King Fahd University of Petroleum & Minerals Computer Engineering Dept

COE 543 – Mobile and Wireless Networks

Term 082

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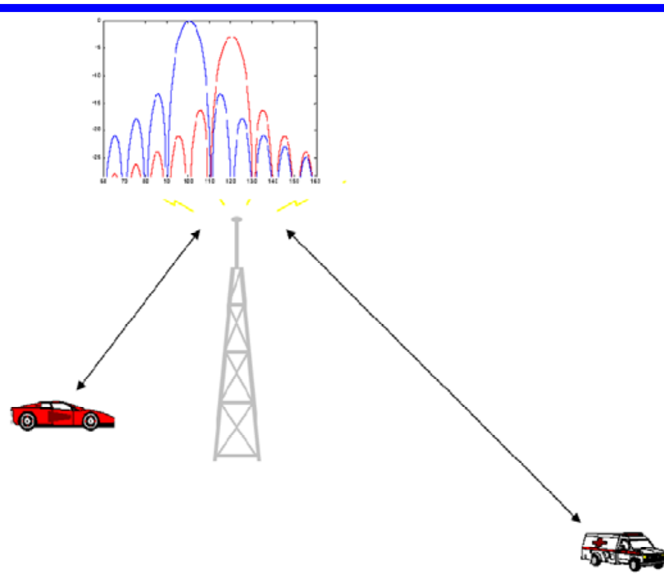
Lecture Contents

Consideration in the Design of Wireless Modems

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

Adjacent Channel Interference

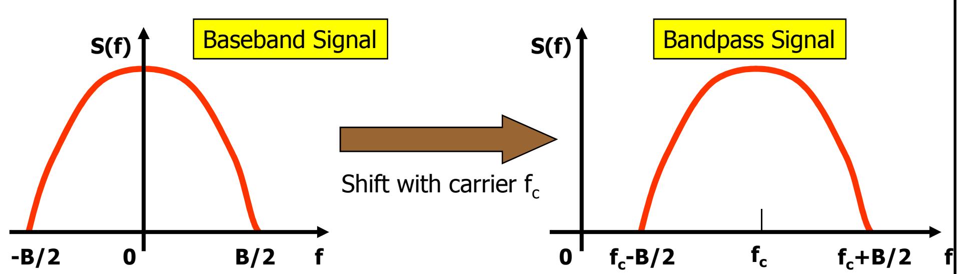


Wireless Transmission Techniques

- 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?

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**

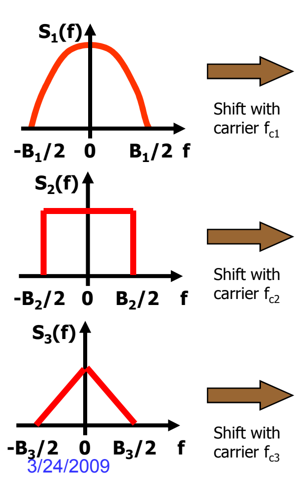


Background

- **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**

Background - Frequency Division Multiplexing

- **Refer to COE 341 Textbook**

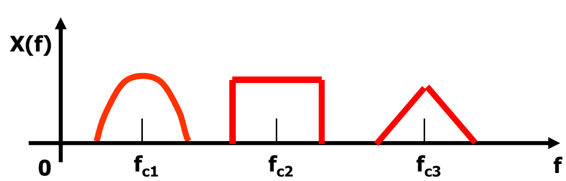


$x(t) = s_1(t) \text{ X } \cos(2\pi f_{c1}t) + s_2(t) \text{ X } \cos(2\pi f_{c2}t) + s_3(t) \text{ X } \cos(2\pi f_{c3}t)$

- 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 $s_1(t)$, s2(t), and s3(t) can be recovered using bandpass filters with appropriate bandwidths centered at f_{c1}, f_{c2}, and f_{c3}, respectively.

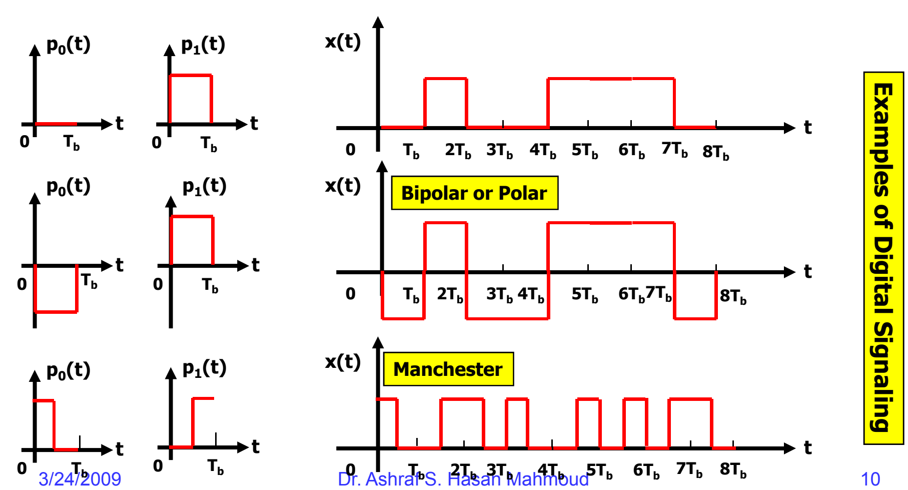


Background - Signal Elements or Pulses

- 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

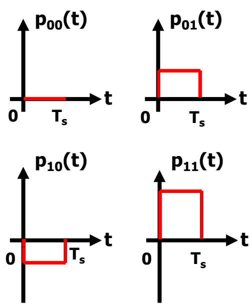
Background - Signal Elements or Pulses

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

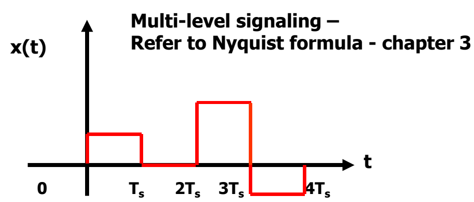


Background - Signal Elements or Pulses

Pluses Definitions



Encoded Signal: 0 1 0 0 1 1 1 0

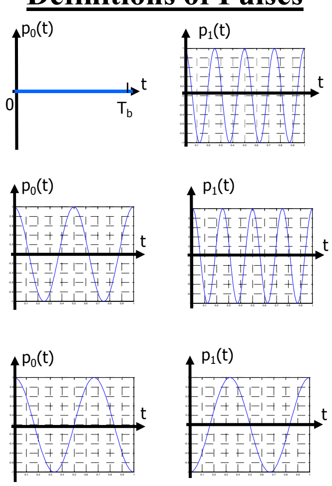


- Note that each symbol or pulse caries 2 bits
- Symbol duration is $T_s = 2T_b$
- Bit rate R equal to $1/T_b$
- Symbol rate or *baud rate* R_s equal to $1/T_s$ ➔ $R = 2R_s$
- In general to encode n bits per pulse, you need 2^n pulses

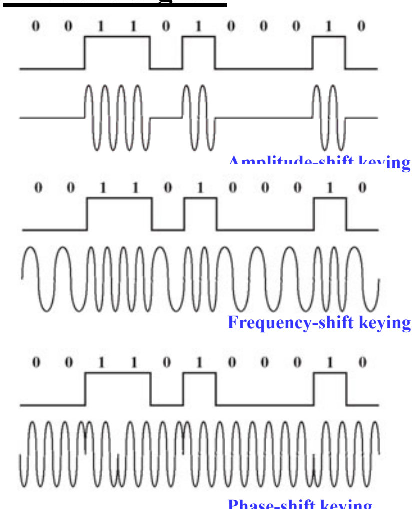
Example of Digital Signaling

Background - Signal Elements or Pulses

Definitions of Pulses



Encoded Signal:



Example of Analog Signaling

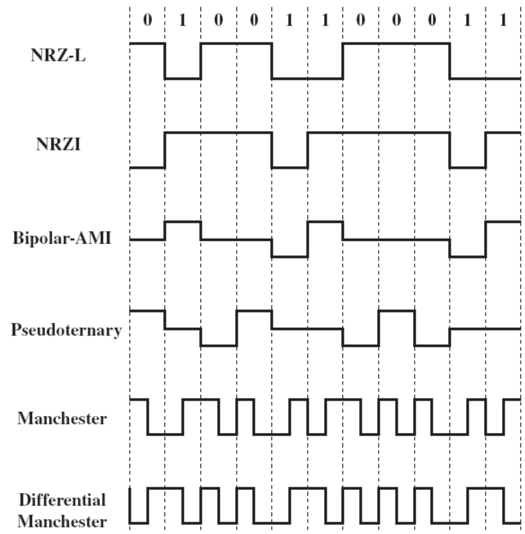
Baseband Transmission

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

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**

Digital Signal Encoding Formats



Baseband Pulse Modulation

- Pulse Amplitude Modulation (PAM)
- Pulse Position Modulation (PPM)
- Pulse width duration Modulation (PWM)

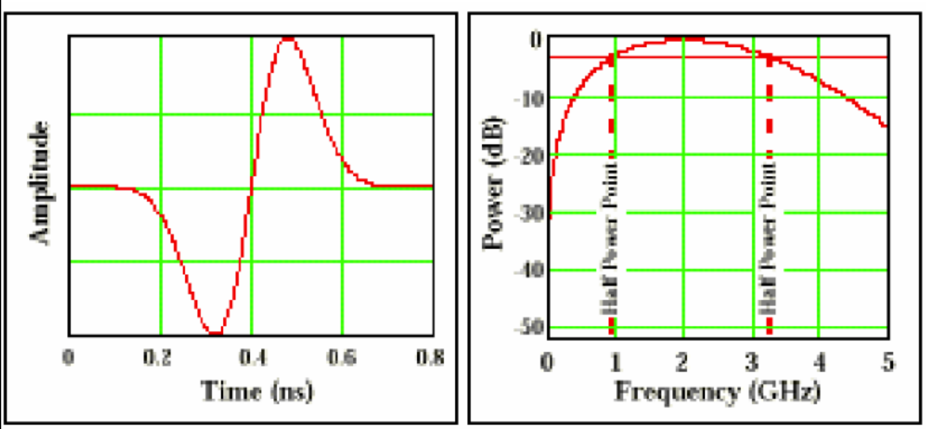
- PAM is not popular in wireless operation
  - Wireless channel suffer from extensive fluctuations caused by fading and near-far problems.

- PPM is used for IEEE802.11 IR option

UWB Pulse Transmission

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

UWB Pulse Example

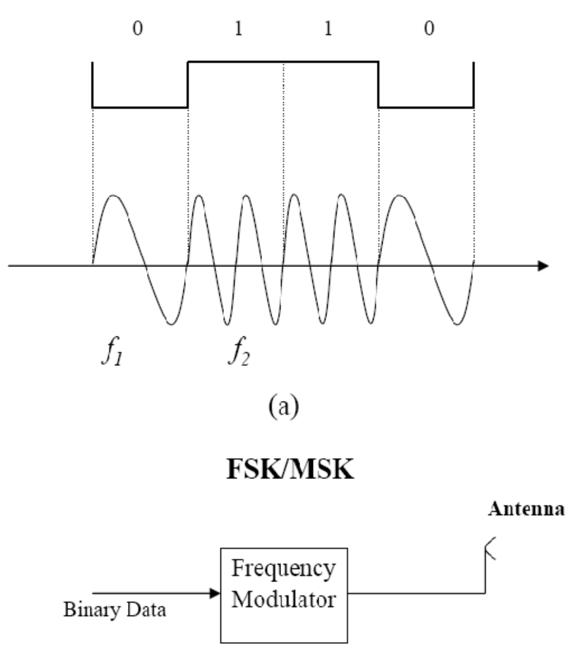


Carrier Modulation Transmission

- 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
  - π/4-QPSK adopted for IS-136

Frequency Shift Keying

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



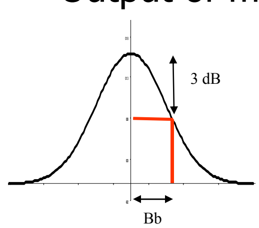
Frequency/Minimum Shift Keying - F/MSK

- 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

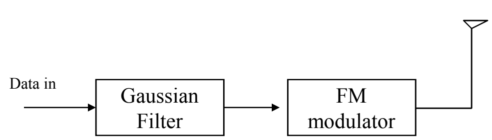
  Where T is the symbol duration
- FSK modulator using 1/(2T) spacing ➔ MSK
- MSK is an example of constant-envelope continuous-phase modulation – abrupt phase changes at the bit transition times (characteristic of FSK in general) are eliminated

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



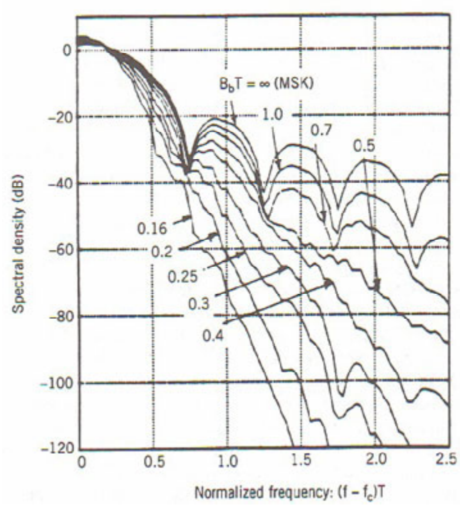
Gaussian filter frequency response
Note: no side lobes!!



Block diagram of GMSK modulator

Spectra of GMSK Signals for Different Time-Bandwidth Product

- What is Time-Bandwidth product?
  - BbXT – where Bb = 3 dB bandwidth of the Gaussian filter, and T is the bit duration
  - For Bb = ∞ ➔ 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 ➔ increased bit error rate
- Compromise!!
- Typical values:
  - GSM uses BbT = 0.3
  - CDPD uses BbT = 0.5



Example 3.6 – Bandwidth Efficiency

- ARDIS – 4-FSK – supports 19.2 kb/s in 25 kHz channels ➔ Efficiency = 19.2/25 = 0.77 b/s/Hz
- Mobitex – 8 kb/s in 12.5 kb/s channels ➔ Efficiency = 8/12.5 = 0.64 b/s/Hz
- CDPD – GMSK – 19.2 kb/s over 30 kHz channels ➔ Efficiency = 0.64 b/s/Hz
- DECT – GFSK – supports 1.152 Mb/s over 1.728 MHz ➔ Efficiency = 0.67 b/s/Hz
- CT-2 – GFSK – 72 kb/s in 100 kHz ➔ Efficiency = 0.72
- GSM – GMSK – supports 270.833 kb/s in 200 kHz channels ➔ Efficiency = 1.35 b/s/Hz

- Solution: compute bits/sec/Hz for each system

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
- Differentially encoded BPSK (DBPSK) signal can be detected with out the knowledge of the carrier (i.e. non-coherently) – refer to figure 3.11

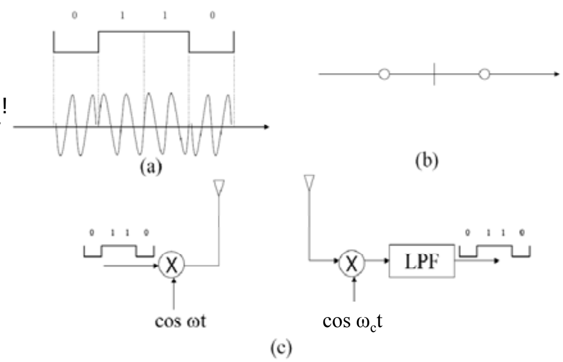


Figure 3.10: (a) Binary phase shift keying signal (b) BPSK constellation (c) block diagram of a BPSK system

Digital Phase Modulation - QPSK

- Increase the number of symbols in the transmission set
- 4 different phases ➔ 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 y1(t) and y2(t))

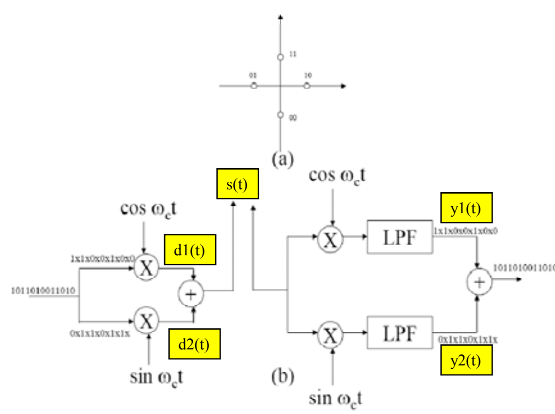


Figure 3.12: (a) Signal constellation for QPSK (b) modulation scheme for transmission of QPSK

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:

$$s(t) \text{ X } \cos(\omega_c t) = d1(t)\cos(2\omega_c t) + d2(t)\sin(\omega_c t)\cos(\omega_c t)$$
$$= (1/2)d1(t) + (1/2)d1(t)\cos(2\omega_c t) + (1/2)d2(t)\sin(2\omega_c t)$$

Use the following identities:

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

For lower branch:

$$s(t) \text{ X } \sin(\omega_c t) = d1(t)\cos(\omega_c t)\sin(\omega_c t) + d2(t)\sin(2\omega_c t)$$
$$= (1/2)d1(t)\sin(2\omega_c t) + (1/2)d2(t) - (1/2)d2(t)\cos(2\omega_c t)$$

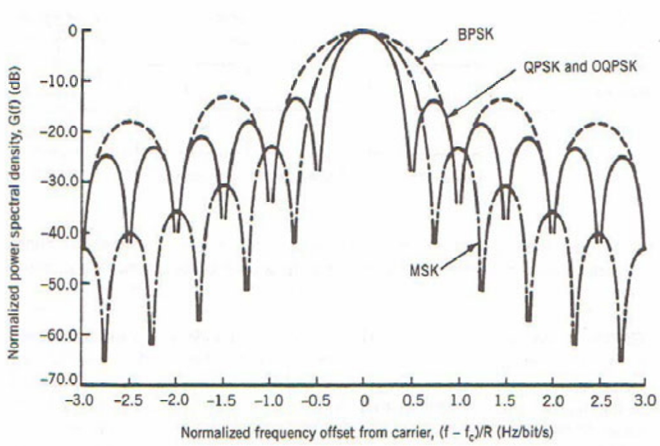
All terms at $2\omega_c$ are filtered out by the low-pass filter, yielding:

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

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

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



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

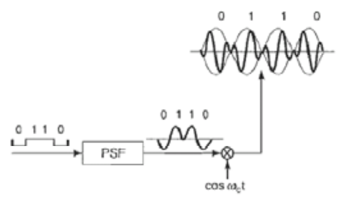
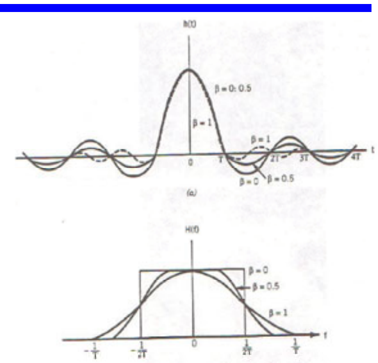
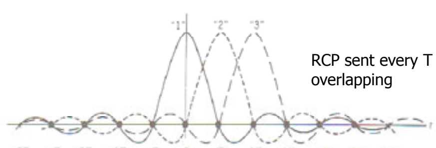


Figure 3.14 Basic implementation of PSFs for BPSK modems.

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 β=0,
  - Max BW = 1/T for β=1
- Time domain side lobes decrease as BW increases
- Typical β = 0.2 ~ 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





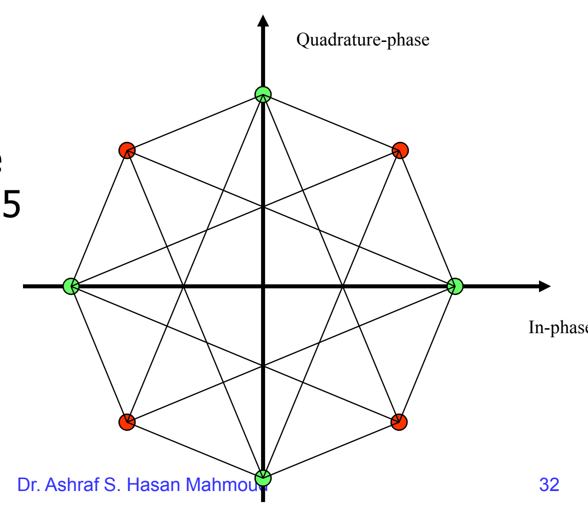
RCP sent every T – overlapping

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 → less amplitude fluctuation in the overall signal
    - ±180 degrees phase jumps are eliminated – instead ±90 degrees jumps
    - OQPSK provides better consistency of envelope and phase continuity than QPSK
    - OQPSK is not optimum for multipath channelswith large Doppler shifts
- $\pi/4$-QPSK
  - Signal constellation for QPSK is shifted ±45 degrees every T seconds (symbol).
  - Diminished amplitude fluctuations
  - Same bandwidth efficiency as QPSK
  - Applications: IS-136 use $\pi/4$-QPSK

Improvements to QPSK – cont'd

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



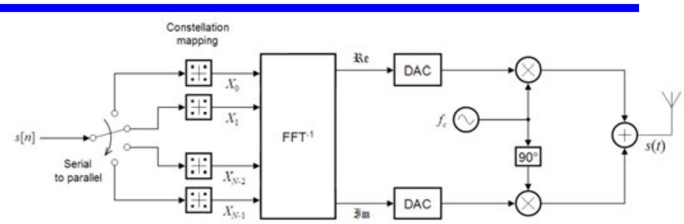
Broadband Modems - OFDM

- Orthogonal Frequency Division Modulation (OFDM)
  - Combines: multi-rate, multi-symbol, and multi-carrier modulation (MCM).
  - MCM – instead of a single carrier at Rs symbols/sec we use N carriers spaced by about Rs/N Hz and modulate each carrier at the rate of Rs/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

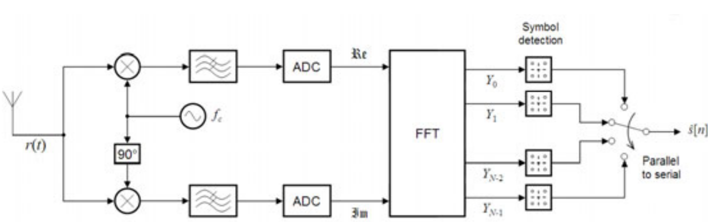
http://en.wikipedia.org/wiki/COFDM

Simple Tx-er/Rx-er Structure

- Transmitter:
  - s[n] (data stream) is demultiplexed into N parallel streams Xi (reduction of symbol rate)
  - Xi is modulated using PSK or QAM (as we did in previous slides) – substreams my 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 resu 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.



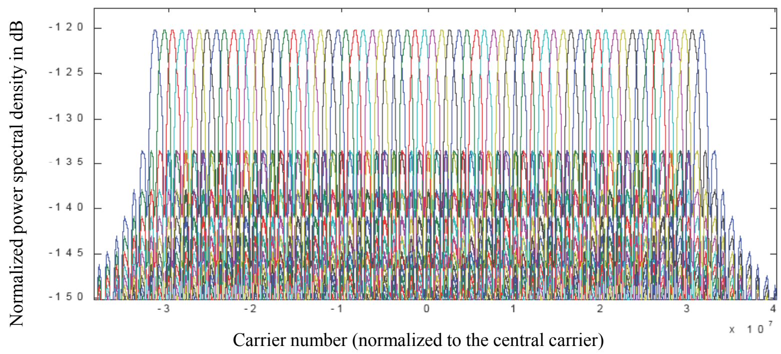
OFDM Transmitter



OFDM Receiver

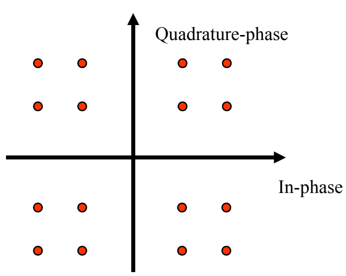
OFDM – Example: IEEE802.11a and HIPERLAN Physical Layer

- 64 subchannels: 48 data subcarriers, 4 pilots, and 12 reserved.
- Each subchannel carries 250 ksps – guard time = 800 nsec
- Total BW = 20 MHz ➔ 20,000/64 = 312.5 kHz per subchannel
- Bandwidth eff = 0.8 symbol/sec/Hz
- User Tx rate = 48X250 = 12 Msps
- Symbol duration = 1/250,000 = 4000 nsec ➔ efficiency = 4000/4800 = 83%

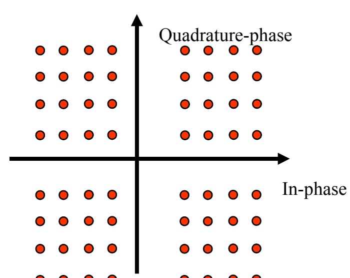


Broadband Modems - QAM

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



16-QAM (4 b/sym)
Rb = 4*Rs



64-QAM (6 b/sym)
Rb = 6*Rs

QAM – Example: IEEE802.11a and HIPERLAN

- 16-QAM (4 bit/symbol)
  - Subchannel rate = 4X250 ksps = 1Mb/s
- 64-QAM (6 bit/symbol)
  - Subchannel rate = 6x250 = 1.5 Mb/s
- Encoding rate = ¾
- ➔ Data bit rate is 36 Mb/s (for 16-QAM) or 54 Mb/s (for 64 QAM).

Multirate Transmission – Example: IEEE802.11a and HIPERLAN

- 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

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 (μs)
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 date bits per symbol.

Spread Spectrum Transmission

- Will be covered when IS-95 and cdma2000 systems are discussed

- Frequency Hopping Spread Spectrum
- Direct Sequence Spread Spectrum

Diversity and Smart Receiving Techniques

- 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