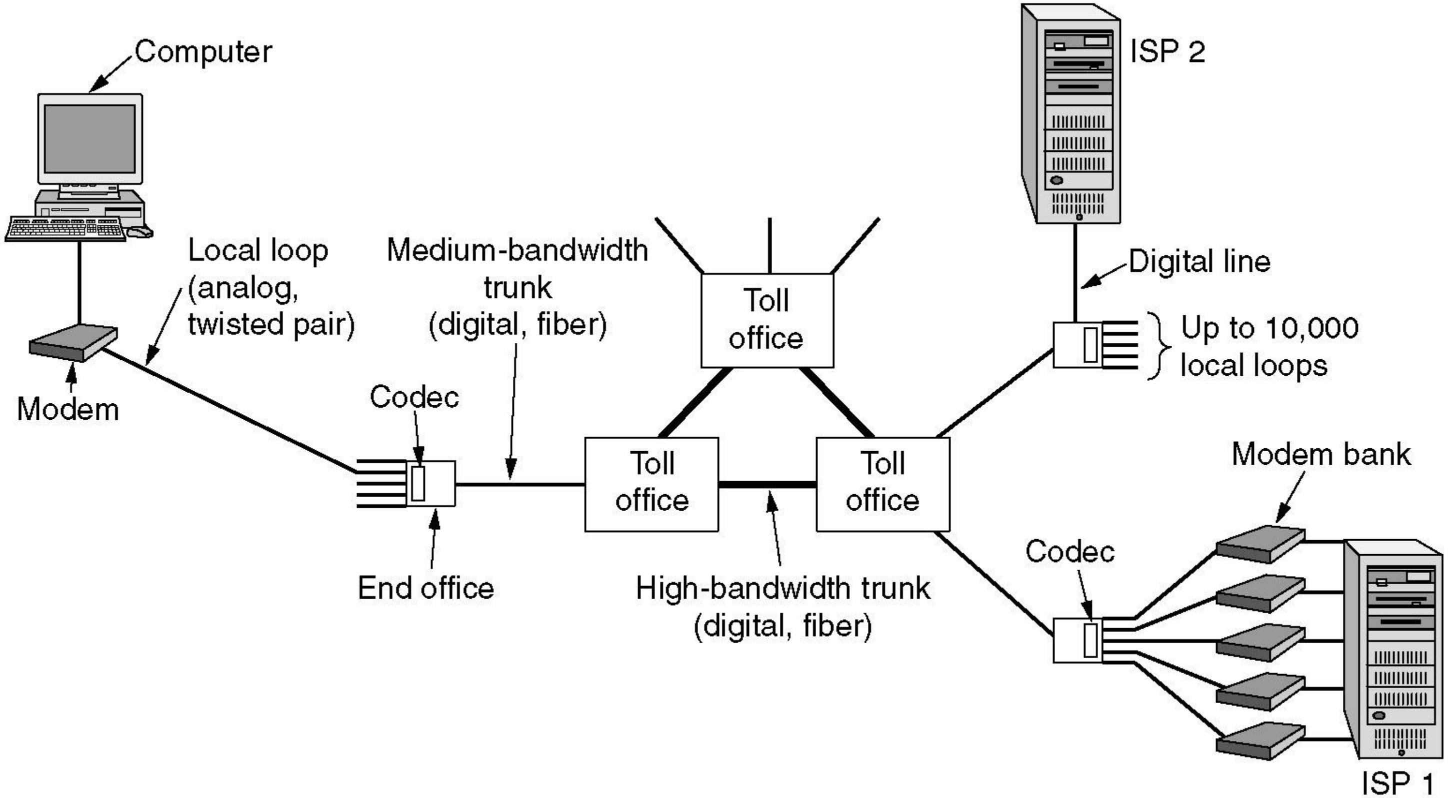
Signal Encoding Techniques

Analog and Digital Transmissions

- Both analog and digital transmissions for a computer to computer call.
  - Conversion is done by the modems and codecs



Signal Encoding Techniques

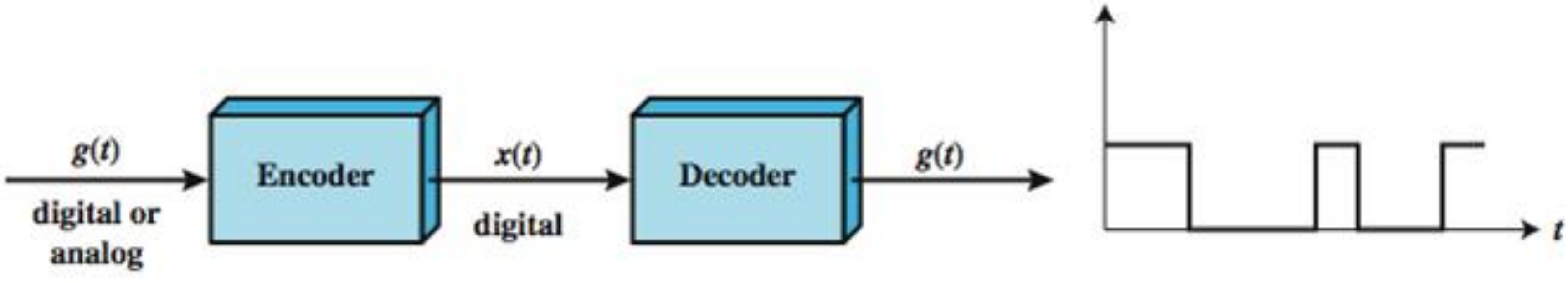
- Analog and Digital information can be encoded as either analog or digital signals:

1. Digital data, digital signals:
   - simplest form of digital encoding of digital data
2. Analog data, digital signals:
   - Analog data, such as voice and video, are often digitized to be able to use digital transmission facilities
3. Digital data, analog signal:
   - A modem converts digital data to an analog signal so that it can be transmitted over an analog
4. Analog data, analog signals:
   - Analog data are modulated by a carrier frequency to produce an analog signal in a different frequency band, which can be utilized on an analog transmission system

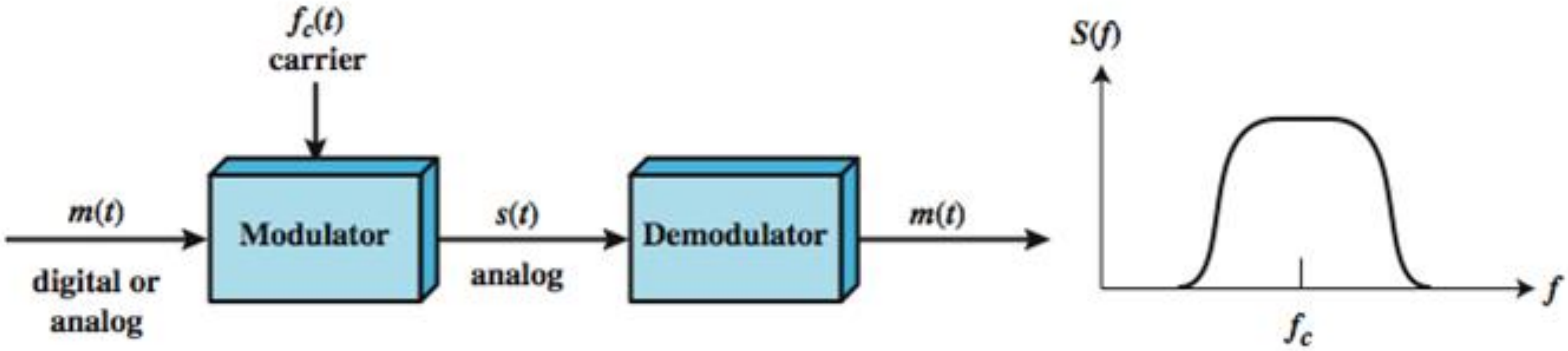
Signal Encoding Techniques

- For digital signaling, a data source $g(t)$, which may be either digital or analog, is encoded into a digital signal $x(t)$.
- Analog signaling is a continuous constant-frequency f_c signal known as the *carrier signal*.
- Data may be transmitted using a carrier signal by modulation, which is the process of encoding source data onto the carrier signal.
- All modulation techniques involve operation on one or more of the three fundamental frequency domain parameters: *amplitude*, *frequency*, and *phase*.
- The input signal $m(t)$ may be analog or digital and is called the *modulating signal*
- The result of modulating the carrier signal is called the *modulated signal* $s(t)$.

Signal Encoding Techniques



(a) Encoding onto a digital signal



(b) Modulation onto an analog signal

Digital Data, Digital Signal

- Digital signal
  - discrete, discontinuous voltage pulses
- Bit duration
  - The time it takes for the transmitter to emit the bit.
- Issues

1. Signal to noise ratio
   - An increase in data rate increases bit error rate (BER).
2. Data rate
   - An increase in SNR decreases bit error rate.
3. Bandwidth
   - An increase in bandwidth allows an increase in data rate.
4. Encoding scheme
   - The mapping from data bits to signal elements

Some Terms

1. Unipolar
   – All signal elements have the same sign
2. Polar
   – One logic state represented by positive voltage the other by negative voltage
3. Data rate
   – Rate of data (R) transmission in bits per second
   – Function of Bandwidth, signal/noise ratio, encoding
4. Duration or length of a bit
   – Time taken for transmitter to emit the bit (1/R)
5. Modulation rate
   – Rate at which the signal level changes
   – measured in baud = signal elements per second.
   – Depends on type of digital encoding used.
6. Mark and Space
   – Binary 1 and Binary 0 respectively

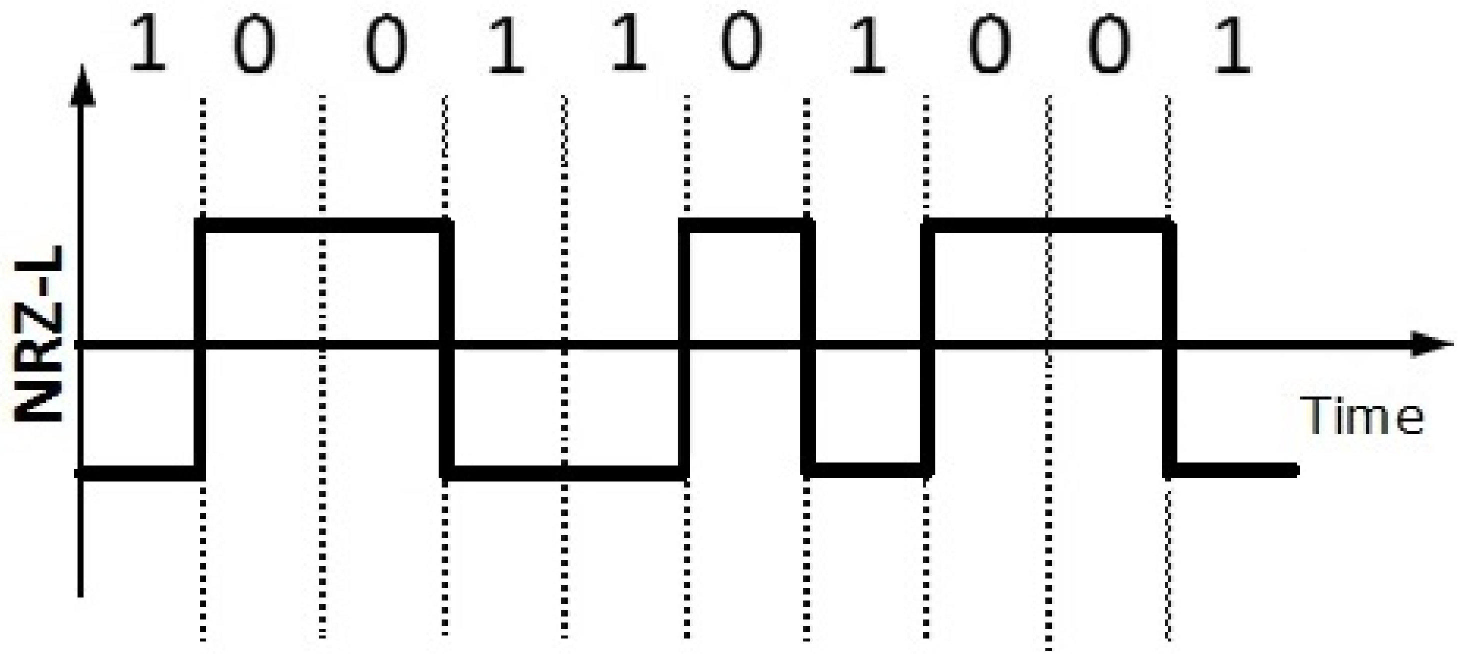
NRZ (Non-Return-to-Zero) Codes

1. NRZ-L (Non-Return-to-Zero-Level)

- Uses two different voltage levels
  - One positive and one negative
  - 1: negative voltage
  - 0: positive voltage
- The voltage is constant during the bit interval.
- NRZ-L is used for short distances between terminal and modem or terminal and computer.

NRZ-L

- Example: Given the following data encoded using NRZ-L



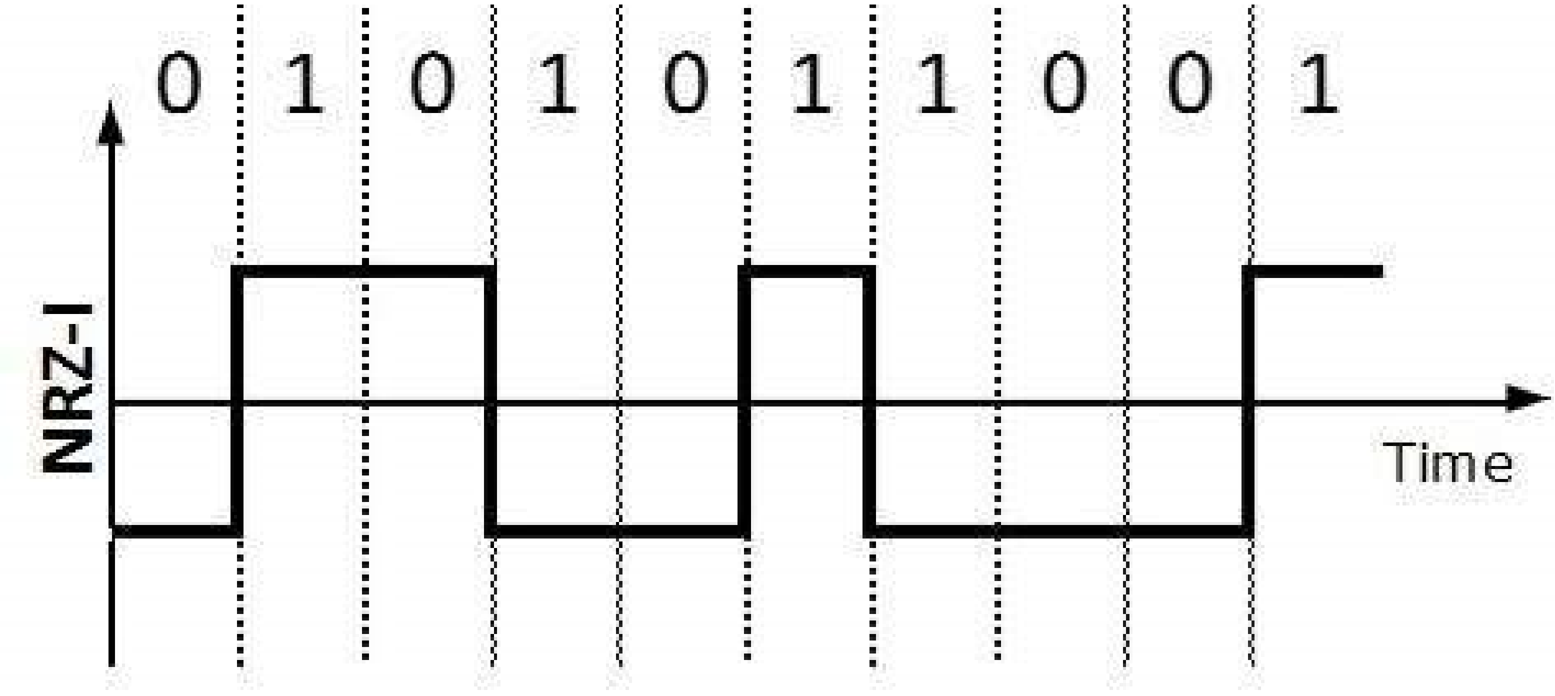
NRZ (Non-Return-to-Zero) Codes

2. NRZ-I (Non-Return-to-Zero-Invert on ones)

- Constant voltage pulse for duration of bit
- Data encoded as presence or absence of signal transition at beginning of bit time
  - Transition (low to high or high to low) denotes binary 1
  - No transition denotes binary 0
- Example of differential encoding since have
  - Data represented by changes rather than levels
  - More reliable detection of transition rather than level

NRZ-I

- Example: Given the same data encoded using NRZ-I



NRZ Pros and Cons

- Pros
  - easy to engineer
  - make good use of bandwidth
- Cons
  - DC component
  - lack of synchronization capability
- Used for magnetic recording
- Not often used for signal transmission

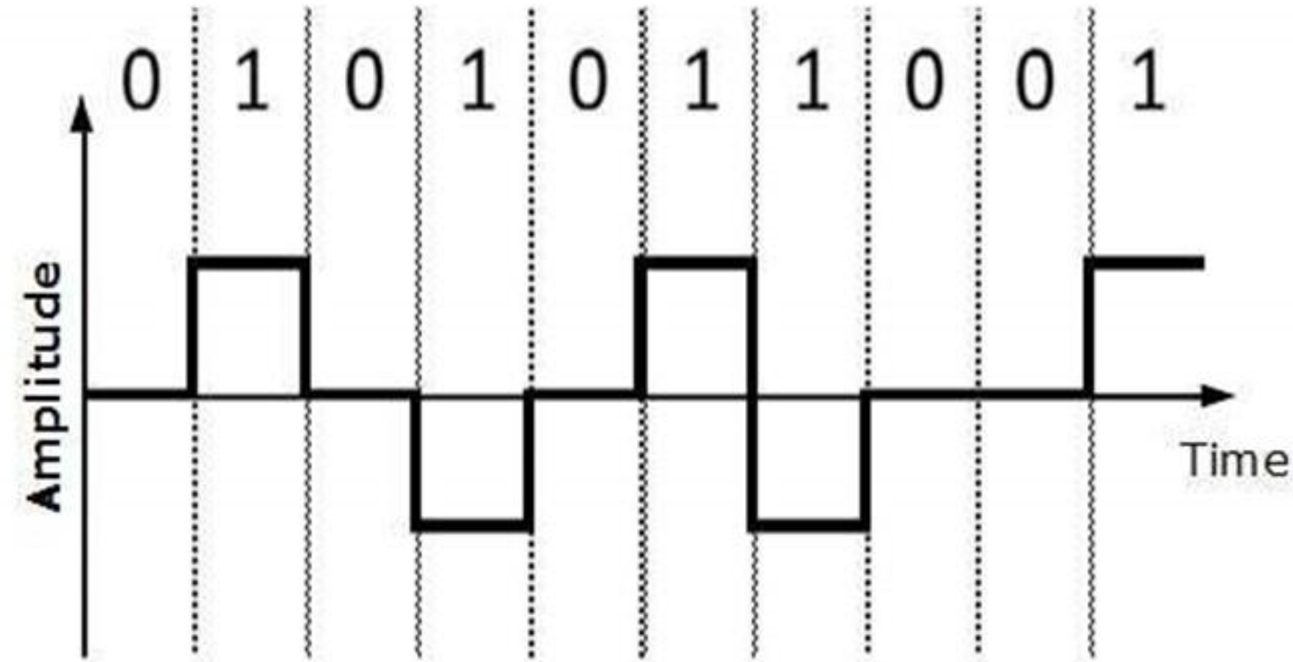
Multi-level Binary Encoding Bipolar-AMI Encoding

- Use more than two levels
- 0 is represented by no line signal
- 1 represented by positive or negative pulse
- 1 pulses alternate in polarity
- Easy error detection
- No loss of synchronization if a long string of 1's
- Problems:

1. A long string of 0s would still be a problem
2. No net DC component
3. Lower bandwidth
   - A 3 level system could represent $\log_2 3 = 1.58$ bits

Bipolar Encoding

- Example: Given the same data encoded using bipolar encoding



Bi-phase
Manchester Encoding

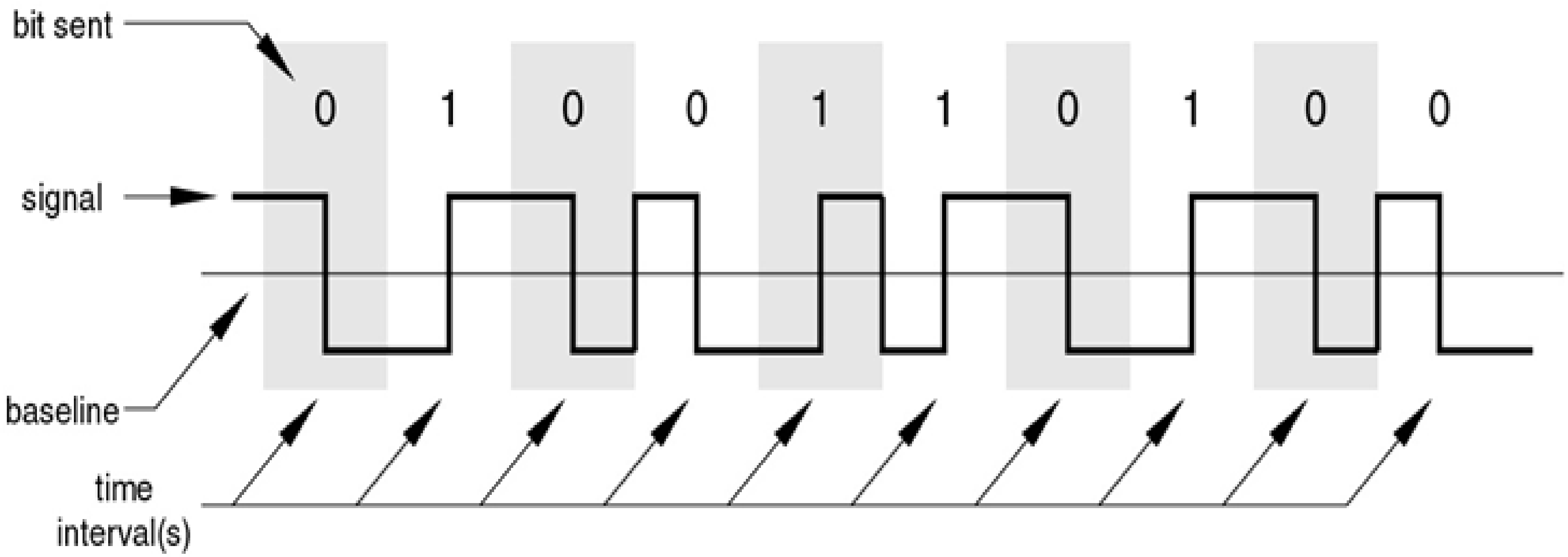
- Has transition in middle of each bit period
  - Transition serves as clock and data
- The direction of the mid-bit transition represents the digital data.

1. Low to high represents one
2. High to low represents zero

- Specified for the IEEE 802.3 (Ethernet) standard for baseband coaxial cable and twisted-pair bus LANs

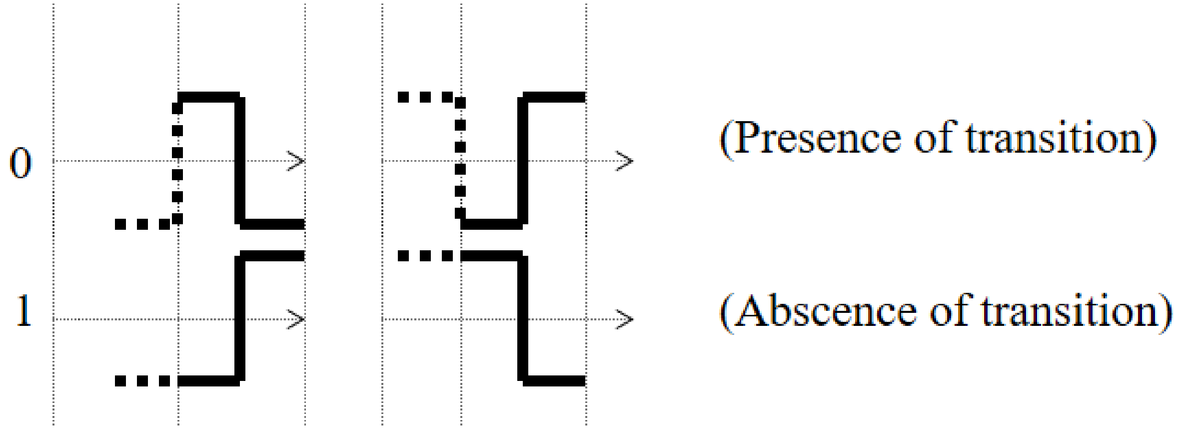
Bi-phase
Manchester Encoding

- Data encoded using Manchester encoding



Bi-phase
Differential Manchester Encoding

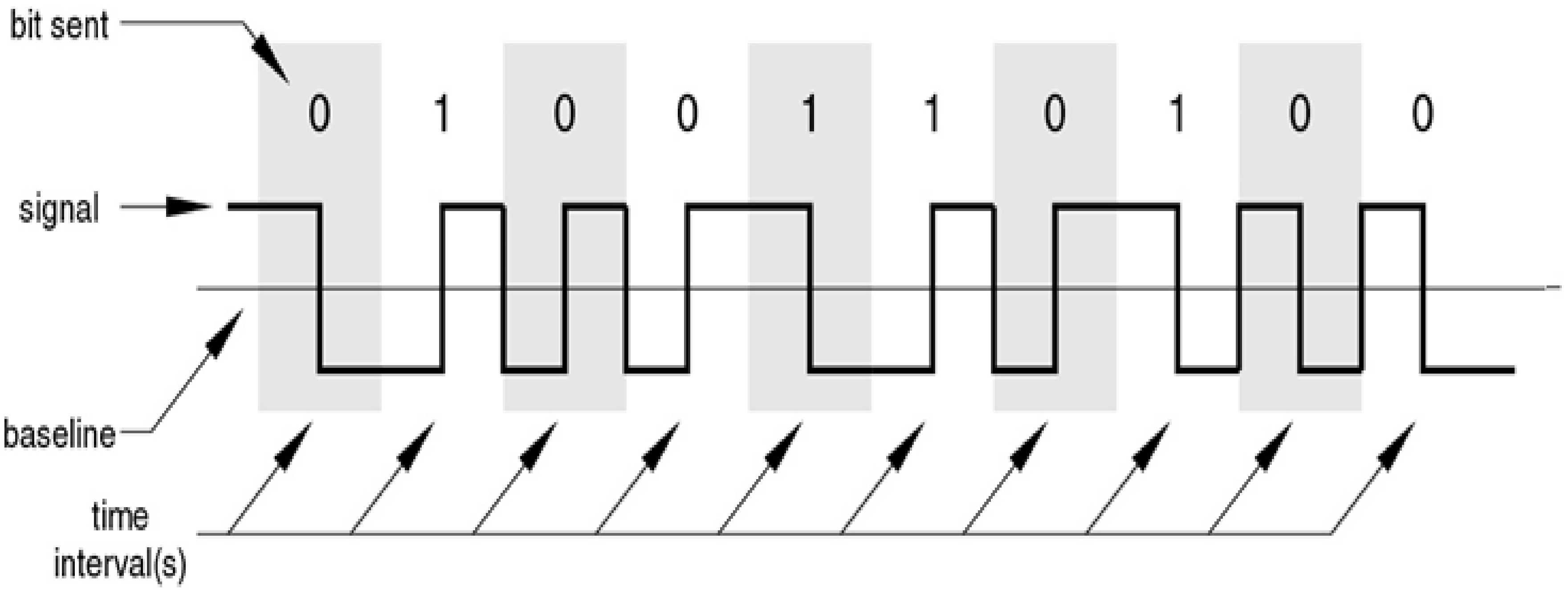
- Mid-bit transition is clocking only
- Transition at *start of bit period* representing 0
- No transition at start of bit period representing 1
  - This is a differential encoding scheme



- Specified for the IEEE 802.5 token ring LAN, using shielded twisted pair

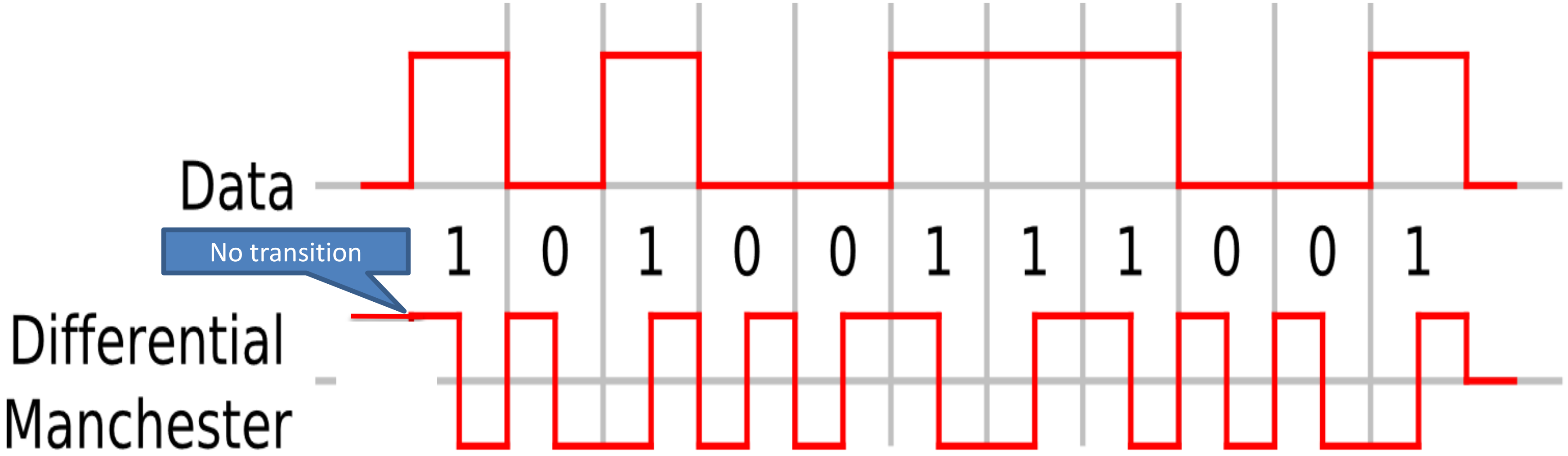
Bi-phase
Differential Manchester Encoding

- Data encoded using Differential Manchester Encoding



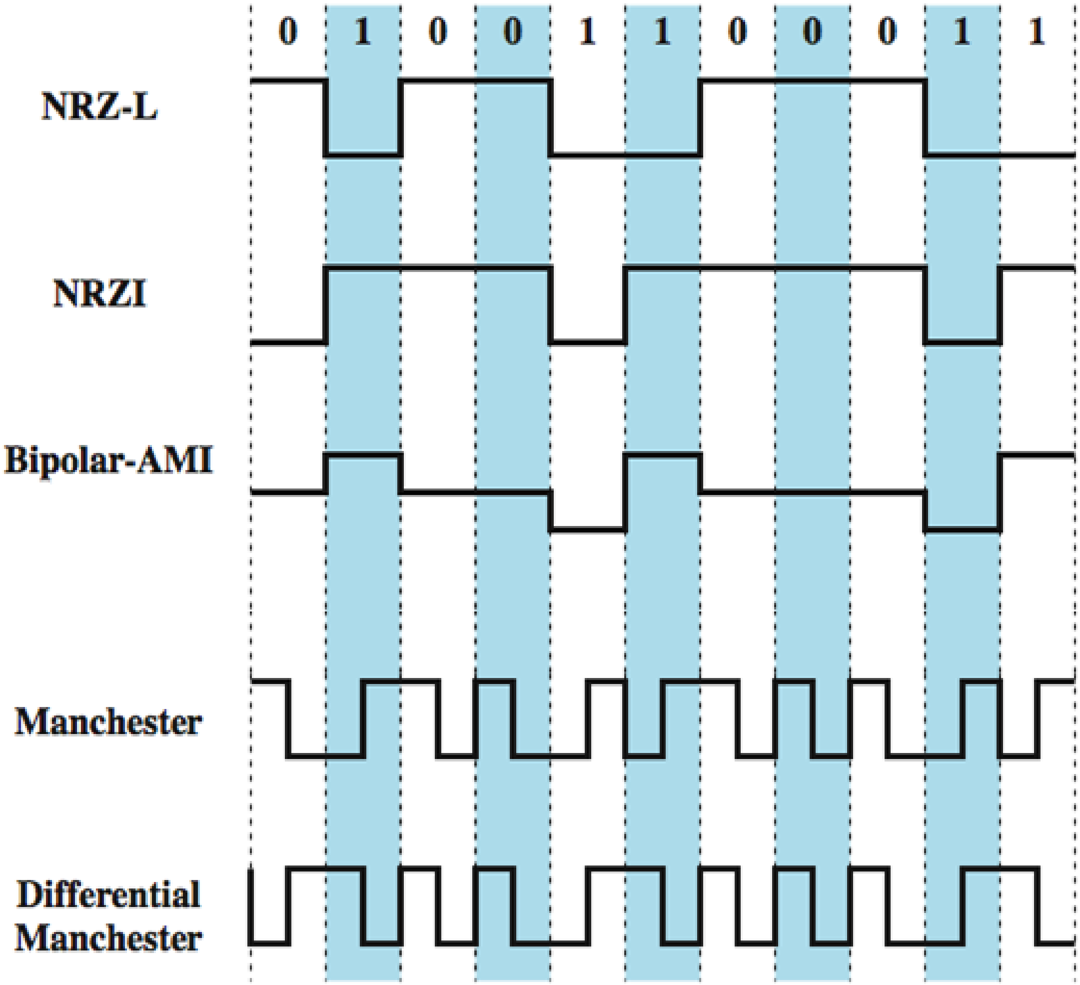
Bi-phase
Differential Manchester Encoding

- Data encoded using Differential Manchester Encoding



Encoding Example

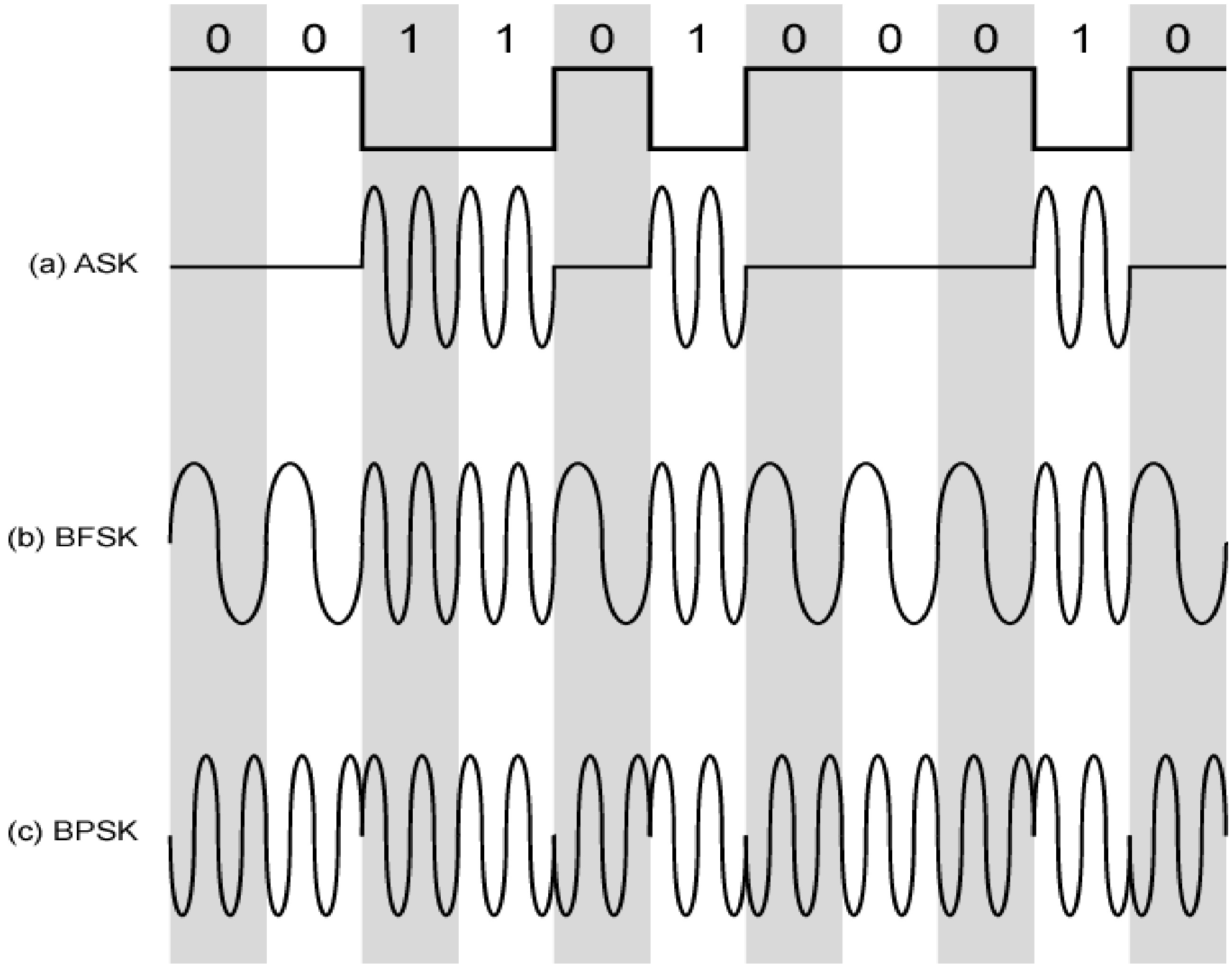
- Given the following data: 01001100011
- Use the different encoding schemes to encode the data



Digital Data, Analog Signals

- Basis for analog signaling is a continuous, constant-frequency signal known as the *carrier frequency*.
- Main use is public telephone system
- Use *modem* (*modulator-demodulator*)
- Encoding techniques
  - Amplitude shift keying (ASK)
  - Frequency shift keying (FSK)
  - Phase shift keying (PSK)

Modulation Techniques



Amplitude Shift Keying ASK

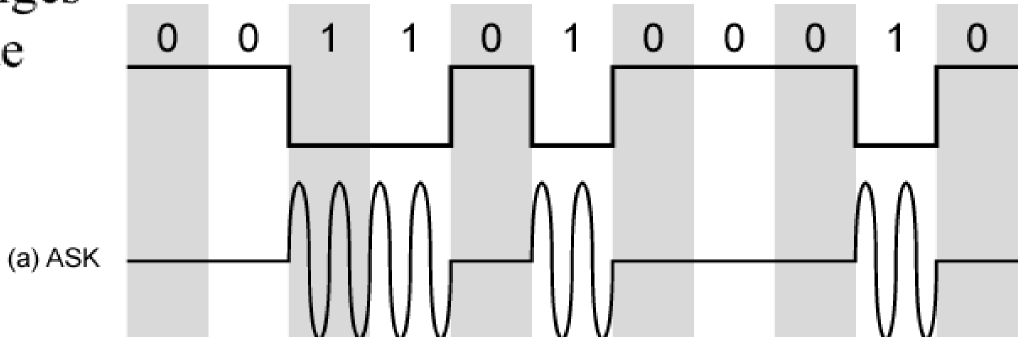
- 0 and 1 are encode by different carrier amplitudes
  - 1 is represented by the presence of the carrier at constant amplitude
  - 0 by the absence of the carrier

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

- Used for:

1. very high speeds over optical fiber
   - 1is represented by a light pulse while 0 is represented by the absence of light.
2. up to 1200bps on voice grade lines

- Problems:
- Susceptible to sudden gain changes
- Inefficient modulation technique



Binary Frequency Shift Keying BFSK

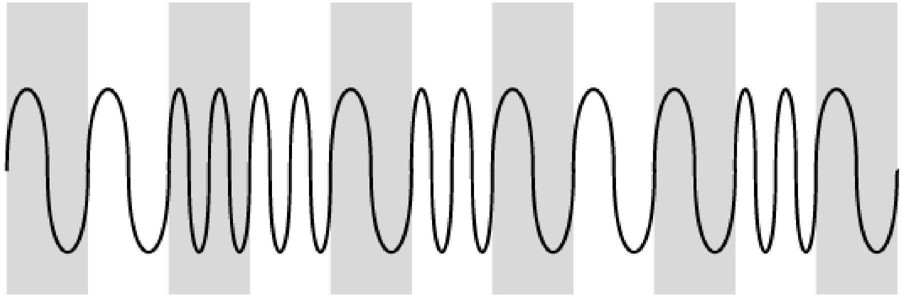
- Most common form
- 0 and 1 are represented by two different frequencies

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

- Less susceptible to error than ASK
- Used for

1. Up to 1200bps on voice grade lines
2. High frequency radio transmission (3 to 30 MHz)
3. Can also be used at even higher frequencies on LAN that use coaxial cable

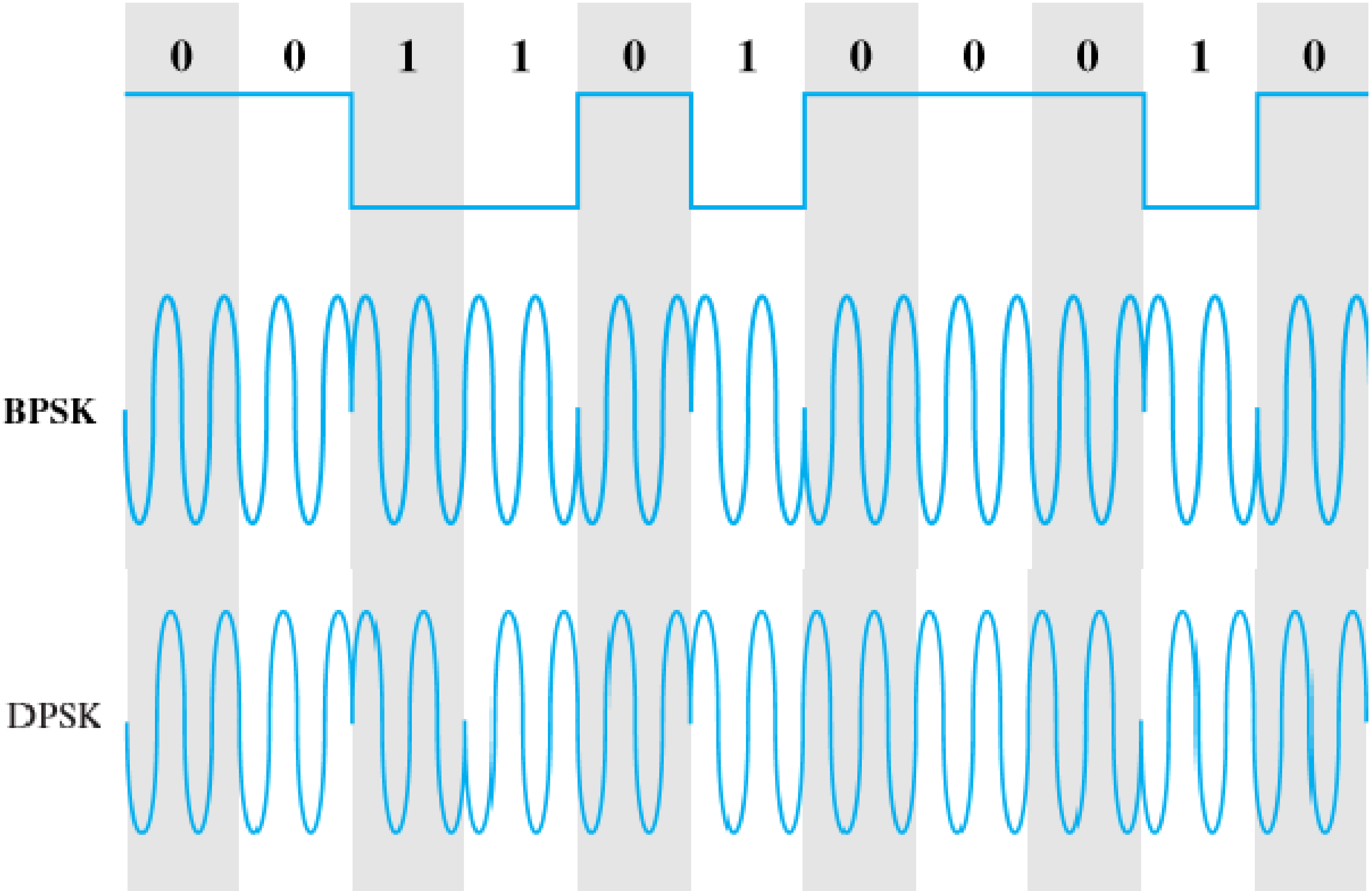
(b) BFSK



Phase Shift Keying PSK

- Phase of carrier signal is shifted to represent data
- Binary PSK (BPSK)
  - Two phases represent two binary digits
- Differential PSK (DPSK)
  - A binary 0 is represented by sending a signal burst of the same phase as the previous signal burst sent.
  - A binary 1 is represented by sending a signal burst of opposite phase to the preceding one

Phase Shift Keying PSK



Modems

- All advanced modems use a *combination of modulation techniques* to transmit *multiple bits per baud*.
- Multiple amplitude and multiple phase shifts are combined to transmit several bits per symbol.
- QPSK (*Quadrature Phase Shift Keying*) uses multiple phase shifts per symbol.
- Modems actually use *Quadrature Amplitude Modulation* (QAM).
- These concepts are explained using constellation points where a point determines a specific amplitude and phase.

PSK

- BPSK (a)
- QPSK (b)
- 8PSK (c)

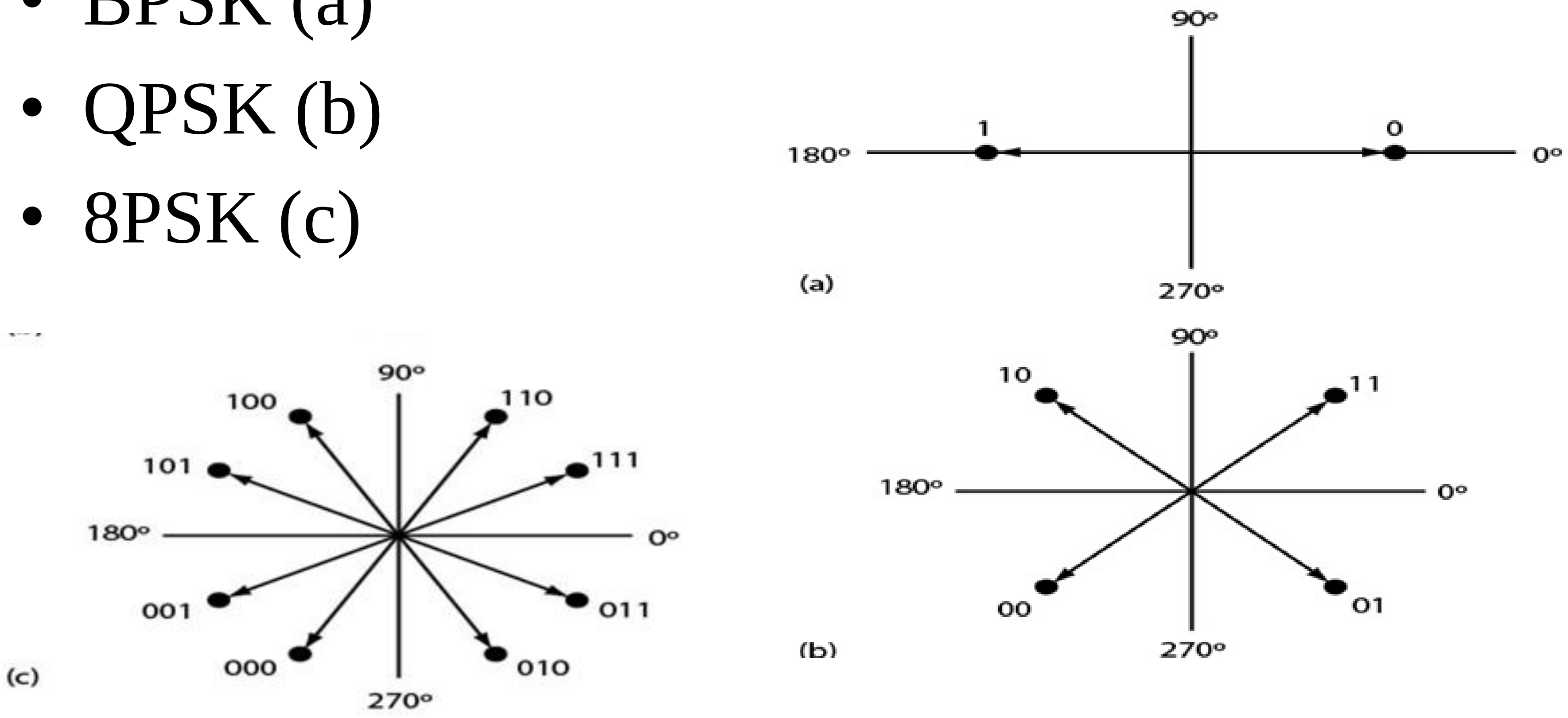


Figure 4. Shown are phase-shift keying (PSK) constellation diagrams for binary PSK (a), quaternary PSK (b), and 8PSK (c).

Quadrature PSK QPSK

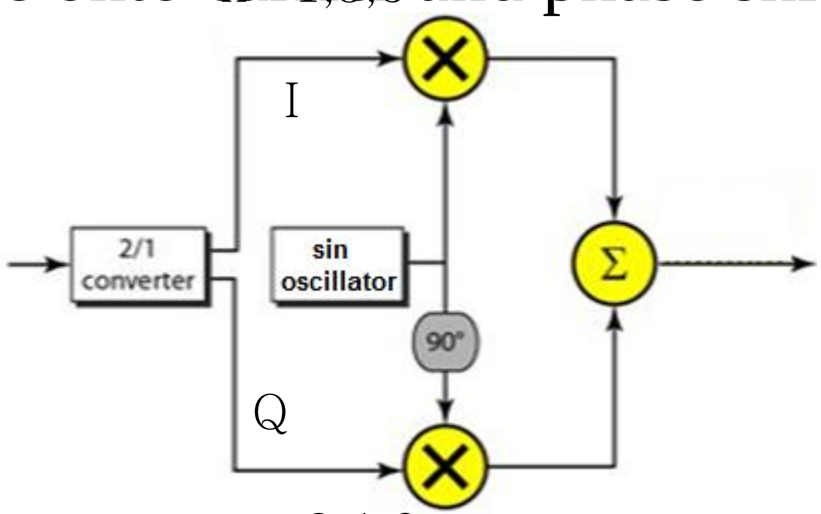
- Get more efficient use if each signal element represents more than one bit
  - Shifts of $\pi/2$ (90^o) means that each element represents two bits

$$s(t) = \begin{cases} A\cos\left(2\pi f_c t + \frac{\pi}{4}\right) & \text{, for 11} \\ A\cos\left(2\pi f_c t + \frac{3\pi}{4}\right) & \text{, for 10} \\ A\cos\left(2\pi f_c t - \frac{\pi}{4}\right) & \text{, for 01} \\ A\cos\left(2\pi f_c t - \frac{3\pi}{4}\right) & \text{, for 00} \end{cases}$$

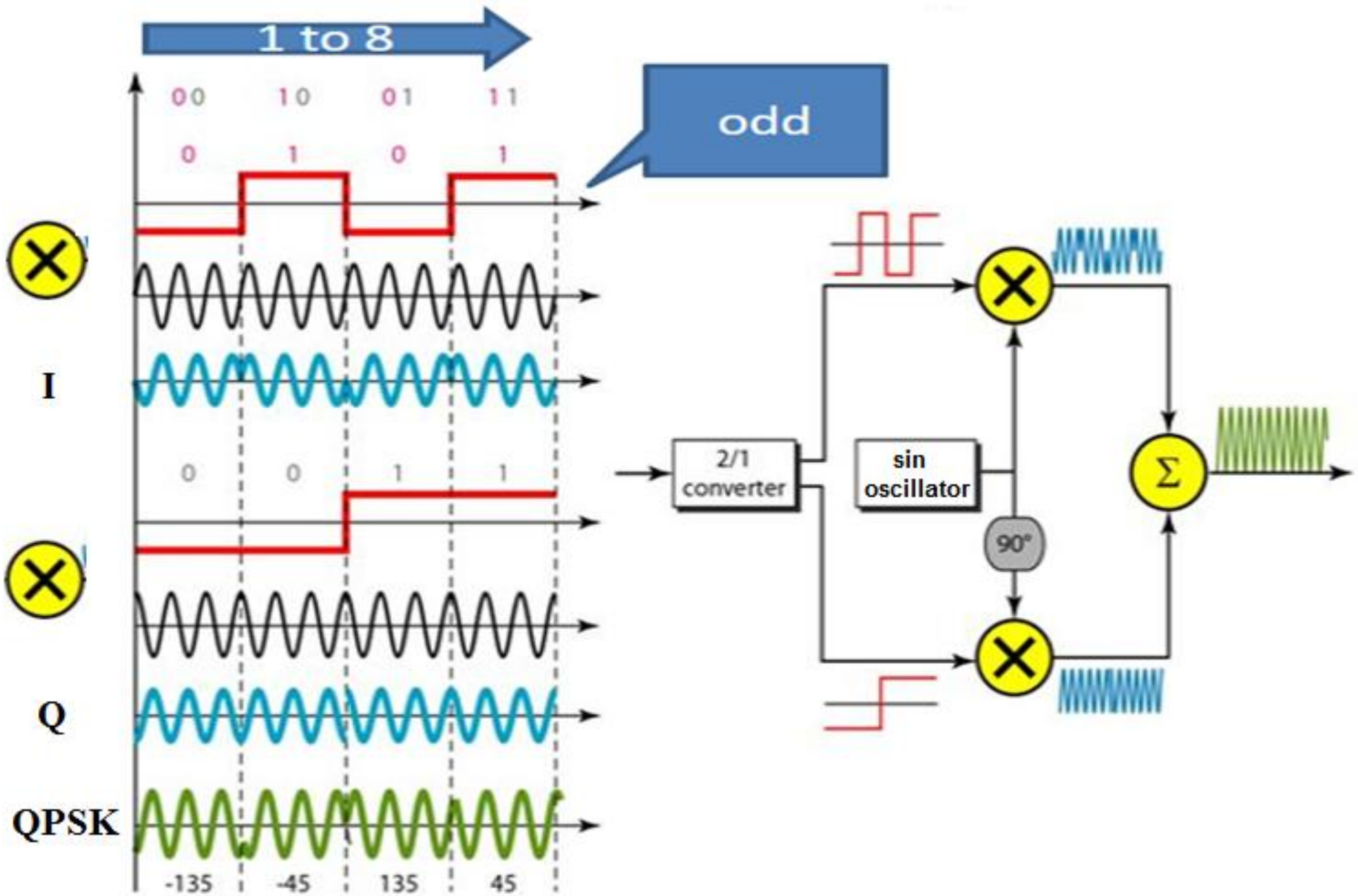
- Can use 8 phase angles and more than one amplitude
  - 9600bps modem uses 12 angles, four of which have two amplitudes

Quadrature PSK QPSK

- Split input data stream in two streams
  - The I (in-phase) and Q (quadrature phase) streams
  - Modulate onto carrier and phase shifted carrier

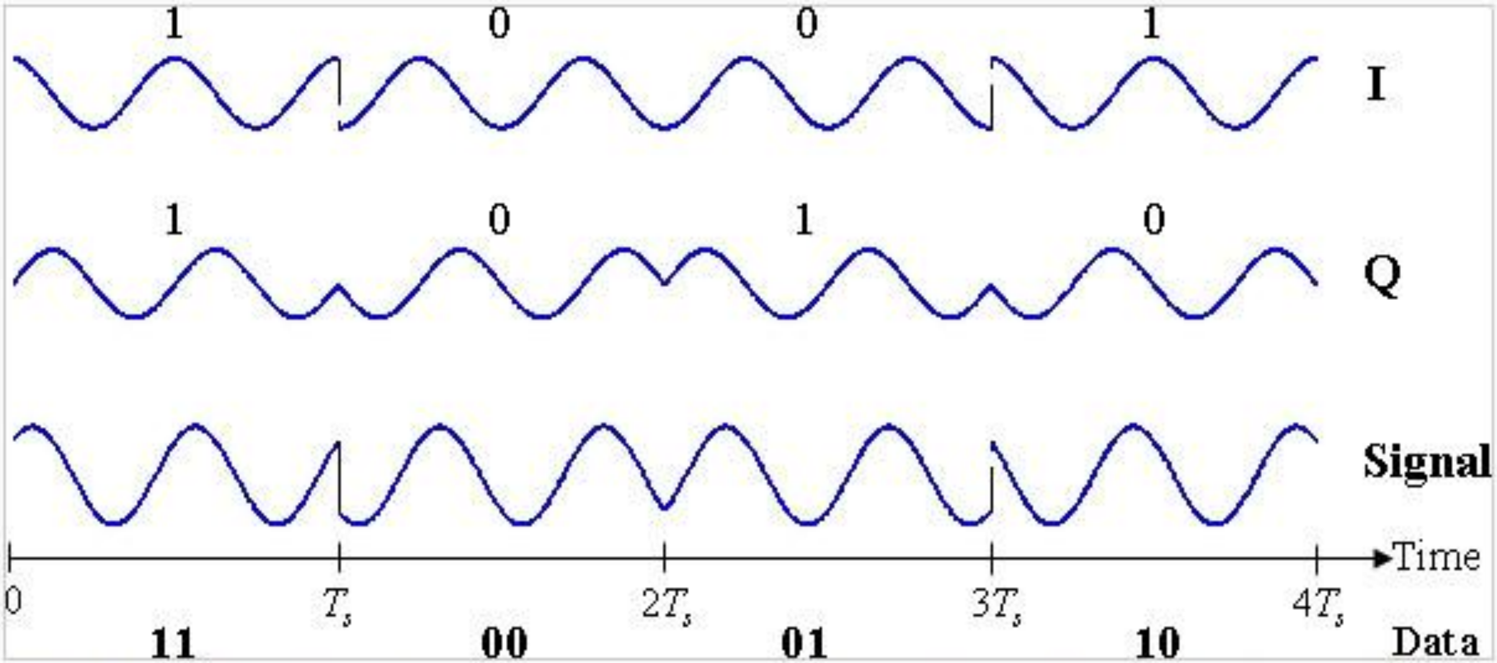


QPSK



1 to 8
00 10 01 11
0 1 0 1
odd
I
0 0 1 1
Q
QPSK
-135 -45 135 45
2/1 converter
sin oscillator
90°
Σ

Example



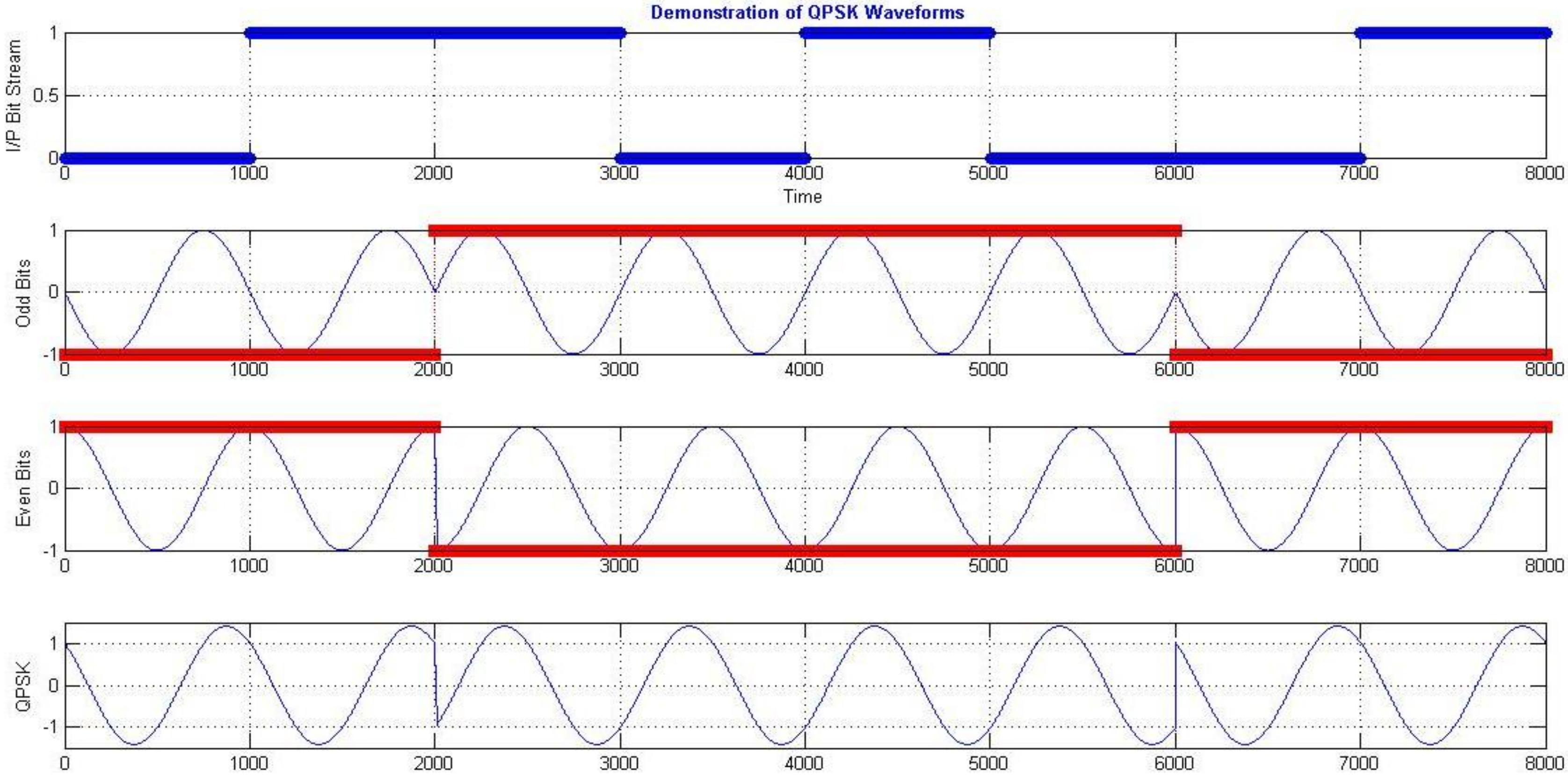
Timing diagram for QPSK. The binary data stream is shown beneath the time axis. The two signal components with their bit assignments are shown the top and the total, combined signal at the bottom. Note the abrupt changes in phase at some of the bit-period boundaries.

The binary data that is conveyed by this waveform is: 1 1 0 0 0 1 1 0.

- The odd bits, highlighted here, contribute to the in-phase component: **1** 1 **0** 0 **0** 1 **1** 0
- The even bits, highlighted here, contribute to the quadrature-phase component: 1 **1** 0 **0** 0 **1** 1 **0**

Example

- Given the following data 01101001

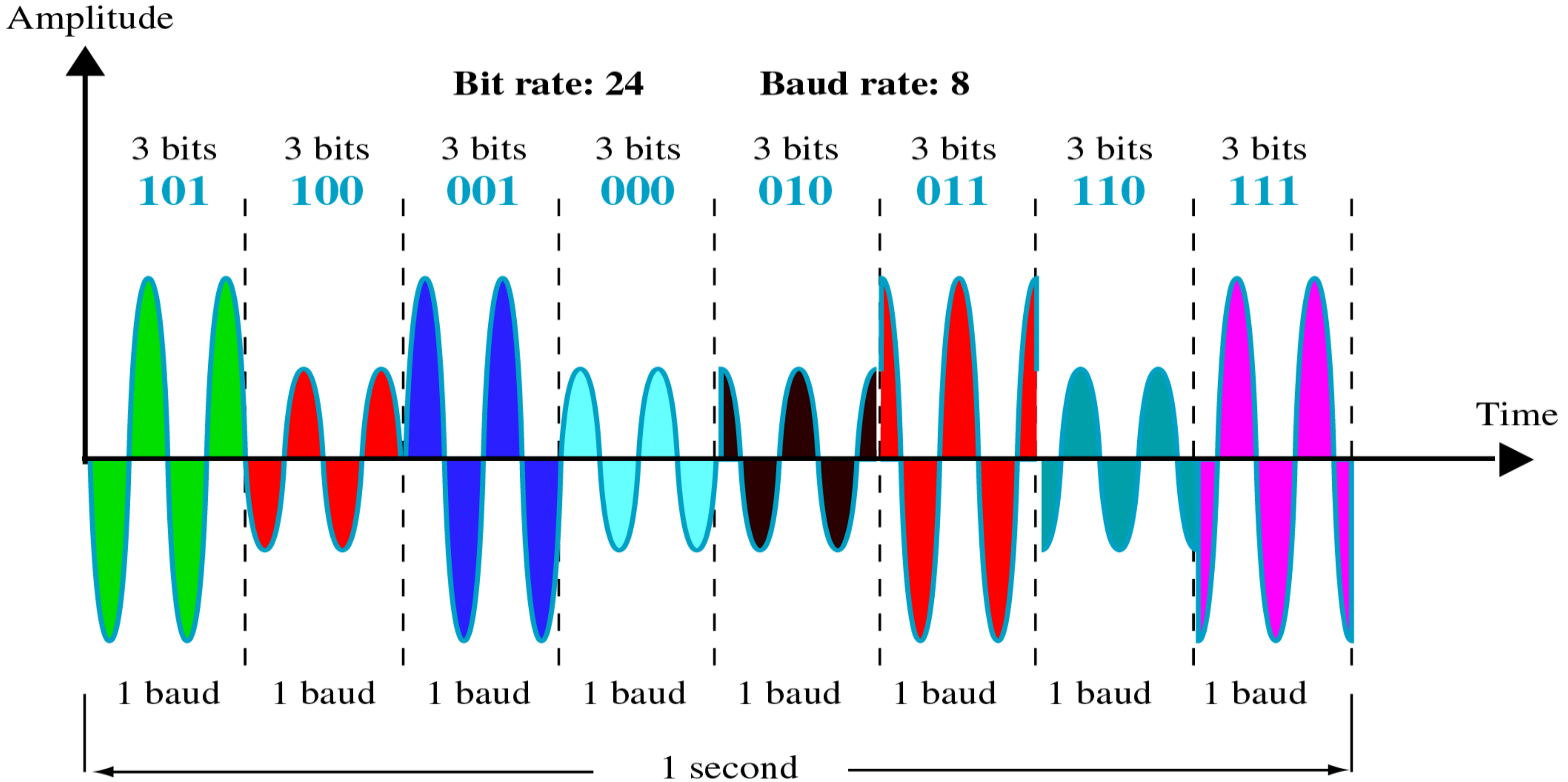


Quadrature Amplitude Modulation QAM

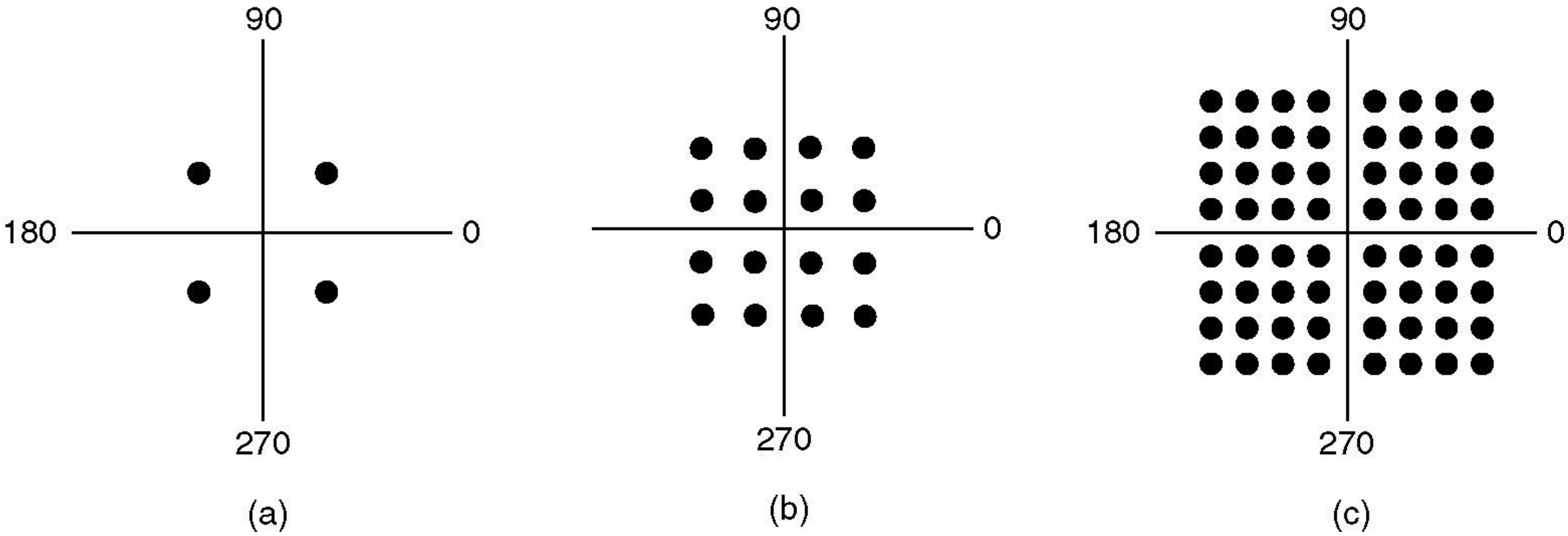
- Popular analog signaling technique used on *asymmetric digital subscriber line* (ADSL)
  - Also in some wireless standards
- Combination of ASK and PSK
- Logical extension of QPSK
- Send two different signals simultaneously on same carrier frequency
  - Use two copies of carrier, one shifted 90° with respect to the other
  - Each carrier is ASK modulated
  - Two independent signals transmitted over same medium
  - Demodulate and combine for original binary output

Quadrature Amplitude Modulation QAM

- Transfer more bits per position as there are multiple points of transfer; thus, the modulation efficiency is increased

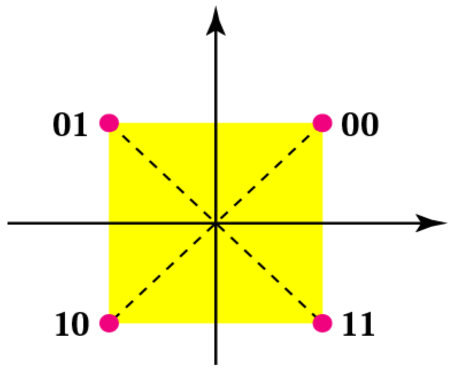


Constellation Diagram of QAMs

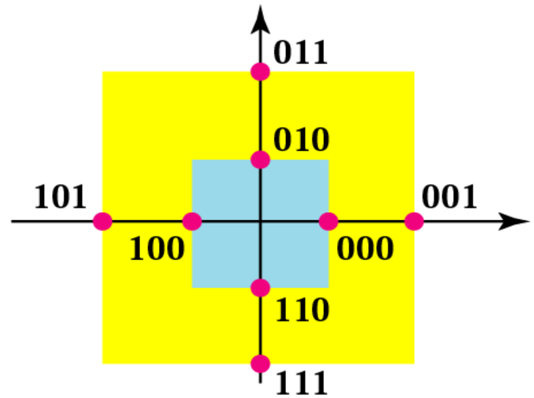


(a) QPSK. (b) QAM-16. (c) QAM-64.

Constellation Diagram of QAMs

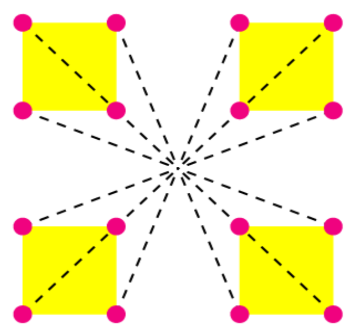


4-QAM
1 amplitude, 4 phases



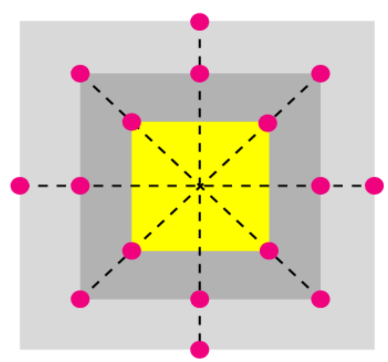
8-QAM
2 amplitudes, 4 phases

3 amplitudes, 12 phases



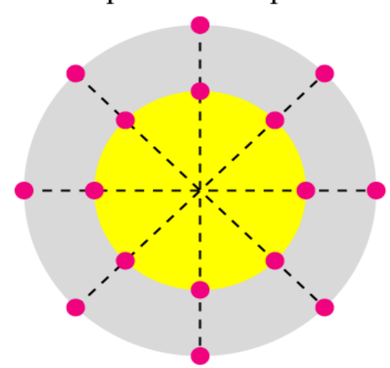
16-QAM

4 amplitudes, 8 phases



16-QAM

2 amplitudes, 8 phases



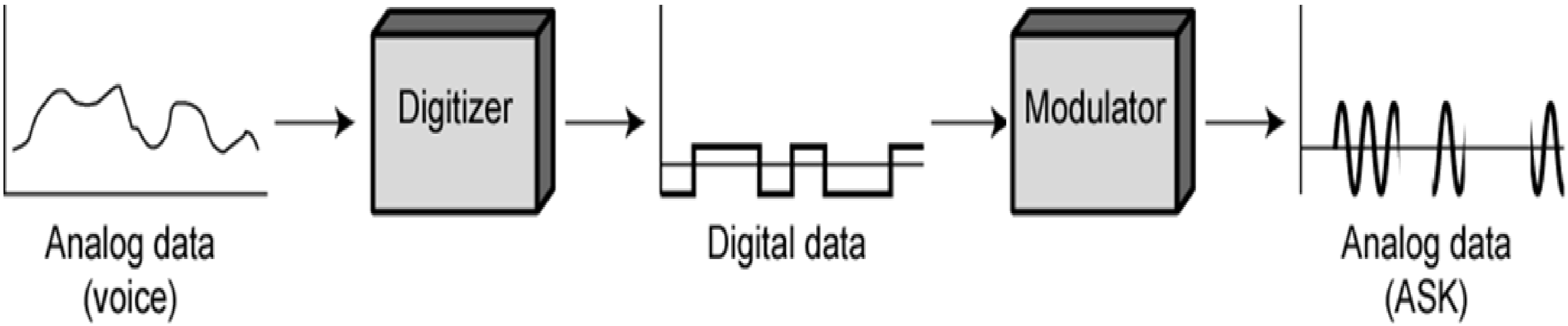
16-QAM

Analog Data, Digital Signal

- Digitization is conversion of analog data into digital
  - To be able to use digital transmission facilities
- Data which can then:
  - Be transmitted using NRZ-L
  - Be transmitted using code other than NRZ-L
  - Be converted to analog signal
- Analog to digital conversion done using a codec (coder-decoder)
  - Pulse code modulation
  - Delta modulation

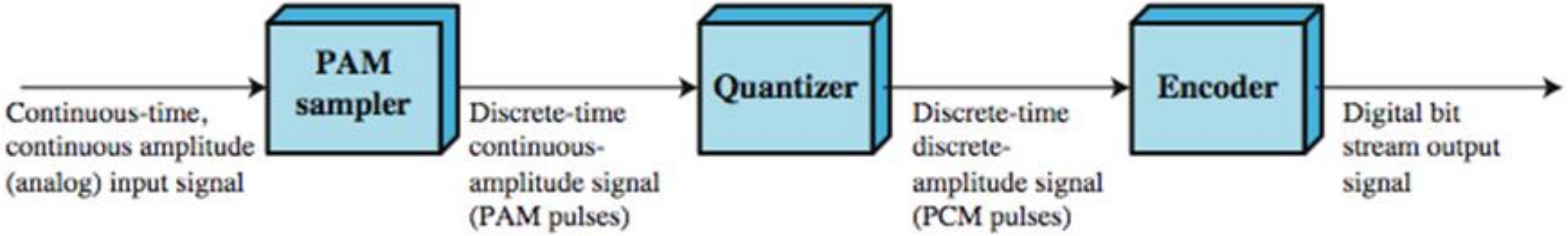
Digitizing Analog Data

- Example: digitized data can be converted to an analog ASK signal



Pulse Code Modulation (PCM)

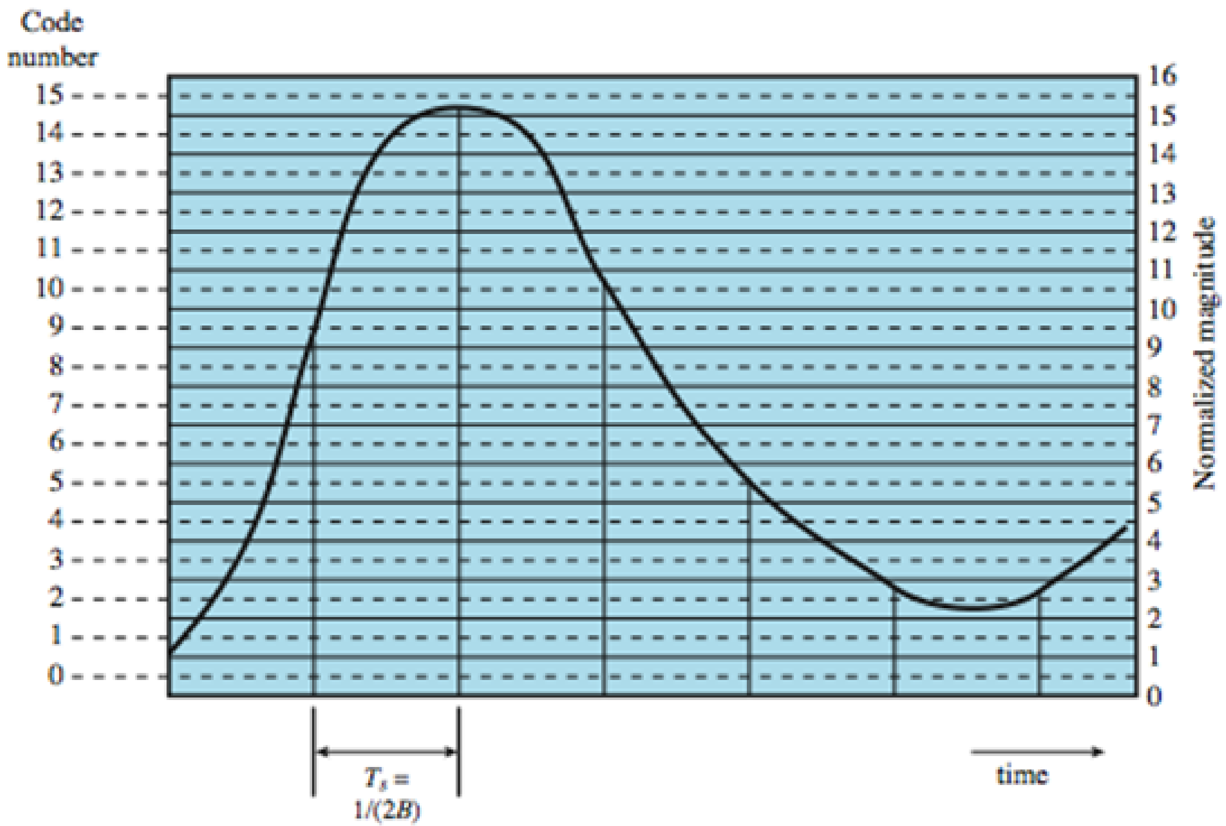
- Sampling the analog data periodically and quantizing the samples
- Sampling Theorem:
  - "If a signal is sampled at regular intervals at a rate higher than twice the highest signal frequency, the samples contain all information in original signal"
  - For example, 4000Hz voice data, requires 8000 sample per sec
- Strictly have analog samples
  - Pulse amplitude modulation (PAM)
- To convert to digital, each of these analog samples must be assigned a binary code



PCM Example

- A signal is assumed to be bandlimited with a bandwidth of B.
- PAM samples are taken at a rate of $2B$
  - or once every $T_s = 1/2B$ seconds.
- Each PAM sample is approximated by being *quantized* into one of 16 different levels.
- Each sample can then be represented by 4 bits.
- But because the quantized values are only approximations, *it is impossible to recover the original signal exactly*.

PCM Example



PAM value	1.1	9.2	15.2	10.8	5.6	2.8	2.7
quantized code number	1	9	15	10	5	2	2
PCM code	0001	1001	1111	1010	0101	0010	0010

Signaling Rate in PCM

- Let the quantizer use ‘*n*' number of binary digits to represent each level.
- Then the number of levels that can be represented by m digits will be :

$$q = 2^n$$

- The number of bits per second is given by :
- Number of bits per second equals the number of bits per samples multiplied by the number of samples per second, or:
- signaling rate = $n * f_s$
- where f_s is number of samples per second

PCM Example

- If the number of binary bits = 8 and the sampling rate is 8000 sample/sec find the signaling rate, number of quantization levels?
- Solution:
- f_s=8000, n=8

1. Signaling rate = $n * f_s$

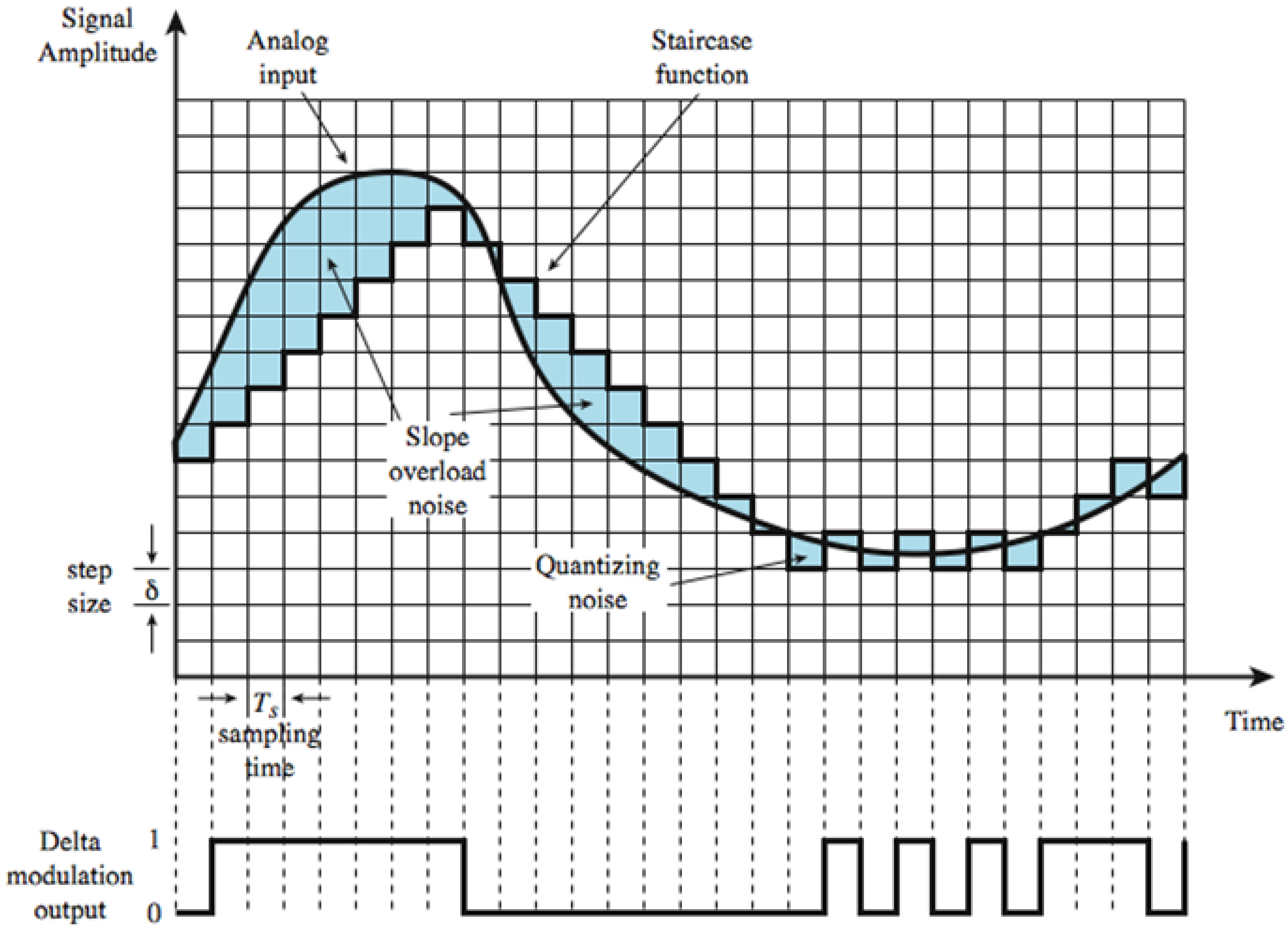
   =8000*8

   =64000 bits/sec
2. Number of quantization $q = 2^n = 2^8 = 256$ levels

Delta Modulation

- Analog input is approximated by a *staircase* function
  - Can move up or down one quantization level (δ) at each sample interval
- Has binary behavior
  - Since function only moves up or down at each sample interval
  - Hence can encode each sample as single bit
  - 1 is generated if the staircase function is to go up during the next interval
  - 0 is generated otherwise.
- The staircase function tracks the original analog waveform as closely as possible.

Delta Modulation Example



Delta Modulation Example

- Two important parameters in a DM scheme:
1. The size of the step assigned to each binary digit, δ,
2. The sampling rate.
- δ must be chosen to produce a balance between two types of errors or noise.
1. When the analog waveform is changing very slowly, there will be quantizing noise.
   - This noise increases as δ is increased.
2. When the analog waveform is changing more rapidly than the staircase can follow, there is slope overload noise.
   - This noise increases as δ is decreased.
- It should be clear that the accuracy of the scheme can be improved by increasing the sampling rate.
- However, this increases the data rate of the output signal.

Analog Data, Analog Signals

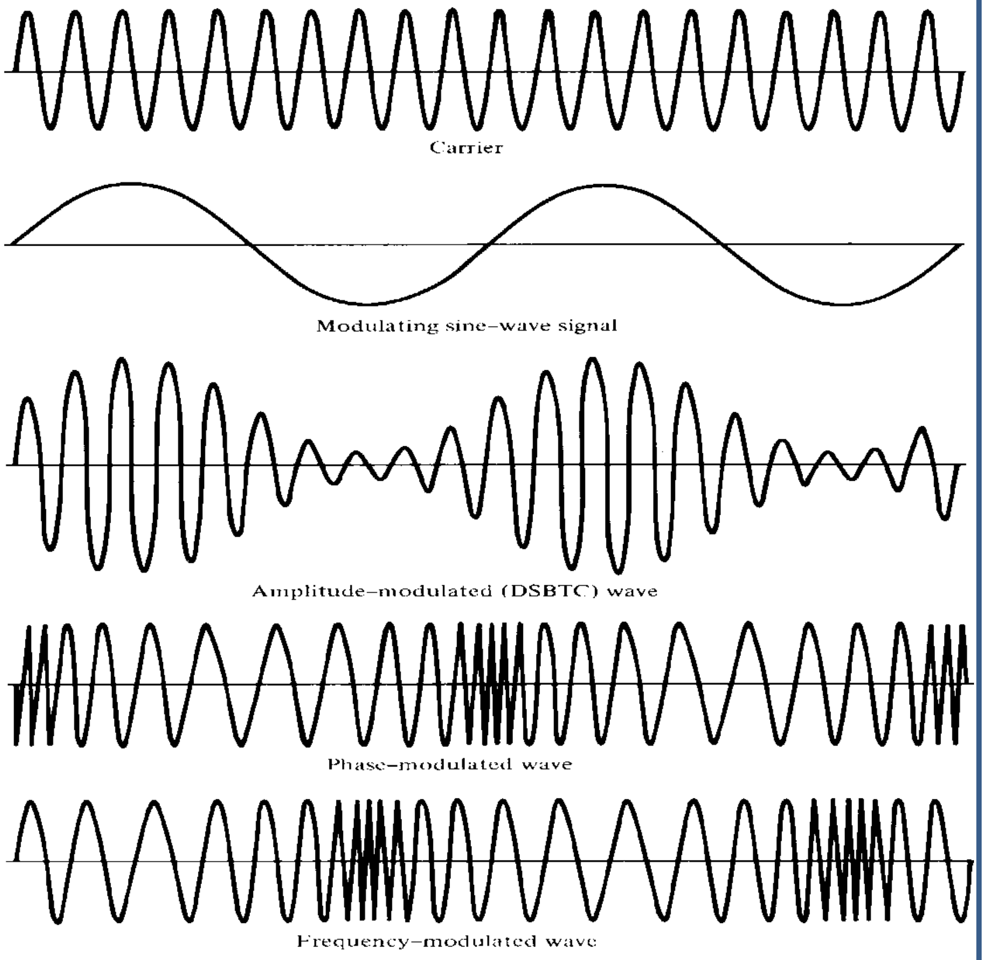
- Modulate carrier frequency with analog data
  - Produce an analog signal in a different frequency band
  - Can be utilized on an analog transmission system
- Two principal reasons for analog modulation of analog signals
  - Higher frequency can give more efficient transmission
  - Permits frequency division multiplexing
- Types of modulation

1. Amplitude Modulation
2. Frequency Modulation
3. Phase Modulation

Analog Modulation Techniques

- Carries signal
- Data

1. Amplitude Modulation
2. Frequency Modulation
3. Phase Modulation

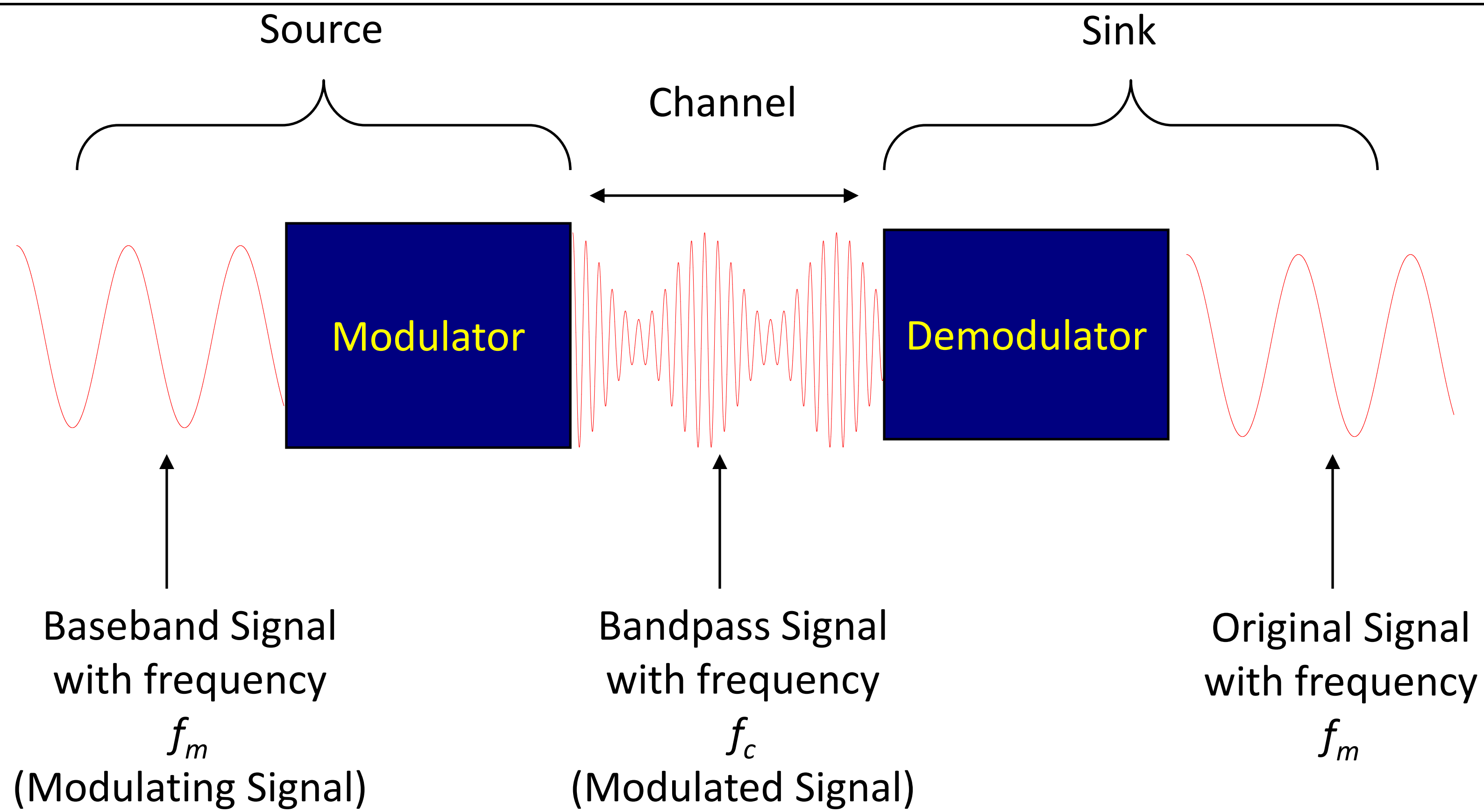


Amplitude Modulation (AM)

- The simplest form of modulation
- A carrier wave whose amplitude is varied in proportion to the instantaneous amplitude of a modulating voltage
  - Carrier wave: usually sinusoidal
  - For the purpose of conveying information.
- This carrier wave is usually a much higher frequency than the input signal.

1. Carrier signal = $\cos(2\pi f_c t)$ *or* $\cos(\omega_c t)$
2. Modulating Message signal $m(t) = \cos(2\pi f_m t)$ *or* $\cos(\omega_m t)$
3. The AM signal $S(t) = [A_c + m(t)]\cos(2\pi f_c t)$

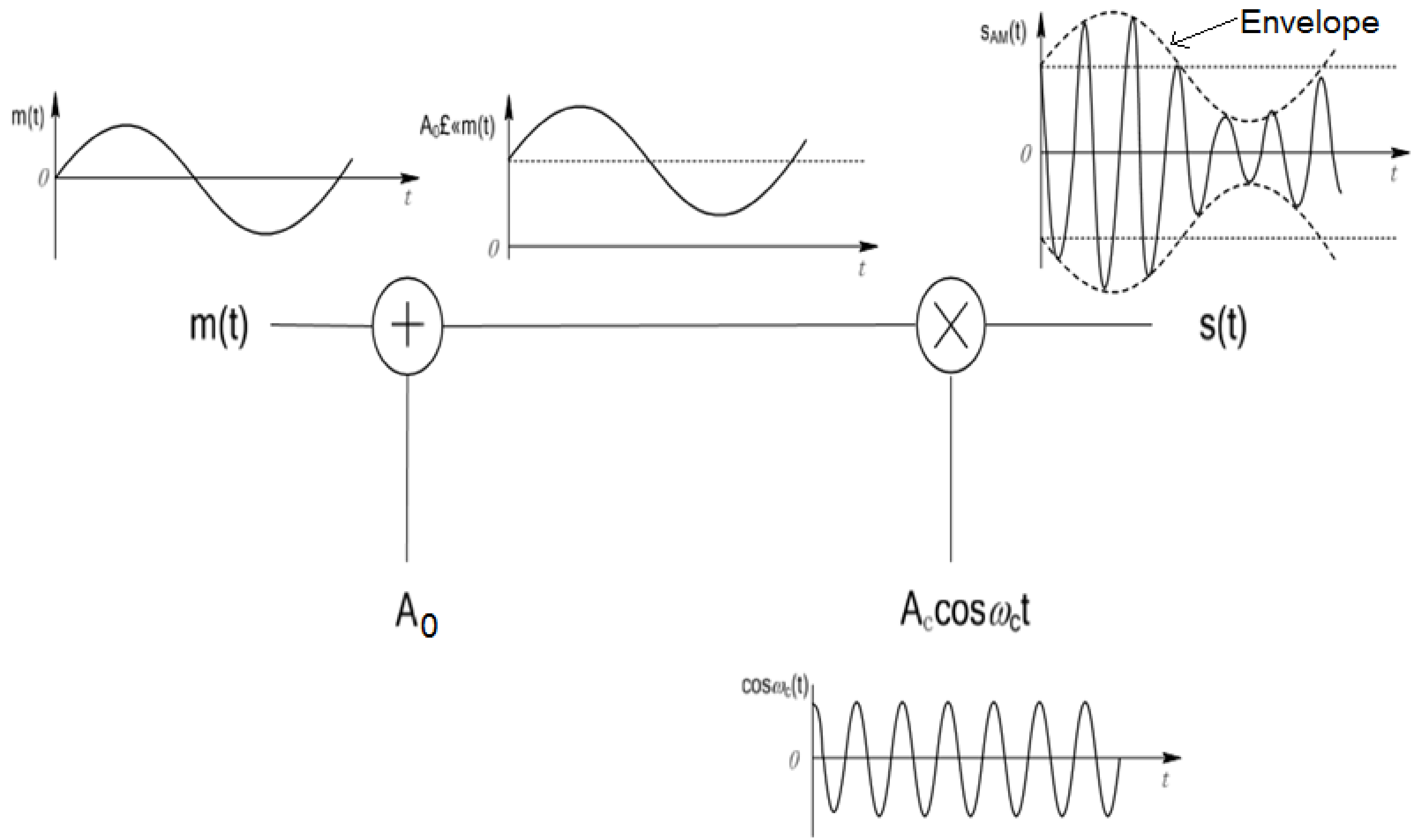
AM Modulation/Demodulation



$f_c >> f_m$

Voice: 300-3400Hz GSM Cell phone: 900/1800MHz

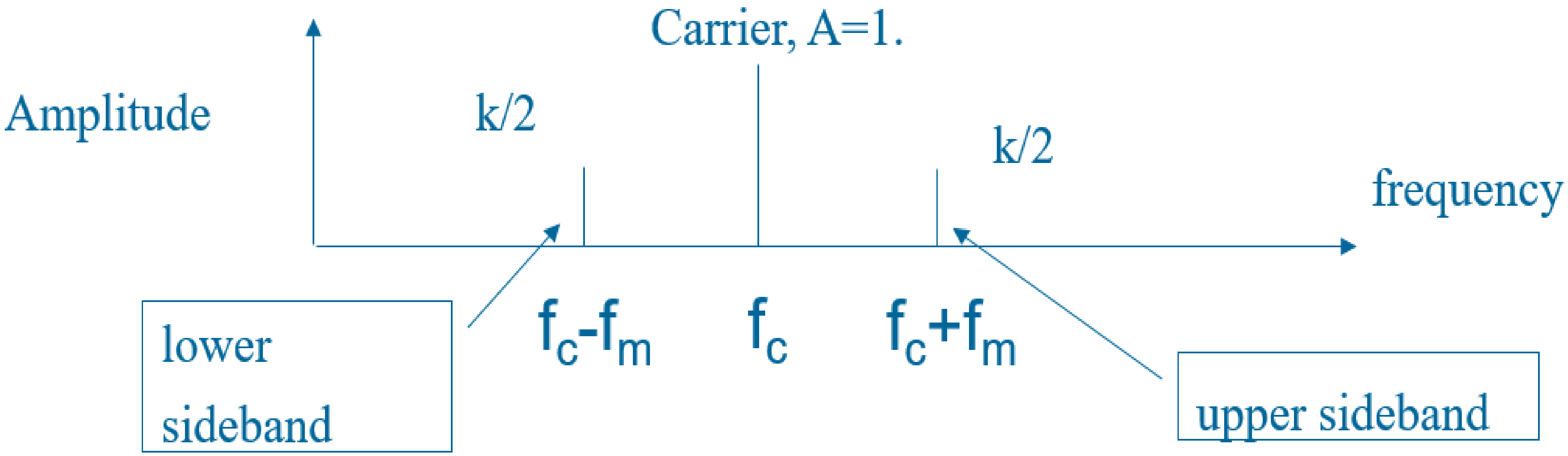
Amplitude Modulation (AM)



Amplitude Modulation (AM)

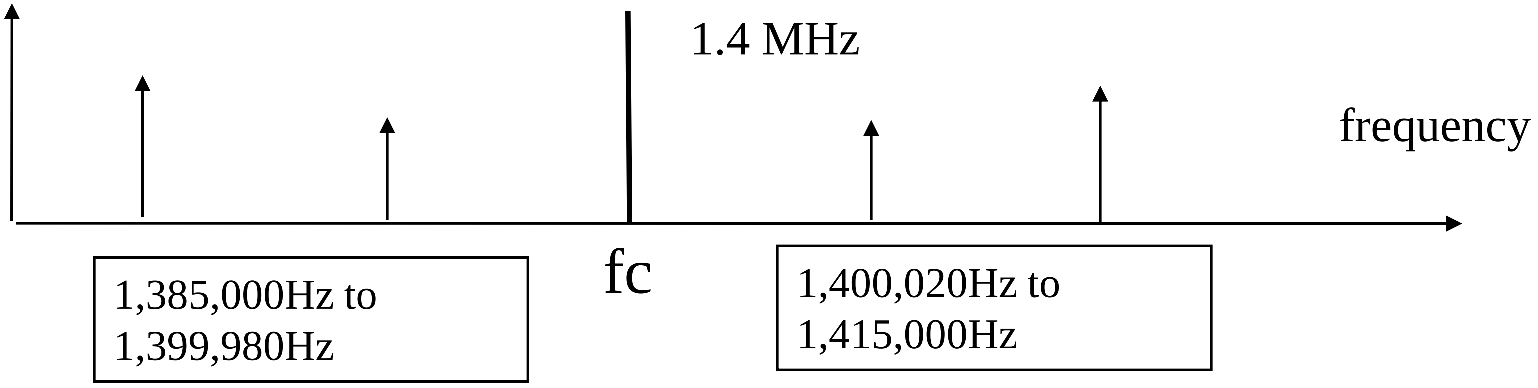
- In the frequency domain, the AM waveform are:

1. The lower-side frequency/band: (f_c - f_m)
2. The carrier frequency f_c
3. The upper-side frequency/band (f_c + f_m)



AM Modulation – Example

- The information signal is usually not a single frequency but a range of frequencies (band).
- For example, frequencies from 20Hz to 15KHz.
- Bandwidth: 2x(15K-20)Hz.
- If we use a carrier of 1.4MHz, the AM spectrum will be:

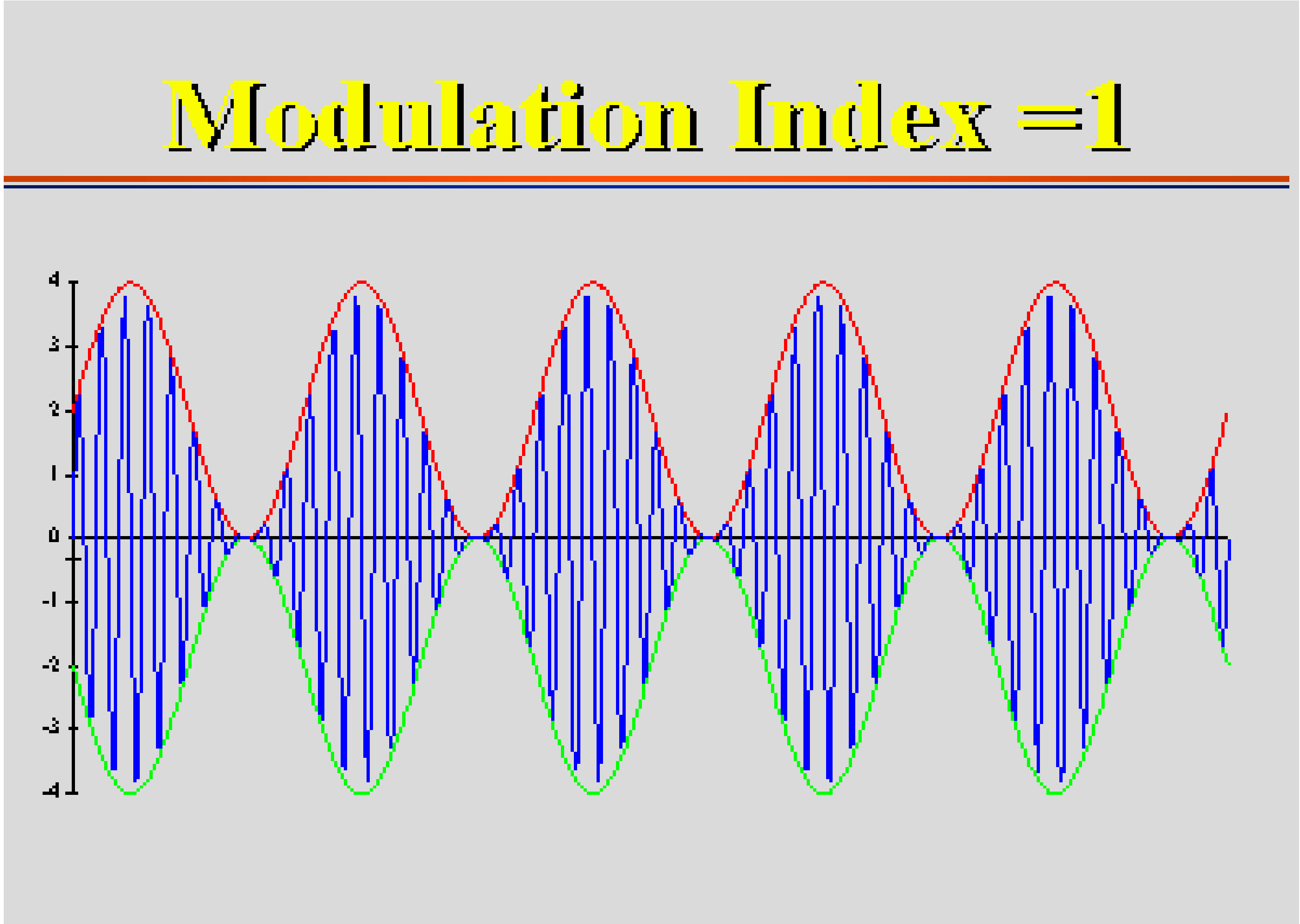


Modulation Index of AM Signal

- Modulation index k is a measure of the extent to which a carrier voltage is varied by the modulating signal.
- Modulation index is defined as: $k = \frac{A_m}{A_c}$

1. When k=0 → no modulation
2. When k=1 → 100% modulation
3. When k>1 → over modulation

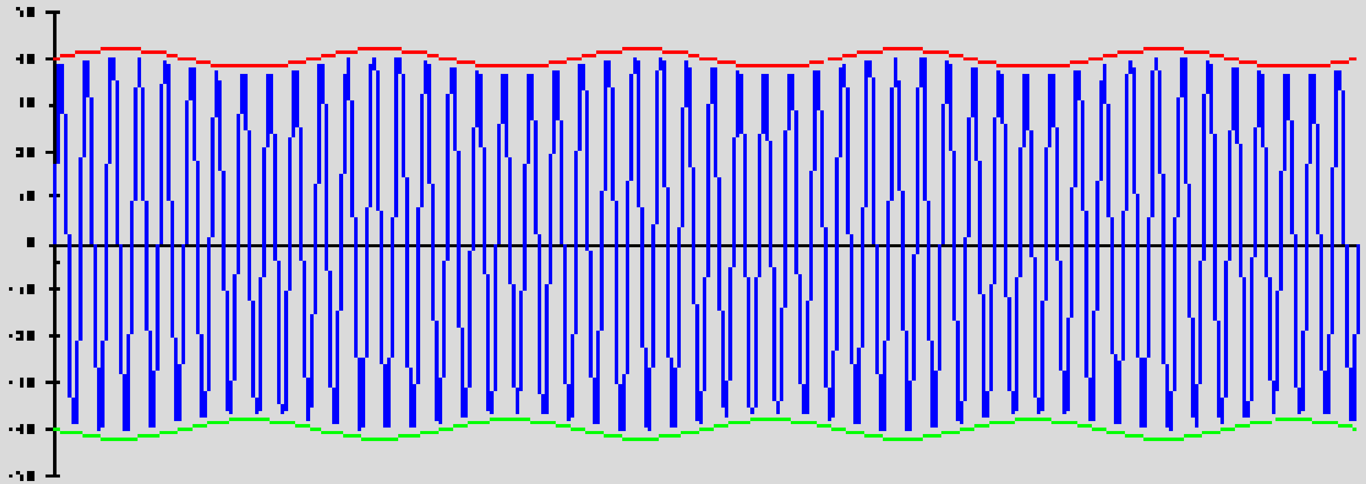
Modulation Index of AM Signal



Modulation Index of AM Signal

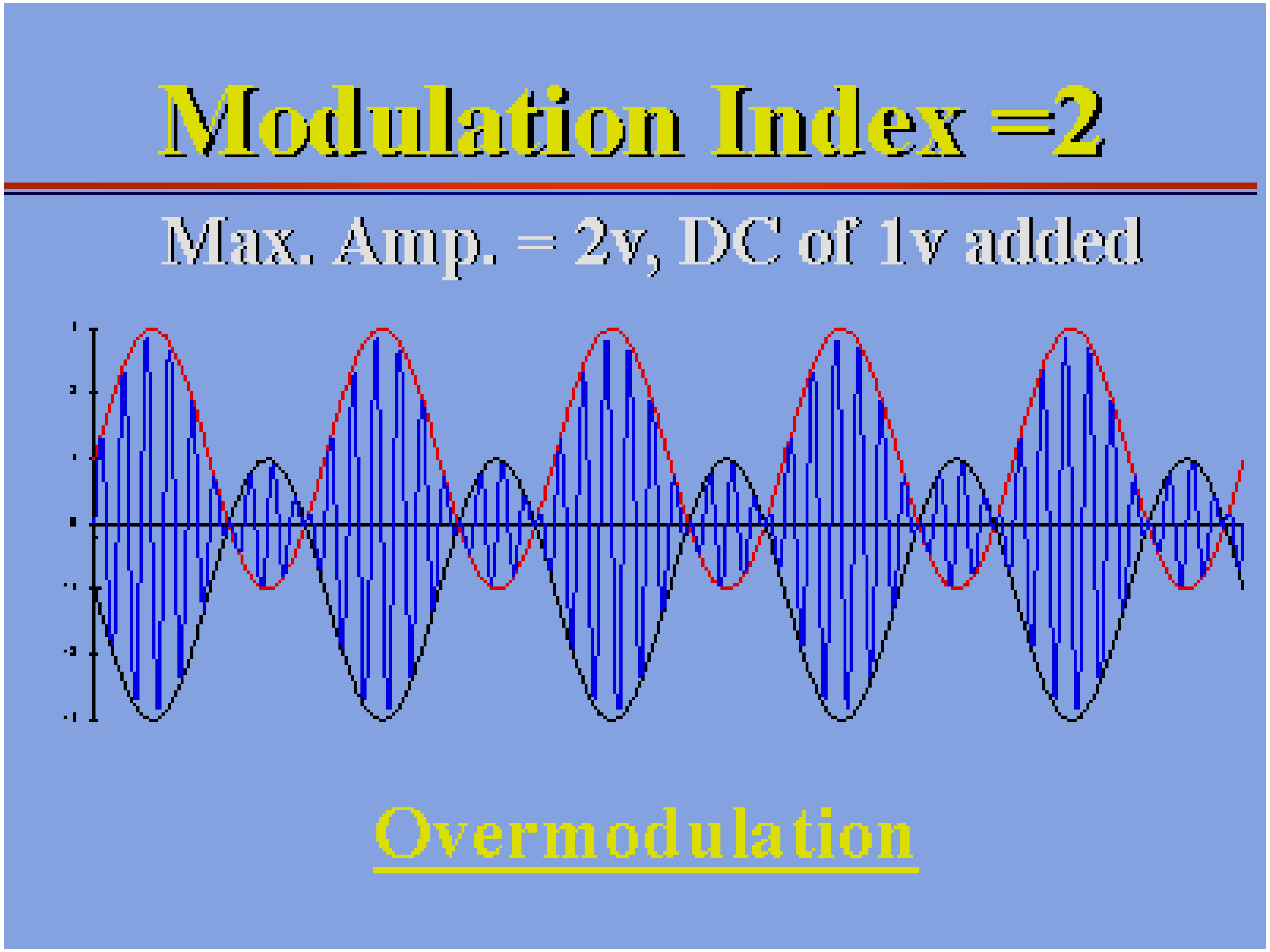
Modulation Index =.05

Max. Amp. = 2v, DC of 40v added



Undermodulation

Modulation Index of AM Signal

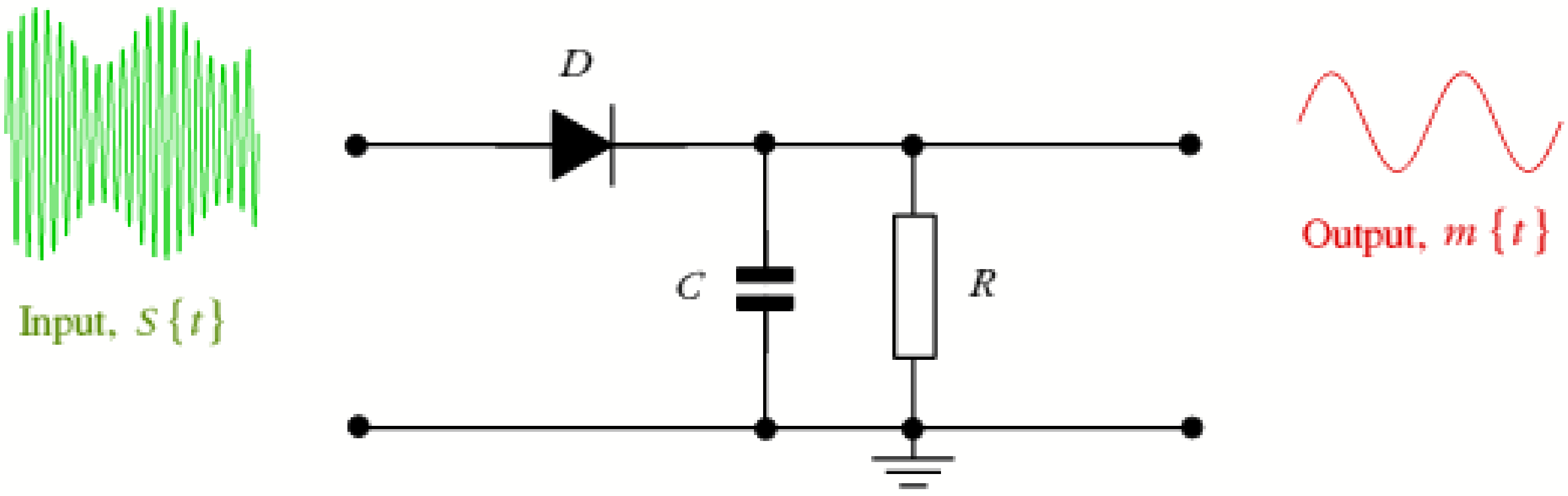


High Percentage Modulation

- It is important to use as high percentage of modulation as possible (k=1) while ensuring that over modulation (k>1) does not occur.
- The sidebands contain the information and have maximum power at 100% modulation.
- Useful equation: $Pt = Pc\left(1 + \frac{k^2}{2}\right)$
- Where:
- P_t =Total transmitted power (sidebands and carrier)
- P_c = Carrier power

Envelope Detector

- *Demodulation* is extracting the baseband message from the carrier.
- Simple and inexpensive demodulator



Double-Sideband Suppressed-Carrier Amplitude Modulation DSBSC-AM

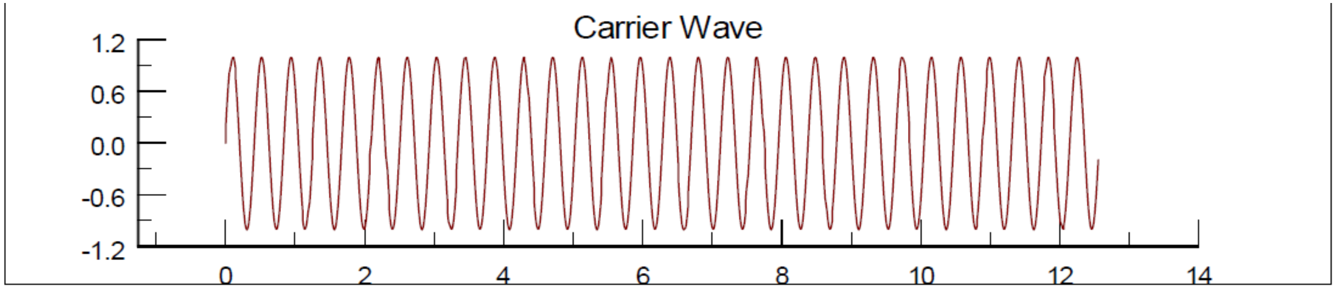
- Let $m(t)$ be a bandlimited baseband message signal with cutoff frequency ω
- The *DSBSC-AM* signal corresponding to $m(t)$ is:

$$s(t) = A_c m(t)\cos(\omega_c t)$$

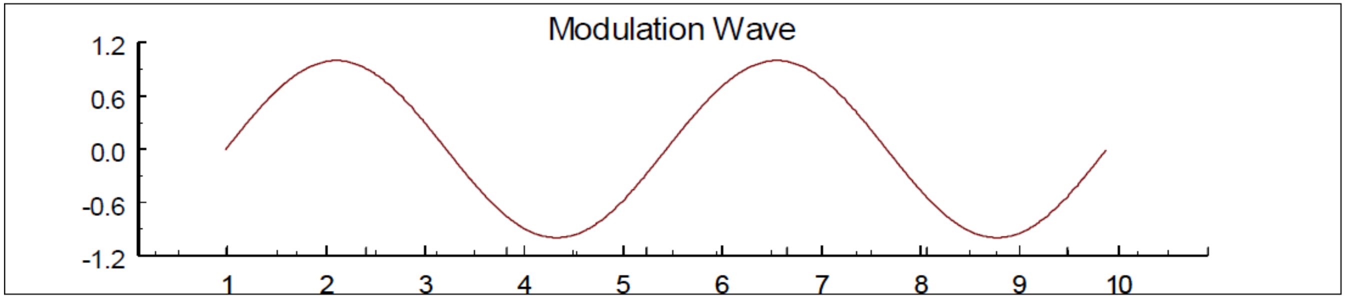
- This is the same as AM except with the sinusoidal carrier component eliminated.
- A message $m(t)$ typically has positive and negative values so it can not be recovered from $s(t)$ by an envelope detector.

DSBSC-AM

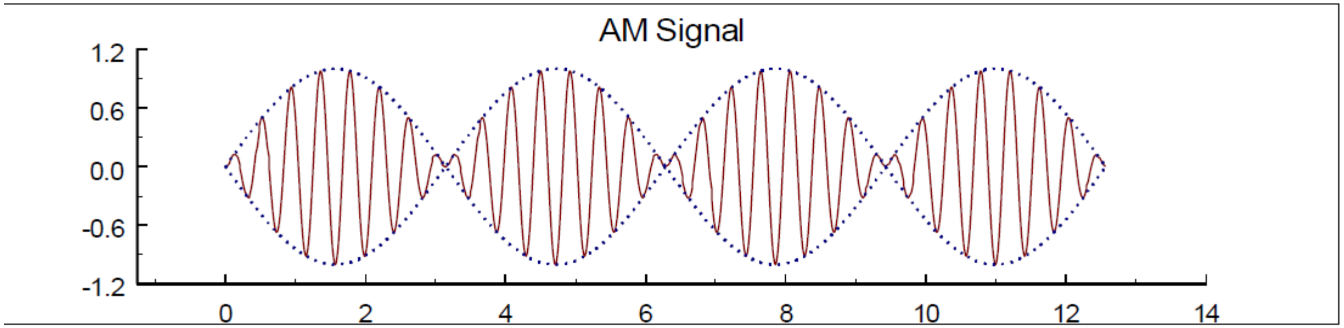
$$\cos(\omega_c t)\,.$$



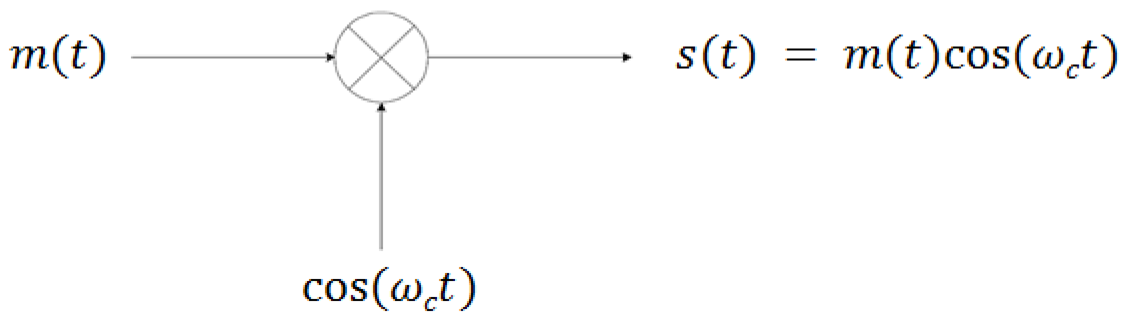
$m(t)$

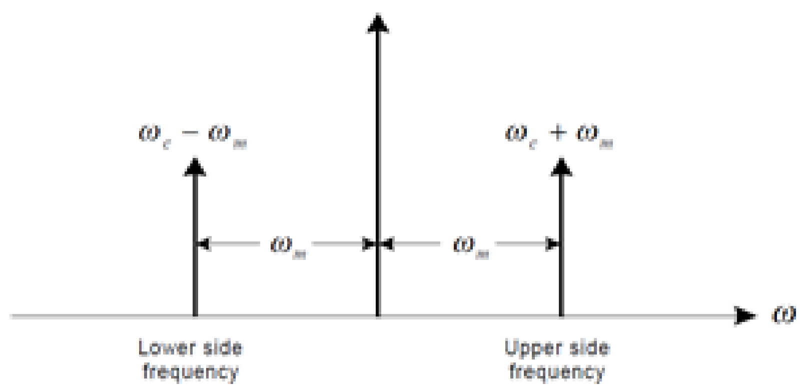


$$s(t) = m(t)\cos(\omega_c t)$$



DSBSC-AM Transmitter – Modulation

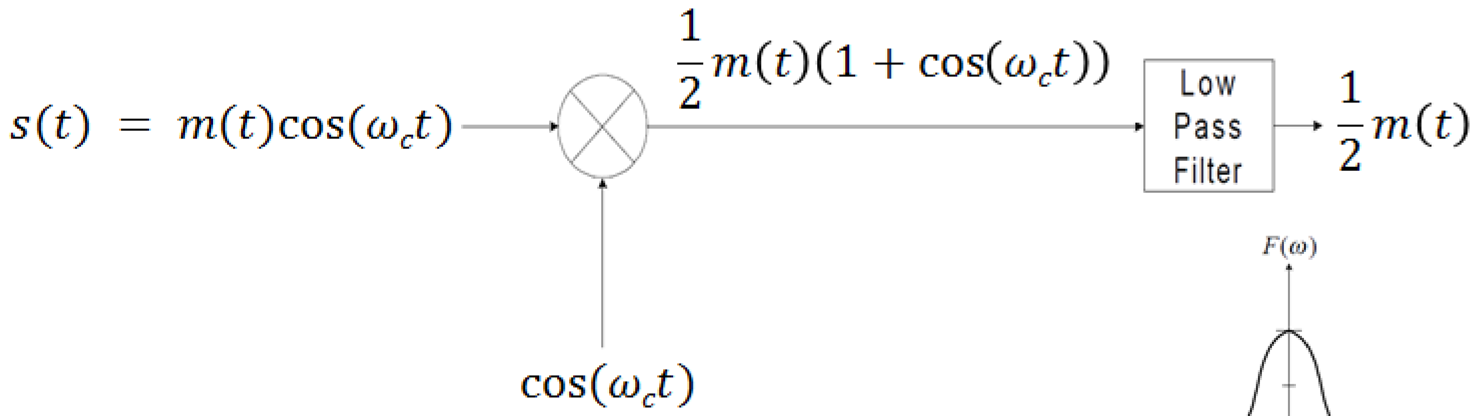


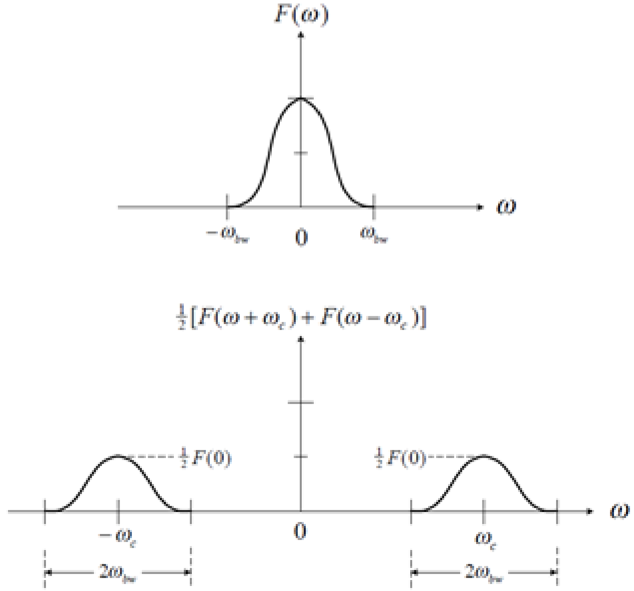


Single modulating frequency AM signal spectrum.

DSBSC-AM
Receiver – Demodulation

$$s(t)\cos(\omega_c t) = m(t)\cos^2(\omega_c t) = \frac{1}{2}m(t)(1+\cos(\omega_c t))$$





Spectra of modulating wave and resulting AM waveform

Angle Modulation

- The intelligence of the modulating signal can be conveyed by varying the *frequency* or *phase* of the carrier signal.
- When this is the case, we have *angle modulation*, which can be subdivided into two categories:

1. Frequency Modulation (FM)
2. Phase Modulation (PM)

Frequency Modulation (FM)

- E. Armstrong has been credited with developing in 1936 the first frequency modulation (FM) radio communication system
  - A system that is much more immune to noise than its AM counterpart.
- FM has remained one of the most prevalent modulation techniques in the telecommunications industry
  - Used in applications such as cellular and cordless telephony, paging systems, modem technology, television, commercial FM broadcast, amateur radio, and more.

Frequency Modulation (FM)

- The carrier's *instantaneous frequency* deviation from its unmodulated value varies in proportion to the *instantaneous amplitude* of the modulating signal.

$$e_{FM} = A_c \sin(\omega_c t + m_f sin\omega_m t)$$

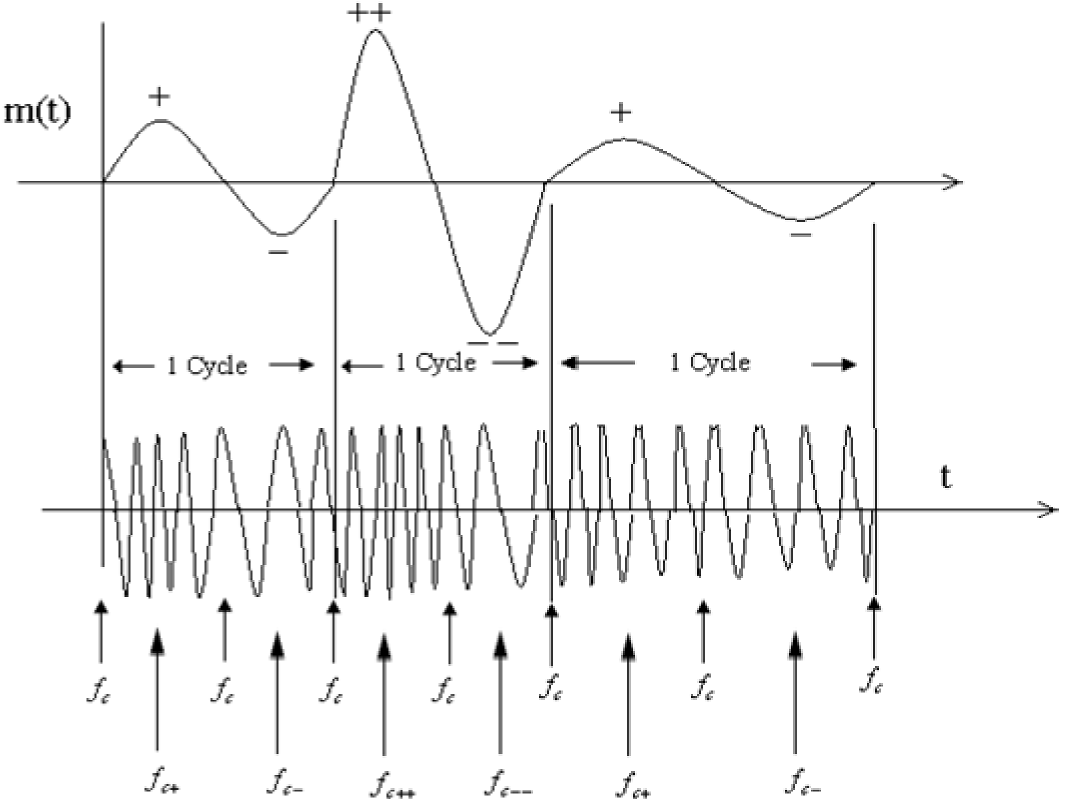
- Where:

1. e_{FM} = instantaneous voltage of the FM wave
2. m_f = FM modulation index

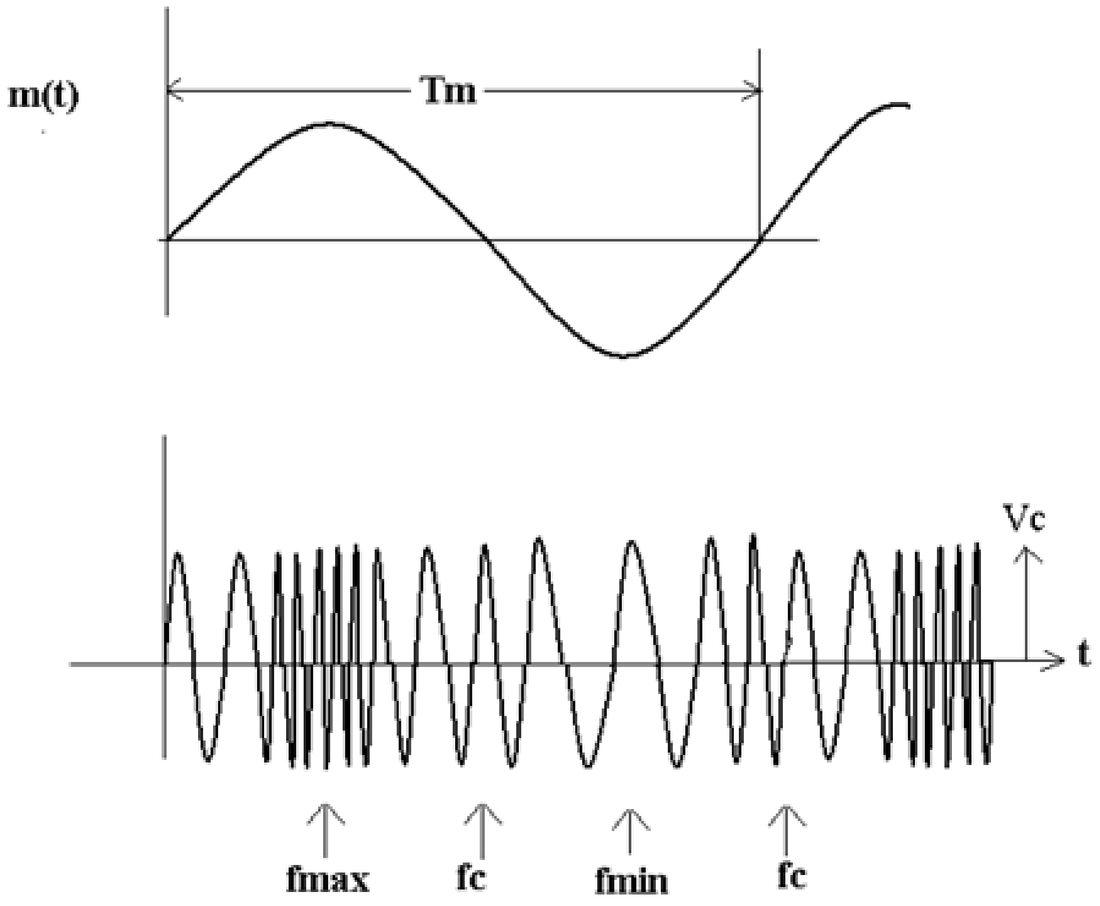
- It is the best choice for fidelity and offers a much *higher* *SNR* than its AM counterpart.

FM Signal Waveforms.

- Frequency changes at the input are translated to rate of change of frequency at the output.



FM Signal Waveforms.



Frequency Modulation (FM)

- Notice that:

1. As the amplitude of the information signal increases above 0 volts, the frequency of the carrier increases,
2. As the amplitude of the information signal decreases below 0 volts, the frequency of the carrier decreases.
3. When the information signal is zero, then no deviation of the carrier will occur.

- The frequency f_m of the information signal controls the rate at which the carrier frequency increases and decreases.
- As with AM, f_m must be less than f_c
  - The amplitude of the carrier *remains* constant throughout this process.

Modulation Index m_f

- The ratio of the maximum frequency deviation to the modulating signal's frequency

$$m_f = \frac{\Delta f_c}{f_m}$$

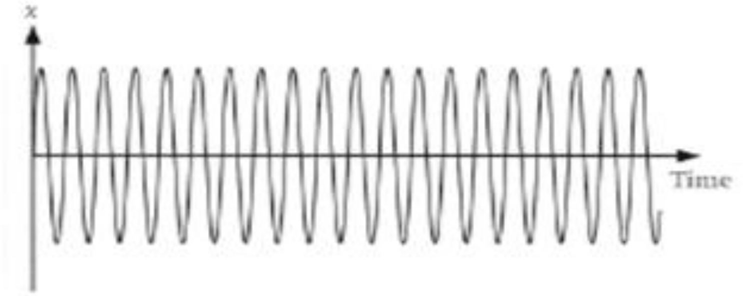
- Where:

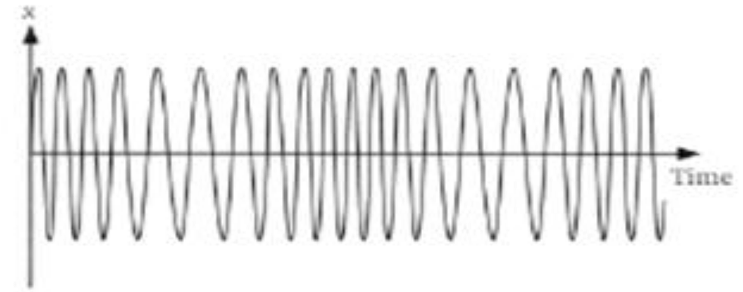
1. Δf_c = maximum *frequency deviation* of the carrier from its base value fc caused by the amplitude of the modulating signal
2. f_m = frequency of the modulating signal

- Note that the modulation index, m_f, is *proportional* to the amplitude of the modulating signal through Δf_c and *inversely proportional* to the frequency of the modulating signal.

Modulation Index m_f

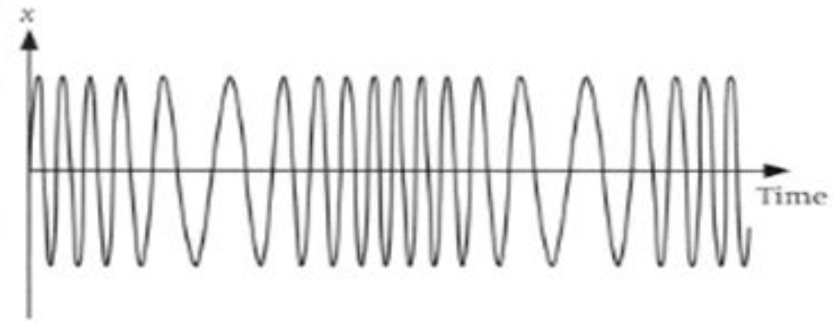
- The diagrams show examples of how the modulation index affects the FM output for a simple sinusoidal information signal of fixed frequency.
- The carrier signal has a frequency of ten times that of the information signal.
- The first graph shows the information signal, the second shows the unmodulated carrier.
- This graph shows the frequency modulated carrier when the modulation index = 3.



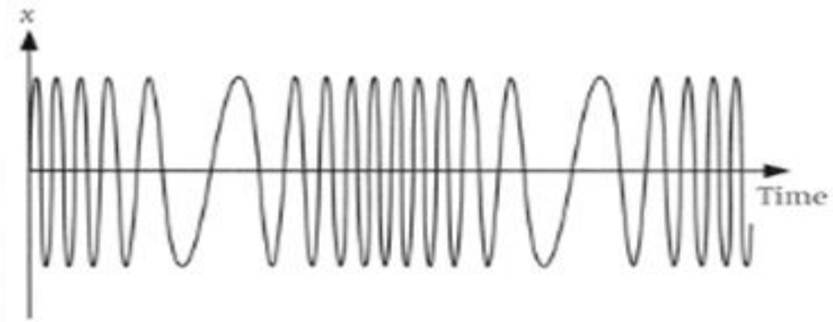


Modulation Index m_f

- This graph shows the frequency modulated carrier when the modulation index = 5.



- This graph shows the frequency modulated carrier when the modulation index = 7.



- As the modulation index increases you should notice that the peaks of the high frequency get closer together and low frequency get further apart.
- For the same information signal therefore, the carrier signal has a higher maximum frequency.

Example

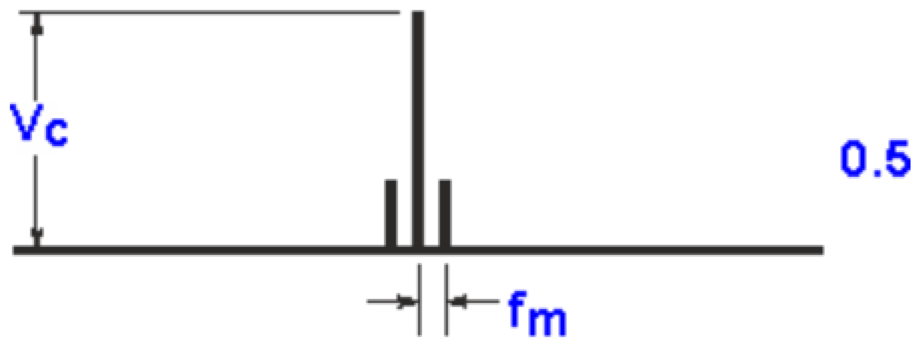
- A 400kHz sinusoidal carrier of amplitude 5V is frequency modulated by a 3kHz sinusoidal information signal of amplitude 3V. If the behaviour of the carrier is governed by the frequency deviation per volt and for this system is 25kHz per volt. Describe how the resulting FM signal changes with time.
- Solution:
- The FM carrier will change in frequency from 400kHz to 475kHz to 400kHz to 325kHz and back to 400kHz, 3000 times per second.
- This is because the frequency deviation Δf_c = 3 x 25kHz = 75kHz.
- The amplitude of the carrier will remain fixed at 5V.

Example

- If the same system were used and the amplitude of the information signal decreased to 1V, how would this affect the resulting FM signal?
  Solution:
- The FM carrier will change in frequency from 400kHz to 425kHz to 400kHz to 375kHz and back to 400kHz, 3000 times per second.
- This is because the frequency deviation
  Δf_c = 1x 25kHz = 25kHz.
- The amplitude of the carrier will remain fixed at 5V

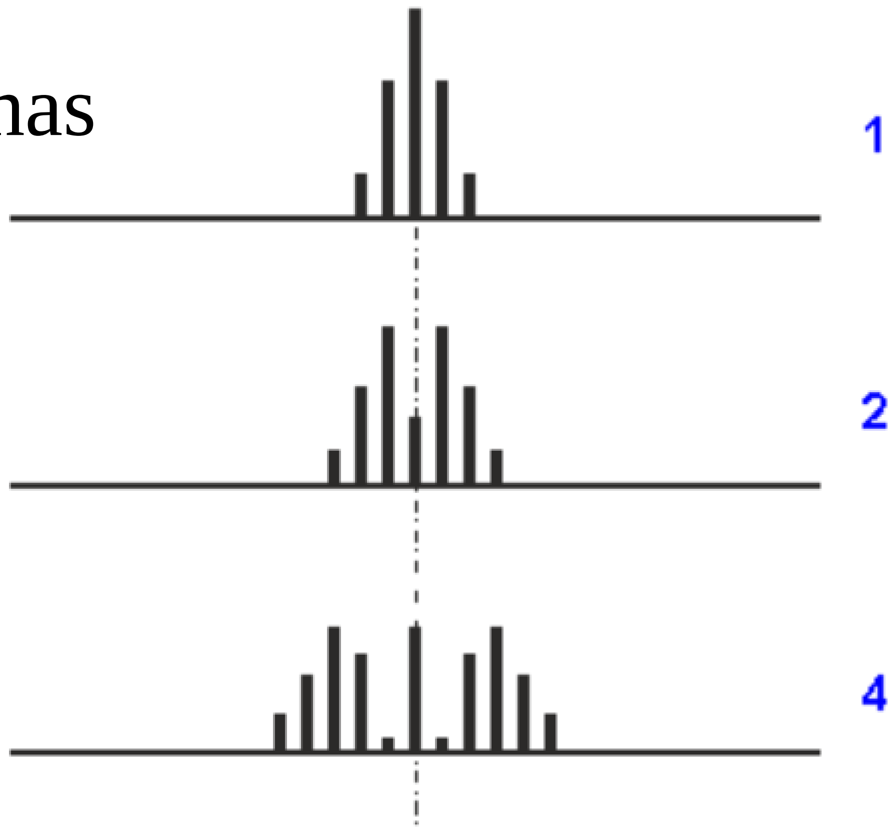
Relative Levels of m_f

- For small values of modulation index, when using *narrow-band FM*, the FM signal consists of the carrier and the two sidebands spaced at the modulation frequency either side of the carrier
  - The spectrum looks very similar to that for an AM carrier



Relative Levels of m_f

- From the spectrum, we can see that the number of significant sidebands has increased



Frequency Modulation Bandwidth Carson's Bandwidth Rule

- Defines the approximate bandwidth requirements
  - for a carrier signal that is frequency modulated by a continuous or broad spectrum of frequencies rather than a single frequency
- The rule is expressed by:

$$CBR = 2\,(\Delta f_c + f_m)$$

- *Guard band* is a narrow frequency range used to separate two wider frequency ranges to ensure that both can transmit simultaneously without *interfering* with each other
  - above and below the upper and lower FM sidebands.

Commercial FM Broadcast Band

- The maximum permissible carrier deviation, Δf_c, is ±75kHz
- Modulating frequencies (voice or music) is ranging from 50 Hz to 15 kHz
- The modulation index m_f can range from as low as 5 for f_m = 15 kHz (75 kHz/15 kHz) to as high as 1500 for f_m = 50 Hz (75 kHz/50 Hz).
- Bandwidth requirement:
- CBR = 2(75+15) = 180 kHz
- With a guard band, the bandwidth becomes 200kHz

Further Examples of Information Transmitted using FM

1. Mobile Phones:

- Some mobile phone companies use FM with a very low modulation index, $m_f < 1$.
  - *This is known as narrowband FM.*
- Mobile phone companies use this because it offers many of the advantages of FM, with the minimum bandwidth requirement.

Further Examples of Information Transmitted using FM

2. *Television Sound:*

- In terrestrial TV broadcasts, the video information is transmitted using AM
  – This to make the most effective use of the bandwidth available.
- However the sound information is transmitted using FM
  – In order to reduce possible interference between the video and sound signals.
- In this case, the maximum deviation of the carrier, Δf_c , is chosen to be 50kHz, and the information baseband is again the high fidelity range 20Hz to 15kHz.
- Therefore the bandwidth required for TV Sound is:
- CBR = 2(50+15) = 130kHz

Further Examples of Information Transmitted using FM

3. Analogue Satellite TV

- Some satellite TV transmissions broadcast an analogue video signal using FM.
  - This helps to obtain an acceptable signal at the receiving station even though the transmitter is some 36,000 km out into space!
- In this case, the maximum deviation of the carrier, Δf_c , is chosen to be about 10 MHz, with a video baseband of around 5MHz. Therefore the bandwidth required for Satellite TV is:
- CBR = 2(10+5) = 30MHz
- Note : Satellite broadcasting companies are changing from analogue to digital formats.
  - From Frequency Modulation to Pulse Code Modulation

Narrowband FM (NBFM)

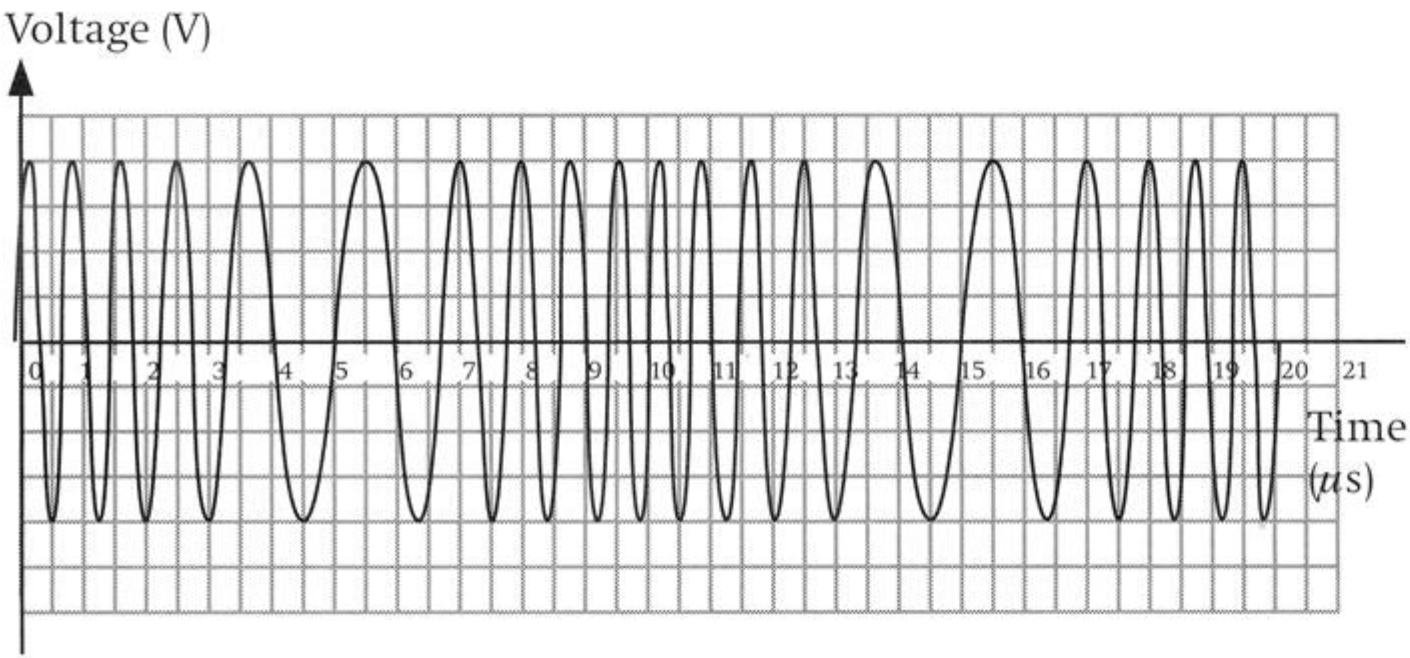
- NBFM uses low modulation index values, with a much smaller range of modulation index across all values of the modulating signal.
  - $m_f < 1$
- An NBFM system restricts the modulating signal to the minimum acceptable value, which is 300 Hz to 3 KHz for intelligible voice.
  - Used to conserve the bandwidth
- Used in police, fire, and Taxi radios, GSM, amateur radio, etc.

Exercises

1. A 10MHz carrier is frequency modulated by a pure signal tone of frequency 8kHz. The frequency deviation is 32kHz. Calculate the bandwidth of the resulting FM waveform.
2. An audio signal, with a base band of 200Hz to 4kHz, frequency modulates a carrier of frequency 50MHz. The frequency deviation per volt is 10kHz per volt and the maximum audio voltage it can transmit is 3V. Calculate the frequency deviation and the bandwidth of the FM signal.

Exercises

3. The diagram below shows an FM carrier modulated by a pure tone (sinusoidal wave). Calculate the carrier frequency and the pure tone frequency.



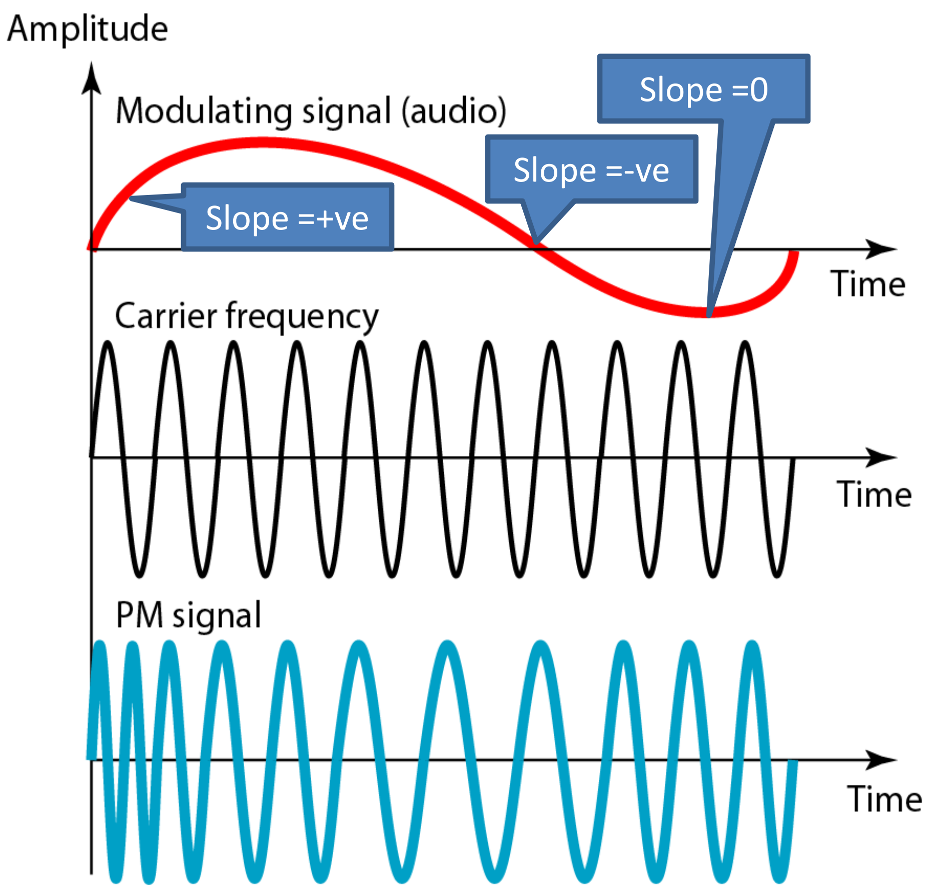
Phase Modulation (PM)

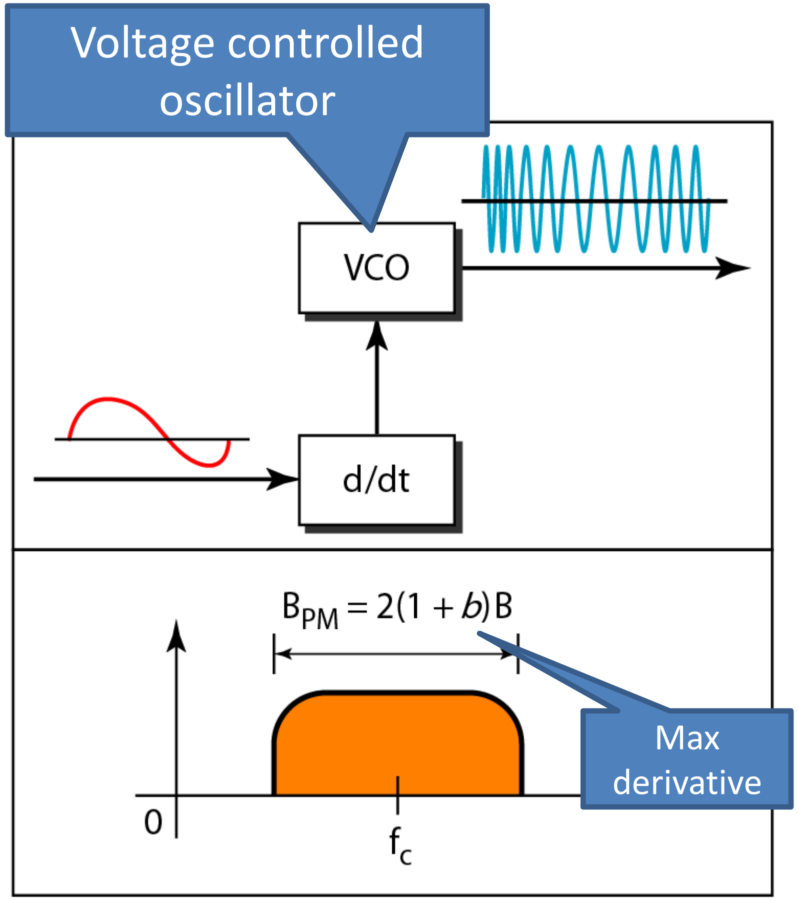
- The modulating signal only changes *the phase of the carrier signal*.
- The phase change manifests itself as a frequency change but the instantaneous frequency change is proportional to the derivative of the amplitude.
  - The bandwidth is higher than for AM.
- The carrier's instantaneous phase deviation from its unmodulated value varies as a function of the instantaneous amplitude of the modulating signal;

$$e_{FM} = A_c \sin(\omega_c t + \varphi_m sin\omega_m t)$$

- φ_m = maximum phase deviation in radians caused by the modulating signal
  - Also regarded as the PM modulation index

Phase Modulation (PM)





Observations from the FM and PM Waveforms

- Both FM and PM waveforms are identical except the phase shift.

1. For FM, the maximum frequency deviation takes place when modulating signal is at positive and negative peaks.
2. For PM, the maximum frequency deviation takes place near **zero crossing of the modulating** signal.

Max slope=Max derivative

- It is difficult to know from modulated waveform whether the modulation is FM or PM.

Observations from the FM and PM Waveforms