EEE 432 Introduction to Data Communications

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SIGNAL ENCODING TECHNIQUES

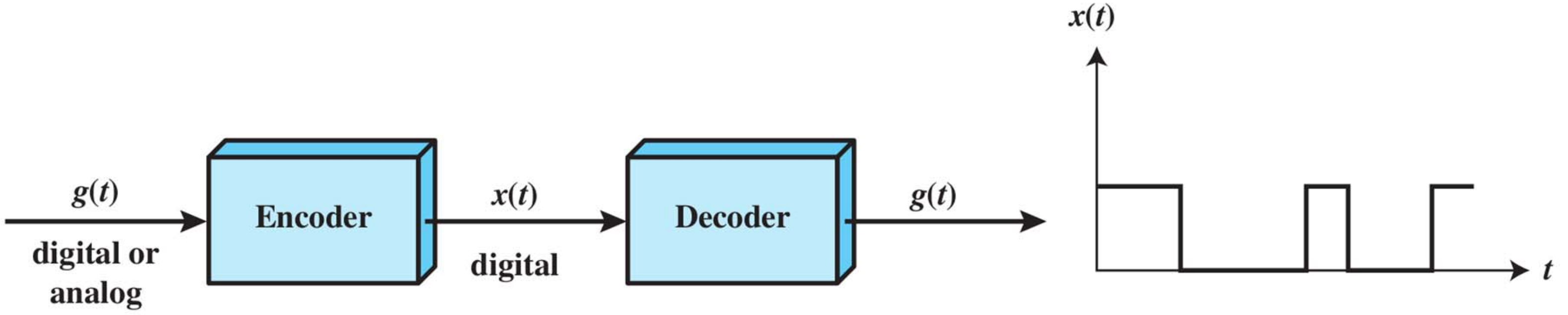
Course Information

1. Data Communications and Networks
2. Data Transmission
3. Transmission Media
4. **Signal Encoding Techniques**
5. Digital Data Communication Techniques
6. Multiplexing
7. Networking and Protocol Architectures
8. Switching
9. Routing in Switched Networks
10. LANs and WANs
11. Ethernet
12. The Internet

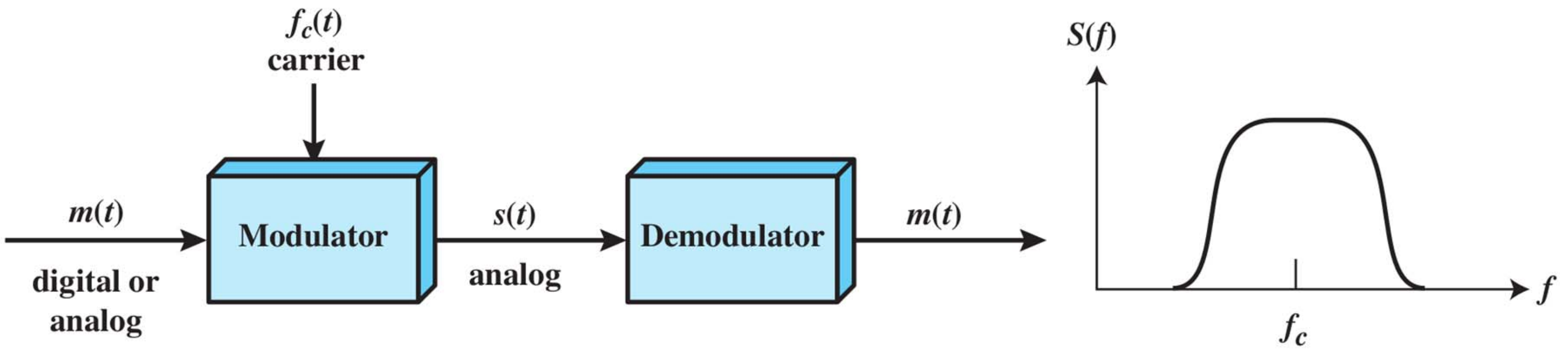
Signal Encoding Techniques

- Signals transmitted chosen to optimize use of transmission medium
  - E.g. conserve bandwidth, minimize errors
- **Digital signaling:** digital or analog data, *g(t)*, encoded into digital signal, *x(t)*
- **Analog signaling:** digital or analog data transmitted by analog **carrier signal** using modulation
  - **Modulation:** process of encoding source data onto a carrier signal with frequency f_c
  - Input signal, *m(t)*, is called **baseband signal**
  - Result of modulating carrier signal is called **modulated signal,** *s(t)*

Encoding and Modulation Techniques



(a) Encoding onto a digital signal



(b) Modulation onto an analog signal

Reasons for Using Different Techniques

Digital data, digital signal: Equipment less complex/expensive than digital-to-analog modulation equipment

Analog data, digital signal: Permits use of digital transmission equipment

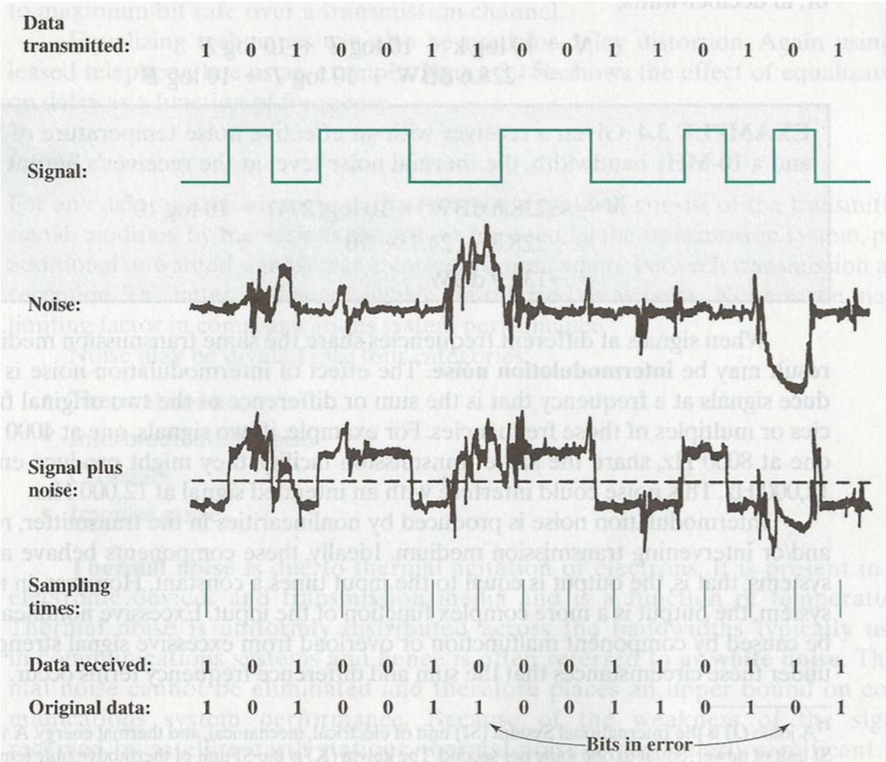
Digital data, analog signal: Some media only propagate analog signals, e.g. optical fibre, wireless

Analog data, analog signal: Some analog data can easily be transmitted as baseband signals, e.g. voice; enables multiple signals at different positions in spectrum to share transmission media

Digital Data, Digital Signals

- **Digital signal:** Sequence of discrete voltage pulses
- Each pulse is a signal element
- Binary data transmitted by encoding each bit (data element) into signal elements
  - E.g. binary 1 represented by lower voltage level, binary 0 for higher level
- **Data rate** = Data elements or bits per second; signalling or modulation rate = signal elements per second (baud)
- Our digital data is encoded into signal elements.
- **For ex**: Binary 1 as we say low level voltage, negative -5V and binary 0 as a high level so +5V. Or it could be the opposite. But we map our digital data to one of the levels of digital signal. That signal is transmitted for a period of time and that represents a single signal element.

Receiver Interpreting Incoming Signal



- Important factors for successful reception: SNR, data rate, bandwidth
  - Increase in data rate increases bit error rate (BER)
  - Increase in SNR decreases BER
  - Increase in bandwidth allows increase in data rate
- Also encoding scheme . . .

Definition of Digital Signal Encoding Formats

Nonreturn to Zero-Level (NRZ-L)

0 = high level
1 = low level

When we have a bit 0, we transmit a signal for some duration at high level and bit 1 at a low level. NRZ-L means signal never becomes zero

Nonreturn to Zero Inverted (NRZI)

0 = no transition at beginning of interval (one bit time)
1 = transition at beginning of interval

Bipolar-AMI

0 = no line signal
1 = positive or negative level, alternating for successive ones

Pseudoternary

0 = positive or negative level, alternating for successive zeros
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 a transition in middle of interval
0 = transition at beginning of interval
1 = no transition at beginning of interval

B8ZS

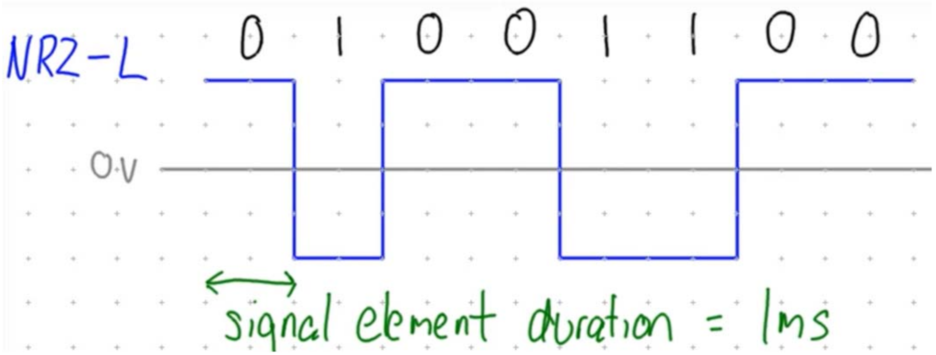
Same as bipolar AMI, except that any string of eight zeros is replaced by a string with two code violations

HDB3

Same as bipolar AMI, except that any string of four zeros is replaced by a string with one code violation

Definition of Digital Signal Encoding Formats

Ex: For the given NRZ-L plot if the signal element duration is 1ms. What are the signalling rate and data rate?



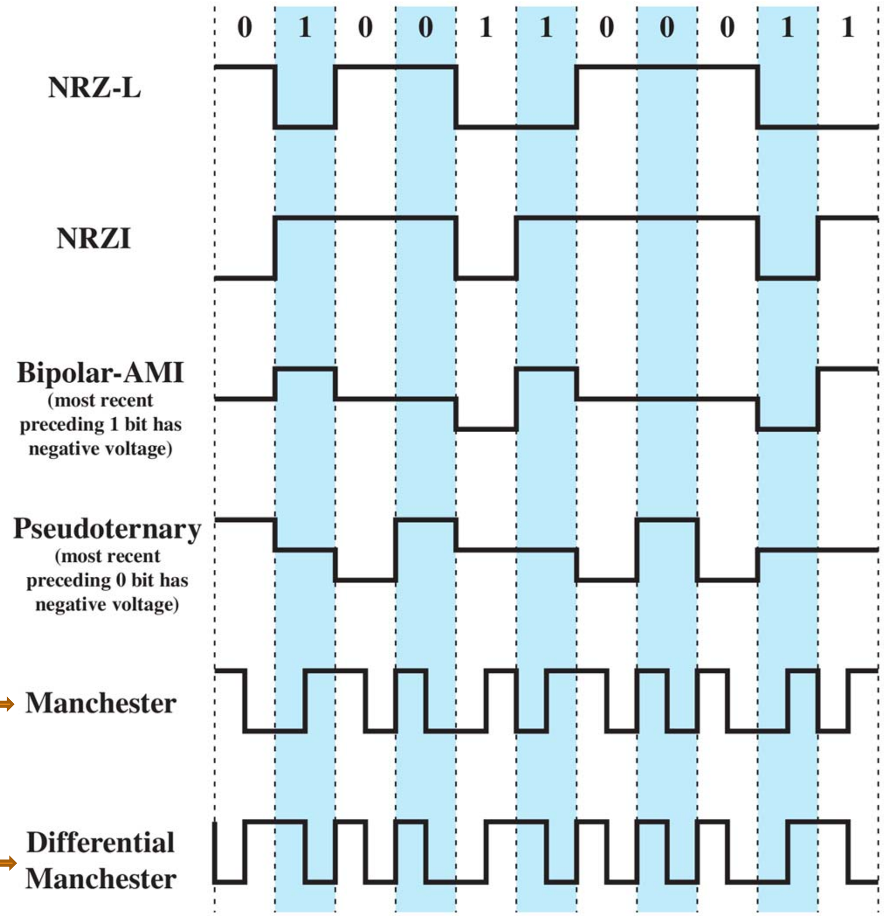
One signal element duration is 1ms, which means 1000 signal elements in 1 second. Therefore, signalling rate is 1000 SE/s. Don't be confused with bits.

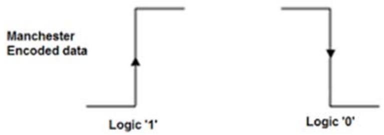
In this example, there are 1000 signal elements per second if each signal element has a duration of 1ms.

Data rate=1000bits/s. Because in this scheme each signal element represents a single bit so 1000 signal elements per second is the same as sending the 1000 bits per second.

Digital Signal Encoding Formats

Fig. Example for Digital Signal Encoding Techniques





When 1, make transition
When 0, make transition and go back to same state

Digital Signal Encoding Formats

NRZ-L/NRZI: RS 232, HDLC (**H**igh- Level **D**ata **L**ink **C**ontrol), USB…

Manchester: Ethernet, Token Ring,…

Multilevel Binary (Bipolar-AMI and Pseudoternary): US- T Carrier and European E-carrier telecommunication systems

Comparing Different Encoding Schemes

- **Signal Spectrum**
  - Desire no high frequency components so less bandwidth is required
  - Desire no DC component so AC coupling can be used (reduces bit error rate)
  - Concentrate transmitted power in middle of bandwidth
- **Clocking and Synchronization**
  - Transmitted signal can be used by receiver to synchronize bit timing

Comparing Different Encoding Schemes

- **Error Detection**

Receiver can detect some bit errors from the received signal

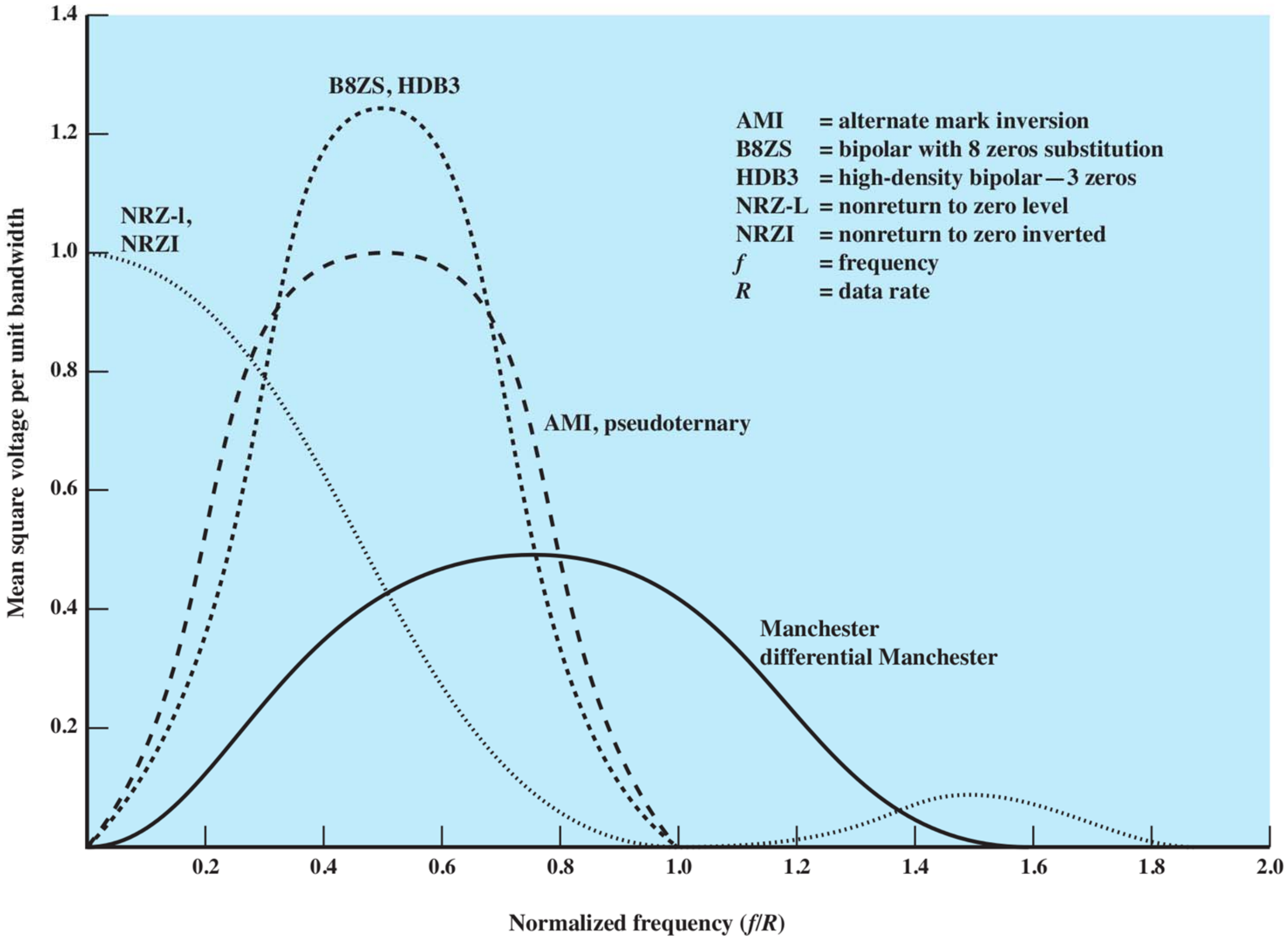
- **Signal Interference**

Provide good performance (few bit errors) in presence of noise

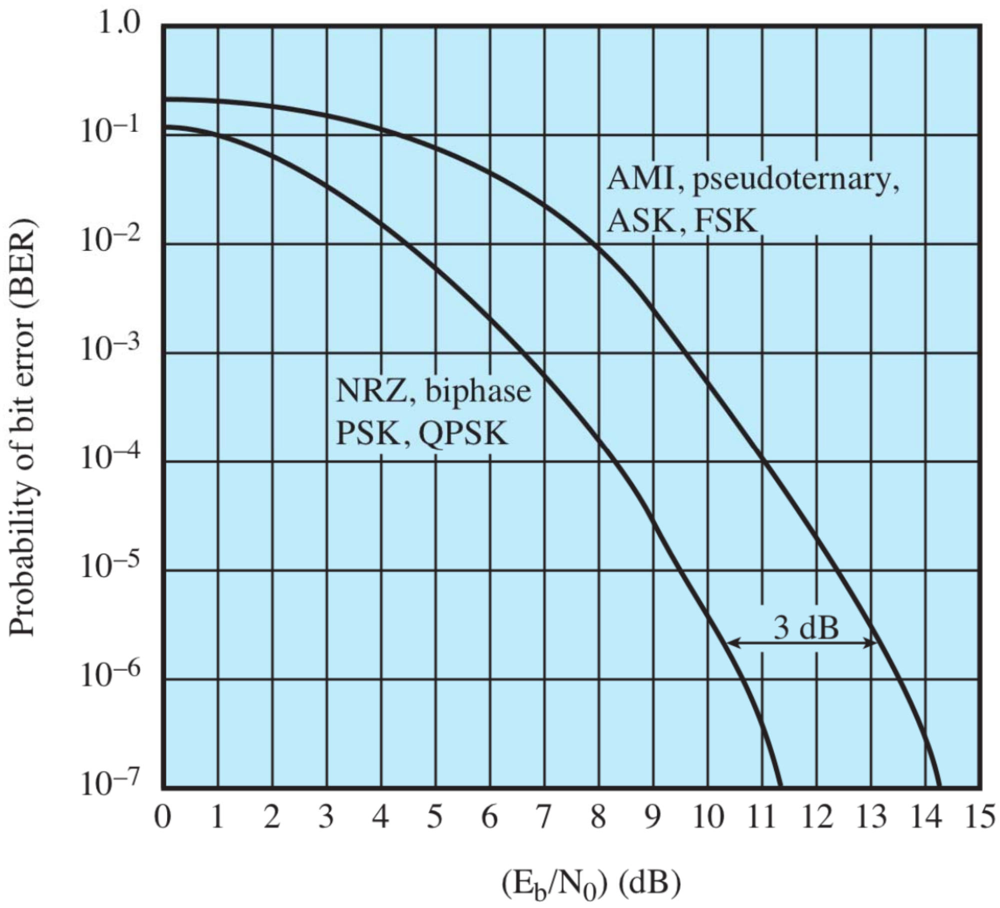
- **Cost and Complexity**

Desire smaller signalling rate to achieve a given data rate

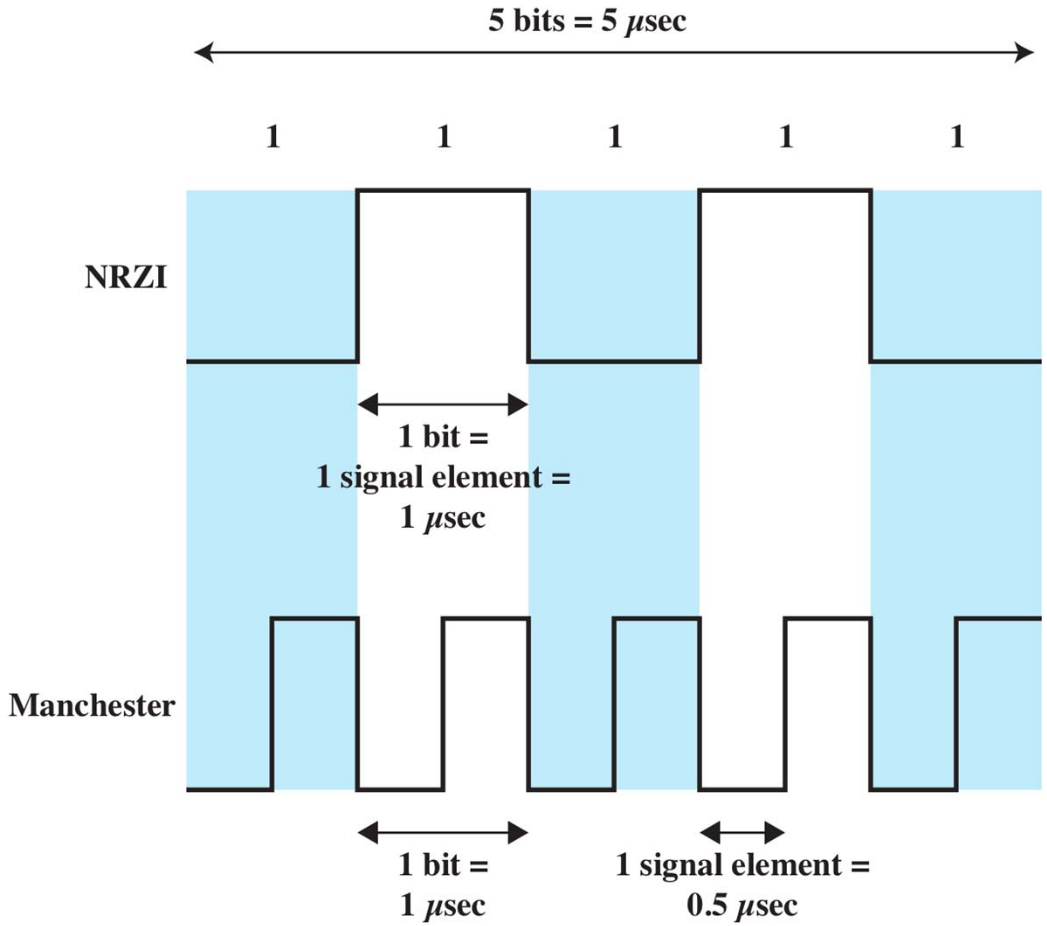
Spectral Density of Various Signal Encoding Schemes



Theoretical Bit Error Rate for Various Encoding Schemes



A Stream of Binary Ones at 1 Mbps



Improving on NRZ

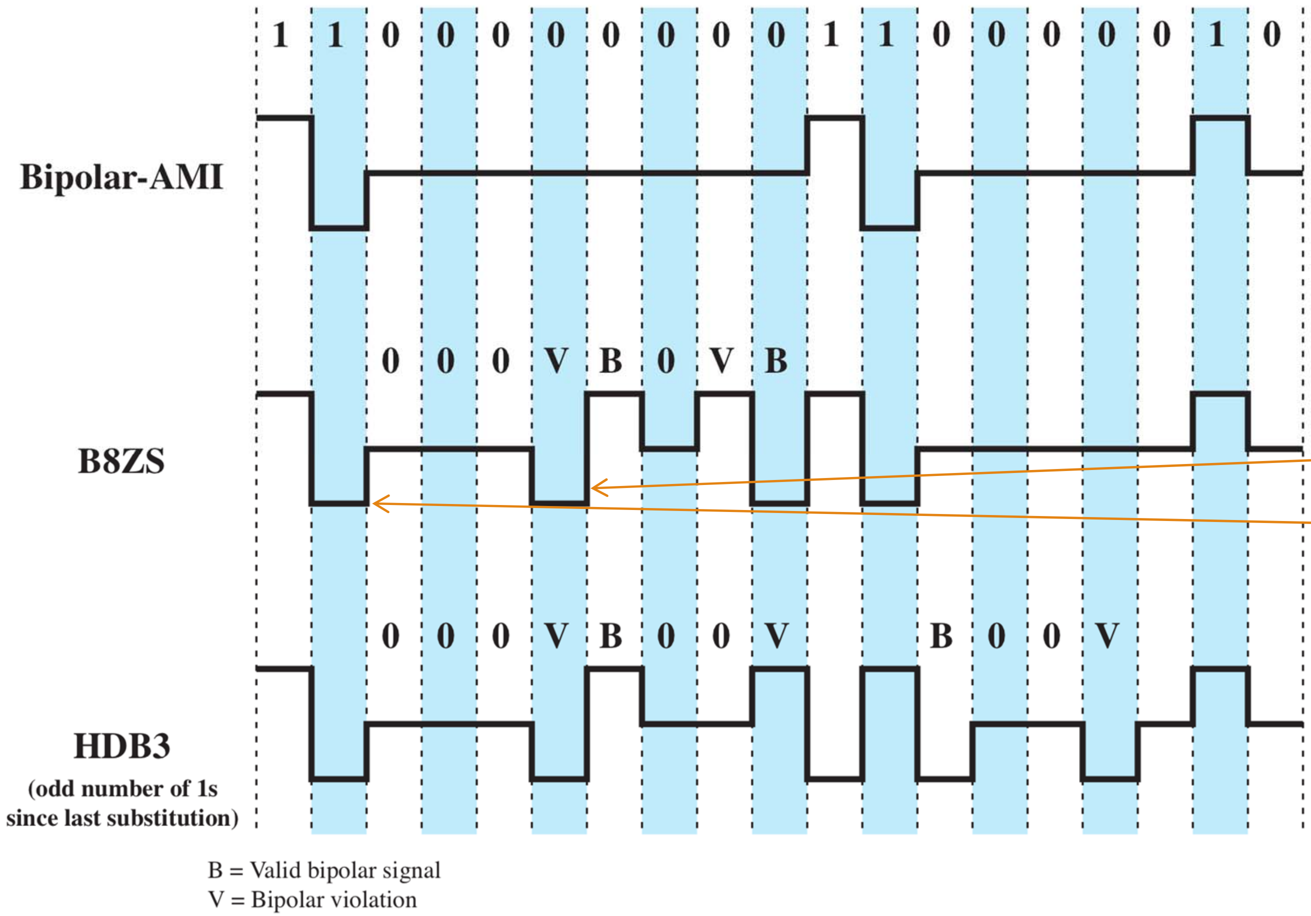
- **Multilevel Binary Schemes**
  - Bipolar AMI, Pseudoternary
  - Use more than two signal levels
  - No DC component, simple error detection, no loss of synchronization (in some cases), small bandwidth needed
  - Requires more transmit power for same level of BER as two-level schemes
- **Biphase Schemes**
  - Manchester, Differential Manchester
  - More than 1 transition per bit
  - Similar features to multilevel schemes, but larger bandwidth required

Improving Synchronization

- In Bipolar AMI a long sequence of 0's makes it difficult for the receiver to synchronize
- Solution: if long sequence of same bit, replace with special sequence of bits
- B8ZS (**B**ipolar with **8**-**Z**eros **S**ubstitution)
  - If 8 0's and last pulse was positive, replace 8 0's with 000+ - 0 - +
  - If 8 0's and last pulse was negative, replace 8 0's with 000- + 0 + -
  - HDB3 (**H**igh **D**ensity **B**ipolar **3**-Zeros)

	Number of Bipolar Pulses (ones) since Last Substitution	
Polarity of Preceding Pulse	**Odd**	**Even**
–	000–	+00+
+	000+	–00–

Encoding Rules for B8ZS and HDB3



V is called violation. Because, in Bipolar AMI, alternating signal element can not be the same of the previous one.

Digital Data, Analog Signals

- Transmit digital data over media that only support analog signals, e.g. telephone network, microwave systems
  - Telephone network designed to transmit signals in voice-frequency (300 to 3400 Hz)
  - Modems (Modulator-Demodulator) convert digital data to signals in this frequency range
- 3 basic modulation techniques:
  - 1. Amplitude Shift Keying (ASK)
  - 2. Phase Shift Keying (PSK)
  - 3. Frequency Shift Keying (FSK)
- Resulting signal occupies bandwidth centered on carrier frequency

Digital Data, Analog Signals

Amplitude Shift Keying (ASK): is a form of amplitude modulation that represents digital data as variations in the amplitude of a carrier wave.

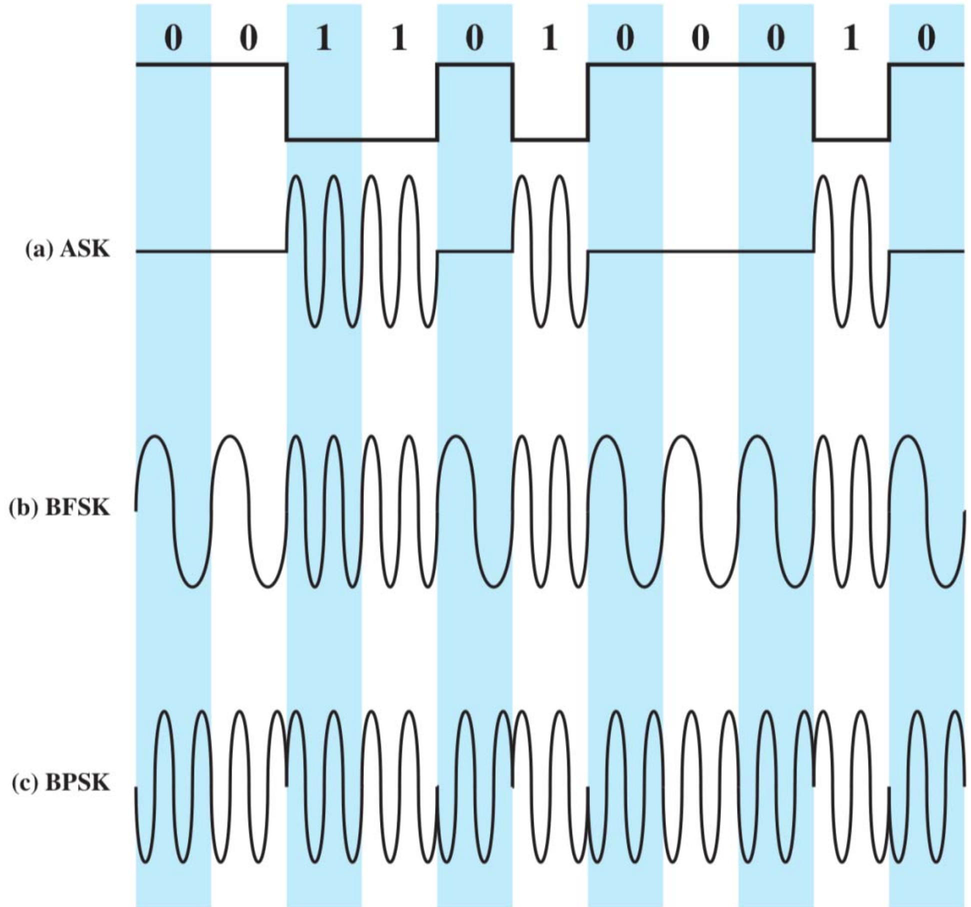
Phase Shift Keying (PSK): is a digital modulation process which conveys data by changing (modulating) the phase of a constant frequency reference signal (the carrier wave)

Binary Phase Shift Keying (BPSK) is a digital modulation scheme that conveys data by changing, or modulating, two different phases of a reference signal (the carrier wave).

Frequency Shift Keying (FSK): is a frequency modulation scheme in which digital information is encoded on a carrier signal by periodically shifting the frequency of the carrier between several discrete frequencies

Binary FSK(BFSK): is a constant-envelope form of angle modulation similar to conventional frequency modulation except that the modulating signal varies between two discrete voltage levels (i.e., 1's and 0's) rather than with a continuously changing value, such as a sine wave. Binary FSK is the most common form of FSK.

Modulation of Analog Signals for Digital Data



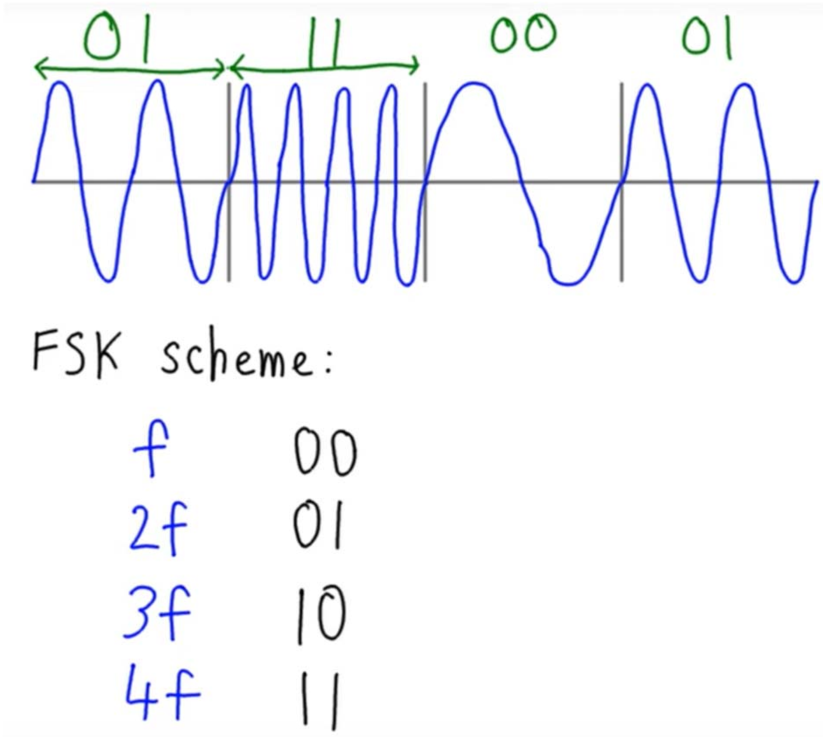
Modulation of Analog Signals for Digital Data

- We transmit an analog signal for the fixed duration at a particular frequency but it represents 2 bits in this case.

  If we had 8 different frequencies we would have three bits per signal element.

  We need to be able to represent any sequence of bits we need to have a power of two the number of different levels.

  We can do the same with Phase Shift Keying instead of 2 phases we can have more phases like 4, 16, 256.

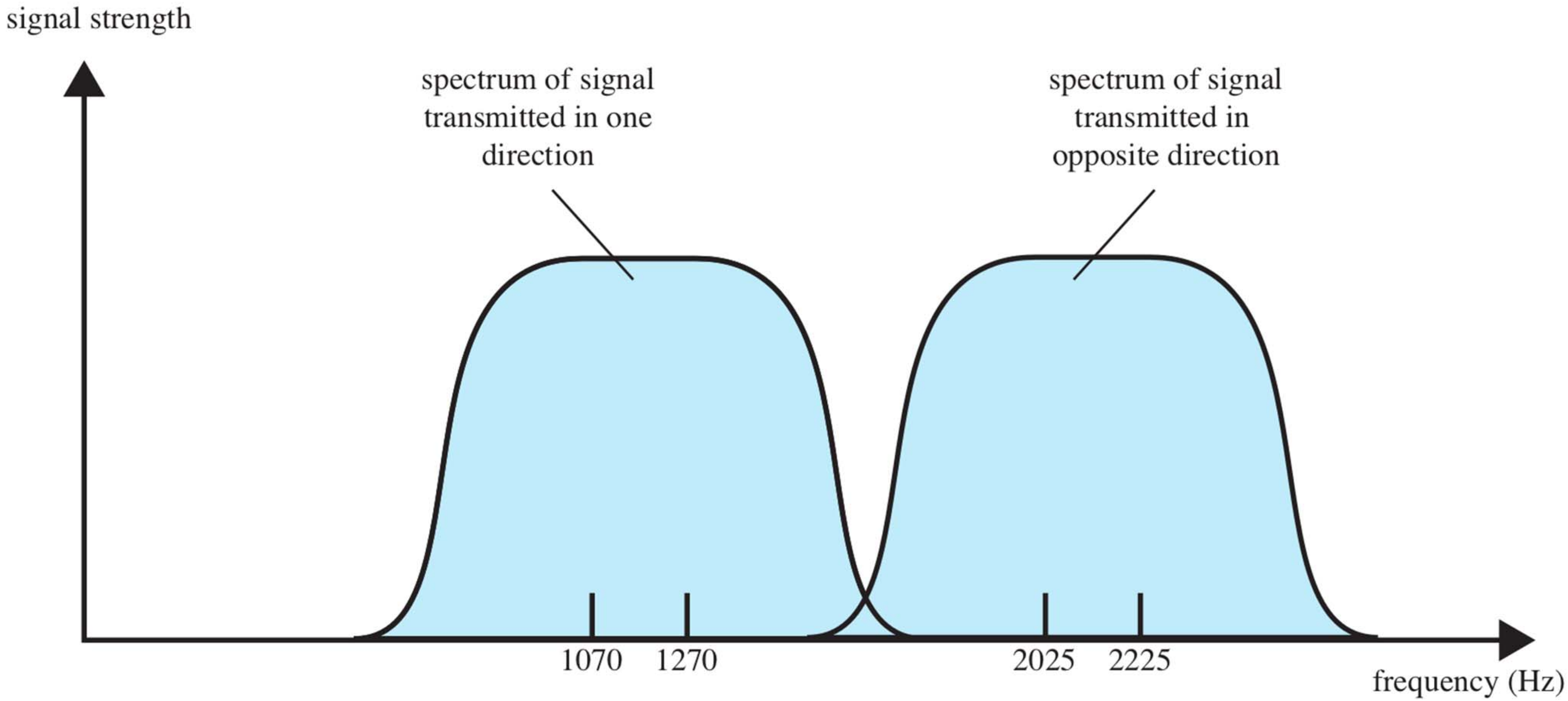


Comparing the Shift Keying Schemes

- **Amplitude Shift Keying (ASK)**
  - Inefficient modulation technique
  - Used on voice lines < 1200 bps and optical fibre
- **Frequency Shift Keying (FSK)**
  - Used on voice lines, coaxial cable, HF radio systems
  - Extended with M frequencies: improve efficiency, higher error rate
- **Phase Shift Keying (PSK)**
  - Used in wireless transmission systems
  - Extended with M phases, e.g. QPSK (M = 4),
  - Combined with ASK: Quadrature Amplitude Modulation (QAM); used in ADSL and wireless systems

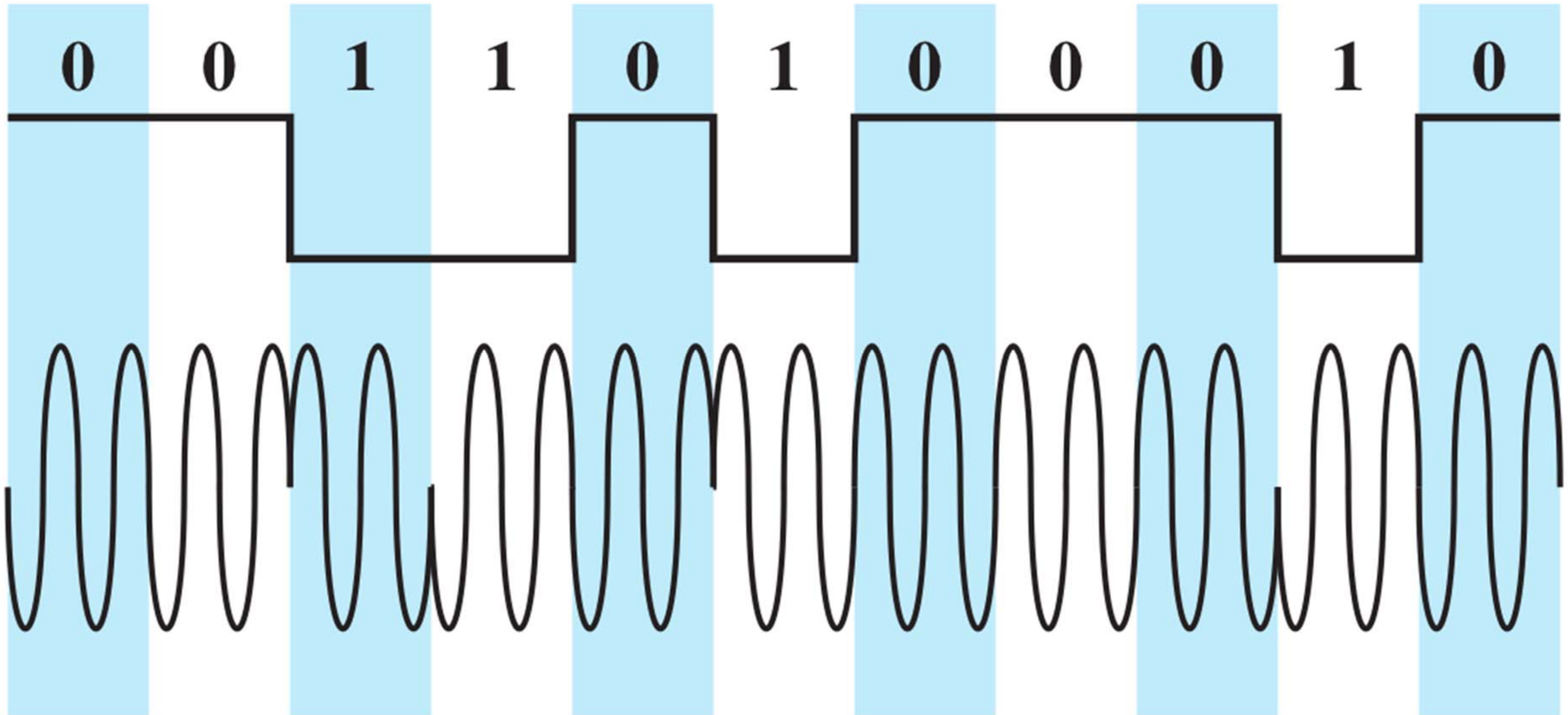
Example of FSK

Full-Duplex FSK Transmission on a Voice-Grade Line



Example of PSK

Differential Phase-Shift Keying



Example of QAM (Quadrature Amplitude Modulation)

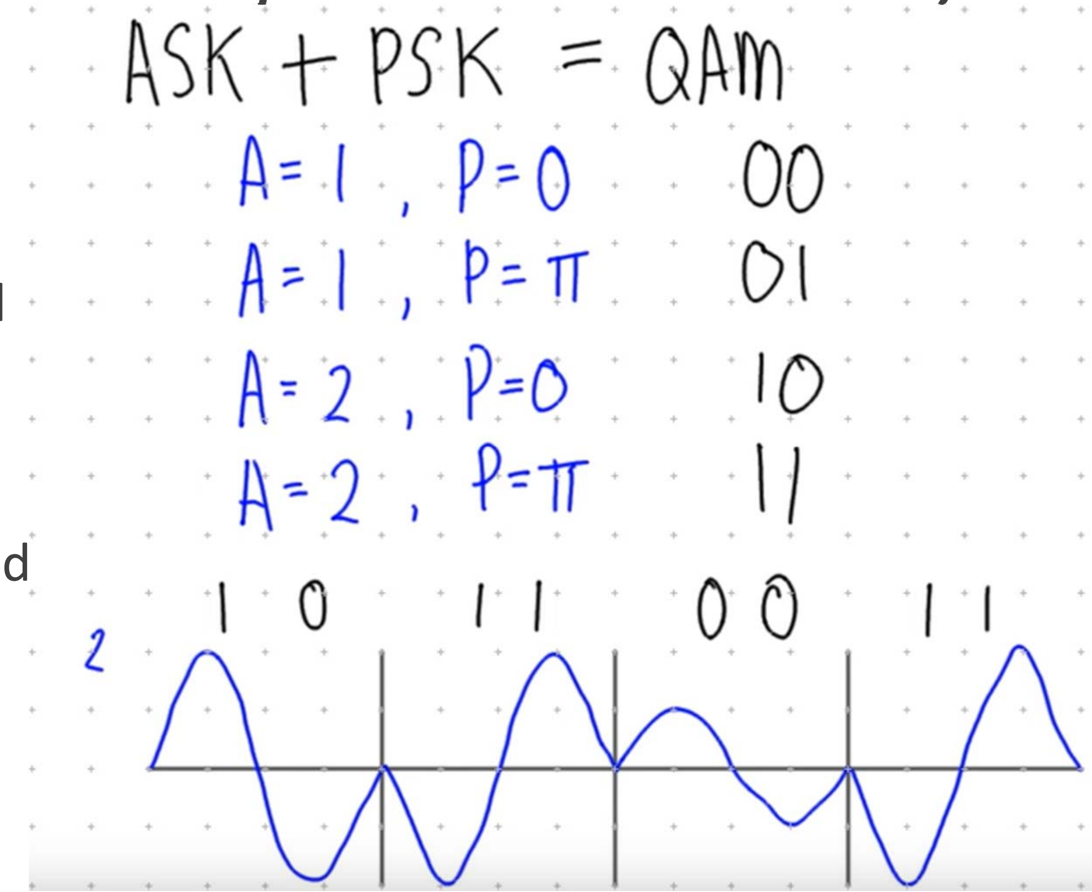
It is very common in real communication

It is not limited only to 4 levels. There are Also 16QAM, 256QAM and even higher.

The more levels the more bits we can send per signal element.

Here we have 2 bits per signal element.

The faster we can send bits. But like we said Before, if we have less difference between the levels, there is more probability for errors due to receiver sensitivity issues.



Example Technologies using Shift Keying

ASK: Optical fibre, RFID

FSK: HF/shortwave radio, UHF/VHF radio communications, RFID

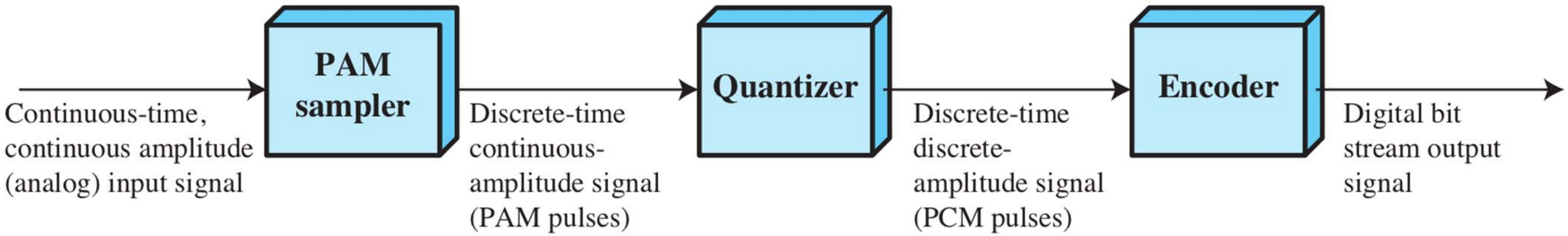
PSK and QAM: Mobile phones, Wi-Fi, cable modems, xDSL, DVB, …..

Analog Data, Digital Signals

- **Two options:**
  - 1. Convert analog data to digital data; transmit digital, data as digital signal (e.g. using NRZ)
  - 2. Convert analog data to digital data; modulate the data to transmit as analog signal (e.g. PSK)

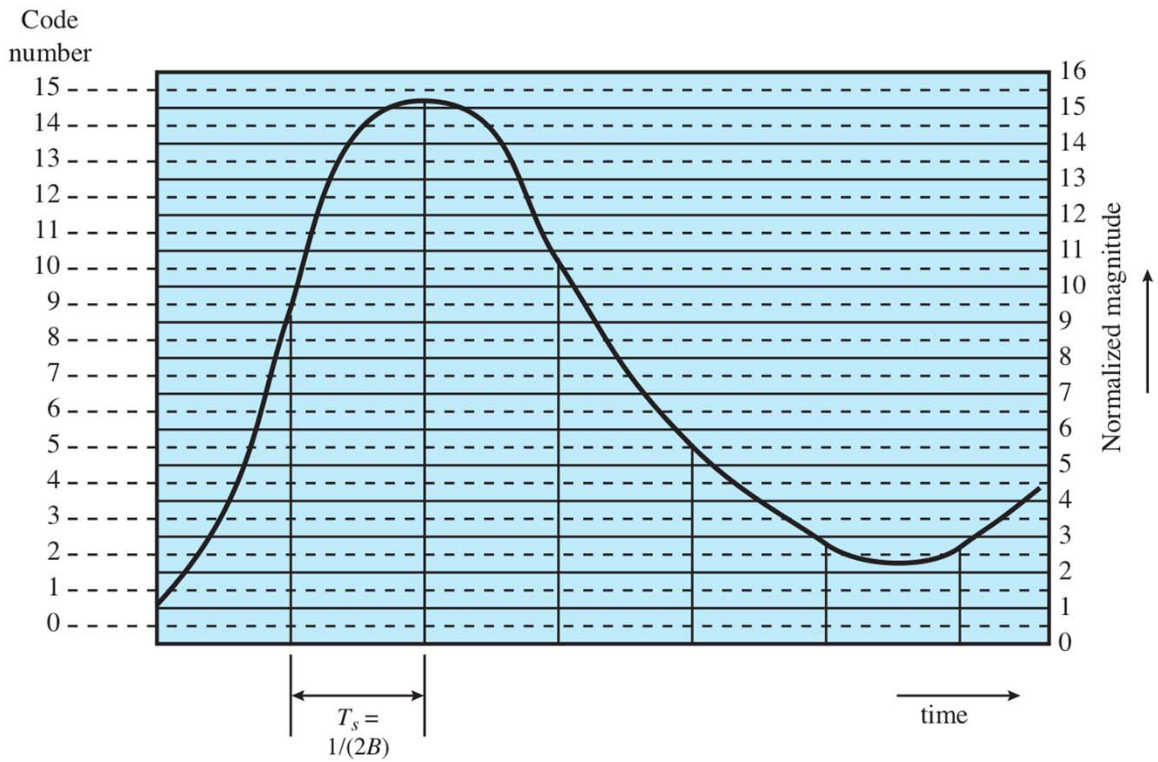
- **How to digitize analog data?**
  - Codec converts analog to digital data, and recovers digital data from analog data
  - Consider two techniques used in codecs: Pulse Code Modulation and Delta Modulation

Pulse Code Modulation (PCM)



1. Divide the normalized input magnitude into 2^n different levels, with corresponding code numbers
2. Sample analog input every *Ts* seconds → Pulse Amplitude Modulation (PAM) value
3. Map PAM value to nearest code number
4. Convert code number to n-bit binary PCM code

Pulse Code Modulation 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

Analog Data, Analog Signals →Modulating Signals

- Combine input signal, *m(t)*, and carrier at frequency f_c to produce signal *s(t)* whose bandwidth is centered on f_c

- Why? If analog transmission systems . . .
  - Digital data must be converted to analog form (e.g. PSK, FSK)
  - Analog signals may need to be transmitted at higher frequency than analog data
  - Changing frequency of analog data allows for frequency division multiplexing (sending different analog data in one analog signal)

- Principal techniques: amplitude modulation (AM), frequency modulation (FM), phase modulation (PM)

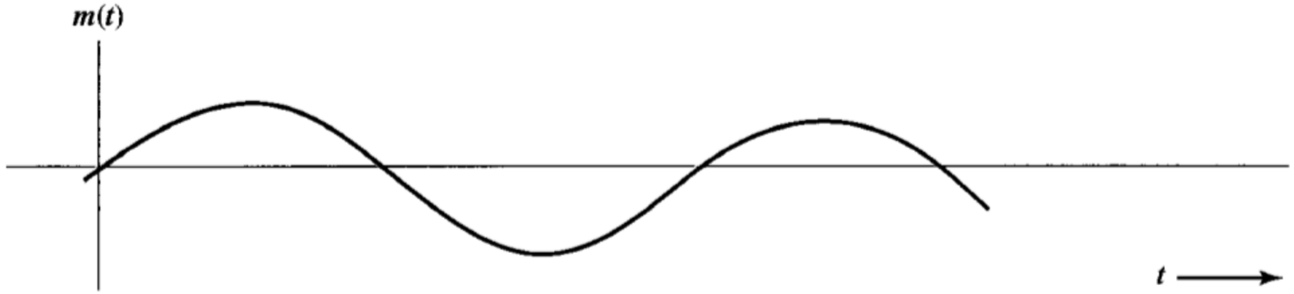
Analog Data, Analog Signals → Modulating Signals

- **Amplitude modulation** is a process by which the wave signal is transmitted by modulating the amplitude of the signal.

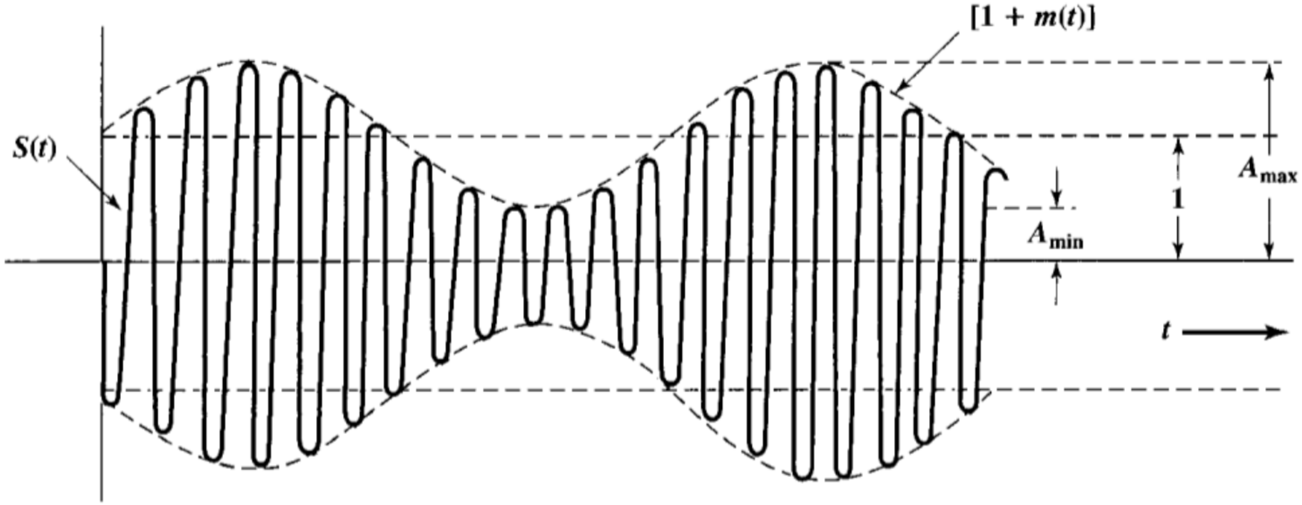
- **Phase modulation (PM)** is a modulation pattern for conditioning communication signals for transmission. It encodes a message signal as variations in the instantaneous phase of a carrier wave.

- **Frequency modulation (FM)** is the encoding of information in a carrier wave by varying the instantaneous frequency of the wave.

Amplitude Modulation

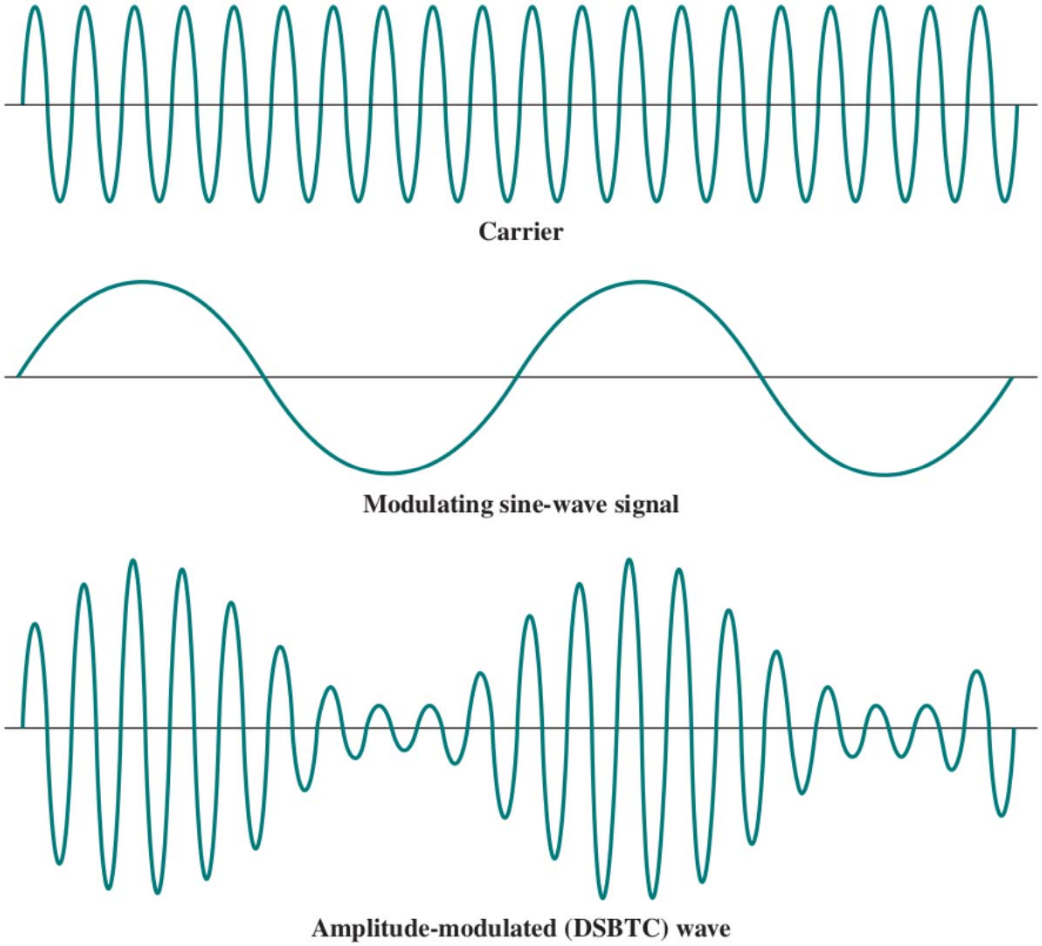


(a) Sinusoidal modulating wave

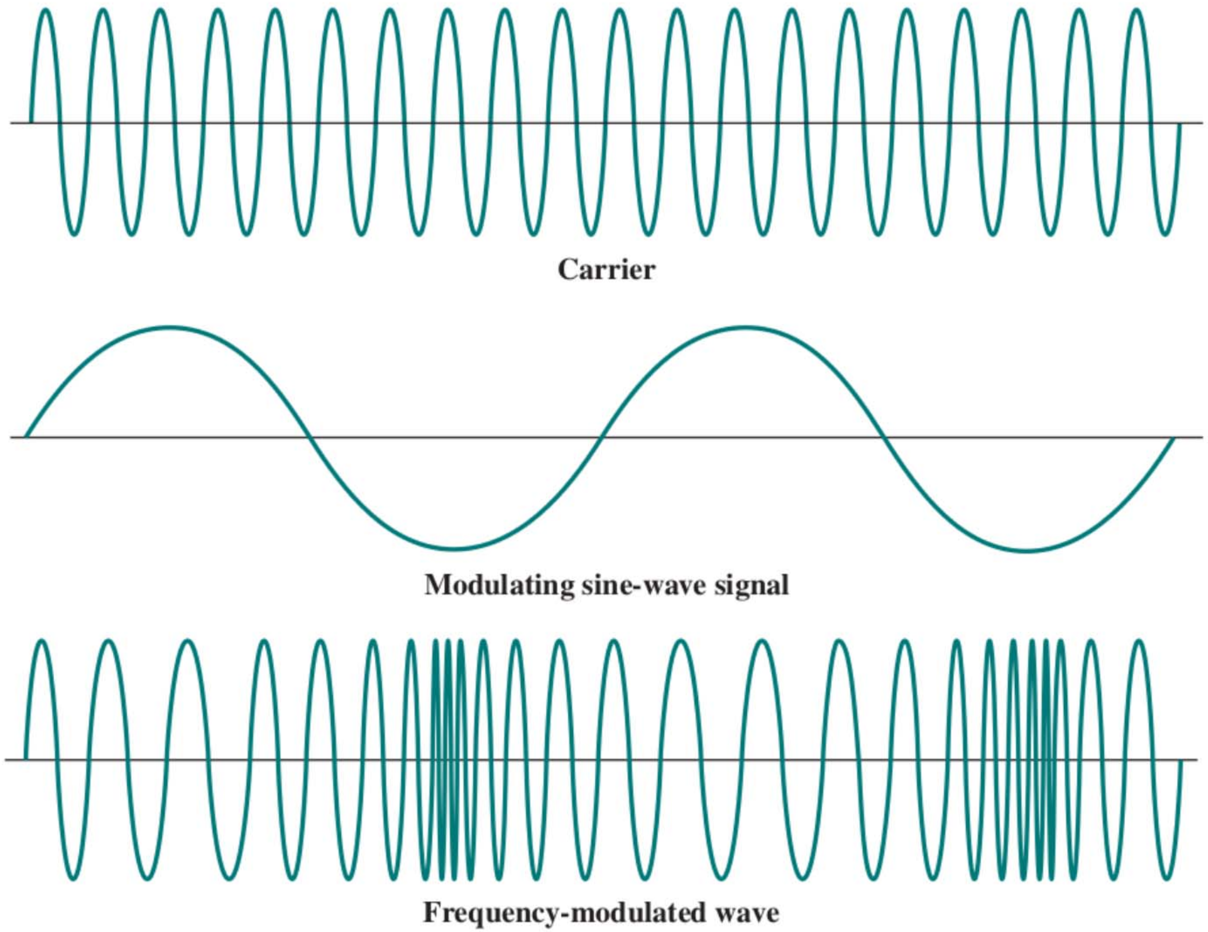


(b) Resulting AM signal

Amplitude Modulation of a Sine-Wave Carrier by a Sine-Wave Signal

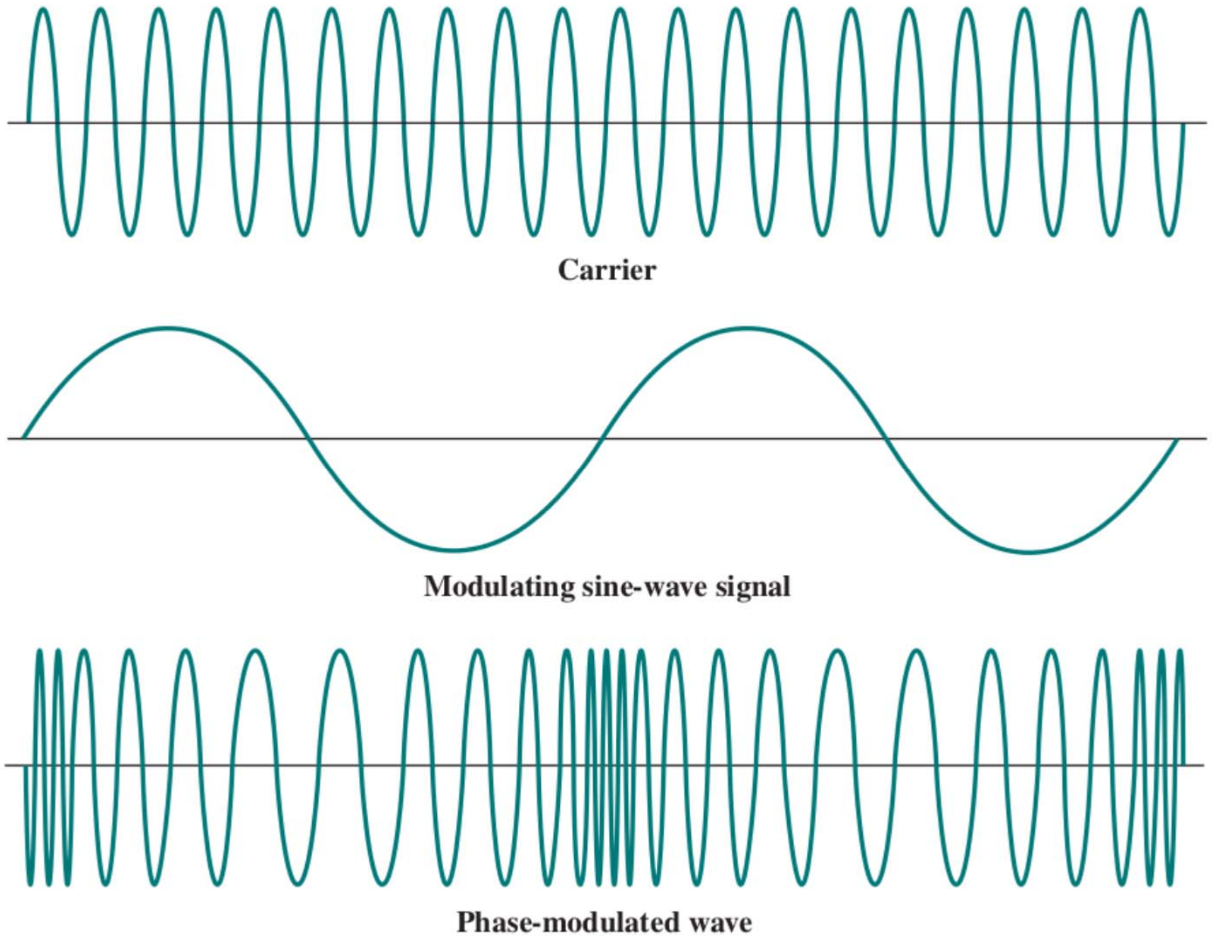


Frequency Modulation of a Sine-Wave Carrier by a Sine-Wave Signal



If the frequency of the modulated wave is slightly lower than the carrier it means the amplitude of the modulating signal is positive and vice versa

Phase Modulation of a Sine-Wave Carrier by a Sine-Wave Signal



Very similar to FM, now the changing phase instead of frequency.
It encodes a message signal as variations in the instantaneous phase of a carrier wave.