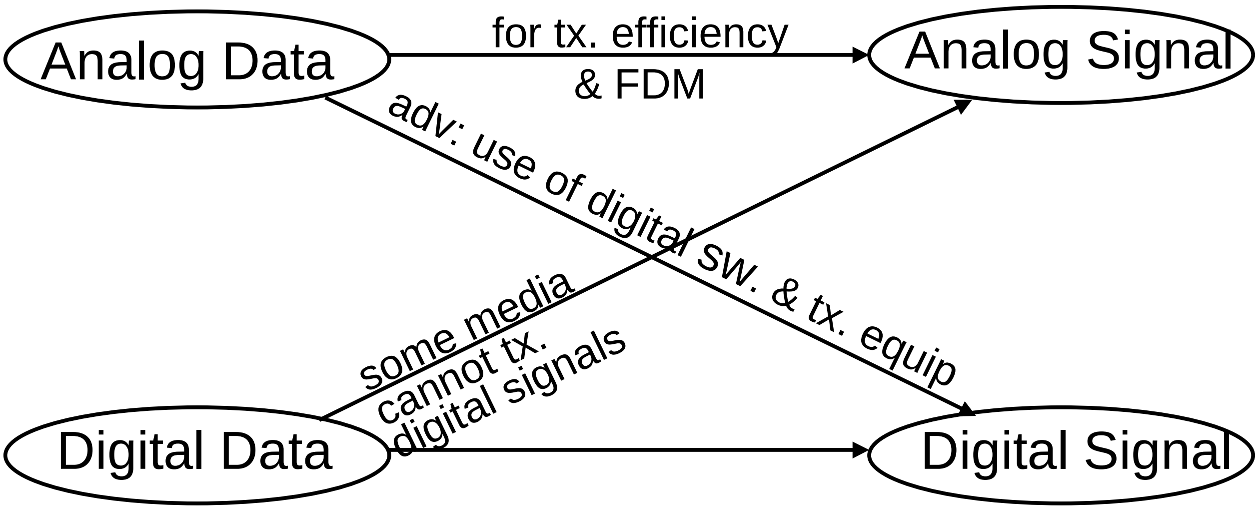
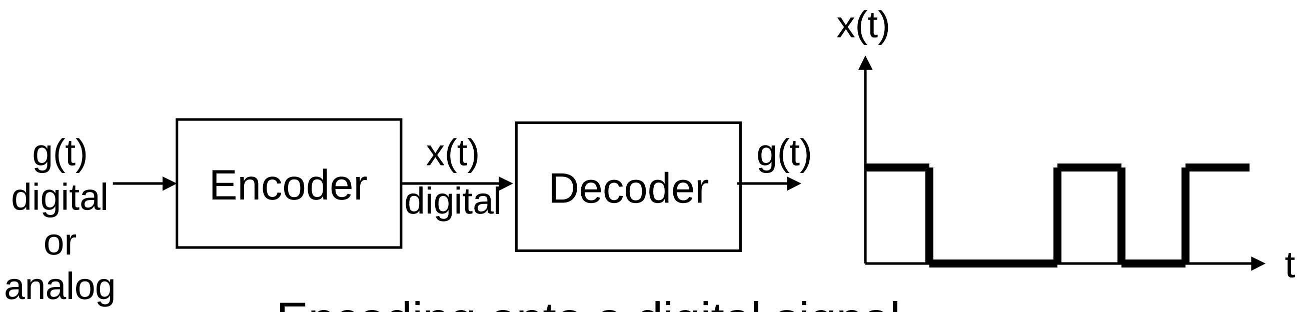
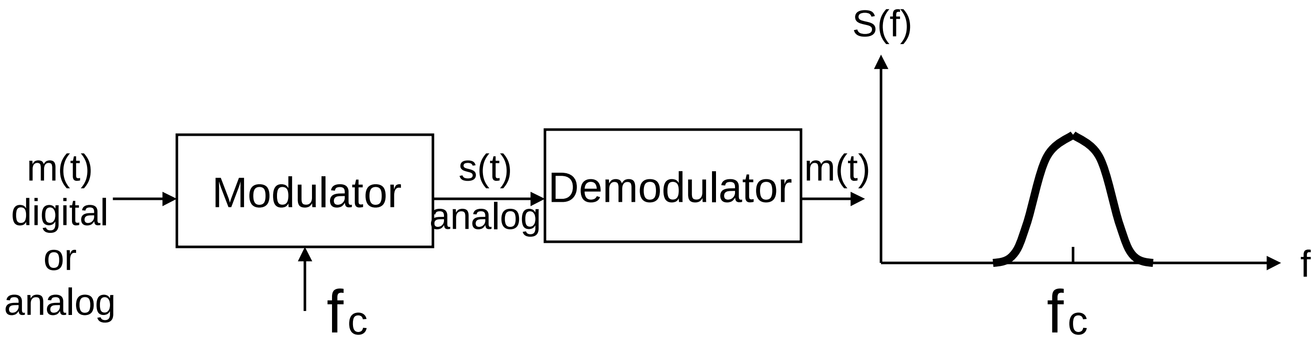


Encoding and modulation techniques



Encoding onto a digital signal



Modulation onto an analog signal

m(t) = baseband signal or modulating signal

fc = carrier signal

s(t) = modulated signal

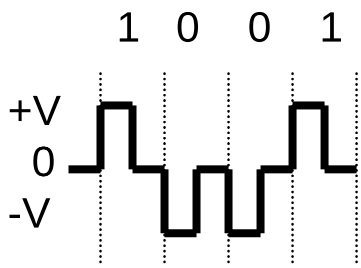
1. Digital Data ⇒ Digital Signals

- A **digital signal** is a sequence of discrete, discontinuous voltage pulses. Each pulse is a **signal element**
- Binary data are transmitted by encoding each data bit into signal elements
- Encoding scheme: Mapping from data bits to signal elements
- Key data transmission terms

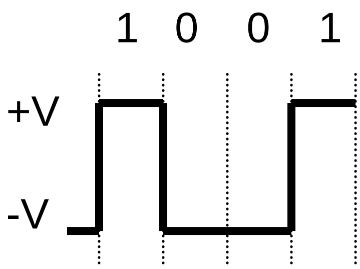
Term	Units	Definition
Data element	bits	A single binary one or zero.
Data rate	bits per second (bps)	The rate at which data elements are transmitted.
Signal element	Digital: a voltage pulse of constant amplitude. Analog: a pulse of constant frequency, phase, and amplitude.	That part of a signal that 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

- Mark: binary digit 1; Space: binary digit 0

- Various encoding schemes
- Evaluation factors
  - Signal spectrum: less bandwidth, no dc component, shape of spectrum (better to center in the middle of bandwidth)
  - Clocking: self-clocking capability is desired for synchronization
  - Error detection: better to have error-detection capability
  - Signal interference and noise immunity:
  - Cost and complexity:



- RZ (Return to Zero)
  - 0: positive pulse
  - 1: negative pulse
  - Signal returns to zero after each encoded bit
- NRZ (Nonreturn to Zero)
  - Voltage level is constant during bit interval (no return to a zero voltage level)



  - NRZ-L (NRZ Level)
    - 0: positive voltage
    - 1: negative voltage
  - NRZ-I (NRZ Inverted)
    - a form of differential encoding
    - 1: transition at the beginning of bit interval
    - 0: no transition

- NRZ is simple, and efficiently use bandwidth
- NRZ limitations
  - presence of dc component
  - lack of synchronization capability

- Multilevel Binary
  - Bipolar-AMI (Alternate Mark Inversion)
    - Three voltage levels (positive, zero, negative)
    - 0: zero voltage
    - 1: alternately by positive and negative voltages
    - Better synchronization than NRZ
    - no dc component
    - error detection capability
  - Pseudoternary
    - Same as bipolar-AMI, except representation of 0 and 1 is interchanged
- Biphase
  - Always a transition at the middle of each bit interval
  - Manchester
    - 0: high to low transition
    - 1: low to high transition
  - Differential Manchester
    - 0: transition at the beginning of bit interval
    - 1: no transition
  - Synchronization and error detection capability, and no dc component

Definition of 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 (one bit time), 1 = transition at beginning of interval

Bipolar-AMI: 0 = no line signal, 1 = positive or negative level, alternating for successive ones

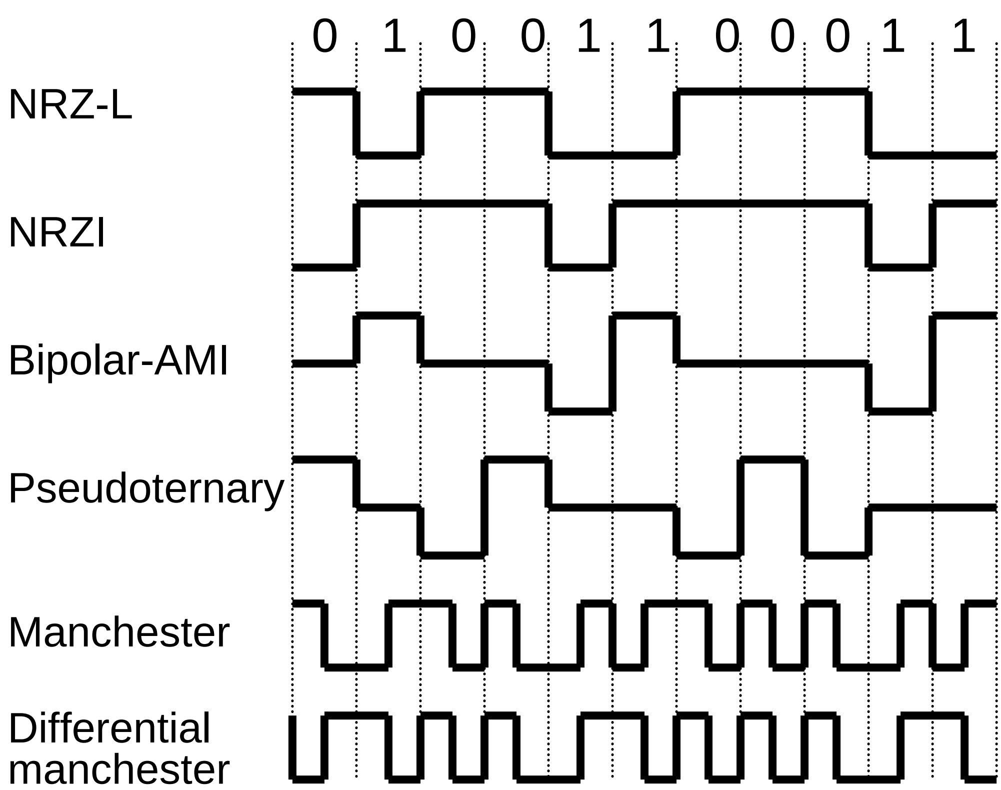
Pseudoternary: 0 = positive or negative level, alternating for successive zeros, 1 = no line signal

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

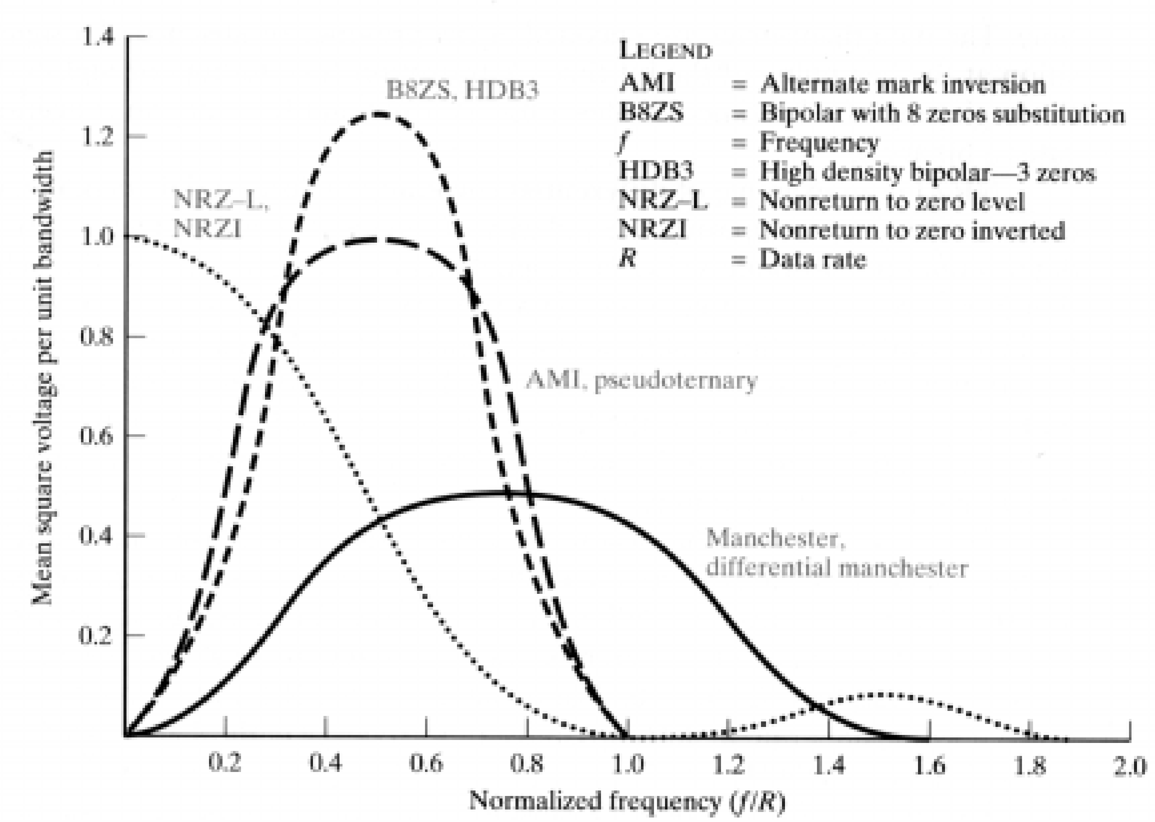


- Modulation Rate
  - Data rate (expressed in bps) = modulation rate (or signaling rate or signal transition rate)(expressed in baud) times the number of bits per signal elemet

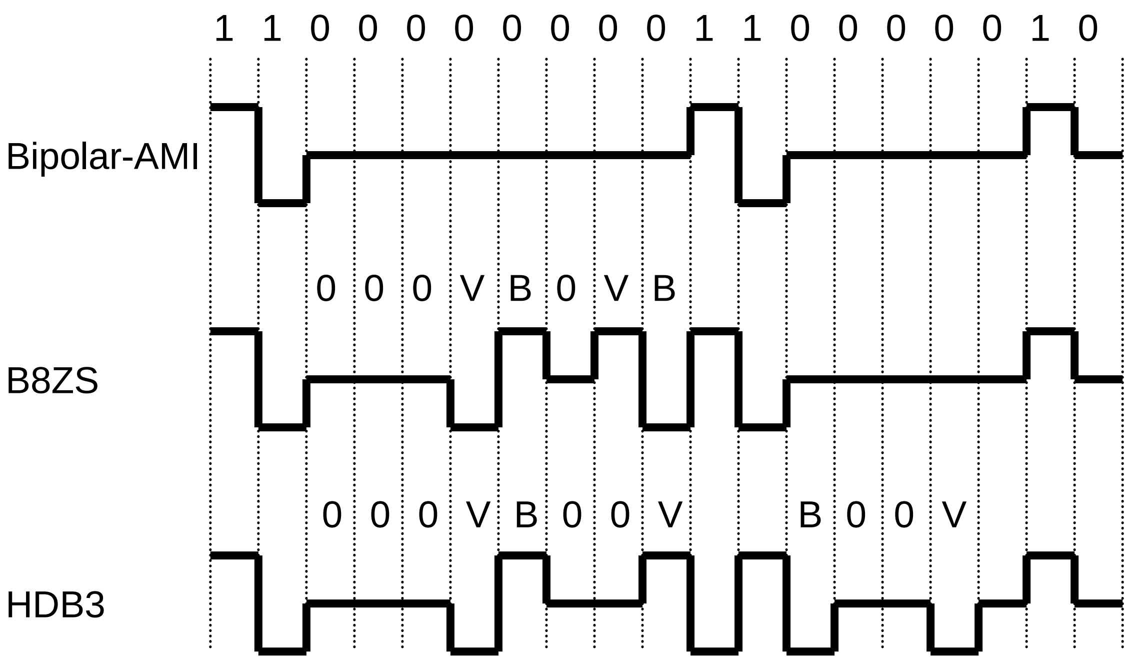
Normalized signal transition rate of various encoding schemes

	Minimum	101010…	Maximum
NRZ-L	0 (all 0’s or 1’s)	1.0	1.0
NRZI	0 (all 0’s)	0.5	1.0 (all 1’s)
Binary-AMI	0 (all 0’s)	1.0	1.0
Pseudoternary	0 (all 1’s)	1.0	1.0
Manchester	1.0 (1010…)	1.0	2.0 (all 0’s or 1’s)
Diff Manchester	1.0 (all 1’s)	1.5	2.0 (all 0’s)

Spectral density of various signal encoding schemes



- Scrambling Techniques
  - For long-distance communications
  - No dc component, good synchronization and error detection capability, without reduction in data rate
  - B8ZS (Bipolar with 8-Zeros Substitution)
    - Based on bipolar-AMI
    - 8 consecutive zeros are encoded as either **000+-0-+** or **000-+0+-**, s.t. two code violations always occur
  - HDB3 (High-Density Bipolar 3-Zeros)
    - 4 zeros are encoded as either **000-, 000+, +00+, or -00-**
    - Substitution rule is s.t. the 4th bit is always a code violation, and successive violations are of alternate polarity (not to introduce dc component)



B = Valid bipolar signal, V = Bipolar violation

Summary

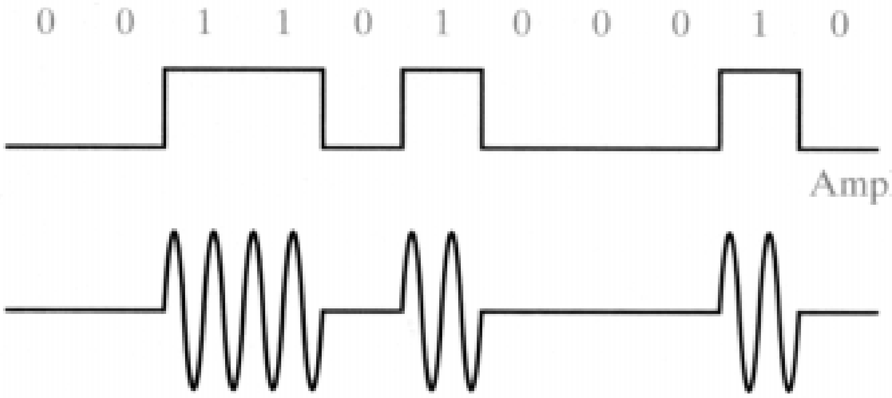
	NRZ (NRZ-L, NRZI*)	Multilevel Binary (Bipolar AMI, Pseudo ternary)	Biphase (Manchester, Diff. Man.*)	Scrambling (B8ZS, HDB3)
dc Comp.?	Yes	No	No	No
BW Required	B	B	2B	B
Self-clocking?	No	Yes, but ①	Yes	Better than multilevel
Error-detection?	No	Yes	Yes	Yes
Application	-Simple -Digital mag. recording		LAN	Long dist. comm.

* Differential encoding
① A long string of 0's cause a problem in AMI
A long string of 1's cause a problem inPseudoternary

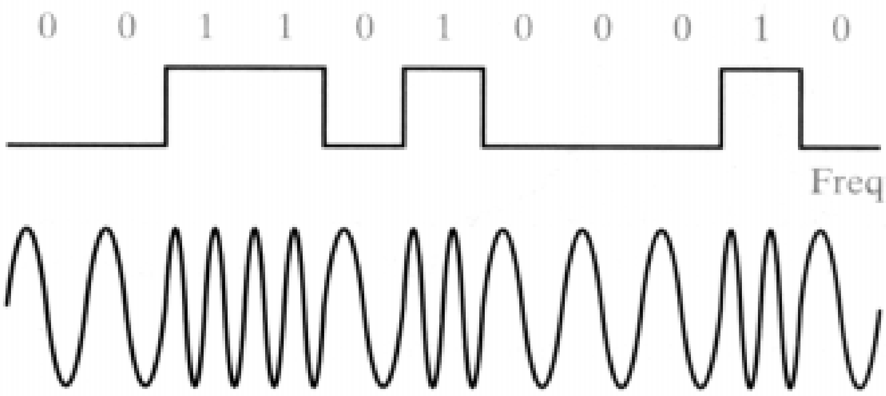
2. Digital Data ⇒ Analog Signals

- Encoding is by modulation of a continuous sinusoidal carrier signal. This involves alteration of some characteristics of the carrier signal - amplitude, frequency, or phase.
- Various encoding techniques, ASK, FSK, PSK,...

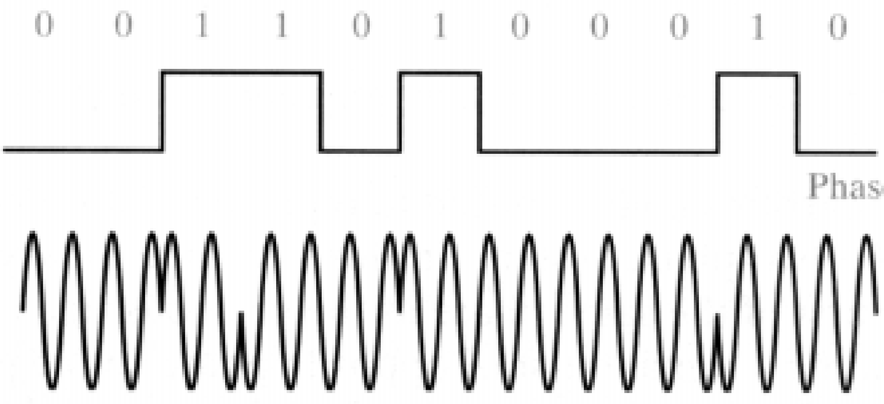
	ASK	FSK	(Diff.) PSK
Binary 1	$A\cos(2\pi f_c t + \theta c)$	$A\cos(2\pi f_1 t + \theta c)$	$A\cos(2\pi f_c t + 180°)$
Binary 0	0	$A\cos(2\pi f_2 t + \theta_c)$	$A\cos(2\pi f_c t)$



Amplitude-shift keying
(ASK)

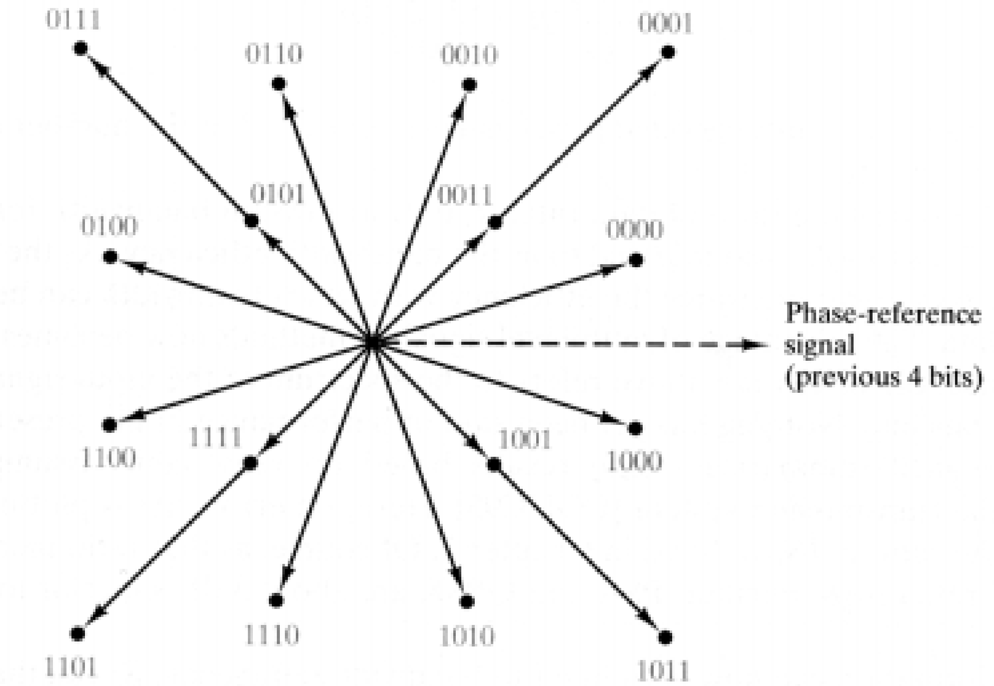


Frequency-shift keying
(FSK)



Phase-shift keying
(PSK)

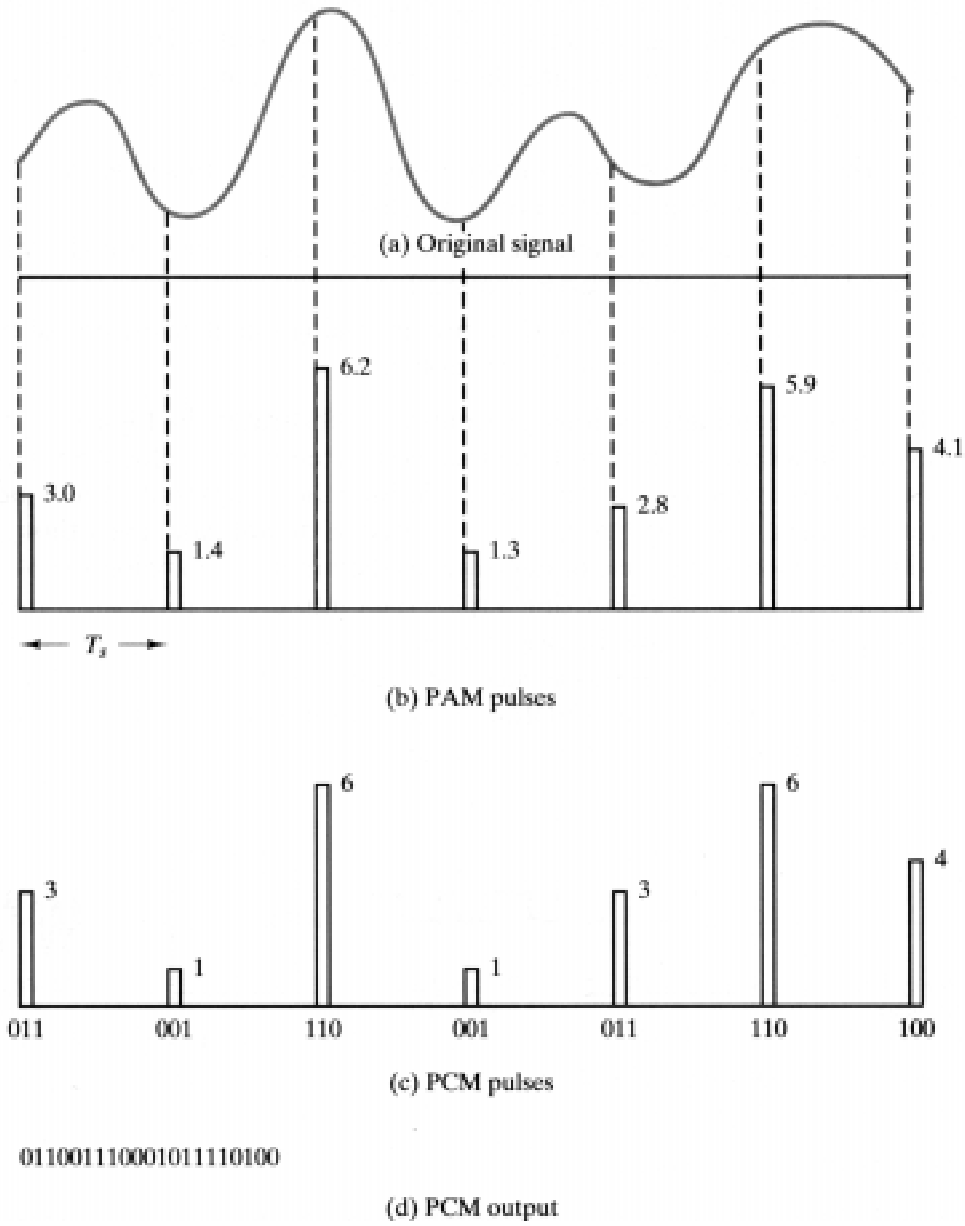
- QPSK(Quadrature PSK)
  - Each signal element represents two bits
    - Binary 11: $\cos(2\pi f_c t + 45°)$
    - Binary 10: $\cos(2\pi f_c t + 135°)$
    - Binary 00: $\cos(2\pi f_c t + 225°)$
    - Binary 01: $\cos(2\pi f_c t + 315°)$
- PSK using 12 angles and two amplitudes
  - 9,600 bps modem (2,400 baud x 4)



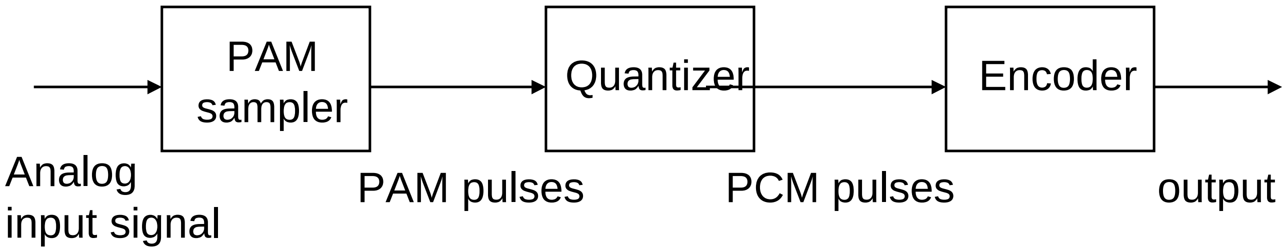
- Those patterns showing legal combinations of amplitude and phase are called **constellation patterns**
- 14,400 bps modem ⇒ 64 points constellation pattern
- 28,800 bps modem ⇒ 128 points

3. Analog Data ⇒ Digital Signals

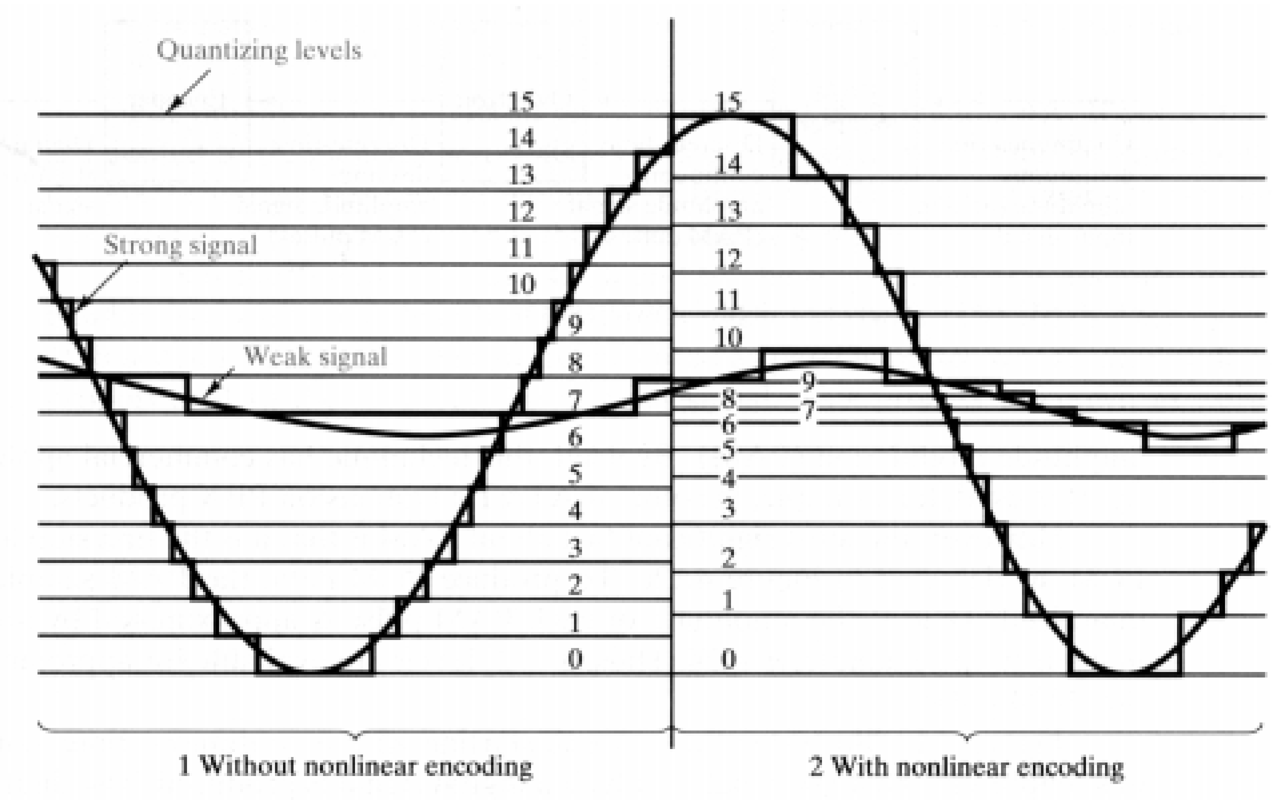
- PCM (Pulse Code Modulation)
  - Based on the **Nyquist's Sampling Theorem**: If a signal is periodically sampled at a rate ≥ twice the highest significant frequency component in the signal, then it can be reconstructed from the samples by using a low-pass filter



Analog-to-digital conversion

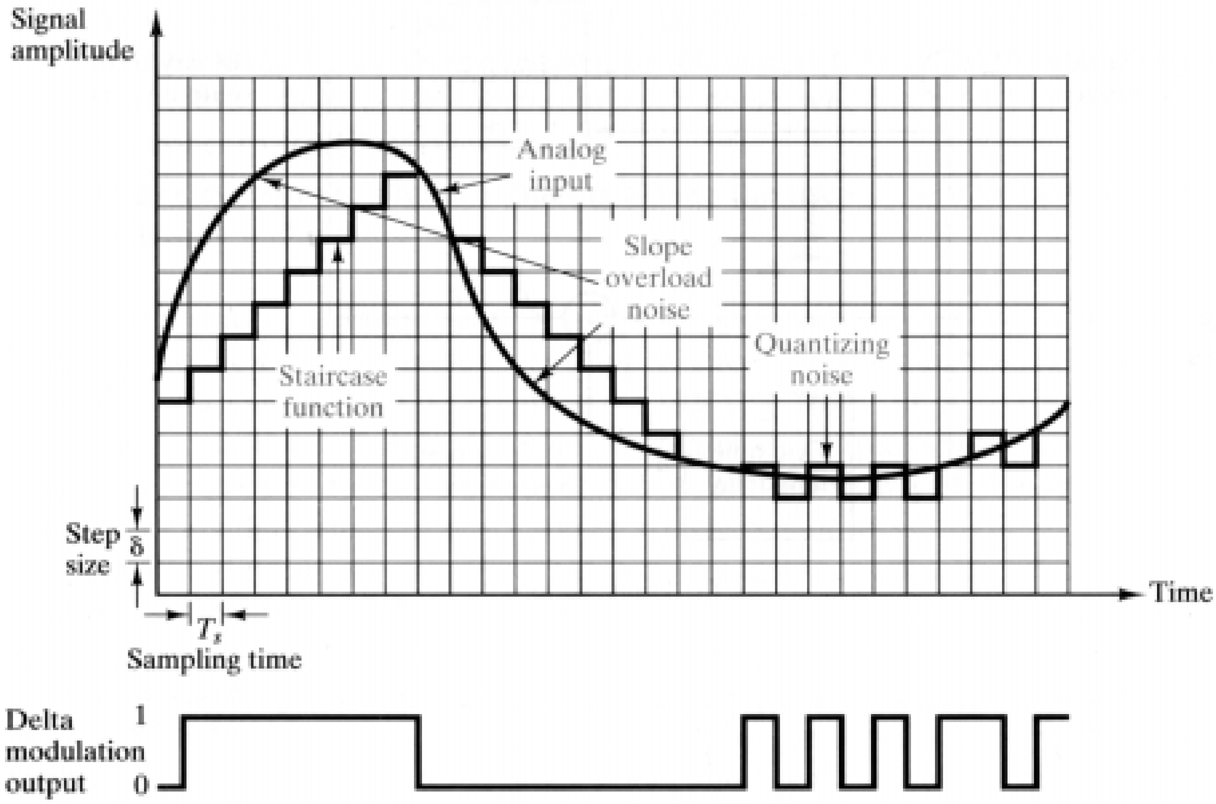


- Quantization noise: S/N = 6n + 1.8 dB, where n is # of bits used
- To reduce quantization noise
  - large n or
    - Nonlinear coding
    - Companding

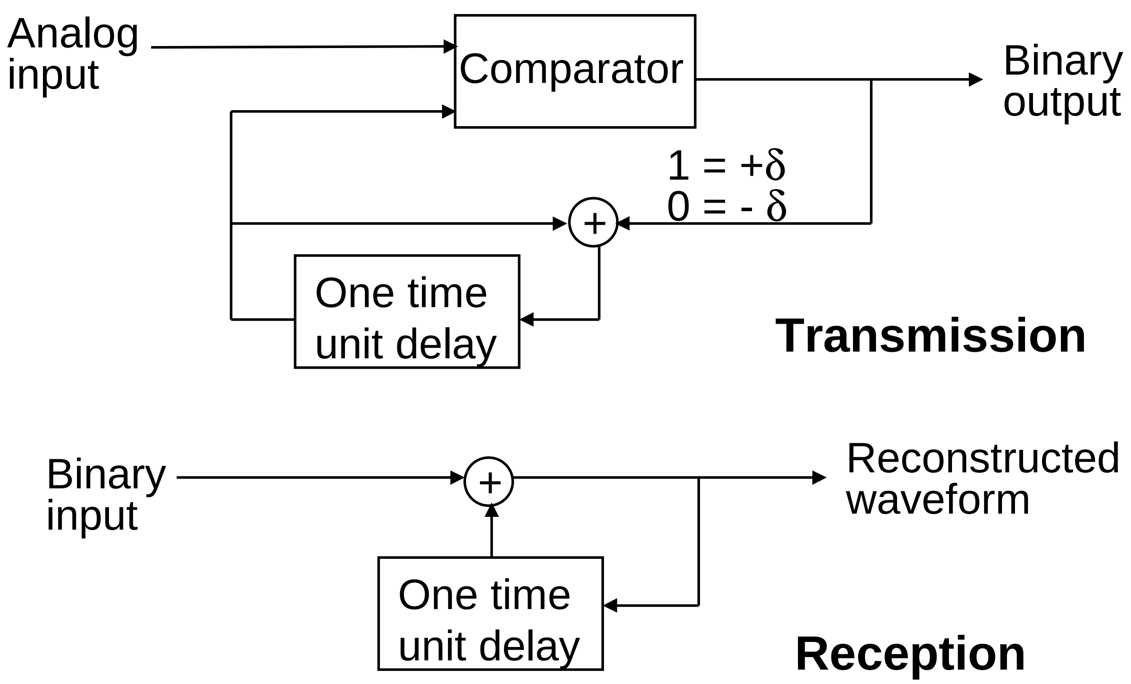


Effect of nonlinear coding

- DM (Delta Modulation)
  - Uses “n” = 1, I.e., binary digital signal is produced; “0” stands for change of -δ and “1” for change of + δ.
  - Higher sampling rate than PCM (Nyquist’s rate) is needed, but each sample uses only 1 bit instead of n.
  - Implementation much simpler than PCM.



Delta Modulation

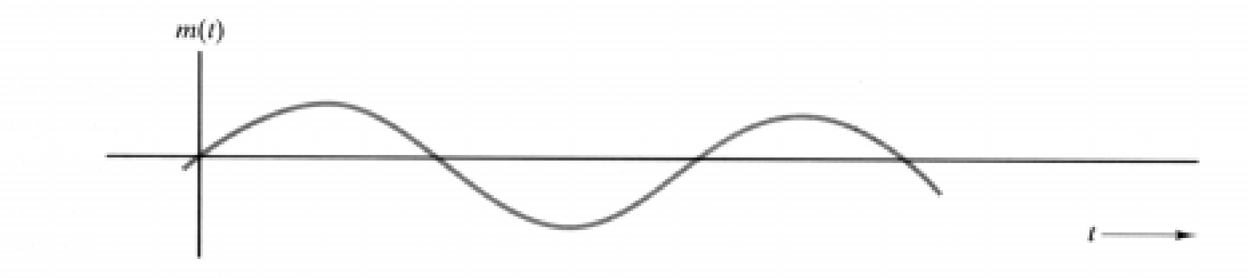


4. AnalogData ⇒ Analog Signals

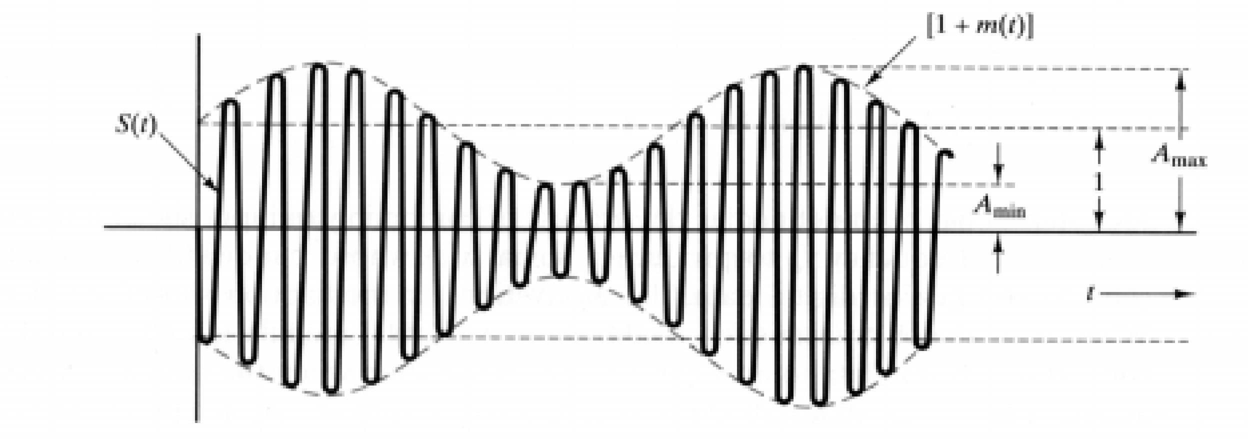
- Motivation
  - Low frequency analog signals cannot be transmitted on unguided media. (would require antennas with km diameters) ⇒ higher frequency needed.
  - For FDM (Frequency Division Multiplexing)

- AM (Amplitude Modulation)

$$s(t) = [1 + m(t)]\cos 2 f_c t$$

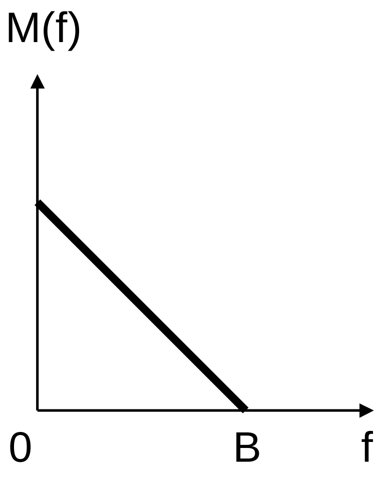


(a) Sinusoidal modulating wave

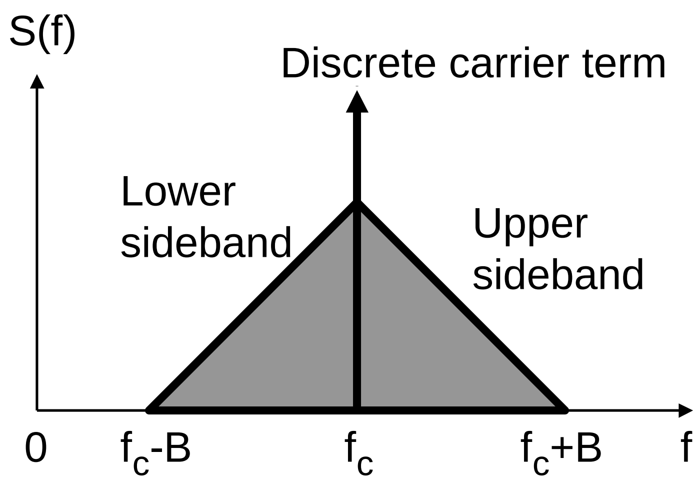


(b) Resulting AM signal

Spectrum of an AM signal



Spectrum of modulating signal



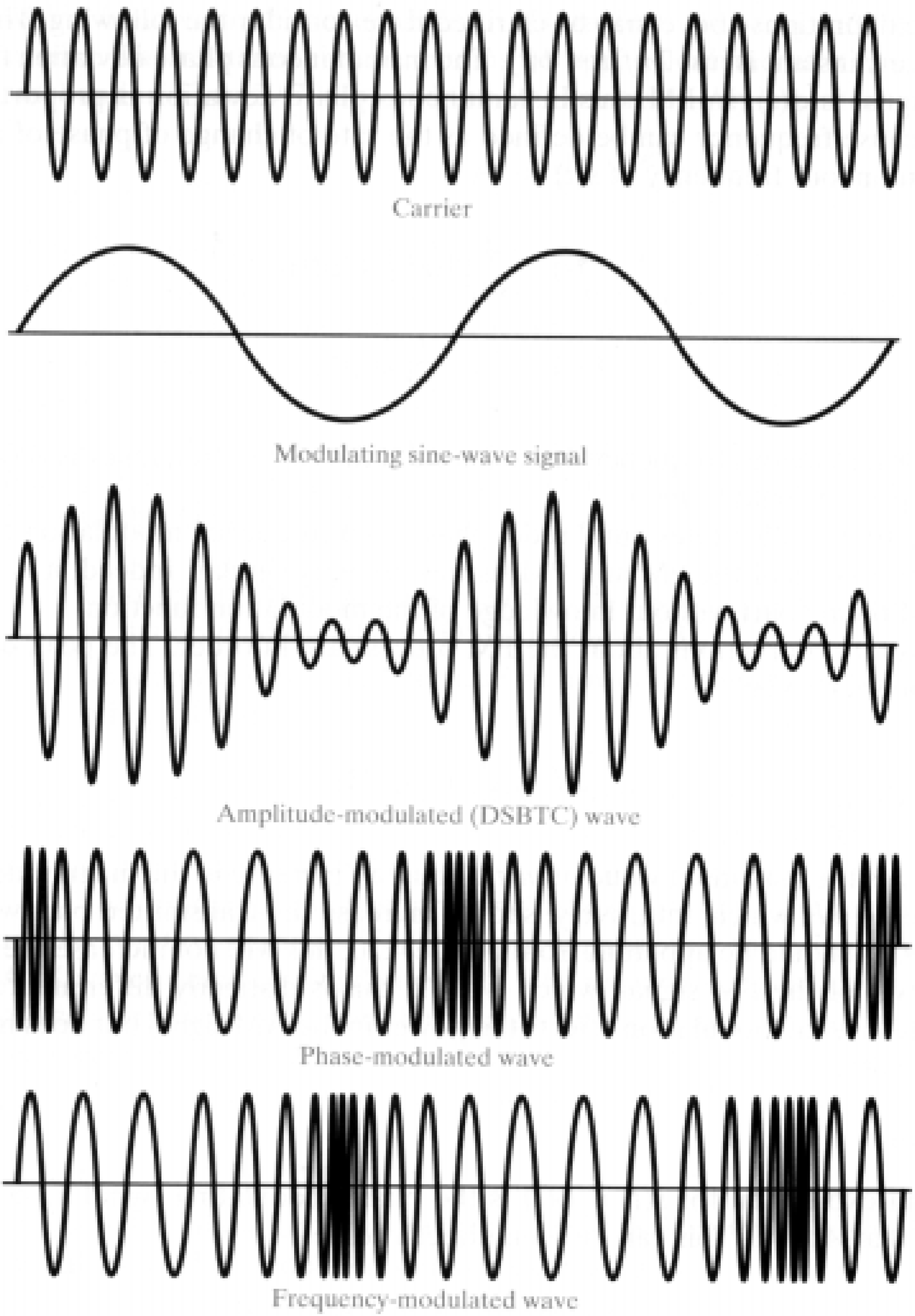
Spectrum of AM signal with carrier at f_c

DSBTC

- Angle Modulation (FM and PM)

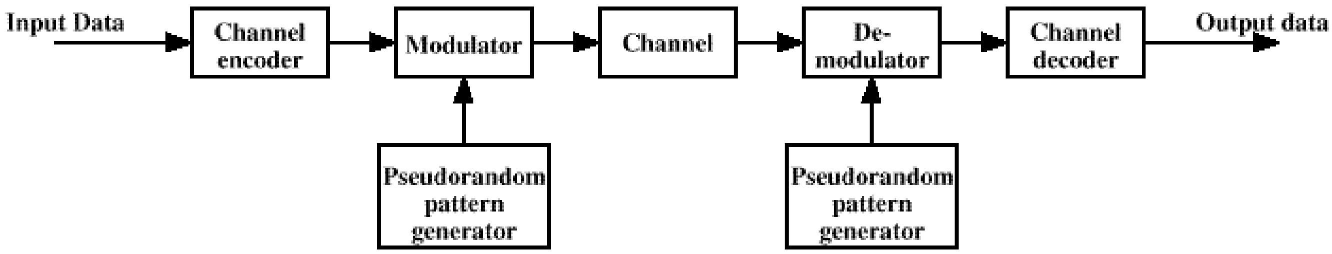
$$s(t) = A\cos[2 f_c t + \phi(t)]$$

  - PM: $\phi(t) = n_p m(t)$
  - FM: $\phi'(t) = n_f m(t)$



5. Spread Spectrum

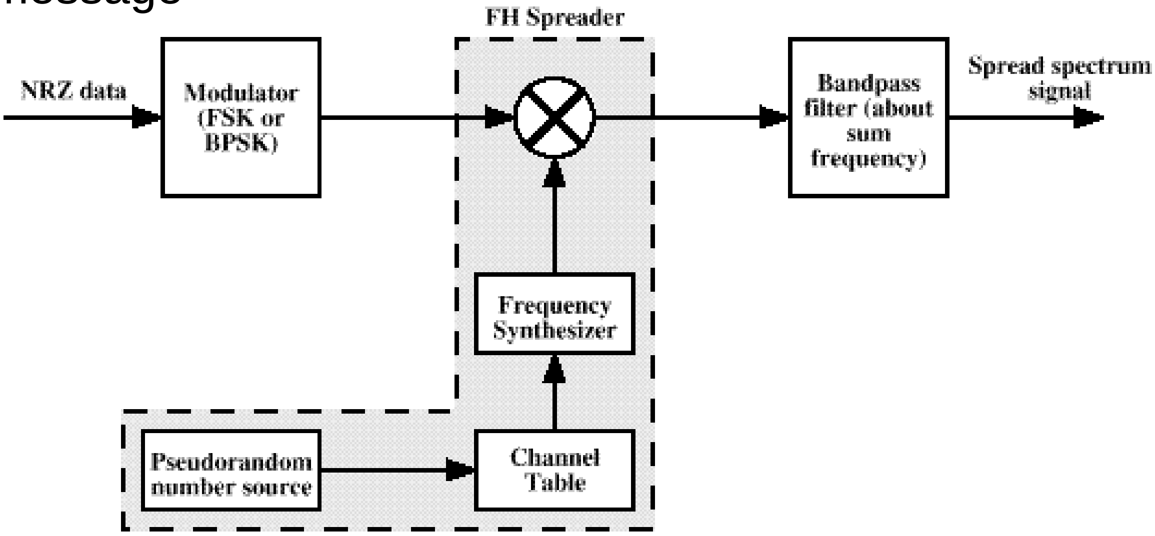
- Developed initially and popular for military and intelligence application
- Spread the info signal over a wider bandwidth in order to make jamming and interception more difficult



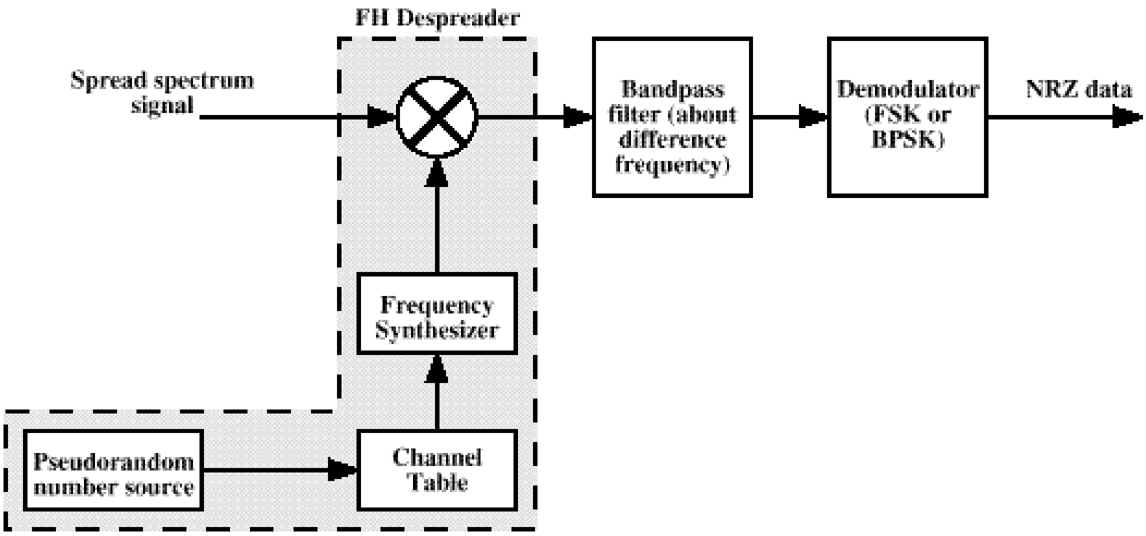
General model of spread spectrum digital communication system

- Two types:
  - Frequency hopping and Direct sequence
- Basis for CDMA (Code Division Multiple Access)

- Frequency-Hopping
  - Signal is transmitted over a seemingly random series of frequencies, hopping from frequency to frequency at split-second intervals.
  - A receiver, hopping between frequencies in synchronization with the transmitter, picks up the message

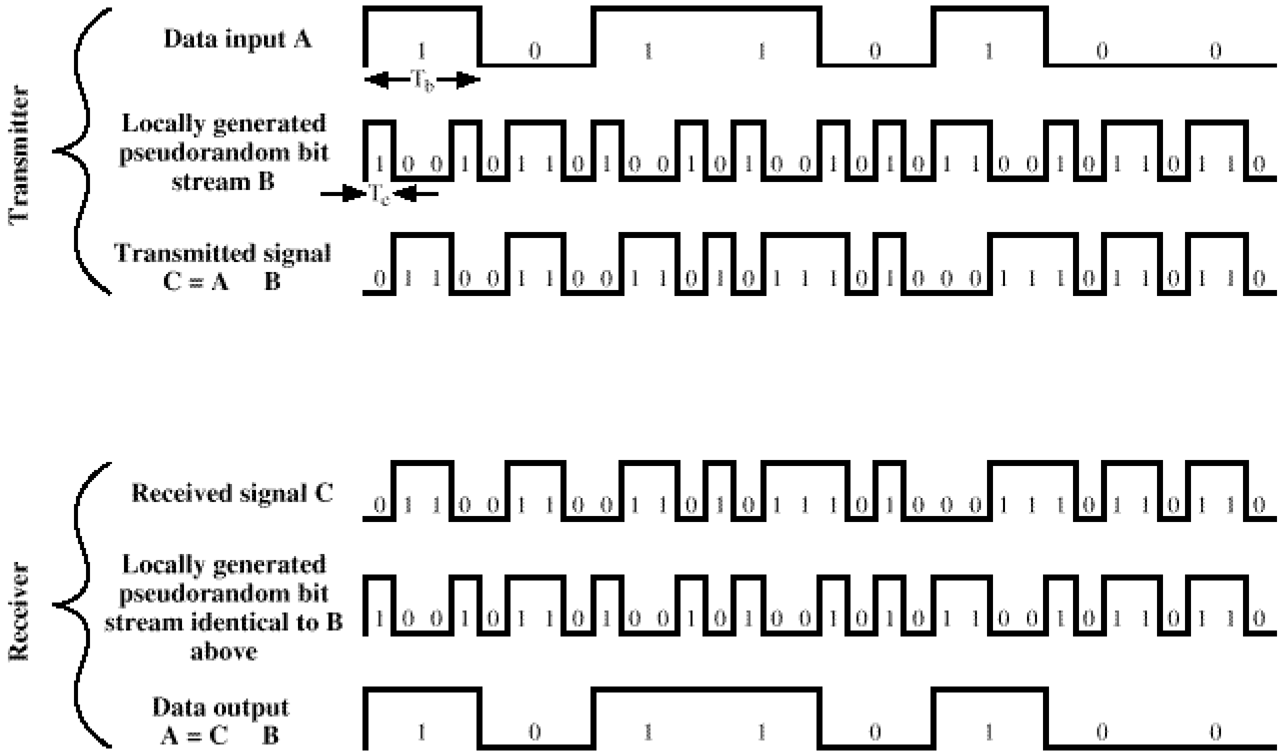


(a) Transmitter



(b) Receiver

- Direct Sequence
  – Each bit in the original signal is represented by multiple bits (**chip code**) in the transmitted signal
  – The chipping code spreads the signal across a wider frequency band in direct proportion to the number of bits used



Example of direct sequence spread spectrum