Concepts for the Data Communications and Computer Interconnection

Aim: overview of existing methods and techniques

Terms used:
-*Data* – entities conveying meaning (of information)
-*Signals* – data carrier; electric or electromagnetic representations of data
-*Transmission* – data communications process, using the signal's propagation and processing

Main attributes of data, signals and transmission:
- digital
- analog

Towards *all digital?* Not yet!

Why? Important legacy (old telephone system); everything around (from environment) comes as analog

Today the digital technology offers:

-low cost, due to VLSI technology

-low attenuation, even in the past the analog technology led

-low noise influence

-better capacity utilization

-better data integrity

-security and privacy

-integration of digital and analog data.

Analog Data

Continuous values within some interval; e.g. sound, video.

Digital Data

Discrete values, e.g. text, integers.

Continuous signal

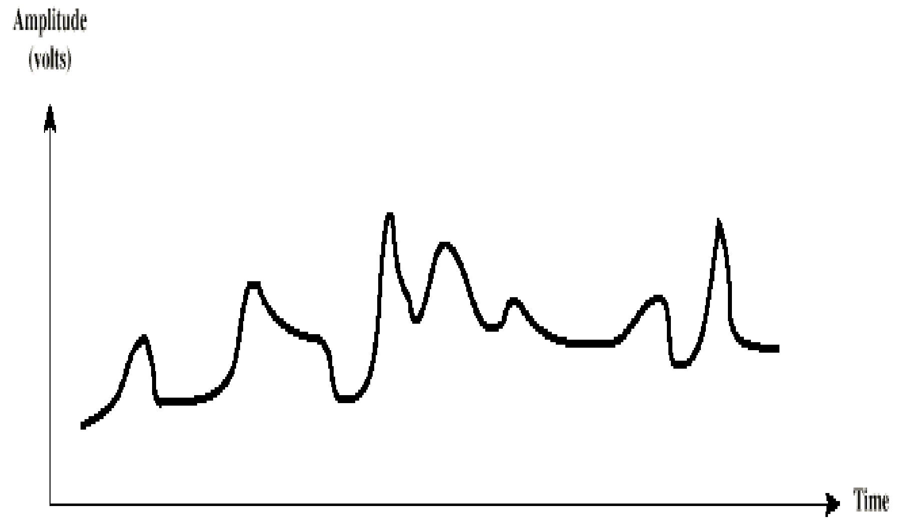
Various in a smooth way over time, may have any values.

Discrete signal

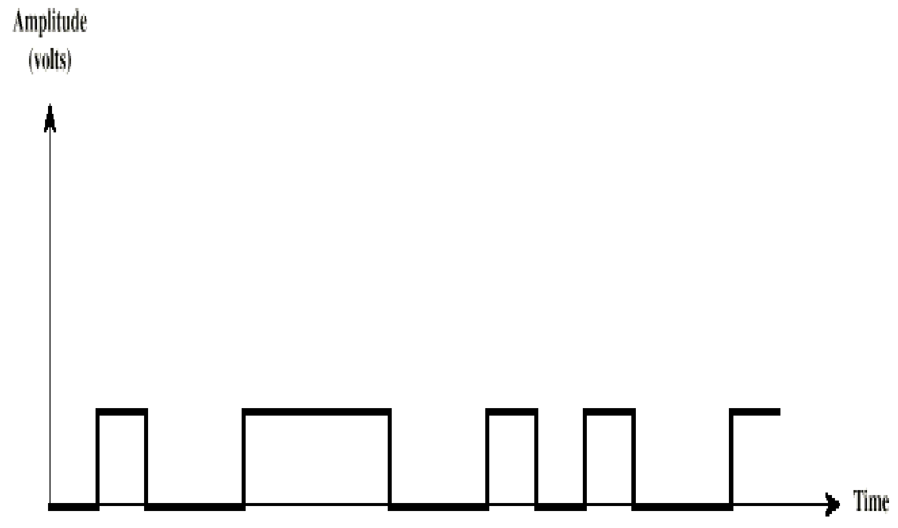
Maintains a constant level, then changes to another constant level. May have one of some (e.g. two) level values.

Mark denotes signal for ‘1’

Space denotes signal for ‘0’ data



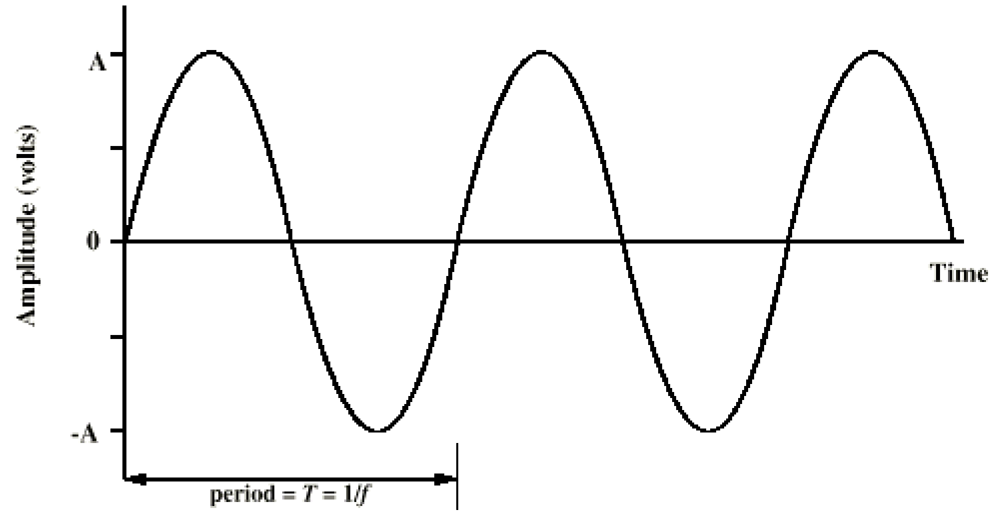
(a) Continuous



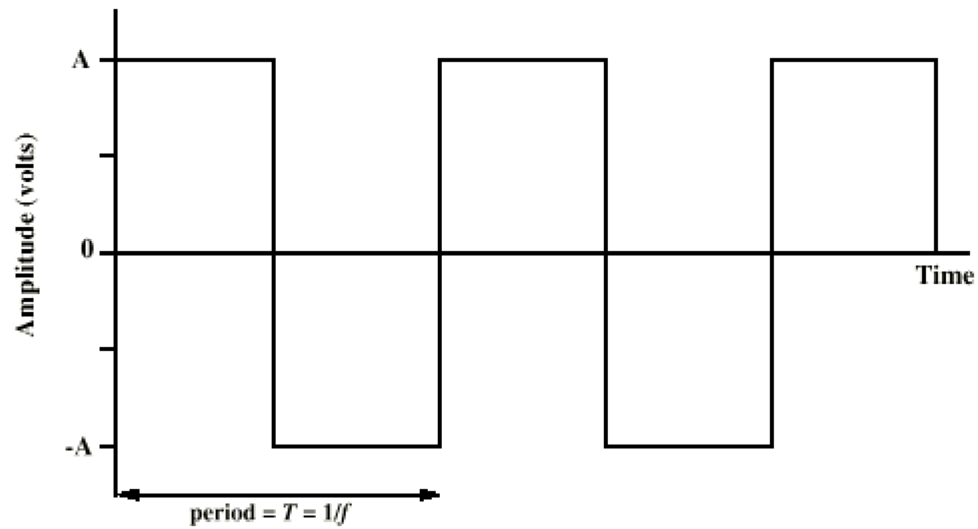
(b) Discrete

Periodic signal

Presents a pattern repeated over time.



(a) Sine wave



(b) Square wave

Parameters of the Sinus Wave (analytical, as function of time):

$$A \cdot \sin(2\pi ft + \phi)$$

Peak Amplitude (A): the maximum strength of signal, expressed in volts

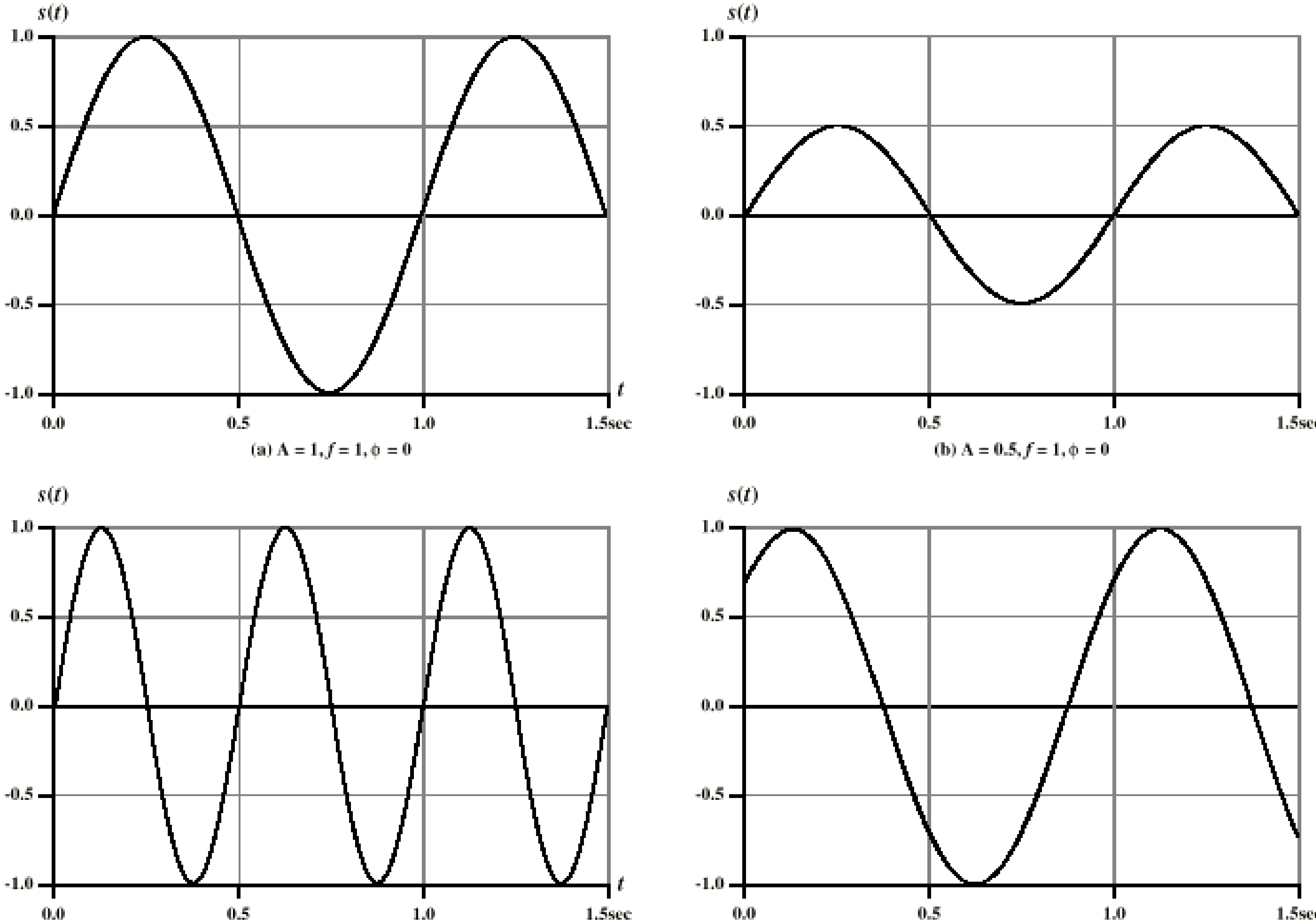
Frequency (f): the rate of change of signal, expressed in Hertz (Hz) or cycles per second

Period of the signal = time for one repetition (T)

$T = 1/f$

Phase (ϕ): means the relative position in time

Wavelength (λ): Distance between two points of corresponding phase in two consecutive cycles. Relations: $\lambda = vT$; $\lambda f = v$, where v: signal speed expressed in m/s.



(a) A = 1, f = 1, ϕ = 0

(b) A = 0.5, f = 1, ϕ = 0

(c) A = 1, f = 2, ϕ = 0

(d) A = 1, f = 1, ϕ = $\pi/4$

Frequency Domain

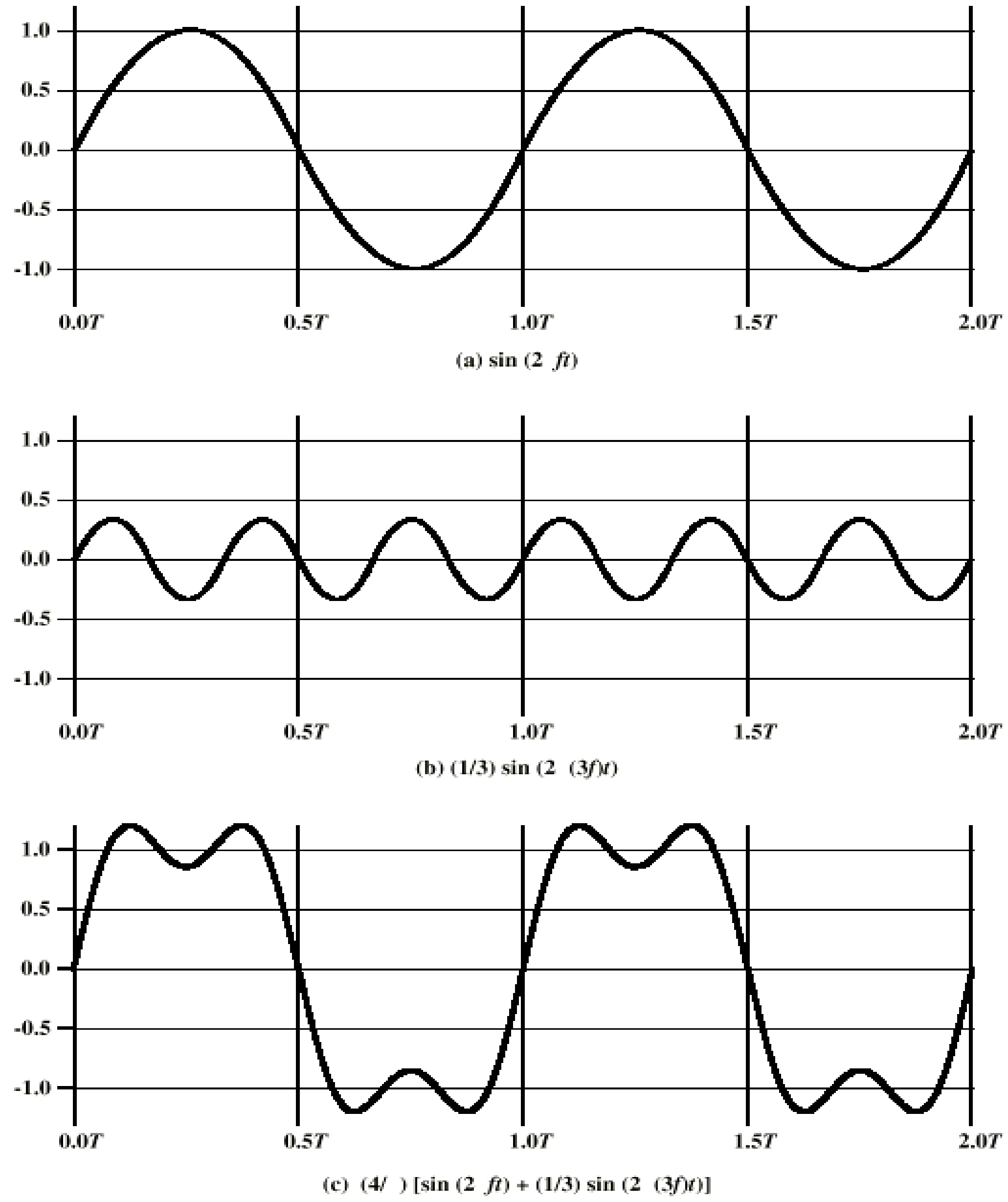
In practice, an electromagnetic signal is made up of many frequencies (has sinus components – Fourier analysis); one is the fundamental frequency, others are multiples.

Spectrum – range of frequencies a signal contains.

Bandwidth – signal's width of the spectrum.

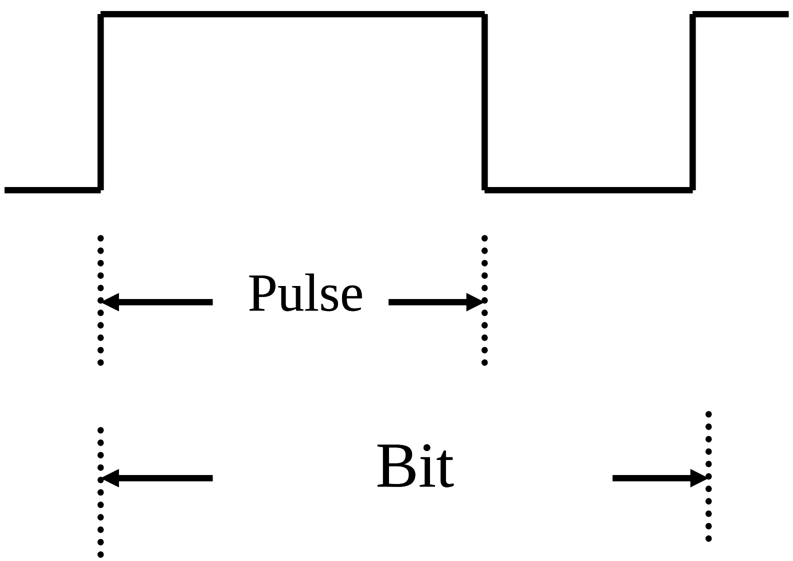
dc Component (continuous component) – component with zero frequency.

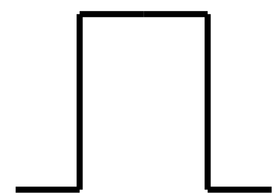
Any signal has a limited bandwidth => limited data rate!!!



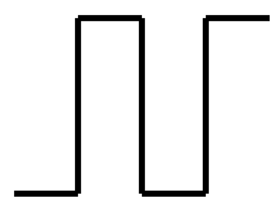
Data Coding terminology

Signal element: Pulse
Modulation rate: 1/Duration of the smallest element or rate at which the signal level changes = Baud rate
Data rate: Number of bits per second (bps)
Data rate = Fn(Bandwidth, signal/noise ratio, encoding technique)





NRZI: 1 bit = 1 signal element



Manchester: 1 bit = 2 signal elements,
Twice modulation rate required than NRZI

How to compare encoding techniques?

Various criteria:

-required bandwidth (lack of higher frequencies => low bandwidth)

-lack of the dc component: allows ac coupling, providing isolation

-how power is spread within the frequency spectrum (main power in the middle of the bandwidth)

-allows error detection (mechanism built in)

-avoid signals interference and allows high noise immunity

-synchronization mechanism built in (no external clock)

-cost and complexity

  -higher signal rate (data rate) => higher costs

  -need for a signal rate greater than data rate

Data Encoding

Digital Data, Digital Signals
Methods:

NRZ (Non Return to Zero-Level) – uses two voltage levels (H,L); may have any polarities

- difficult to find the bit margins
- no transitions between similar bits **=>** dc component, damaging the passive connecting devices

NRZI (Non Return to Zero, Invert on Ones), also known as NRZ-M – codes data using a transition at the beginning of the bit period (‘1’: transition, ‘0’: no transition).

Differential coding – compares polarities of successive signals, not their absolute values => better noise immunity

Multilevel Binary codes

Use more than two voltage levels

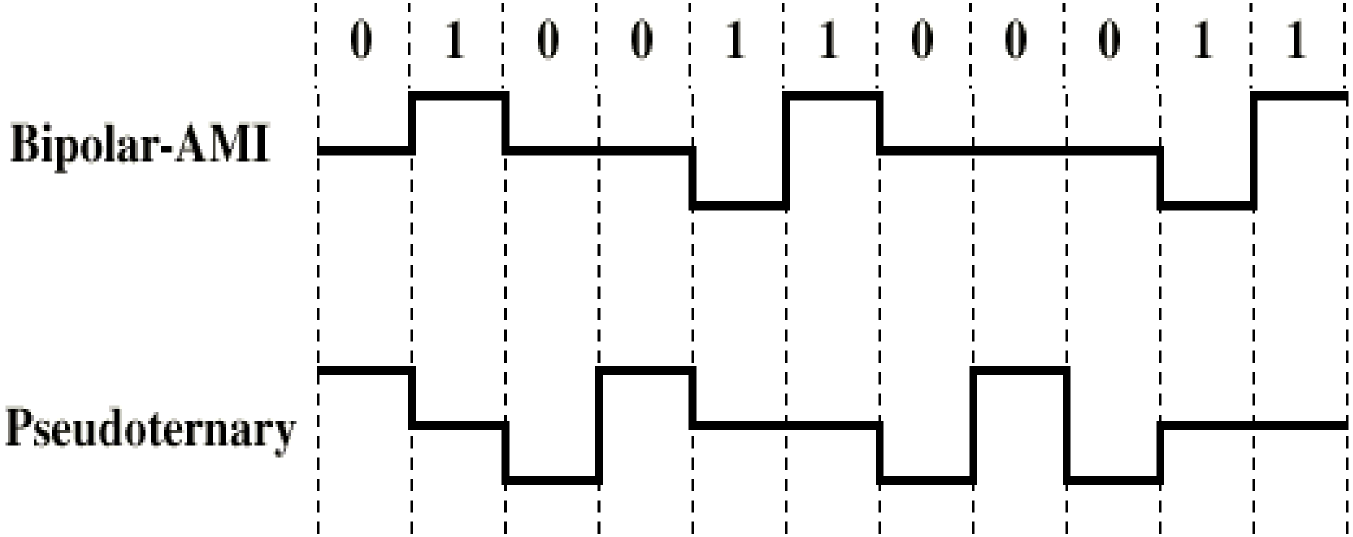
Bipolar-AMI (Alternate Mark Inversion) – ‘0’: no line signal, ‘1’: alternating positive and negative pulses => better synchronization (but avoid long ‘0’ string), lower bandwidth, improved error detection

Pseudo-ternary – reverse coding, ‘1’: no line signal, ‘0’: alternating positive and negative pulses => similar problems as for bipolar-AMI

Drawback:

Receiver must distinguish between three levels: (A, -A, 0)

Requires approx. 3dB more signal power for same probability of bit error

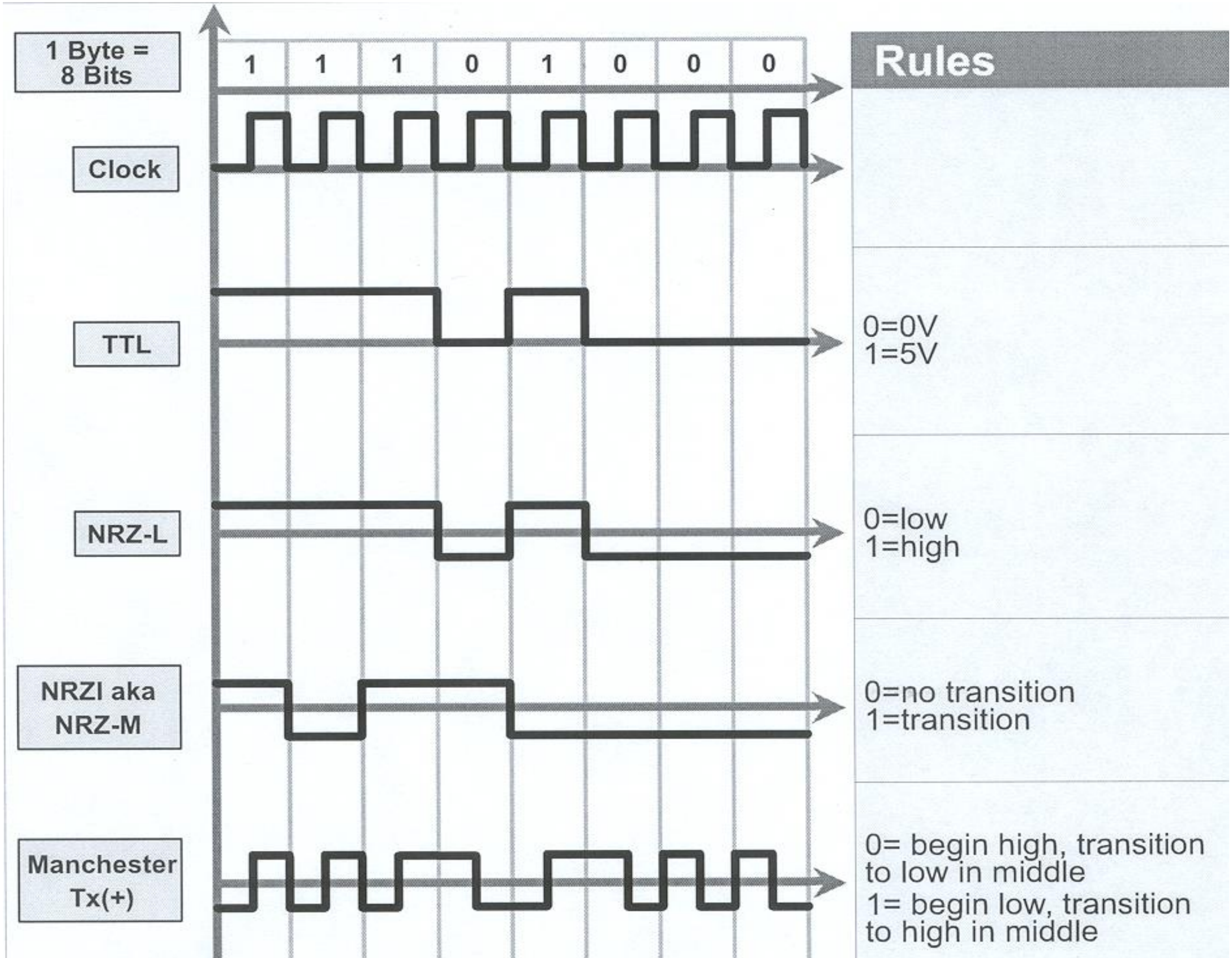


Data Encoding (continued)

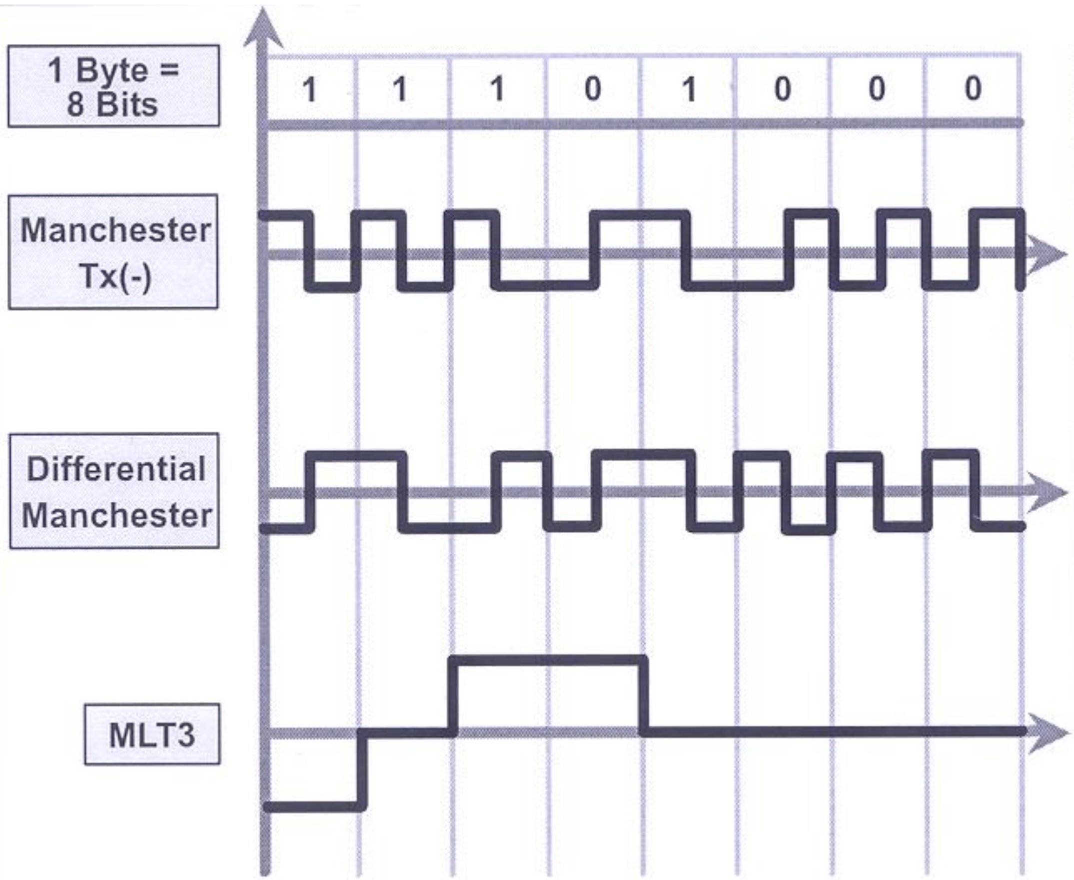
Biphasic coding: one or two transitions on a bit period => higher bandwidth, but provides synchronization, better error detection, less noise influence, no dc component

Manchester – always a transition at the middle of the bit period (used as clock signal): data coding by the transition sense (‘0’: Low to High, ‘1’: High to Low for Tx-, and reverse for Tx+)

Differential Manchester – middle transition as clock signal, data coding by a transition at the beginning of bit period (‘0’: transition, ‘1’: no transition). Most used for twisted pair based networks.



1 Byte = 8 Bits
1 1 1 0 1 0 0 0
Rules
Clock
TTL
0=0V
1=5V
NRZ-L
0=low
1=high
NRZI aka NRZ-M
0=no transition
1=transition
Manchester Tx(+)
0= begin high, transition to low in middle
1= begin low, transition to high in middle



Rules

0= begin low, transition to high in middle
1= begin high, transition to low in middle

Always a transition in middle of interval
0 = transition in beginning of interval
1 = no transition in beginning of interval

3 level amplitude,
Level = -1V, 0V, +1V, 0V, -1V, etc...
0 = no transition
1 = transition to next level in cycle

TTL = Transistor-Transistor Logic
NRZ-L = Non-Return to Zero-Level
NRZI = Non-Return to Zero-Inverted
NRZ-M = Non-Return to Zero-Mark
Tx = Transmit
MLT3 = Multi-Level Threshold-3

For WANs, for sake of bandwidth costs: **scrambling techniques** (long constant data streams replaced by filling sequences):

Bipolar With 8 Zeros Substitution B8ZS

Based on bipolar-AMI, but introducing AMI code violation

IF:

Octet of all zeros and last voltage pulse preceding was positive, encode as 000+-0-+

Octet of all zeros and last voltage pulse preceding was negative, encode as 000-+0+-

Causes two violations of AMI code; Unlikely to occur as a result of noise

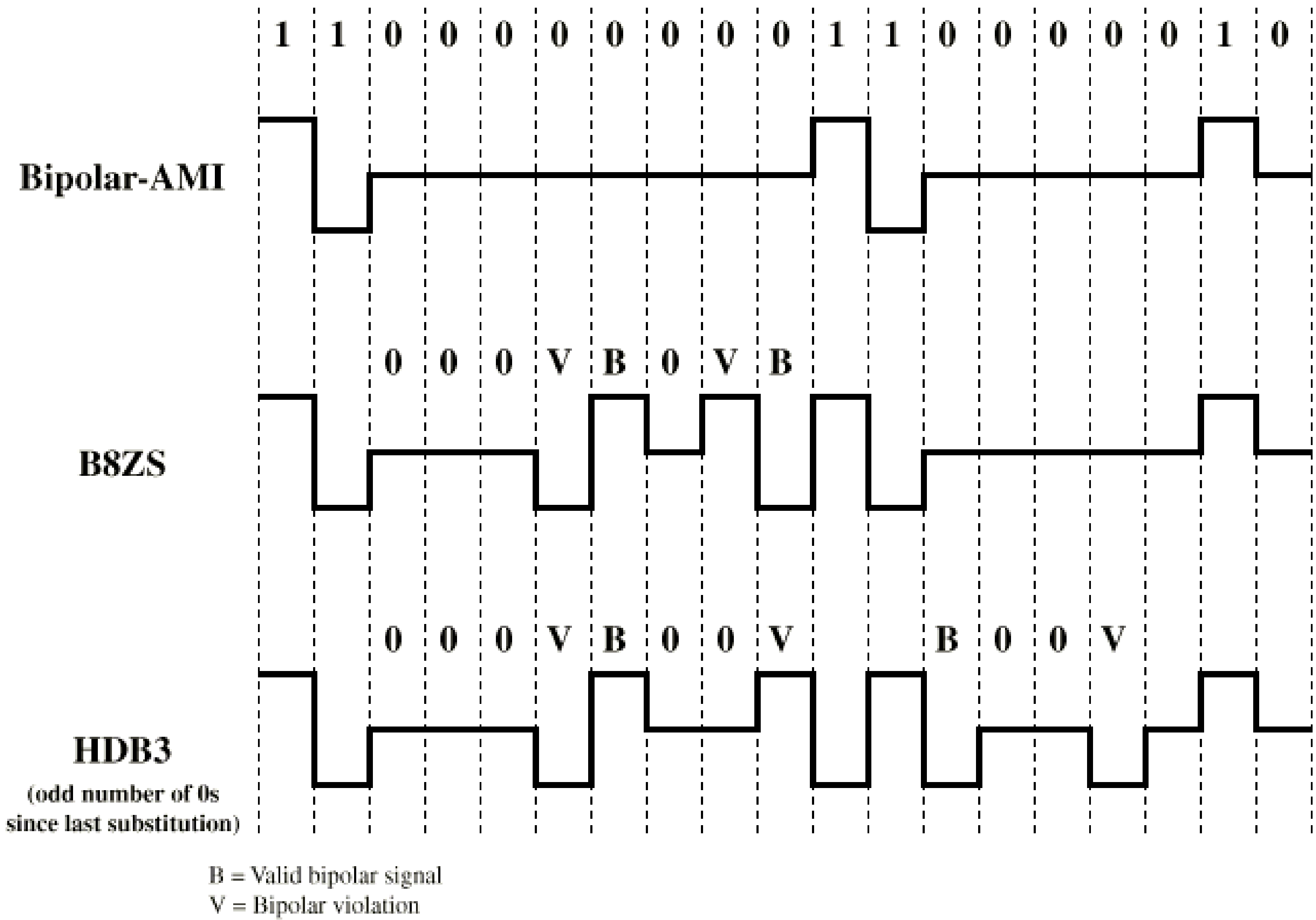
Receiver detects and interprets as octet of all zeros.

High Density Bipolar 3 Zeros HDB3

Based on bipolar-AMI, but introducing code violation (not valid AMI bipolar signal)

String of four zeros replaced with one or two pulses (the AMI code violation sequence).

Also alternation of polarities for the violation codes.



1 1 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 1 0
Bipolar-AMI
0 0 0 V B 0 V B
B8ZS
0 0 0 V B 0 0 V B 0 0 V
HDB3
(odd number of 0s
since last substitution)
B = Valid bipolar signal
V = Bipolar violation

Digital Data, Analog Signals

Use of a constant frequency signal: **data carrier**, modulated conform with the data

Amplitude Shift Keying (ASK) – presence or not of the carrier, at constant amplitude; non efficient for data transmissions; variant for fiber optic transmissions: presence or absence of the light

Frequency Shift Keying (FSK) – two (symmetric) frequencies, near the carrier basic frequency

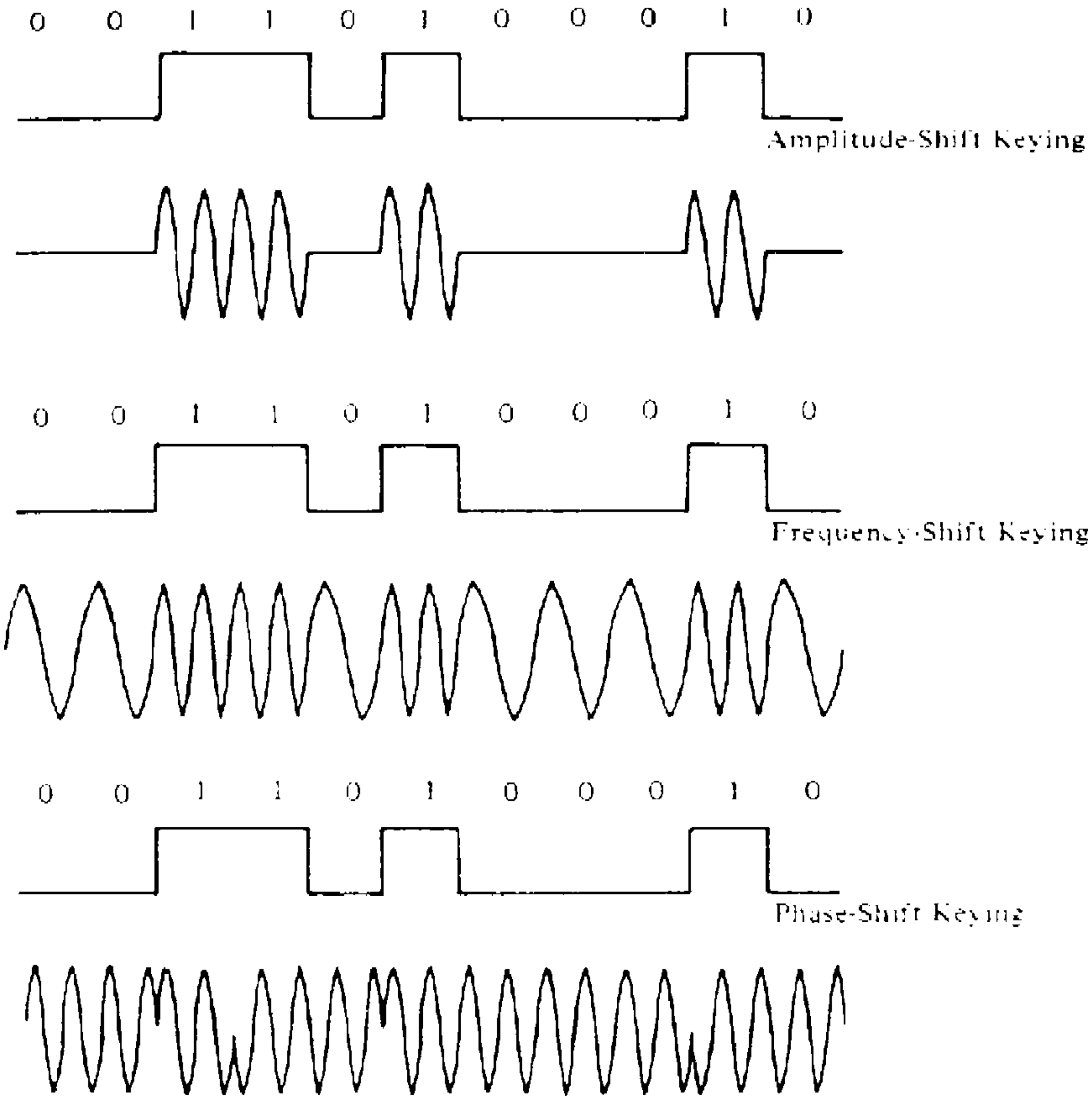
Phase Shift Keying (PSK) – short burst signals

coherent PSK: constant signals having a phase difference of 180º

differential PSK: ‘0’ burst signal with the same phase as the previous (0º shift), ‘1’ burst signal with opposite phase as previous (shift with 0º+ π)

best error resistant, determining the phase shift magnitude, not its absolute value.

Quadrature-PSK coding – codes 2 bits by a burst signal, having more than two phase-shifts per signal: phase shifts of multiples of 90º. Possible extensions…


0 0 1 1 0 1 0 0 0 1 0
Amplitude-Shift Keying
0 0 1 1 0 1 0 0 0 1 0
Frequency-Shift Keying
0 0 1 1 0 1 0 0 0 1 0
Phase-Shift Keying

Analog Data, Digital Signals

Theoretical background: Nyquist sampling theorem: sample at twice the highest signal frequency (for a voice carrying signal with bandwidth of 4kHz, sample at 8kHz, or every 125μsec, having 8000samples/sec)

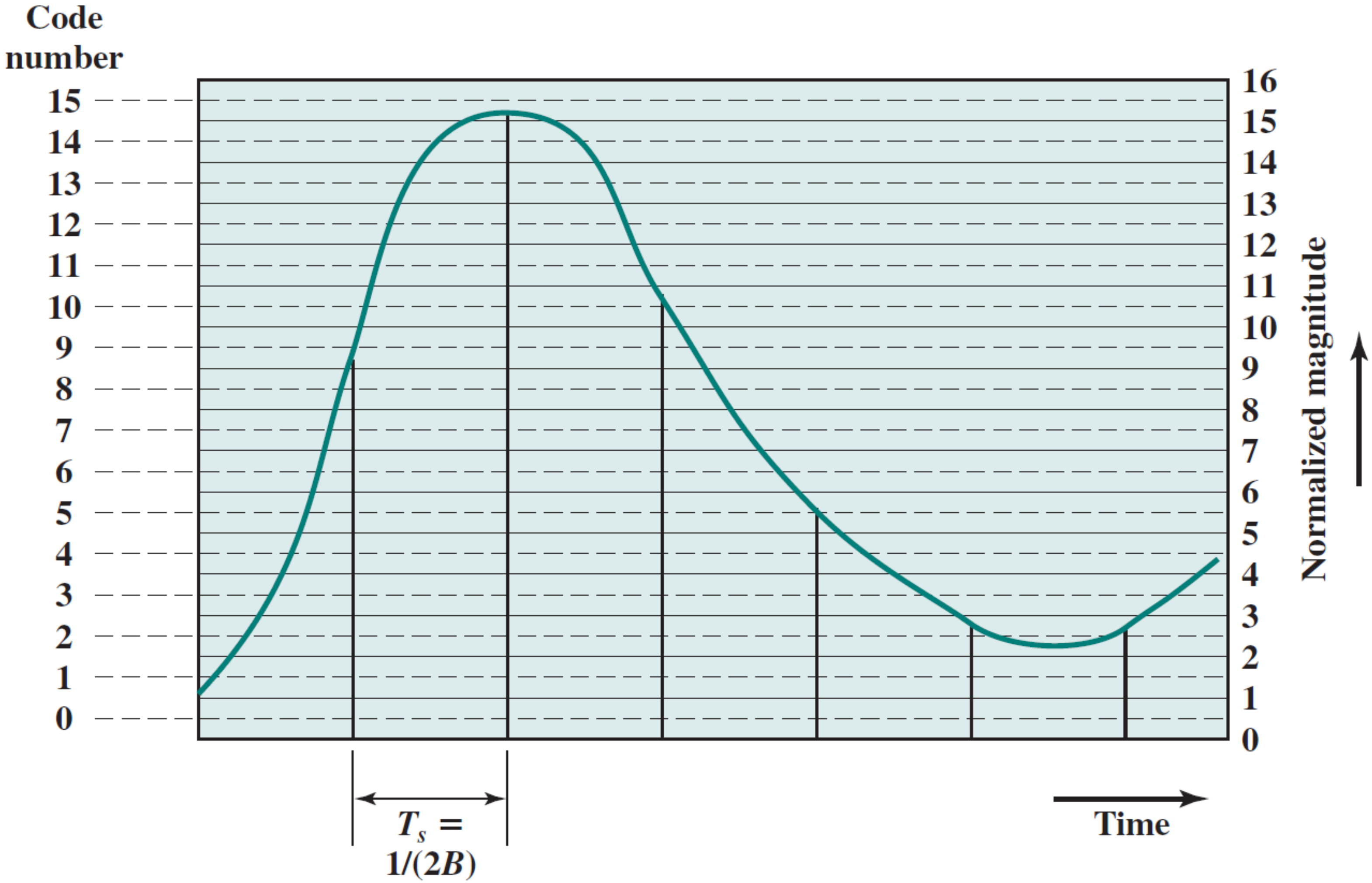
Pulse Code Modulation (PCM), with the following 3 steps:

-signal ***sampling***, using the proper sampling frequency (higher than twice the highest signal frequency); samples represented as PAM (Pulse Amplitude Modulation) pulses

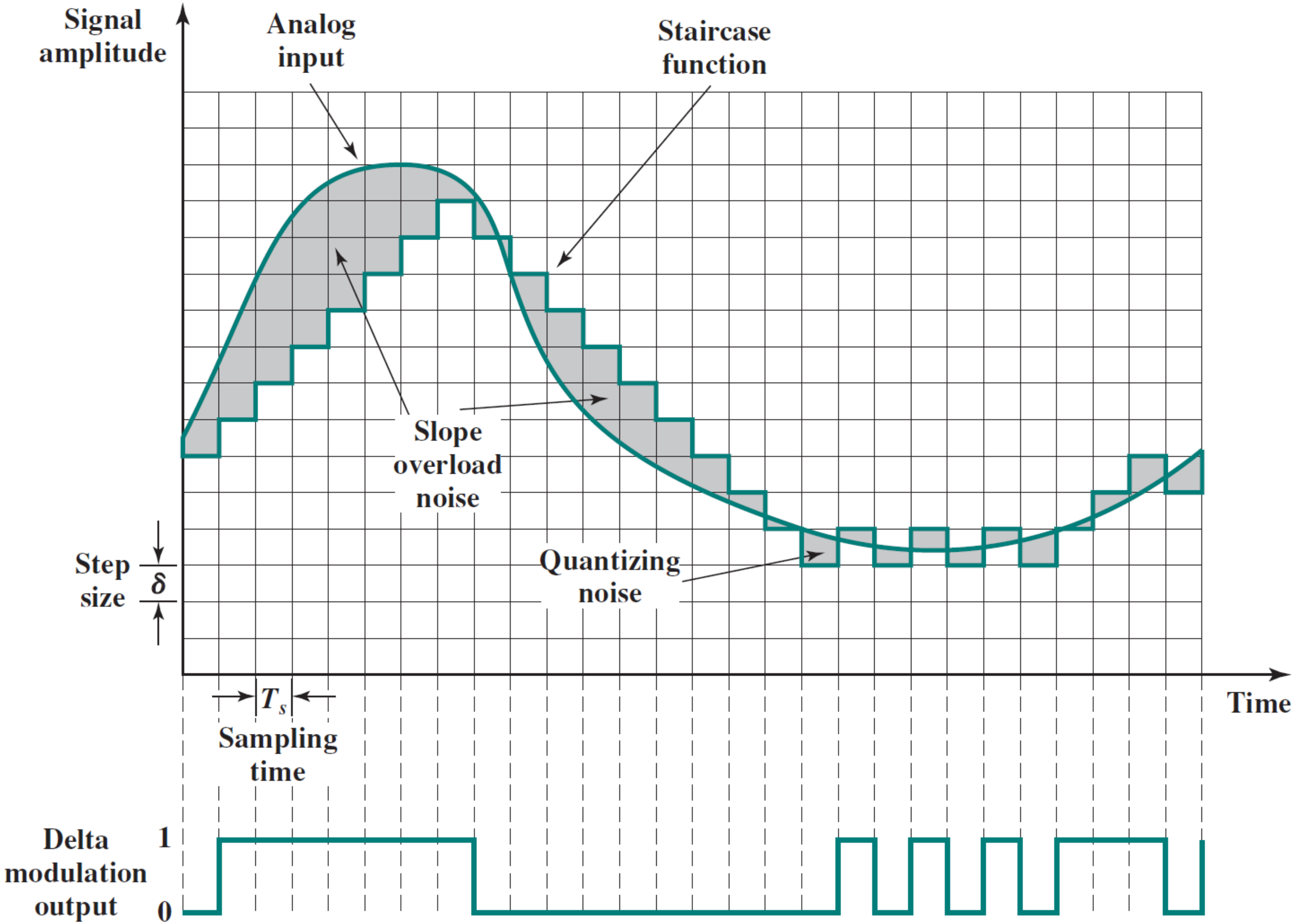
-***quantification*** of the samples, using the available number of digits, obtaining the PCM pulses and their digital values; more digits, more accuracy, greater cost

-digital values representation as pulse trains - ***coding***

Delta Modulation – approximates the analogue signal by a staircase function moving up/down by one quantization level at each sampling interval; output function has a binary behavior (moves up or down at each sample interval); method less used in computer networks

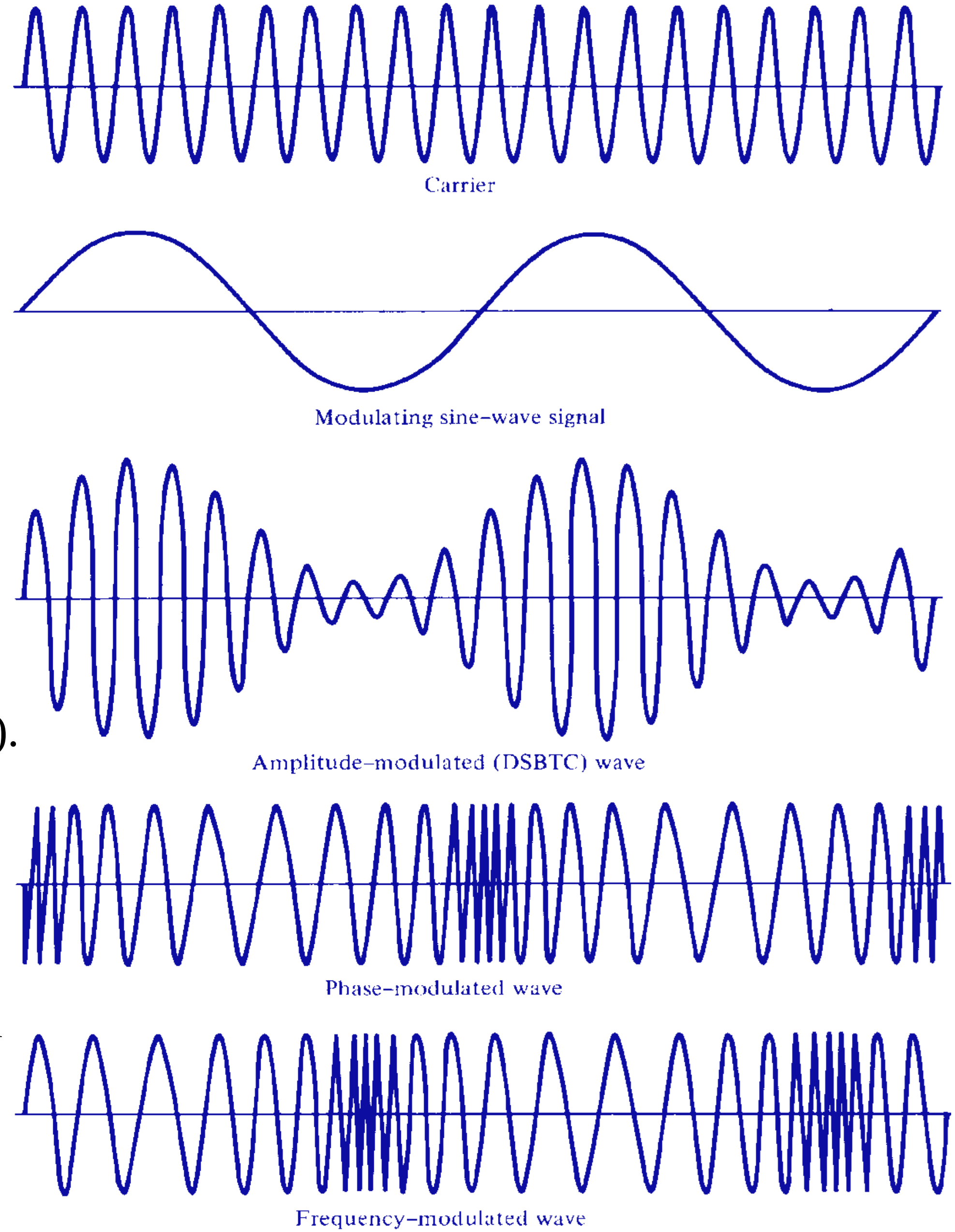


PAM value	1.1	9.2	15.2	10.8	5.6	2.8	2.7
Quantized code number	1	9	15	10	5	2	2
PCM code	0001	1001	1111	1010	0101	0010	0010


Signal amplitude
Analog input
Staircase function
Slope overload noise
Step size
δ
Quantizing noise
Time
T_s
Sampling time
Delta modulation output
1
0

Analog Data, Analog Signals

Used when only analog facilities available.
Why analog data if the voice signals are transmitted in the baseband ?
-higher frequency may be needed for unguided transmission (impossible to transmit baseband signals), or optical
-modulation permits FDM.



Amplitude Modulation

Amplitude of the carrier is varied accord. with some characteristic of the modulating signal (ex: double-sideband transm. carrier).

Phase Modulation

Data carrier's phase is varied linearly according to the data.

Frequency Modulation

Data carrier wave's frequency departs from the center frequency (carrier's) by an amount depending on the value of the modulating signal.

Spread Spectrum

Analog or digital data sent using analog signal (radio transmissions)

Spread data over wide bandwidth

Makes jamming and interception harder

Two schemes:

Frequency hoping

- Signal broadcast over seemingly random series of frequencies
- Hop from one frequency to other at split-second intervals

Direct Sequence

- Each bit is represented by multiple bits in transmitted signal (chipping code)
- Chipping code is obtaining combining original data with pseudorandom bit stream
- Chipping code spreads the signal across a wider frequency band

Transmission impairments

For any communication system, the received signal will differ from the transmitted signal – not an ideal transmission!

Due to various transmission impairments, introducing signal degradation (analog transmissions), bit errors (digital); most encountered transmission impairments are:

Attenuation and attenuation distortion

Delay distortion

Noise

Attenuation

The reduction of signal's strength (power) with distance.

For guided media attenuation is logarithmic and expressed in dB/m.
For unguided media transmissions, it depends on distance and makeup of atmosphere.

Attenuation = $10 \cdot \log_{10} P_{in}/P_{out}$ [dBel]
Attenuation = $20 \cdot \log_{10} V_{in}/V_{out}$ [dBel]

Received signal strength:

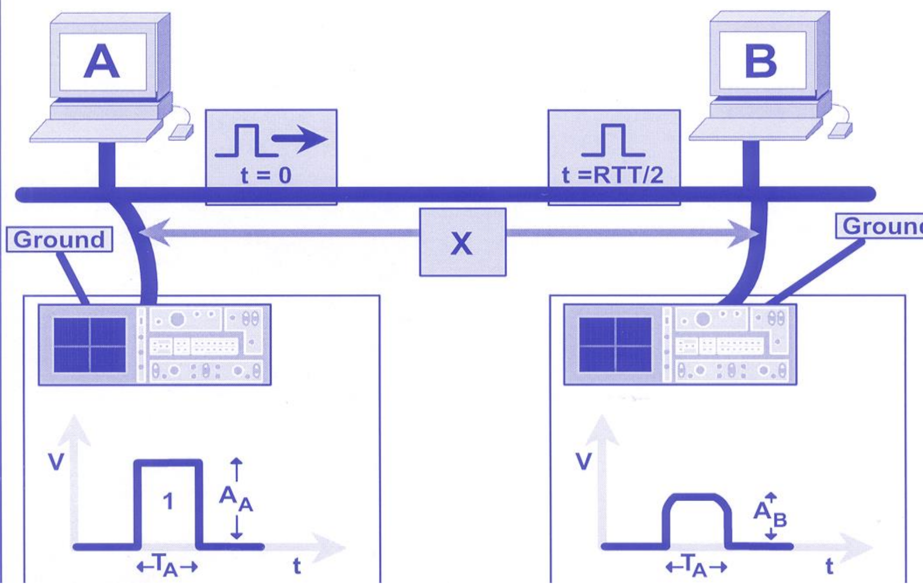
- must be enough to be detected
- must be sufficiently higher than noise, to be received without error.

Use of amplifiers and repeaters for maintaining the signal strength.

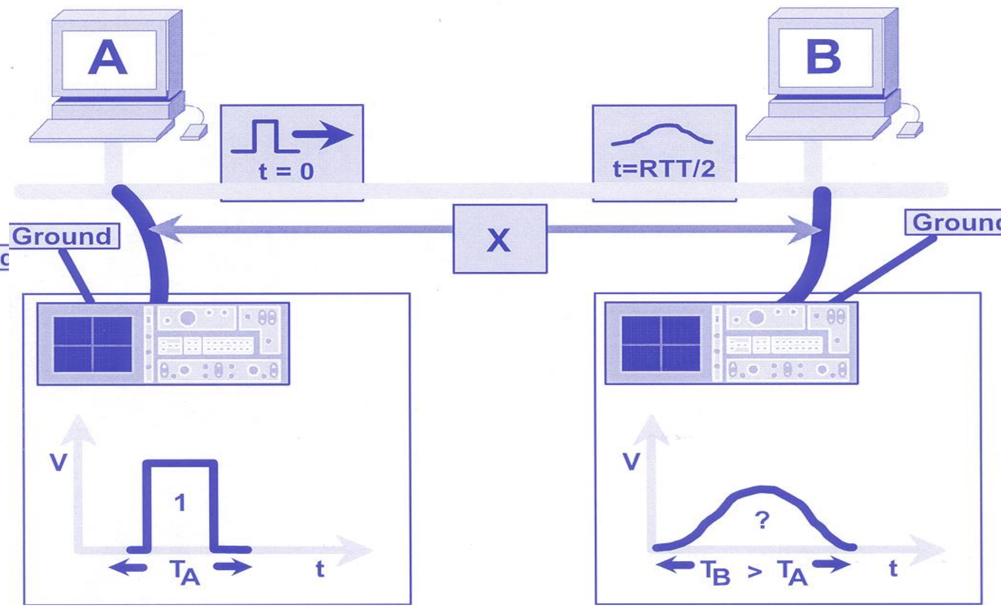
Attenuation depends increasingly of signal frequency =>problems for HF transmissions, but mainly for analog transmissions, resulting signal distortions => techniques for attenuation equalization across the frequency spectrum.

Digital signal concentrates power near the fundamental frequency.

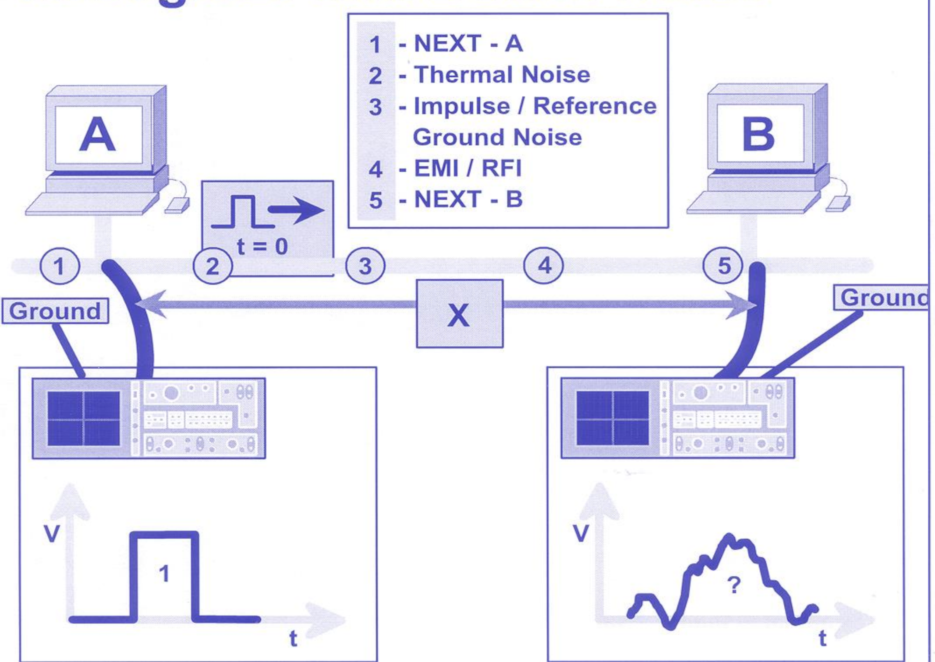
Attenuation



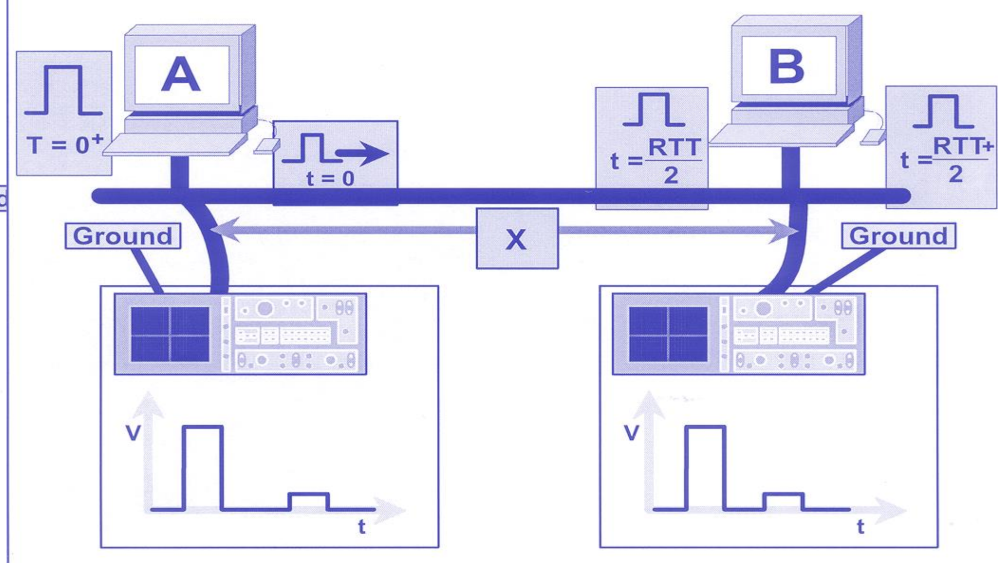
Delay Distortion (Dispersion)



Recognize and Define Noise



Reflection



Delay Distortion

Only in guided media, where the signal’s propagation speed depends on frequency => signal distortions, centred frequency components have greater velocity than those from band edges. Use of equalizers.

Noise

Plus to above mentioned distortions: additional signals inserted between transmitter and receiver (generally called **noise**)!

Thermal noise (depends on temperature, not on frequency, intrinsic to structure):

- Due to thermal agitation of electrons
- Uniformly distributed across the spectrum (called white noise)
- Can not be eliminated => an upper bound for communications performances.

Intermodulation noise

Noise signals that are the sum and difference of original frequencies sharing a medium, or multiples of them – due to the nonliniarities of the transmission system.

Crosstalk

A signal from one line is picked up by another (is a coupling between signal paths). Experienced by anyone with the telephone.

Impulse noise

Non predictable, caused by external electromagnetic disturbances, faults and flaws in the system; critical for digital transmissions

Irregular pulses or spikes with short duration, random amplitude (thus may be high), and spectral content.