EEN 1043/EE452 Wireless and Mobile Communication

Signal Encoding Techniques

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Digital Communication System

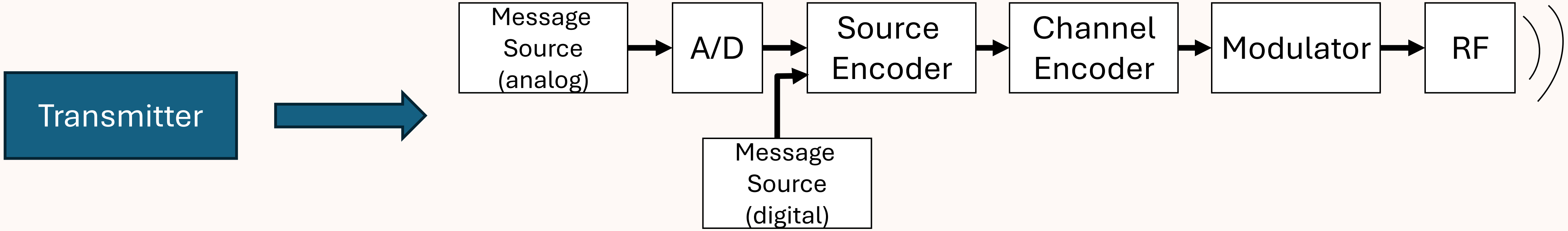
Digital Communication System

- The purpose of a digital communication system is to effectively convey information from sender (source) to receiver (sink).

- In our case, the *physical transmission* of the message occurs via a *radio link*.
  - “radio wave” = sinusoidal signal
- The information (message) may originally be in analogue or digital form
  - Analogue = voice
  - Digital
    - Coded video
    - Files
    - Control signals
    - etc.

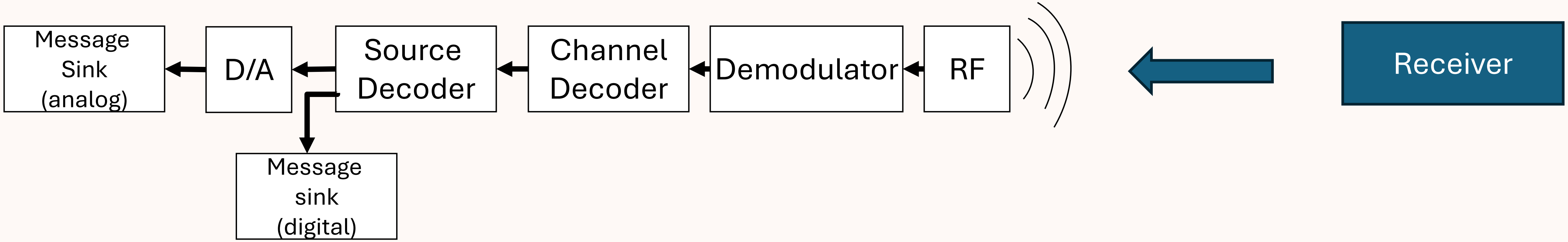
Transmitter

- Analogue to digital converter
  - Converts initial voice signal into a digital form
- Source encoder
  - efficiently represents the bits with little or no redundancy.
- Channel coder
  - Adds redundancy to combat effects of information loss introduced in transmission.
- Modulator
  - Converts the digital information sequence into a waveform representation which is consistent with the characteristics of the channel.

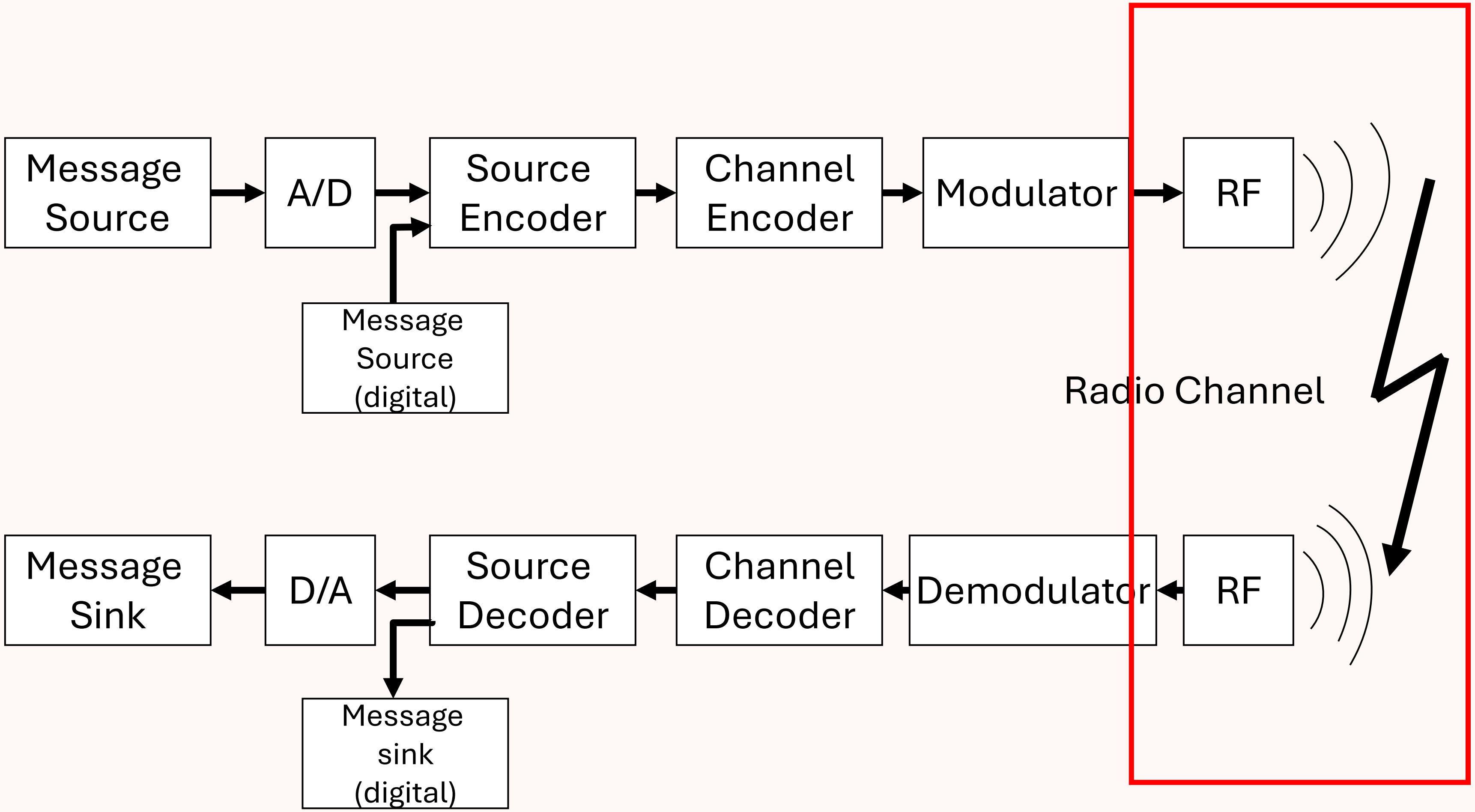


Receiver

- Demodulator
- Equalization
  - Counteract the multipath effects of the channel
- Channel Decoder
- Source Decoder
- D/A



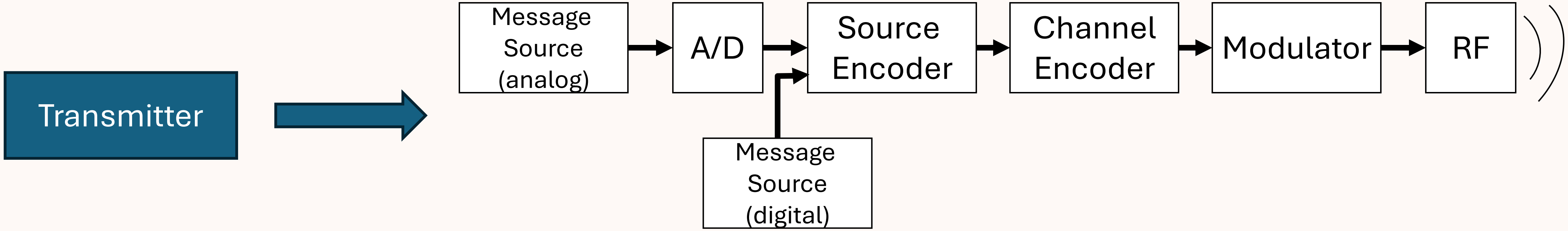
Radio Link



Message Source
A/D
Source Encoder
Channel Encoder
Modulator
RF
Message Source (digital)
Radio Channel
Message Sink
D/A
Source Decoder
Channel Decoder
Demodulator
RF
Message sink (digital)

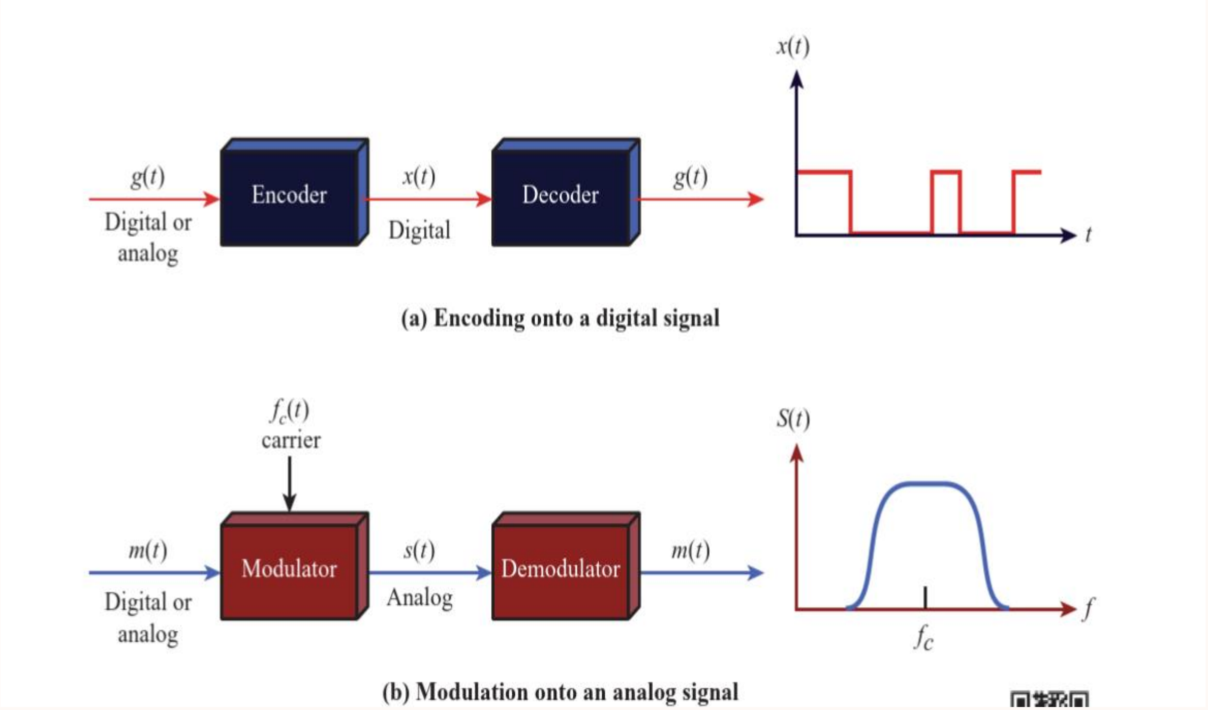
Signal Encoding Techniques

1. Digital Data, Analog Signal
2. Analog Data, Analog Signals
3. Analog Data, Digital Signals



Digital/Analog Signaling

- Digital Signaling: Data source g(t) is encoded into a digital signal x(t)
- Analog Signaling: Data may be transmitted using a carrier signal by modulation
- Carrier Signal: a continuous constant frequency signal f_c
- Modulation: Process of encoding source data onto a carrier signal with frequency f_c



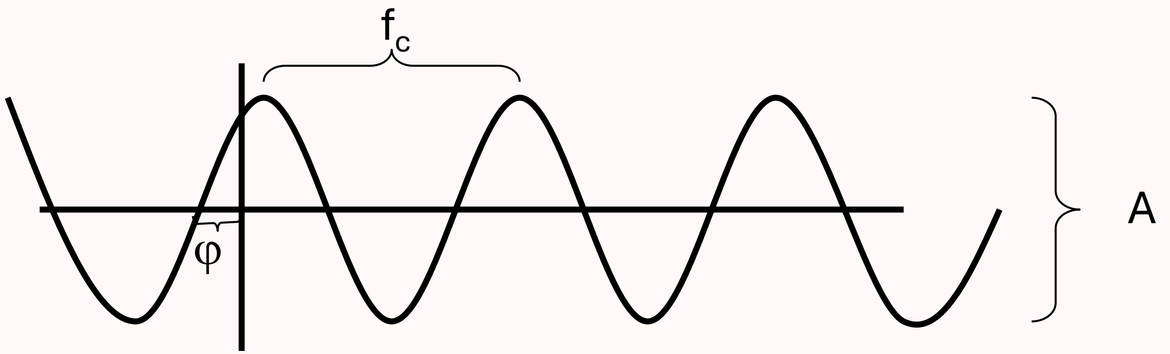
Key Data Transmission Terminologies

- Data rate R
- Modulation Rate D
- Bits in each signal Element L
- Total Combination M
- $D = \frac{R}{L} = R/\log_2 M$

Term	Units	Definition
Data element	Bits	A single binary one or zero
Data rate	Bits per second (bps)	The rate at which data elements are transmitted
Signal element	Digital: a voltage pulse of constant amplitude Analog: a pulse of constant frequency, phase, and amplitude	That part of a signal that occupies the shortest interval of a signaling code
Signaling rate or modulation rate	Signal elements per second (baud)	The rate at which signal elements are transmitted

Modulation: Carrier Signal

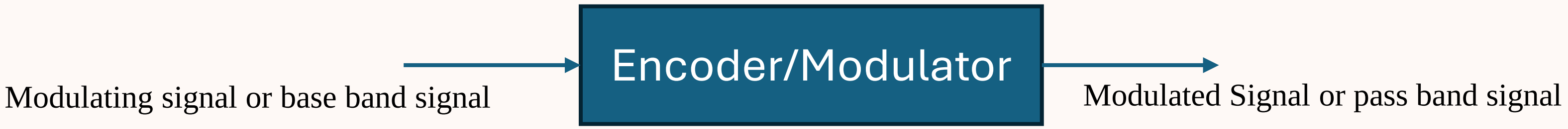
- Process of encoding source data onto a carrier signal with frequency f_c
- A single frequency audio tone, known as the *Carrier*, is selected to lie within acceptable range of frequencies giving signal $A\cos(2\pi f_c t+\varphi)$.



- Amplitude, Frequency or Phase is then varied, in accordance with the data signal to be transmitted.

Modulation Terminologies

- Analog wireless transmission (old technology)
- Digital wireless transmission (widely used today)

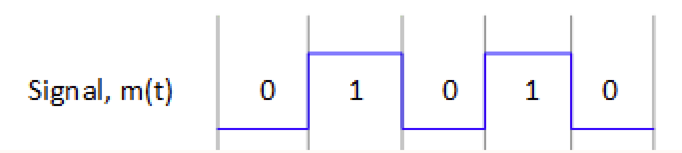


1. Digital Data, Analog Signal

- Transforming digital signal into analog signal
- Three basic encoding or modulation techniques
  - Amplitude Shift Keying (ASK)
  - Frequency Shift Keying (FSK)
  - Phase Shift Keying (PSK)
- In all these cases the resulting signal occupies a bandwidth centered on the carrier frequency

Digital Modulation: Amplitude Shift Keying

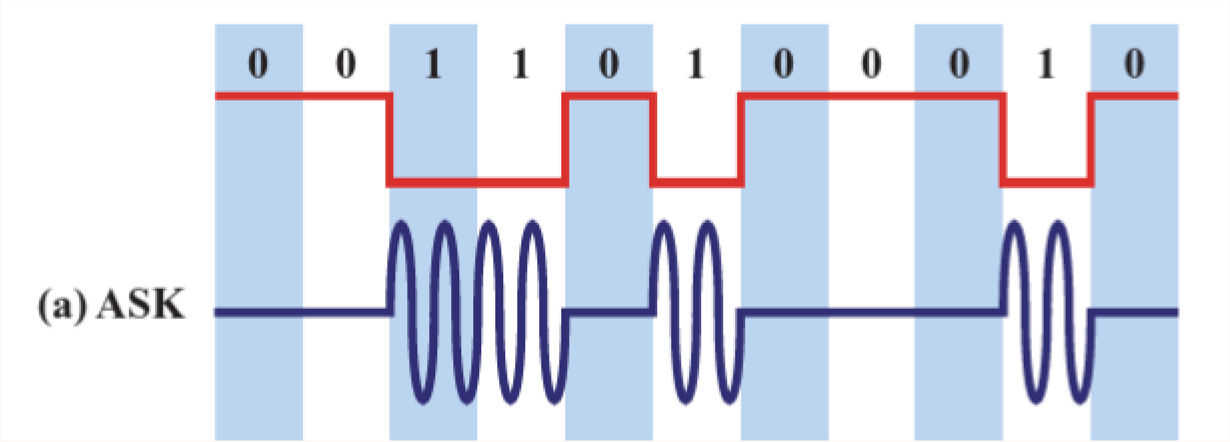
- For Amplitude Shift Keying, bits are represented by different amplitudes.
- Carrier signal c(t) = $Acos(2\pi f_c t)$

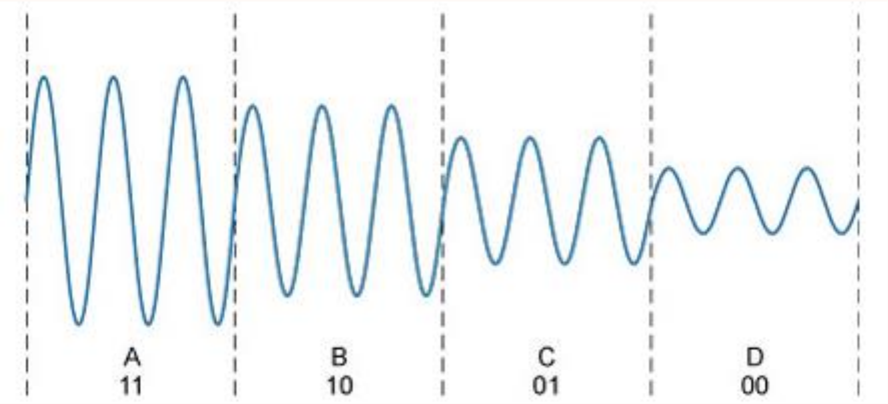


- The modulated signal s(t) $= \begin{cases} Acos(2\pi f_c t), binary\ 1 \\ 0, \qquad\qquad\qquad binary\ 0 \end{cases}$

Digital Modulation: Amplitude Shift Keying

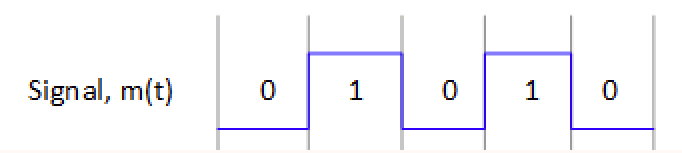
- Used to transmit data over optical fiber.
- Binary ASK, ON-OFF keying
- Multi level-ASK (M-ASK): It has multiple amplitude levels.





Digital Modulation: Frequency Shift Keying

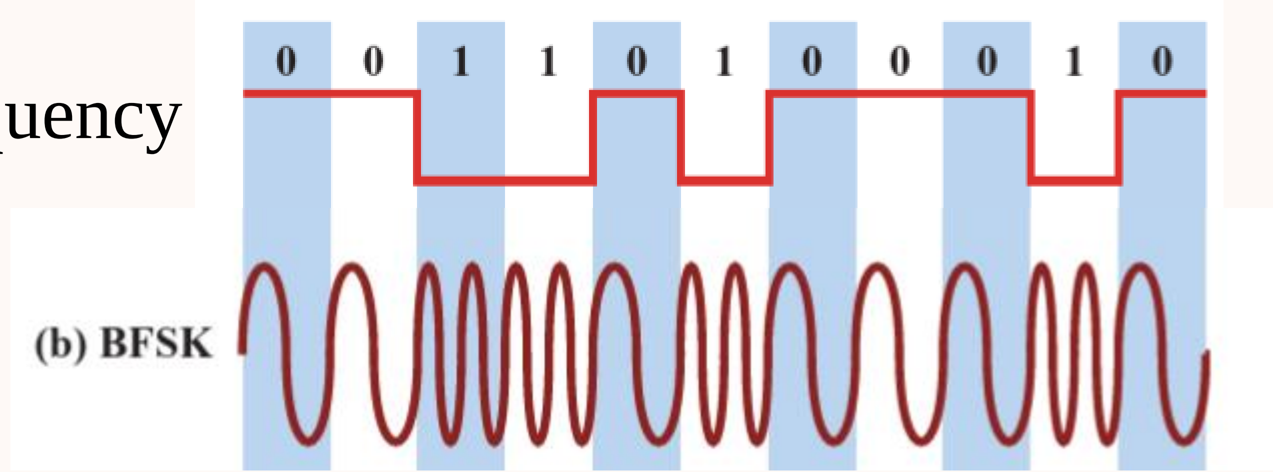
- For Binary Frequency Shift Keying (BFSK), bits are represented by different frequencies.
- Carrier signal c(t) = $Acos(2\pi f_c t)$



- The modulated signal $s(t) = \begin{cases} Acos(2\pi f_1 t), binary\ 1 \\ Acos(2\pi f_2 t), binary\ 0 \end{cases}$
- Where $f_1=f_c+f_0$ and $f_2=f_c-f_0$

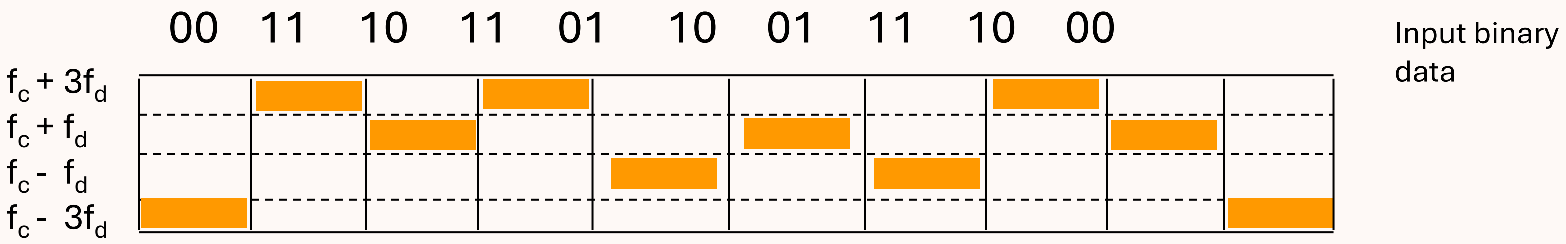
Digital Modulation: Frequency Shift Keying

- BFSK commonly used in high frequency radio transmissions
  - 3-30Mhz
- Binary FSK
- Multi Level FSK (M-FSK)
  - $s_i(t) = A\cos(2\pi f_i t)$ $1 \le i \le M$ where
    - Where $f_i = f_c + (2i-1-M)f_d$
      - f_c= the carrier frequency
      - f_d= the difference frequency
      - M = number of signal elements $=2^L$
      - L = number of bits per signal element



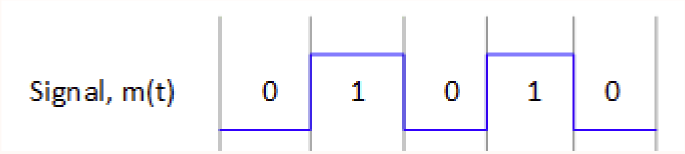
Digital Modulation: Frequency Shift Keying

- Example M=4



Digital Modulation: Phase Shift Keying

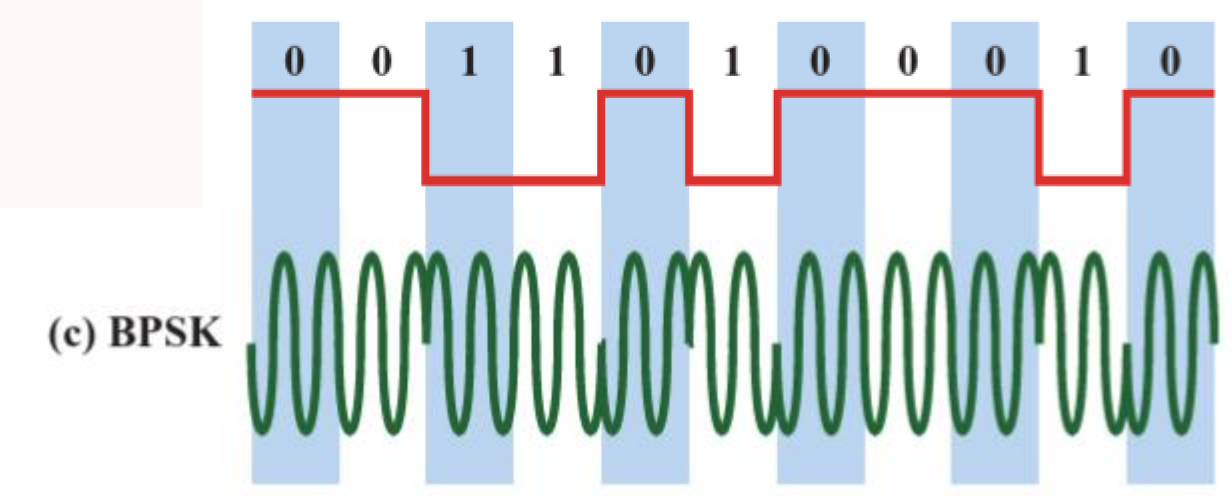
- The phase of the carrier signal is shifted to represent data
- Carrier signal c(t) = $Acos(2\pi f_c t)$



- The modulated signal s(t) $= \begin{cases} Acos(2\pi f_c t + 0), binary\ 1 \\ Acos(2\pi f_c t + \pi), binary\ 0 \end{cases}$

Digital Modulation: Phase Shift Keying

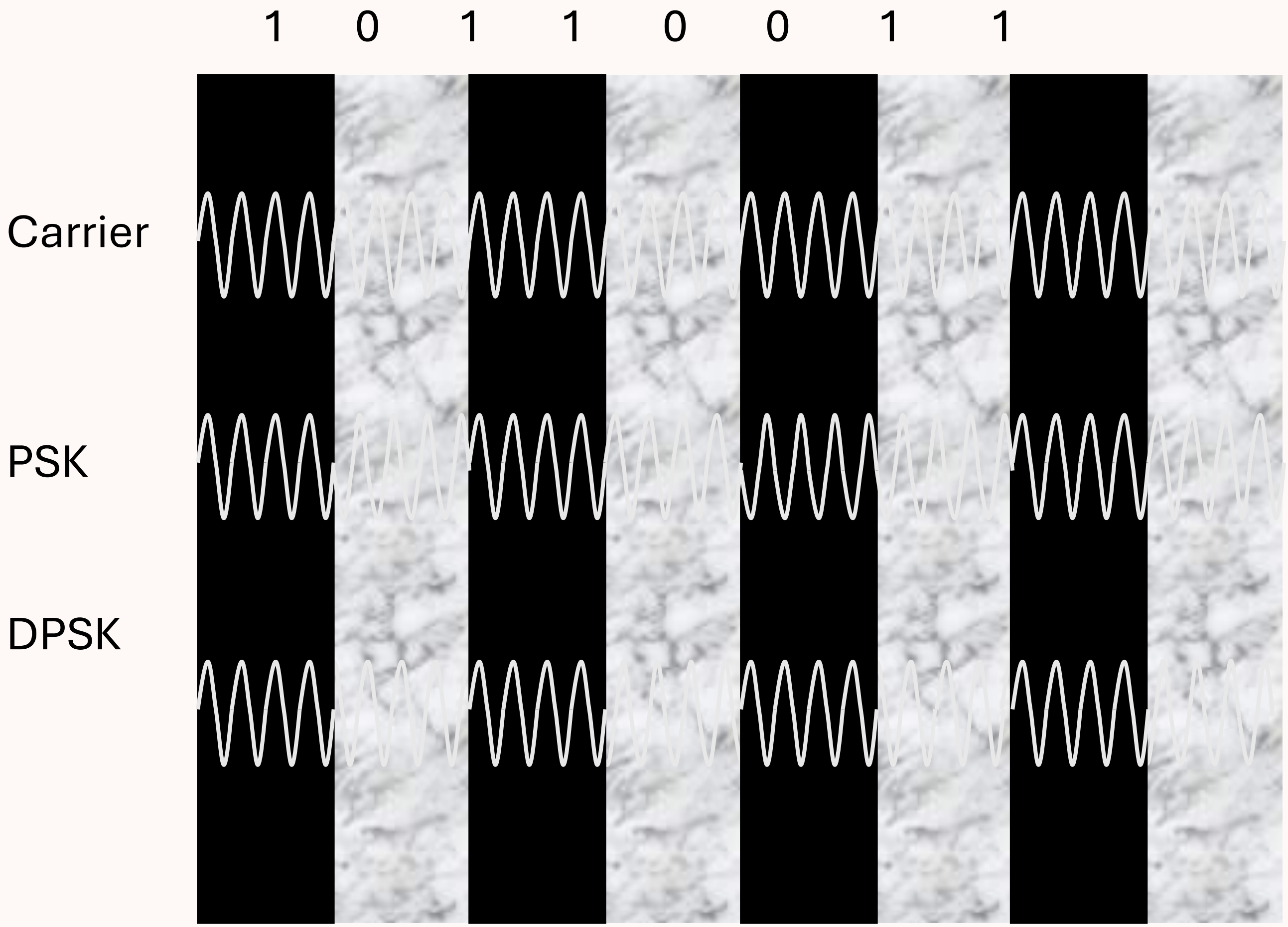
- Binary PSK (BPSK)
- Multi level PSK MPSK
- Four level PSK is also called quadrature phase shift keying (QPSK)



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

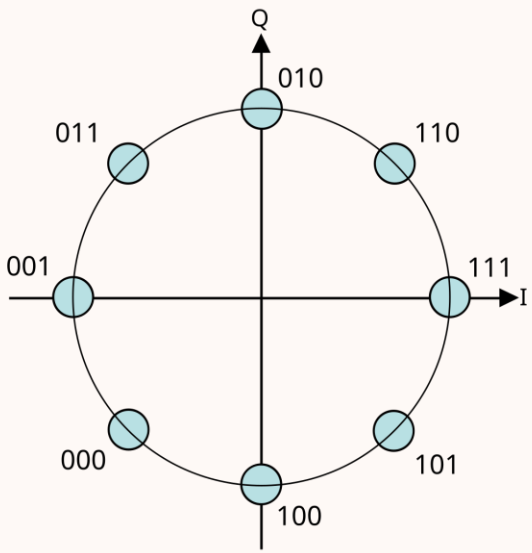
Digital Modulation: Differential PSK

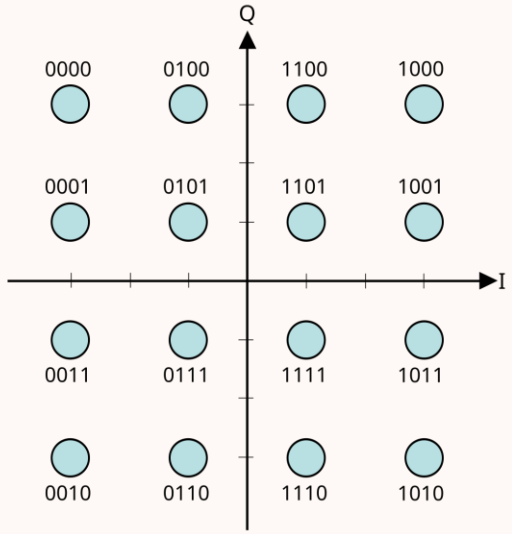
- Differential PSK (DPSK): Uses a phase shift of 90 relative to the current signal to indicate a binary 0, and a 270 phase shift for binary 1.
  - This has simpler demodulation equipment.



Constellation Diagram

- Modulation schemes are commonly represented using constellation diagram
- It displays the signal as a two-dimensional xy plane scatter diagram in the complex plane
- "I" or *in-phase* carrier,
- "Q“ or *quadrature* carrier.

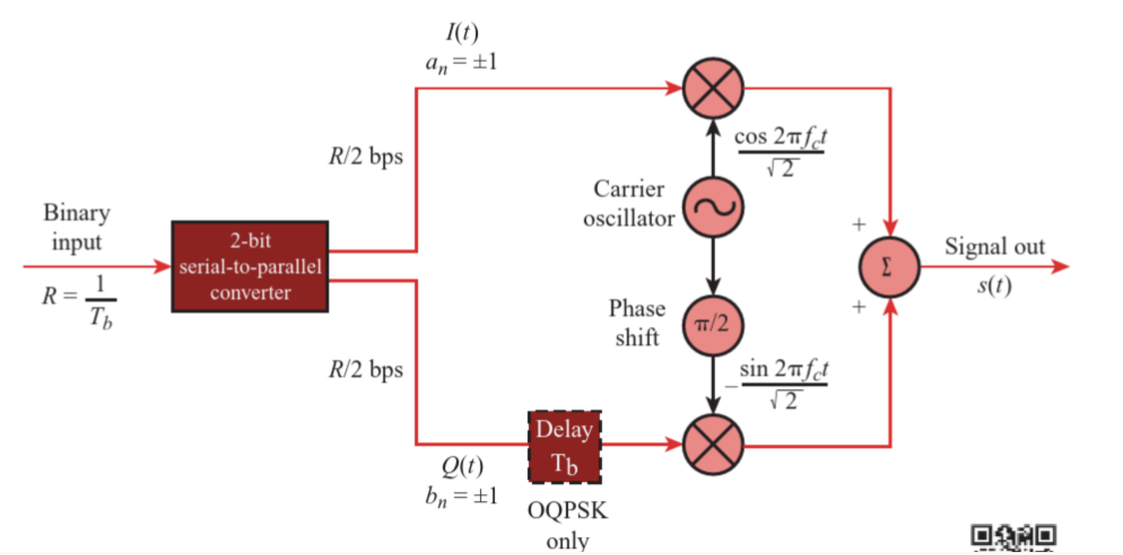




QPSK and Orthogonal QPSK (OQPSK)

QPSK

- $s(t) = 1/\sqrt{2}\ I(t)\cos(2\pi f_c t) - 1/\sqrt{2}\ Q(t)\sin(2\pi f_c t)$
  - Where
    - I(t) is in-phase data stream
    - Q(t) is quadrature phase data stream
    - Phase may change by up to 180º



OQPSK (Offset QPSK)

- $s(t) = 1/\sqrt{2}\ I(t)\cos(2\pi f_c t) - 1/\sqrt{2}\ Q(t-T_b)\sin(2\pi f_c t)$
  - Phase may only change by 90º
  - Allows phase modulator to achieve higher transition rates
  - May also have better resistance to error depending on channel characteristics.

QPSK and Orthogonal QPSK (OQPSK)

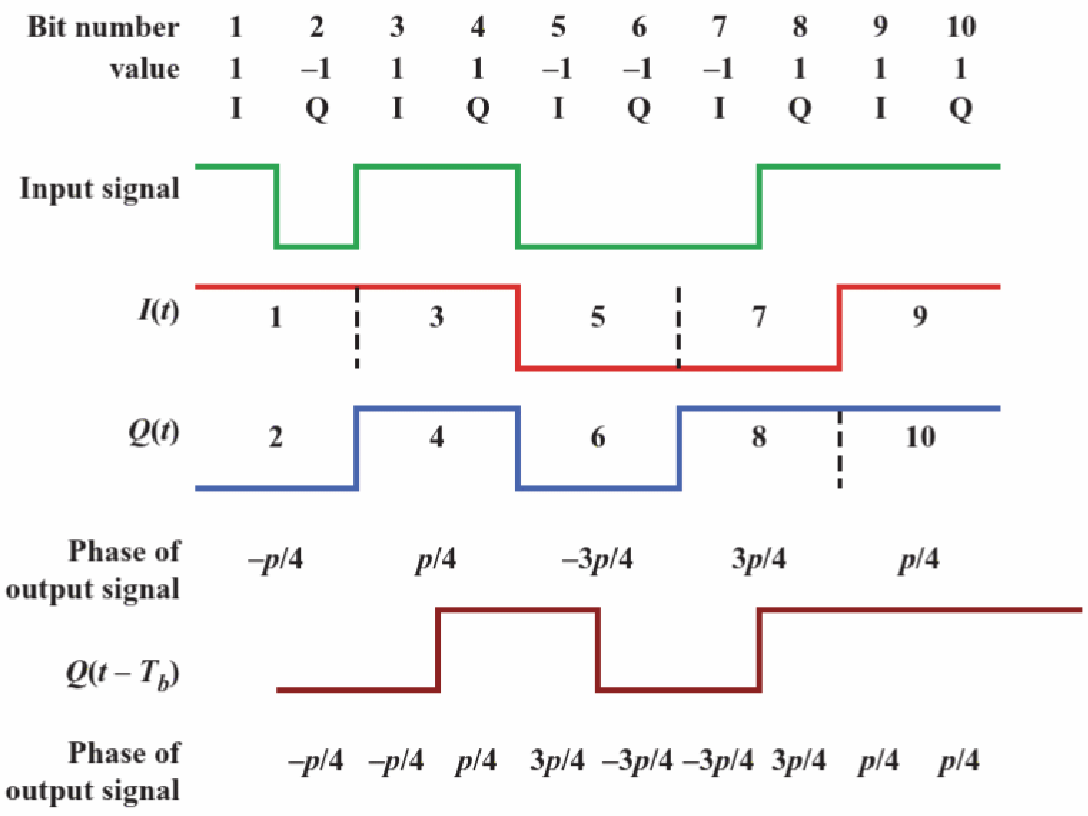


Figure 7.8 Example of QPSK and OQPSK Waveforms

Energy per bit to noise power density per hertz

- Consider a signal with bit rate R, the energy per bit
- $E_b = ST_b = S/R$
  - S is the signal power
  - T_b is the time required to send one bit
- $N_o = \frac{N}{B}$
  - N is the noise power density
  - B is the Band width
  - $\frac{E_b}{N_o} = \frac{SB}{NR}$

Digital Modulation: Performance

- Two factors by which performance of modulation schemes can be measured are
  - Bandwidth, which affects the efficiency with which the spectrum can be used and,
  - E_b/N_0 which also impacts channel capacity.
- Bandwidth
  - ASK – $B_T = (1+r)\,R$ where
    - r is related to the filtering technique and the value is between 0 and 1
    - R is the bit rate.
  - MPSK -- $B_T = [(1+r)/L]\,R$
    - L is the number of bits per signal element
  - MFSK -- $[(1+r)2^L/L]\,R$
- R/B_T is the transmission *bandwidth ratio* or *bandwidth efficiency*
  - Reflects how well bandwidth can be used to transmit data

Digital Modulation: Performance

Bandwidth Efficiency/ Spectral Efficiency: Transmission Bandwidth Ratio R/B_T

	r = 0	r = 0.5	r = 1
ASK	1.0	0.67	0.5
FSK	0.5	0.33	0.25
MFSK			
M=4, L=2	0.5	0.33	0.25
M=8, L=3	0.375	0.25	0.1875
M=16, L=4	0.25	0.167	0.125
M=32, L=5	0.156	0.104	0.078
PSK	1.0	0.67	0.5
MPSK			
M=4, L=2	2.0	1.33	1.0
M=8, L=3	3.0	2.0	1.5
M=16, L=4	4.0	2.67	2.0
M=32, L=5	5.0	3.33	2.5

The higher the ratio, the better.

We see that it decreases with r

For MFSK it decreases with the number of levels.

For MPSK it increases With the number of levels.

Digital Modulation: Performance

BER vs. E_b/N_0

- The bit error rate is dependent on the modulation technique used.

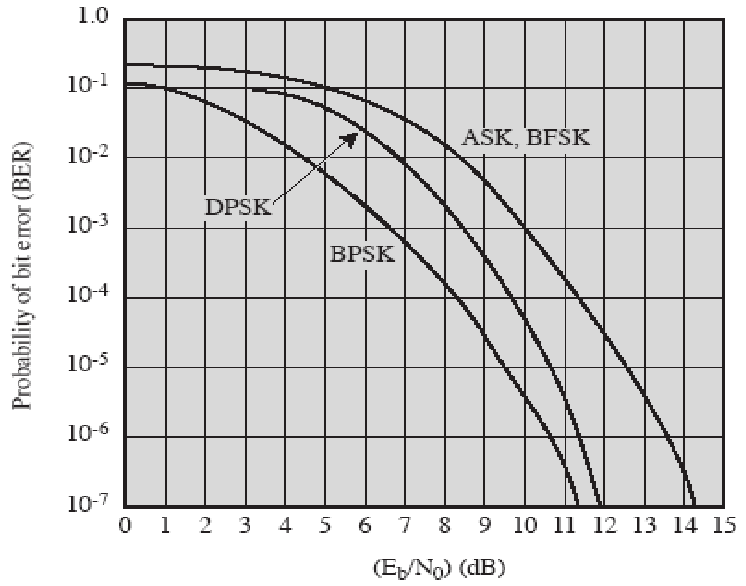


Figure 6.8 Theoretical Bit Error Rate for Various Encoding Schemes

Stallings, Wireless Communications and Networks, Ch. 6

Digital Modulation: Performance

BER vs. E_b/N_0

- For multilevel schemes, the bit error rate is dependent on number of levels.

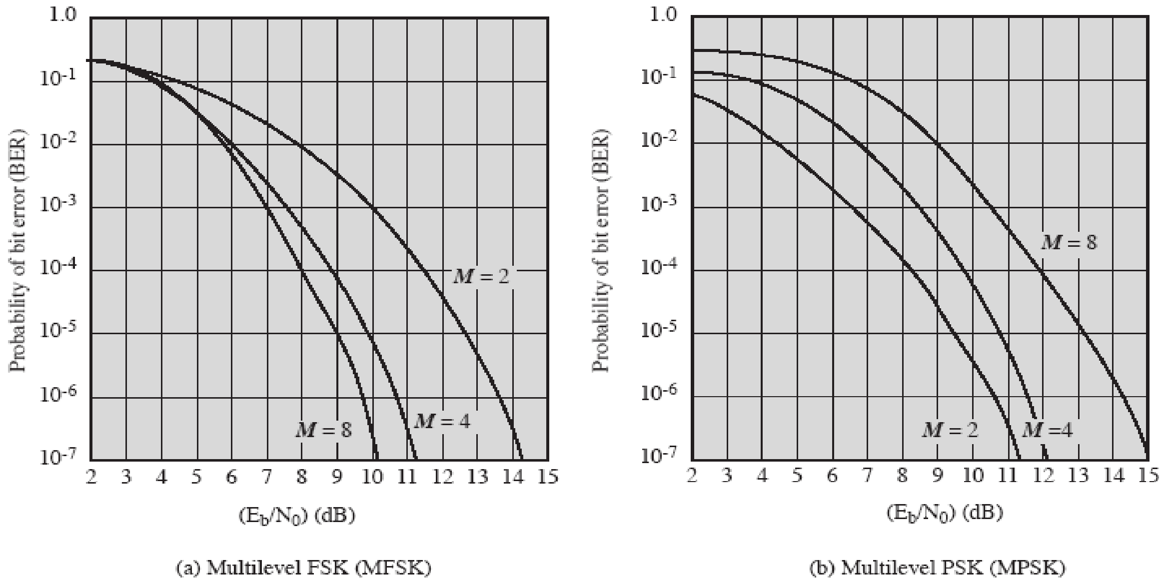


Figure 6.9 Theoretical Bit Error Rate for Multilevel FSK and PSK

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Sample Problem 1

Bandwidth Efficiency vs. BER

- What is the required bandwidth efficiency for FSK, ASK, PSK and QPSK for BER=10^{-7} on a channel with SNR = 12dB?

Sample Problem 1
Bandwidth Efficiency vs. BER

- In the notes, we showed a relationship between BER, E_b/N_0, and transmission bandwidth efficiency.
- Recall:
  - By definition E_b/N_0 = SNR B_T/R
    - Where R/B_T the bandwidth efficiency
    - If we convert to decibels we get:
    - $(E_b/N_0)_{dB} = (SNR)dB + 10 \log(B_T/R)$
    - $(E_b/N_0)_{dB} = (SNR)dB - 10 \log(R/B_T)$

Sample Problem 1
Bandwidth Efficiency vs. BER

- We have also examined the relationship between E_b/N_0 and BER for different modulation schemes.
- For FSK and ASK,
  - $(E_b/N_0)_{dB} = 14.2dB$
  - Giving $(R/B_T)_{dB} = -2.2$ dB or $R/B_T = 0.6$
- For PSK
  - $(E_b/N_0)_{dB} = 11.2dB$
  - Giving $(R/B_T)_{dB} = 0.8$ dB or $R/B_T = 1.2$
- For QPSK the baud rate is R/2. Thus
  - $R/B_T = 2.4$
- Are these bandwidth efficiencies achievable?

Sample Problem 1
Bandwidth Efficiency vs. BER

Transmission Bandwidth Ratio R/B_T

	r = 0	r = 0.5	r = 1
ASK	**1.0**	**0.67**	**0.5**
FSK	**0.5**	**0.33**	**0.25**
MFSK			
M=4, L=2	**0.5**	**0.33**	**0.25**
M=8, L=3	**0.375**	**0.25**	**0.1875**
M=16, L=4	**0.25**	**0.167**	**0.125**
M=32, L=5	**0.156**	**0.104**	**0.078**
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M=32, L=5	**5.0**	**3.33**	**2.5**

The higher the ratio, the better.

We see that it decreases with r

For MFSK it decreases with the number of levels.

For MPSK it increases With the number of levels.

Sample Problem 1
Bandwidth Efficiency vs. BER

- The bit error rate is dependent on the modulation technique used.

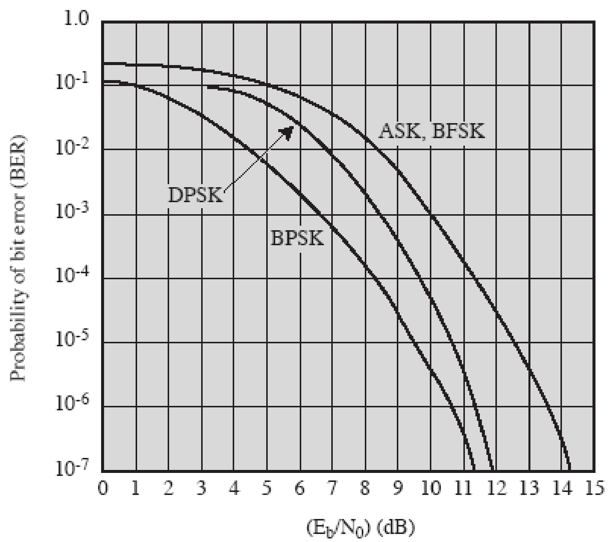

Figure 6.8 Theoretical Bit Error Rate for Various Encoding Schemes

Sample Problem 2

Bandwidth Efficiency vs. BER for multilevel encoding

- Consider a multilevel FSK system.
  - Suppose $E_b/N_0 = 10$ dB.
  - Calculate and compare BER and bandwidth efficiency for the different levels.
  - Additionally, calculate SNR for the different levels.

Sample Problem 2

Bandwidth Efficiency vs. BER for multilevel encoding

- The BER may be found from figure (a) below.

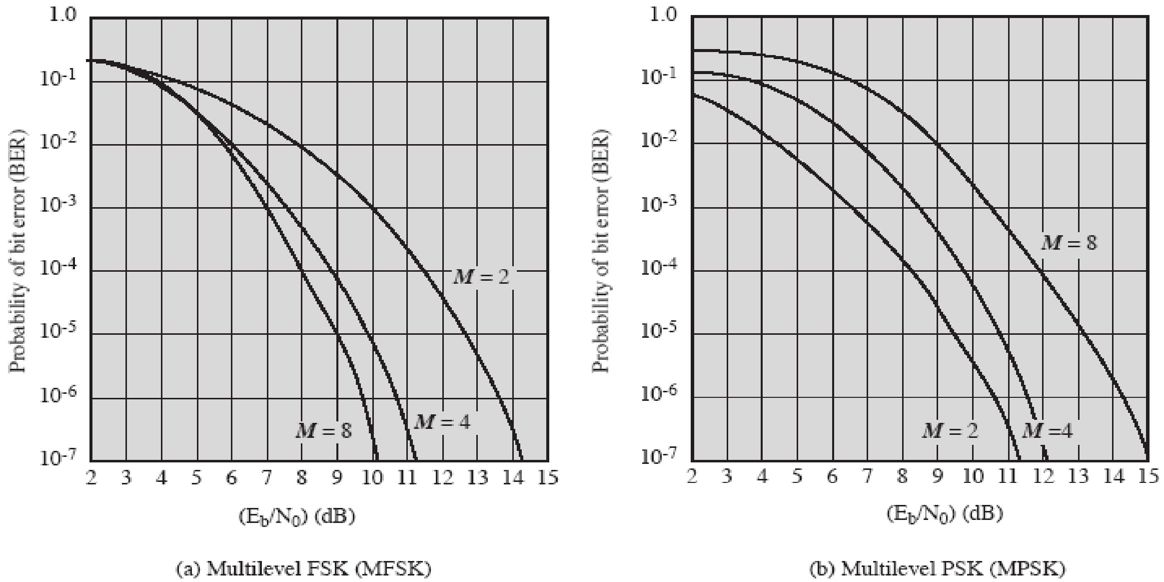

Figure 6.9 Theoretical Bit Error Rate for Multilevel FSK and PSK

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Sample Problem 2

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And the transmission bandwidth ratio is obtained from the table according to the filter properties r.

Sample Problem 2
Bandwidth Efficiency vs. BER for multilevel encoding

- The bandwidth efficiency is dependent on the filtration technique.
  - We will assume r=0.
- So, we get the following values for BER and R/B_T

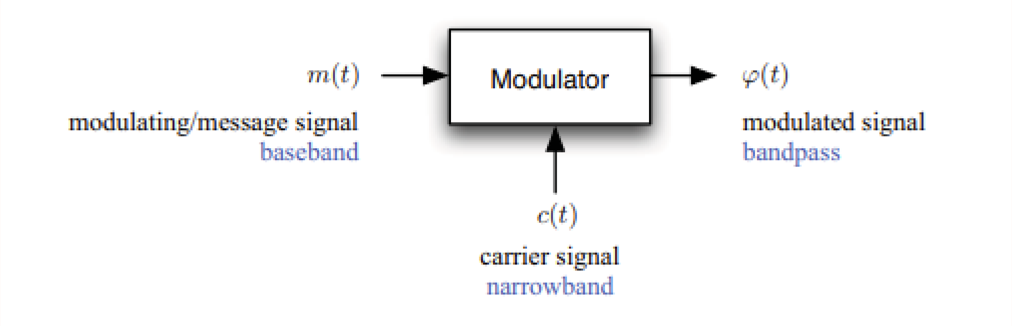
M	BER	R/B_T
2	10^{-3}	0.5
4	$2x10^{-6}$	0.5
8	$6x10^{-7}$	0.375

Thus we observe that BER decreases with the number of levels, but the bandwidth efficiency decreases as well.

- What happens to SNR?

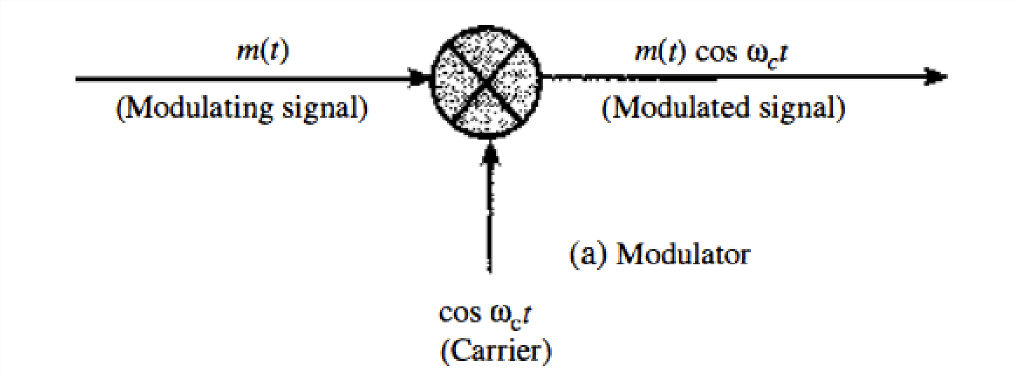
2. Analog Data, Analog Signals

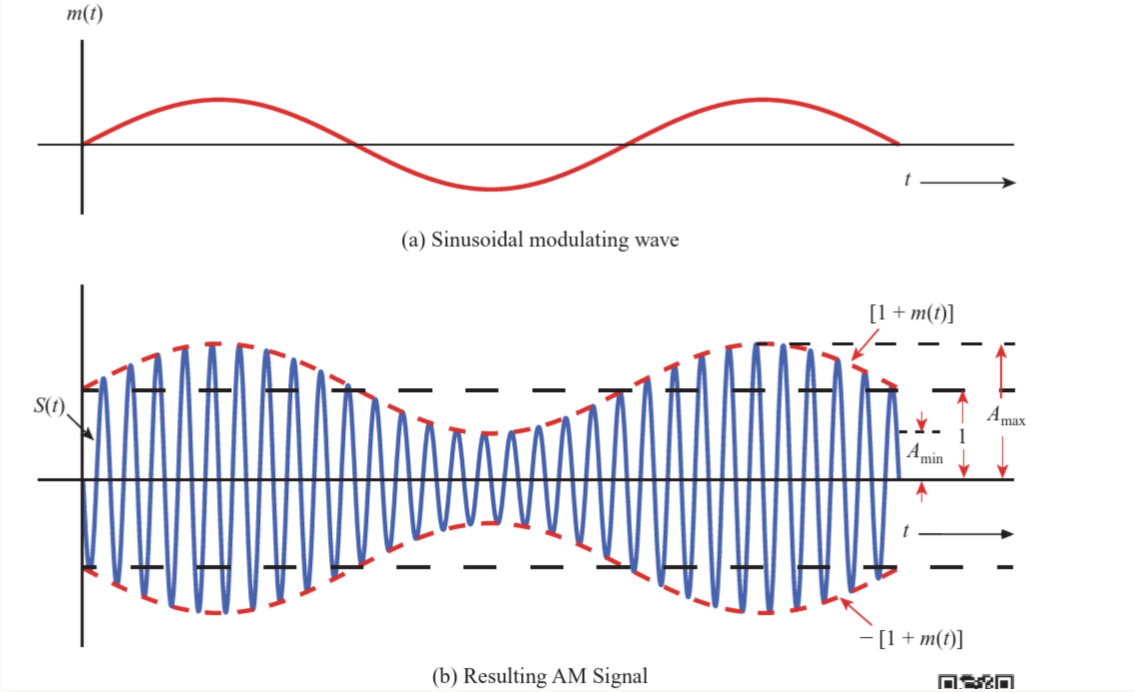
- Why is modulation required for analog data?
- A higher frequency is needed for effective transmission
- Principal techniques
    - Amplitude Modulation (AM)
    - Angle Modulation
        - Frequency Modulation (FM)
        - Phase Modulation (PM)



Analog Signals: Amplitude Modulation (AM)

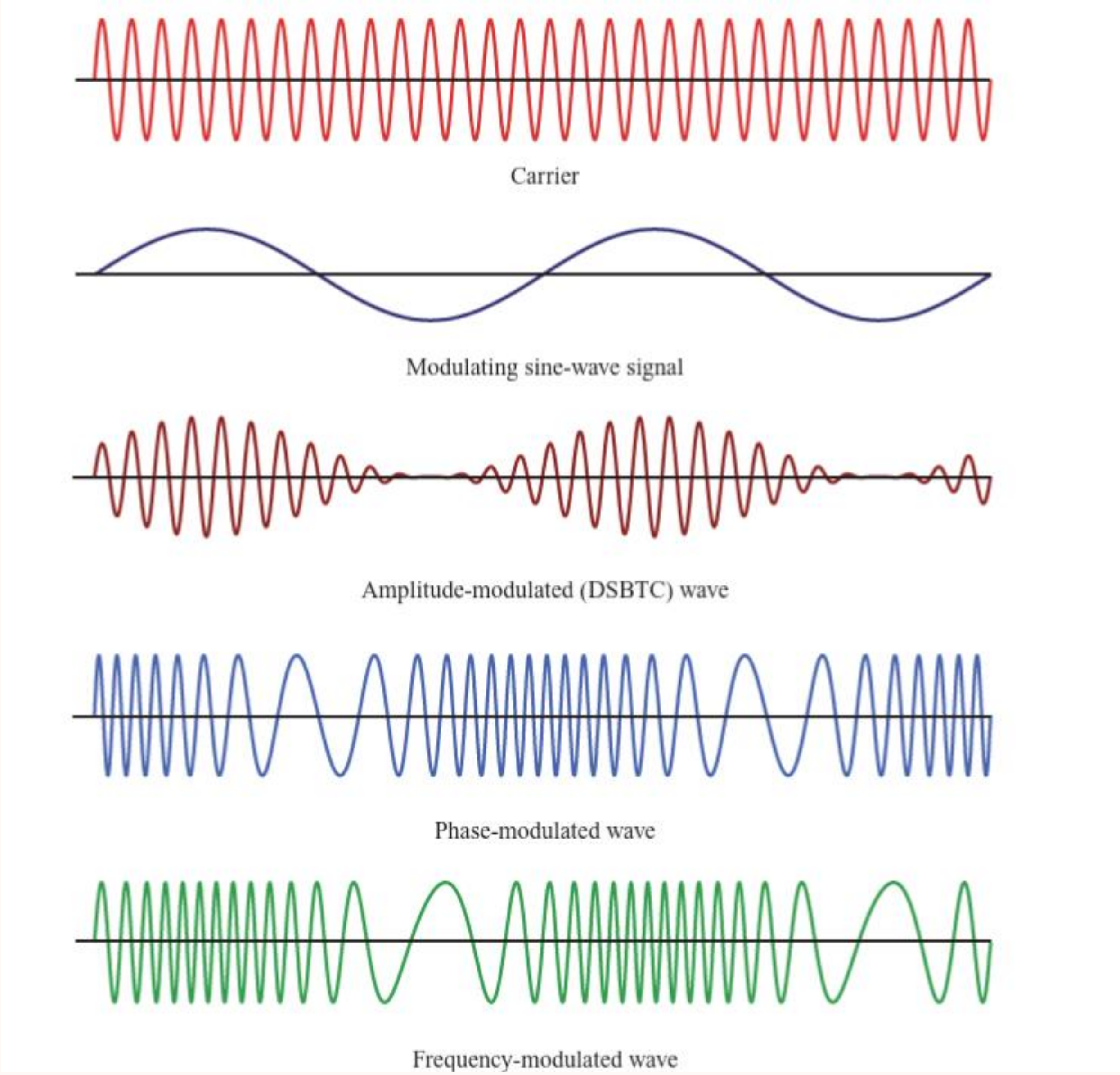
- The amplitude of a carrier signal is altered according to an information.
- Carrier signal c(t) = $A cos(2\pi f_c t)$
- $\phi(t) = Am(t)\cos(2\pi f_c t)$





Angle Modulation

- The modulated signal is expressed as
- $s(t) = A cos(2\pi f_c t + \phi(t)]$
- For phase modulation, phase is proportional to the modulating signal
- $\phi(t) = n_p m(t)$
  - n_p is the modulation index
- $\phi'(t) = n_f m(t)$
  - n_f is the modulation index


Carrier
Modulating sine-wave signal
Amplitude-modulated (DSBTC) wave
Phase-modulated wave
Frequency-modulated wave

Analog Data, Digital Signals

- Analog data to digital signal
    - Pulse code modulation (PCM)
    - Delta modulation (DM)

PCM

- Based on the sampling theorem

If a signal f(t) is sampled at regular intervals of time and at a rate higher than twice the highest signal frequency, then the samples contains all the information of the original signal.

- Each analog sample is assigned a binary code
- Analog samples are referred to as pulse amplitude modulation (PAM) samples
- The digital signal consists of block of n bits, where each n-bit number is the amplitude of a PCM pulse

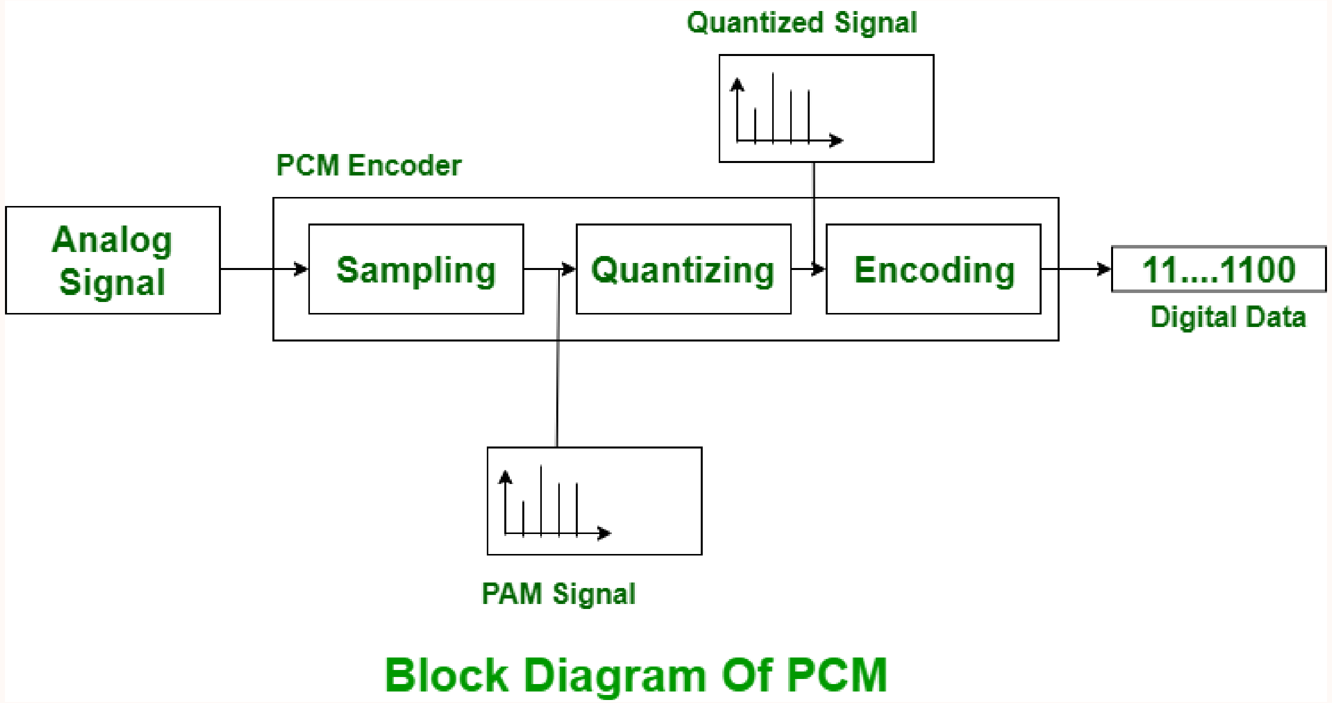


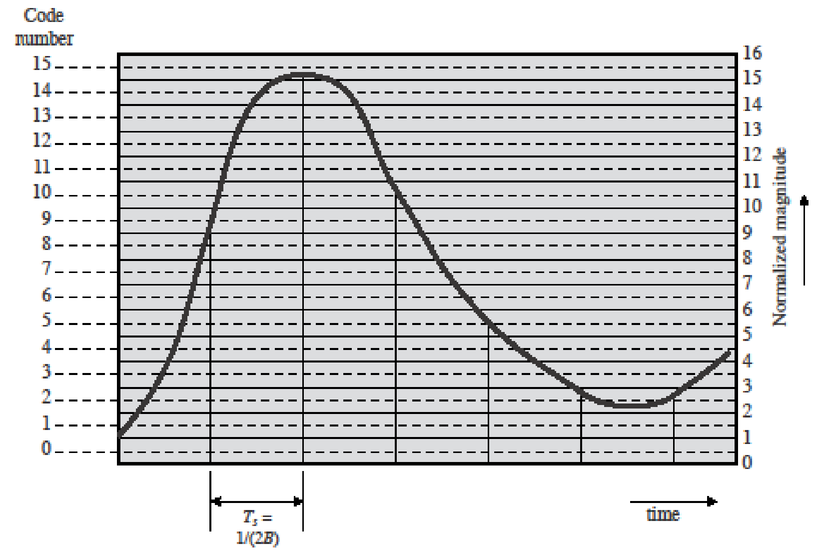
Image coutesyhttps://www.geeksforgeeks.org/difference-between-pulse-code-modulation-pcm-and-delta-modulation-dm/

PCM

- PCM introduces quantisation noise:

$$SNR_{dB} = 20\log 2^{n} + 1.76\ dB$$
$$= 6.02n + 1.76\ dB$$

  - Where n is the number of bits used for quantisation.
    - Thus, SNR increases with increase in number of bits
  - Frequencies over 4kHz are lost.



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

Figure 6.15 Pulse-Code Modulation Example

Delta Modulation

- Only two level quantiser used for quantisation of the samples difference
  - Up or down by quantisation amount
  - Large quantisation errors
- Accuracy can be improved by increasing the sampling rate.
- Can achieve data rates of 16kbps
- Used primarily by military.

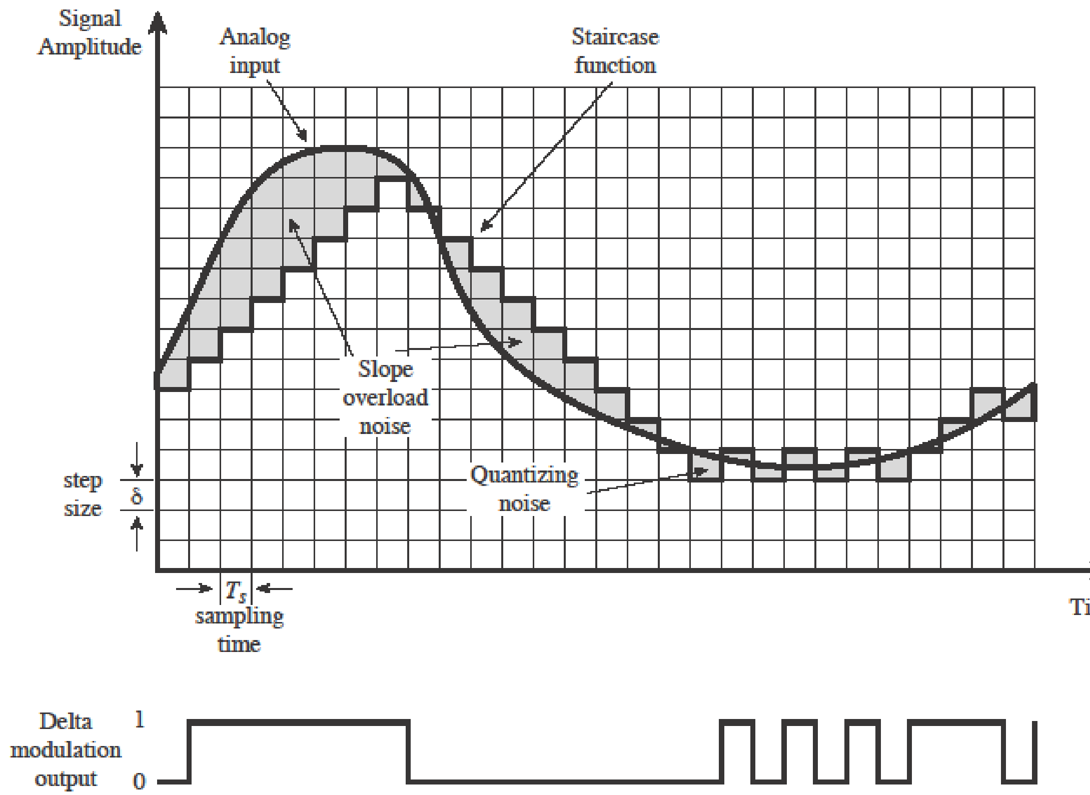


Figure 6.18 Example of Delta Modulation

Summary

1. Digital Data, Analog Signal
2. Analog Data, Analog Signals
3. Analog Data, Digital Signals

Chapter 7 Signal Encoding Techniques