Signal Encoding Techniques

ITS323: Introduction to Data Communications
CSS331: Fundamentals of Data Communications

Sirindhorn International Institute of Technology
Thammasat University

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Introduction

Digital Data, Digital Signals

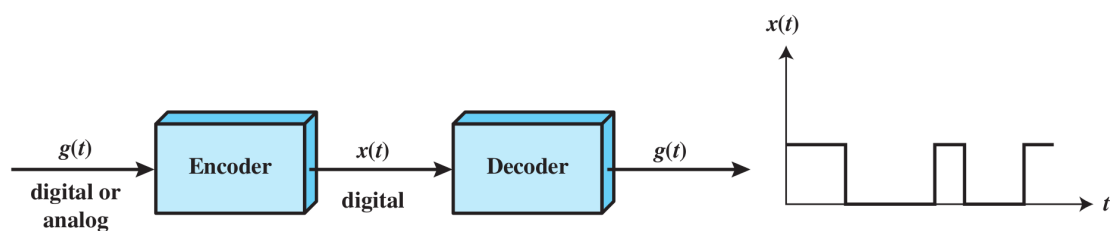## Digital Data, Analog Signals

Analog Data, Digital Signals

Analog Data, Analog Signals

Signal Encoding Techniques
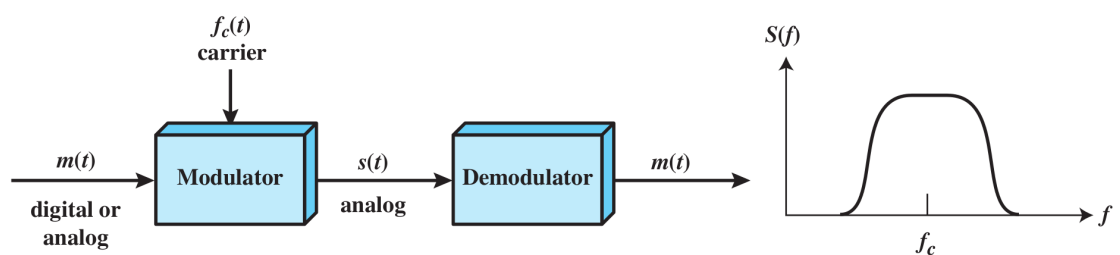
- Signals transmitted chosen to optimize use of transmission medium
  - E.g. conserve bandwidth, minimize errors
- Digital signaling: digital or analog data encoded into digital signal
- Analog signaling: digital or analog data transmitted by analog carrier signal using modulation
  - Baseband signal is the input data signal
  - Carrier signal has frequency $f_{carrier}$
  - Modulated signal is output

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Encoding and Modulation Techniques

$g(t)$

digital or analog

Encoder

$x(t)$

digital

Decoder

$g(t)$

$x(t)$

t

(a) Encoding onto a digital signal

$f_c(t)$
carrier

$m(t)$

digital or analog

Modulator

$s(t)$

analog

Demodulator

$m(t)$

$S(f)$

f_c

f

(b) Modulation onto an analog signal

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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

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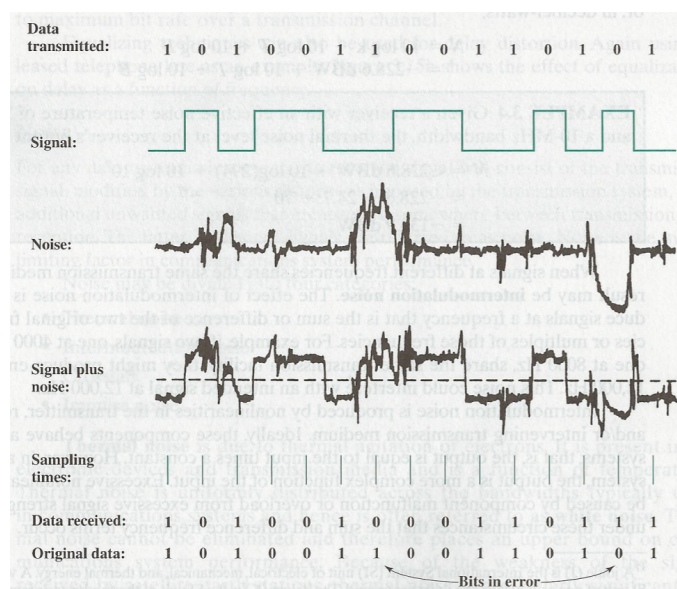
Analog Data, Digital Signals

Analog Data, Analog Signals

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
- ▶ Signaling or modulation rate = signal elements per second (baud)

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

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

Digital Signal Encoding Formats

NRZ-L

NRZI

Bipolar-AMI
(most recent preceding 1 bit has negative voltage)

Pseudoternary
(most recent preceding 0 bit has negative voltage)

Manchester

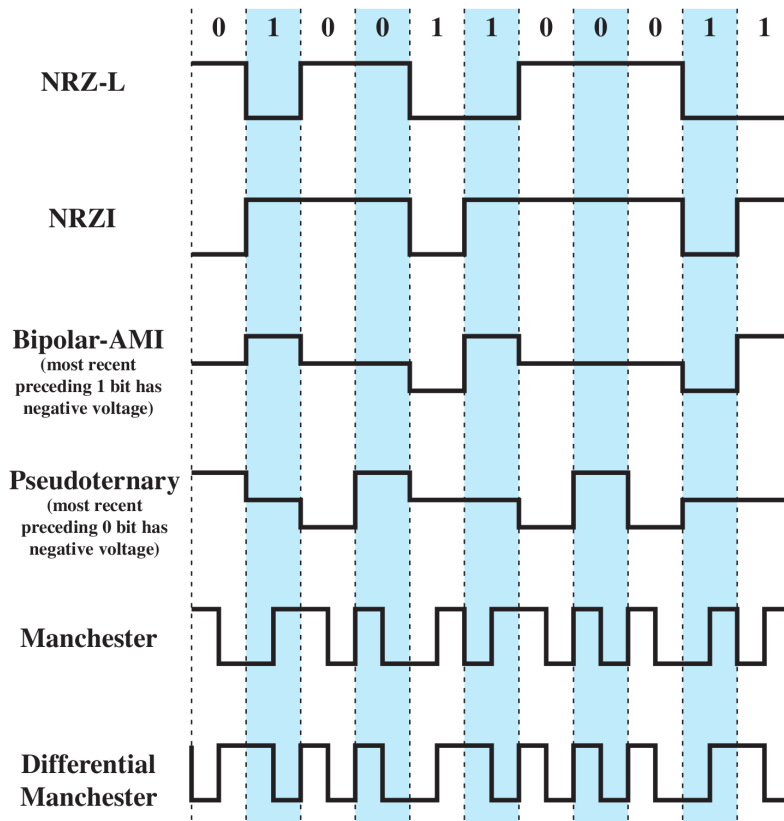Differential Manchester

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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 trasmitted power in middle of bandwidth

Clocking and Synchronization

- ▶ Transmitted signal can be used by receiver to synchronise bit timing

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Comparing Different Encoding Schemes

Error Detection

- ▶ Receiver can detect some bit errors from the received signal

Signal Interference

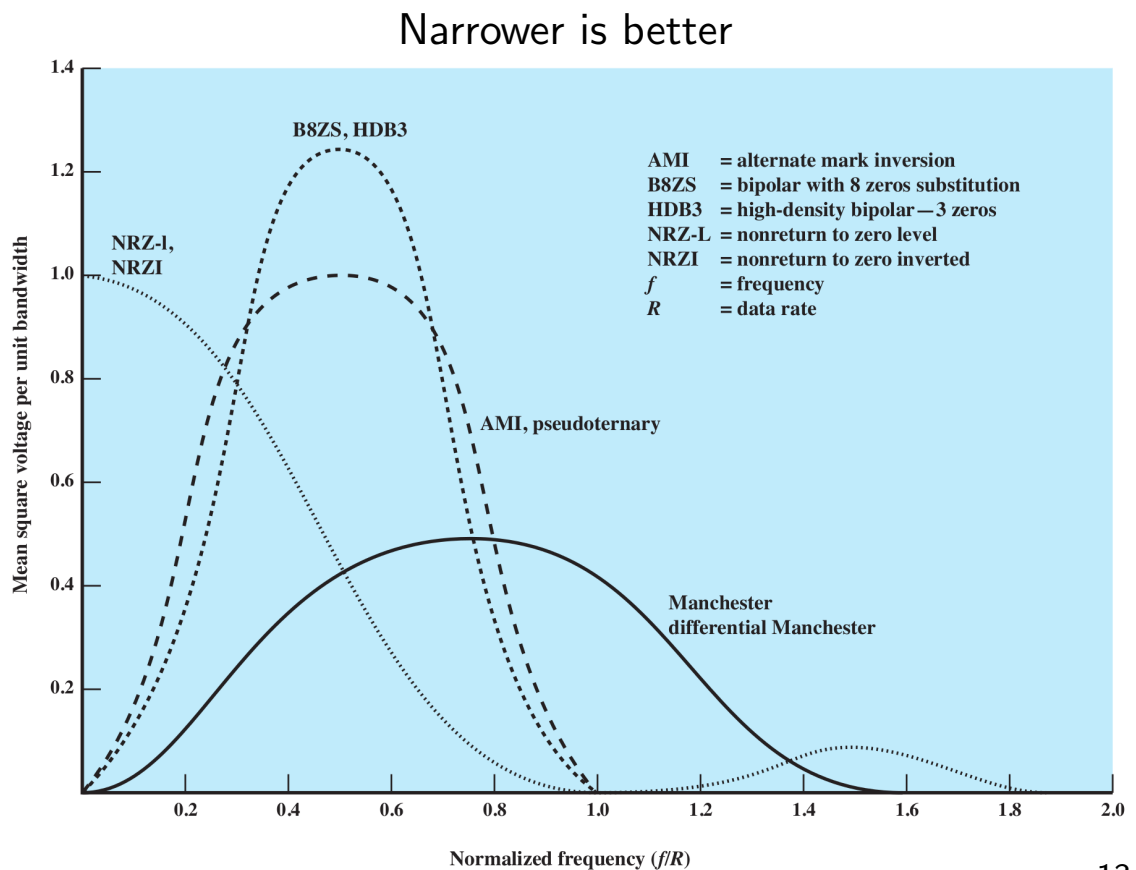- ▶ Provide good performance (few bit errors) in presence of noise

Cost and Complexity

- ▶ Desire smaller signaling rate to achieve a given data rate

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Spectral Density of Various Signal Encoding Schemes

Narrower is better

AMI = alternate mark inversion
B8ZS = bipolar with 8 zeros substitution
HDB3 = high-density bipolar—3 zeros
NRZ-L = nonreturn to zero level
NRZI = nonreturn to zero inverted
f = frequency
R = data rate

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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

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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 (Bipolar with 8-zeros substitution)
  - ▶ 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 (High density bipolar 3-zeros)

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

Encoding Rules for B8ZS and HDB3

B = Valid bipolar signal
V = Bipolar violation
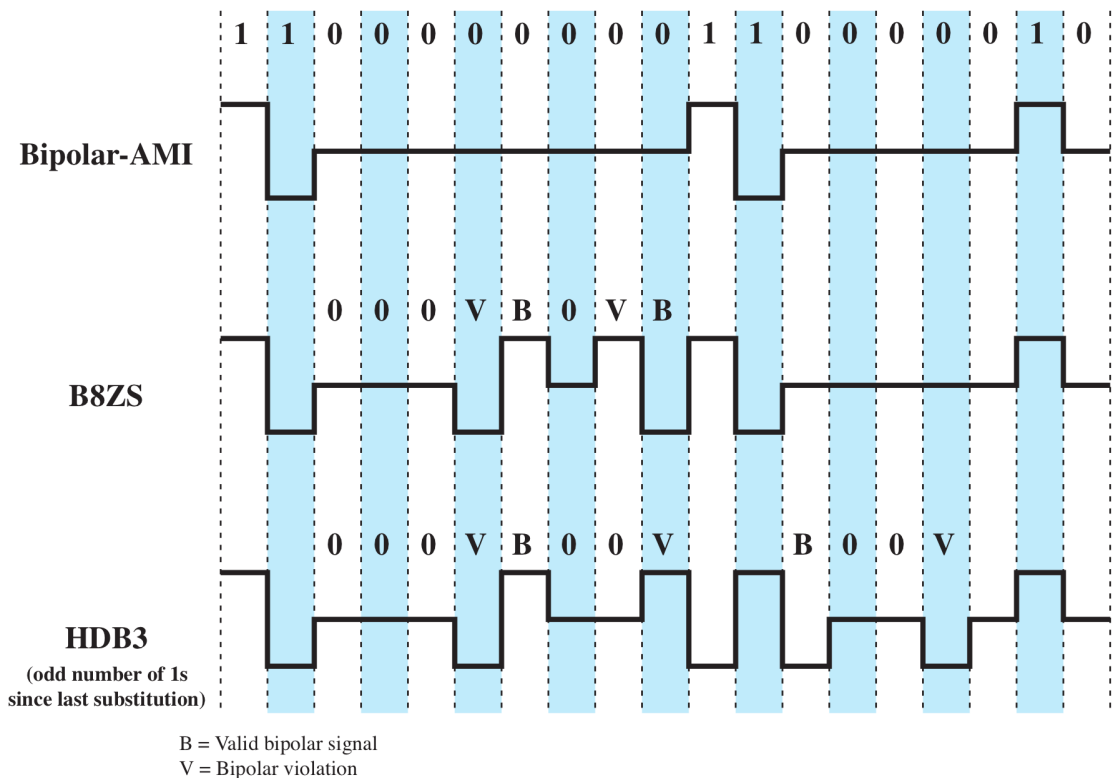
Example Technologies using Encoding Schemes

- NRZ/NRZI: RS-232, HDLC, USB, ...

- Manchester: Ethernet, Token Ring, ...

- Multilevel Binary: US T-carrier and European E-carrier telecommunication systems

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## Digital Data, Analog Signals

Analog Data, Digital Signals

Analog Data, Analog Signals

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 centred on carrier frequency

Modulation of Analog Signals for Digital Data
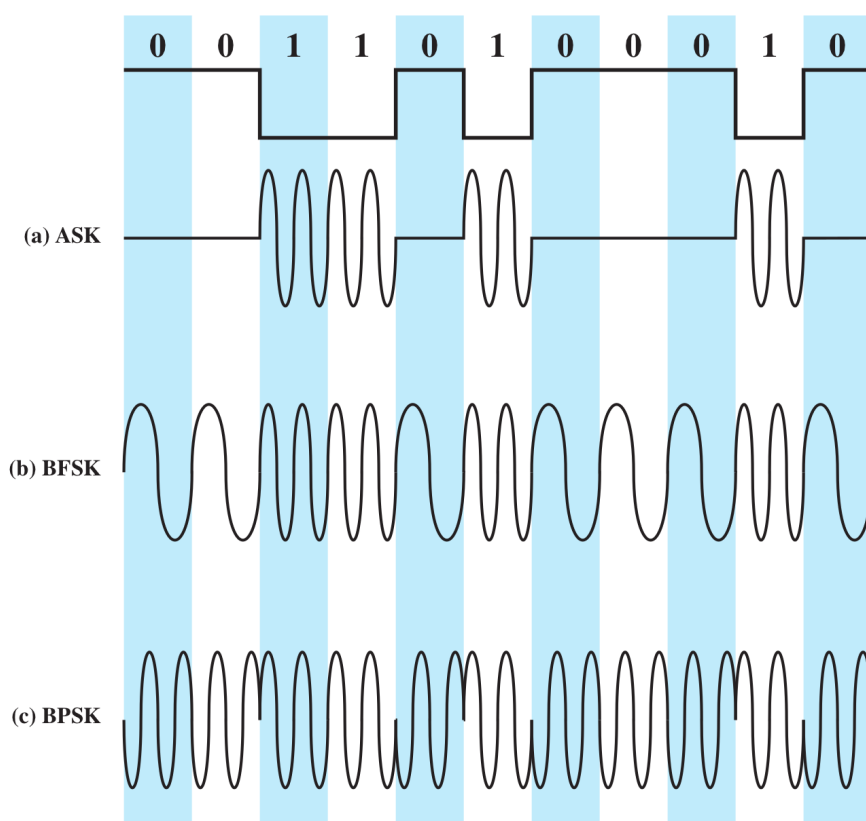
Comparing the Shift Keying Schemes

Amplitude Shift Keying

- Inefficient modulation technique
- Used on voice lines < 1200 bps and optical fibre

Frequency Shift Keying

- Used on voice lines, coaxial cable, HF radio systems
- Extended with M frequencies: improve efficiency, higher error rate

Phase Shift Keying

- 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

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Example Technologies using Shift Keying

- ASK: Optical fibre, RFID
- FSK: HF/shortwave radio, UHF/VHF radio comms, RFID
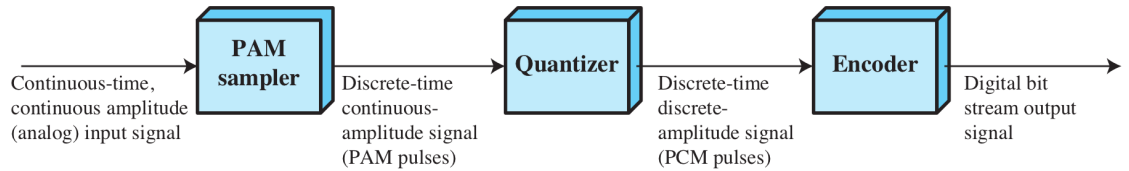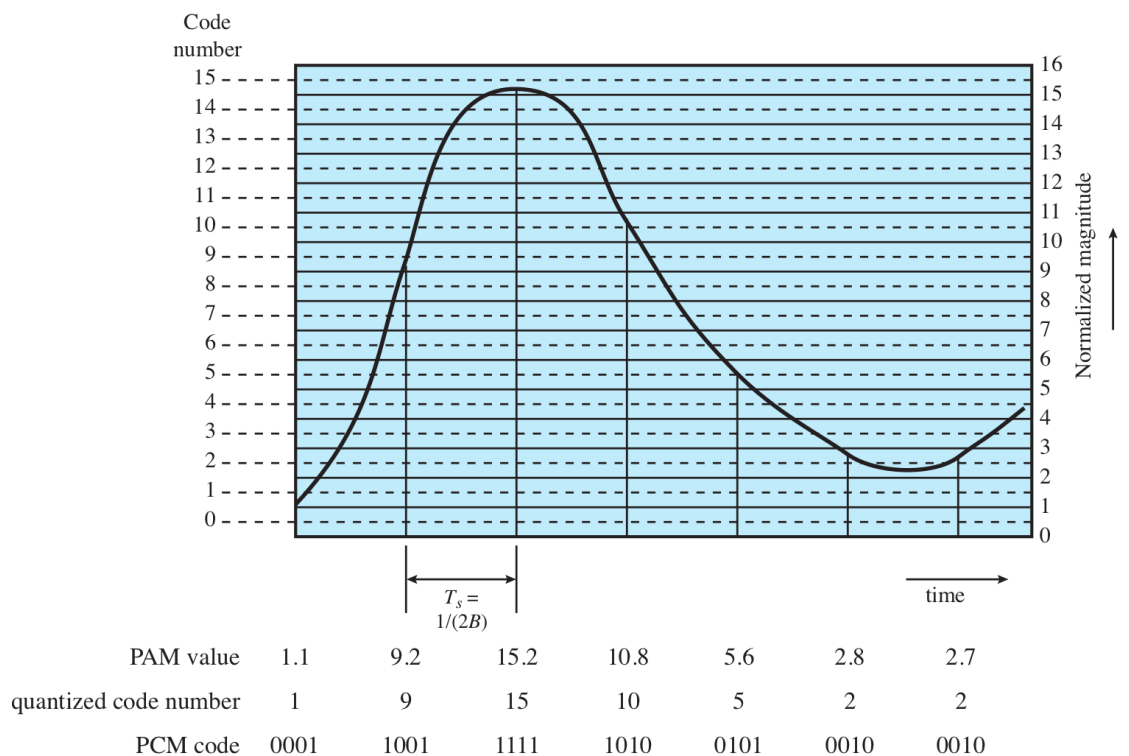- PSK and QAM: mobile phones, Wi-Fi, cable modems, xDSL, DVB, . . .

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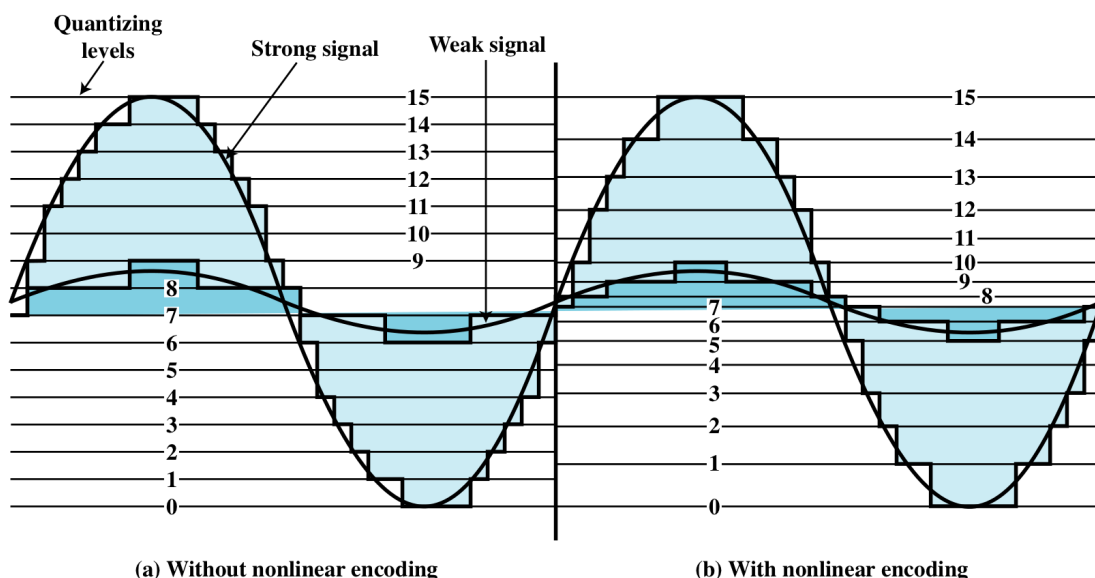
Analog Data, Digital Signals

Analog Data, Analog Signals

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 analog data from digital data
    - ► Consider two techniques used in codecs: Pulse Code Modulation and Delta Modulation

Pulse Code Modulation

Continuous-time, continuous amplitude (analog) input signal → **PAM sampler** → Discrete-time continuous-amplitude signal (PAM pulses) → **Quantizer** → Discrete-time discrete-amplitude signal (PCM pulses) → **Encoder** → Digital bit stream output signal

1. Divide the normalised input magnitude into 2^n different levels, with corresponding code numbers

2. Sample analog input every T_s seconds → pulse amplitude modulation (PAM) value

3. Map PAM value to nearest code number

4. Convert code number to n-bit binary PCM code

See also "Pulse Code Modulation" handout

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

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 contain all the information of the original signal

▶ Example: voice is between 0 and 4000 Hz; sampling at 8000 samples per second is sufficient to reproduce analog voice at receiver

▶ BUT . . . quantizing the PAM values introduces error (or noise); each additional bit increases SNR by 6 dB

▶ Good voice reproduction can be achieved with 128 quantization levels (7-bit coding)

Improving PCM with Nonlinear Coding

▶ Linear spacing of quantization levels can result in poor reproduction of weak signals

▶ Non-linear encoding: more steps for low amplitude, less steps at high amplitude

▶ Can lead to significant improvement for voice

(a) Without nonlinear encoding   (b) With nonlinear encoding

Delta Modulation

- ▶ Popular alternative to PCM
- ▶ Input analog data approximated by staircase function
- ▶ Moves up/down by one quantization level (δ) each sampling interval (T_s)
- ▶ If signal goes up, bit 1 is output; otherwise bit 0

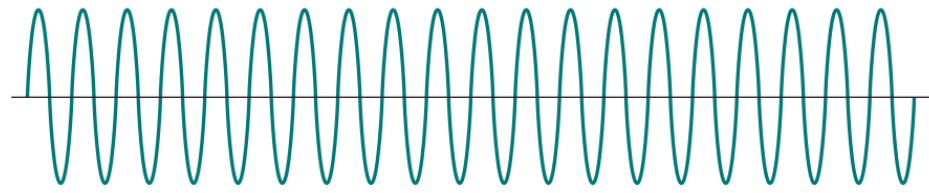33

Example of Delta Modulation
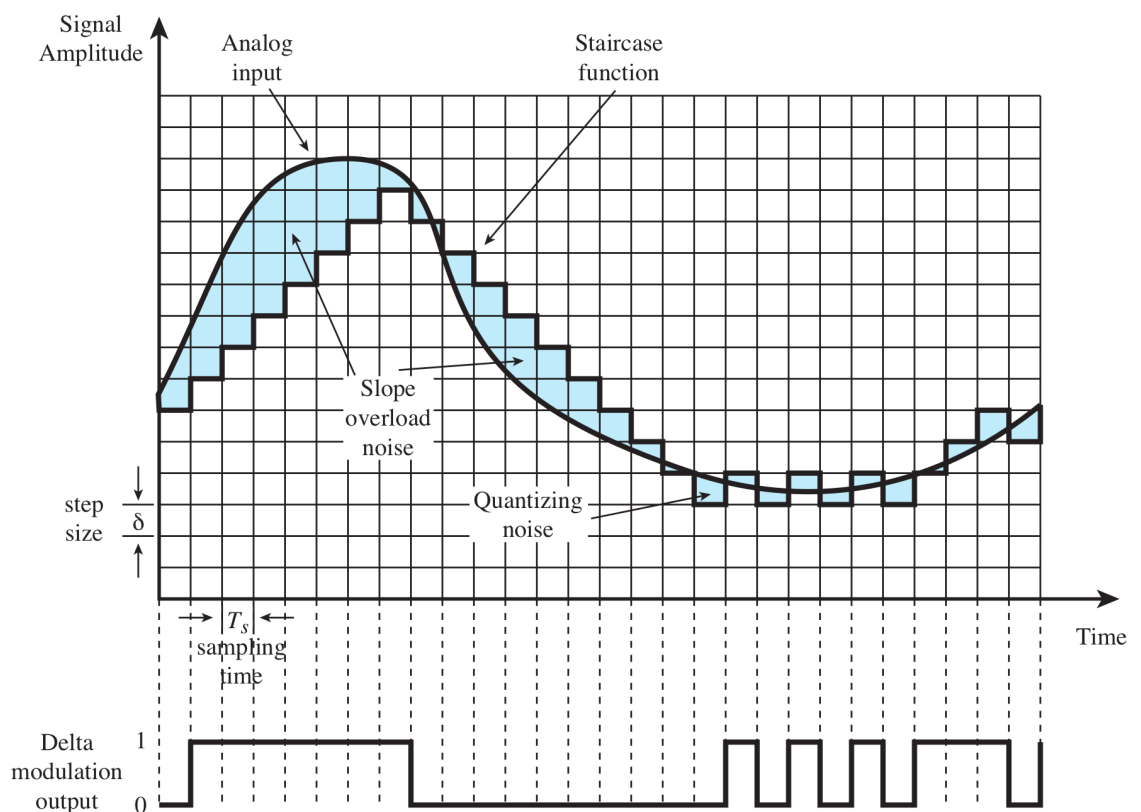
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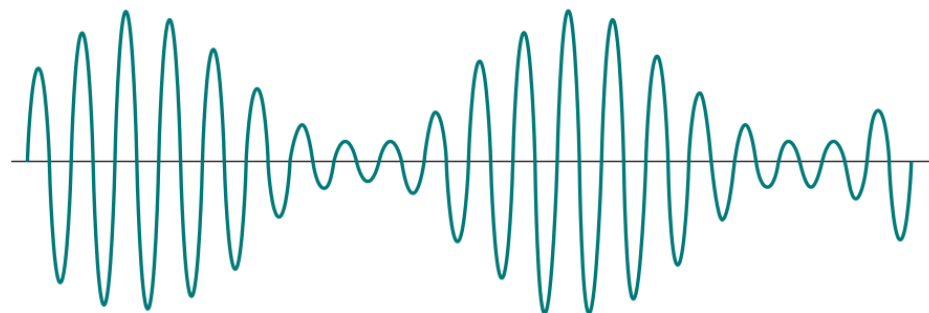**Analog Data, Analog Signals**

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 convereted 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 ananlog data in one analog signal)
- ▶ Principal techniques: amplitude modulation (AM), frequency modulation (FM), phase modulation (PM)

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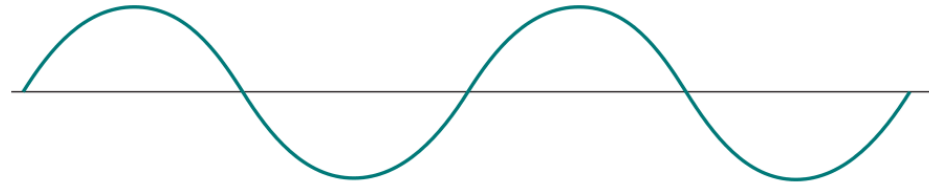
Carrier

Modulating sine-wave signal
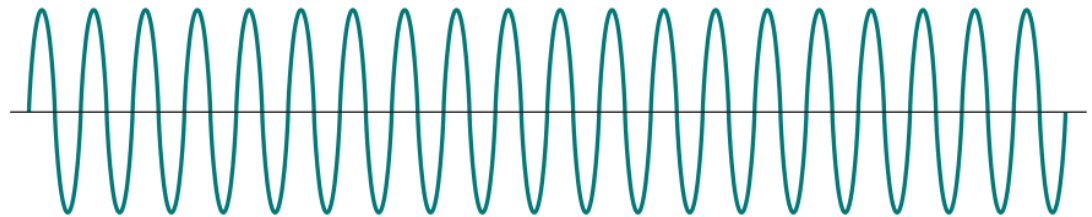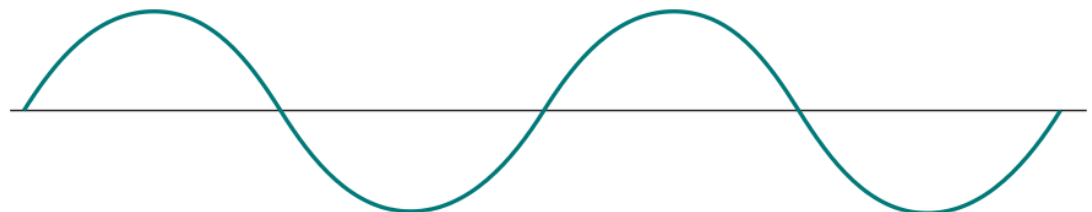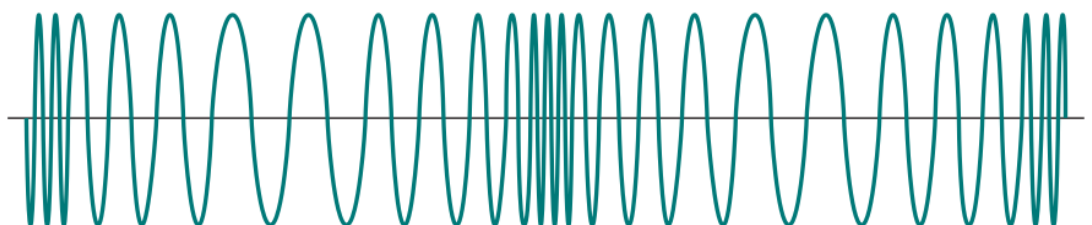
Amplitude-modulated (DSBTC) wave

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Signal Encoding

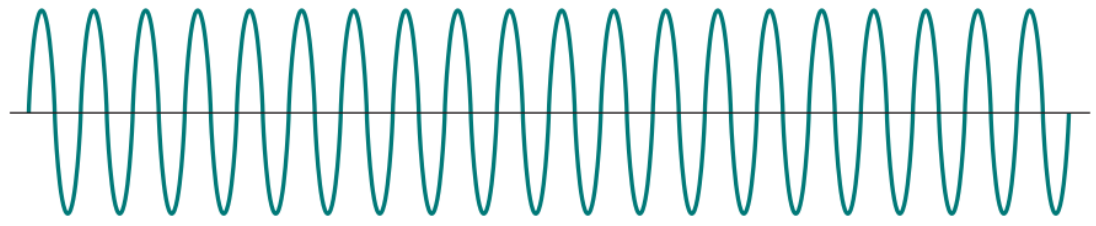Introduction

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

Carrier

Modulating sine-wave signal

Phase-modulated wave

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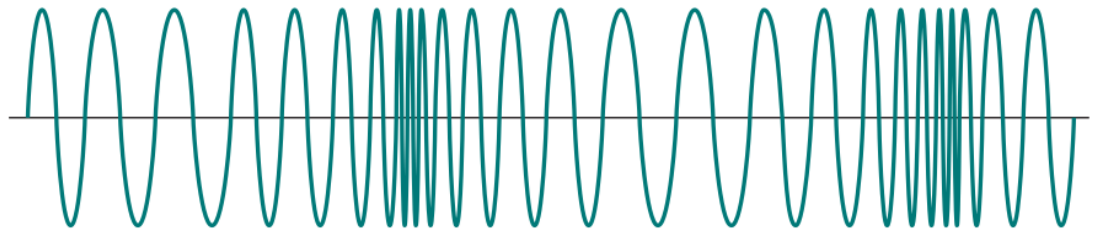

Carrier
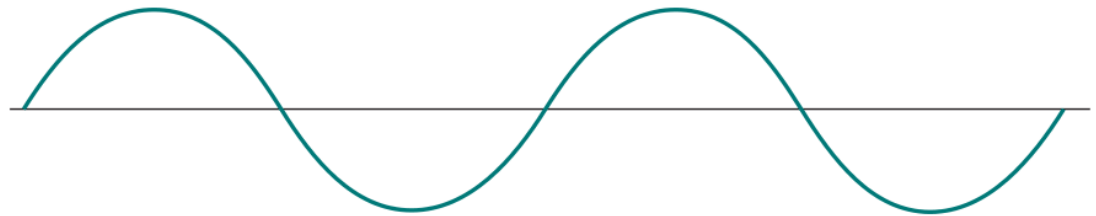
Modulating sine-wave signal

Frequency-modulated wave

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