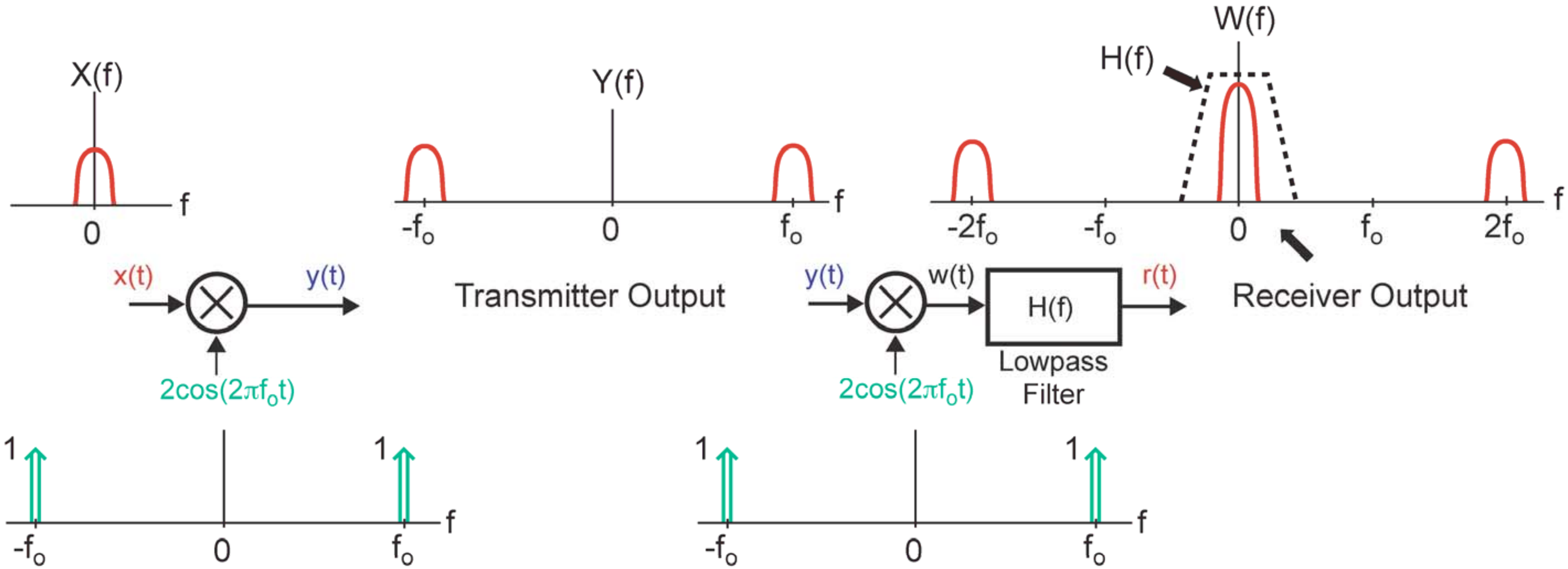
I-Q Transmission
Lecture 17

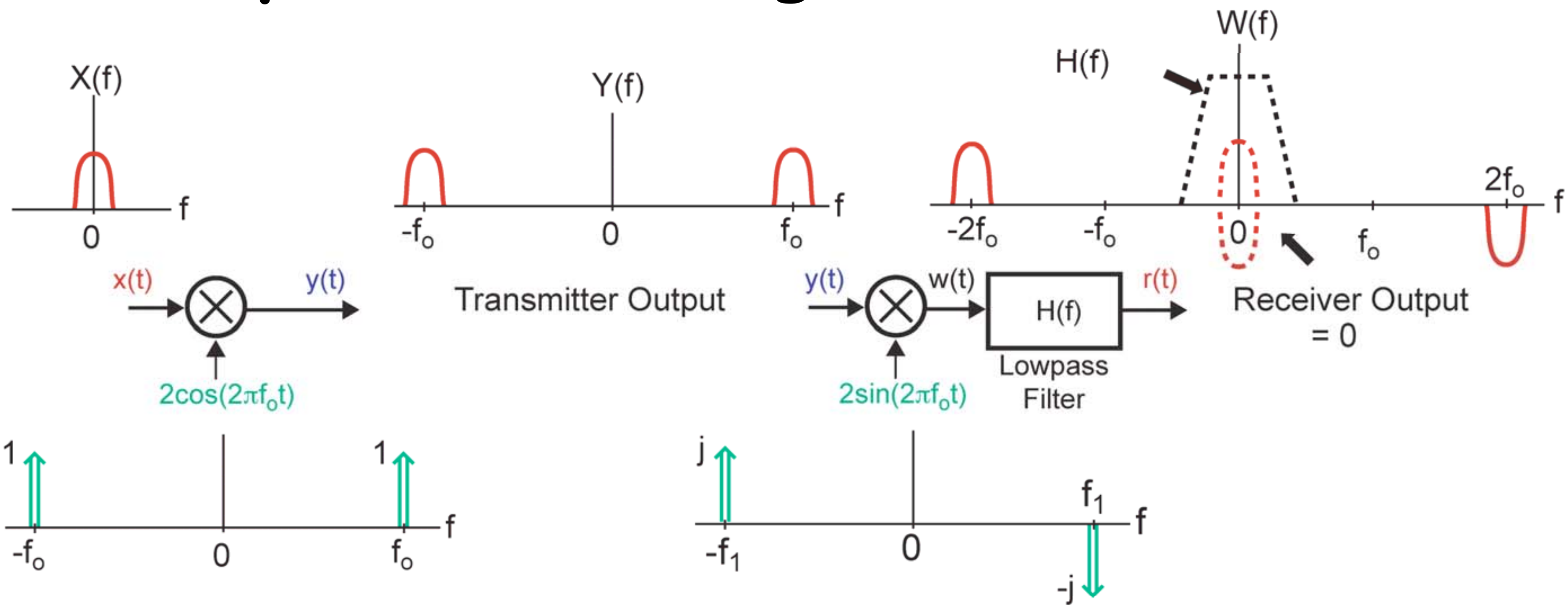
- I-Q transmission
- Sending Digital Data
  - Binary Phase Shift Keying (BPSK): sending binary data over a single frequency band
  - Quadrature Phase Shift Keying (QPSK): sending twice the amount of binary data
  - Constellation Diagrams and Eye Diagrams
- Summary

Modulation and Demodulation



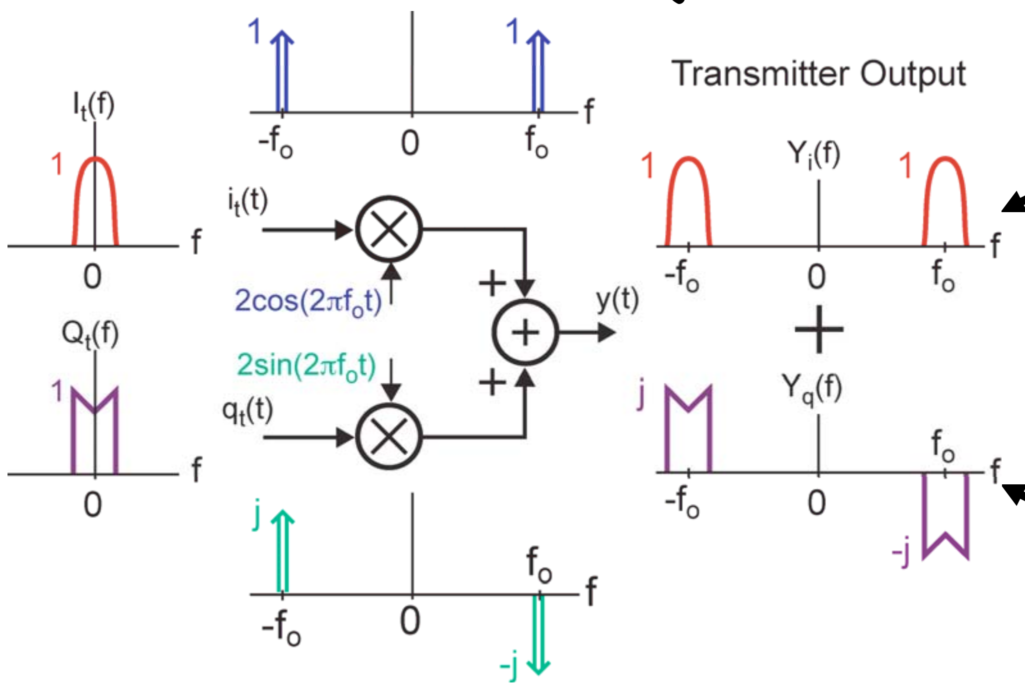
- **When transmitter and receiver local oscillators are matched in phase:**
  - **Demodulated signal *constructively* adds at baseband**

Impact of 90 Degree Phase Shift



- When transmitter and receiver local oscillators are 90 degree offset in phase:
  - Demodulated signal *destructively* adds at baseband
- I-Q modulation exploits this. We transmit twice as much data in the same frequency band by using two carriers 90 degrees offset in phase.

I/Q Modulation

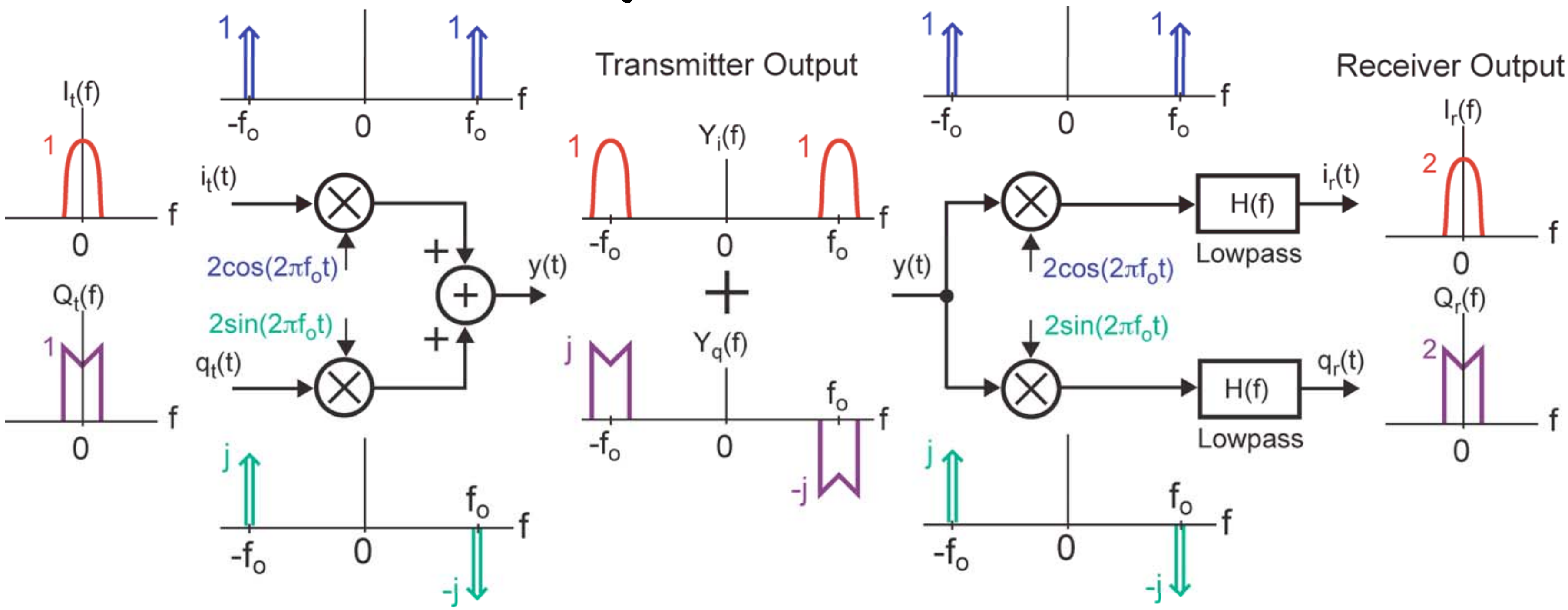


I stands for *in-phase* component

Q stands for *quadrature* component

- Consider modulating with both a cosine and sine wave and then adding the results
  - This is known as I/Q modulation
- The I/Q signals occupy the same frequency band, but one is *real* and one is *imaginary*
  - We will see that we can recover *both* of these signals

I/Q Demodulation

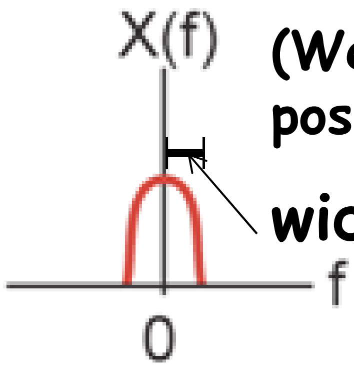


- Here we take advantage of the property that 90 degree shift between the two local oscillators will destructively cancel out the baseband signal
- I/Q modulation allows twice the amount of *information* to be sent over the same frequency band

What can go wrong here?

Modulated Signal requires 2x the Bandwidth

Original Signal

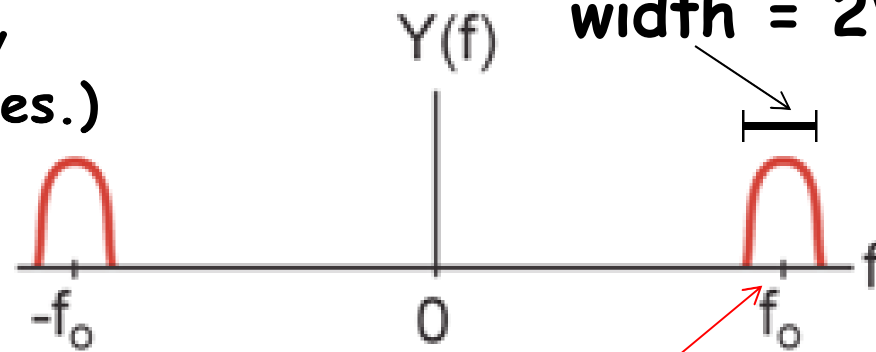


(We consider only positive frequencies.)

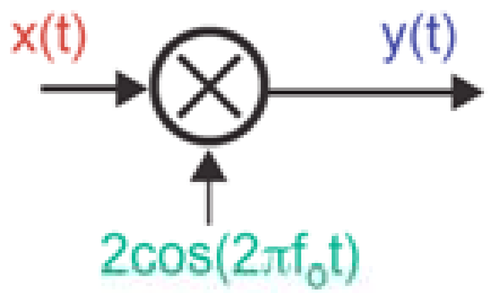
width = W

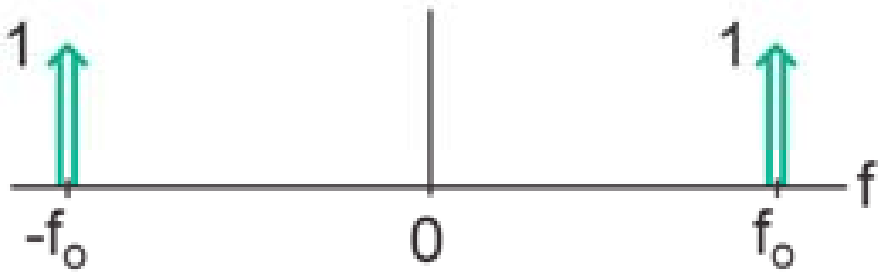
Modulated Signal

width = 2W

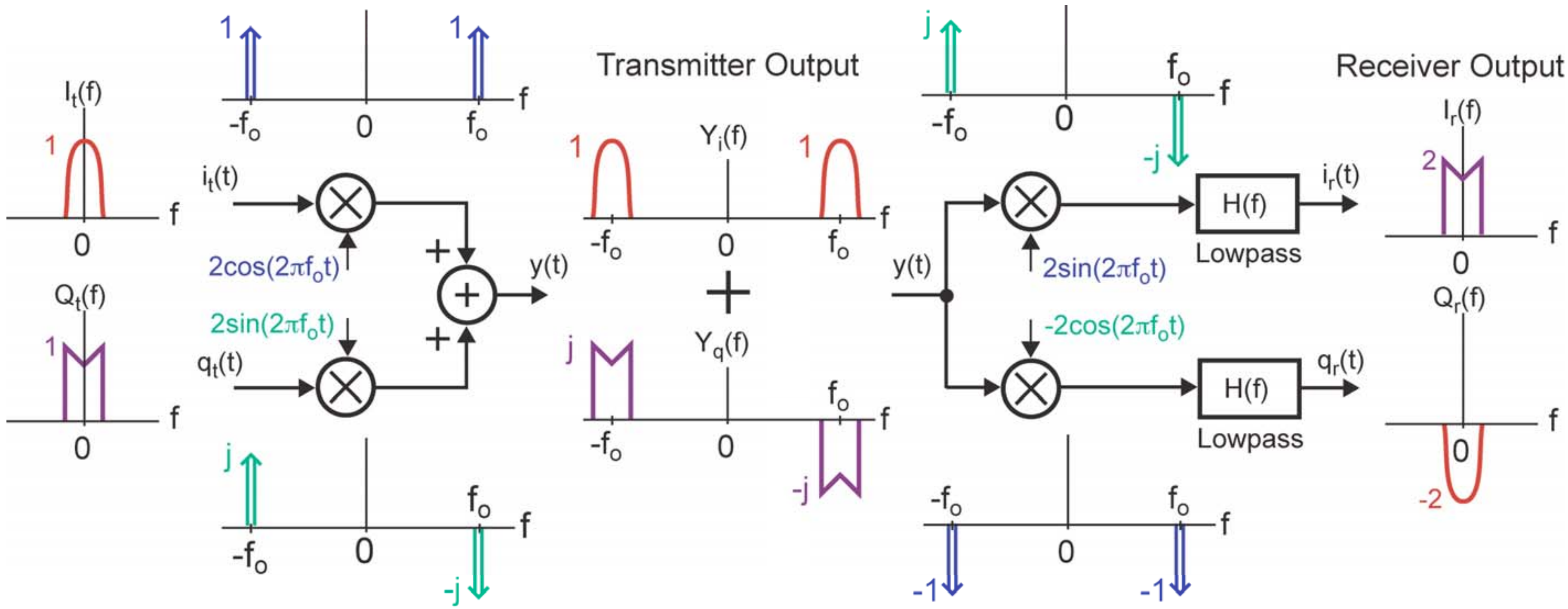


I-Q modulation sends two signals in the same part of the frequency spectrum.





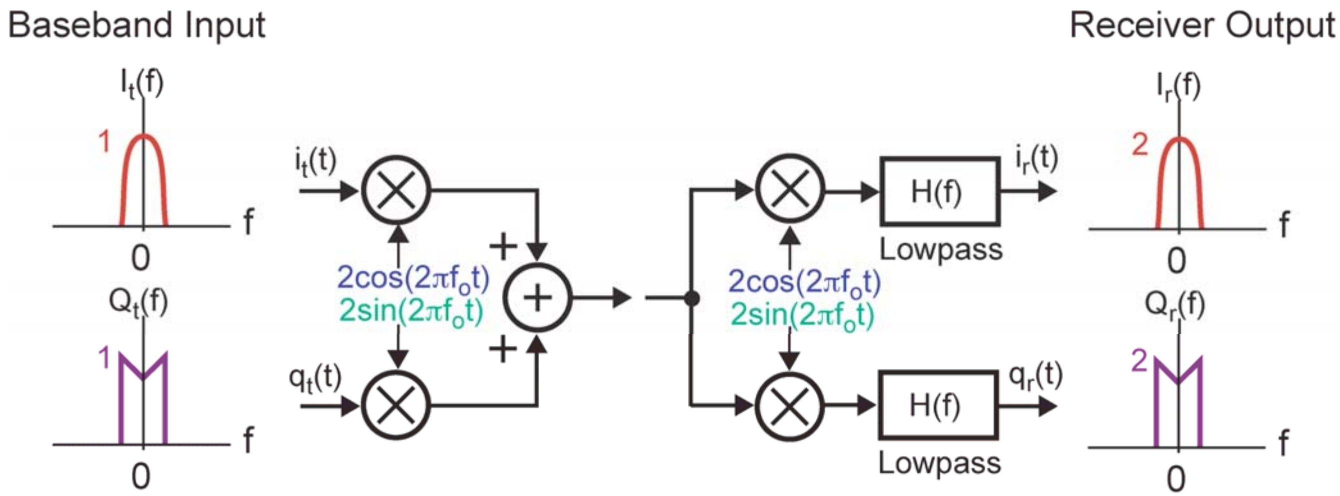
Impact of 90 Degree Phase Shift



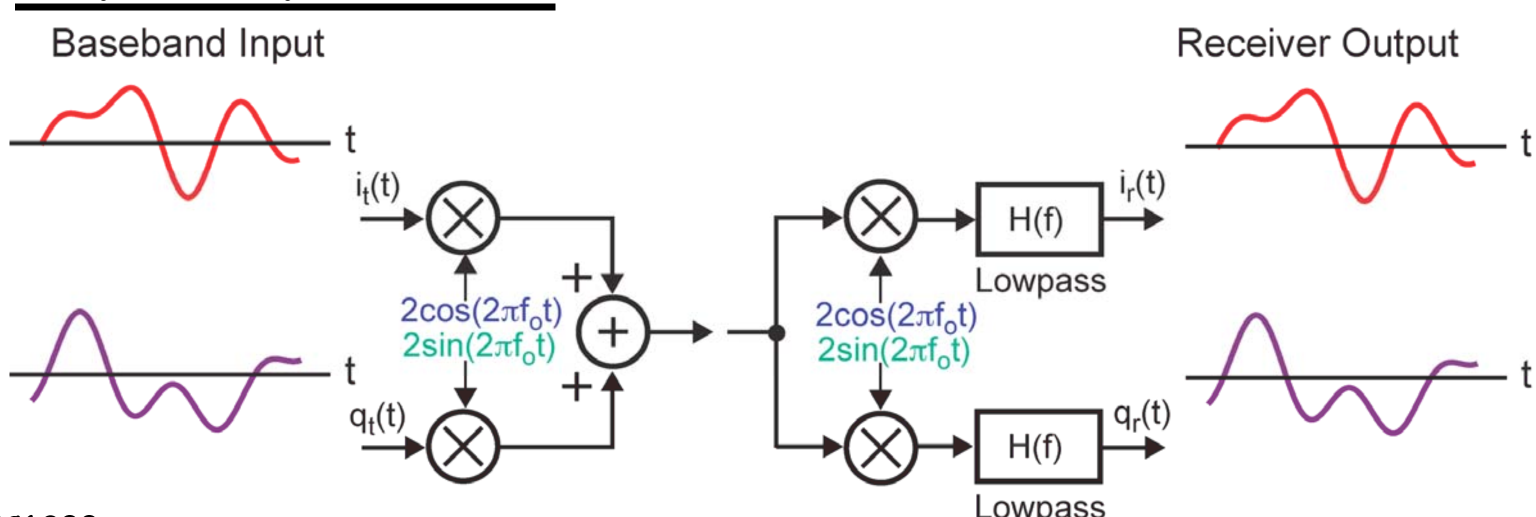
- I and Q channels get swapped at receiver
  - Key observation: no *information* is lost!
- For intermediate phase shifts, the signals are I and Q signals are mixed.

Summary of *Analog* I/Q Modulation

- **Frequency domain view**



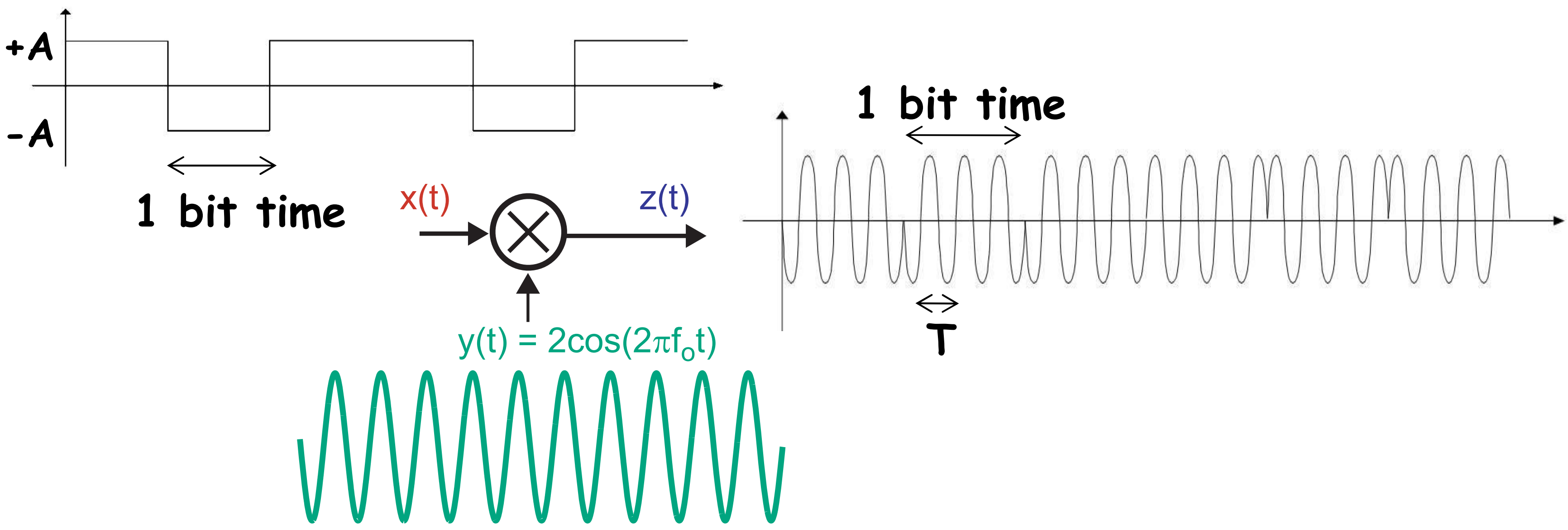
- **Time domain view**



Digital I&Q Modulation

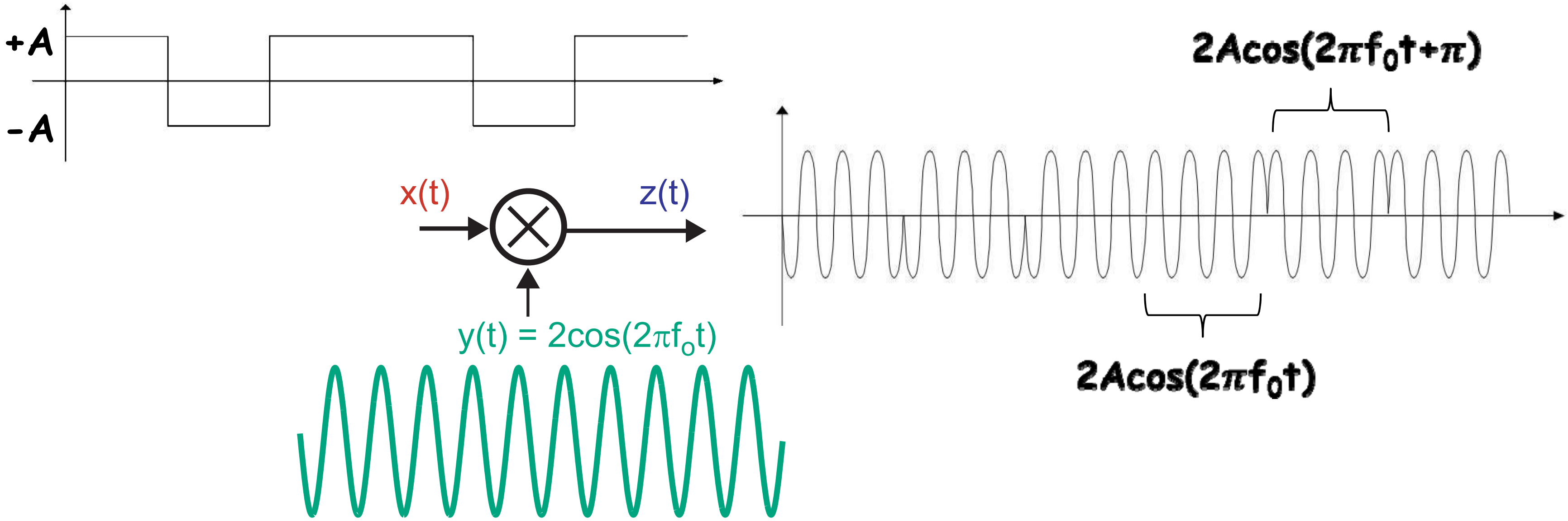
- Allows communication systems to be constructed from "computers", like micro processors
  - Sophisticated processing becomes possible
  - Inexpensive to build
- Allows information to be "packetized"
  - Efficiently send information as packets through network
  - Analog signal requires "circuit-switched" connections
- 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

Sending Binary Data with a Carrier



- ***Motivation:*** **leverage *analog communication channel* to send *digital bits***
- **We represent each binary zero or one as a sampled data waveform x(t) held at -A or +A for 1 bit time.**
- **This sampled data waveform modulates a carrier with normalized frequency f_0 Hz. Typically, the period $T = 1/f_0$ is much smaller than 1 bit time.**

Binary Phase Shift Keying (BPSK)

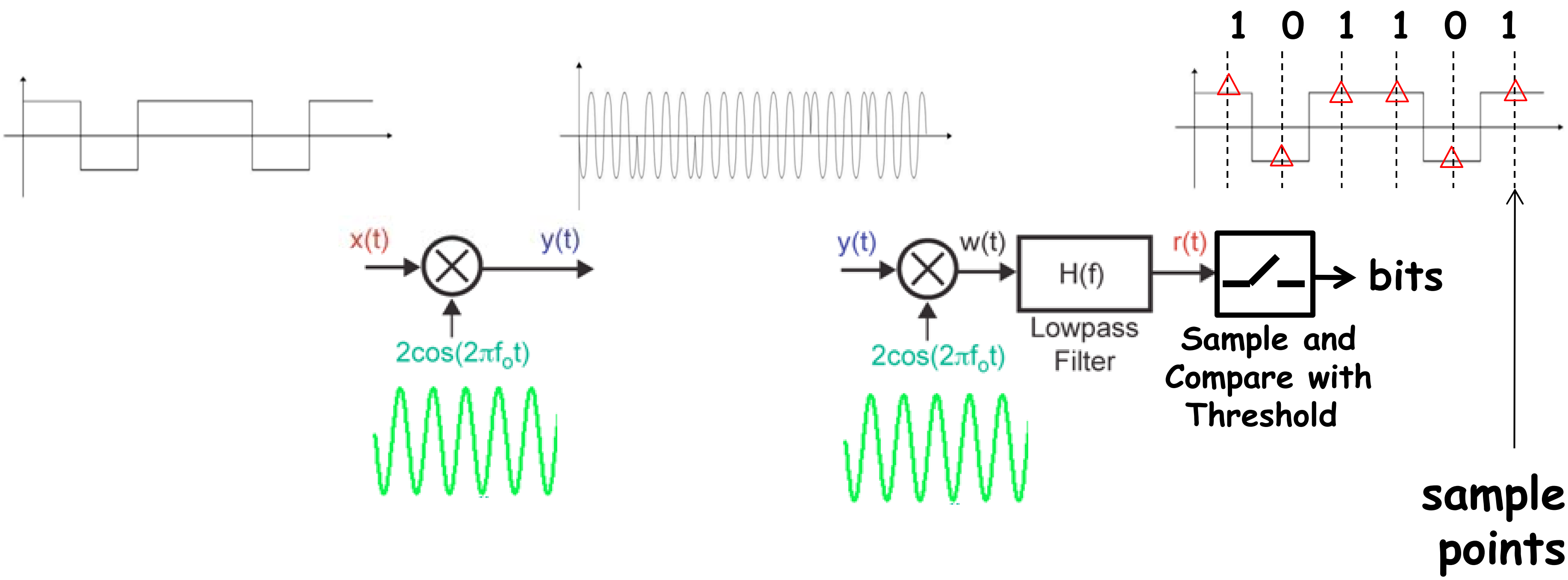


- The modulation is equivalent to send one of two waveforms, depending upon the bit to be transmitted.
  - If the bit is 1, we send $2A\cos(2\pi f_0 t)$
  - If the bit is 0, we send $-2A\cos(2\pi f_0 t) = 2A\cos(2\pi f_0 t+\pi)$

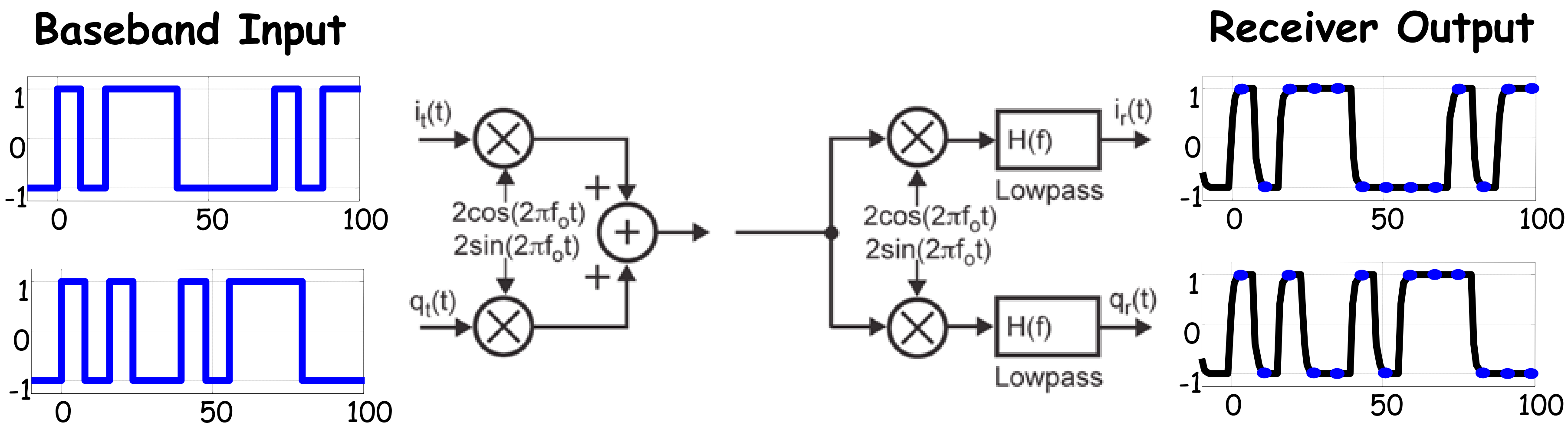
- This method is called Binary Phase Shift Keying (BPSK), since a sign change is equivalent to a shift in carrier phase by π

At the receiver side

- In order to receive the digital data transmitted in this way, we demodulate the received signals and sample the data waveform at the appropriate point at the output



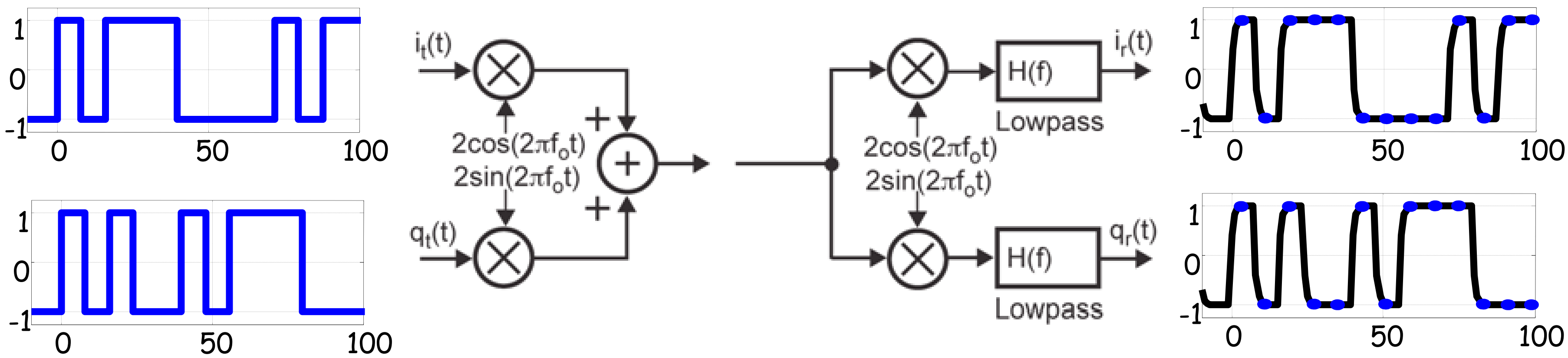
Digital I/Q Modulation



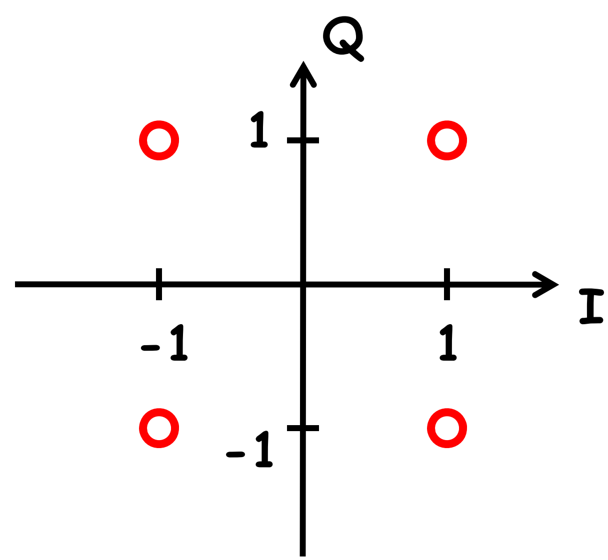
- Using the same principle of I/Q transmission to transmit two baseband signals
- At receiver, demodulate and sample the I/Q waveforms every bit time (e.g. at blue dots)
  - Determine whether the transmitted bit on each channel was a 0 or 1 by comparing the sampled value with a threshold (e.g. 0).

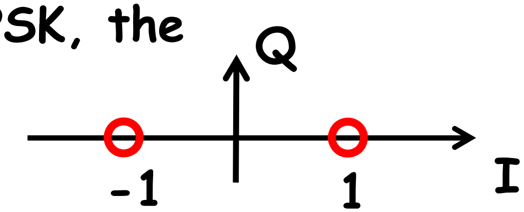
Constellation Diagrams and Quadrature Phase Shift Keying (QPSK)

Baseband Input | Receiver Output

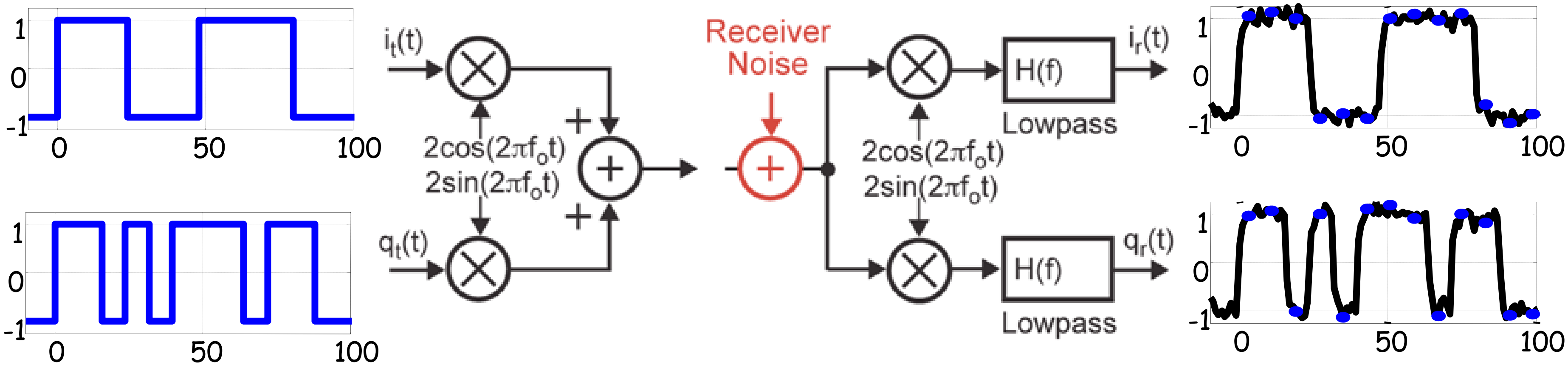


- Plot I/Q sampled values on I-Q (x-y) axis
  - Example: sampled I/Q value of {1,-1} forms a dot at I=1, Q=-1
  - As more samples are plotted, constellation diagram eventually displays all possible symbol values
- Constellation diagram provides a sense of how easy it is to distinguish between different symbols
- For the simple case of BPSK, the constellation diagram is

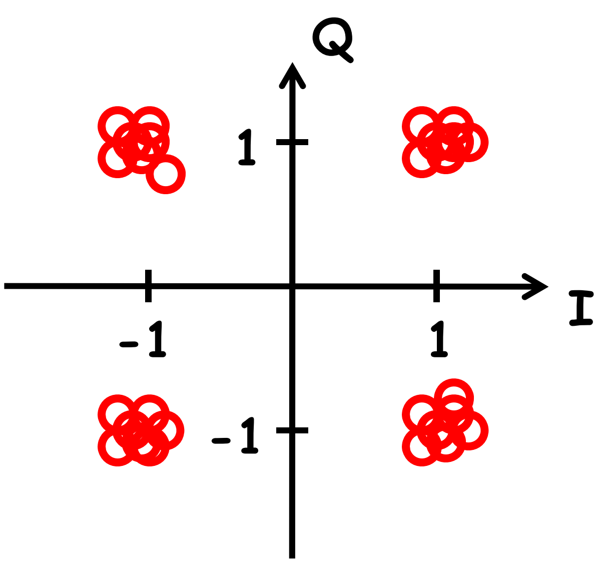




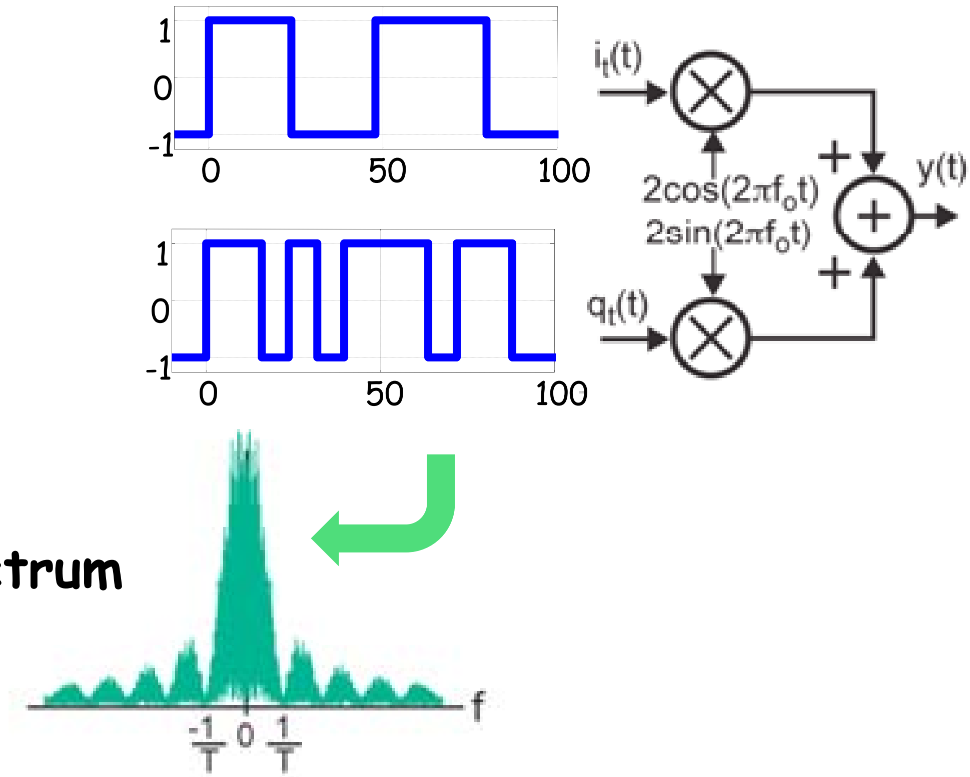
The Impact of Noise



- Noise perturbs sampled I/Q values
  - Constellation points no longer consist of single dots for each symbol
- If noise is big enough, this can cause bit errors!



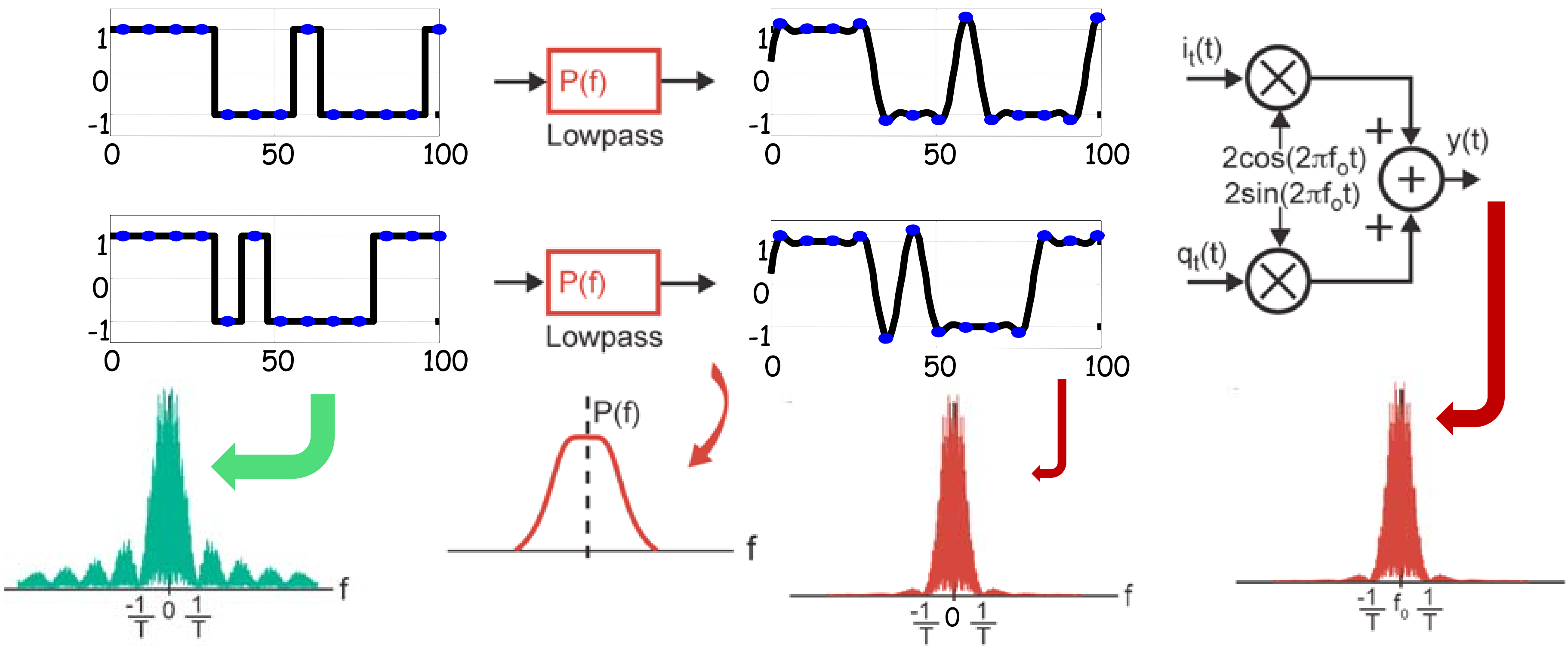
To save transmission bandwidth



spectrum

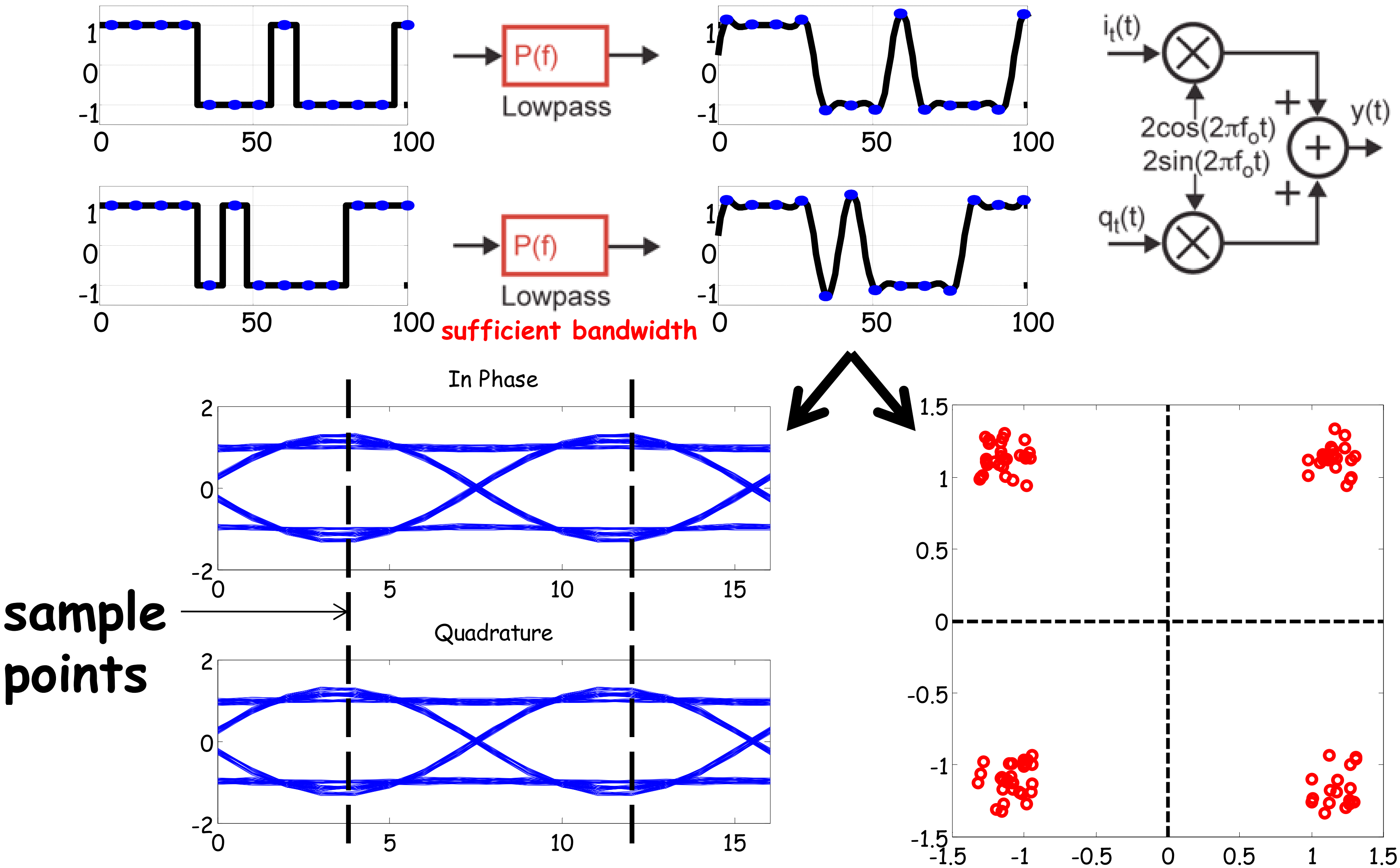
- **Want transmitted spectrum with minimal bandwidth, since wireless communication channels are a shared resource**
  - **However, sharply changing I/Q waveforms lead to a wide bandwidth spectrum**
- **Thus, we add a low pass filter before modulation.**

Impact of Transmit Filter



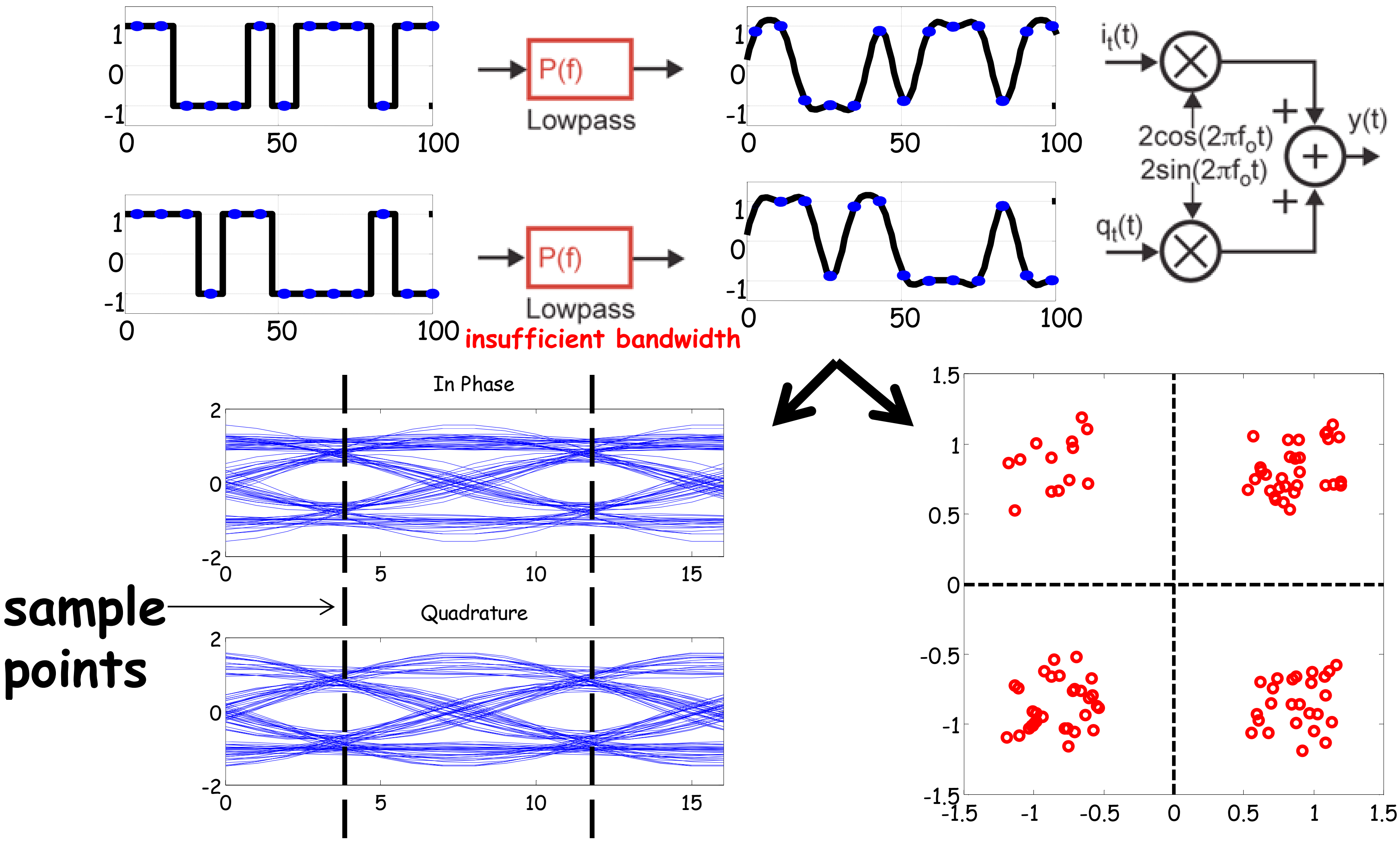
- **Transmit filter enables reduced bandwidth for transmitted spectrum**
- **Issue: can lead to intersymbol interference (ISI)**
  - By removing the high frequency components, the rise time and the fall time of the signal increase
  - Constellation diagram displays vulnerability to making bit errors

Impact of High Bandwidth Filter



- Open eye diagrams lead to tight symbol groupings in constellation

Impact of Low Bandwidth Filter



- Eye diagrams intuitively show increased ISI and sensitivity to sample time placement.

Summary

- I/Q modulation allows twice the amount of information to be sent in the same frequency band
- To leverage the analog communication channel for sending digital bits, we multiply the digital bits with a carrier
- Using the same principle of I/Q transmission, we can transmit two separate digital data over the same frequency band
- There is a tradeoff between saving transmission bandwidth and minimizing intersymbol interference (ISI)