

# King Fahd University of Petroleum & Minerals Computer Engineering Dept

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COE 543 – Mobile and Wireless  
Networks

Term 111

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## Lecture Contents

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## Consideration in the Design of Wireless Modems

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- Bandwidth Efficiency
- Power Efficiency
- Out-of-band Radiation
- Resistance to Multipath
- Constant envelope Modulation

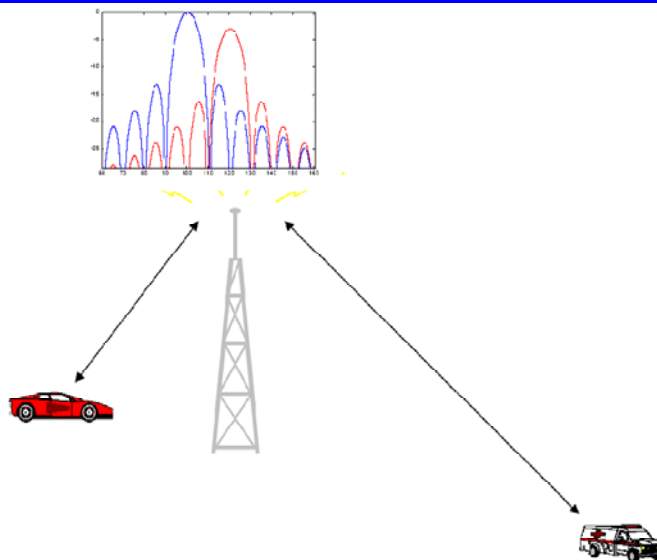
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## Adjacent Channel Interference

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## Wireless Transmission Techniques

- Pulse transmission:
  - Used mostly for IR applications
  - Impulse Radio or Ultra Wideband (UWB)
- Basic modulation techniques
  - TDMA/FDMA
- CDMA
  - Used for 3G and wireless LANs
- OFDMA
  - Wireless LANs and 4G?

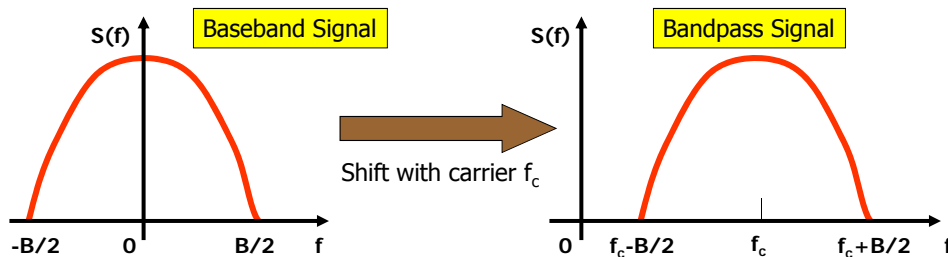
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## Background – Baseband vs. Bandpass Signals

- **Baseband Signal:**
  - Spectrum not centered around non zero frequency
  - May have a DC component
- **Bandpass Signal:**
  - Does not have a DC component
  - Finite bandwidth around or at  $f_c$



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## Background

- **Digital Data, Digital Signaling:**
  - Less complex/expensive than digital-to-analog modulation equipment
- **Analog Data, Digital Signaling:**
  - Conversion of analog data to digital allows the use of modern digital tx and switching technology
- **Digital Data, Analog Signaling:**
  - Some transmission media can *ONLY* propagate analog signals – such as fiber optics and unguided
- **Analog Data, Analog Signaling:**
  - Analog data can be transmitted as baseband signals cheaply
  - Shifting bandwidth of baseband signals to occupy another portion of spectrum – different signals share same medium using frequency division multiplexing

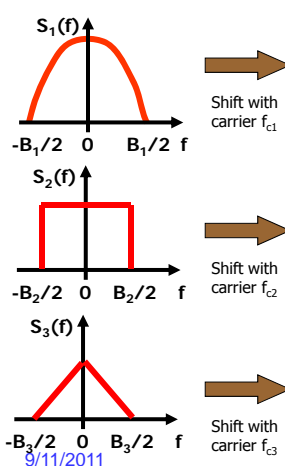
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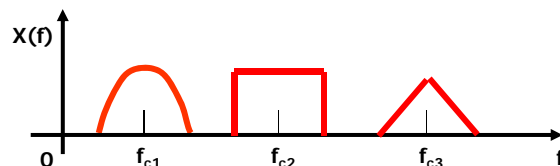
## Background - Frequency Division Multiplexing

- Refer to COE 341 Textbook



$$x(t) = s_1(t) \times \cos(2\pi f_{c1}t) + s_2(t) \times \cos(2\pi f_{c2}t) + s_3(t) \times \cos(2\pi f_{c3}t)$$

- $x(t)$  is transmitted on the media
- The three spectra are not overlapping if  $f_{c1}$ ,  $f_{c2}$ , and  $f_{c3}$  are chosen appropriately
- Original composite signals  $s_1(t)$ ,  $s_2(t)$ , and  $s_3(t)$  can be recovered using bandpass filters with appropriate bandwidths centered at  $f_{c1}$ ,  $f_{c2}$ , and  $f_{c3}$ , respectively.



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## Background - Signal Elements or Pulses

- Unit of transmission – repeated to form the overall signal
- *Shape* of pulse determines the bandwidth of the transmitted signal
- Digital data is mapped or encoded to the different pulses or units of transmission

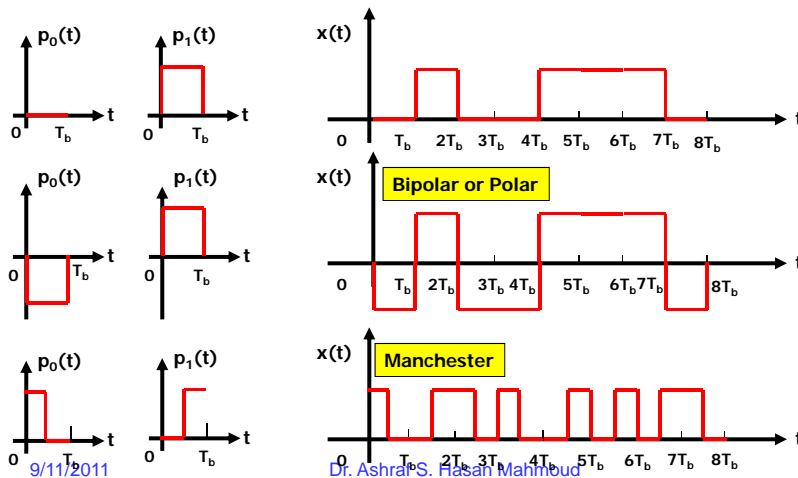
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## Background - Signal Elements or Pulses

### Definitions of Pulses Encoded Signal: 0 1 0 0 1 1 1 0



Examples of Digital Signaling

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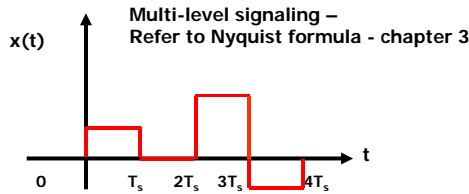
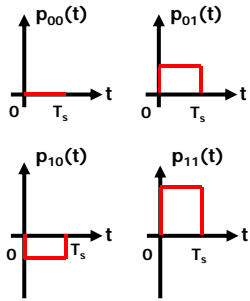
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# Background - Signal Elements or Pulses

## Pluses Definitions

## Encoded Signal: 0 1 0 0 1 1 1 0



- Note that each symbol or pulse carries 2 bits
- Symbol duration is  $T_s = 2T_b$
- Bit rate  $R$  equal to  $1/T_b$
- Symbol rate or *baud rate*  $R_s$  equal to  $1/T_s \rightarrow R = 2R_s$
- In general to encode  $n$  bits per pulse, you need  $2^n$  pulses

Example of Digital Signaling

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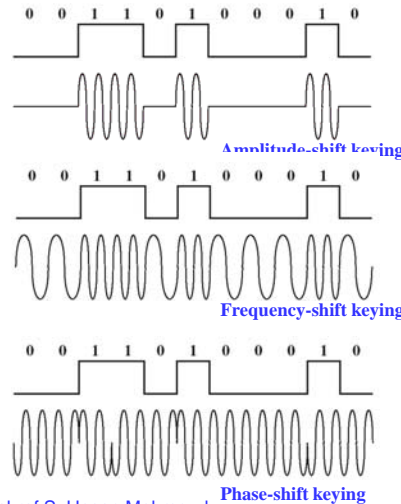
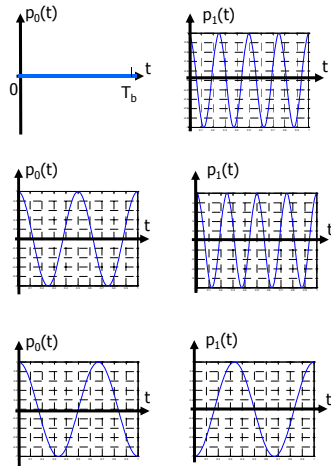
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# Background - Signal Elements or Pulses

## Definitions of Pulses

## Encoded Signal:



Example of Analog Signaling

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## Baseband Transmission

- Digital signal transmitted without modulation with carrier
- Does not support FDM
- Two basic steps:
  - Line coding
  - Pulse modulation (this is NOT carrier modulation)

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## Digital Signal Encoding Formats

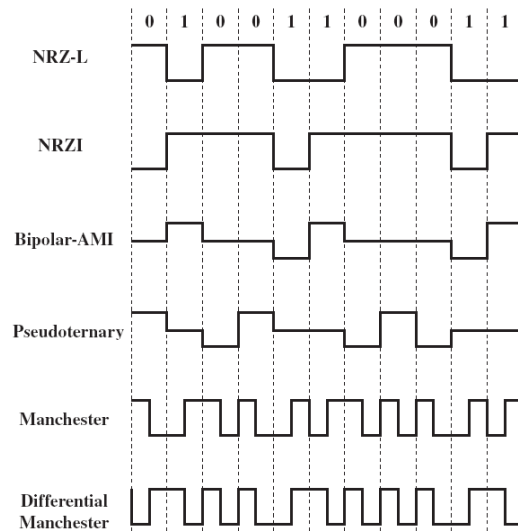
- **Nonreturn to Zero-Level (NRZ-L)**
  - 0 = high level
  - 1 = low level
- **Nonreturn to Zero Inverted (NRZI)**
  - 0 = no transition at beginning of interval
  - 1 = transition at beginning of interval
- **Bipolar-AMI**
  - 0 = no line signal
  - 1 = +ve or -ve level; alternating successive ones
- **Pseudoternary**
  - 0 = +ve or -ve level; alternating for successive ones
  - 1 = no line signal
- **Manchester**
  - 0 = transition from high to low in middle of interval
  - 1 = transition from low to high in middle of interval
- **Differential Manchester: Always transition in middle of interval**
  - 0 = transition at beginning of interval
  - 1 = no transition at beginning of interval
- **Bipolar with 8 Zeros Substitution (B8ZS):** same as bipolar AMI, except that any string of 8 zeros is replaced by a string with two code violations
- **High Density bipolar-3 Zeros (HDB3):** same as bipolar AMI, except that any string of 3 zeros is replaced by a string with one code violation

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## Digital Signal Encoding Formats



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## Baseband Pulse Modulation

- Pulse Amplitude Modulation (PAM)
- Pulse Position Modulation (PPM)
- Pulse width duration Modulation (PWM)
  
- PAM is not popular in wireless operation
  - Wireless channel suffer from extensive fluctuations caused by fading and near-far problems.
  
- PPM is used for IEEE802.11 IR option

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## UWB Pulse Transmission

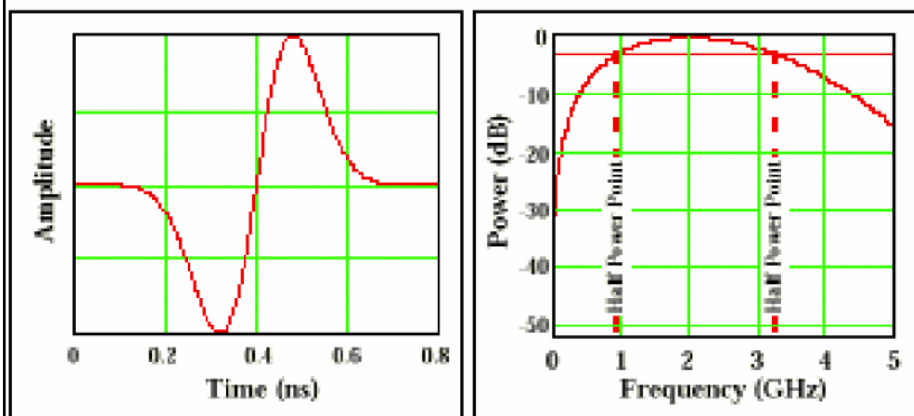
- Characteristics:
  - Very narrow width pulse -  $\sim 10$ s of nano second  $\rightarrow$  wide band (several GHz)
  - Low power
  - Short range
- Can coexist with other radio systems – Why?
- Can resolve multipath components – minimum fading effects

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## UWB Pulse Example



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## Carrier Modulation Transmission

- Signal is “mixed” with a carrier signal at a higher frequency before transmission – refer to slides 6 and 12
- Frequency Division Multiplexing
- Requirements
  - Low side lobes (for reduced ACI)
  - Extensive amplitude fluctuations (AM is not desirable) – as a result phase/frequency-based modulations are more popular
- Examples:
  - GMSK adopted for GSM
  - $\pi/4$ -QPSK adopted for IS-136

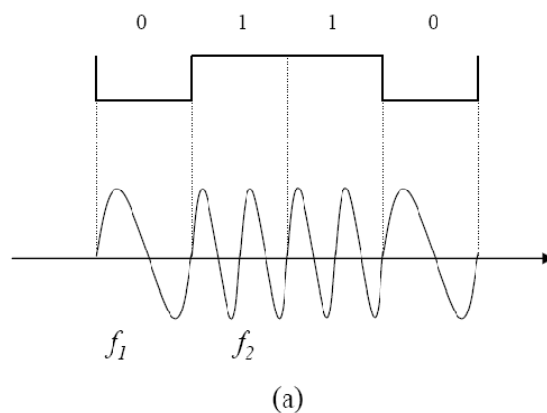
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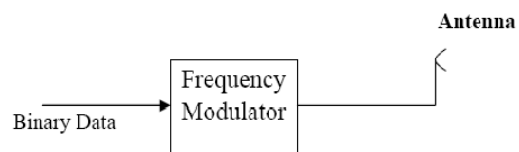
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## Frequency Shift Keying

- Constant envelope output
- Example: 4-FSK - Altair @ 18-19 GHz.



**FSK/MSK**



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## Frequency/Minimum Shift Keying - F/MSK

- Frequency spacing between tones determines the bandwidth of the modulated signal and in general its characteristics
  - Orthogonality
- Minimum frequency spacing between tones:
  - Coherent detection:  $1/(2T)$
  - Non coherent detection:  $1/T$Where  $T$  is the symbol duration
- FSK modulator using  $1/(2T)$  spacing  $\rightarrow$  MSK
- MSK is an example of constant-envelope continuous-phase modulation – abrupt phase changes at the bit transition times (characteristic of FSK in general) are eliminated

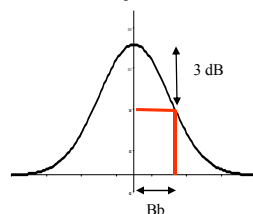
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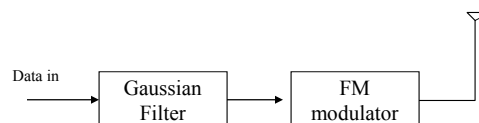
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## Gaussian Minimum Shift Keying - GMSK

- To enhance the performance of MSK – use a Gaussian filter before the FM modulator
- Further reduces side lobes
- Output of modulator still constant envelope



Gaussian filter  
frequency response  
Note: no side lobes!!



Block diagram of GMSK modulator

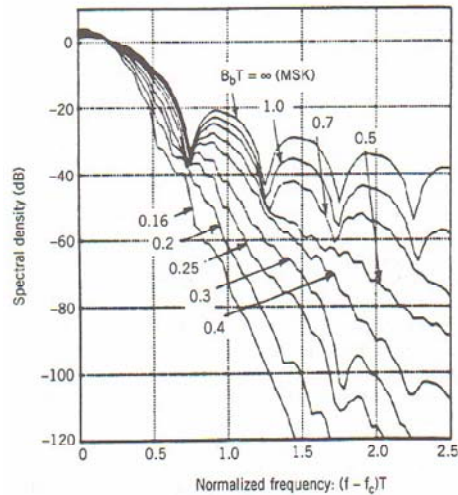
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## Spectra of GMSK Signals for Different Time-Bandwidth Product

- What is Time-Bandwidth product?
  - $B_b T$  – where  $B_b = 3$  dB bandwidth of the Gaussian filter, and  $T$  is the bit duration
  - For  $B_b = \infty \rightarrow$  no Gaussian filter or all-pass function
- As the bandwidth of the filter becomes narrower, the power in the side lobes of the transmitted signal (and therefore adjacent channel interference) reduces
- Narrower BW also corresponds to smoother transitions in the time domain  $\rightarrow$  increased bit error rate
- Compromise!!
- Typical values:
  - GSM uses  $B_b T = 0.3$
  - CDPD uses  $B_b T = 0.5$



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## Example 3.6 – Bandwidth Efficiency

- ARDIS – 4-FSK – supports 19.2 kb/s in 25 kHz channels  $\rightarrow$  Efficiency =  $19.2/25 = 0.77$  b/s/Hz
  - Mobitex – 8 kb/s in 12.5 kHz channels  $\rightarrow$  Efficiency =  $8/12.5 = 0.64$  b/s/Hz
  - CDPD – GMSK – 19.2 kb/s over 30 kHz channels  $\rightarrow$  Efficiency =  $0.64$  b/s/Hz
  - DECT – GFSK – supports 1.152 Mb/s over 1.728 MHz  $\rightarrow$  Efficiency =  $0.67$  b/s/Hz
  - CT-2 – GFSK – 72 kb/s in 100 kHz  $\rightarrow$  Efficiency =  $0.72$
  - GSM – GMSK – supports 270.833 kb/s in 200 kHz channels  $\rightarrow$  Efficiency =  $1.35$  b/s/Hz
- Solution: compute bits/sec/Hz for each system

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## Digital Phase Modulation - BPSK

- Phase Shift Keying (PSK) – refer to slide 12 for example of binary PSK or BPSK
- Typical modulator and demodulator structures are shown below

- Note that the signal constellation (figure b) is comprised of two points only!! One at phase 0 and the other at phase 180 for minimum error performance
- Why do you need the LPF at the receiver?
- The shown receiver uses coherent detection – i.e. the carrier frequency and phase are needed at the receiver

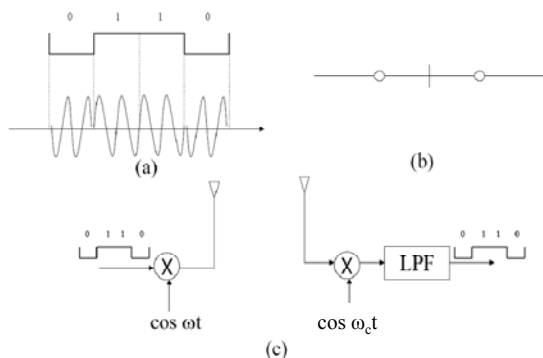


Figure 3.10: (a) Binary phase shift keying signal (b) BPSK constellation (c) block diagram of a BPSK system

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## Differential - BPSK

- Differentially encoded BPSK (DBPSK) signal can be detected without the knowledge of the carrier (i.e. non-coherently) – refer to Figure 3.11
- Use the carrier in the current bit as the reference carrier of the following bit
- Differential encoding  $\rightarrow$  the X-OR of consequent bits are transmitted
- Receiver DOES NOT need to recover the phase of the transmitted carrier
- Disadv – Performance is 1-2 dB less than coherent BPSK.



Figure 3.11 Differentially encoded BPSK.

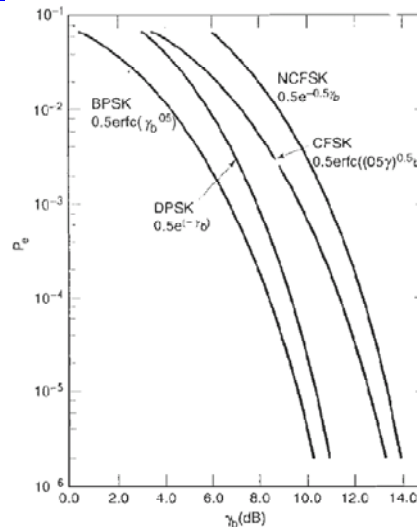
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## Performance of BPSK and DPSK

- DBPSK is 1-2 dB inferior compared to BPSK



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Dr. Ashraf S. Hasa **Figure 3A.3** Probability of error as a function of the SNR per bit for various modulation schemes.

## Digital Phase Modulation - QPSK

- Increase the number of symbols in the transmission set
- 4 different phases  $\rightarrow$  QPSK

- More bits for same bandwidth!!
- Two ORTHOGONAL branches of BPSK
  - The cosine branch – I channel
  - The sine branch – Q channel
- The signal constellation contains 4 points (i.e. 2 bits per symbol)
- The next slide shows how the QPSK modem work mathematically (i.e. how to compute the outputs  $y_1(t)$  and  $y_2(t)$ )

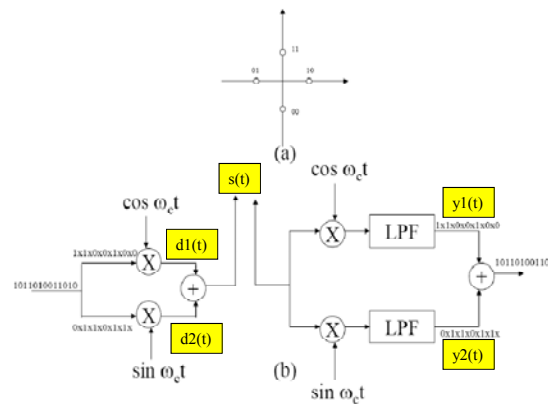


Figure 3.12: (a) Signal constellation for QPSK (b) modulation scheme for transmission of QPSK

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## Operation of Coherent Detection of QPSK

Using the figure in previous slide:

$$s(t) = d1(t)\cos(\omega_c t) + d2(t)\sin(\omega_c t)$$

Use the following identities:

$$\cos(2\alpha) = 2\cos^2(\alpha) - 1; \sin^2(\alpha) = 2\sin(\alpha)\cos(\alpha)$$

For upper branch:

$$\begin{aligned} s(t) \times \cos(\omega_c t) &= d1(t)\cos(2\omega_c t) + d2(t)\sin(\omega_c t)\cos(\omega_c t) \\ &= (1/2)d1(t) + (1/2)d1(t)\cos(2\omega_c t) + (1/2)d2(t)\sin(2\omega_c t) \end{aligned}$$

Use the following identities:

$$\cos(2\alpha) = 1 - 2\sin^2(\alpha); \sin^2(\alpha) = 2\sin(\alpha)\cos(\alpha)$$

For lower branch:

$$\begin{aligned} s(t) \times \sin(\omega_c t) &= d1(t)\cos(\omega_c t)\sin(\omega_c t) + d2(t)\sin(2\omega_c t) \\ &= (1/2)d1(t)\sin(2\omega_c t) + (1/2)d2(t) - (1/2)d2(t)\cos(2\omega_c t) \end{aligned}$$

All terms at  $2\omega_c$  are filtered out by the low-pass filter, yielding:

$$y1(t) = (1/2)d1(t); y2(t) = (1/2)d2(t)$$

Therefore,  $y1(t)$  is  $d1(t)$  (scaled) and  $y2(t)$  is  $d2(t)$  (scaled)

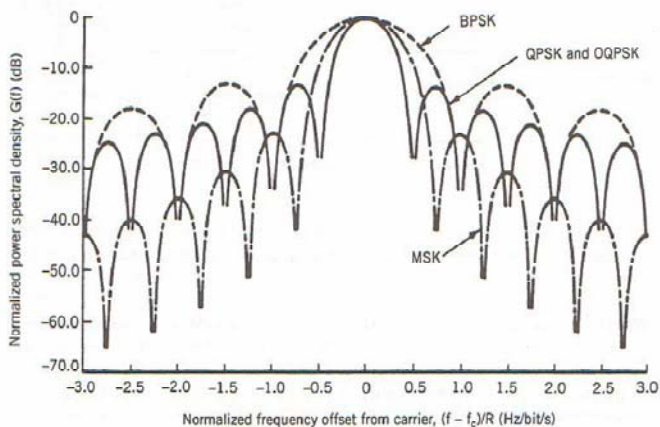
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## Spectrum of QPSK, MSK, QPSK

- Note the main lobe width for QPSK is half of that for BPSK – why?
- QPSK is the most efficient in terms of BW – but has higher side lobes compared to MSK – trade-off



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## Pulse Shape Filter (PSF)

- 2-D modulation schemes (such as QPSK) can utilize PSF to improve spectral characteristics (i.e. reduce side lobes)
- In figure below – the baseband rectangular pulses are changed into pulses with smoother transitions → lower side lobes in the frequency domain
- At receiver the pulses are sampled at the center and the original rectangular pulses can be reconstructed based on the sample values
- Ideally – an ideal low-pass filter is the best PSF
  - Has significant side lobes in the time domain!
- In practice – a Raised Cosine Filter is used

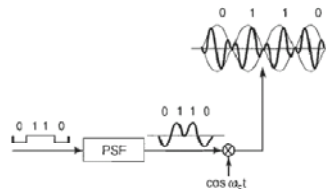


Figure 3.14 Basic implementation of PSFs for BPSK modems.

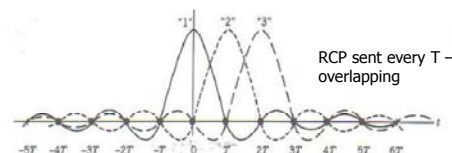
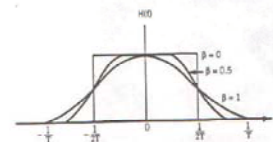
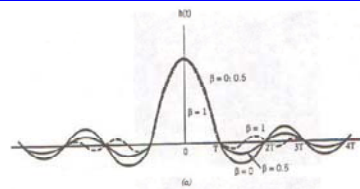
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## Raised-Cosine Pulse (RCP) Shape

- The side lobes of QPSK can be further reduced by employing pulse-shaping filter such as raised-cosine pulse filter – REMEMBER this approach was used with MSK to produce the GMSK
- Frequency BW:
  - Min BW =  $1/(2T)$  for  $\beta=0$ ,
  - Max BW =  $1/T$  for  $\beta=1$
- Time domain side lobes decrease as BW increases
- Typical  $\beta = 0.2 \sim 0.5$  – Produces side lobes that are 40 to 60 dB below main lobe!!
- RCP can be sent every  $2T$  (non-overlapping) or every  $T$  (overlapping)
- Transmission of data using raised-cosine pulses – note ZERO ISI



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## Improvements to QPSK

- Offset or staggered QPSK (OQPSK)
  - Same as QPSK except that the I and Q channels are offset by  $T/2$  seconds.
    - Envelopes of the I and Q symbols overlap  $\rightarrow$  less amplitude fluctuation in the overall signal
    - $\pm 180$  degrees phase jumps are eliminated – instead  $\pm 90$  degrees jumps
    - OQPSK provides better consistency of envelope and phase continuity than QPSK
    - OQPSK is not optimum for multipath channels with large Doppler shifts
- $\pi/4$ -QPSK
  - Signal constellation for QPSK is shifted  $\pm 45$  degrees every  $T$  seconds (symbol).
  - Diminished amplitude fluctuations
  - Same bandwidth efficiency as QPSK
  - Applications: IS-136 use  $\pi/4$ -QPSK

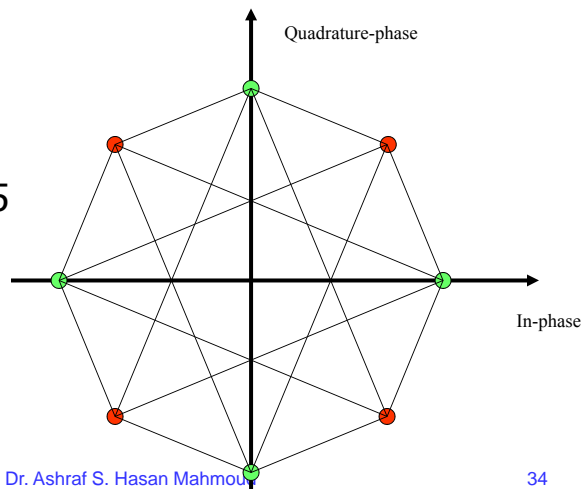
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## Improvements to QPSK – cont'd

- Signal constellation of  $\pi/4$ -QPSK
- The lines represent the  $\pm 45$  and  $\pm 135$  phase jumps allowed



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## Broadband Modems - OFDM

- Orthogonal Frequency Division Modulation (OFDM)
  - Combines: multi-rate, multi-symbol, and multi-carrier modulation (MCM).
  - MCM – instead of a single carrier at  $R_s$  symbols/sec we use  $N$  carriers spaced by about  $R_s/N$  Hz and modulate each carrier at the rate of  $R_s/N$  symbols/sec
    - Symbol interval is reduced by  $N$  – does not need anti-multipath receiver structure (equalization, etc)
    - Performs well in frequency-selective fading channels
    - Error coding can be implemented across symbols in different subchannels – coded OFDMA or COFDMA

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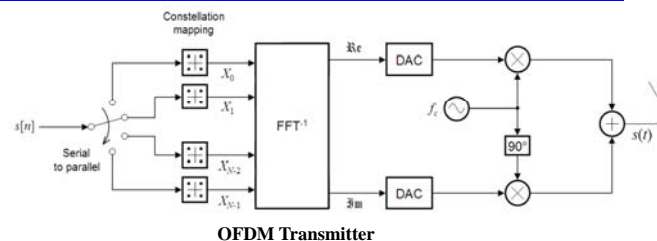
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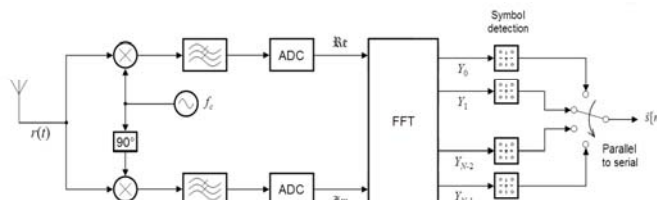
<http://en.wikipedia.org/wiki/COFDM>

## Simple Tx-er/Rx-er Structure

- Transmitter:
  - $s[n]$  (data stream) is demultiplexed into  $N$  parallel streams  $X_i$  (reduction of symbol rate)
  - $X_i$  is modulated using PSK or QAM (as we did in previous slides) – substreams may have different constellations (rates)
  - Inverse FFT is computed on each set of symbols, giving a set of complex time-domain samples
  - The real and imaginary parts of the  $FFT^{-1}$  result are converted from digital to analog
  - The analog real and imaginary results are then modulated using QPSK
- Receiver:
  - QPSK receiver followed by LPF to reject higher frequency terms
  - The steps carried in transmitter are reversed.



OFDM Transmitter



OFDM Receiver

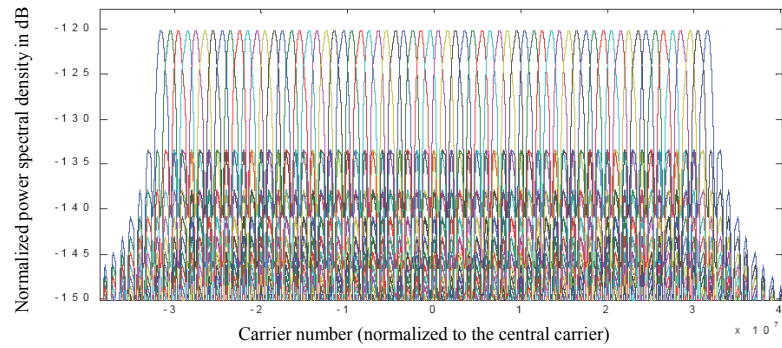
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## OFDM – Example: IEEE802.11a and HIPERLAN Physical Layer

- 64 subchannels: 48 data subcarriers, 4 pilots, and 12 reserved.
- Each subchannel carries 250 ksps – guard time = 800 nsec
- Total BW = 20 MHz  $\rightarrow$   $20,000/64 = 312.5$  kHz per subchannel
- Bandwidth eff = 0.8 symbol/sec/Hz
- User Tx rate =  $48 \times 250 = 12$  Msps
- Guard time between two transmitted symbols = 800 ns
- Symbol duration =  $1/250,000 = 4000$  nsec  $\rightarrow$  efficiency =  $4000/4800 = 83\%$



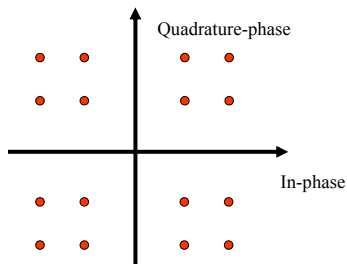
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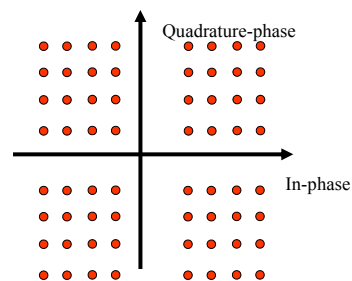
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## Broadband Modems - QAM

- Multi-symbol modulation
  - Utilize multi-amplitude and multiphase modulation and coding techniques for increasing the transmission set size  $\rightarrow$  higher bit rate
- Quadrature amplitude modulation (QAM)



16-QAM (4 b/sym)  
 $R_b = 4 \cdot R_s$



64-QAM (6 b/sym)  
 $R_b = 6 \cdot R_s$

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## QAM – Example: IEEE802.11a and HIPERLAN

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- 16-QAM (4 bit/symbol)
  - Subchannel rate =  $4 \times 250$  ksps = 1Mb/s
- 64-QAM (6 bit/symbol)
  - Subchannel rate =  $6 \times 250$  = 1.5 Mb/s
- Encoding rate =  $\frac{3}{4}$  → actual info rate is 0.75x1Mb/s (for the 16-QAM option) or 0.75x1.5Mb/s (for the 64-QAM option)
- → Data bit rate is 36 Mb/s (for 16-QAM) or 54 Mb/s (for 64 QAM).

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## Multirate Transmission – Example: IEEE802.11a and HIPERLAN

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- Modem has several “fallback” rates depending on SNR
- Rates are obtained by varying the number of bits per symbol (modulation) and the coding rate (strength of the code)
- Example: IEEE802.11a and HIPERLAN support rates of 54, 36, 27, 18, 12, 9, 6 Mb/s to cover distances up to 100 meters

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## Multirate Transmission - Example: IEEE802.11a and HIPERLAN - cont'd

- The Physical layer supports 8 DIFFERENT data rates depending on the perceived channel quality

Data rate (Mb/s)	Modulation	Coding rate	Ndbps*	1472 byte transfer duration ( $\mu$ s)
6	BPSK	1/2	23	2012
9	BPSK	3/4	36	1344
12	4-QAM	1/2	48	1008
18	4-QAM	3/4	72	672
24	16-QAM	1/2	96	504
36	16-QAM	3/4	144	336
48	64-QAM	2/3	192	252
54	64-QAM	3/4	216	224

\*Ndbps – number of data bits per symbol.

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## Spread Spectrum Transmission

- Will be covered when IS-95 and cdma2000 systems are discussed
- Frequency Hopping Spread Spectrum
- Direct Sequence Spread Spectrum

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## Diversity and Smart Receiving Techniques

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- Diversity
  - Multiple antennas (spatial)
  - Multiple frequency bands (carriers - frequency)
  - Multiple arrival times (temporal)
- General combining techniques:
  - Selection
  - Linear combination – summing all branches
  - Maximal ratio combining – weighted sum – optimal but requires channel estimation