King Fahd University of Petroleum & Minerals Computer Engineering Dept

COE 541 – Design and Analysis of Local Area Networks

Term 031

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Analog and Digital Data Transmission

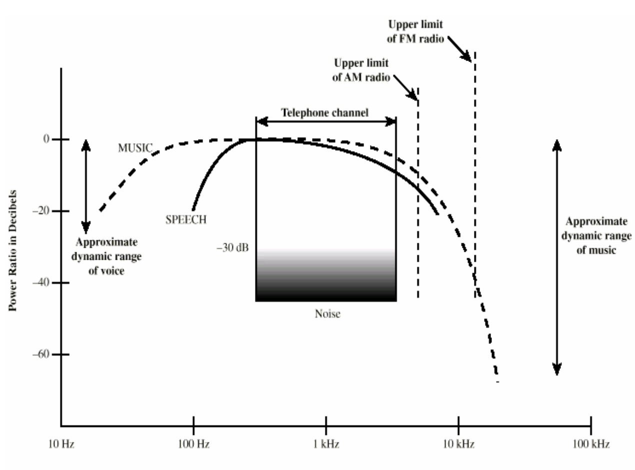
- **The terms:**
  - **Analogue ~ continuous**
  - **Digital ~ discrete**
- **They apply to:**
  - **A) Data: the information to be delivered**
  - **B) Signaling: the electrical or electromagnetic wave that propagates carrying the data**
  - **C) Transmission: the mechanism of delivering the data by processing and propagation of signal**

Examples of Data/Signaling: (1) AUDIO

- **Most familiar type of *analogue* data**
- **Human Ear (Receiver) bandwidth is ~10 Hz to ~20KHz**
  - **You can not hear sounds with frequencies much higher than 20KHz or much lower than 10 Hz – Some other animals can do that (bats, whales, etc)**
- **Human speech (Data) is mostly between 100 Hz and 7K Hz – with most of the energy concentrated in the lower part of this range**

Examples of Data/Signaling: (1) AUDIO – cont'd

- **Typical Speech has a dynamic range of 25 dB – ratio of strongest speech signal to weakest speech signal is 25 dB or $10^{25/10}$ = 300 (in linear scale)**
- **The *Telephone Channel* has a bandwidth of about 3.1KHz (from 300 Hz to 3400 Hz)**
- **Note that Music has a much wider bandwidth than speech (~10 Hz to ~20 KHz) – Hence a good audio system (CD player, high end speakers, etc) should be able to reproduce these signals**
- **Music has also a higher dynamic range too – What is the dynamic range of your audio system?**



Transmission

- **Analog Transmission:**
  - **Analog signal is propagated through amplifiers to compensate for attenuation and to achieve longer distance**
  - **Amplifiers:**
    - **Boost signal and noise equally**
    - **May distort original signal**
    - **Can not be used indefinitely**
- **Digital Transmission:**
  - **To overcome the higher attenuation, repeaters are used at appropriately spaced points**
  - **Repeaters:**
    - **Recover original digital data**
    - **Transmit new signal**
    - **Can be used indefinitely**

Transmission (2)

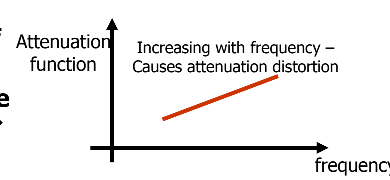
- **Digital Transmission is the prevailing technology:**
  - **Digital Technology: Capitalize on advances in digital circuitry**
  - **Data Integrity: With the use of repeaters, the effects of noise and other signal impairments are not cumulative**
  - **Capacity Utilization: It is easier to multiplex several digital signals (using TDM) on one high capacity link as opposed to multiplexing analog sources using FDM**
  - **Security and Privacy: Use of encryption**
  - **Integration: Provides a uniform vehicle to transport both analog and digital data**

Transmission Impairments

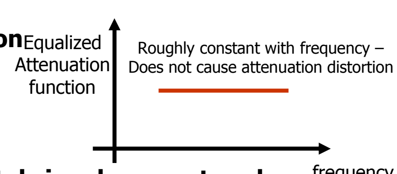
- Impairments can degrade the quality of an analog signal or cause a bit (symbol) error for a digital signal
- Types of Impairments:
  - Attenuation and Attenuation Distortion
  - Delay Distortion
  - Noise
    - Thermal Noise
    - Intermodulation Noise
    - Crosstalk
    - Impulse Noise

Attenuation and Attenuation Distortion

- A received signal must have sufficient strength for proper detection at receiver
- For error-free communication signal strength relative to noise must be high
- Attenuation is an increasing function of frequency:
  - Different components of signal are subject to different attenuation ➔ Distortion in time domain



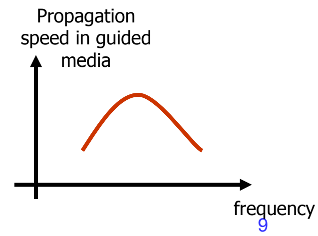
- Solution: Equalize transmission
  - Results in almost equal attenuation (gain) for all frequencies of interest



- Attenuation Distortion is less of a problem for digital signals:
  - Frequencies of interest for a digital signal are centered around the fundamental frequency, f
  - Attenuation function has to be flat around f only

Delay Distortion

- **For guided media – different frequency components have different propagation speeds**
- **For unguided media – multipath (signal being received through more than one path) causes delay distortion**
- **Received signal is distorted due to varying delays experienced at its constituent frequencies**
- **Critical for digital data: Causes Intersymbol interference – a major limitation on maximum bit rate over a transmission channel**
- **Solution: Equalization**



Noise

- **Major limiting factor in communication system performance**
- **Types of Noise:**
  - **Thermal Noise**
  - **Intermodulation Noise**
  - **Crosstalk**
  - **Impulse Noise**

Thermal Noise

- **Due to agitation of electrons**
- **Function of temperature (energy of electrons)**
- **Can not be eliminated ➔ limits communication system performance**
- **Noise power density (noise power found in 1 Hz) , N_0, is given by**

$$No = kT \quad (Watts/Hz)$$

Where k is Boltzman constant = 1.3803×10^{-23} J/degree Kelvin

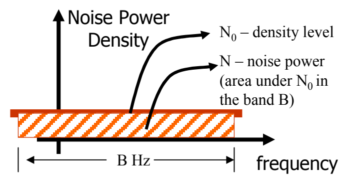
T is the temperature in degrees Kelvin

- **Hence, the thermal noise power in a bandwidth B Hz is given by**

$$N = N_0 \times B = kT \times B \quad (Watts)$$

- **In decibels:**

$$NdB = 10\log k + 10\log T + 10\log B$$
$$= -228.6 \text{ dBW} + + 10\log T + 10\log B$$



Intermodulation Noise

- **Lineal System: $H_L(S) = A_1 x S + A_0$**

E.g. Consider the input S_1+S_2, where $S_1 = \cos(2\pi * f_1 * t)$ and $S_2 = \cos(2\pi * f_2 * t)$. The system output is

$$H_L(S_1+S_2) = A_1 x \cos(2\pi * f_1 * t) + A_1 x \cos(2\pi * f_2 * t) + A_0$$

Note the output signal has frequencies f_1 and f_2 *ONLY*.

- **NonLinear System: $H_{NL}(S) = A_2 x S^2 + A_1 x S + A_0$**

The output (for the same input) is

$$H_{NL}(S_1+S_2) = A_2 x [\cos(2\pi * f_1 * t) + \cos(2\pi * f_2 * t)]^2 + A_1 x [\cos(2\pi * f_1 * t) + \cos(2\pi * f_2 * t)] + A_0$$

Note that $[\cos(2\pi * f_i * t)]^2 = ½ + ½ \cos(2\pi * 2f_i * t)$, and

$$\cos(2\pi * f_1 * t) \cos(2\pi * f_2 * t) = ½ \cos(2\pi * (f_1+f_2) * t) + ½ \cos(2\pi * (f_1-f_2) * t)$$

Output signal contain terms with multiples of (f1+f2) and (f1-f2)

- **Intermodulation noise: *undesired* signals at the frequency that is multiples of sum or difference of the two original input frequencies**
- **Caused by nonlinearity**

Crosstalk/Impulse Noise

- **Crosstalk:**
  - **Unwanted coupling between signal paths**
  - **E.g. electrical coupling between near by twisted pair wires**
  - **Coax cables are more immune to cross talk compared to twisted pairs**
- **Impulse Noise:**
  - **Unlike previous types of noise, this one is:**
    - **Noncontinuous – irregular pulses or spikes for short duration and high amplitude**
  - **Causes:**
    - **Lightening**
    - **Faults or flaws in communication systems**
  - **Major concern for digital data**

Channel Capacity

- **Terminology:**
  - **Data Rate (R): bit rate of channel – bits per second**
  - **Bandwidth (B): bandwidth of transmitted signal – Hz**
  - **Noise power (N): average noise power level for communication channel – Watt/Hz for density or Watt for noise power**
  - **Error rate (Pe): rate at which an erroneous detection is made (detecting 0 for 1 and 1 for 0)**

Nyquist Bandwidth

- For a noise-free channel → data rate is limited by B of channel
- A bandwidth of B Hz is enough to support 2B bits per second – Refer to the RAISED-COSINE filter or pulse shape
- Example: B = 3100 Hz (telephone channel) → C = 6200 b/s
- What if we use multilevel signaling :

$$C = 2B \log_2 M$$

Where M is the number of discrete levels used

- Example: for M = 8, same telephone channel can support C = 2X3100X $\log_2 8$ = 18.6 kb/s
- M = 2 – receiver recognizes two signal levels 1s and 0s
- M > 2 – receiver recognizes discrete levels other than 1 and 0
- In general, multilevel signaling requires more sophisticated receiver structure and perhaps more power for the same bandwidth

Shannon Capacity Formula

- Capacity in the presence of noise

$$C = B \log_2(1 + SNR)$$

where SNR is the ratio of signal power to noise power – a measure of the signal quality

- Example: fmin = 3 MHz, fmax = 4 MHz, SNR = 24 dB, C = ?

  B = 4 – 3 = 1 MHz

  SNR = $10^{24/10}$ = 251 (on the linear scale)

  C = $1X10^6 \log_2(1 + 251) \sim 8 X 10^6$ b/s or 8 M b/s

  One can also calculate the required signaling levels, M, using Nyquist formula: $C = 2B \log_2(M)$ → $M = 2^{C/(2B)} = 16$

- Note the C (calculated by Shannon formula) is the theoretical limit of the channel for the given B and SNR

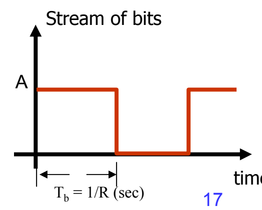
E_b/N_0 Expression

- An alternative representation of SNR
- Consider the bit stream shown in figure – for bit of rate R, then each bit duration is equal to T_b = 1/R seconds
- Energy of signal for the bit duration is equal to A^2X T_b, where its power is equal to bit energy / T_b or A^2.
- Noise power is equal to N_0 X B (refer to thermal noise section)
- Hence, SNR is given by signal power / noise power or

$$SNR = \frac{signalpower}{N_0 B} = \frac{E_b}{N_0} \times \frac{R}{B}$$

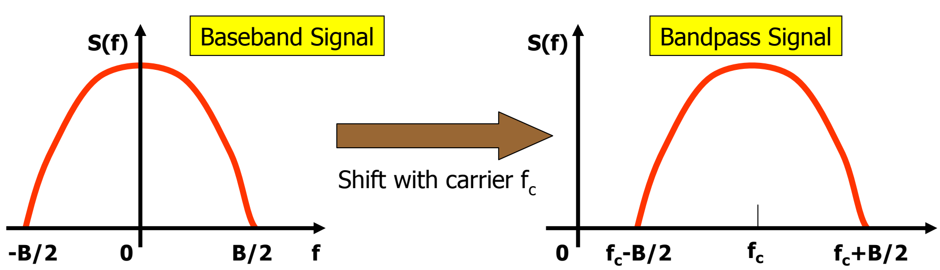
- One can also write

$$\left(\frac{E_b}{N_0}\right)_{dB} = SignalPower(dBW) - 10\log R - 10\log k - 10\log T$$



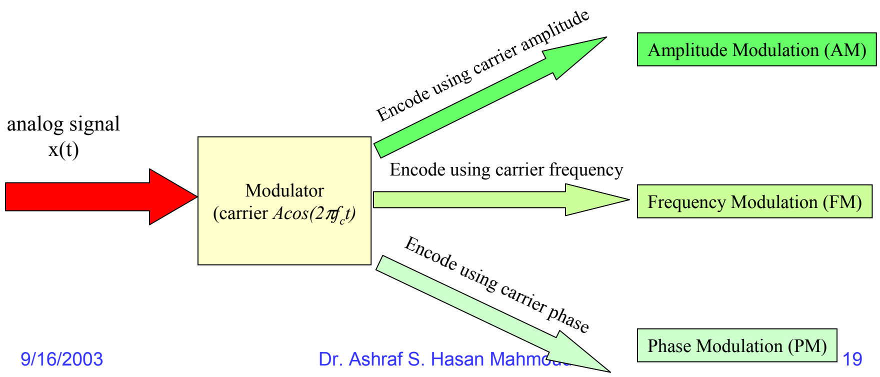
Background – Baseband vs. Bandpass Signals

- **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



Analog Signals

- **Two principle reasons for analog modulation of analog signals:**
  - **High frequency may be more effective for transmission**
  - **Use of FDM**



Amplitude Modulation (AM)

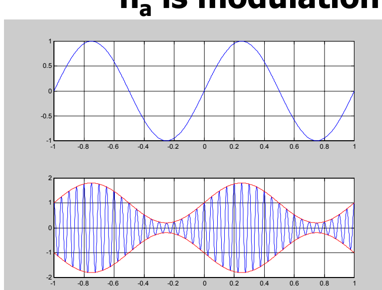
- **Simplest form of modulation:**

$$s(t) = [1 + n_a\, x(t)] \cos(2\pi f_c t)$$

where $\cos(2\pi f_c t)$ is the carrier

$x(t)$ is the input signal (carrying data)

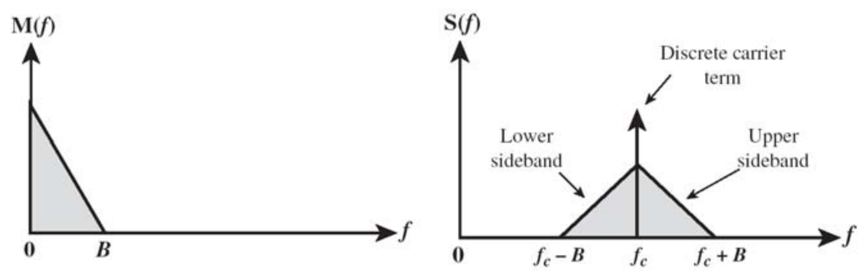
$m(t) = n_a x(t)$ **n_a is modulation index (control parameter)**



Information is "the envelope" of the overall signal s(t)
To preserve the envelope n_a should be < 1; for $n_a > 1$,
The envelope crosses the x-axis (info is lost)

Bandwidth of AM signal

- **S(t) has a double sided spectrum function centered around fc – in addition to the carrier itself ➔Double sideband transmitted carrier (DSBTC)**
- **If B is the bandwidth of x(t), the required transmission bandwidth for the AM signal is B_T = 2B**



Power of AM signal

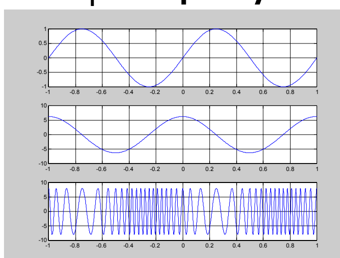
- **Total signal power: $P_t = P_c(1+n_a^2/2)$, where Pc is the transmitted power in carrier**
- **s(t) contains extra info: the carrier itself – removal of carrier (i.e s(t) = m(t)cos($2\pi f_c$t)) is referred to as double sideband suppressed carrier (DSBSC)**
- **DSBSC signal has same BW as DSBTC**
- **Carrier info is useful in helping receiver lock to exact frequency and phase of carrier**

Frequency Modulation (FM)

- **Simplest form of modulation:**

$$s(t) = A_c \cos(2\pi f_c t + \phi(t))$$
$$\phi'(t) = n_f\, m(t)$$

where A_c/f_c are the amplitude/frequency of carrier
$m(t)$ is the input signal (carrying data)
n_f is frequency modulation index (control parameter)



Instantaneous frequency of s(t), $f_i(t)$, is equal to $f_c + n_f m(t)/(2\pi)$

Bandwidth/Power of FM signal

- **If B is the bandwidth of m(t), the required transmission bandwidth for the FM signal is**

$$B_T = 2(1+\beta)B$$
$$\beta = \Delta F/B = n_f A_m/(2\pi B)$$

- **ΔF is the peak deviation around fc, A_m is the maximum amplitude of m(t). Note $\Delta F = n_f A_m/(2\pi)$**
- **Note B_T for PM signal is greater than that of AM signal**
- **Power of FM signal: $A_c^2/2$**

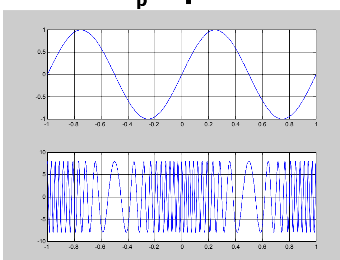
Phase Modulation (PM)

- **Simplest form of modulation:**

$$s(t) = A_c \cos(2\pi f_c t + \phi(t))$$

$$\phi(t) = n_p\, m(t)$$

where A_c/f_c are the amplitude/frequency of carrier
$m(t)$ is the input signal (carrying data)
n_p is phase modulation index (control parameter)



Instantaneous phase of s(t), $\phi(t)$, is equal to $n_p m(t)$

Bandwidth/Power of PM signal

- **If B is the bandwidth of m(t), the required transmission bandwidth for the FM signal is**

$$B_T = 2(1+\beta)B$$

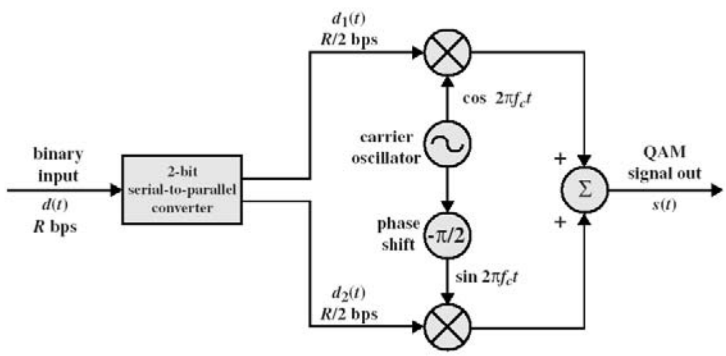
$$\beta = n_p\, A_m$$

- **Note B_T for PM signal is greater than that of AM signal**
- **Power of PM signal: $A_c^2/2$**

Quadrature Amplitude Modulation (QAM)

- QAM

$$s(t) = d_1(t)\cos(2\pi f_c t) + d_2(t)\sin(2\pi f_c t)$$

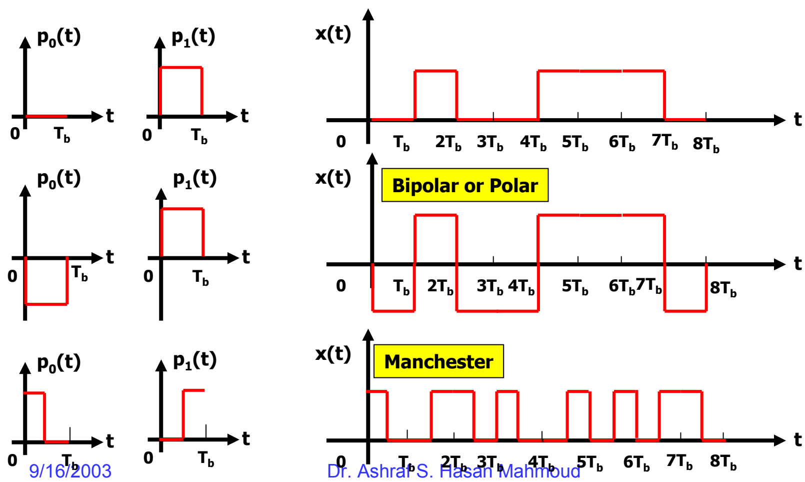


Signal Elements or Pulses

- 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
- Baud/Modulation or Symbol Rate

Signal Elements or Pulses

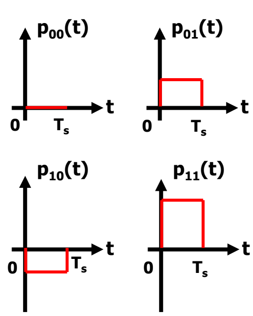
Definitions of Pulses | **Encoded Signal: 0 1 0 0 1 1 1 0**

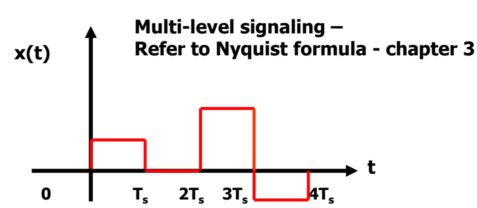


Examples of Digital Signaling

Signal Elements or Pulses

Pluses Definitions | **Encoded Signal: 0 1 0 0 1 1 1 0**



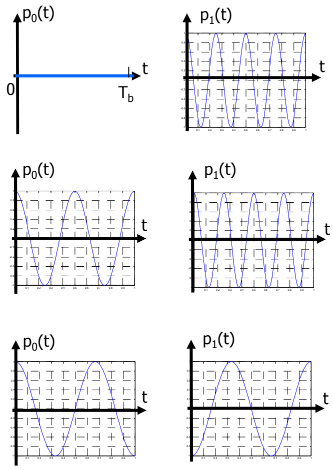


- Note that each symbol or pulse caries 2 bits
- Symbol duration is $T_s = 2T_b$
- Bit rate R equal to $1/T_b$
- Symbol rate or *baud rate* R_s equal to $1/T_s$ ➔ $R = 2R_s$
- In general to encode n bits per pulse, you need 2^n pulses

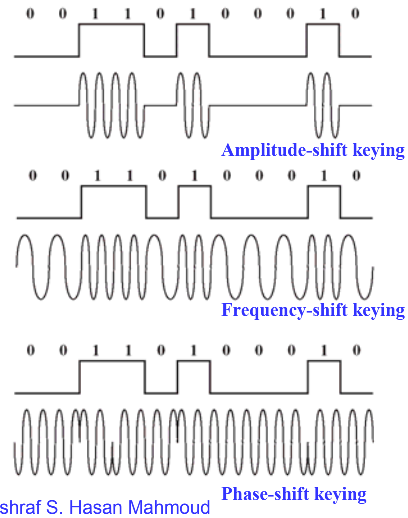
Example of Digital Signaling

Signal Elements or Pulses

Definitions of Pulses



Encoded Signal:



Example of Analog Signaling

Digital Data – Digital Signals

- **Digital signal: sequence of discrete, discontinuous voltage pulses**
- **Digital data (bits) are encoded (or mapped) into signal elements**
- **Baud-rate: number of signal elements per second**
- **Mark – Space = 1 – 0**
- **Communication Tasks – Receiver must have:**
  - **Transmission elements timings**
  - **Pulse voltage level (to know whether it is 0 or 1 for example) – Rxer samples at bit times to find voltage level**

Examples of Baseband signaling for LANs

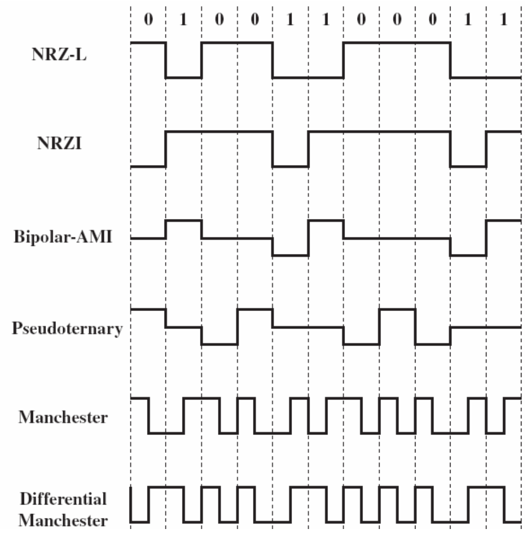
How to Overcome Impairments?

- Faults in detection of received signal register as BIT ERROR RATE at receiver – BER
  - A good communication channel has small or zero BER
- Factors:
  - SNR or Eb/No
  - Data bit rate
  - Channel/system bandwidth
  - Encoding of data bits into signal elements
- Encoding scheme also affects bandwidth of signal

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
- Doubinary
  - 0 = no line signal
  - 1 = +ve or –ve level; depending on number of separating 0s (even – same polarity, odd – opposite polarity)
- 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

Digital Signal Encoding Formats



How to Evaluate Encoding Schemes?

- **Signal spectrum:** (remember this is dependent on pulse shape)
  - Lack of high frequency component ➔ lesser BW – signal does not required large BW - desirable
  - Lack of DC component - desirable
- **Clocking (Synchronization):**
  - Rxer needs to determine bit timing
    - Provide clock signal at receiver – EXPENSIVE
    - Derive clock signal from incoming signal
  - E.g. Differentiating a Manchester encoded signal results in the clock signal!

How to Evaluate Encoding Schemes? (2)

- Error detection:
  - Capability built into physical layer encoding – e.g. for pseudoternary successive ones have opposite signs
  - More sophisticated error detection and correction codes are used
- Signal interference and noise immunity
  - Certain codes are superior than others in the presence of noise and interference (i.e. give lower BER for same SNR or Eb/No)
- Cost and complexity:
  - Not a major factor compared to the rest of factors
  - In general, the higher the data rate the more expensive the hardware is

Nonreturn to Zero (NRZ)

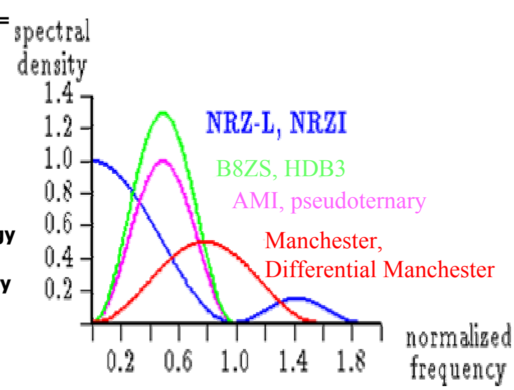
- Nonreturn to Zero – Level (NRZ-L):
  - Binary 0 – constant +ve level
  - Binary 1 – constant -ve level
- Nonreturn to Zero – Invert on Ones (NRZI):
  - Binary 0 – no transition at beginning of bit interval
  - Binary 1 – transition at beginning of bit interval
  - NRZI is an example of *differential encoding*:
    - If bit is equal to 1, bit encoding is opposite to previous bit
  - Benefits of differential encoding

Spectrum Characteristics of NRZ

- **Most of the energy in NRZ and NRZI signals is between DC and half of bit rate – BW ~ $1/T_b$**
  - **For example: When R = 9600 b/s or Tb = 0.104 msec, most of energy of the signal is between 0 Hz and 4800 Hz**
- **Main limitations of NRZ:**
  1. **presence of DC component**
  2. **lack of synchronization capability**
  - **Consider the case of a long string of ones or zeros:**
    - **One constant voltage level for long duration (>> T_b) – may cause drift in clock synchronization**
- **Applications:**
  - **Digital magnetic recording**
  - **Generally not used for signal transmission**

Spectrum Characteristics of NRZ and Other Encoding Schemes

- **Note the x-axis: normalized frequency (f/R)**
  - **E.g. value equal to 1.2, means f = 1.2 R**
- **Schemes NRZ-L and NRZI have DC component**
- **Schemes B8ZS, HDB3, AMI, pseudoternary, Manchester and differential Manchester have no DC component**
- **NRZ-L, NRZI, B8ZS, HDB3, AMI, and pseudoternary have negligible energy beyond f = R**
- **B8ZS, HDB3, AMI, and pseudoternary have their energy concentrated around f = R/2**
- **Manchester and differential Manchester has significant energy concentration beyond f = R (because of the per bit transitions!)**



Multilevel Binary – Bipolar - AMI

- Family of codes that uses more than two signal levels
- Bipolar-AMI:
  - Binary 0 – no signal level
  - Binary 1 – +ve or -ve level; alternating
- Advantages of Bipolar-AMI:
  - Synch: long string of 1s is not a problem – but a long string of 0s is
  - No net DC component
  - Alternating pulses – simple error detection (no two consecutive ones can have same polarity)
  - BW ~ $1/T_b$

Multilevel Binary – Pseudoternary

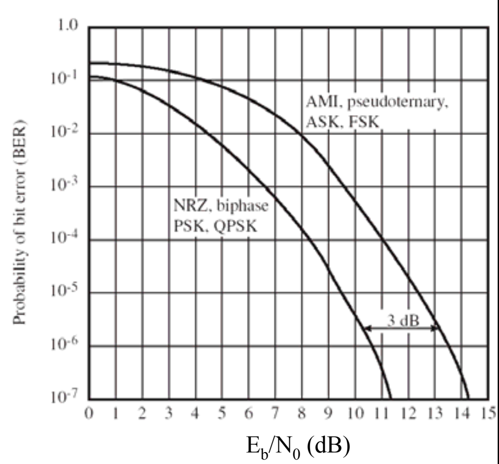
- Pseudoternary:
  - Binary 0 – +ve or -ve level; alternating
  - Binary 1 – no signal level
- Same advantages as bipolar-AMI
- To provide clock synch info:
  - Insert additional bits to force transition – used in ISDN for low bit rate connections – results in increased bit rate
  - Can not be used for already high bit rate connections – expensive
  - Use SCRAMBLING

NRZ V.S. Multilevel Binary

- **Spectrum:**
  - **NRZ has DC component**
  - **Multilevel binary does not have DC component – smaller bandwidth**
- **Synch:**
  - **NRZ: long strings of 1s AND 0s present a problem**
  - **Multilevel binary: long strings of 1s for bipolar-AMI or long strings of 0s for pseudoternary present a problem**

NRZ V.S. Multilevel Binary (2)

- **Efficiency:**
  - **NRZ: two symbols – one for 0 and the other for 1 – i.e. $\log_2 2 = 1$ information bit per symbol**
  - **Multilevel binary: three symbols – one for 0 and two for 1 (or the reverse for pseudoternary) – i.e. $\log_2 3 = 1.58$ information bits per symbol**
  - **NRZ is more efficient – requires 3 dB less (1/2) signal power to give same BER as Multilevel**



Biphase Encoding

- Manchester: transition at the middle of each bit
  - Binary 0 – high to low transition in the middle
  - Binary 1 – low to high transition in the middle
- Differential Manchester: transition at the middle of each bit
  - Binary 0 – transition at beginning of interval
  - Binary 1 – no transition at beginning of interval
- THERE IS ALWAYS a TRANSION at midbit – This provides the needed clock signal
- Biphase schemes require at least on transition per bit interval and sometimes two transitions per bit interval → Generate signal with higher frequency components compared to NRZ for same rate!!

Advantages of Biphase Encoding

- Synchronization:
  - There is a predictable transition during each bit time
  - To derive clock signal – differentiate biphase signal
  - Biphase = Self clocking codes
- No DC component
- Error Detection:
  - A transition must happen at mid bit – if not present → ERROR
- Applications:
  - Manchester coding: IEEE 802.3 coaxial cable and TP CSMA/CD bus LANs
  - Differential Manchester: IEEE 802.5 token ring LANs on STP

Modulation Rate

- **Modulation (Baud) Rate - D: number of symbols or signal elements transmitted per second**
- **Data (or bit) Rate - R: number of bits transmitted per second**
- **D = R/b – where b is number of bits per symbol**

Transitions Per Bit Time

- **The more transitions per bit time, the greater is the required bandwidth of the encoding scheme**

Encoding	Minimum	10101010…	Maximum
NRZ-L	0 (all 0s or 1s)	1.0	1.0
NRZI	0 (all 0s)	0.5	1.0 (all 1s)
Bipolar-AMI	0 (all 0s)	1.0	1.0
Pseudoternary	0 (all 1s)	1.0	1.0
Manchester	1.0 (10101…)	1.0	2.0 (all 0s or 1s)
Differential Manchester	1.0 (all 1s)	1.5	2.0 (all 0s)

Note that Manchester and differential Manchester encoding have the maximum number of transitions per bit time – This is the reason, their spectrum have significant components for f/R greater than 1.0 (refer to slide 33)

Digital Data – Analog Signals

- Digital data (bits) transmitted using analog signals:
  - E.g. computer-modem-PSTN
- Subscriber–to–PSTN connection designed to carry analog (voice) signal from 300 Hz to 3400 Hz
- 56K Modem – encodes data and generates a signal occupying the same range for voice signals → one line - one signal
- DSL Modem – encodes data and generates signal occupying higher range than that usually occupied by voice → one line – two signals

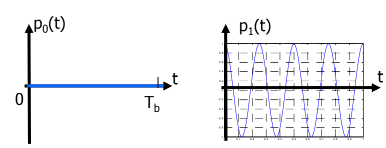
Encoding Techniques – Amplitude Shift Keying (ASK)

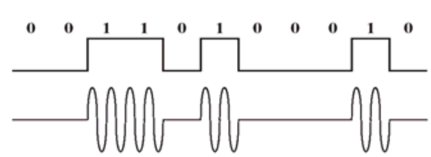
- Analog pulses (signal elements) used are:

$$s(t) = \begin{cases} A\cos(2\pi f_c t) & bit = 1 \\ 0 & bit = 0 \end{cases}$$

- Spectrum of overall signal is centered around f_c

- Application: on voice-grade lines used up to 1200 bps



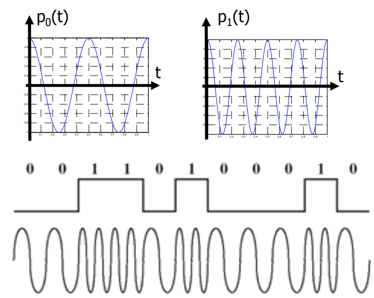


Encoding Techniques – Frequency Shift Keying (FSK)

- **Analog pulses (signal elements) used are:**

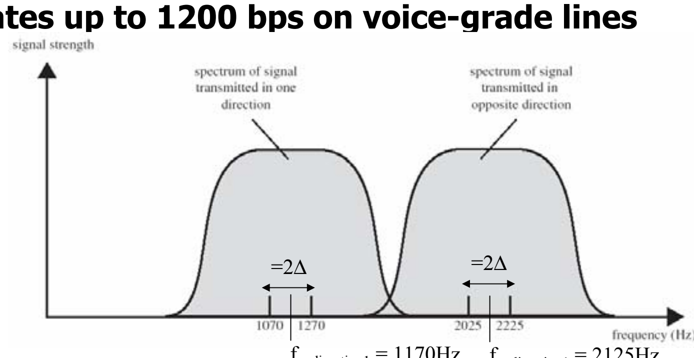
$$s(t)=\begin{cases} A\cos(2\pi f_1 t) & bit=1 \\ A\cos(2\pi f_2 t) & bit=0 \end{cases}$$

- **Spectrum of overall signal is centered around $f_1$and f_2**



Encoding Techniques – Frequency Shift Keying (FSK) (2)

- **Application: full duplex**
  - **Direction 1: f1 = 1070 Hz, f2 = 1270 Hz**
  - **Direction 2: f1 = 2025 Hz, f2 = 2225 Hz**
- **Less susceptible to errors (compared to ASK) – used for rates up to 1200 bps on voice-grade lines**
  - **Also used for high frequency (3 to 30 MHz) radio transmission**
  - **LANs – coaxial cables**



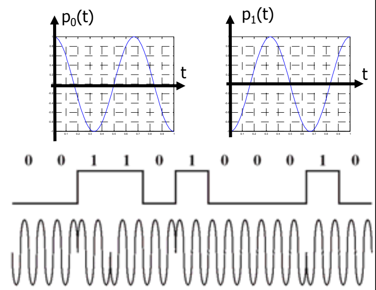
Encoding Techniques – Phase Shift Keying (PSK)

- **Analog pulses (signal elements) used are:**

$$s(t)=\begin{cases} A\cos(2\pi f_c t+\pi) & bit=1 \\ A\cos(2\pi f_c t) & bit=0 \end{cases}$$

- **Spectrum of overall signal is centered around f_c**

- **Example of 2-phase system**

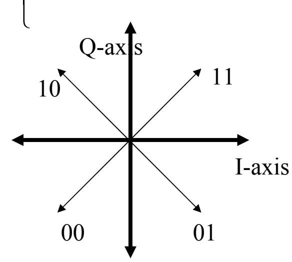


Encoding Techniques – Quadrature Phase Shift Keying (QPSK)

- **Analog pulses (signal elements) used are:**

$$s(t)=\begin{cases} A\cos(2\pi f_c t+\pi/4) & bits=11 \\ A\cos(2\pi f_c t+3\pi/4) & bits=10 \\ A\cos(2\pi f_c t+5\pi/4) & bits=00 \\ A\cos(2\pi f_c t+7\pi/4) & bits=01 \end{cases}$$

- **Example of 4-phase system**
- **Each signal element carries 2 bits**
- **One can extend this scheme to obtain: 8PSK for example**
- **One can use ASK together with PSK to get more signal elements – e.g. 9600 kb/s modem uses 12 phase angles four of which have two amplitude values**



Signal Constellation for QPSK

Encoding Techniques – Quadrature Phase Shift Keying (QPSK) (2)

- **One can extend this scheme to obtain: 8PSK for example**
- **One can use ASK together with PSK to get more signal elements – e.g. 9600 kb/s modem uses 12 phase angles four of which have higher amplitude values**
  - **For this example: b = 4**

  (i.e. every signal element carries 4 bits)

- **In general:**

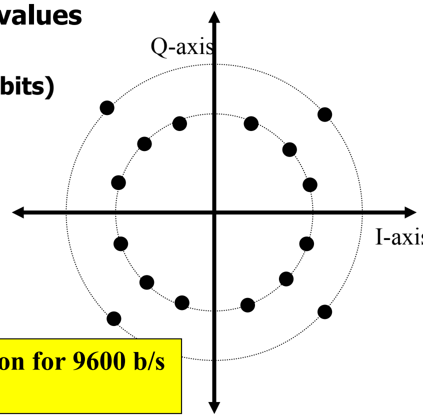
  $D = R/b = \log_2 L$

  where D: modulation rate or baud rate

  R: data rate, bps

  L: # of signal levels

  b: # of bits per signal element



Signal Constellation for 9600 b/s modem standard

Performance - Bandwidth

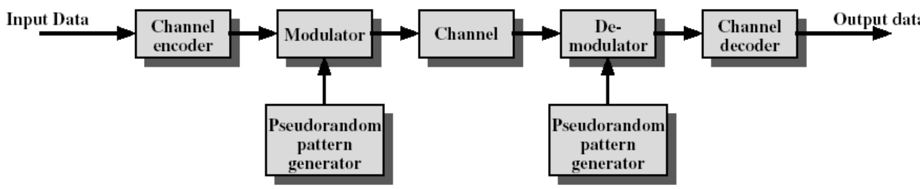
- **Signal (ASK, PSK, FSK, etc) BW depend on:**
  - **Definition of BW**
  - **Filtering technique**
- **r – depends on filtering technique (0<r<1)**
- **For FSK: $\Delta f = f_2 - f_c = f_c - f_1$**

Encoding Scheme	BW (Signal Spectrum)
ASK	$B_T=(1+r)R$
PSK	$B_T=(1+r)R$
FSK	$B_T=2\Delta f + (1+r)R$

- **For multi-level PSK**

  $B_T=(1+r)D = (1+r)R/b = (1+r)/\log_2 L \times R$
- **R/B_T = data rate to transmission bandwidth → *Bandwidth Efficiency***
  - **The higher this number the more efficient the scheme is (i.e. less number of Hzs is required to transmit the bits)**

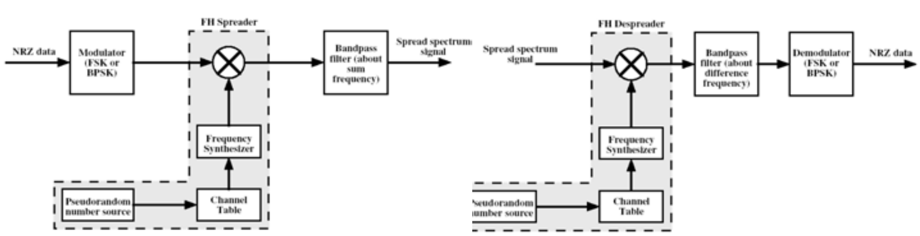
Spread Spectrum



- **Key Characteristics:**
  - **Input data is encoded➔ NARROWBAND analog signal**
  - **Further modulated using Pseudorandom numbers**
    - **This results in BROADBAND signal**
  - **At receiver – exact same pseudorandom number are generated and used to demodulate signal**
  - **The resulting narrowband signal is then decoded to retrieve original data**

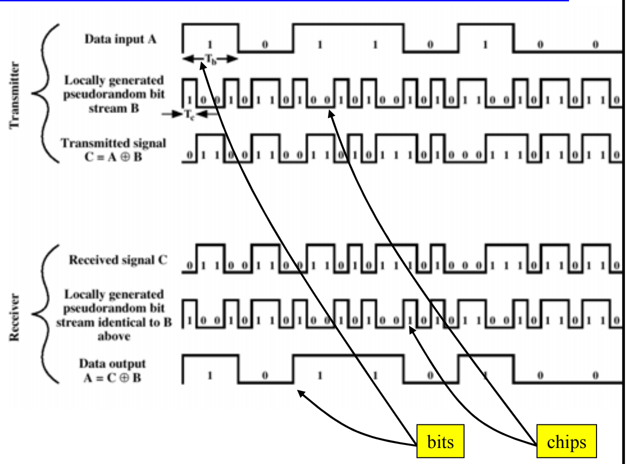
Spread Spectrum – Frequency Hopping

- **The signal is transmitted over a *seemingly* random series of frequencies: jumping from one frequency to the next ➔ HOPPING**
- **A receiver, hopping between frequencies and in SYNCHRONIZATION with transmitter, is able to demodulate and decode the original message**



Spread Spectrum – Direct Sequence

- **Data input A is "spread" or multiplied by pseudorandom chip stream B → T_b/T_c chips per bit**
- **$R_c = 1/T_c$, $R = 1/T_b$**
- **SPREADING GAIN (G) = T_b/T_c or R_c/R**
- **Intended receiver using SAME pseudorandom chips to recover original data**
- **Original data: A**
- **Transmitter forms: C = A XOR B**
- **Receiver forms: C XOR B = (A XOR B) XOR B = A XOR 0 = A → which is the original data**



Remember (from COE-200) that B XOR B = 0, and A XOR 0 = A

Spread Spectrum – Direct Sequence (2)

Transmitter **Receiver**