EE230-02 RFIC II
Fall 2018

Lecture 2: RF Basics Review1

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How to send data without wire?

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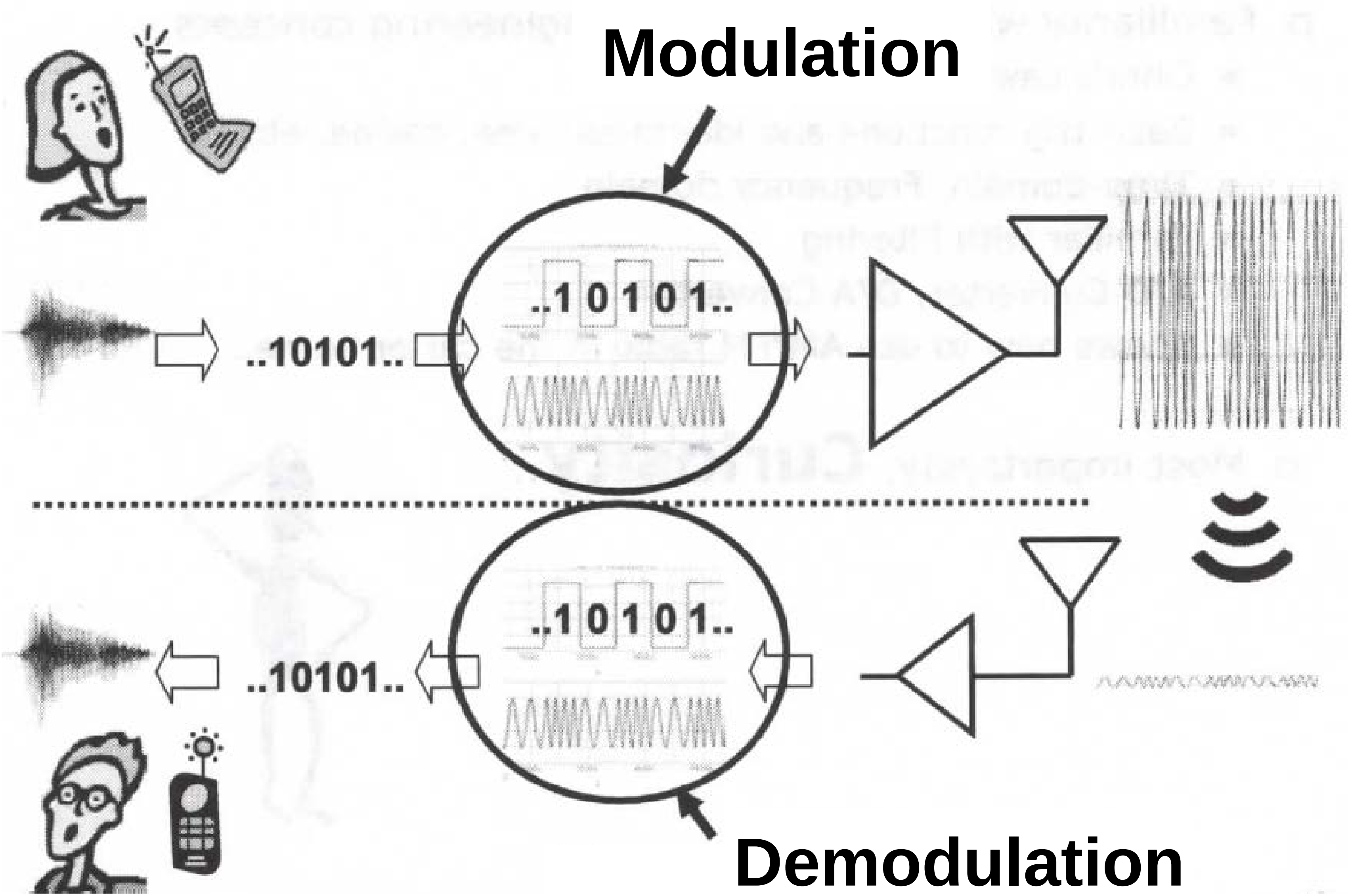
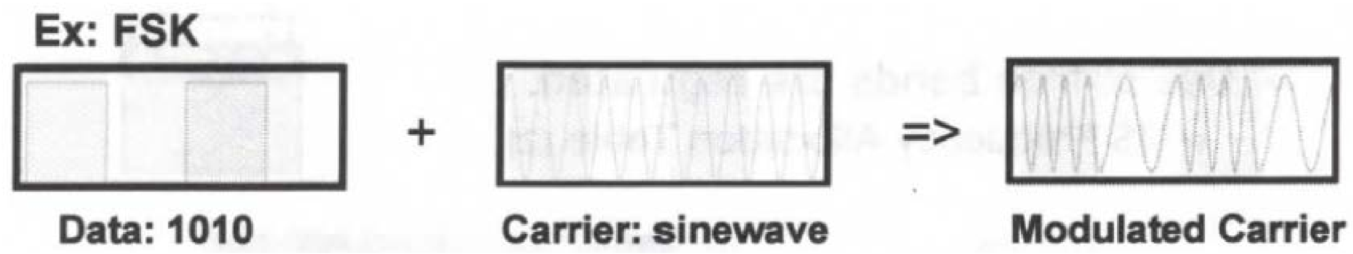
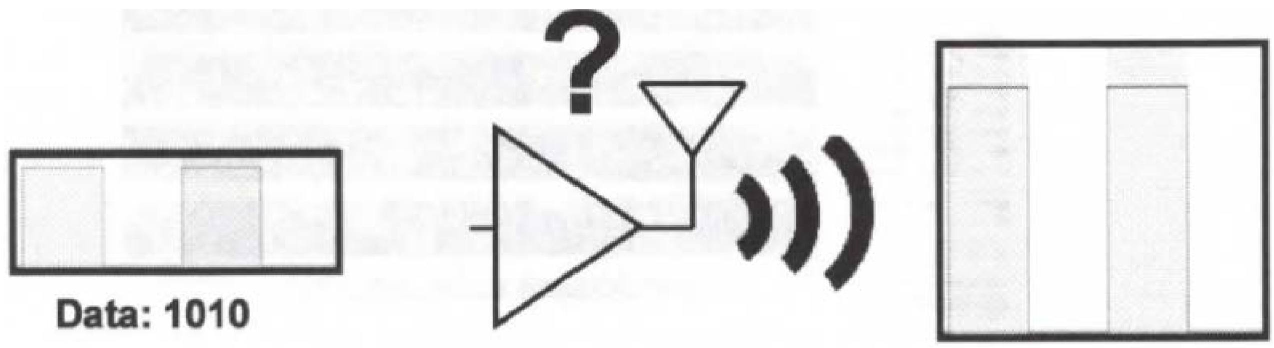


Modulation

- Process of adding information (or signal) to a carrier signal, typically a sinewave.

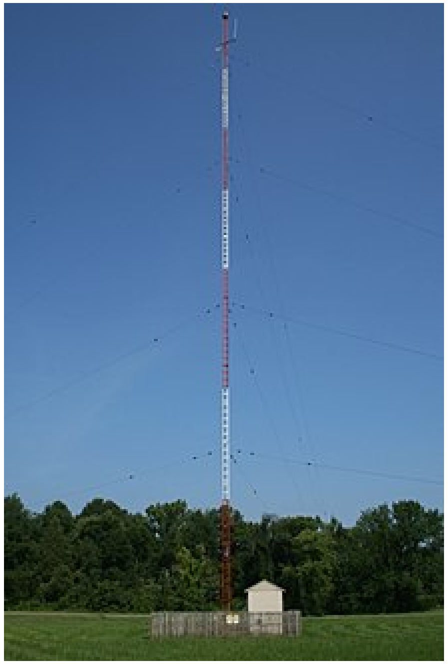


- Why do we need to modulate? Why not just send the data as is?



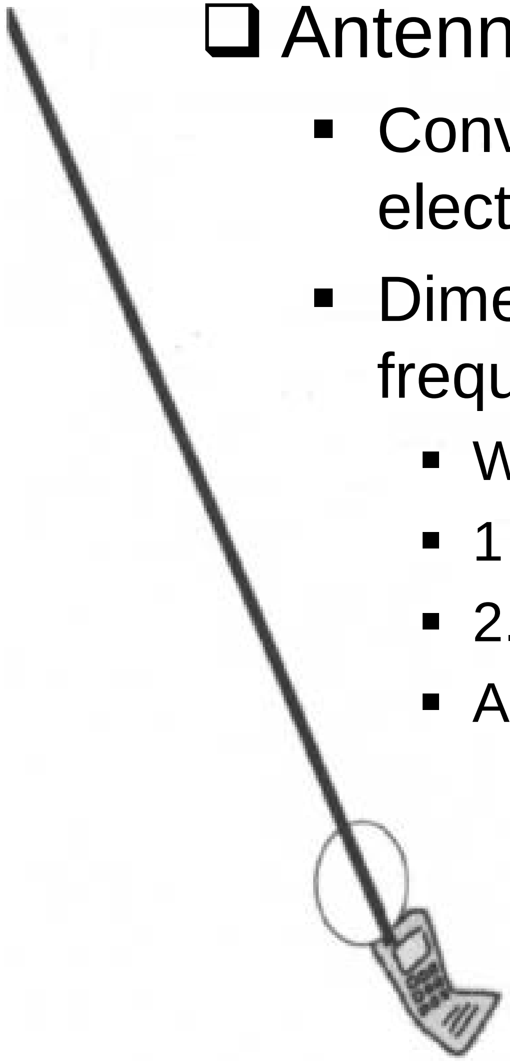
Why Modulation?

Large Antenna



Why Modulation?

- Antenna
  - Converts an electrical signal into an electromagnetic wave radiated in free space
  - Dimension is proportional to wavelength of carrier frequency
    - Wavelength = 300 meter / Freq (in MHz)
    - 1 MHz → 300 meter
    - 2.4 GHz → 12.5 cm
    - Antenna usually ½ or ¼ wavelength long



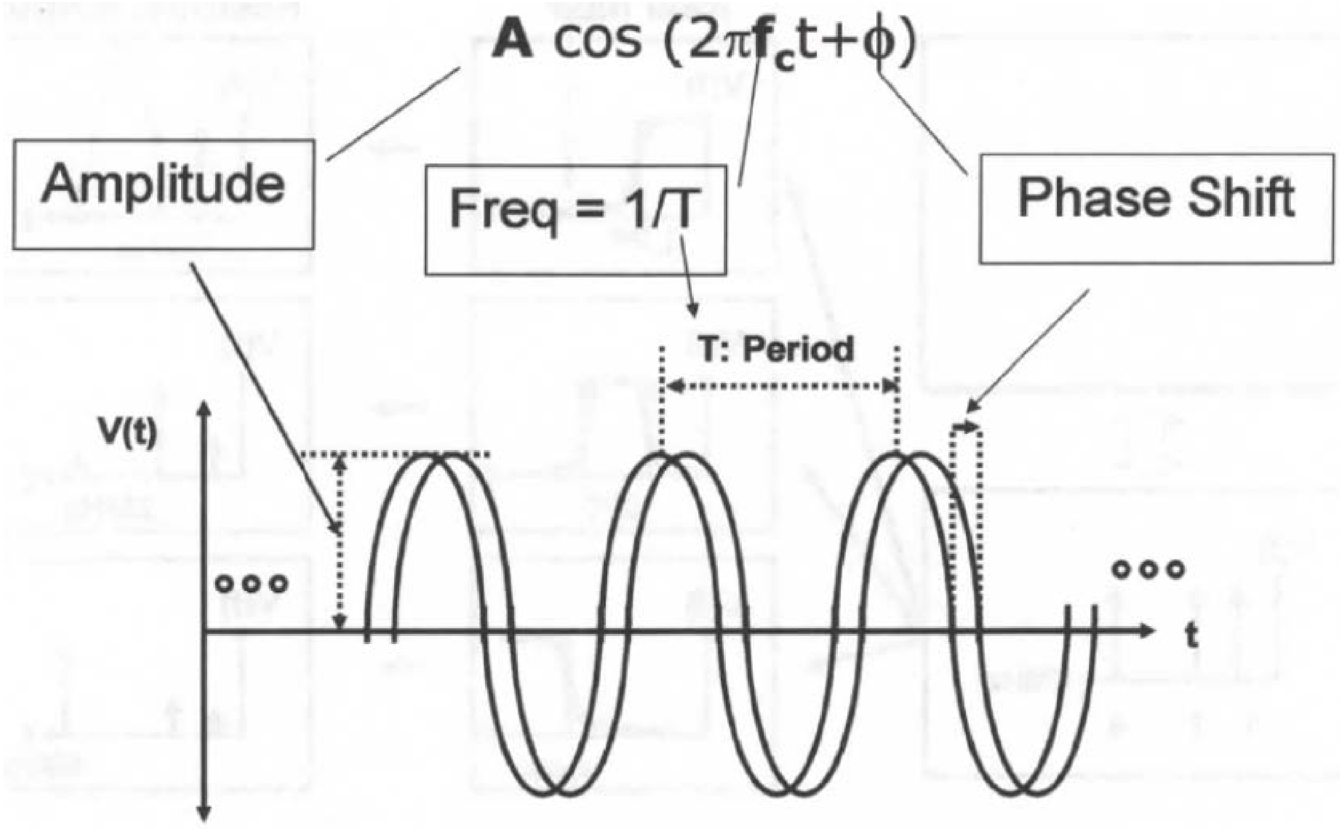
OR

Review of Some Basic Concepts

- Sinewave Signal
- Time Domain vs. Frequency Domain
- Filtering
- Frequency Translation
- Modulation
- Demodulation

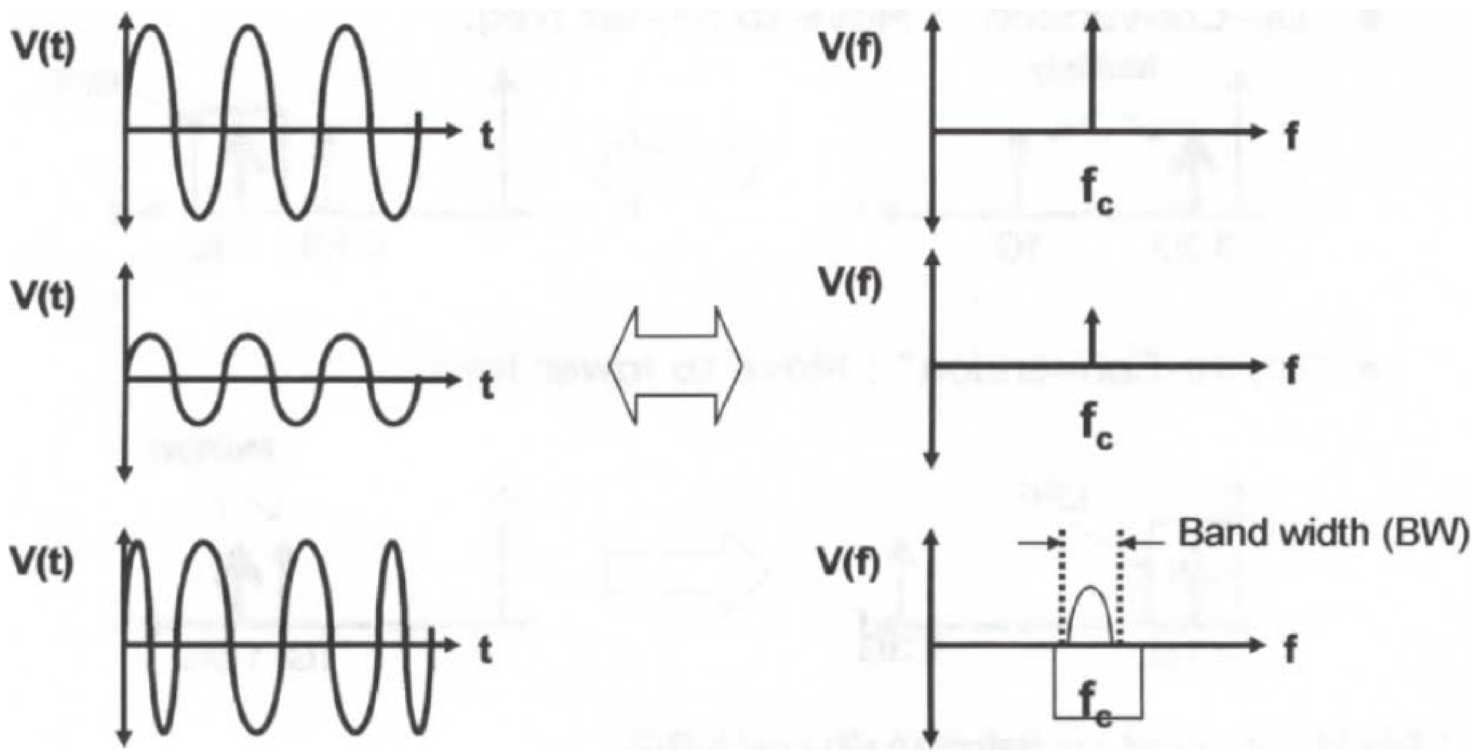
Review: Sinewave Signal

- Basis for RF signal is sinewave
- Three key parameters



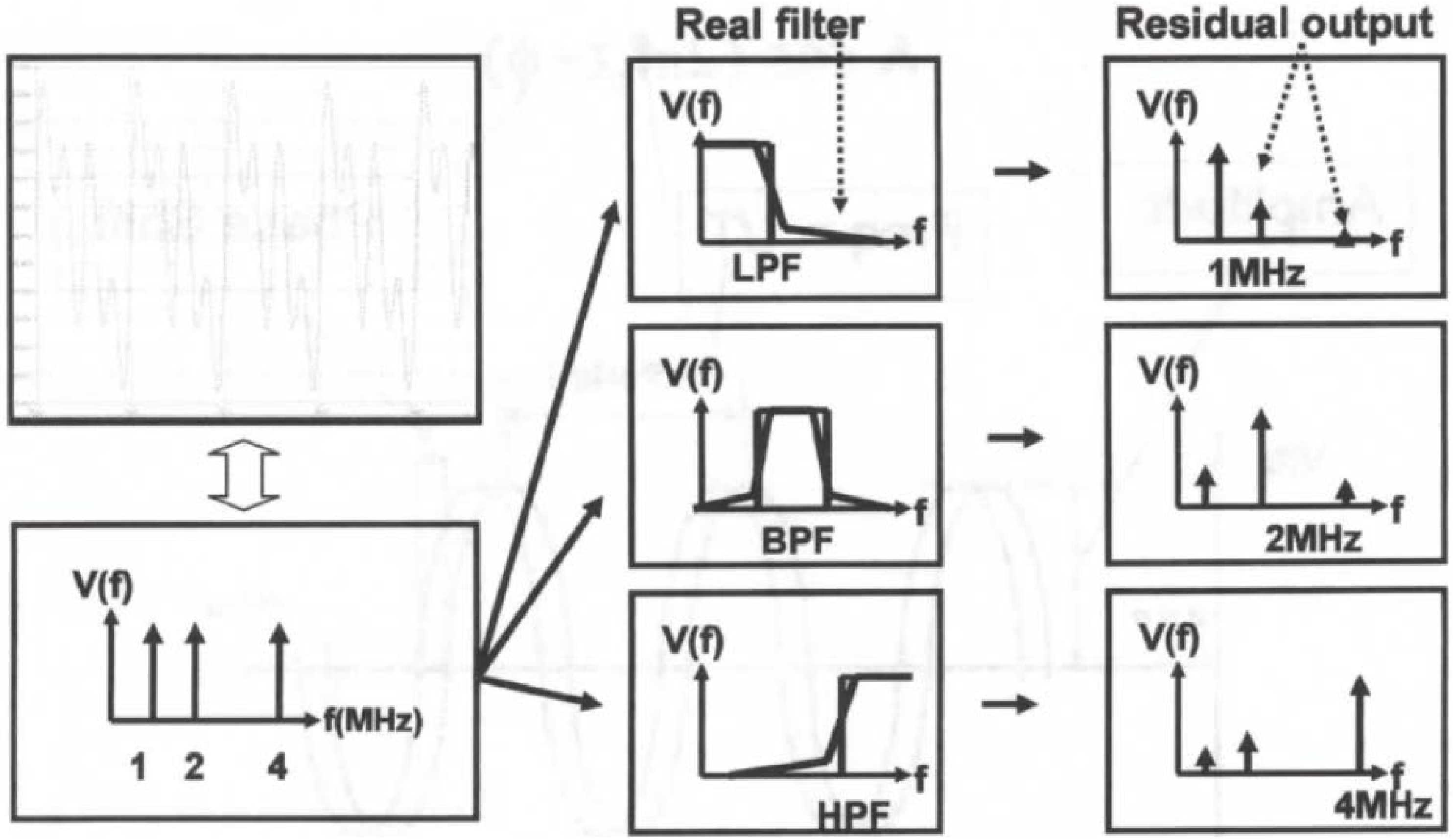
Review: Time Domain vs Freq Domain

- Signal can be represented in both time and frequency domains.
  - Time-domain: How signal changes over time
  - Freq-domain: How much signal is within each frequency band



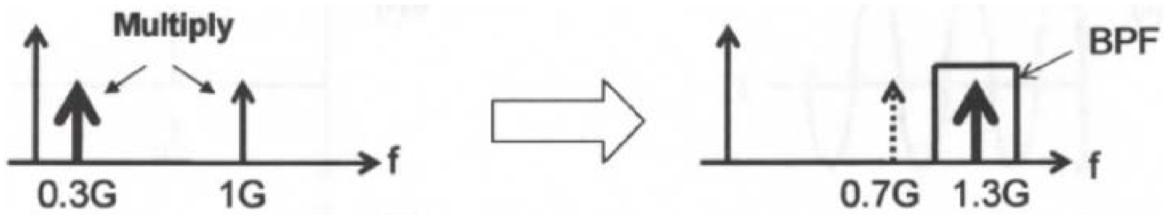
Review: Filtering

- Process of selecting signals in the frequency band of interest.
- Examples: High pass filter (HPF), Low pass filter (LPF), Band pass filter (BPF)

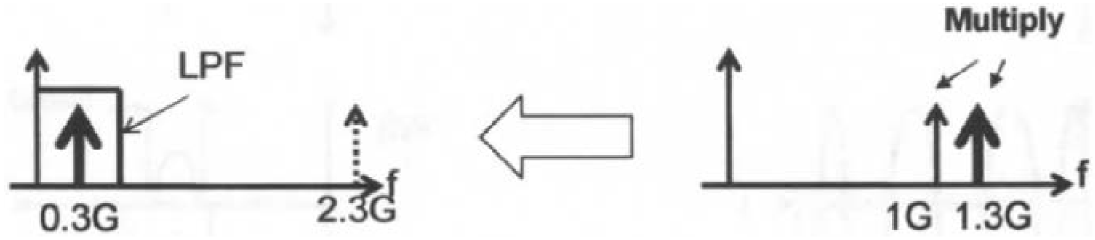


Review: Frequency Translation

- **Move signal to a different frequency band.**
  - Trig Identity*: The product of two sinewaves produces **sum and difference** frequencies
  - **“Up-Conversion” : Move to higher frequency**

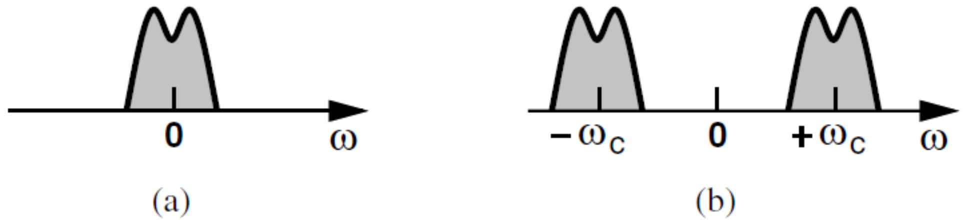


  - **“Down-Conversion” : Move to lower frequency**

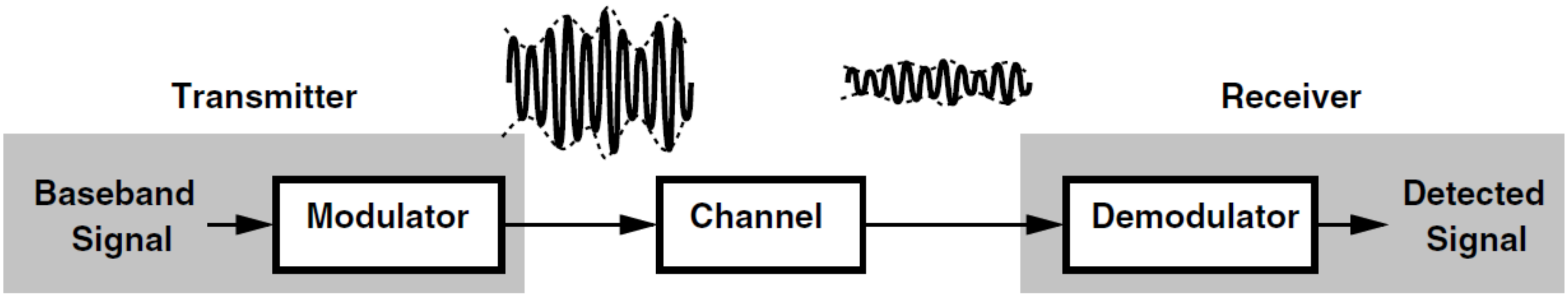


Trig Identity*: cosA cosB = [cos(A+B)-cos(A-B)]/2

Review: Modem



Baseband & Passband



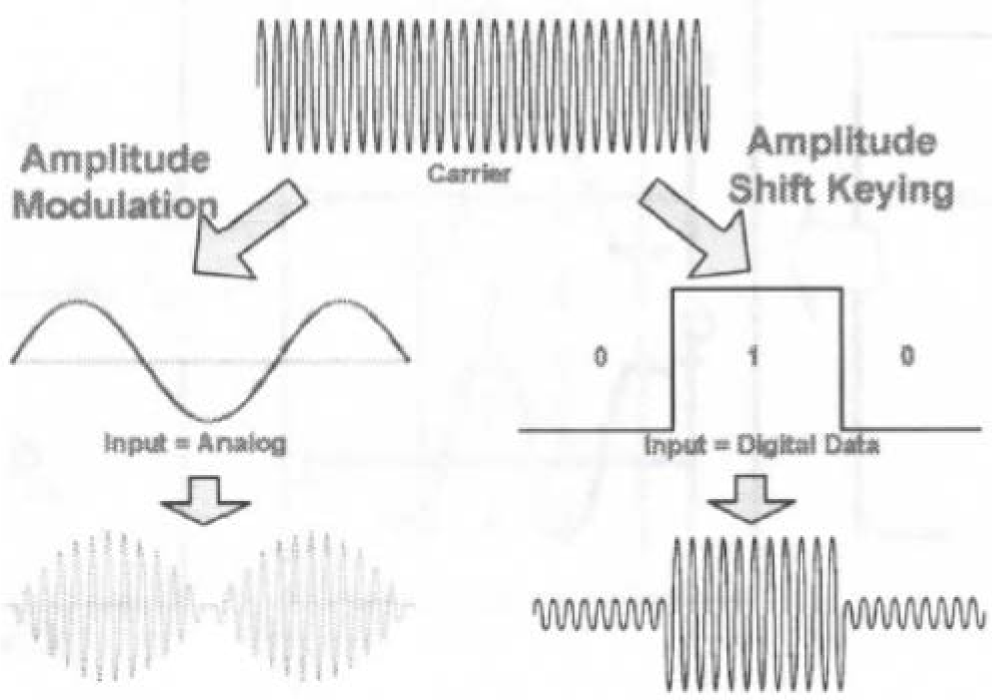
Modulator & Demodulator

Modem

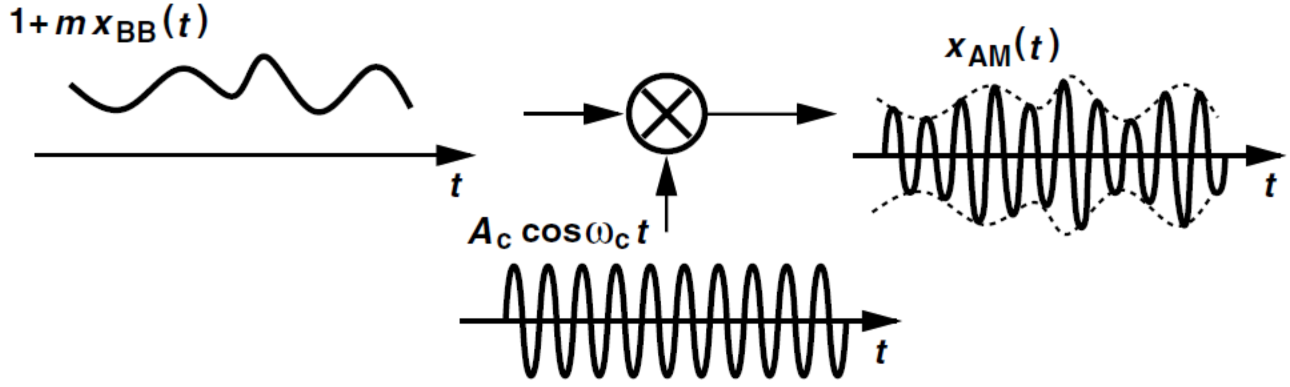
Review: Modulation Terminology

Amplitude Modulation (AM) vs. Amplitude Shift Keying (ASK)

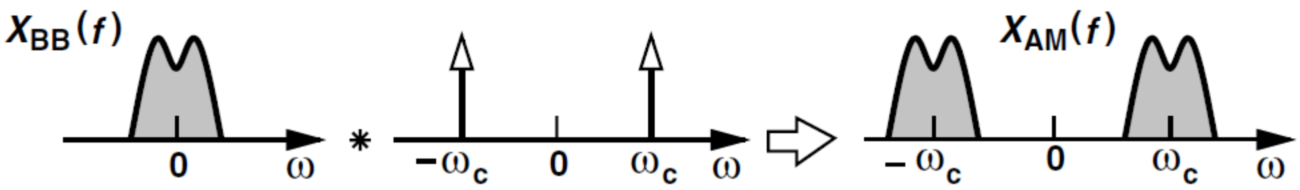
- Amplitude modulation vs. Digital modulation
- If modulating signal is continuous analog, it is called “AM”
- If modulating signal is digital signal, it is called “ASK”
- Similarly, FM vs. FSK, PM vs. PSK



Review: Modulation

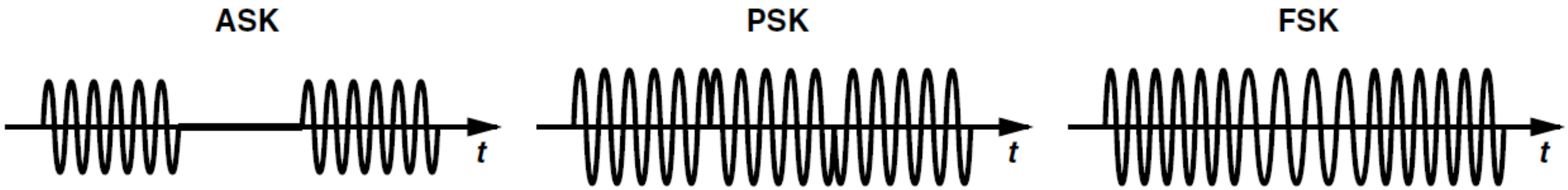


(a)



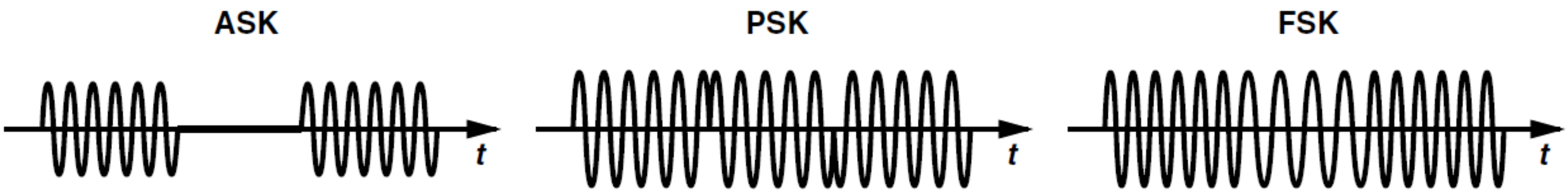
(b)

Review: Digital Modulation



(a) (b) (c)

Review: Signal Constellation



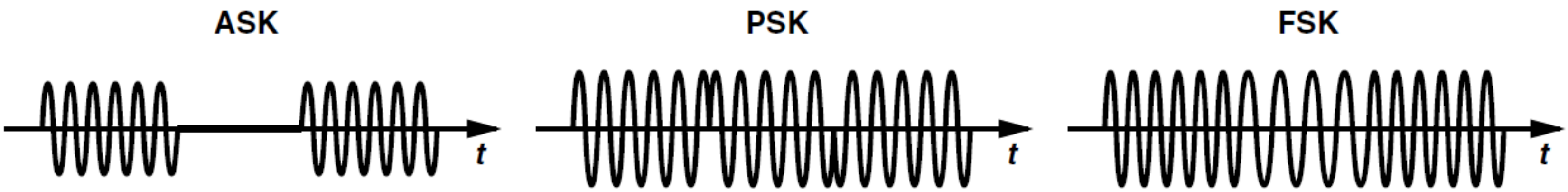
(a) (b) (c)

$$x_{PSK}(t) = a_n \cos \omega_c t \qquad a_n = \pm 1$$

(a) (b)

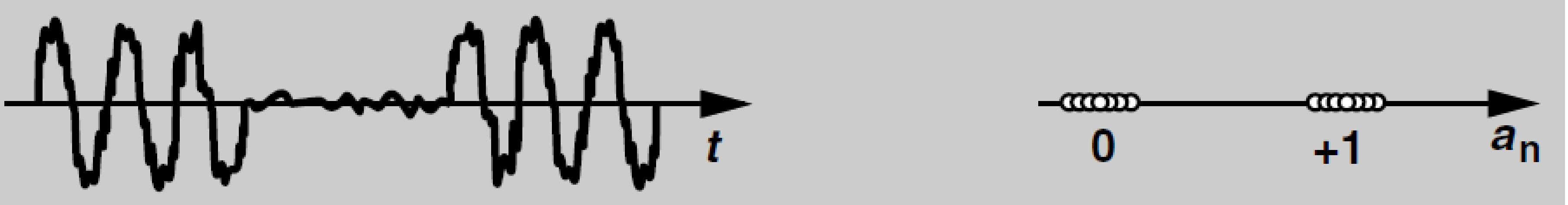
Ideal & Noisy PSK Constellation

Constellation of ASK Signal



(a) (b) (c)

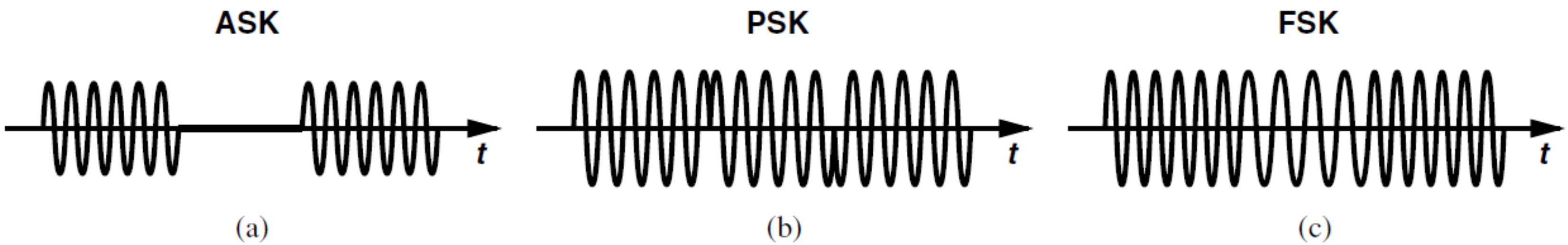
$$x_{ASK}(t) = a_n \cos \omega_c t \qquad a_n = 0,\ 1$$



(a) (b)

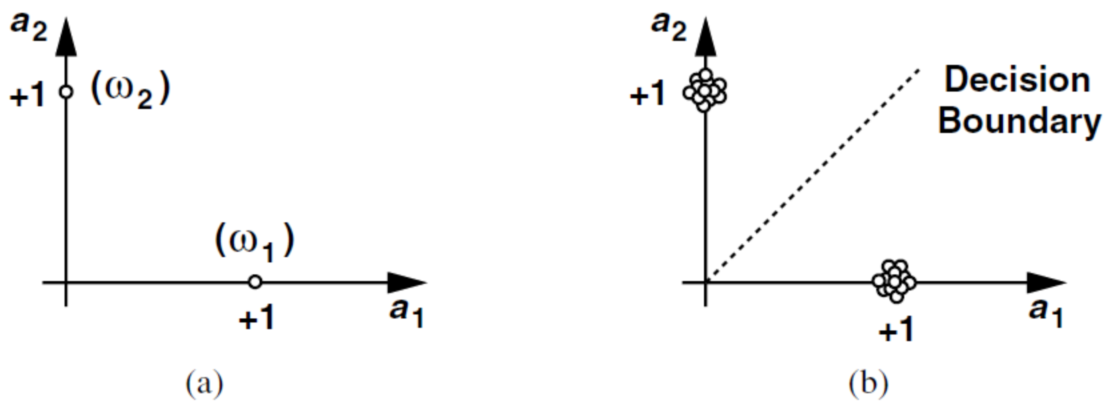
Noisy Signal & Constellation

Constellation of FSK Signal



(a) (b) (c)

$$x_{FSK}(t) = a_1 \cos \omega_1 t + a_2 \cos \omega_2 t \qquad a_1 a_2 = 10 \text{ or } 01$$

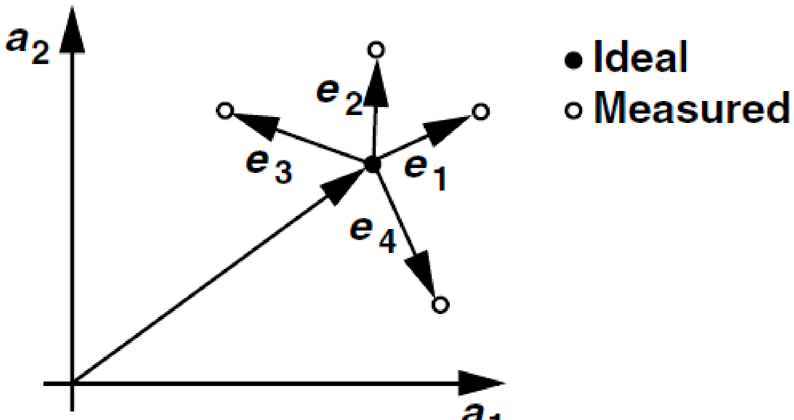


(a) (b)

Ideal & Noisy Constellation

Error Vector Magnitude (EVM)

- Quantitative measure of the impairments that corrupt the signal.
- The deviation of the constellation points from their ideal positions.



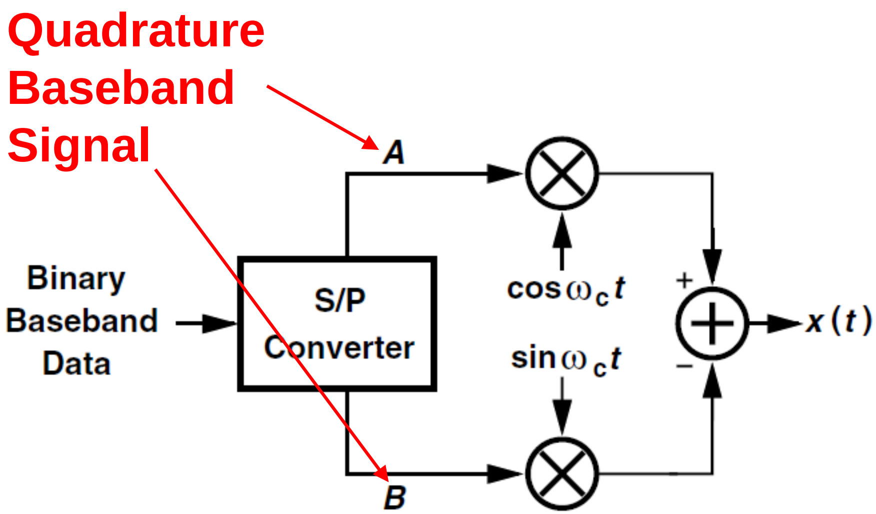
$$\mathrm{EVM}_1 = \frac{1}{V_{rms}} \sqrt{\frac{1}{N} \sum_{j=1}^{N} e_j^2}$$

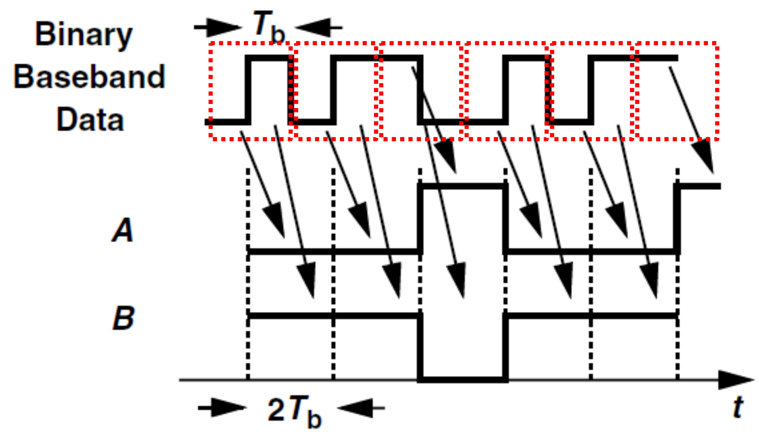
$$\mathrm{EVM}_2 = \frac{1}{P_{avg}} \cdot \frac{1}{N} \sum_{j=1}^{N} e_j^2$$

Review: Quadrature Modulation

$$A\cos(2\pi f_c t + \emptyset) = A\cos(2\pi f_c t)\cos(\emptyset) + A\sin(2\pi f_c t)\sin(\emptyset)$$
$$= \mathbf{I}\cos(2\pi f_c t) + \mathbf{Q}\sin(2\pi f_c t)$$

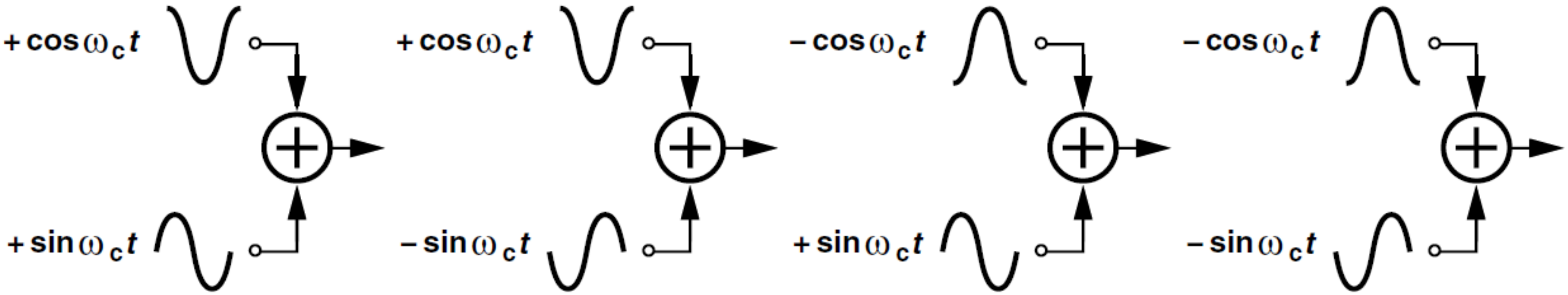
where $\mathbf{I} = A\cos(\emptyset)$ and $\mathbf{Q} = A\sin(\emptyset)$



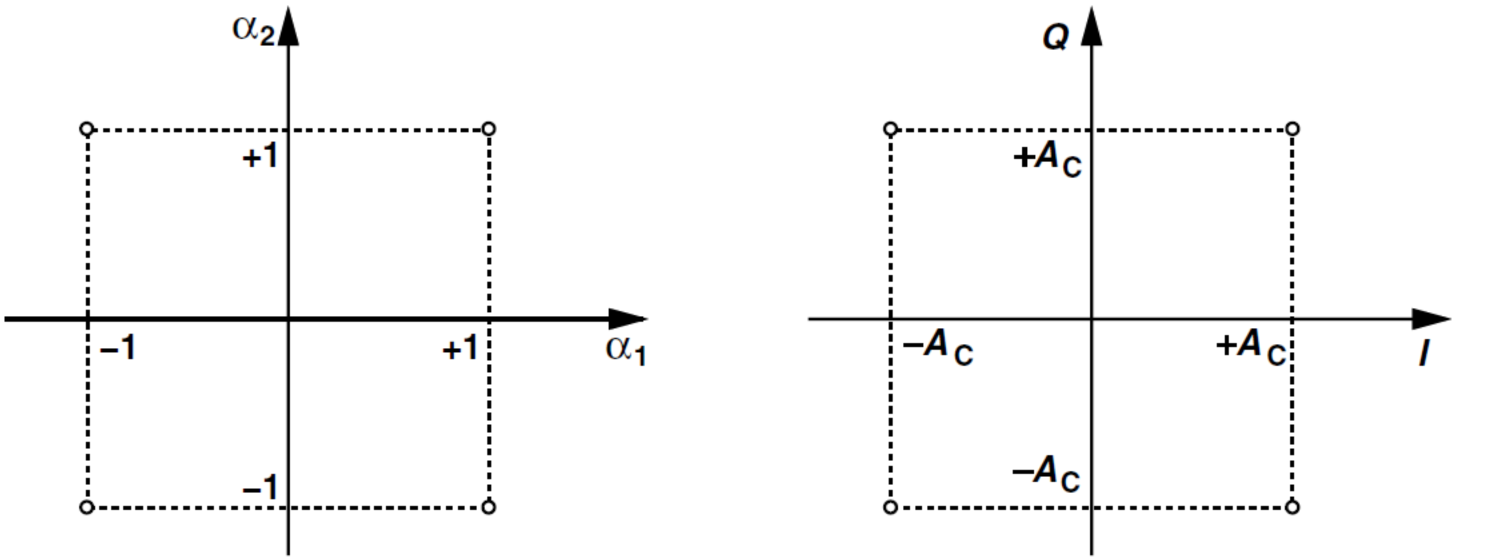


Symbol rate = ½ Bit rate

Review: QPSK Constellation



(a)

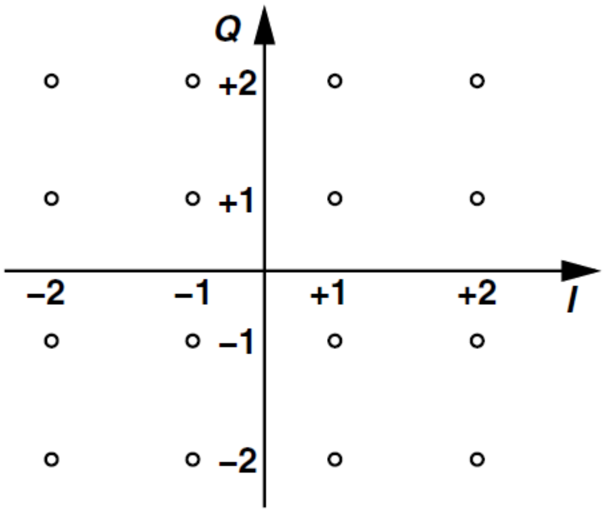


(a) (b)

Review: 16QAM

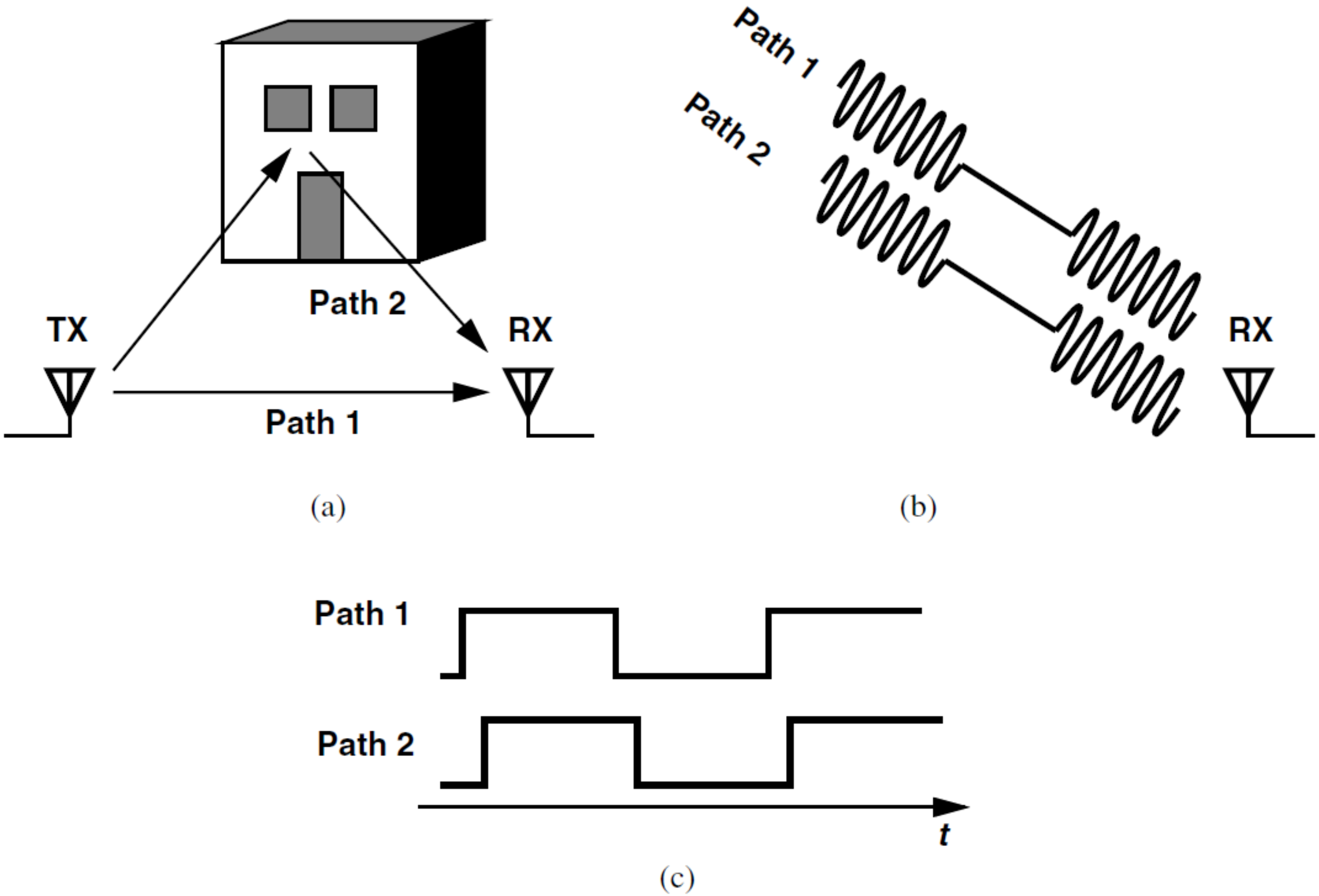
- Four possible amplitudes for the sine and cosine waveforms e.g., ±1 and ±2, thus obtaining 16 possible output waveforms.
- Group four consecutive bits of the binary baseband stream select one of the 16 waveforms accordingly.
- The resulting output occupies one-fourth the bandwidth of PSK

$$x_{16QAM}(t) = \alpha_1 A_c \cos \omega_c t - \alpha_2 A_c \sin \omega_c t \quad \alpha_1 = \pm 1, \pm 2, \;\; \alpha_2 = \pm 1, \pm 2$$

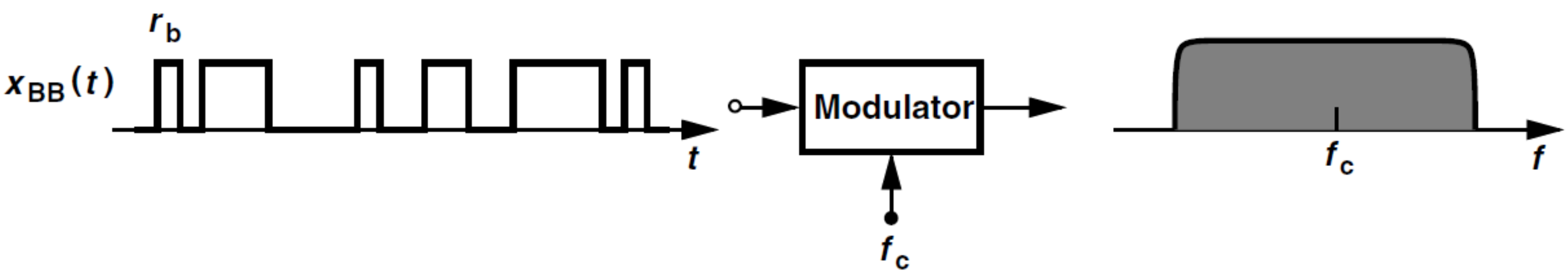


Symbol rate = ¼ Bit rate

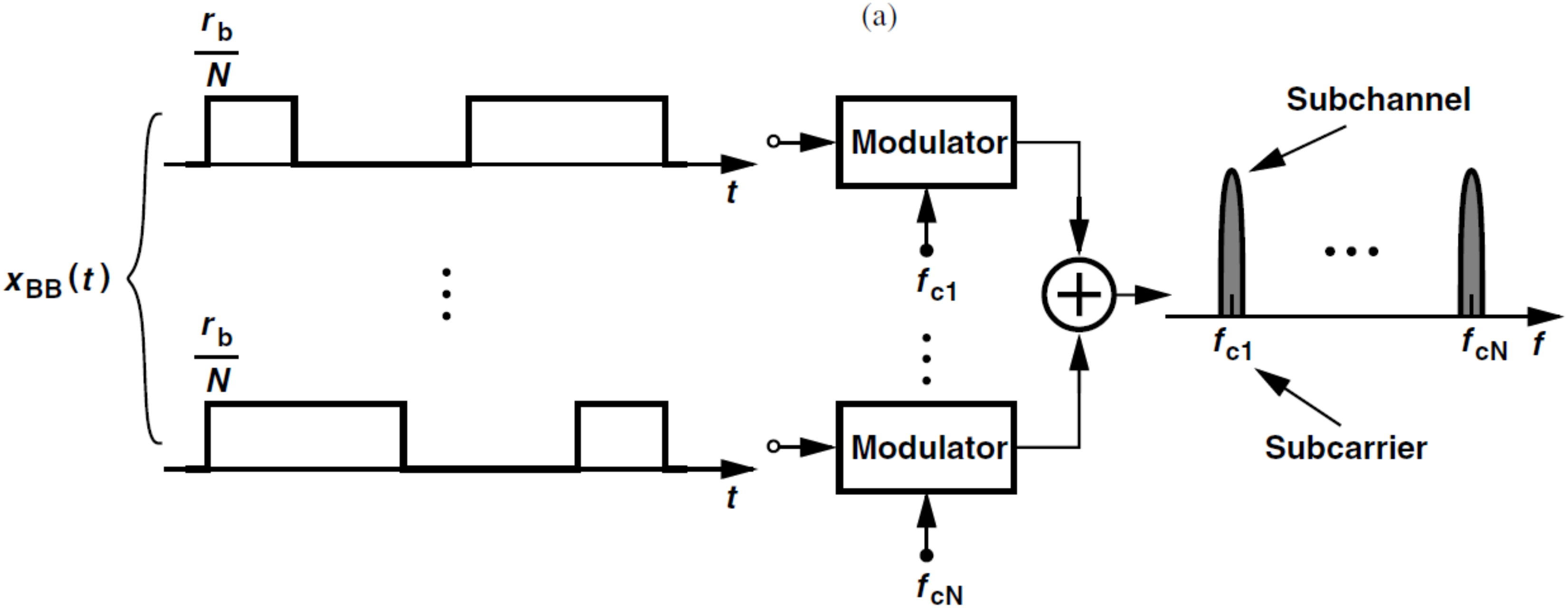
Review: Multipath Propagation



Review: OFDM



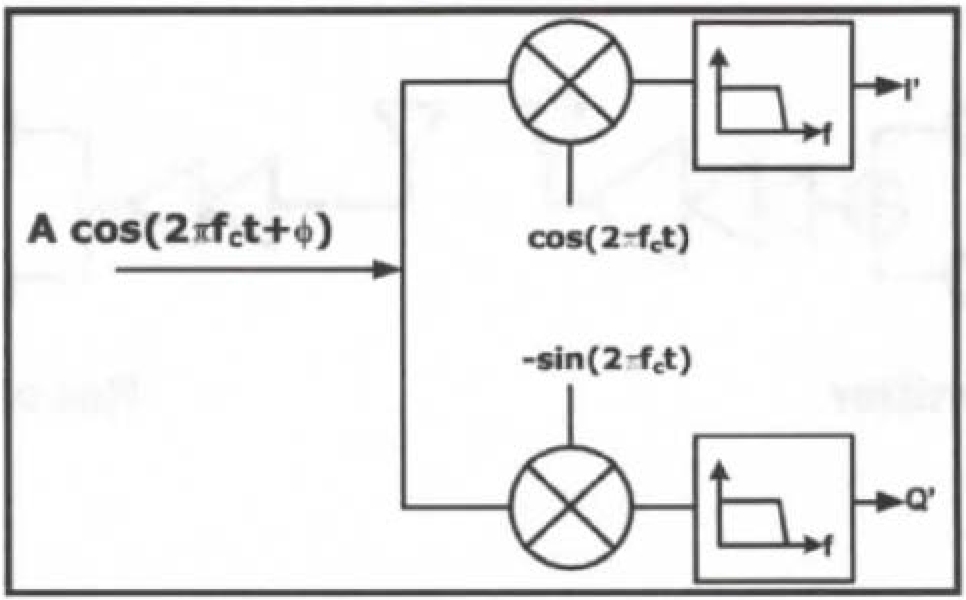
(a)



(b)

Review: Demodulation

- Inverse of Modulation
- Extract original I and Q from received modulated signal
- Example: Demodulate Quadrature modulated signal
  - Multiply input signal with two 90 deg phase related sine waves
  - LPF to eliminate high freq. signal components
  - Recover scaled version of original I and Q

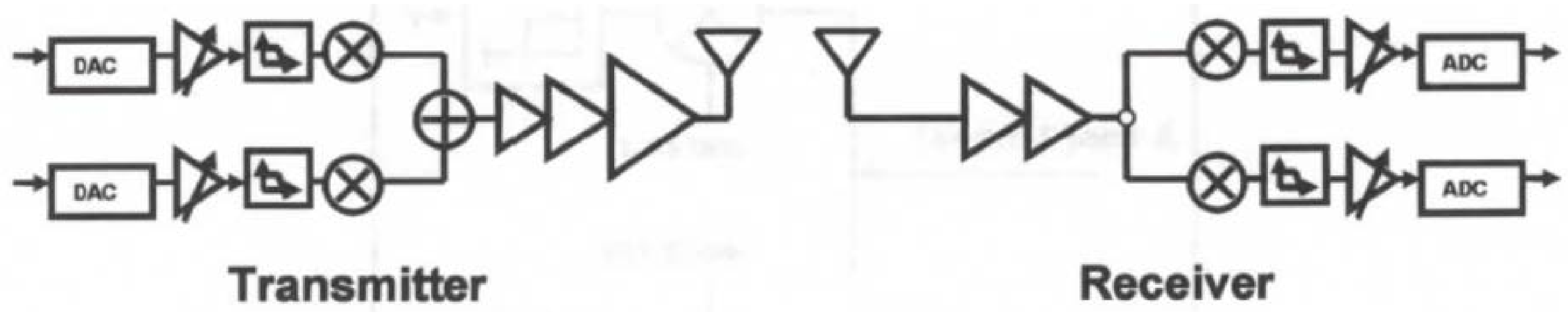


Key Specs for Transceivers

- Direct Conversion Transceiver
- Non-idealities in RF circuits
- Key Specs for Transmitter
- Key Specs for Receiver
- Important System Level Concepts

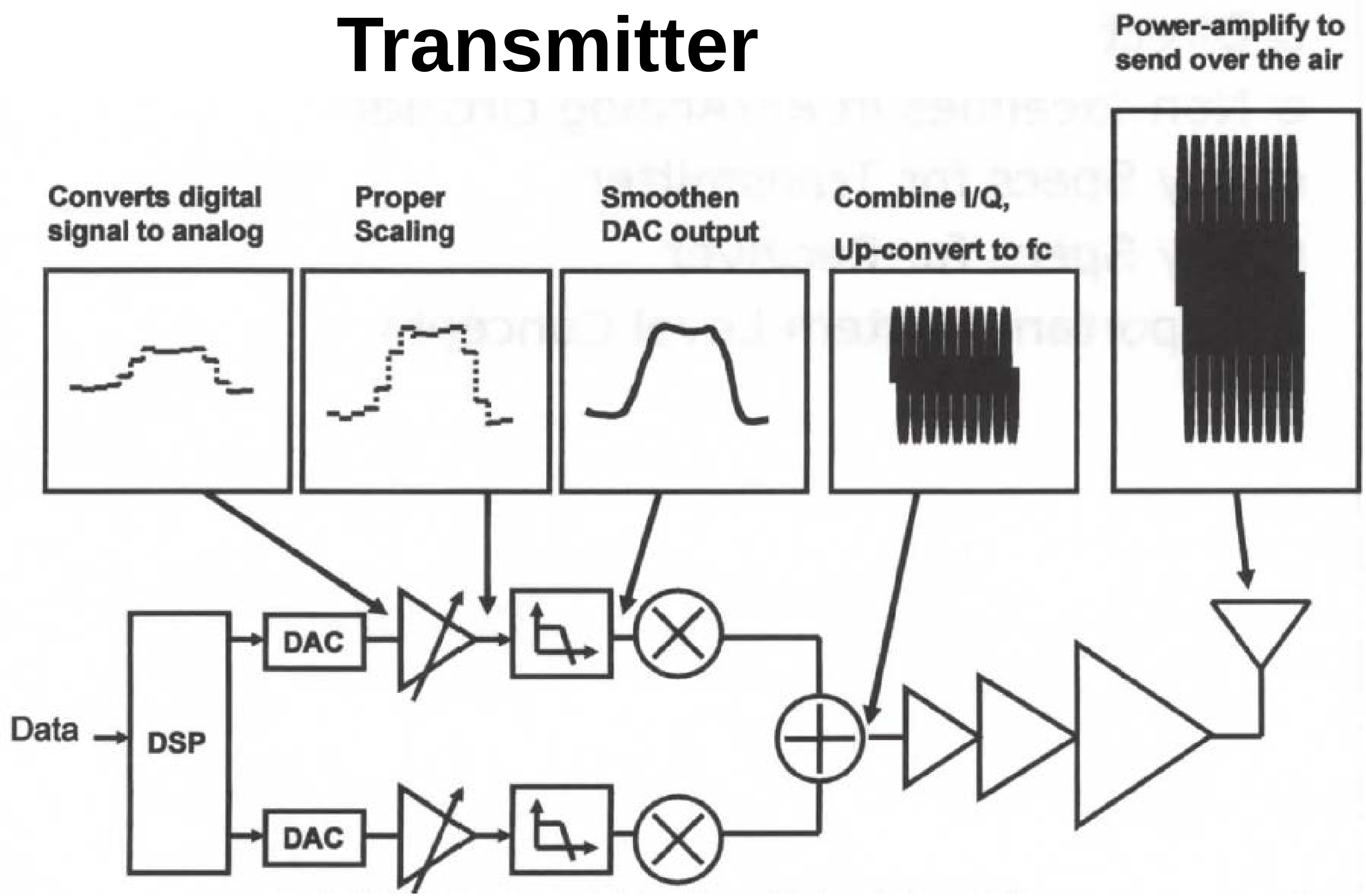
Direct Conversion Transceiver

- Also known as “Homodyne” or “Zero-IF”
- Simplest analog implementation compared to other radio architectures
- RF section mainly performs up/down freq translation
- Channel selection and most of AGC are performed at low frequency



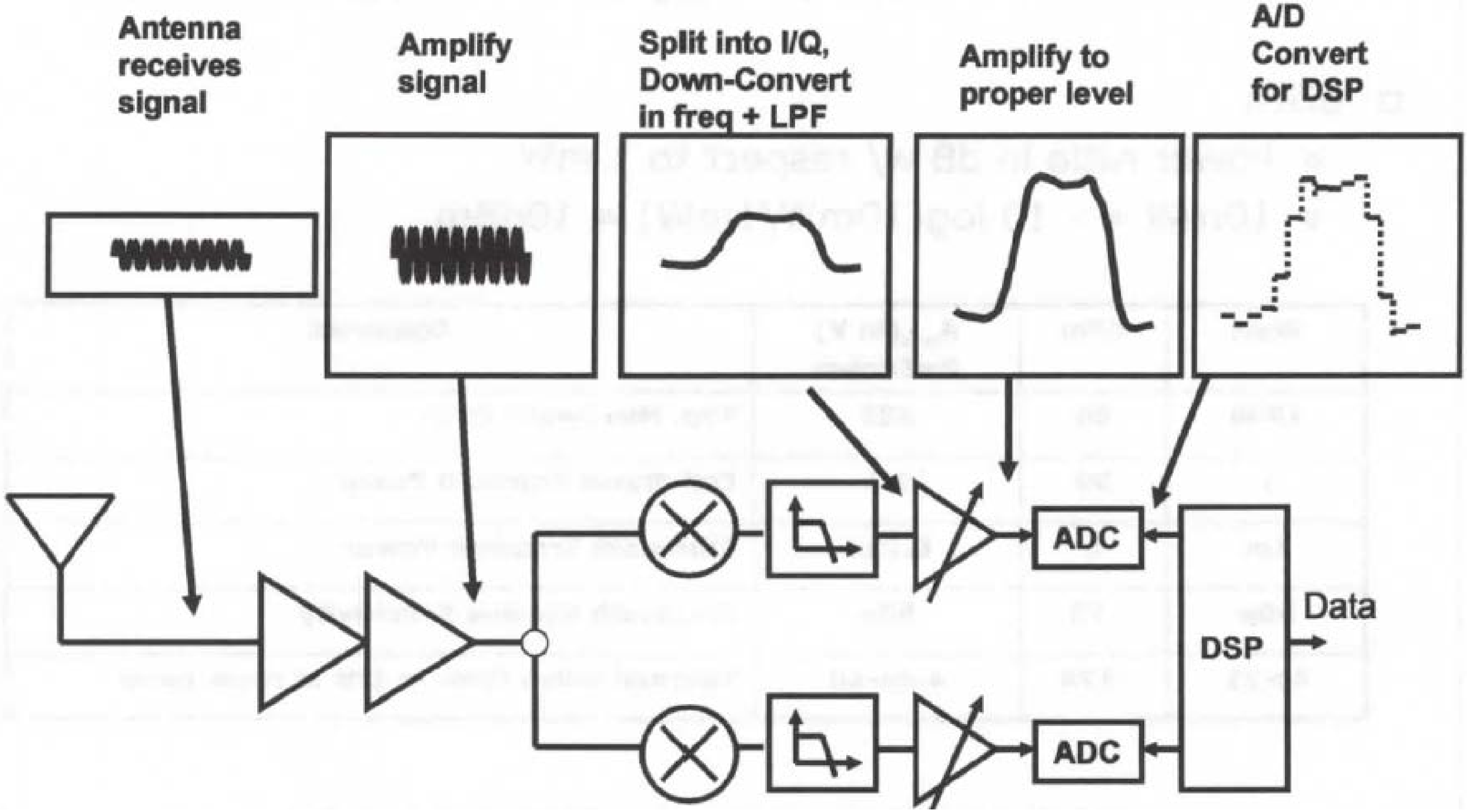
Direct Conversion Transceiver

Transmitter



Direct Conversion Receiver

Receiver



Non-idealities in RF Circuits

- Definition: Signal Power
- Noise
- Linearity
- Clock Noise

Definitions related to Signal Power

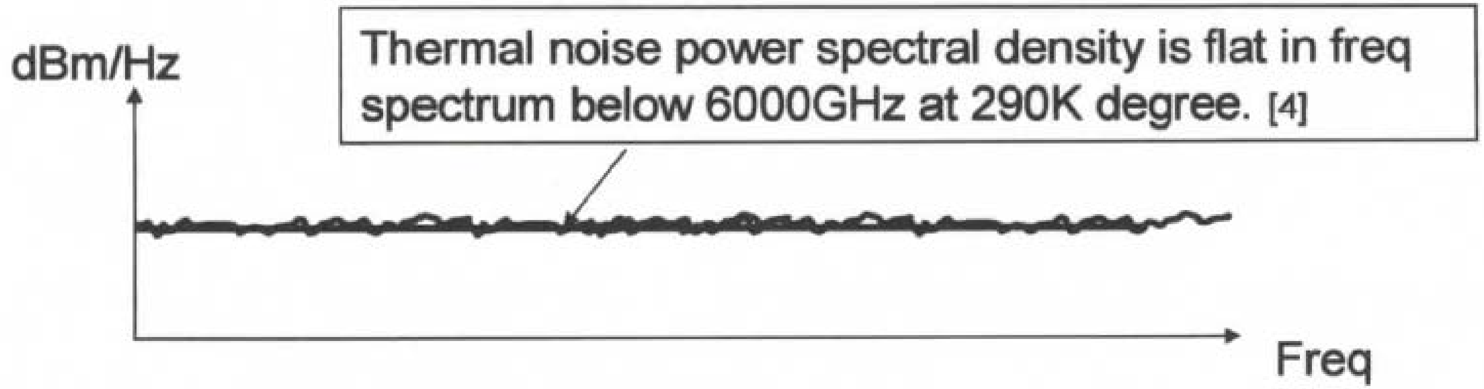
- Signal power on resistor R
  - Voltage swing is sinusoidal with amplitude A (0-pk).
  - Power (Watt) = $A^2/(2R) = A_{rms}^2/R$ where $A_{rms} = A/\mathrm{sqrt}(2)$

- dBm
  - Power ratio in dB w/ respect to 1 mW.
  - 10mW => 10 log(10mW/1mW) = 10dBm

Watt	dBm	A_{rms}(in V) R=50ohm	Comment
1000	60	223	Typ. Microwave Oven
1	30	7.1	Cell Phone Transmit Power
1m	0	0.225	Bluetooth Transmit Power
50p	-73	50u	Bluetooth Receive Sensitivity
4e-21	-174	4.4e-10	Thermal Noise Floor in 1Hz at room temp

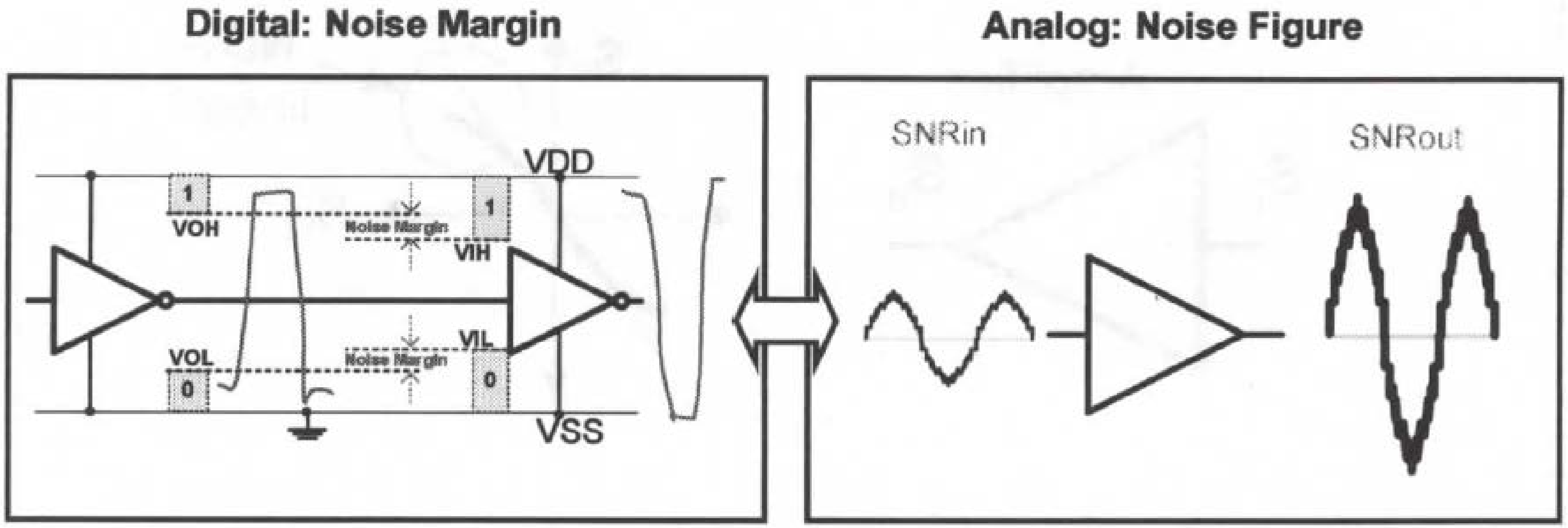
Noise: Thermal Noise

- Due to random charge carrier motion in any conducting medium whose temp is above absolute zero.
- Important noise source in Wireless.
- Thermal noise sets the noise floor given the bandwidth (BW).
- kTB = -174dBm + 10log(BW) at room temp
  - K: Boltzmann's constant = 1.38×10^{-23} J/K
  - T: Temp in Kelvin (K) = 273 + degree in C
  - B: BW in Hz.
  - Example: Noise in 1MHz BW
    = -174dBm/Hz + 10log(1e6) = -114dBm (0.45uVrms on 50ohm)



Noise: Noise Figure

- Noise on the digital signal does not propagate if "Noise Margin" is met.
- Analog amplifier adds noise* to the signal, degrading signal quality.
- Noise Factor (F) = SNRin/SNRout
- Noise Figure (NF) = 10log(F) (in dB)
  - Ideal Amplifier: SNRin = SNRout, F=1, NF=0dB
  - Real Amplifier: SNRin>SNRout, Good NF=1-3dB



* Also, circuit other types of noise, such as flicker, shot, etc. See [5]

Noise: Cascaded NF

- Cascaded amplifiers are used when a single stage gain is not high enough.
- Friis formula to calculate total equivalent F.
  - Ftotal = F1 + (F2-1)/G1 + (F3-1)/(G1G2) + … [6]
  - F2, F3, … are reduced by the gain of preceding stages.
  - If G1 is sufficiently large enough, F1 is **most critical** to achieve low Ftotal.