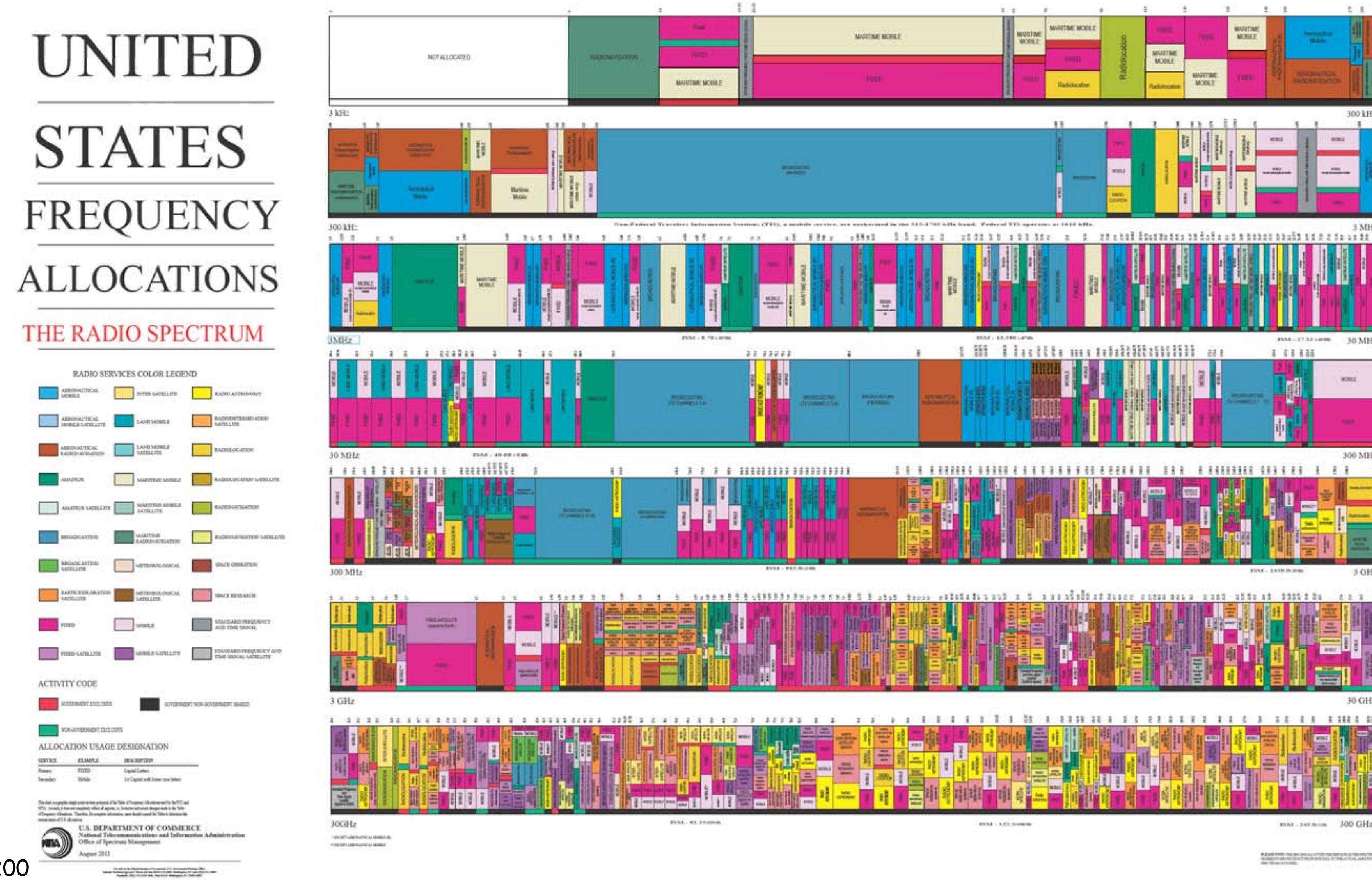
Signal Transmission- Demodulation
Lecture 16

- De-Multiplexing
- Demodulation
- Bandpass and low pass filtering
- Time and Frequency Domain Pictures
- Practical receivers Radio Spectrum

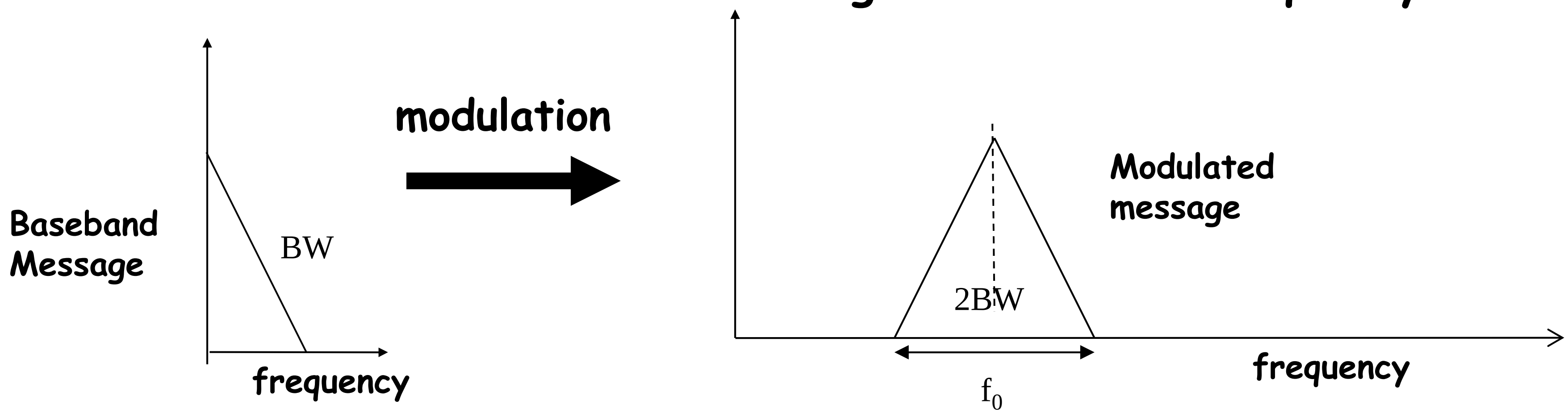
Radio Spectrum

- The radio spectrum provides us with sufficient spectrum to allow us to transmit many signals simultaneously

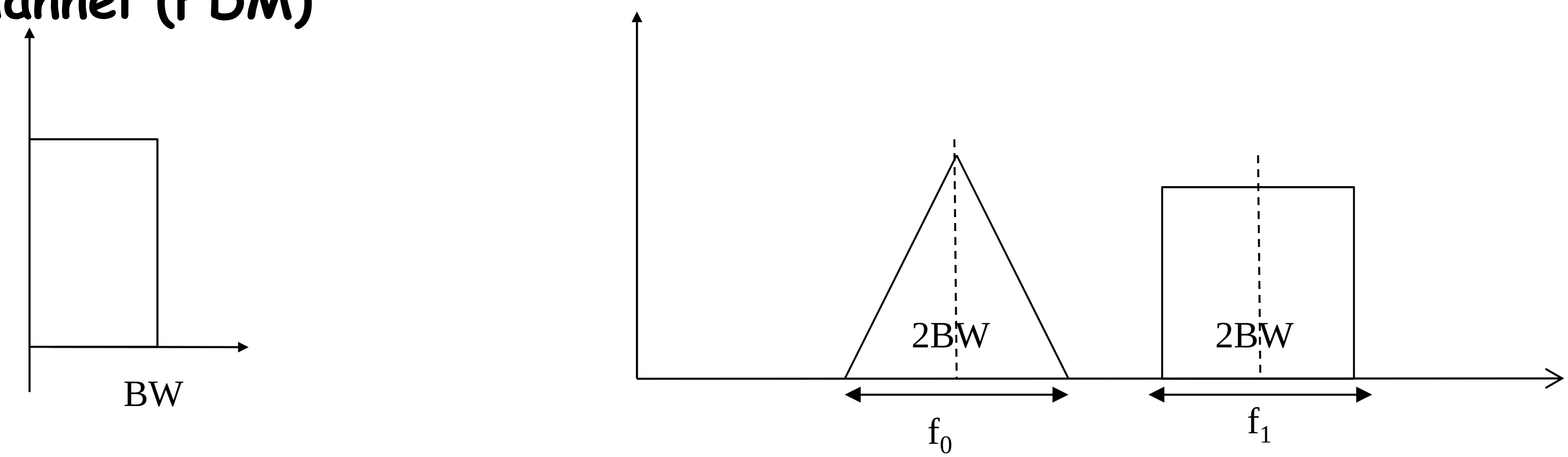


Frequency Division Multiplexing (FDM)

- We first translate baseband signal to center frequency fo



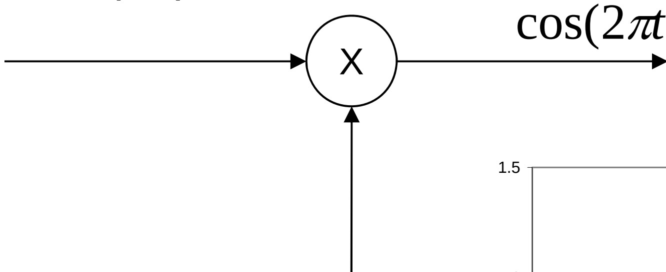
- Then translate second message to f_1 so we share the channel (FDM)



A simple example

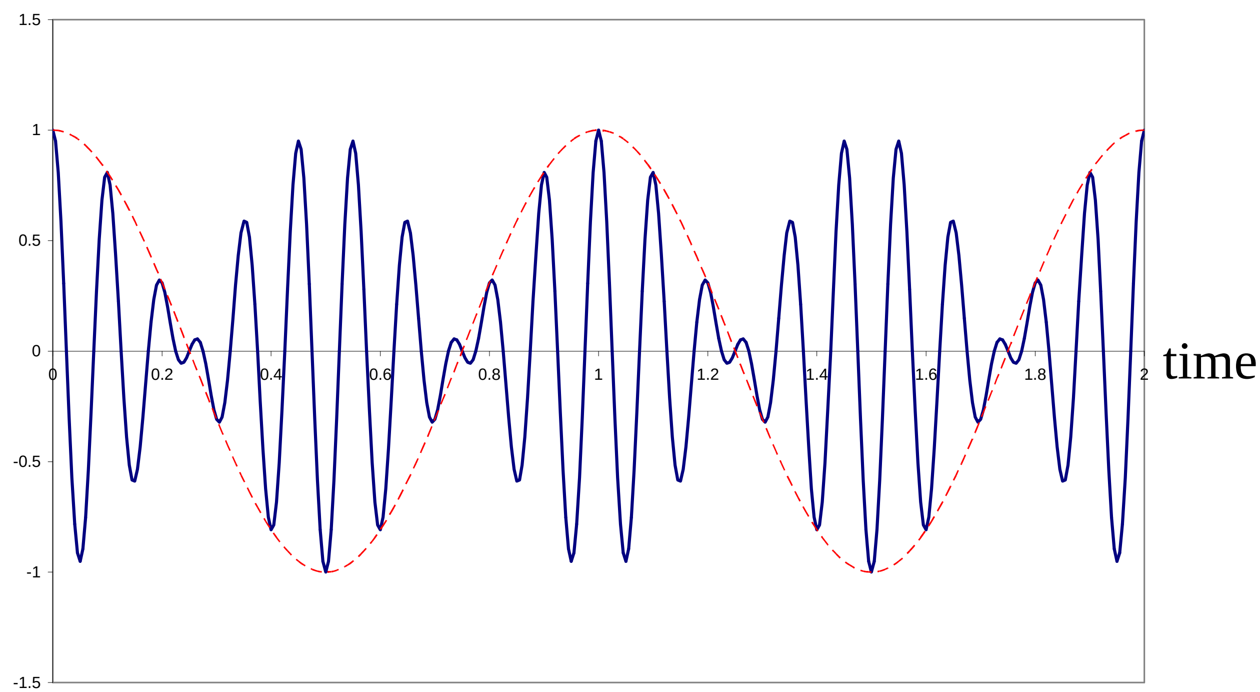
Consider modulating a 1 Hz sinusoidal signal to a carrier frequency at 10 Hz

m(t) = cos(2π*t)*



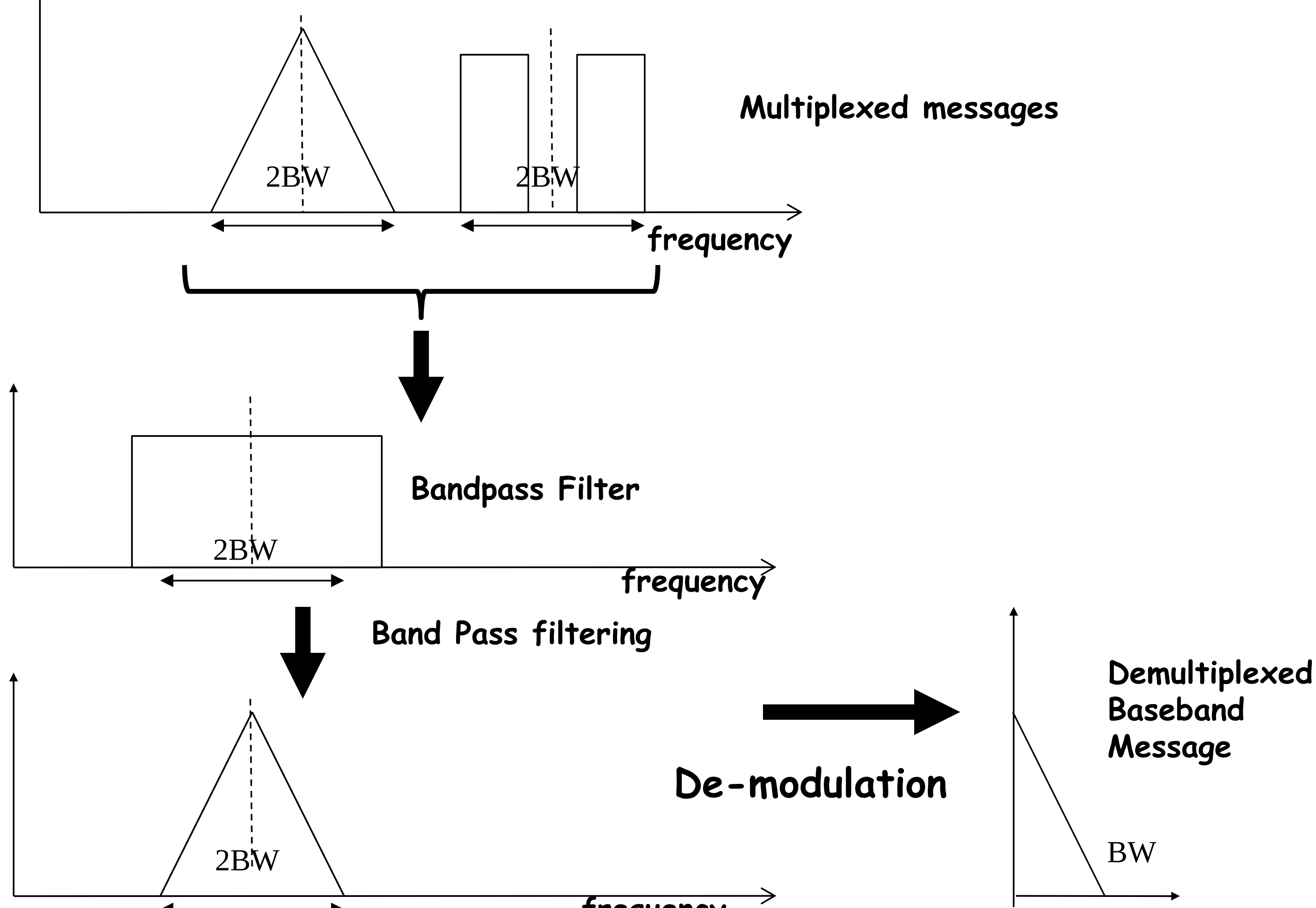
cos(2π*10t)*

$$\cos(2\pi t)\times\cos(2\pi\times 10t)=\frac{1}{2}\cos(2\pi\times 9t)+\frac{1}{2}\cos(2\pi\times 11t)$$



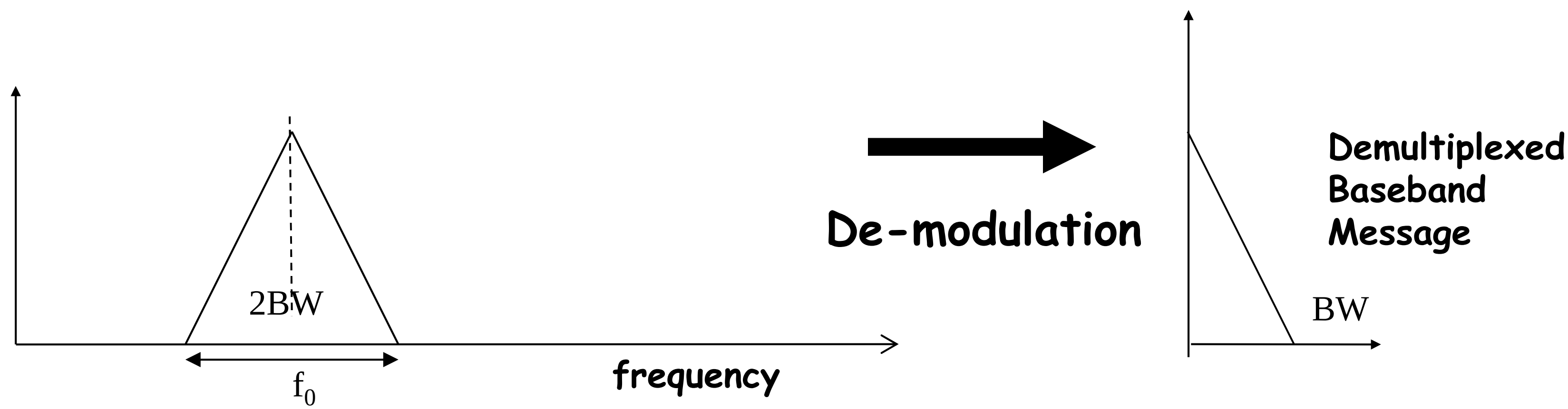
De-Multiplexing

- **We must also retrieve or de-multiplex the signals too**



De-Modulation

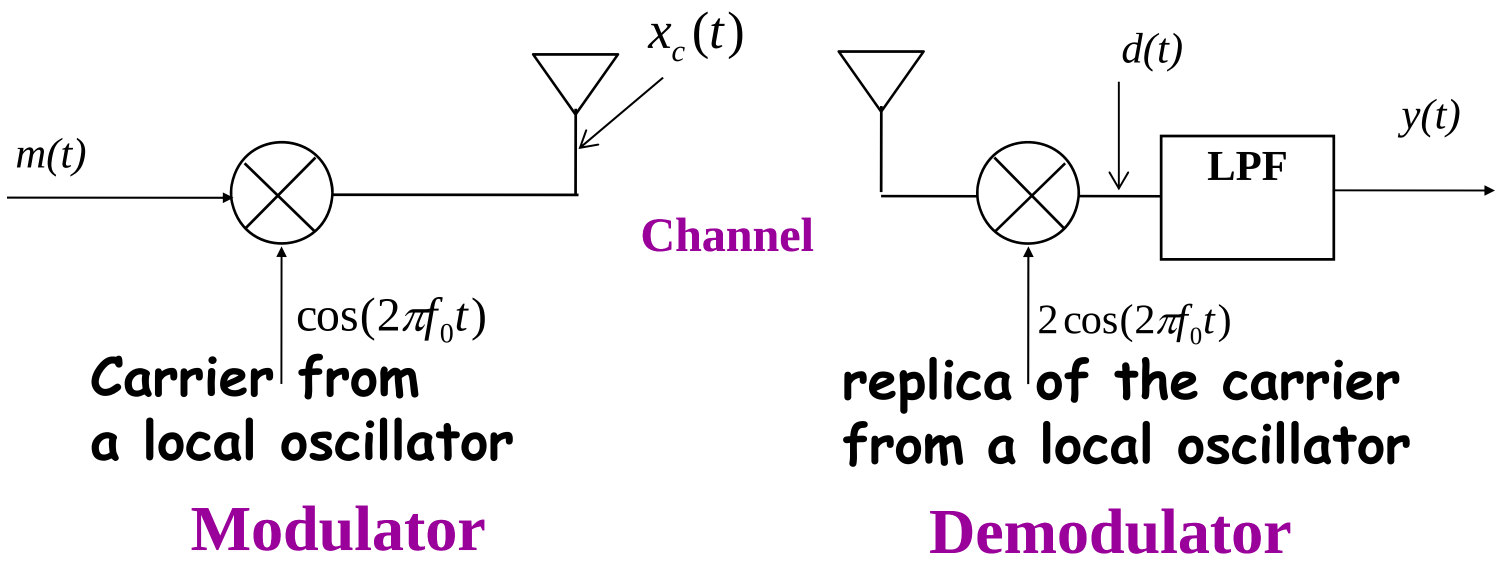
- We must somehow translate the signal back to baseband and this is known as demodulation



- Since it is just a frequency translation again we can simply use multiplication or mixing again as in in modulation

Demodulation

- Demodulation is the process of recovering the original message from the modulated signal
- Demodulation is performed by (i) mixing the modulated signal with a replica of the carrier and (ii) low pass filtering (LPF)



Understanding demodulation

$$\begin{aligned} d(t) &= \boxed{2x_c(t)}\cos(2\pi f_0 t) \\ &= 2\boxed{(A_c m(t)\cos(2\pi f_0 t))}\cos(2\pi f_0 t) \\ &= \underbrace{A_c m(t)}_{\text{baseband}} + \underbrace{A_c m(t)\cos(2\pi \bullet 2 f_0 t)}_{\text{high frequency}} \end{aligned}$$

- **If a low-pass filtering (LPF) is then used to remove the high frequency term ($2f_0$), we will recover the original message - Demodulation**

$$y(t) = A_c m(t)$$

Demodulation (complex exponentials)

$$d(t) = 2x_c(t)\left[\frac{e^{j2\pi f_0 t} + e^{-j2\pi f_0 t}}{2}\right]$$

$$= 2A_c m(t)\left[\frac{e^{j2\pi f_0 t} + e^{-j2\pi f_0 t}}{2}\right]\left[\frac{e^{j2\pi f_0 t} + e^{-j2\pi f_0 t}}{2}\right]$$

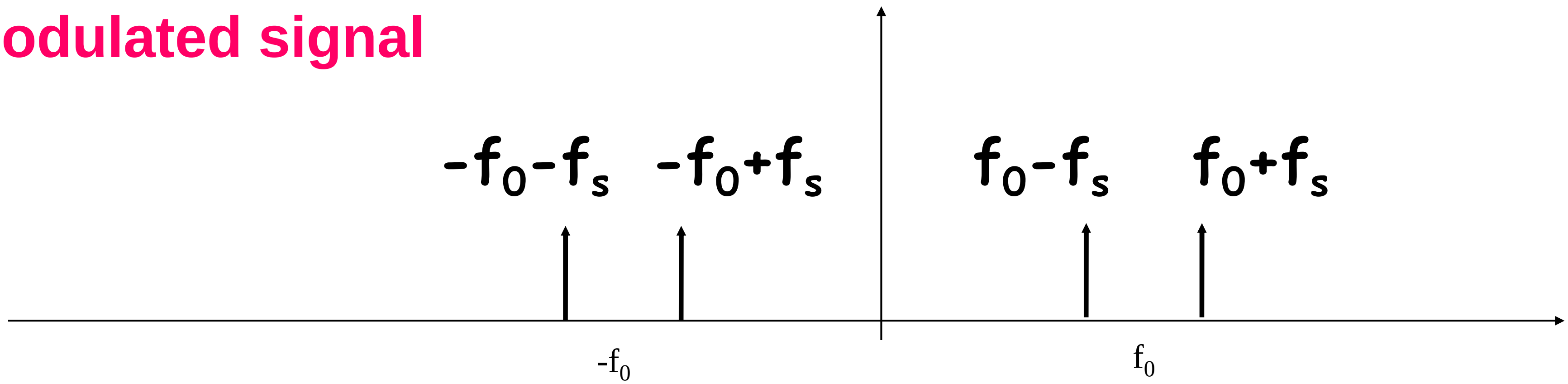
$$= \underbrace{A_c m(t)}_{\text{baseband}} + A_c m(t)\underbrace{\left[\frac{e^{j2\times 2\pi f_0 t} + e^{-j2\times 2\pi f_0 t}}{2}\right]}_{\text{high frequency}}$$

- **If a low-pass filtering (LPF) is then used to remove the high frequency term ($2f_0$), we will recover the original message - Demodulation**

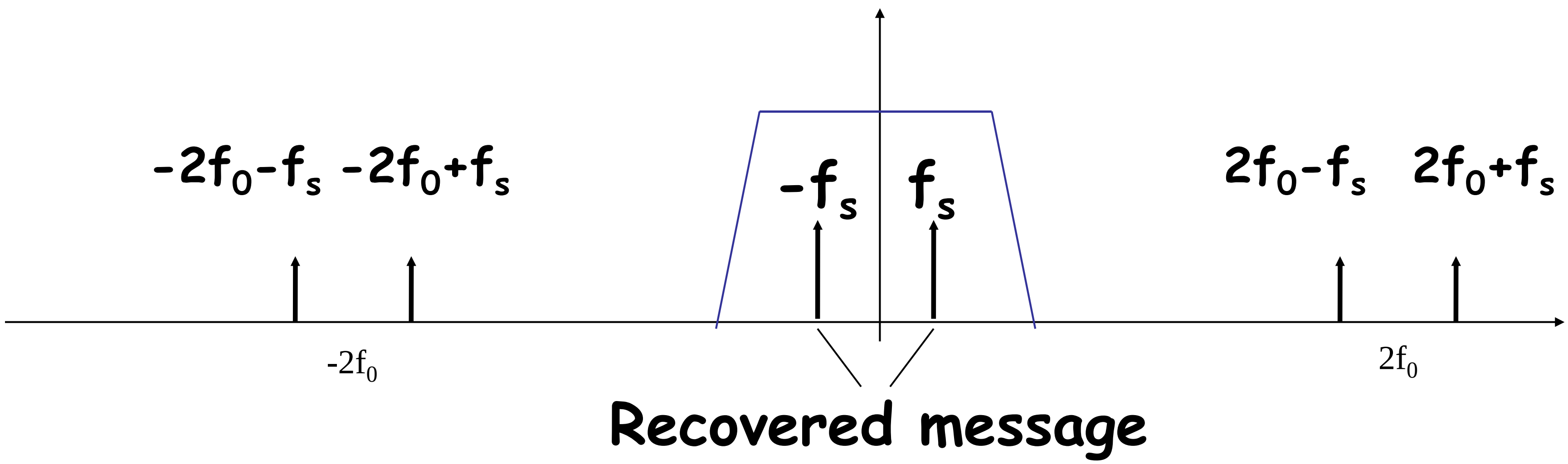
$$y(t) = A_c m(t)$$

Picture of demodulation

Modulated signal

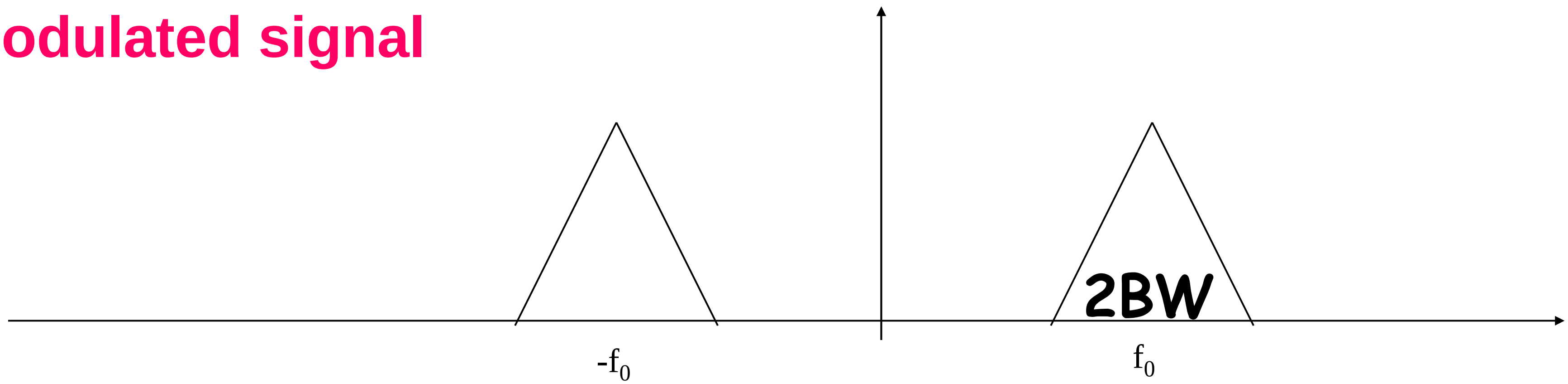


Demodulation (freq. mixing + LPF)

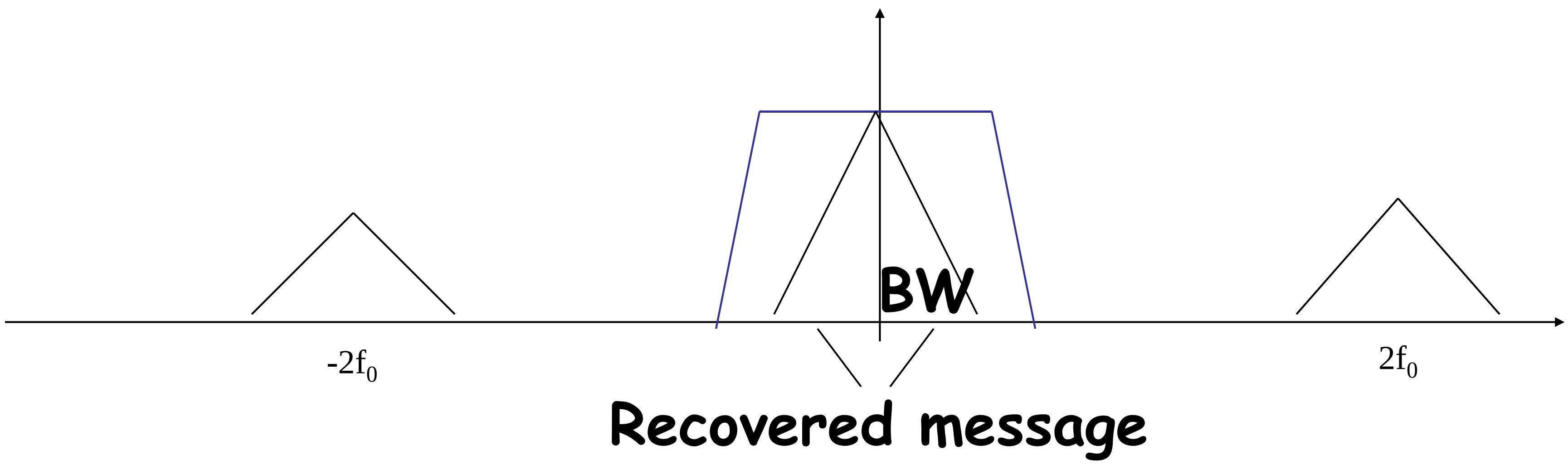


Picture of demodulation

Modulated signal



Demodulation (freq. mixing + LPF)

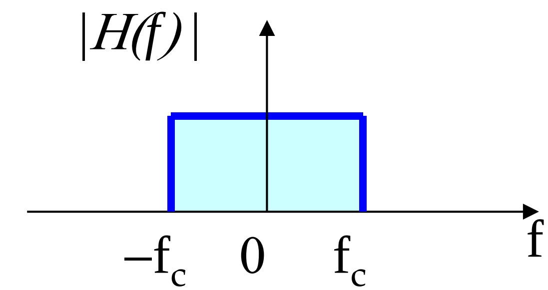


Ideal Frequency Selective Filters

Low-Pass

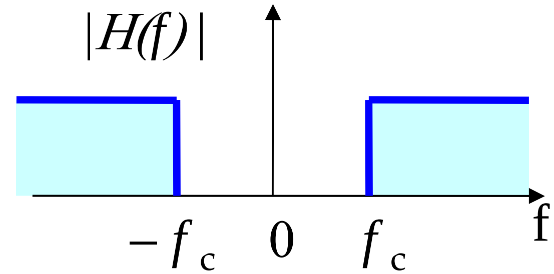
$$H(f)=\begin{cases}1 & |f|<f_c\\ 0 & f>f_c\end{cases}$$

f_c: cutoff frequency



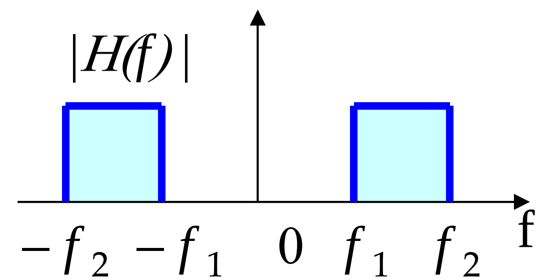
High-Pass

$$H(f)=\begin{cases}0 & |f|<f_c\\ 1 & |f|>f_c\end{cases}$$



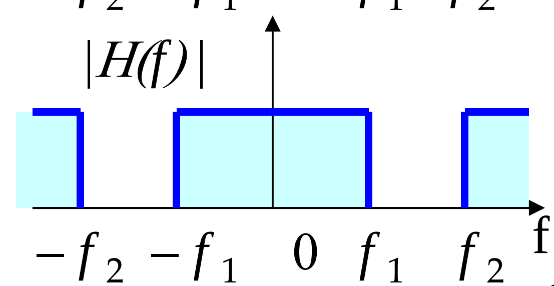
Band-Pass

$$H(f)=\begin{cases}1 & f_1<|f|<f_2\\ 0 & \text{otherwise}\end{cases}$$



Band-Stop

$$H(f)=\begin{cases}0 & f_1<|f|<f_2\\ 1 & \text{otherwise}\end{cases}$$

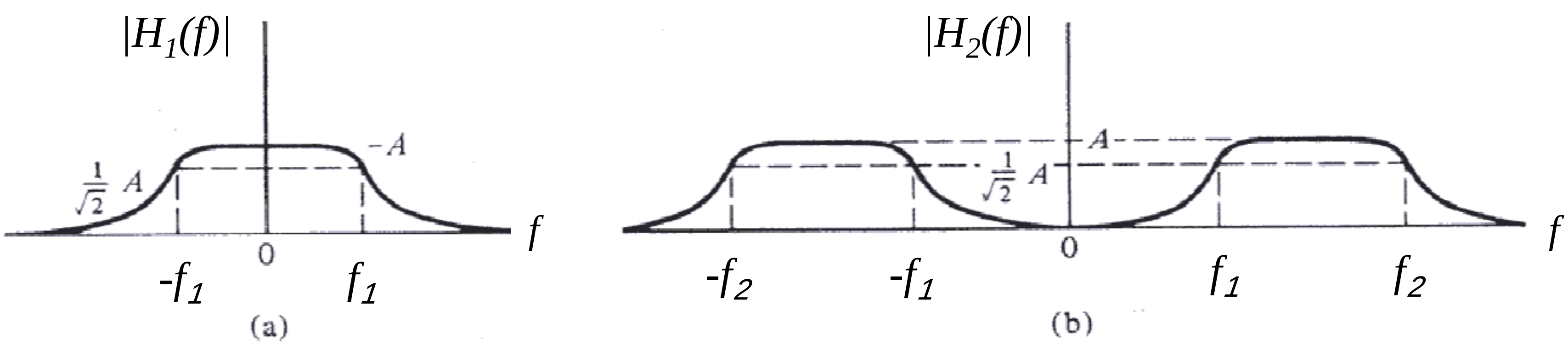


Filter Bandwidth

The bandwidth (BW_{system}) of a system *h(t)* is defined as the interval of *positive* frequencies over which the *magnitude* |*H(f)*| remains within a given numerical factor.

A popular factor is $1/\sqrt{2}$. At this frequency, the energy or power spectrum has ½ (3dB) of its peak value. For this reason, we often refer the corresponding bandwidth as (-)3dB bandwidth.

Some system may use more than one bandwidth to describe the *shape* of |*H(f)*|. For example, both –1dB and –3dB bandwidth are stated.

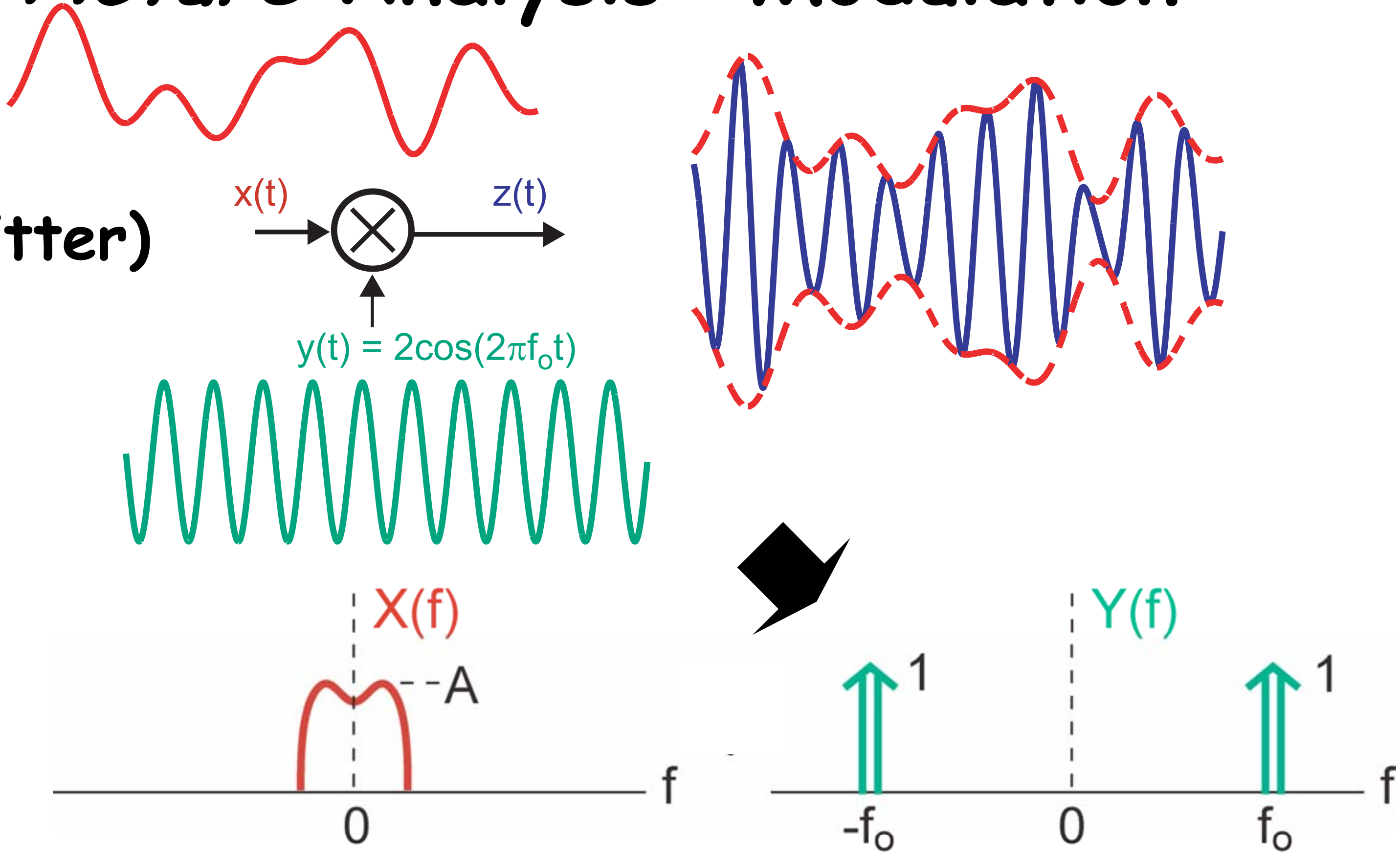


$BW = f_1$

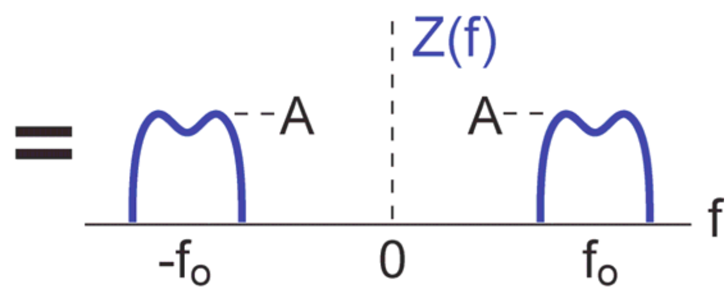
$BW = (f_2 - f_1)$

Frequency and Time Domain *Picture* Analysis- Modulation

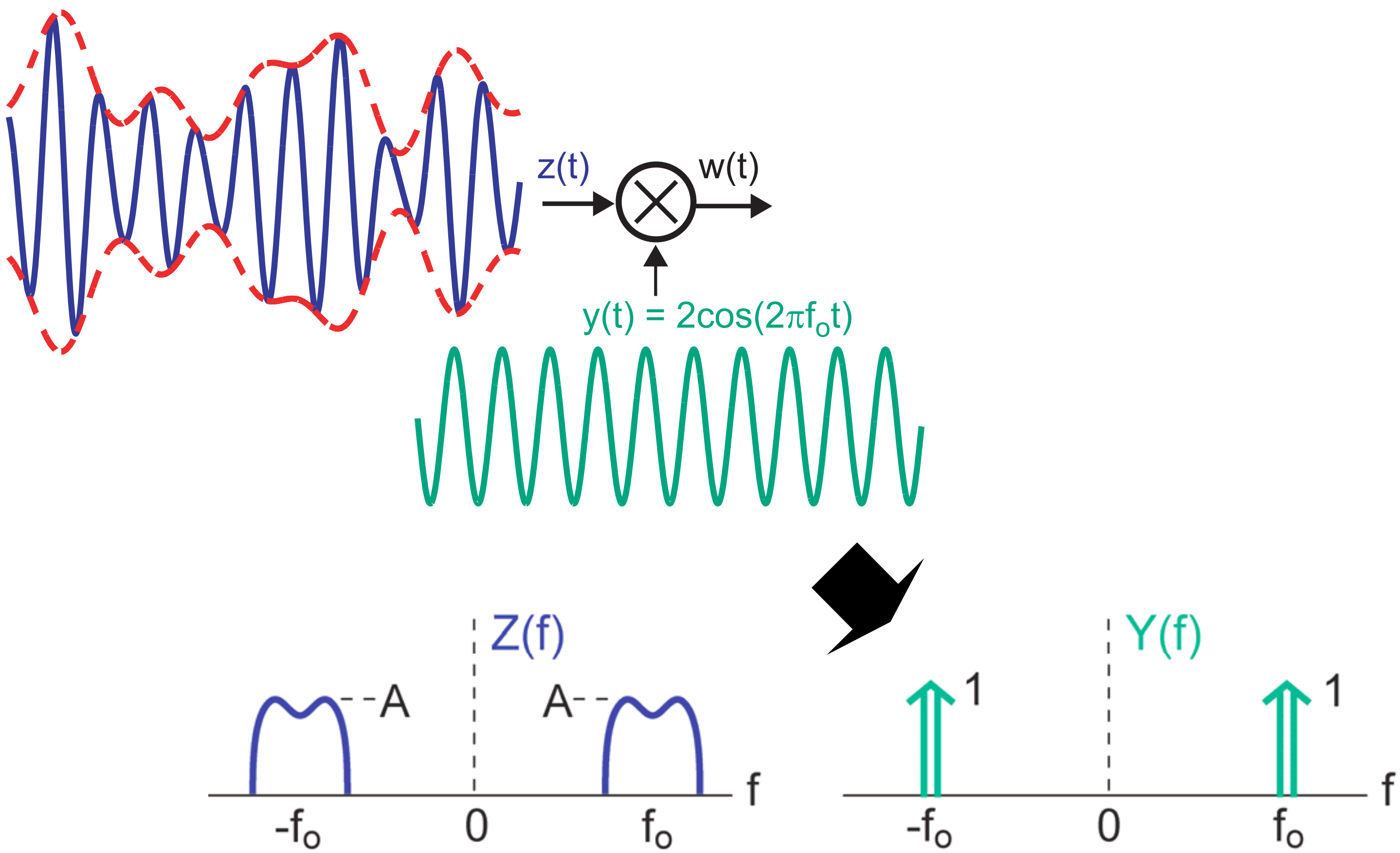
(Transmitter)



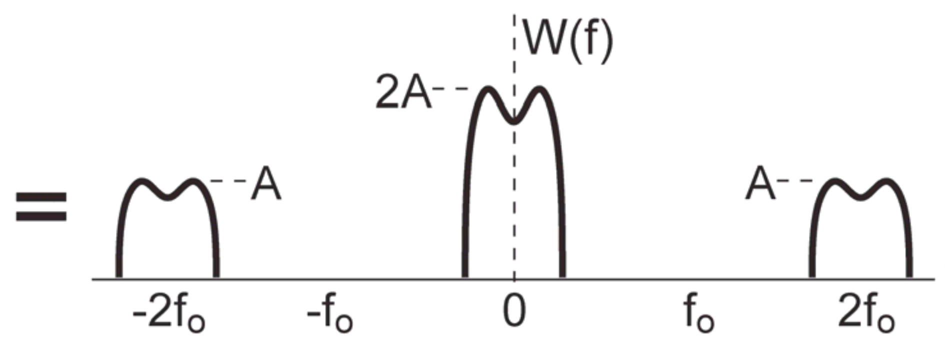
- Input signal is shifted to higher frequency band



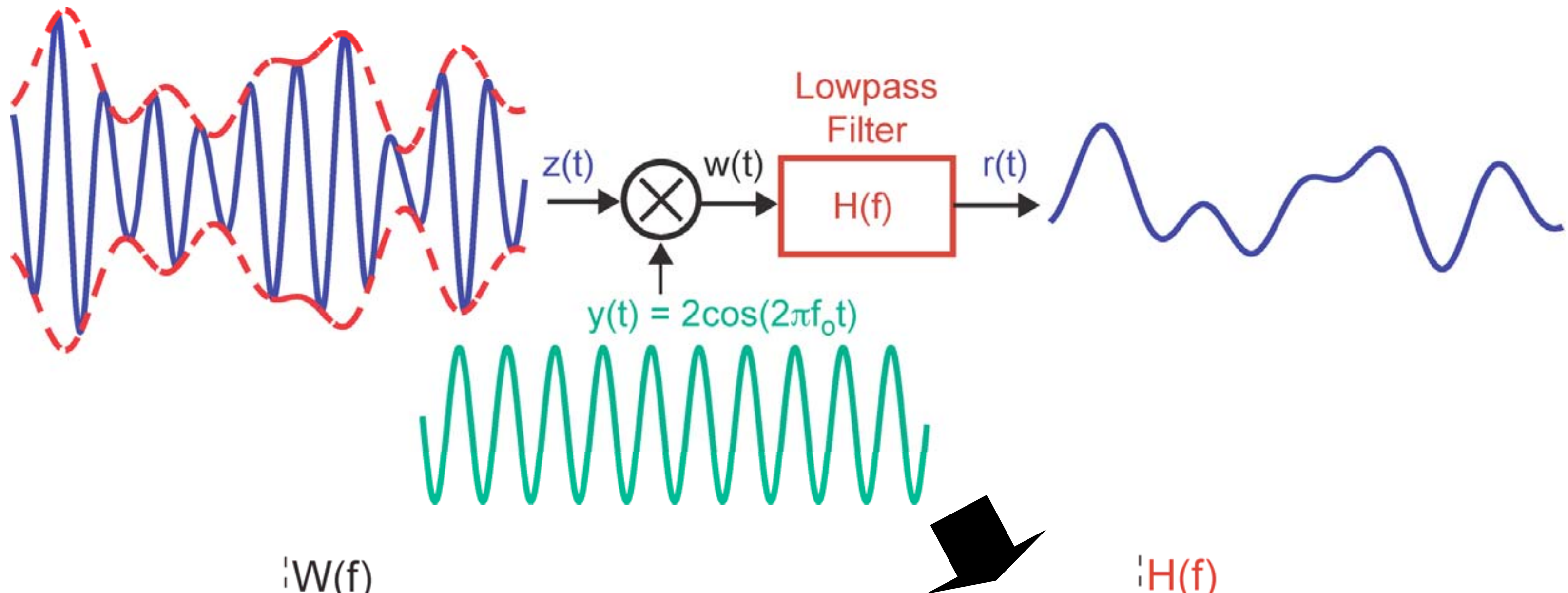
Demodulation (Receiver)

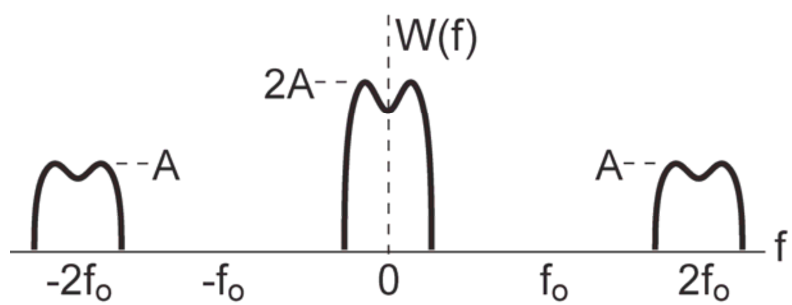


- **Input signal is shifted to lower *and* higher frequency bands**
  - **Want *baseband* portion**

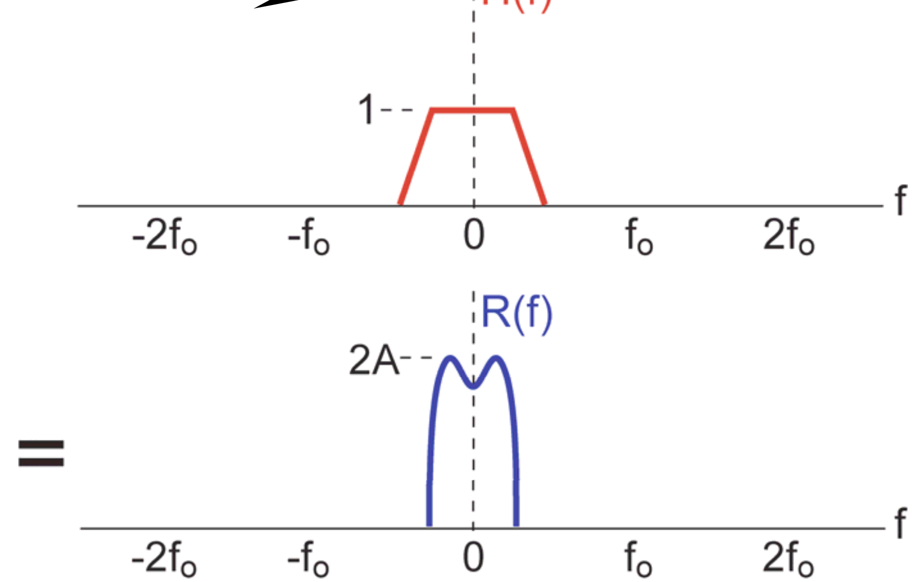


Demodulation and Lowpass Filtering

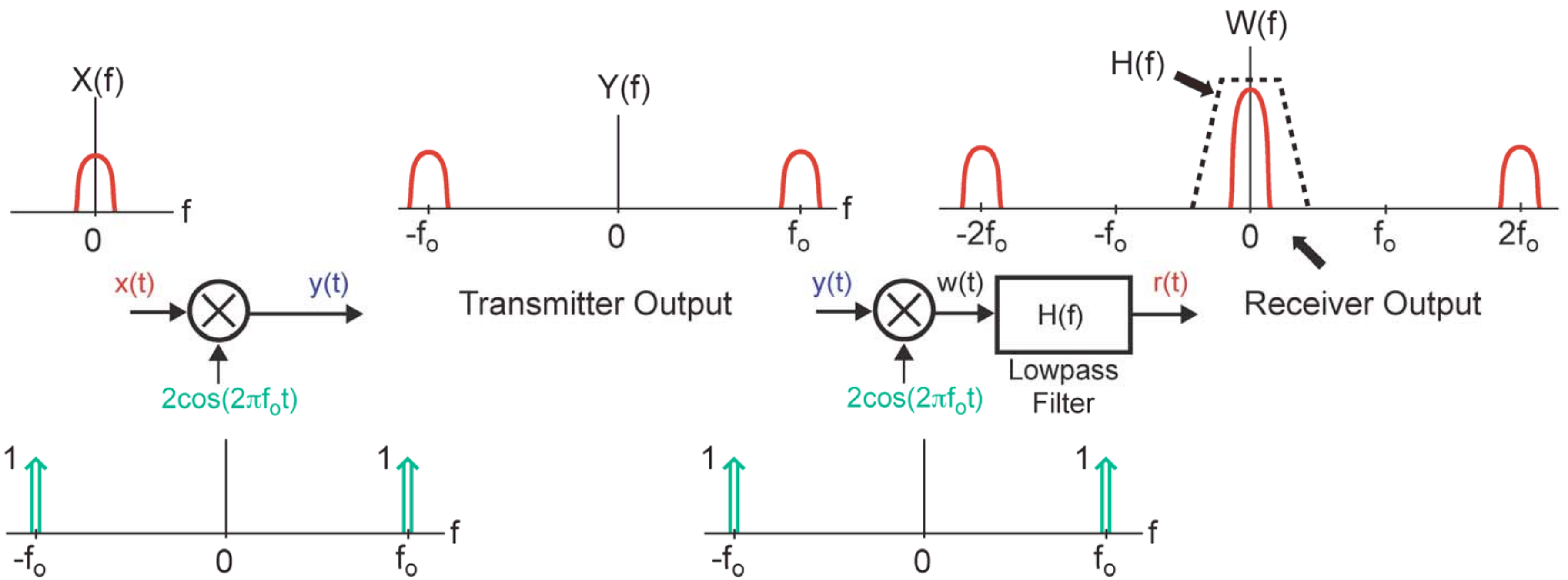




- **Only low frequency (i.e. *baseband*) portion remains**



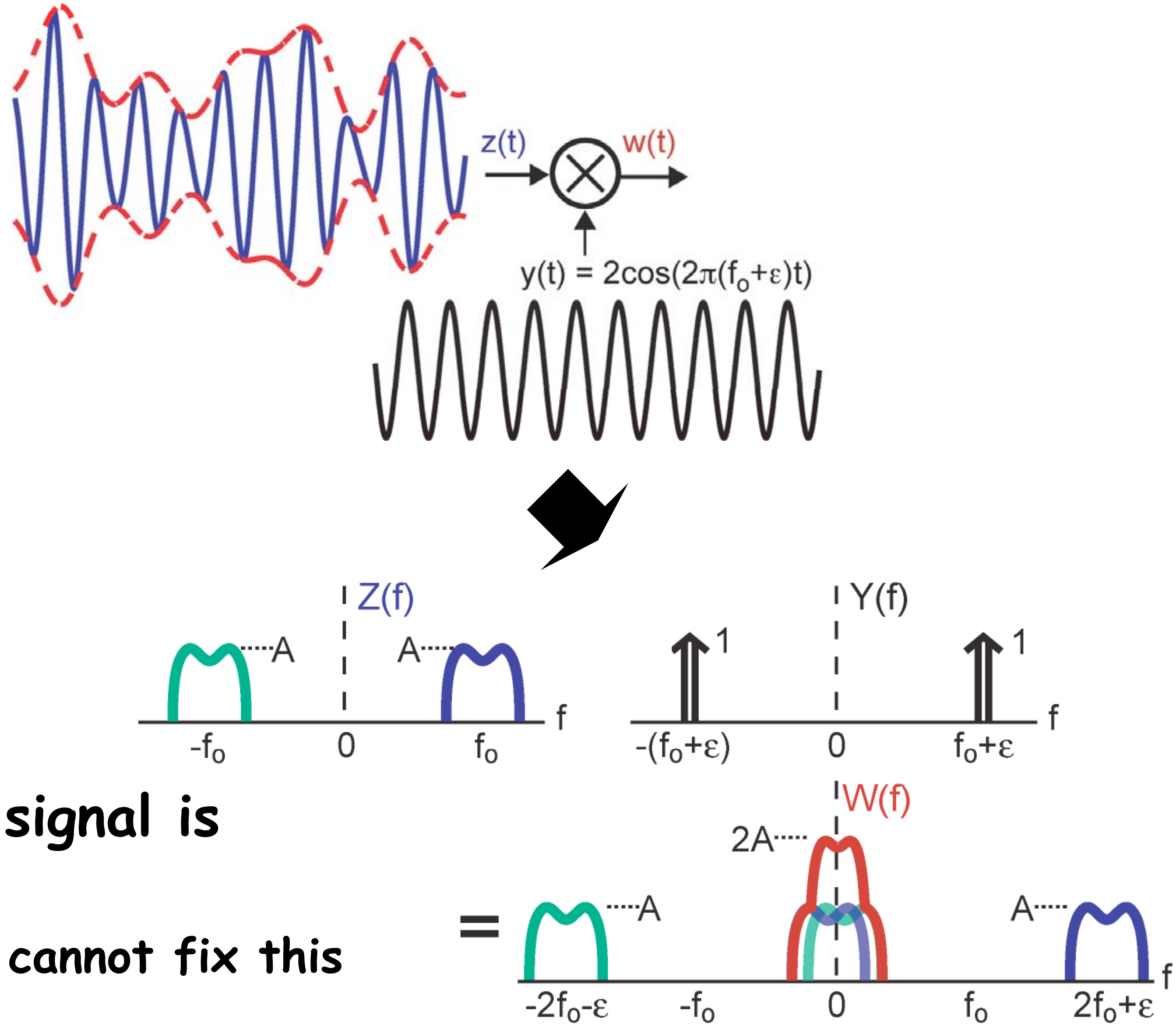
Transmitter and Receiver Pair



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

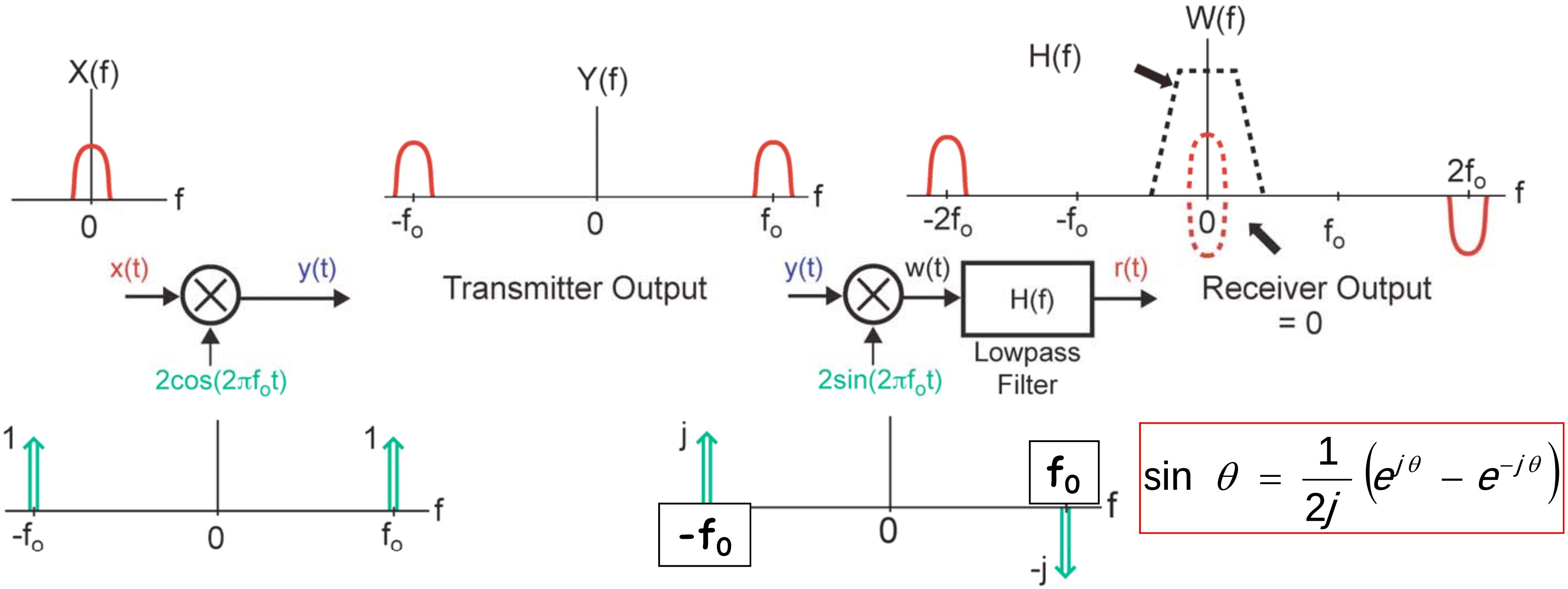
What can go wrong here?

Impact of Frequency Offset



- **Baseband signal is corrupted!**
  - **Filtering cannot fix this**

Impact of 90 Degree Phase Shift

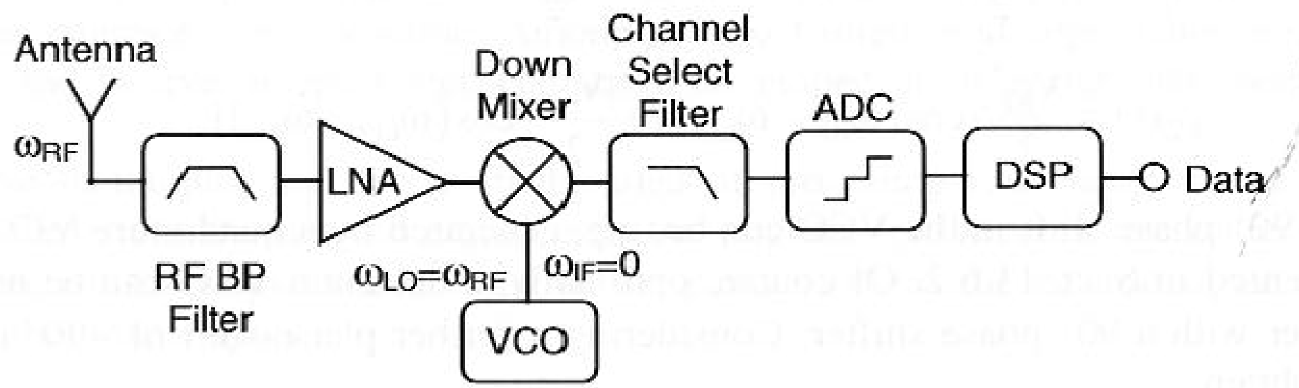


- When transmitter and receiver local oscillators are 90 degree offset in phase:
  - Demodulated signal *destructively* adds at baseband
- We suddenly receive no baseband signal!
  - We need to *synchronize* the phase of the transmitter and receiver *local oscillators* (*i.e.* the transmit and receive carriers need to be *synchronized* to be <u>both sin</u> or <u>both cos)</u>

This is known as *coherent* modulation/demodulation

Receivers Structures

- You now know many of the fundamentals to design a receiver



(Homodyne or Direct Conversion)

Consider "DC offset" issues

- **Question:** Bandwidth of the modulated signal is twice as much as that of the baseband signal. Can you suggest a more efficient bandwidth utilization for signal transmission using filtering techniques?

- There are many advanced modulation techniques available.

- Next time you will learn about I/Q modulation where you can use the extra bandwidth to send an additional channel

Summary

- De-multiplexing is a critical part of signal transmission
- De-modulation is the key part in translating the transmitted signals back to baseband
- Bandpass and lowpass filtering allows us to extract the signals from the radio spectrum that we desire
- Practical receivers use all these concepts in their design