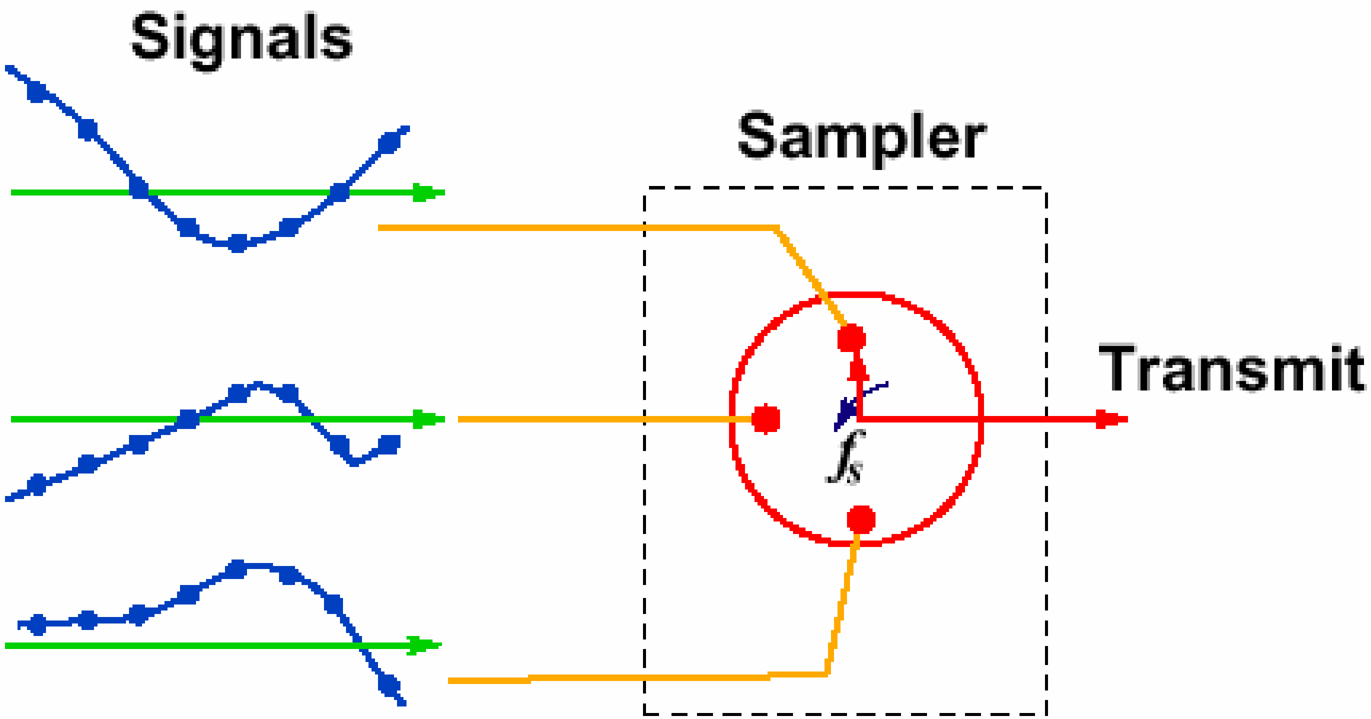
Speech Telephony

- Bandwidth 300 – 3400 Hz
- Filtered to 4 kHz
- Sampled at 8 kHz
- 8 bit A-Law or μ-Law to give
- 64 kbit/s data rate

Time Division Multiplexing

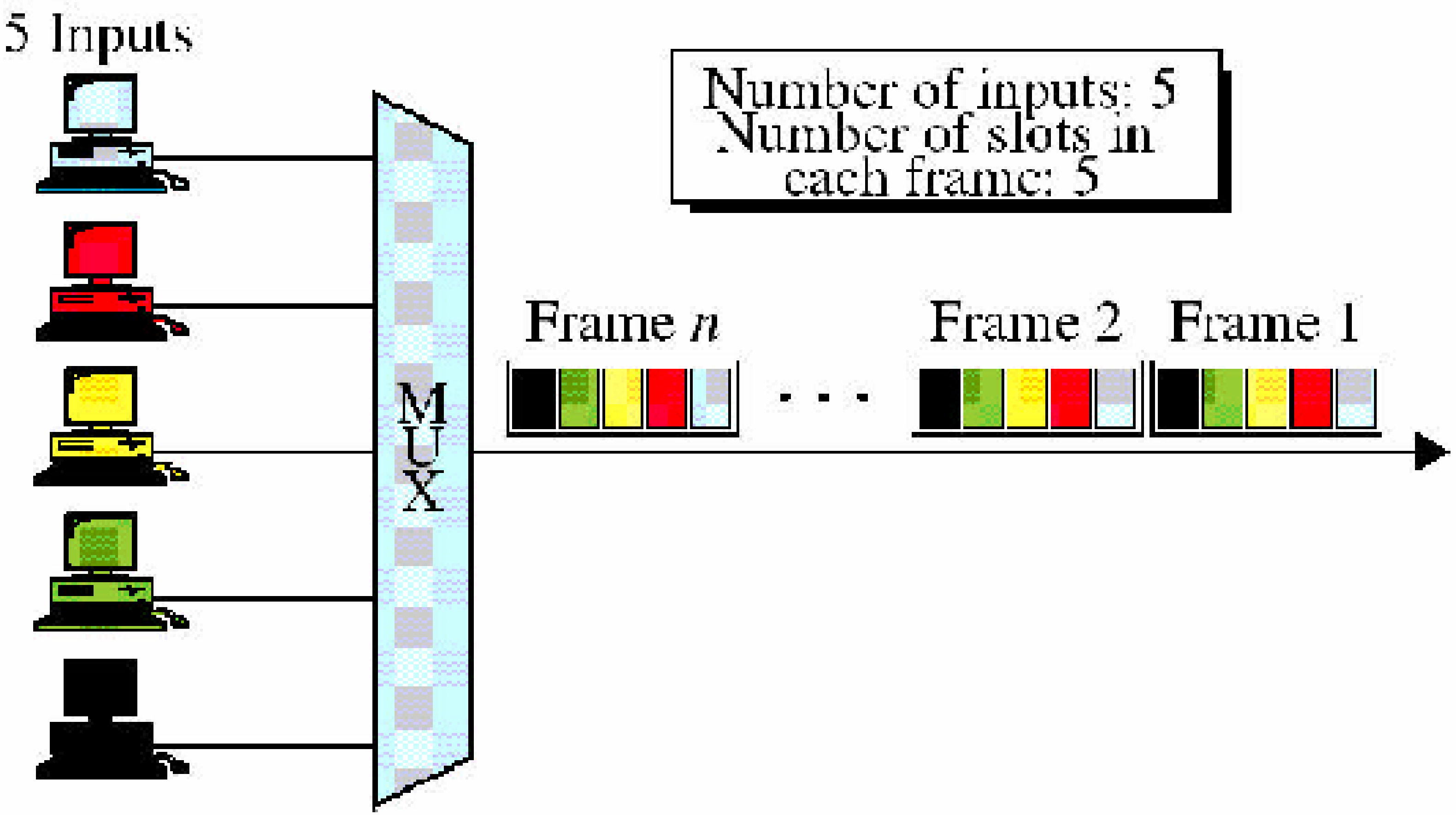
Definition 1 *Time-division multiplexing (TDM) is the time interleaving of samples from several sources so that the information from these sources can be transmitted serially over a singe communications channel.*



Time-Division Multiplexing

- In TDM, each information signal is allowed to use all available bandwidth
- In theory, it is possible to divide the bandwidth or the time among the users of a channel
- Continuously variable signals, such as analog, are not well adapted to TDM because the signal is present all the time

TDM – view 1

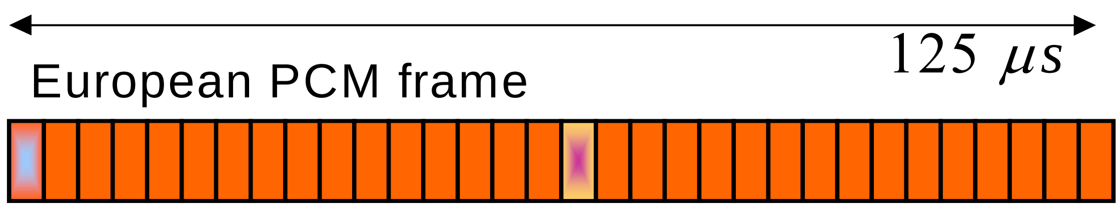

5 Inputs
Number of inputs: 5
Number of slots in each frame: 5
MUX
Frame n
Frame 2
Frame 1
. . .

TDM in Telephony

- TDM is used extensively in telephony
- The most common US standard is the DS-1 signal, which consists of 24 PCM voice channels, multiplexed using TDM
- Each channel is sampled at 8 kHz with 8 bits per sample, which gives a bit rate of 64 kb/s for each voice channel
- The samples must be transmitted at the rate they were obtained to be reconstructed
- The overall bit rate is 1.544 Mb/s
- This US system is known as a *T1 Carrier*

PCM systems and digital time division multiplexing (TDM)

- In digital multiplexing several messages are transmitted via same physical channel. For multiplexing 64 kbit/s channels in digital exchanges following three methods are available:
  - **PDH** (plesiochronous digital hierarchy) (the dominant method today, E1 & T1) ('50-'60, G.702)
  - **SONET** (synchronous optical network) ('85)
  - **SDH** (synchronous digital hierarchy) (CCITT '88)



32 time slots x 8 bits x 8000 Hz = 2048 kbit/s

frame synchronization slot

signaling or traffic

traffic

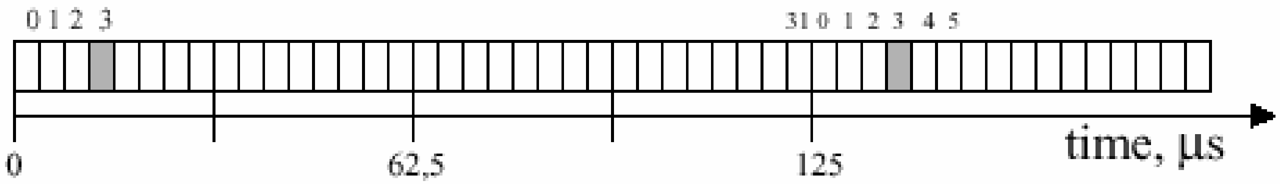
PDH E-1 frame

PCM-hierarchy

- **PCM-hierarchy is created by overlapping time division multiplexed signal connections byte by byte (sample by sample). Bits become shorter.**
- **The basic speed in the hierarchy is the bitrate of a single voice channel**

$$S = 8000\text{Hz} * 8\text{bit} = 64\text{kbit/s},$$

- **in time in a 2Mbit/s PCM system, this looks like:**



- **The following voice channel groups are defined**
  - **30 voice channels**
  - **120 voice channels**
  - **480 voice channels**
  - **1920 voice channels**

PCM 30 (E1)

- The most common information switching and transmission format in the telecommunication network is PCM 30.
- PCM 30 contains:
  - 1 synchronization and management channel
  - 1 signaling channel
  - 30 voice channel
- A channel is a time slot in the PCM-frame (125µs), created by TD multiplexing.
- PCM 30 system carries 32 time slots, each 64kbit/s. This gives a total bit rate of 2048kbit/s.

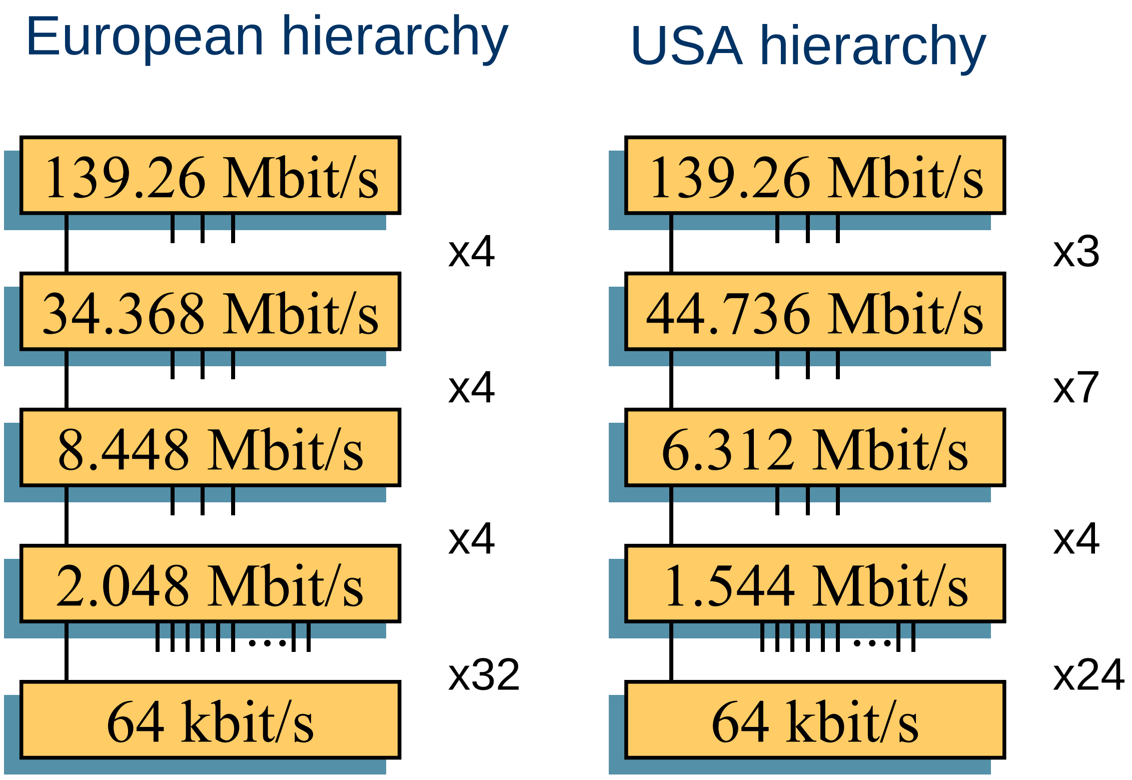
PCM 30 frame

- PCM 30 -frame contains 32 time slots
  - time slot 0 is dedicated for synchronization and management information
  - Time slot 16 is assigned for signaling information (CAS)
  - Time slots 1-15 and 17-32 are voice or user information channels
- Even and odd frame structures differ
  - In even numbered frames time slot 0 carries the frame alignment signal (C0 01 10 11). C is the CRC-bit (cyclic redundancy check) for ensuring the frame alignment recovery in case someone is sending X0 01 10 11 on a user information channel – this addition was forced by ISDN which supports transparent 64kbit/s service for data transfer.
  - Time slot 0 in odd frames carries alarm information. To avoid wrong frame alignment, the second bit in tsl 0 is set to the constant value of 1.

US Digital Signal Hierarchy

Carrier	Signal	Voice Channels	Bit Rate (Mb/s)	Typical Medium
T1	DS-1	24	1.544	Twisted-pair
T1C	DS-1C	48	3.152	Twisted-pair
T2	DS-2	96	6.312	Low-capacitance twisted-pair microwave
T3	DS-3	672	44.736	Coax, microwave
T4	DS-4	4032	274.176	Coax, fiber-optic
T5	DS-5	8064	560.16	Fiber optics

PCM hierarchy in PDH



If one wishes to disassemble a tributary from the main flow the main flow must be demultiplexed step by step to the desired main flow level in PDH.

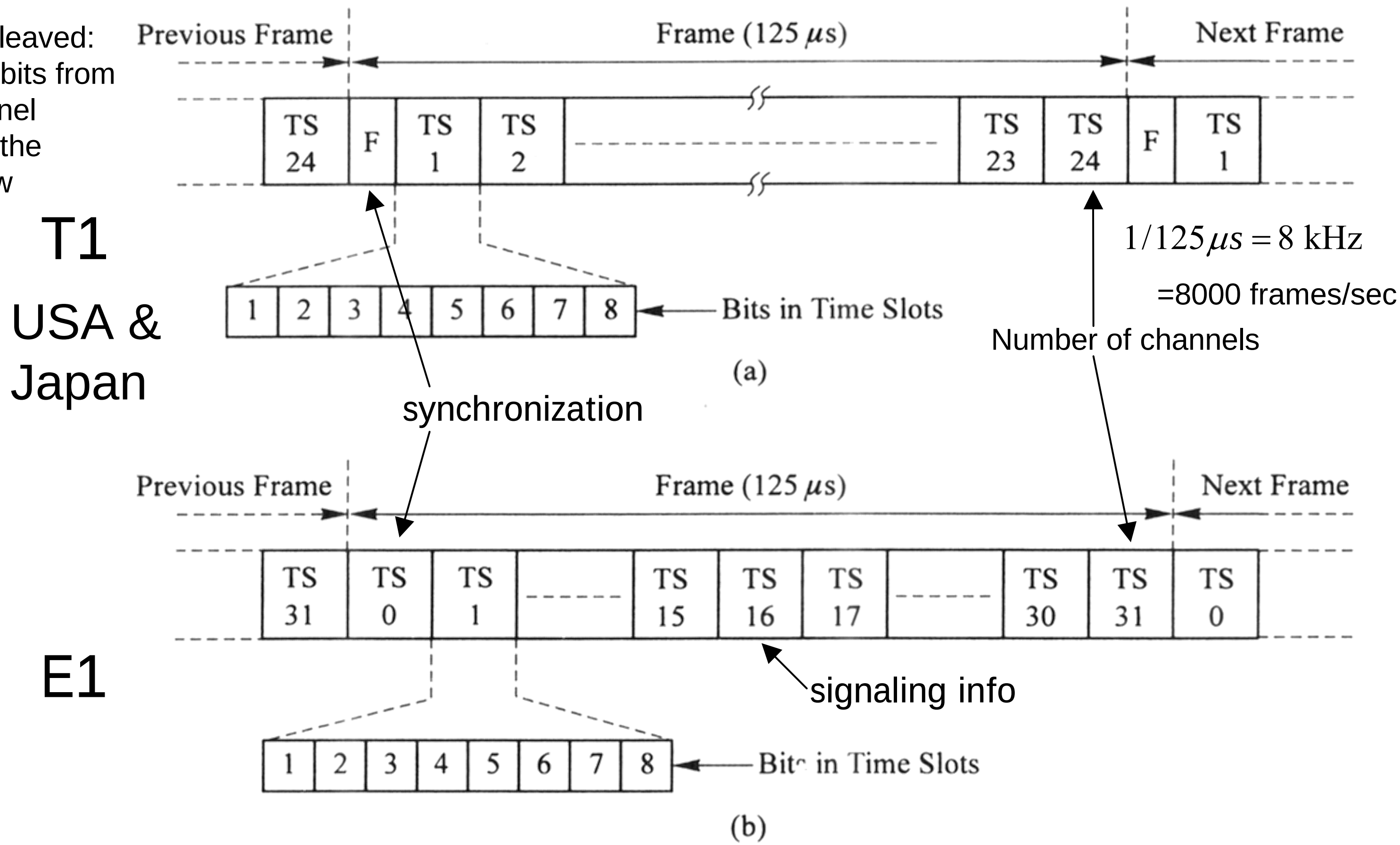
T1 and E1 summarized

- In PSTN two PCM systems dominate:
  - T1, developed by Bell Laboratories, used in USA & Japan
  - E1, developed by CEPT* used in most of the other countries
- In both data streams divided in frames of 8000 frames/sec
- In T1
  - 24 time-slots and a framing (F) bit serves 24 channels
  - Frame length: 1+ 8x24=193 bits
  - Rate 193x8000 bits/second=**1544 kb/s**
- In E1
  - frame has 32 time-slots, TS 0 holds a synchronization pattern and TS 16 holds signaling information
  - An E1 frame has 32x8=256 bits and its rate us 8000x256=**2048 kb/s**

*European Conference of Postal and Telecommunications Administration

E1 and T1 first order frames compared*

T1 is byte-interleaved: blocks of eight bits from the same channel are inserted to the multiplexed flow



NOTE: In T1 one bit in each time slot in every sixth frame is replaced by signaling information yielding 56 kb/s only

*John G. van Bosse: Signaling in Telecommunication Networks

Some codecs and their characteristics

Coding Standard	Algorithm	Sample Size (msec)	Rate Kbit/s	Mean Opinion Score	Year
G.711	PCM	0.125	64	4.10	1972
GSM 06.10	RPE-LTP	20.000	13	3.50	1987
G.726,G727	ADPCM	0.125	16, 24, 32, 40	3.85	1990
G.728	LDCELP	0.625	16	3.61	1992, 1994
IS-96	VSELP	20.000	8.5, 4, 2, 0.8		1993
G.729, G.729a	CS-ACELP	10.000	8	3.92, 3.70	1995
G.723.1	MPC-MLQ	10.200	6.3, 5.3	3.90	1995
PDC	PSI-CELP	40.000	3.45		1996
FS-1015	LPC	25.700		2.40	-
AMR-NB					
AMR-WB				>PCM	

Line Codes

- Line Codes are used to condition the baseband signal for optimum transmission over a given medium (line).
- Unipolar NRZ (non-return-to-zero) means that there is no requirement for a signal to return to zero at the end of each element
- RZ (return-to-zero) methods are used to eliminate low-frequency ac components and dc components

Line coding

- Line codes are used to **enable baseband transmission** in
  - Fiber optic systems
  - Cable transmission
  - Data access and storage
- In PCM-links line coding is used to alleviate clock **synchronization** at the receiver (F-transform of the pulse train should contain spikes that the receiver clock can be synchronized)
- Line codes should
  - be immune to **long strings of zeros** that can lead to missing receiver clock synchronization
  - contain zero long term averaged **DC-component**
  - have minimum **bandwidth**
- Line codes can also be used for **error detection**

Line coding (cont.)

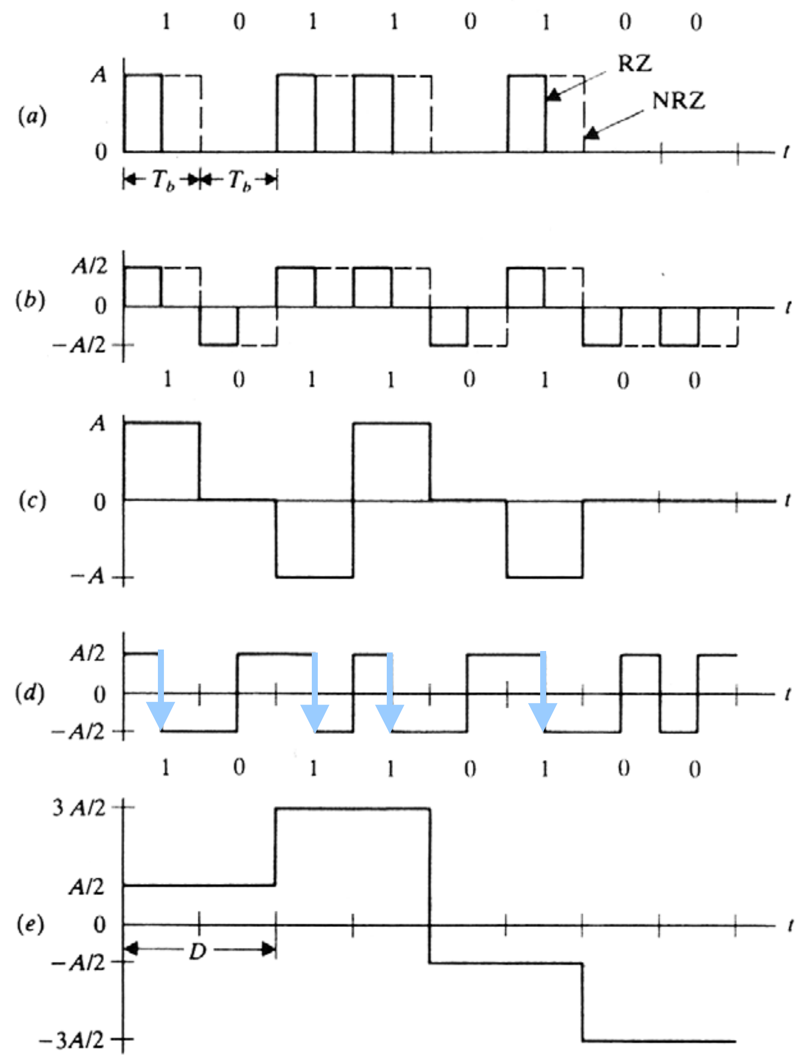
Unipolar [0,A] RZ and NRZ

Polar [-A/2,A/2] RZ and NRZ

Bipolar [-A/2,0,A/2] AMI

Split-Phase Manchester

Split-Polar quaternary NRZ



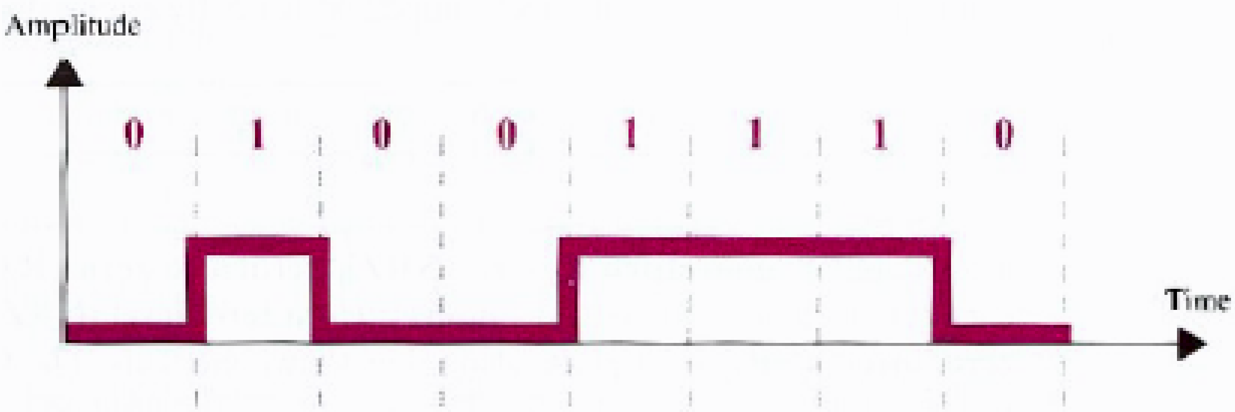
Code rate reduced by *n*

$$M = 2^n$$

$$r_{be} = r / n = r / \log_2 M$$

3.2.1.1. Unipolar Encoding

- Unipolar encoding:
  - Uses only one level of amplitude.
  - Is very simple and very primitive.
  - Almost obsolete today.

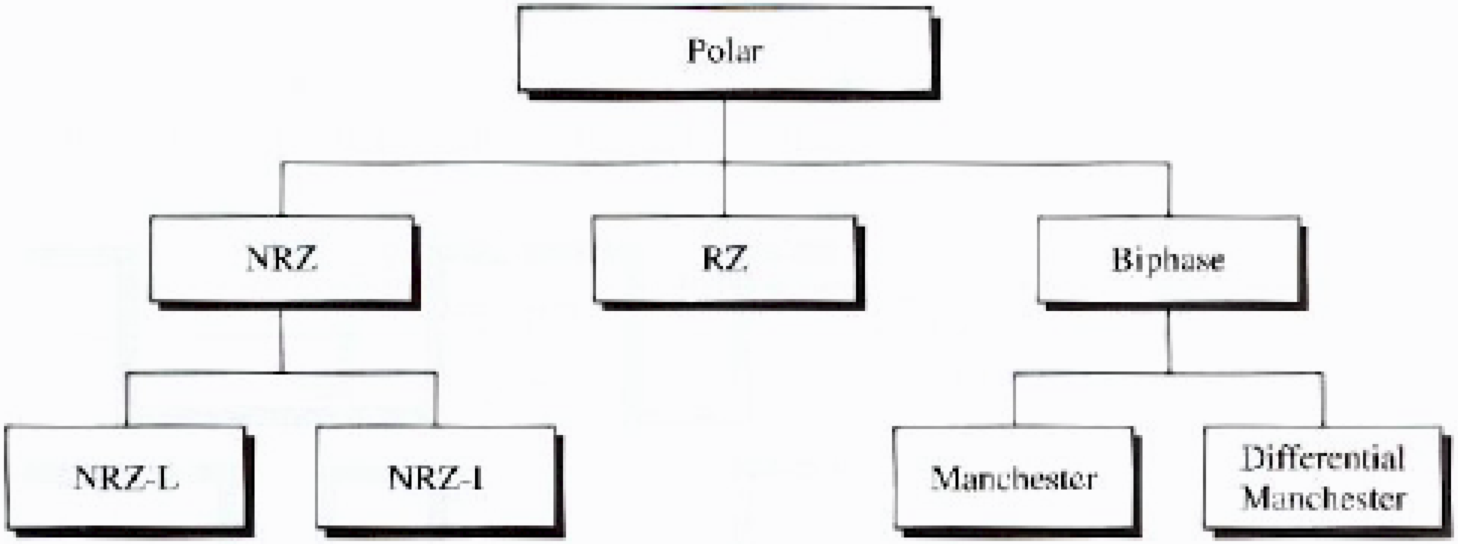


3.2.1.1. Unipolar Encoding

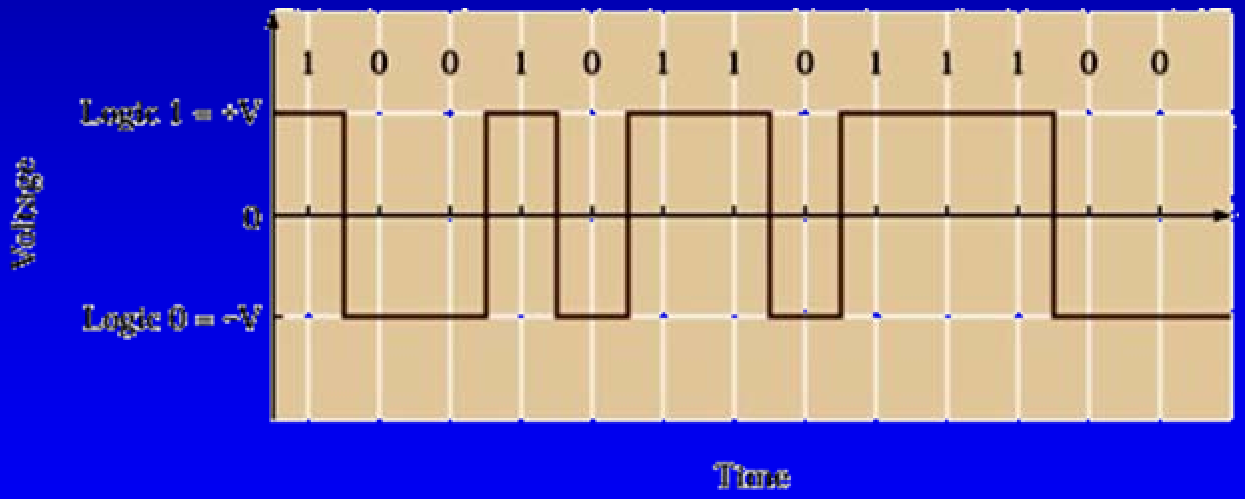
- Two problems:
  - DC component
    - Average amplitude of encoded signal is nonzero.
    - Can not travel through media that can not handle DC components.
  - Synchronization
    - Lack of synchronization between sender and receiver clock can distort the timing of the signal.
    - Results in misinterpretation of the number of 1s or 0s whenever the data stream include a long uninterrupted series of 1s or 0s.

3.2.1.2. Polar Encoding

- Polar encoding:
  - Uses two levels (positive and negative) of amplitude.
  - Reduces the DC component problem.
  - Three popular variations:

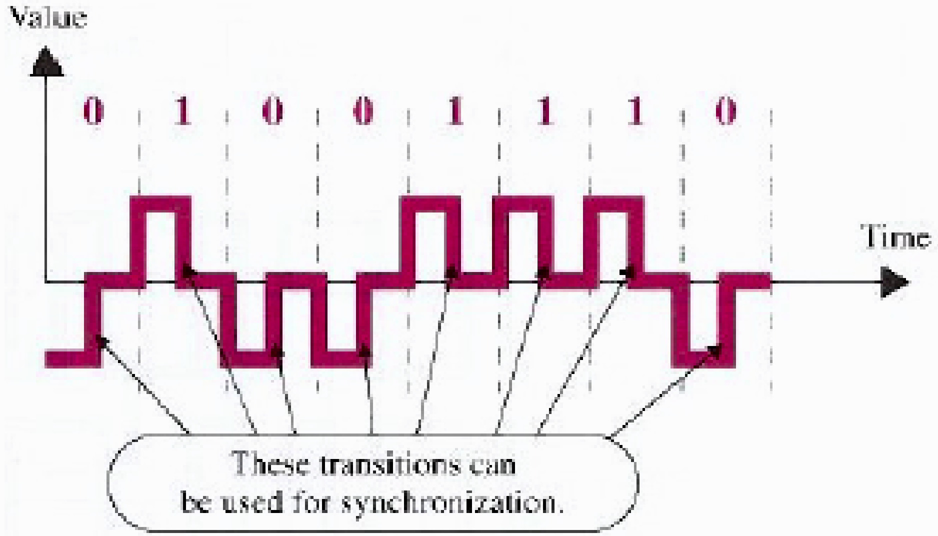


Bipolar NRZ Code



3.2.1.2. Polar Encoding

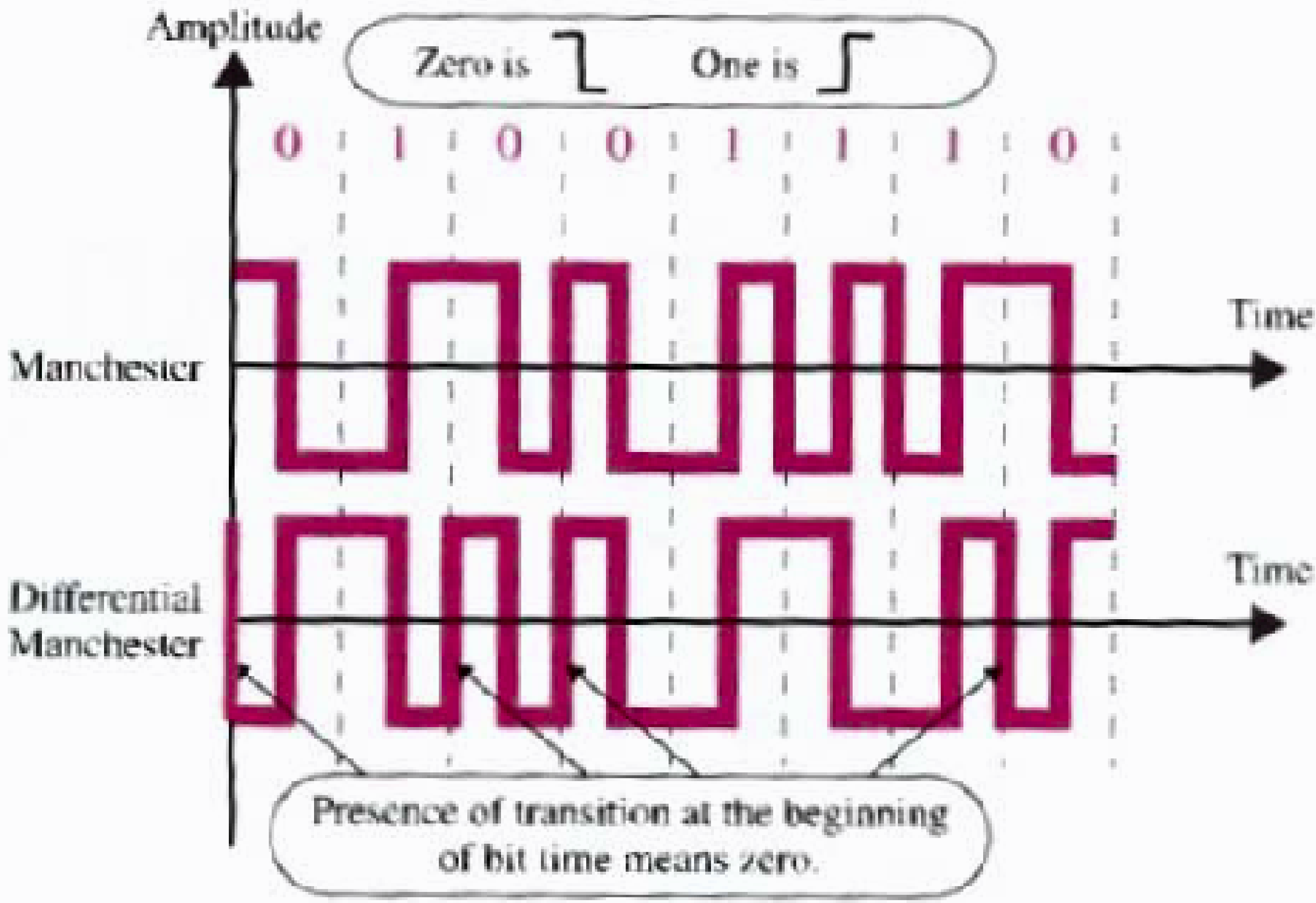
- Return to zero (RZ) encoding:
  - Uses three values: positive, negative, and zero.
  - Signal changes not between bits, but during each bit.
  - Provides for clock synchronization.



3.2.1.2. Polar Encoding

- Biphase encoding:
  - Signal changes at the middle of bit interval but does not return to zero.
  - Provides for clock synchronization.
  - Two possible implementations:
    - Machester:
      - the transition at the middle of the bit is used for both synchronization and bit representation.
    - Differential Manchester:
      - the transition at the middle of the bit is used only for synchronization.
      - the bit representation is shown by the inversion or noninversion at the beginning of the bit.

3.2.1.2. Polar Encoding

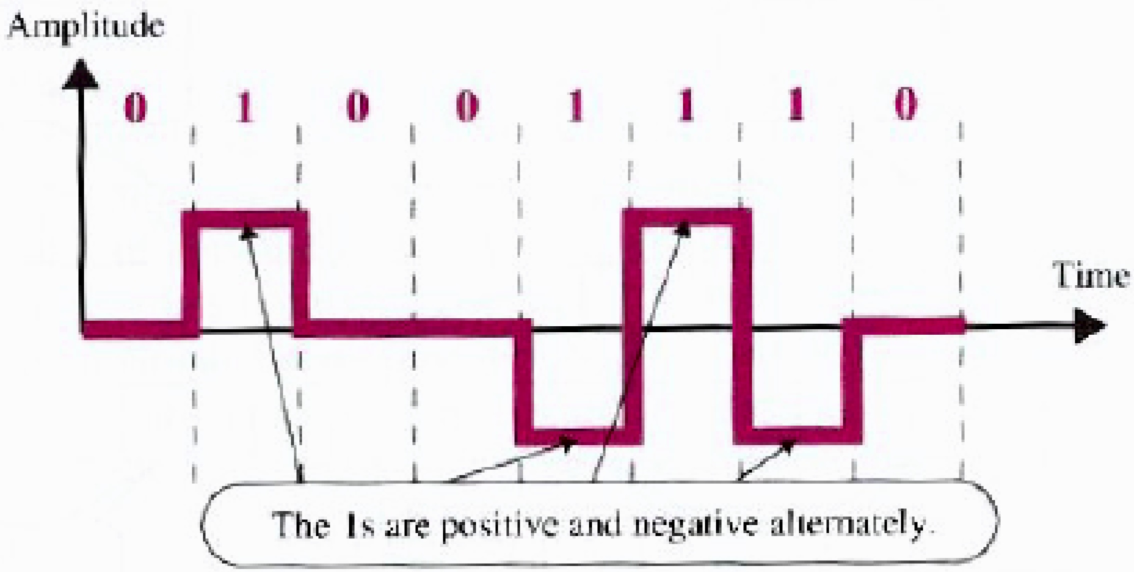


3.2.1.3. Bipolar Encoding

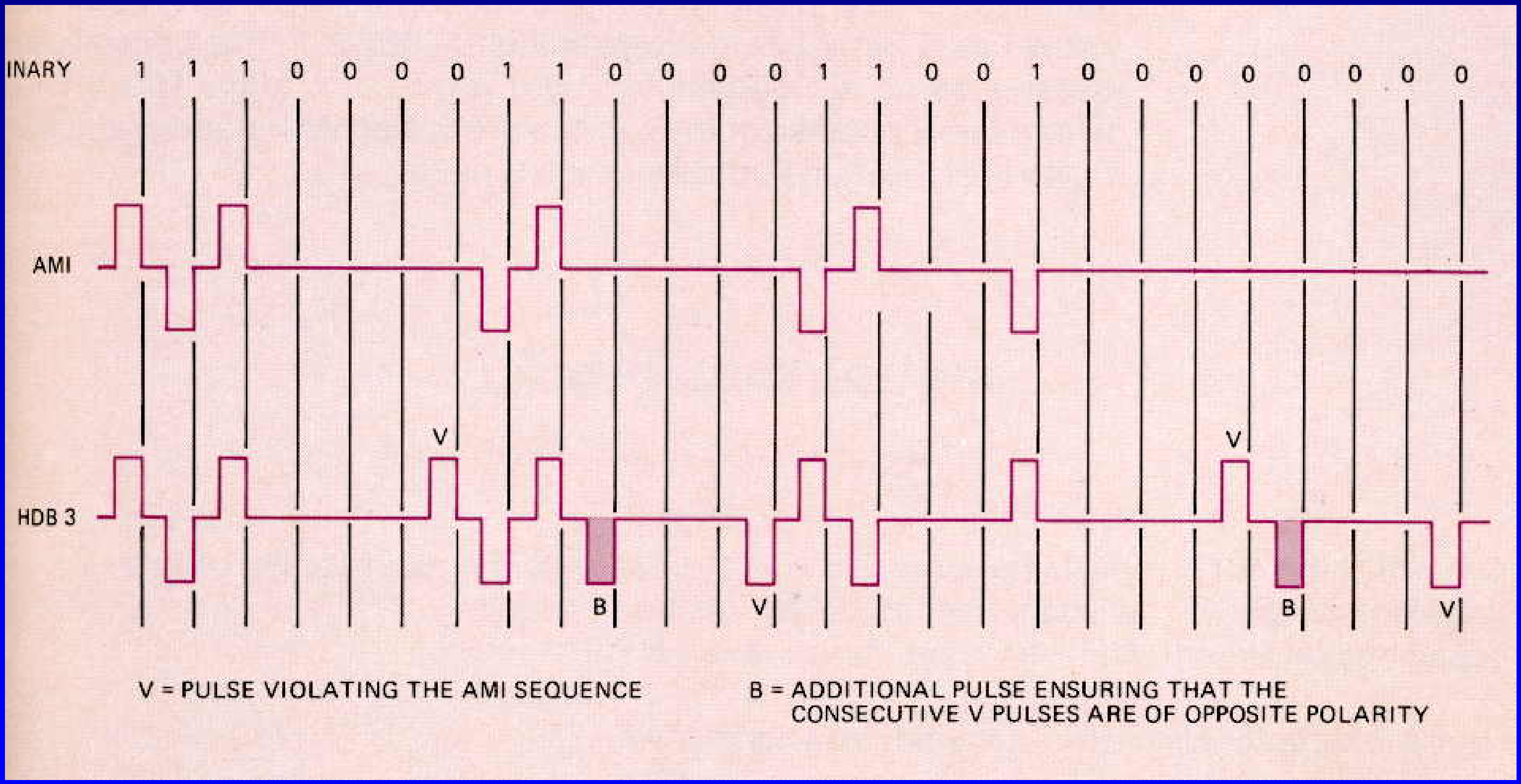
- Bipolar encoding:
  - Uses three voltage levels: positive, negative, and zero.
  - Unlike RZ, the zero level is used to represent binary 0.
  - Provides for synchronization.

3.2.1.3. Bipolar Encoding

- The simplest type of bipolar encoding:
  - Alternate Mark Inversion (AMI):
    - Binary 0 is represented by a neutral, zero voltage.
    - Binary 1 is represented by alternative positive and negative voltages.



HDB3


INARY
1 1 1 0 0 0 0 1 1 0 0 0 0 1 1 0 0 1 0 0 0 0 0 0 0 0
AMI
HDB 3
V
V
B
V
B
V
V = PULSE VIOLATING THE AMI SEQUENCE
B = ADDITIONAL PULSE ENSURING THAT THE CONSECUTIVE V PULSES ARE OF OPPOSITE POLARITY

HDB3 - Rules

- 4 zeros => 000V (V is violation pulse with same polarity as preceding AMI pulse
- Successive V pulses must be of opposite polarity =>number of pulses between successive V pulses must be odd
- Additional (Balancing) pulses added where necessary to ensure above