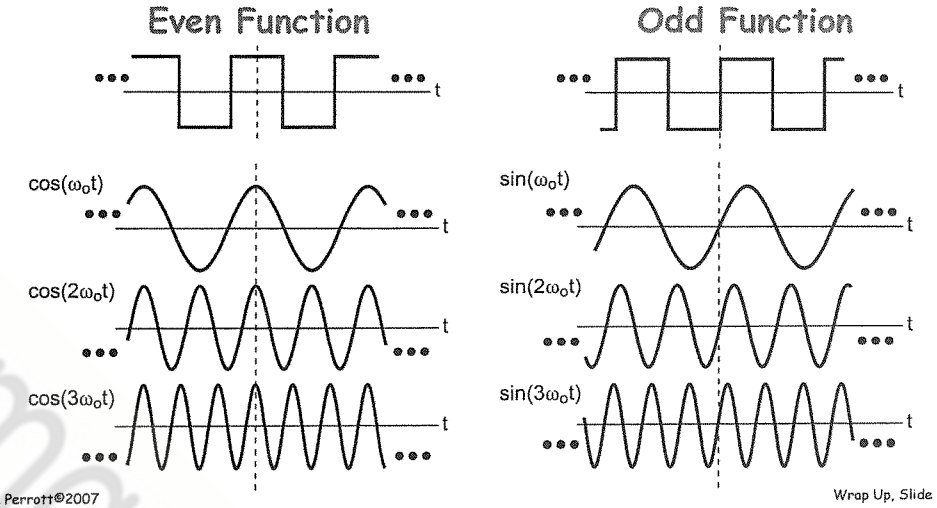
Wrap Up

- Fourier Transform
- Sampling, Modulation, Filtering
- Noise and the Digital Abstraction
- Binary signaling model and Shannon Capacity

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Cosines and Sines as Basis Functions

- Periodic functions can be approximated by the addition of weighted cosine and sine waveforms with progressively increasing frequency



Fourier Series and Fourier Transform

- The Fourier Series deals with *periodic* signals

$$x(t) = \sum_{n=-\infty}^{\infty} \hat{X}_n e^{jnw_o t}$$

$$\hat{X}_n = \frac{1}{T}\int_{t_o}^{t_o+T} x(t)e^{-jnw_o t}dt$$

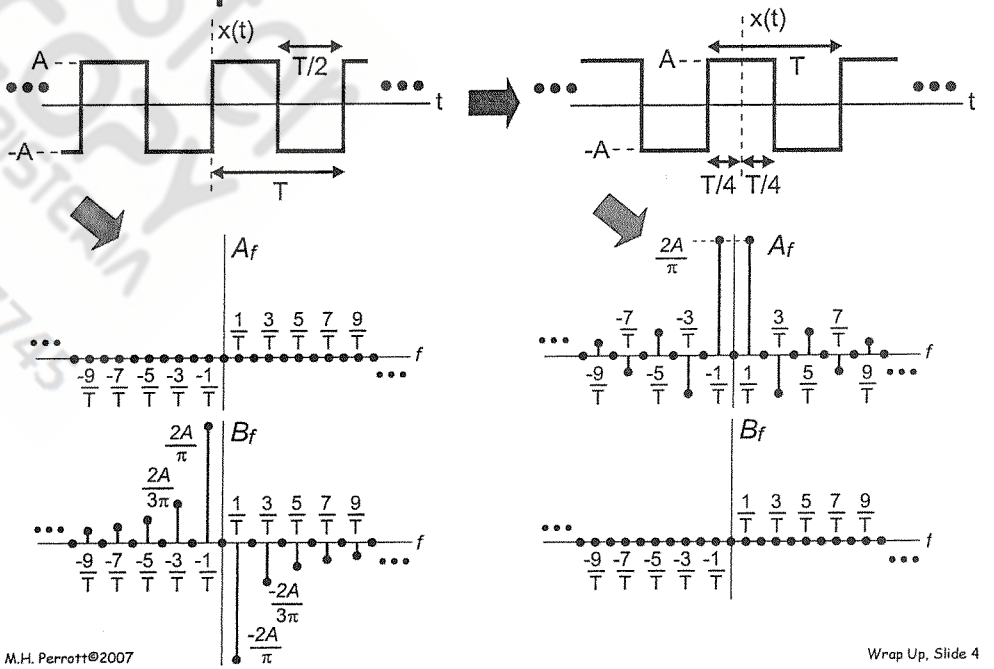
- The Fourier Transform deals with *non-periodic* signals

$$x(t) = \int_{-\infty}^{\infty} X(f)e^{j2\pi ft}df$$

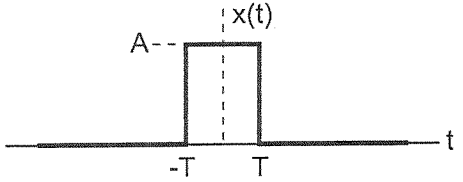
$$X(f) = \int_{-\infty}^{\infty} x(t)e^{-j2\pi ft}dt$$

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Graphical View of Fourier Series

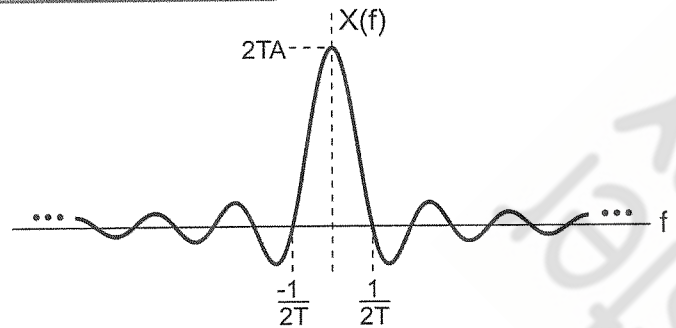


Graphical View of Fourier Transform



$$X(f) = \frac{A\sin(2\pi fT)}{\pi f}$$

This is called a *sinc* function



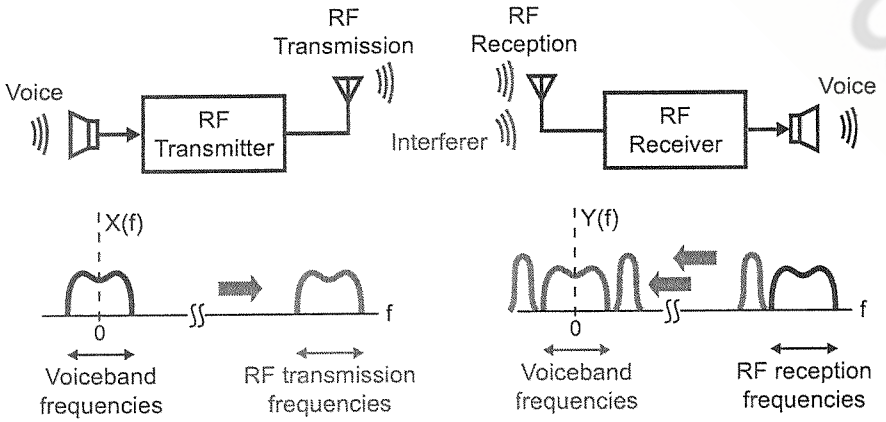
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Filtering in Continuous and Discrete Time

- Lowpass, highpass, bandpass filtering
- Filter response to cosine wave inputs
- Discrete-Time Fourier Transform
- Filtering based on difference equations

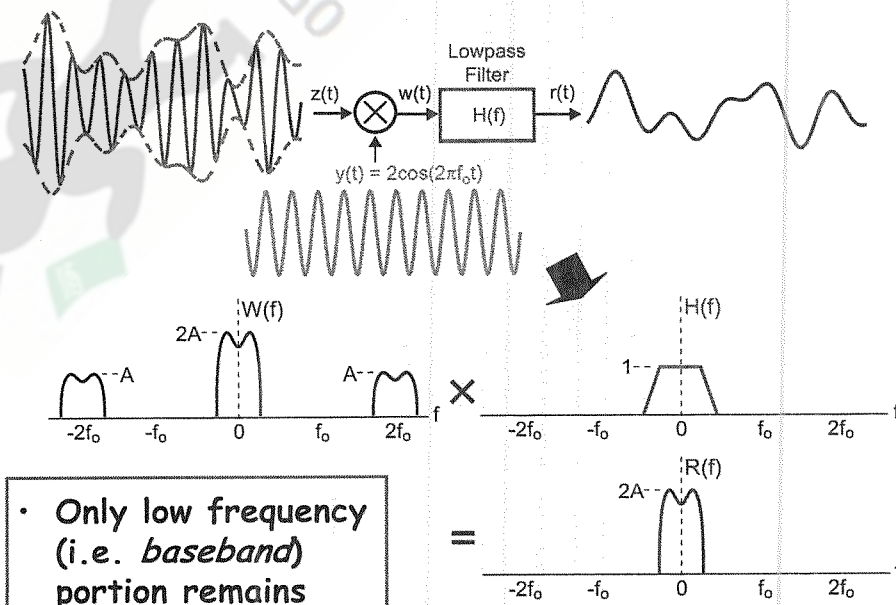
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Motivation for Filtering



- Filtering is used to remove undesired signals outside of the frequency band of interest
  - Enables selection of a specific radio, TV, WLAN, cell phone, cable TV *channel* ...
  - Undesired channels are often called interferers

Lowpass Filter



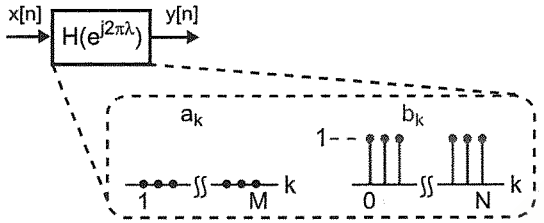
- Only low frequency (i.e. *baseband*) portion remains

FIR Filters

- Finite Impulse Response (FIR) filters use only *b* coefficients in their implementation

$$y[n] = \sum_{k=0}^{N} b_k x[n-k] \quad \Rightarrow \quad \boxed{H(e^{j2\pi\lambda}) = \sum_{k=0}^{N} b_k e^{-j2\pi\lambda k}}$$

- Example:

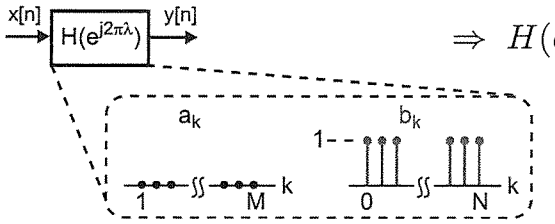


Note:

$$\sum_{k=0}^{N} r^k = \frac{1-r^{N+1}}{1-r}$$

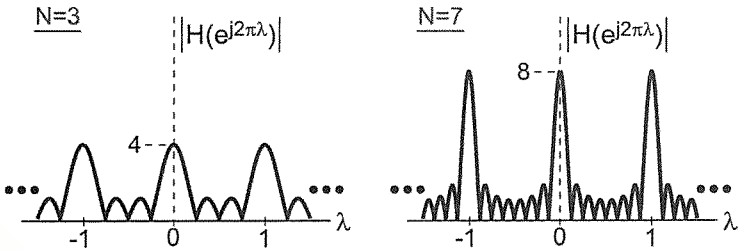
$$H(e^{j2\pi\lambda}) = \sum_{k=0}^{N} 1e^{-j2\pi\lambda k} = \boxed{\frac{1-e^{-j2\pi\lambda(N+1)}}{1-e^{-j2\pi\lambda}}}$$

Filter Order for FIR Filters



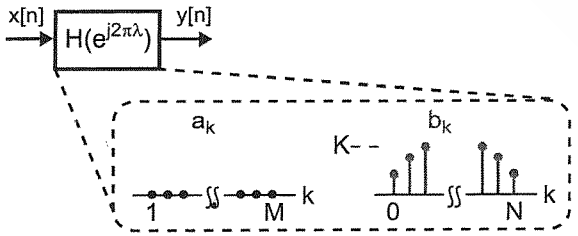
$$\Rightarrow H(e^{j2\pi\lambda}) = \frac{1-e^{-j2\pi\lambda(N+1)}}{1-e^{-j2\pi\lambda}}$$

- Consider two different values for *N*



- Higher *N* leads to steeper filter response
  - We refer to *N* as the *order* of the filter

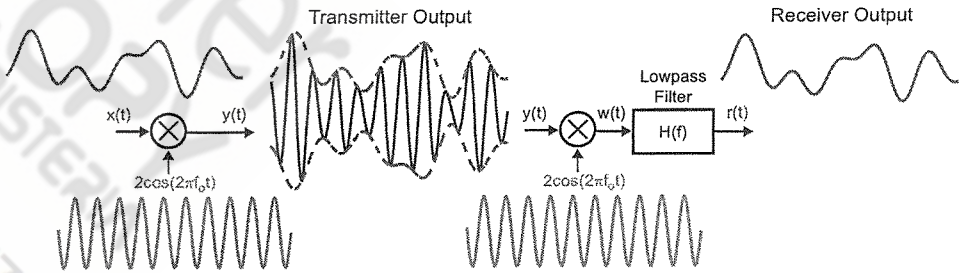
FIR Filter Design in Matlab



- Lowpass, highpass, and bandpass filters can be realized by appropriately scaling the relative value of the *b* coefficients
  - Higher order (i.e., higher *N*) leads to steeper responses
- Perform FIR filter design using *fir1* command
- Frequency response observed with *freqz* command

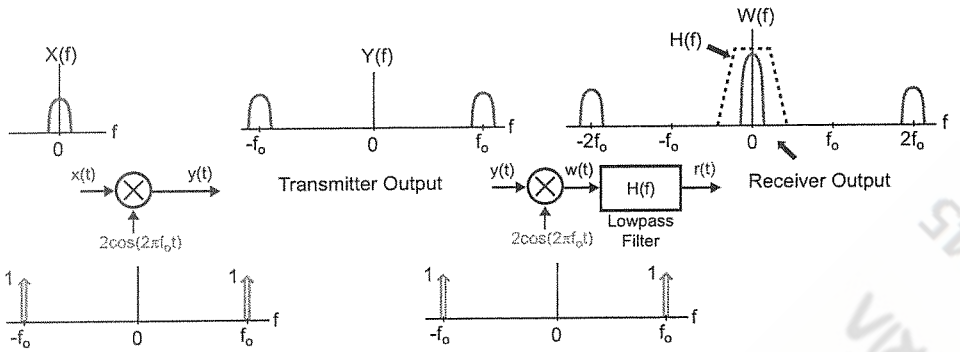
See Prelab portion of Lab 3 for details …

AM Modulation and Demodulation



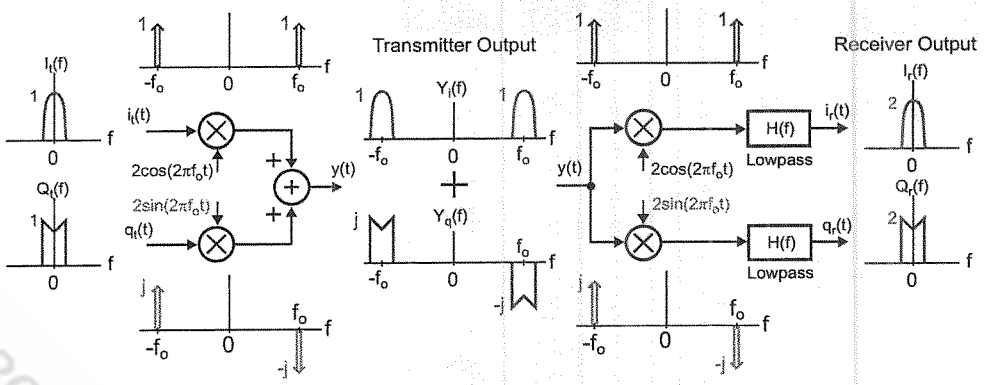
- Multiplication (i.e., *mixing*) operation shifts in frequency
  - Also creates undesired high frequency components at receiver
- Lowpass filtering passes only the desired *baseband* signal at receiver

Frequency Domain Analysis



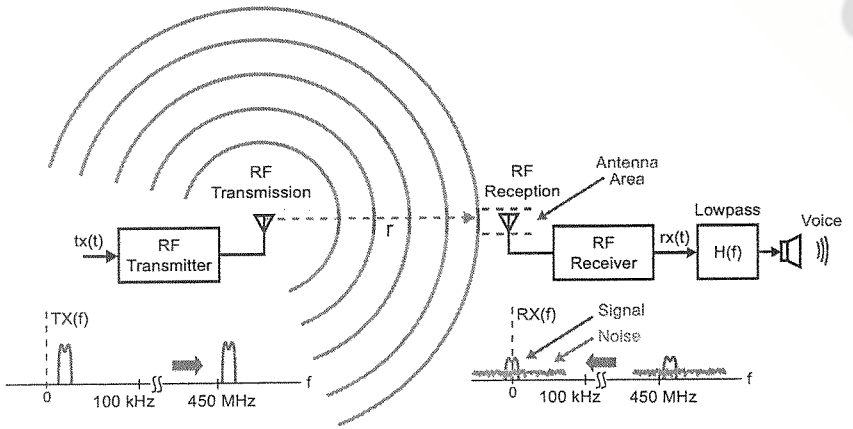
- When transmitter and receiver local oscillators are matched in phase:
  - Demodulated signal *constructively* adds at baseband

I/Q Modulation



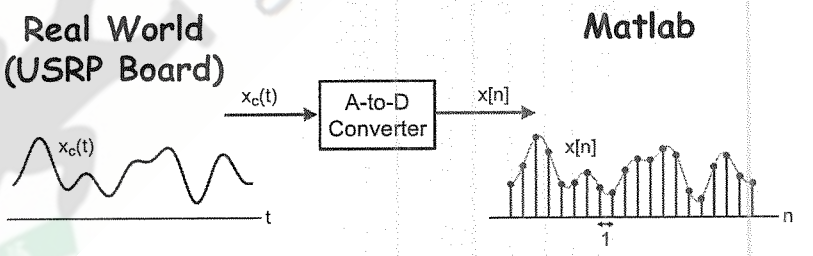
- Modulate with *both* a cosine and sine wave
  - I and Q channels can be broadcast over the *same* frequency band
- I/Q modulation allows twice the amount of *information* to be sent compared to basic AM modulation with same *bandwidth*

Energy Transfer in Wireless Communication



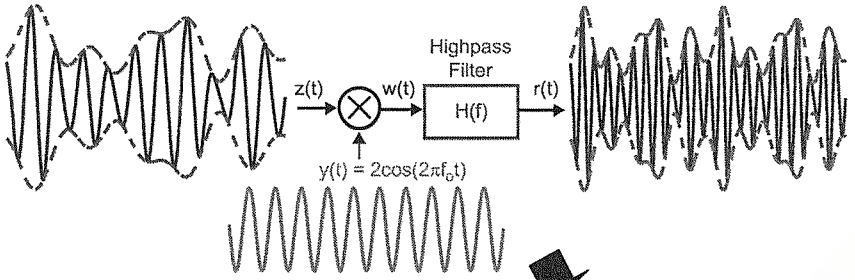
- Receiver antenna is limited in its ability to capture transmitter energy according to its *area* and *distance, r,* from transmitter
- Noise in the receiver causes corruption
  - Amount of corruption depends on signal-to-noise ratio

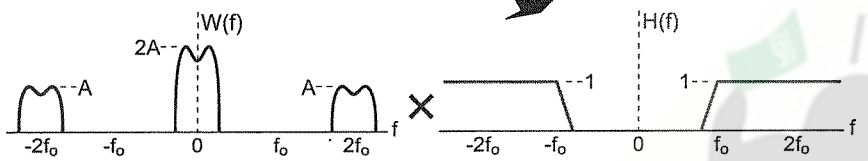
The Need for Sampling



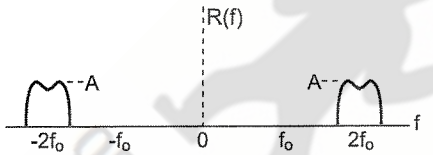
- The boundary between *analog* and *digital*
  - Real world is filled with *continuous-time signals*
  - Computers (i.e. Matlab) operate on *sequences*
- Crossing the analog-to-digital boundary requires *sampling* of the continuous-time signals

Highpass Filter

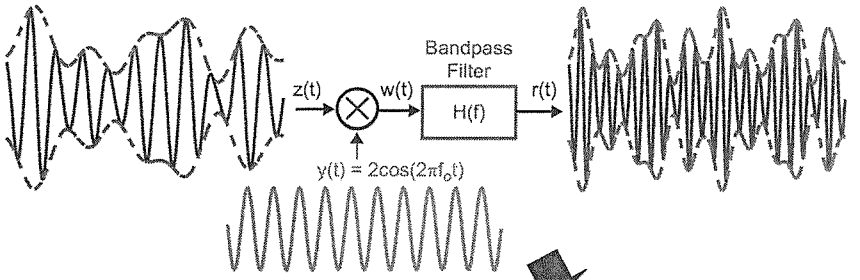


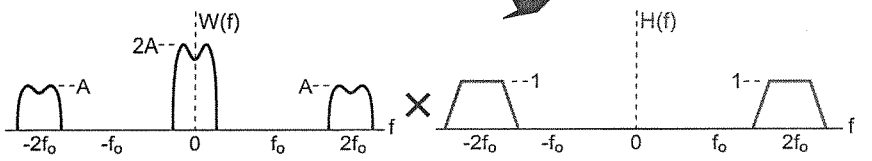


- Only high frequency (i.e. *RF*) portion remains

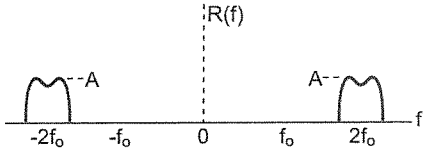


Bandpass Filter



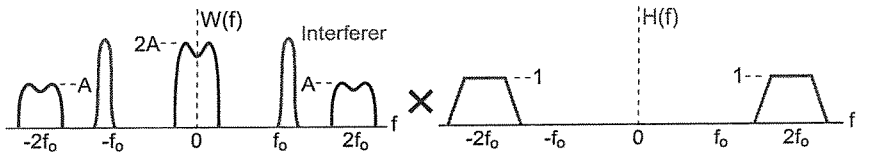


- Only high frequency (i.e. *RF*) portion remains

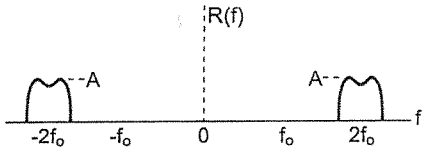


Why is Bandpass Filtering Useful?

- Allows removal of interfering signals
  - Highpass filtering would be of limited use here
- Typically higher complexity implementation than with lowpass or highpass filters
  - Many RF systems such as cell phones use specialized components called *SAW filters* to achieve bandpass filtering



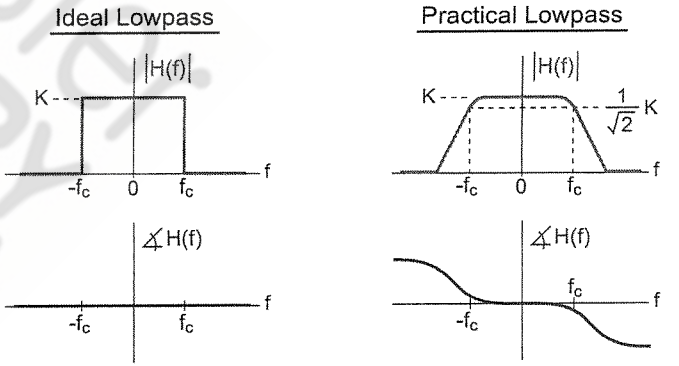
- Only *desired* RF portion remains
  - Interferer eliminated



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A More Formal Treatment of Filters



- An ideal filter would have a "brickwall" magnitude response and zero phase response
  - Practical filters have a more gradual magnitude *rolloff* and a non-zero phase response
- Design of the filter usually focuses on getting a reasonable magnitude rolloff with a specified cutoff frequency f_c (i.e., filter *bandwidth*)