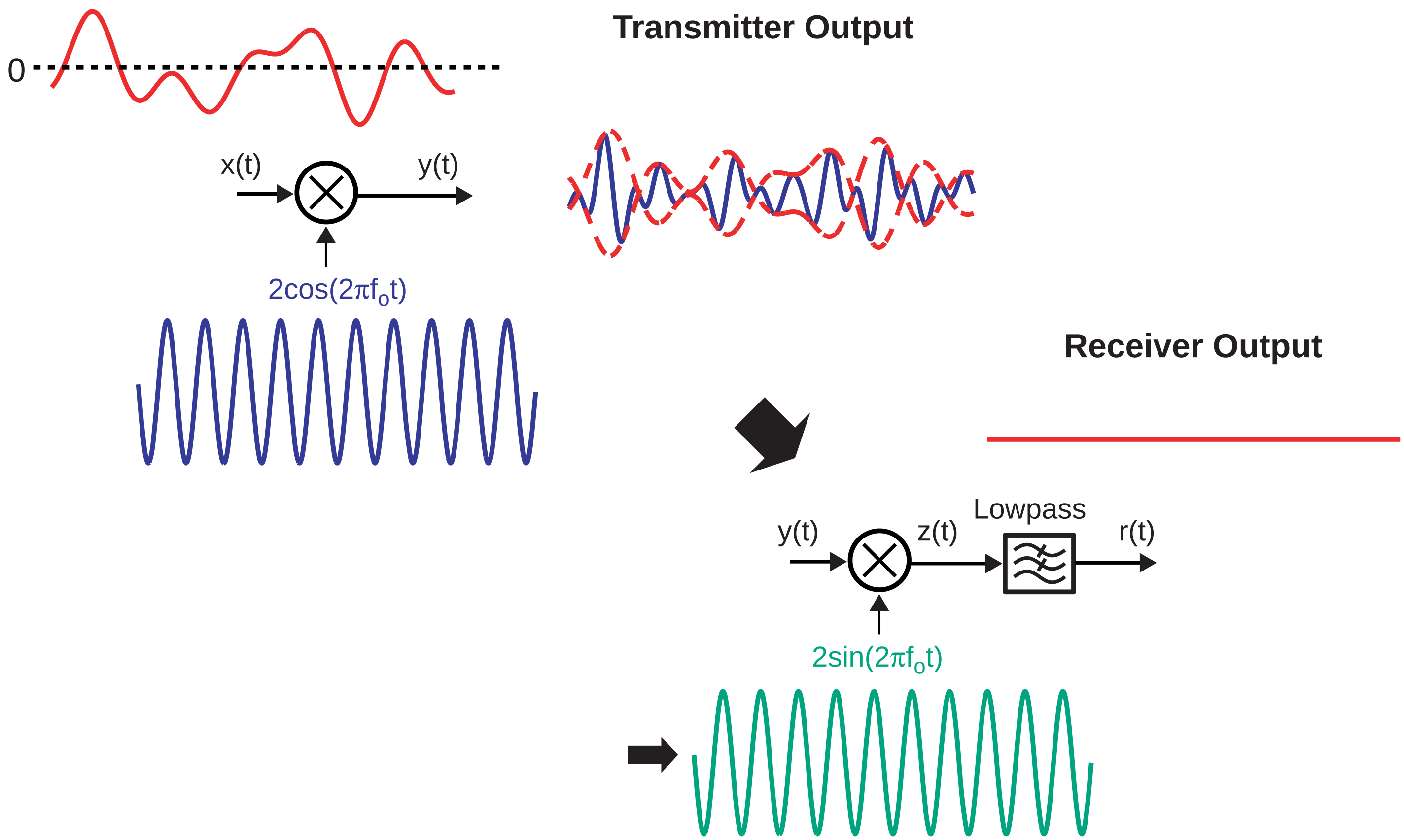
11/4/2006

Coherent Detection



- Requires receiver local oscillator to be accurately aligned in phase and frequency to carrier sine wave

Impact of Phase Misalignment in Receiver Local Oscillator

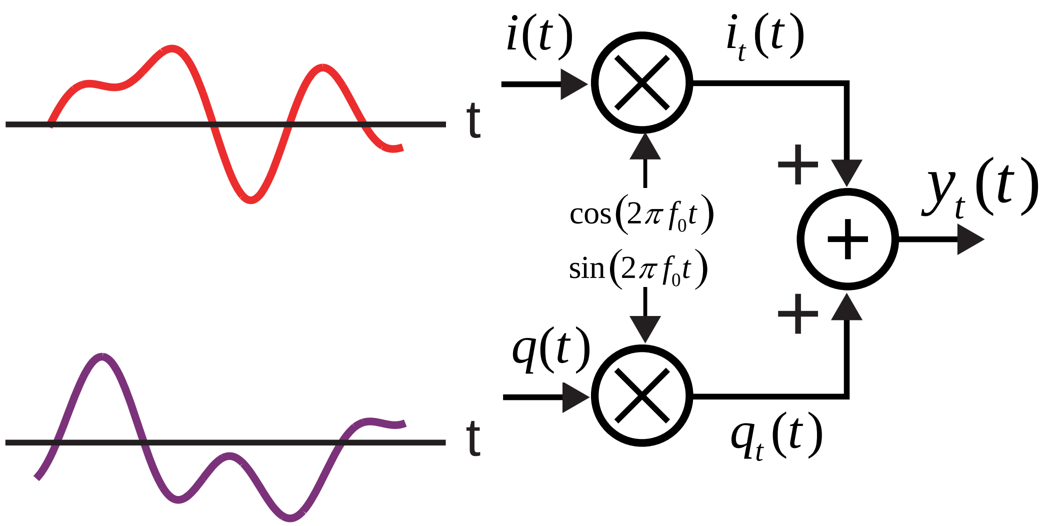


Output is zero

- Worst case is when receiver LO and carrier frequency are phase shifted 90 degrees with respect to each other

Analog I/Q Modulation

Baseband Input



- Analog signals take on a continuous range of values (as viewed in the time domain)
- I/Q signals are orthogonal and therefore can be transmitted simultaneously and fully recovered

Polar View of Analog I/Q Modulation

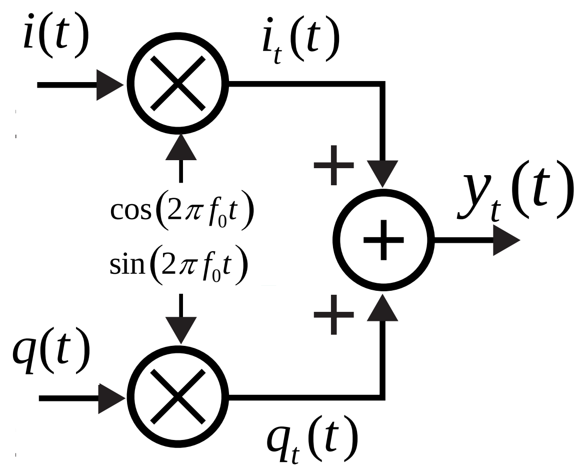
$$i_t(t) = i(t)\cos\left(2\pi f_o t + 0°\right)$$

$$q_t(t) = q(t)\cos\left(2\pi f_o t + 90°\right) = q(t)\sin\left(2\pi f_o t\right)$$

$$y_t(t) = \sqrt{i^2(t) + q^2(t)}\cos\left(2\pi f_o t + \theta(t)\right)$$

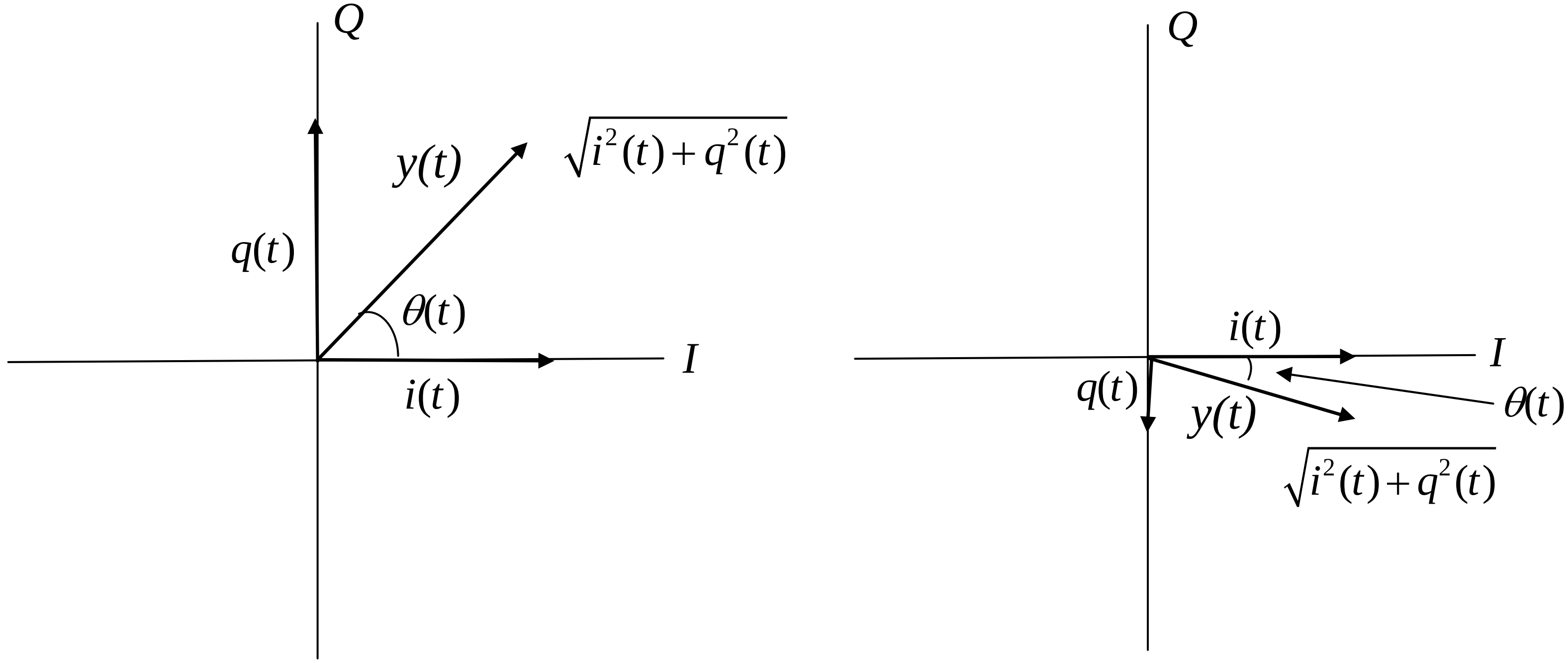
$$where \;\; \theta(t) = \tan^{-1} q(t)/i(t)$$

$$-180° < \theta < 180°$$

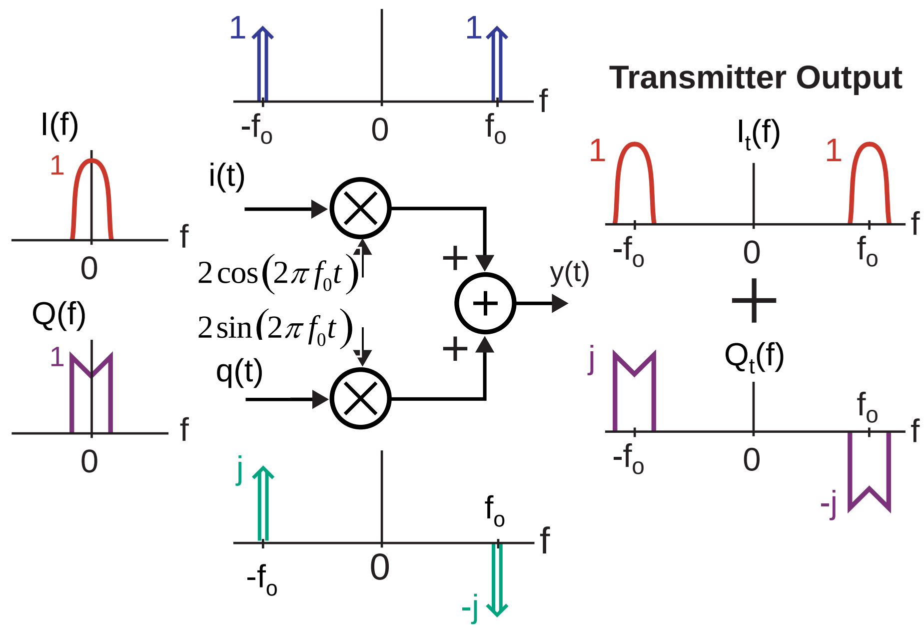


Polar View of Analog I/Q Modulation (Con't)

- Polar View shows amplitude and phase of $i_t(t)$, $q_t(t)$ and $y_t(t)$ combined signal for transmission at a given frequency f.
- Magnitude of $i(t)$ and $q(t)$ vary with time, representing information in the analog domain.

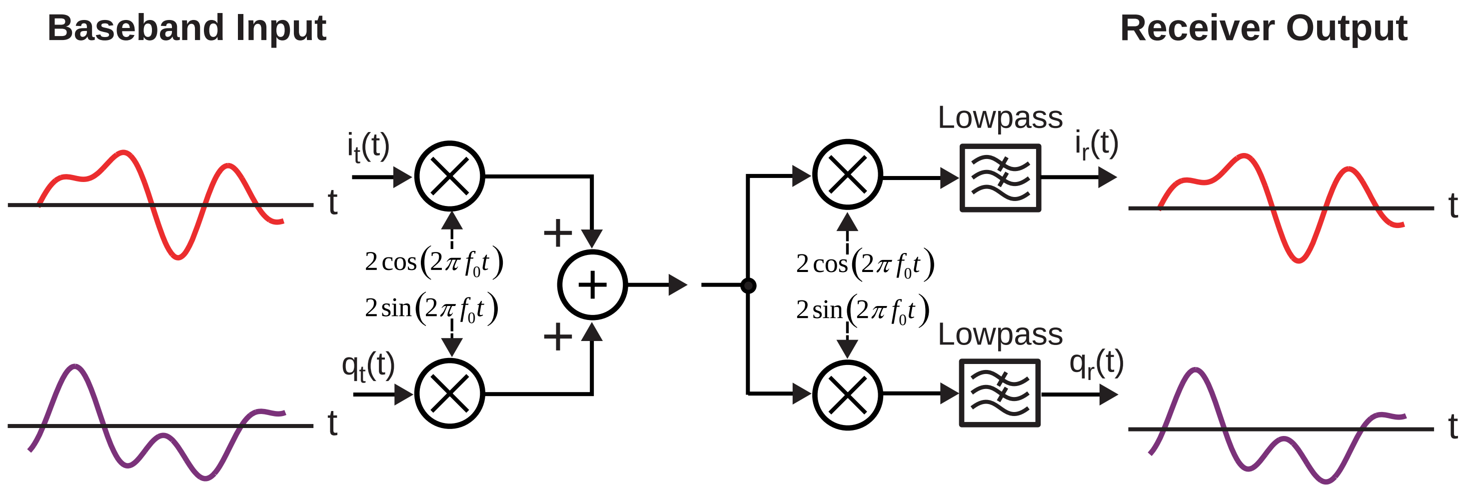


Frequency Domain View of Analog I/Q Modulation



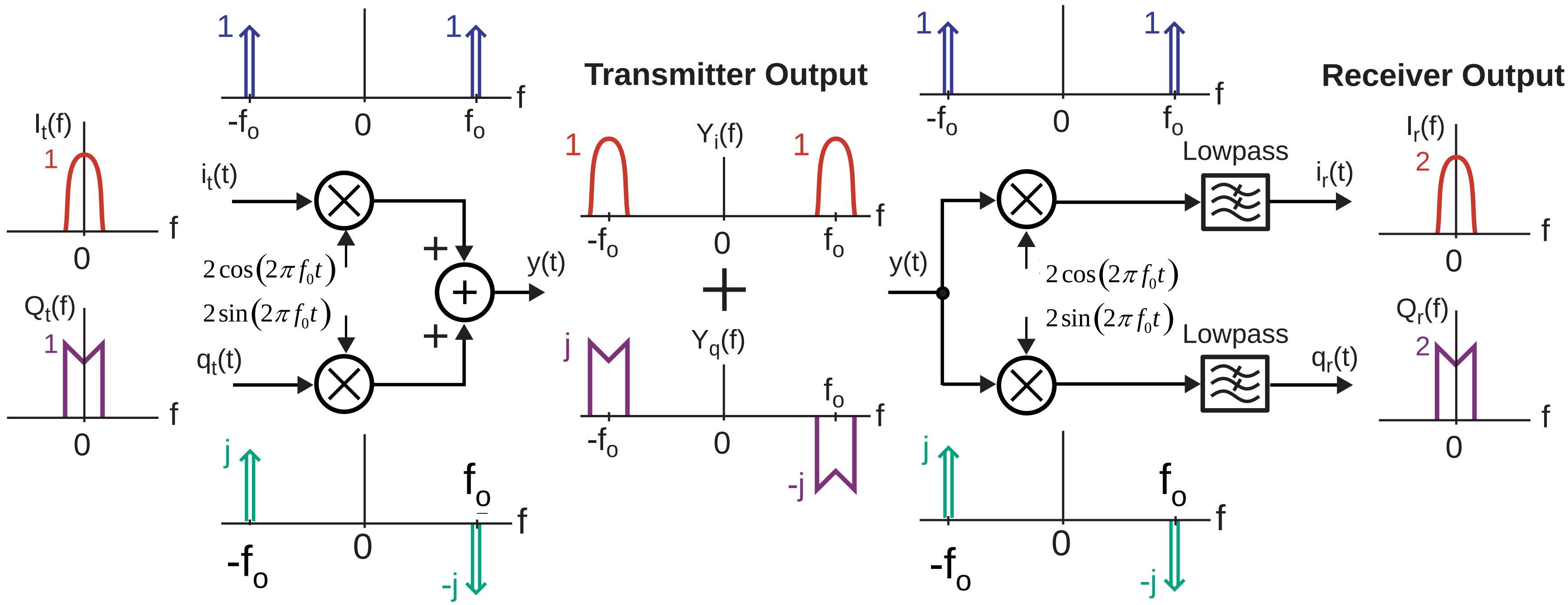
- Takes advantage of coherent receiver's sensitivity to phase alignment with transmitter local oscillator
  - We have two orthogonal transmission channels (I and Q) available to us
  - Transmit two independent baseband signals (I and Q) with two sine waves in quadrature at transmitter

Analog I/Q Modulation-Transceiver



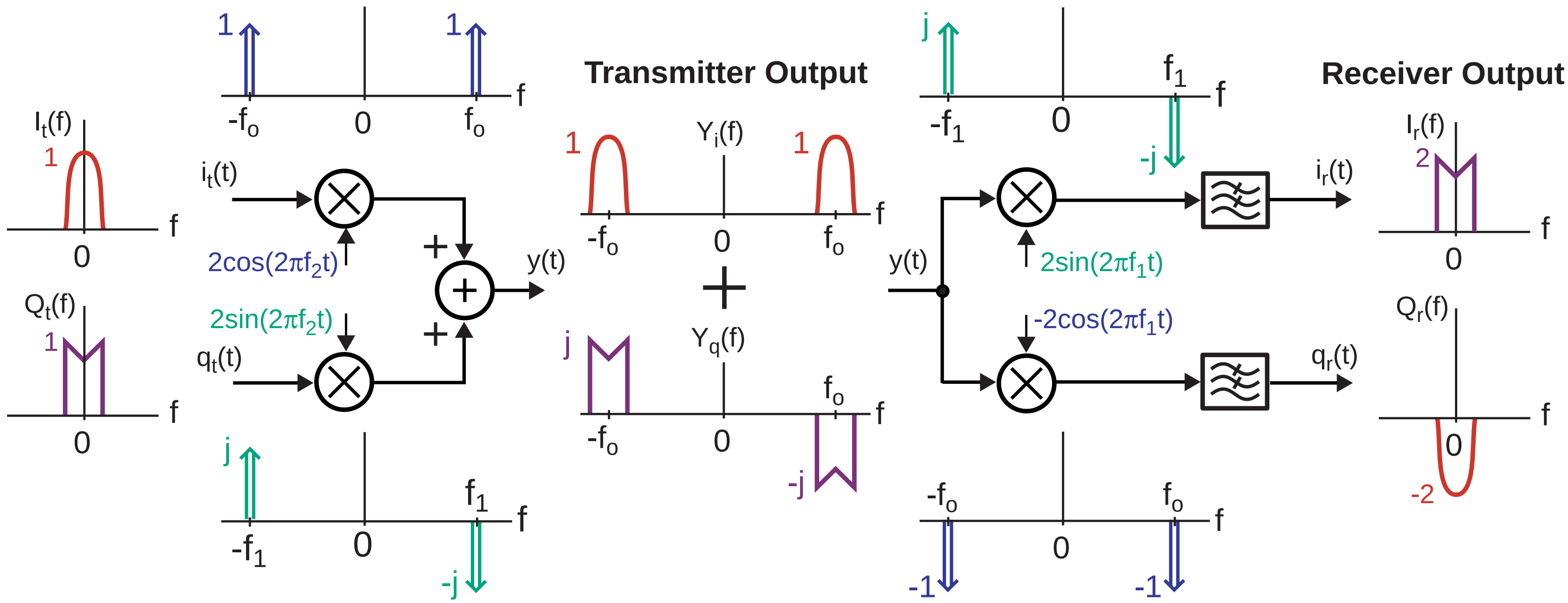
- I/Q signals take on a continuous range of values (as viewed in the time domain)
- Used for AM/FM radios, television (non-HDTV), and the first cell phones
- Newer systems typically employ digital modulation instead

I/Q Transceiver Frequency Domain View



- Demodulate using two sine waves in quadrature at receiver
  - Must align receiver LO signals in frequency and phase to transmitter LO signals
    - Proper alignment allows I and Q signals to be recovered as shown

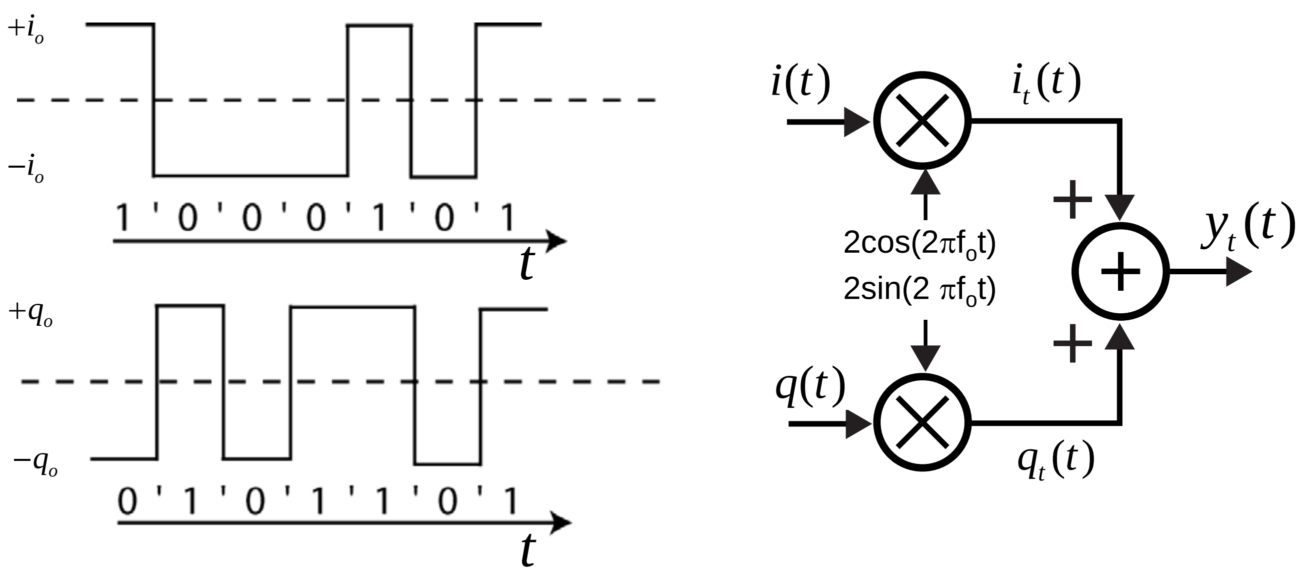
Impact of 90 Degree Phase Misalignment



- I and Q channels are swapped at receiver if its LO signal is 90 degrees out of phase with transmitter
  - However, no information is lost!
  - Can use baseband signal processing to extract I/Q signals despite phase offset between transmitter and receiver

Digital I/Q Modulation

Baseband Input



- I/Q signals take on discrete values at discrete time instants corresponding to digital data

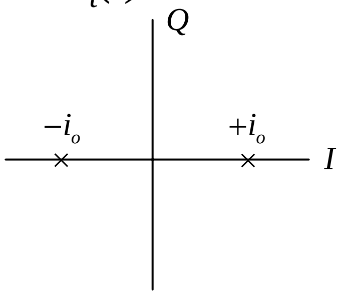
Polar View of Digital I/Q Modulation

Polar View shows amplitude and phase of $i_t(t)$, $q_t(t)$ and $y_t(t)$ combined signal for transmission at a given frequency f.

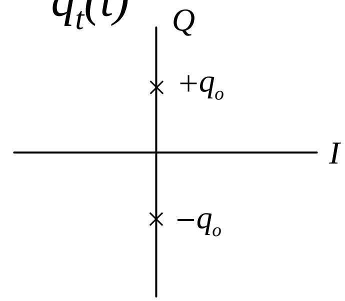
$i(t)$ and $q(t)$ have discrete values. In this case, binary values. $\pm i_o \quad \pm q_o$

$$i_t(t) = \pm i_o \cos(2\pi f_o t)$$
$$q_t(t) = \pm q_o \sin(2\pi f_o t)$$

$i_t(t)$



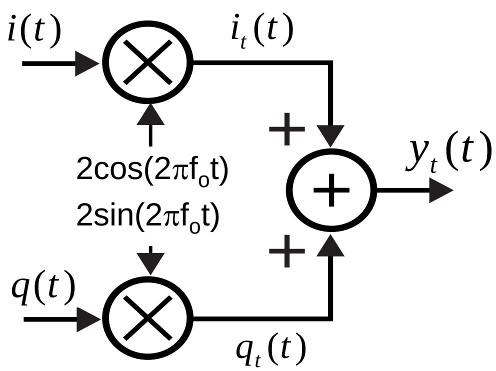
$q_t(t)$

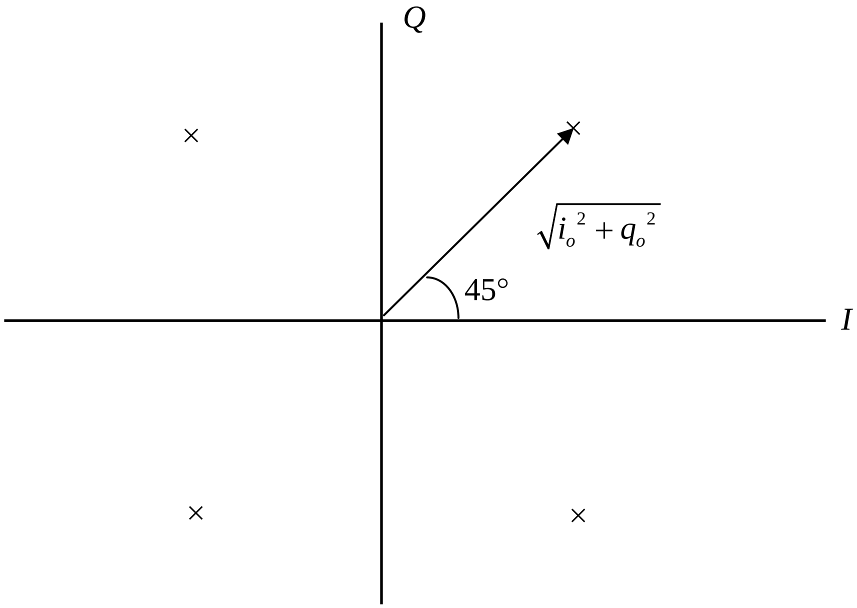


$$y_t(t) = \sqrt{i_o^{\,2} + q_o^{\,2}} \cos(2\pi f_o t + \theta(t))$$

$$where \;\; \theta(t) = \tan^{-1} \frac{\pm q_o}{\pm i_o}$$

Polar View of Digital I/Q Modulation (cont'd)





4 QAM
Quadrature
Amplitude
Modulation

$$Given\ \ i_o = q_o = 1$$

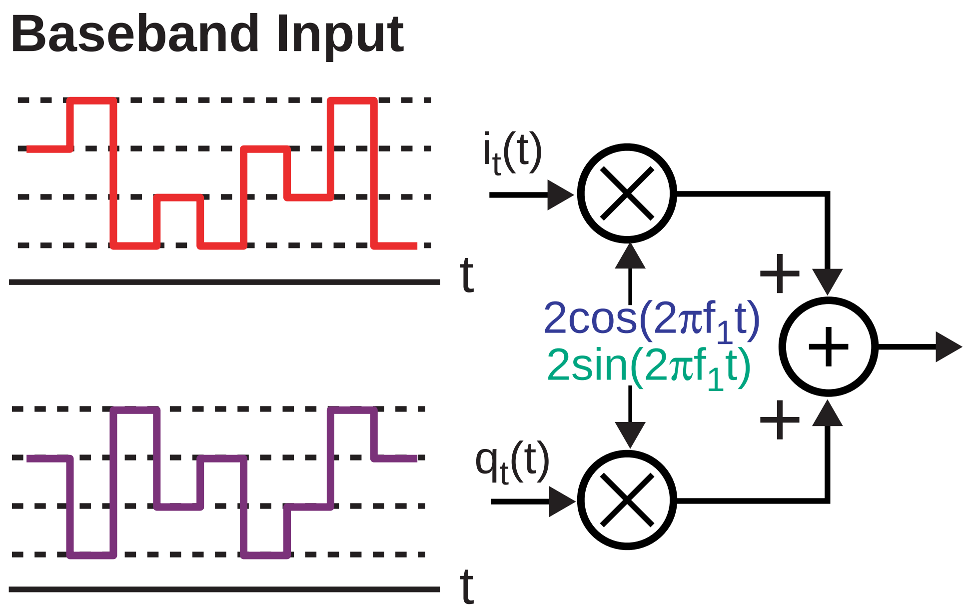
$$|y_t(t)| = \sqrt{2}$$

$$\theta(t)\ \ can\ have\ 4\ values$$

$$45°, 135°, -45°, -135°$$

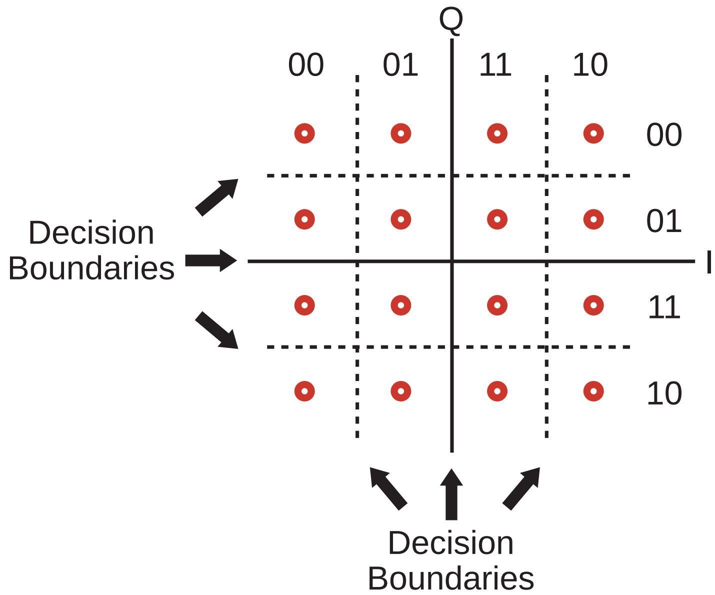
Transmission signal is sine wave at frequency f_0 with information encoded in discrete values of amplitude and phase.

Digital Modulation: 16-QAM



- I/Q signals take on discrete values at discrete time instants corresponding to digital data
- I/Q signals may be binary or multi-bit
  – Multi-bit shown above (4 levels each)

Constellation Diagram:16-QAM



- We can view I/Q values at sample instants on a two-dimensional coordinate system
- Decision boundaries mark up regions corresponding to different data values
- Gray coding used to minimize number of bit errors that occur if wrong decisions made due to noise

Advantages of Digital Modulation

- Allows information to be “packetized”
  - Can compress information in time and efficiently send as packets through network
  - In contrast, analog modulation requires “circuit-switched” connections that are continuously available
    - Inefficient use of radio channel if there is “dead time” in information flow
- Allows error correction to be achieved
  - Less sensitivity to radio channel imperfections
- Enables compression of information
  - More efficient use of channel
- Supports a wide variety of information content
  - Voice, text and email messages, video can all be represented as digital bit streams