CS 294-7: Digital Modulation

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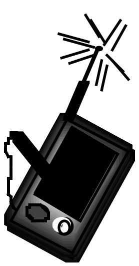
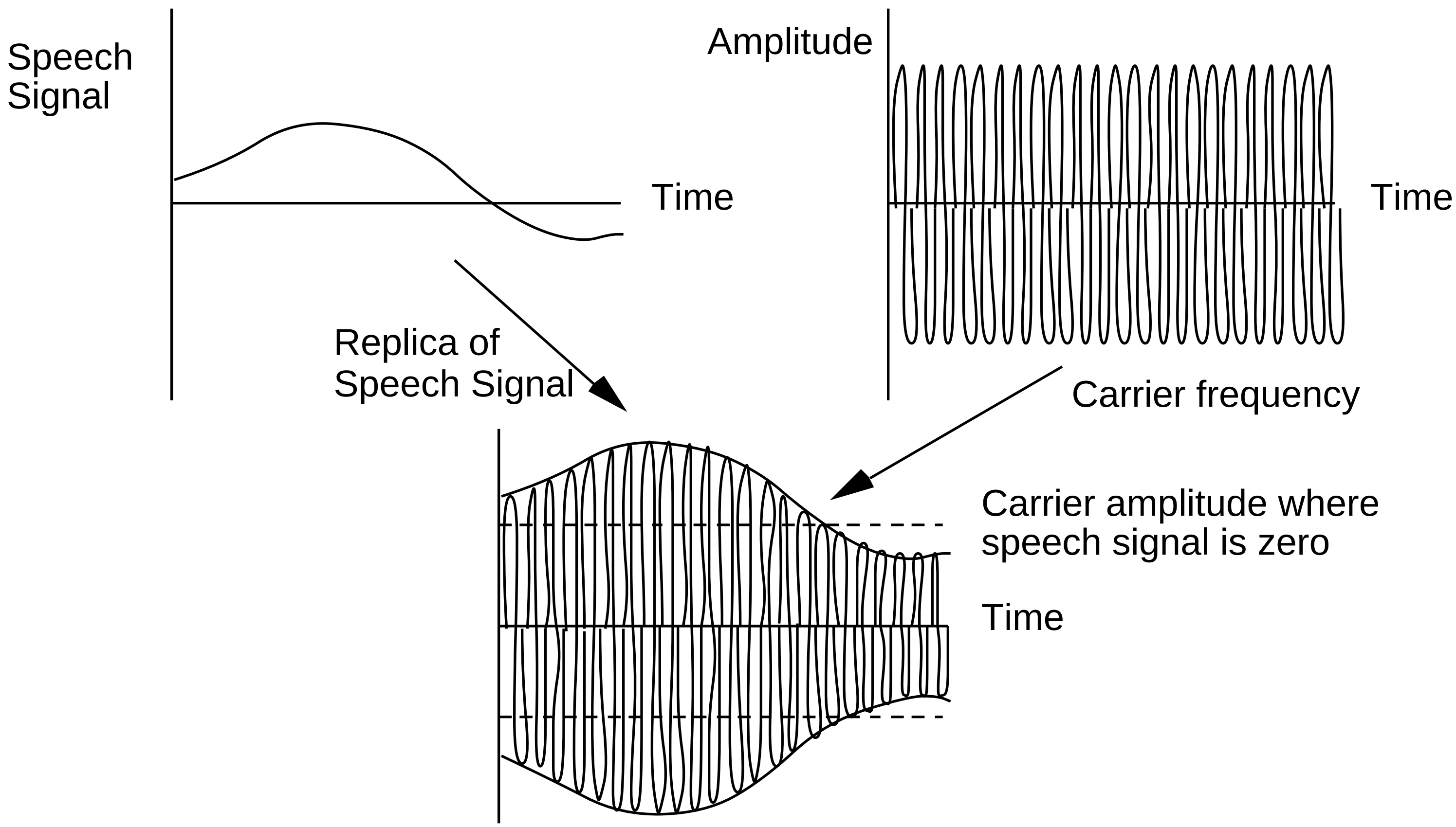


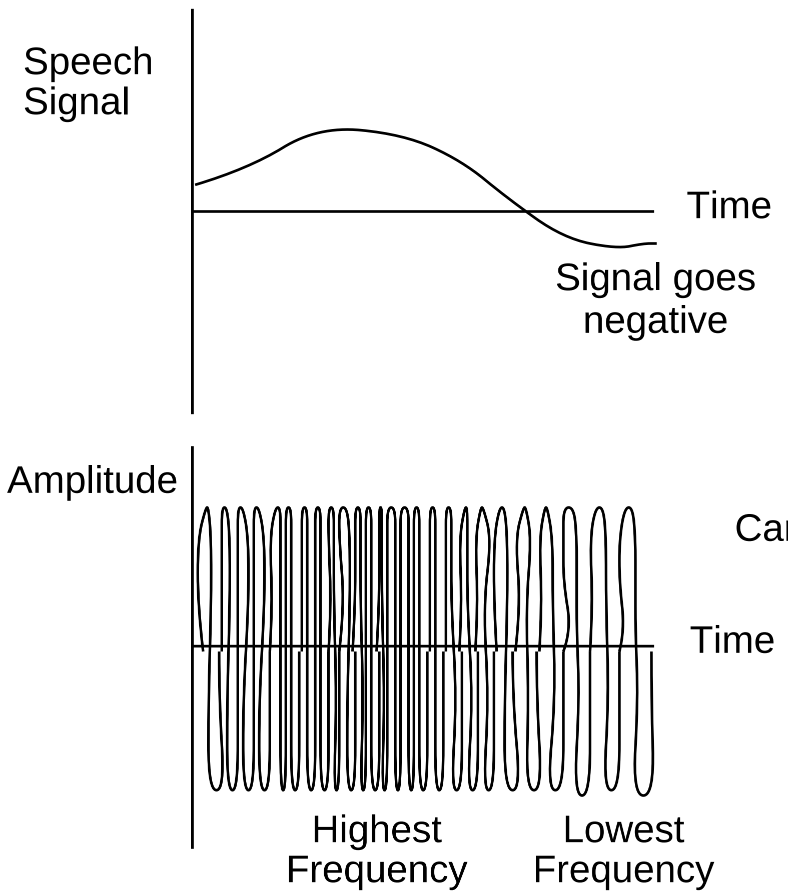
Analog Modulation: AM Radio

Amplitude Modulation (AM)



Analog Modulation: FM Radio

Frequency Modulation (FM)



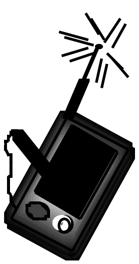
Noise has a greater effect on amplitude than frequency

Sufficient to detect zero crossings to reconstruct the signal

Easy to eliminate amplitude distortion

Constant envelope, i.e., envelope of carrier wave does not change with changes in modulated signal

This means that more efficient amplifiers can be used, reducing power demands

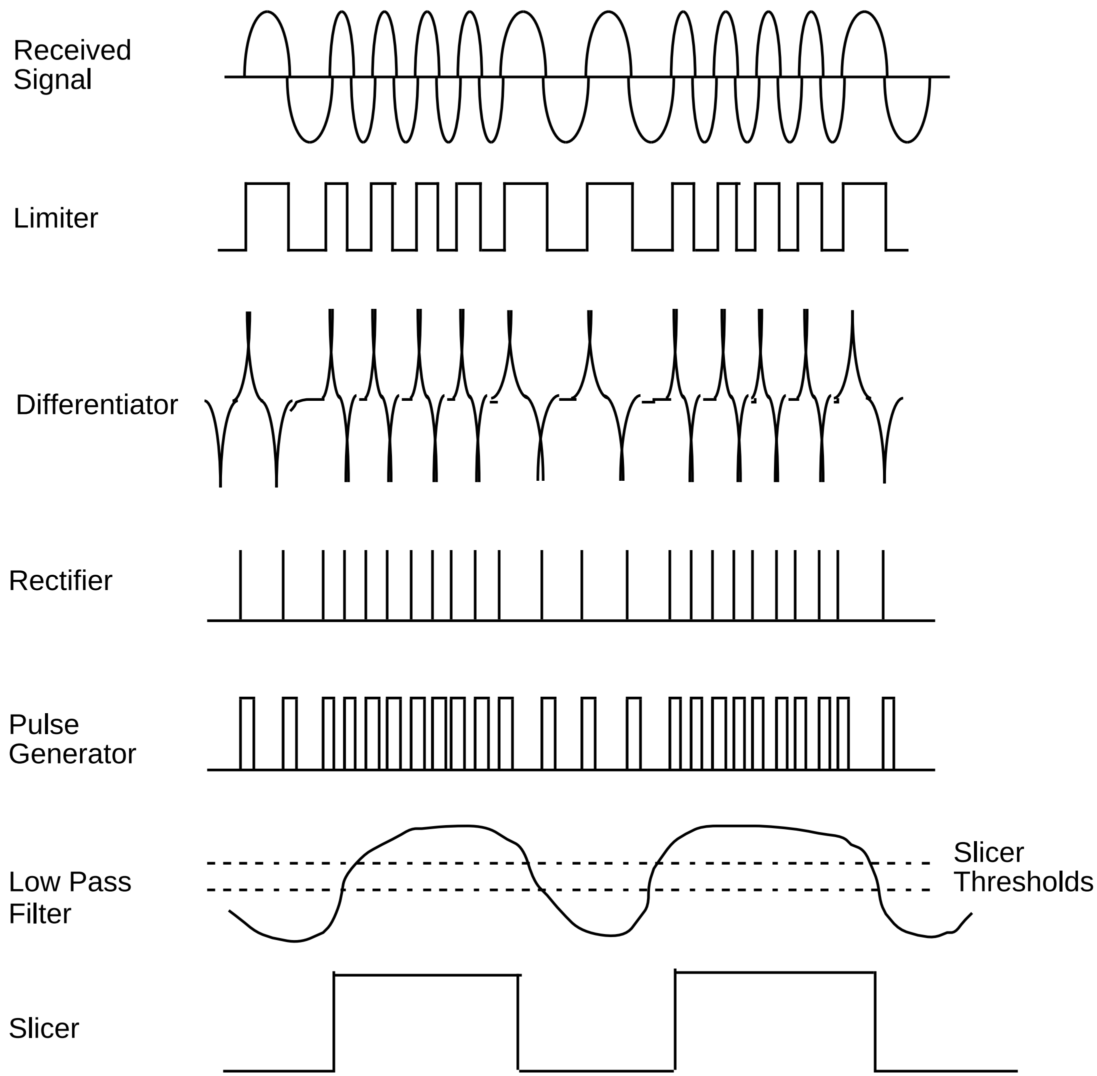


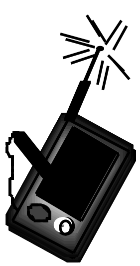
Detection of FM Signal

Noise translates into amplitude changes, and sometimes frequency changes

Detection based on zero crossings: the limiter

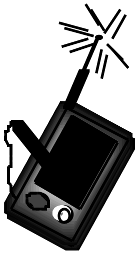
Alternative schemes to translate limited signal into bit streams





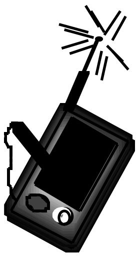
Digital Modulation Techniques

- **Carrier wave s:**
  - **$s(t) = A(t) * \cos[\Theta(t)]$**
  - **Function of time varying amplitude A and time varying angle Θ**
- **Angle Θ rewritten as:**
  - **$\Theta(t) = \omega_0 + \varphi(t)$**
  - **ω_0 radian frequency, phase $\varphi(t)$**
- **$s(t) = A(t) \cos[\omega_0 t + \varphi(t)]$**
  - **ω radians per second**
  - **relationship between radians per second and hertz**
    - » $\omega = 2 \pi f$



Digital Modulation Techniques

- Demodulation
  - Process of removing the carrier signal
- Detection
  - Process of symbol decision
  - Coherent detection
    - » Receiver users the carrier phase to detect signal
    - » Cross correlate with replica signals at receiver
    - » Match within threshold to make decision
  - Noncoherent detection
    - » Does not exploit phase reference information
    - » Less complex receiver, but worse performance

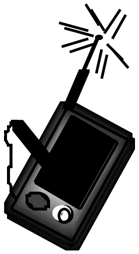


Digital Modulation Techniques

Coherent	Noncoherent
Phase shift keying (PSK)	FSK
Frequency shift keying (FSK)	ASK
Amplitude shift keying (ASK)	Differential PSK (DPSK)
Continuous phase modulation (CPM)	CPM
Hybrids	Hybrids

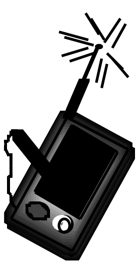
Coherent (aka synchronous) detection**: process received signal with a local carrier of same frequency and phase**

Noncoherent (aka envelope) detection**: requires no reference wave**



Metrics for Digital Modulation

- **Power Efficiency**
  - Ability of a modulation technique to preserve the fidelity of the digital message at low power levels
  - Designer can increase noise immunity by increasing signal power
  - Power efficiency is a measure of how much signal power should be increased to achieve a particular BER for a given modulation scheme
  - Signal energy per bit / noise power spectral density: E_b / N_0
- **Bandwidth Efficiency**
  - Ability to accomodate data within a limited bandwidth
  - Tradeoff between data rate and pulse width
  - Thruput data rate per hertz: R/B bps per Hz
- **Shannon Limit: Channel capacity / bandwidth**
  - $C/B = \log_2(1 + S/N)$



Digital Modulation Techniques

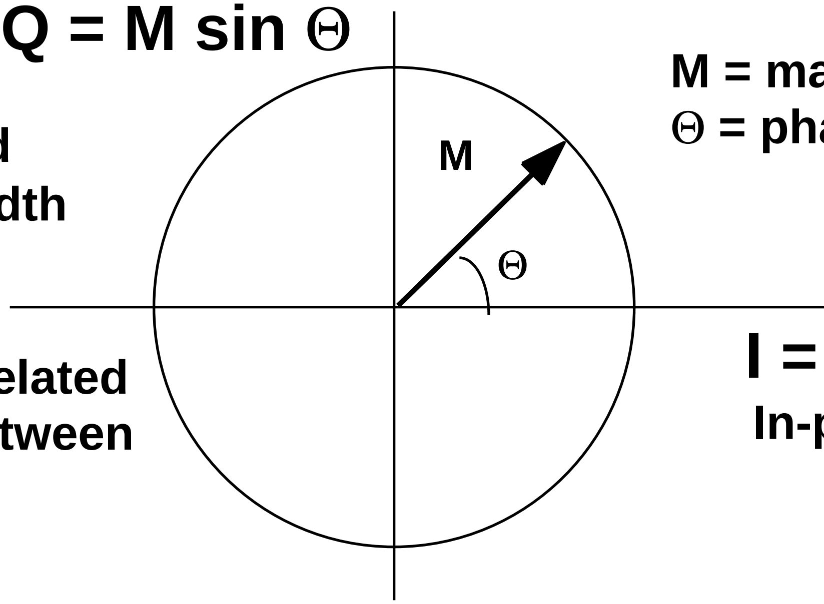
- **Modify carrier's amplitude and/or phase (and frequency)**
- **Constellation: Vector notation/polar coordinates**

Quadrature component (carrier shifted 90°)

$Q = M \sin \Theta$

Densely packed implies bandwidth efficient

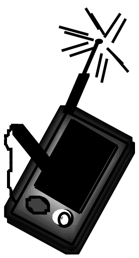
Bit error prob related to distances between closest points



M = magnitude
Θ = phase

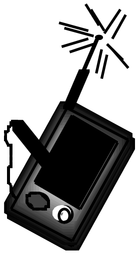
$I = M \cos \Theta$

In-phase component



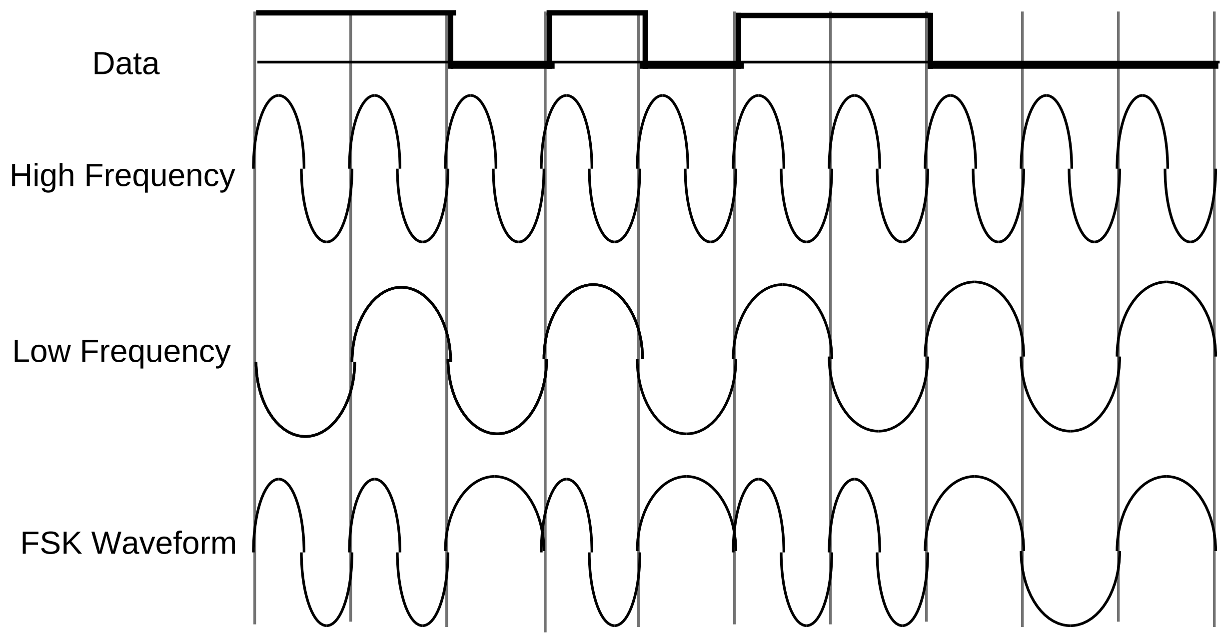
Considerations in Choice of Modulation Scheme

- High spectral efficiency
- High power efficiency
- Robust to multipath effects
- Low cost and ease of implementation
- Low carrier-to-cochannel interference ratio
- Low out-of-band radiation
- Constant or near constant envelope
  - Constant: only phase is modulated
  - Non-constant: phase and amplitude modulated



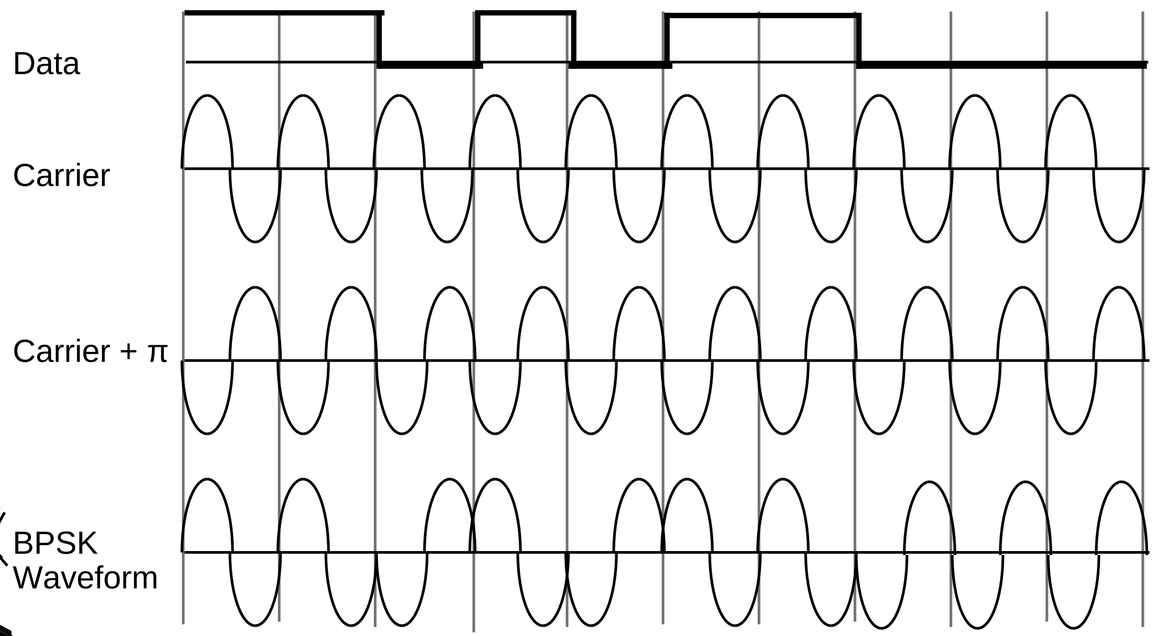
Binary Modulation Schemes

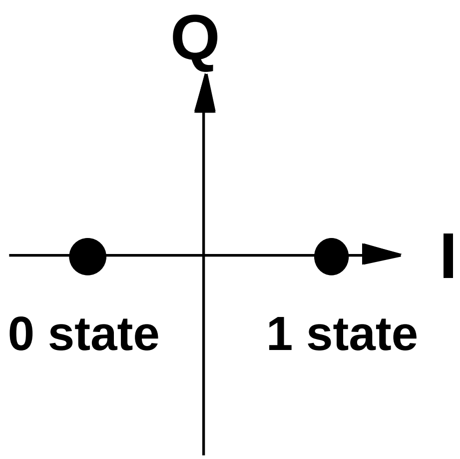
- **Amplitude Shift Keying (ASK)**
  - **Transmission on/off to represent 1/0**
  - **Note use of term “keying,” like a telegraph key**
- **Frequency Shift Keying (FSK)**
  - **1/0 represented by two different frequencies slightly offset from carrier frequency**



Phase Shift Keying

- **Binary Phase Shift Keying (BPSK)**
  - **Use alternative sine wave phase to encode bits**
  - **Simple to implement, inefficient use of bandwidth**
  - **Very robust, used extensively in satellite communications**

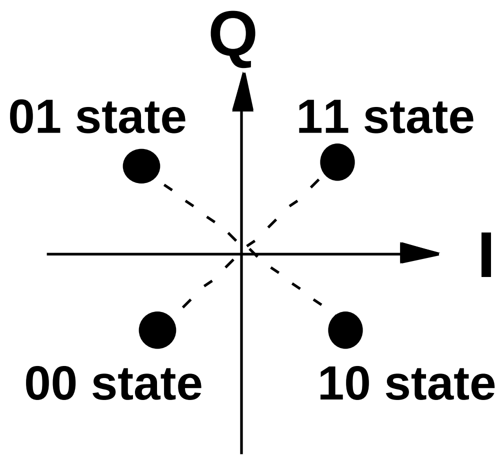




Phases separated by 180°
(π radians)

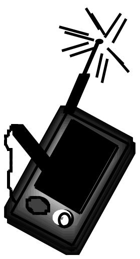
Phase Shift Keying

- Quadrature Phase Shift Keying (QPSK)
  - Multilevel modulation technique: 2 bits per symbol
  - More spectrally efficient, more complex receiver



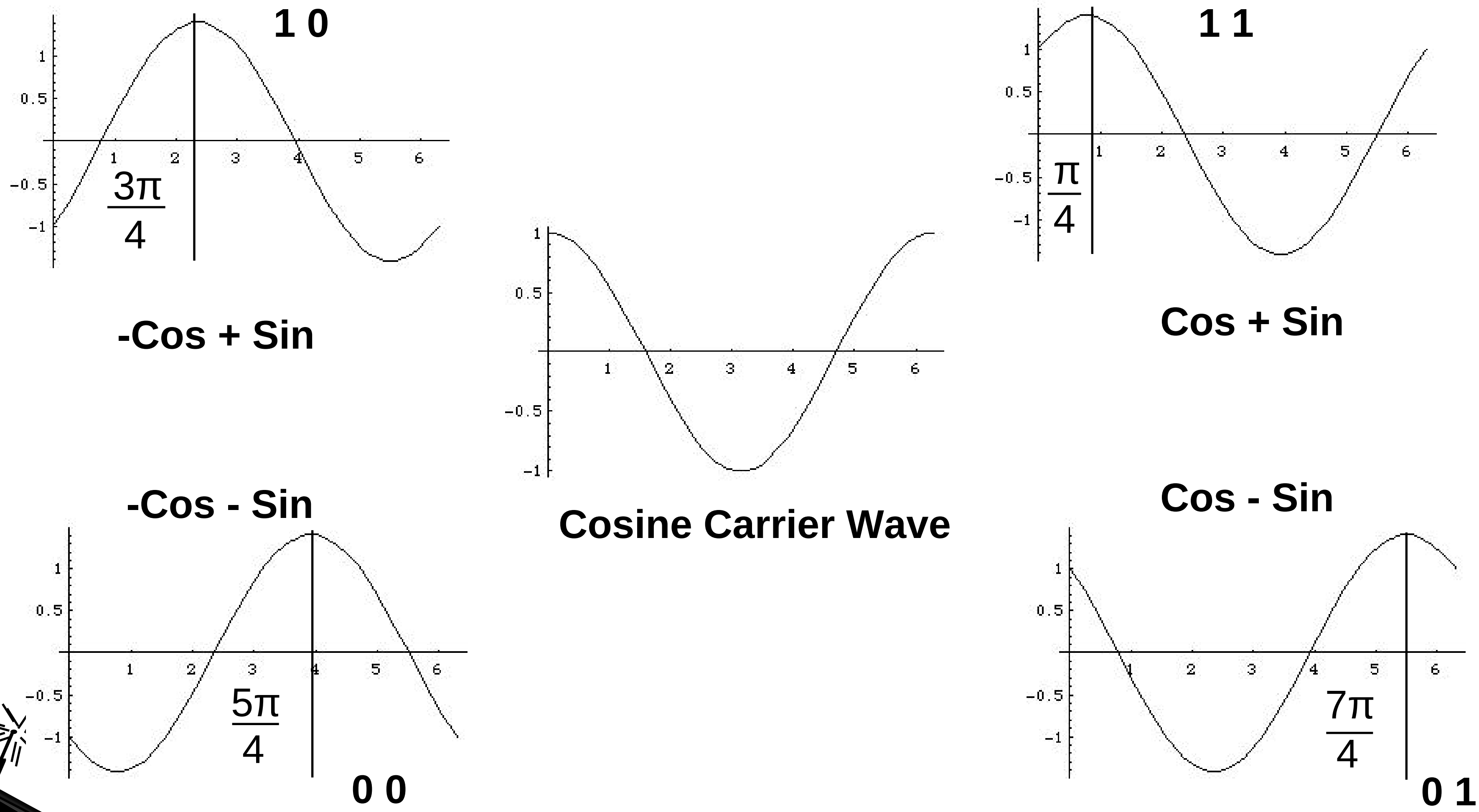
Phase of carrier:
π/4, 3π/4, 5π/4, 7π/4

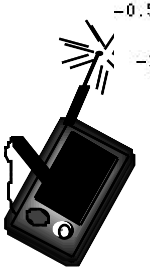
Output waveform is sum of modulated ± Cosine and ±Sine wave



2x bandwidth efficiency of BPSK

Quadrature Phase Shift Keying

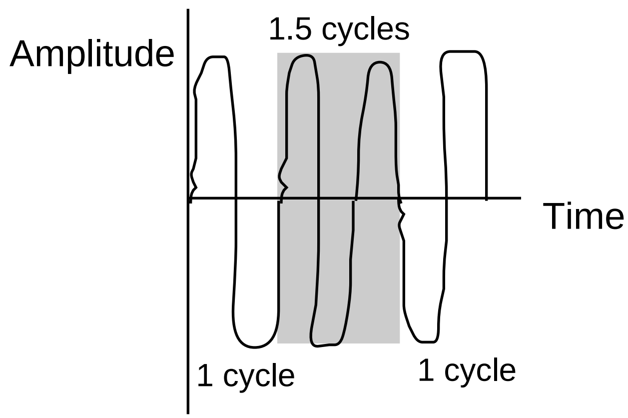


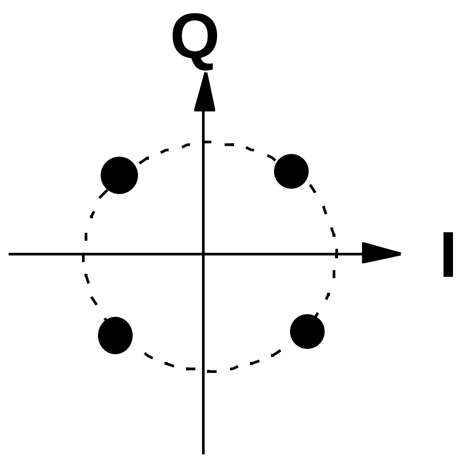


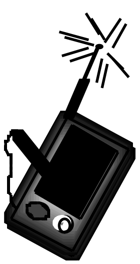
Minimum Shift Keying

- Special form of (continuous phase) frequency shift keying
  - Minimum spacing that allows two frequencies states to be orthogonal
  - Spectrally efficient, easily generated

Minimum Shift Keying (MSK)







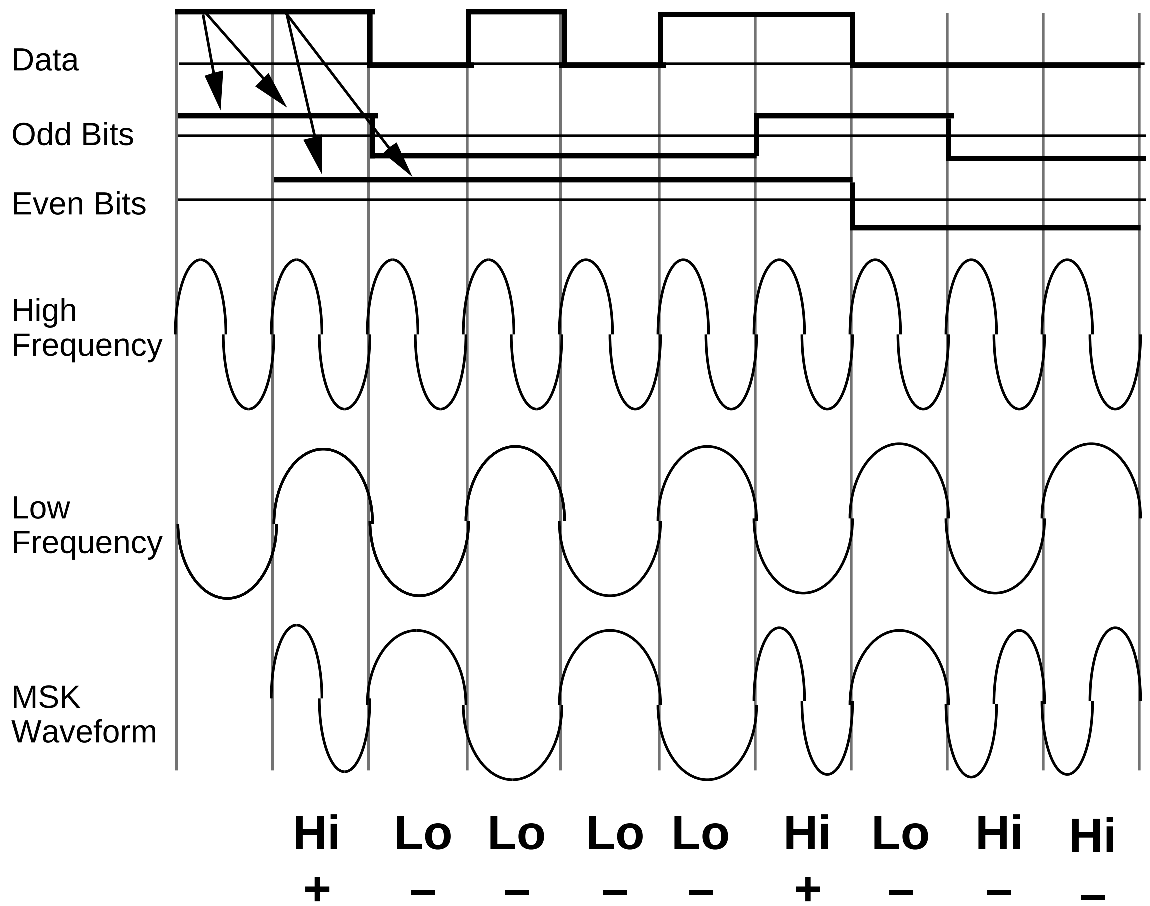
Phase continuity at the bit transitions

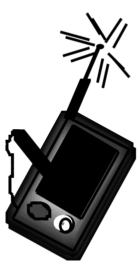
Generating Minimum Shift Keying

Odd, Even Bits stretched to 2 bit times

Bit Value		MSK Output	
Odd	Even	Freq	Sense
1	1	Hi	+
-1	1	Lo	–
1	-1	Lo	+
-1	-1	Hi	–

Notice smooth phase transitions!

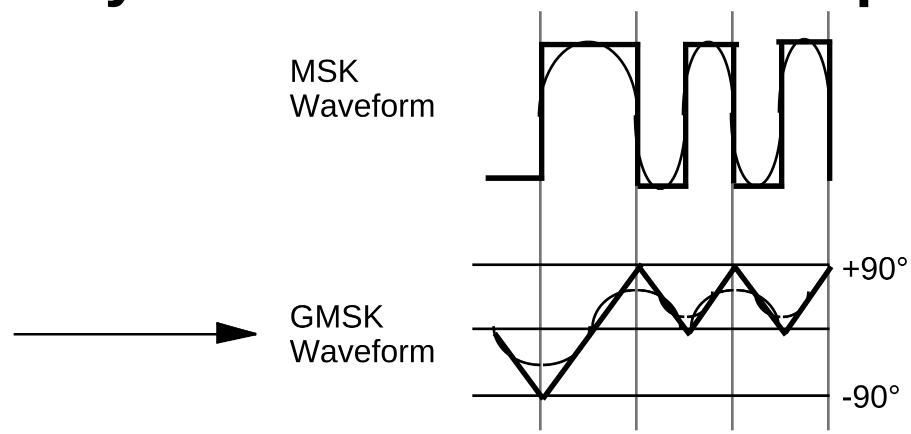




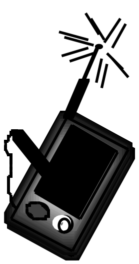
Gaussian Minimum Shift Keying (GMSK)

- **MSK + premodulation Gaussian low pass filter**
- **Increases spectral efficiency with sharper cutoff, excellent power efficiency due to constant envelope**

No sudden shifts in phase

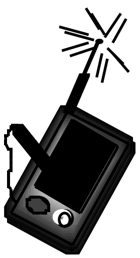


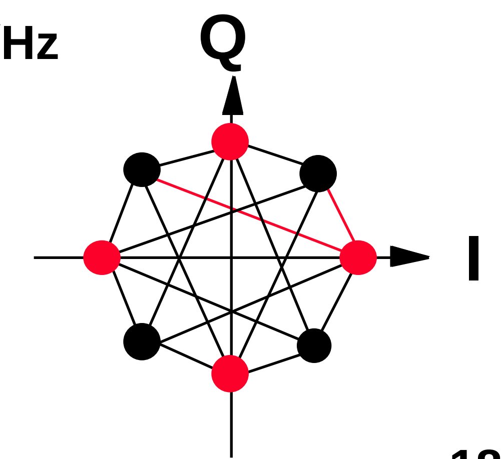
- **Used extensively in second generation digital cellular and cordless telephone applications**
  - **GSM digital cellular: 1.35 bps/Hz**
  - **DECT cordless telephone: 0.67 bps/Hz**
  - **RAM Mobile Data**



π/4-Shifted QPSK

- **Variation on QPSK**
  - Restricted carrier phase transition to +/- π/4 and +/- 3π/4
  - Signaling elements selected in turn from two QPSK constellations, each shifted by π/4
  - Maximum phase change is ±135° vs. 180° for QPSK, thus maintaining constant envelope (i.e., amplitude of QPSK signal not constant for short interval during 180° phase changes)
- **Popular in Second Generation Systems**
  - North American Digital Cellular (IS-54): 1.62 bps/Hz
  - Japanese Digital Cellular System: 1.68 bps/Hz
  - European TETRA System: 1.44 bps/Hz
  - Japanese Personal Handy Phone (PHP)



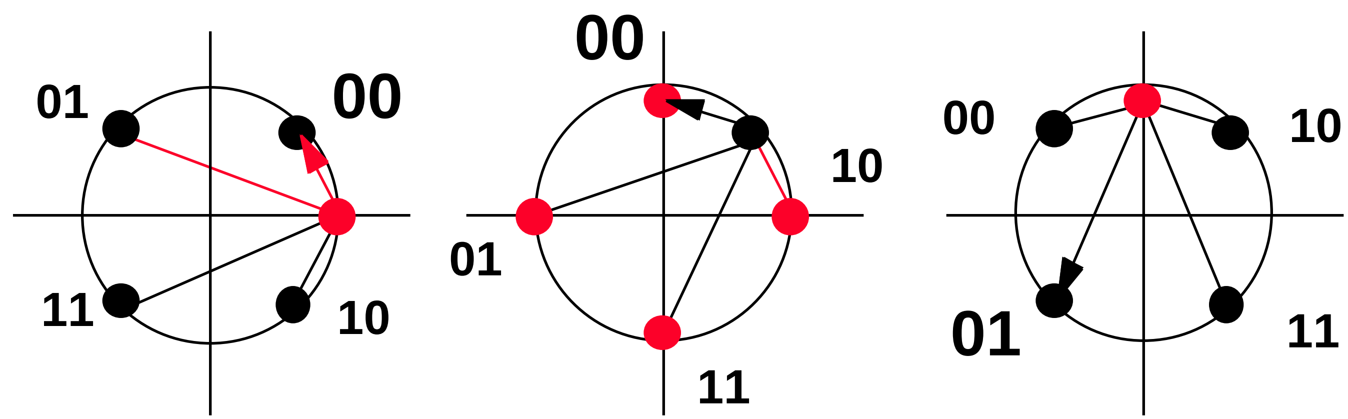


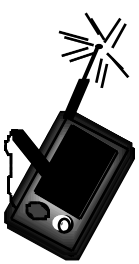
π/4-Shifted QPSK

- **Advantages:**
  - Two bits per symbol, twice as efficient as GMSK
  - Phase transitions avoid center of diagram, remove some design constraints on amplifier
  - Always a phase change between symbols, leading to self clocking

Data	Phase Change
00	45°
01	135°
10	-45°
11	-135°

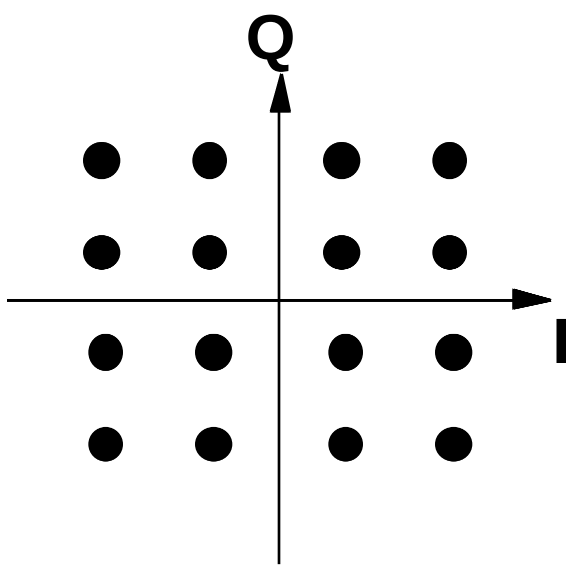
… 00 00 01 …





Quadrature Amplitude Modulation

- Quadrature Amplitude Modulation (QAM)
  - Amplitude modulation on both quadrature carriers
  - 2^n discrete levels, n = 2 same as QPSK
- Extensive use in digital microwave radio links



16 Level QAM