ITT 036:
Data Communication

Module 5: Digital Transmission

Instructor: Dr. Iqra Altaf Gillani

Data to signal conversion

Data	Signal	Approach
Digital	Digital	Encoding (Line encoding)
Analog	Digital	Encoding (PCM, DM)
Analog	Analog	Modulation (AM, FM, PM)
Digital	Analog	Modulation (Shift keying)

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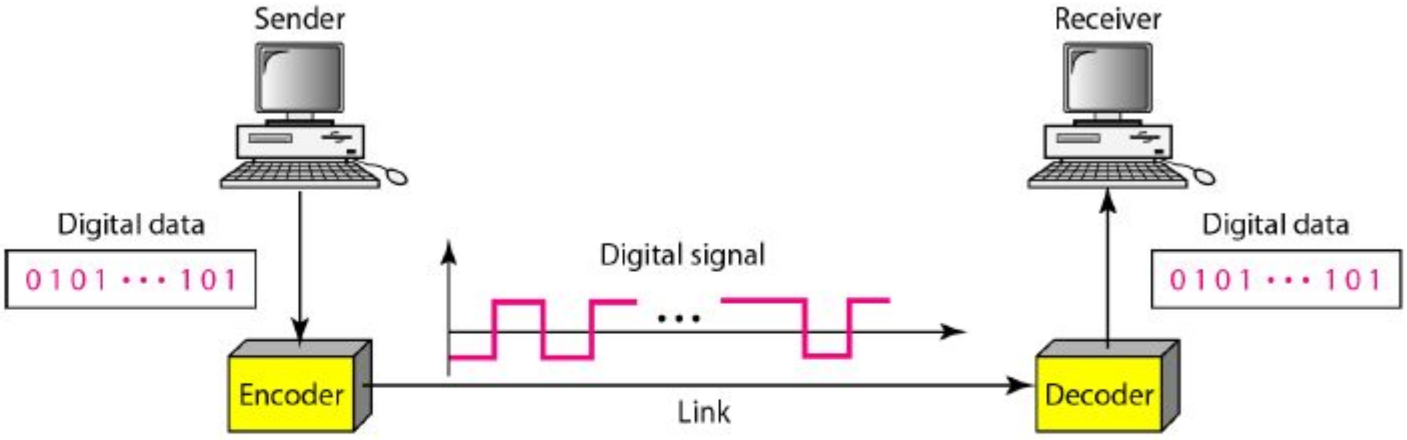
Line encoding

Motivation: We need to match bandwidth of signal to bandwidth of media so that signal can pass efficiently without much attenuation/distortion. This requires good encoding techniques.

Line encoding: technique for converting digital data into digital signal.



Characteristics of line encoding

Data element and signal element:

Data element is the smallest entity that can represent piece of information, i.e., a bit.

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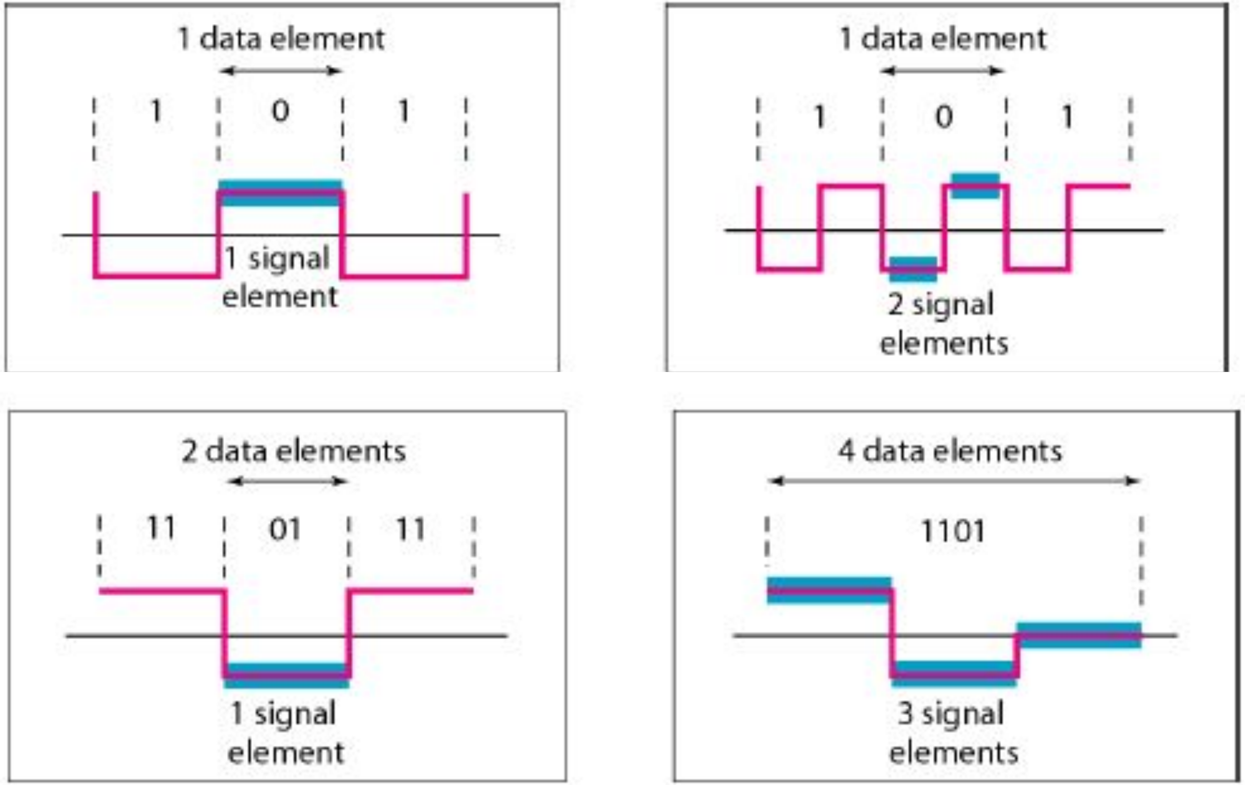
Data element: what we need to send or needs to be carried.

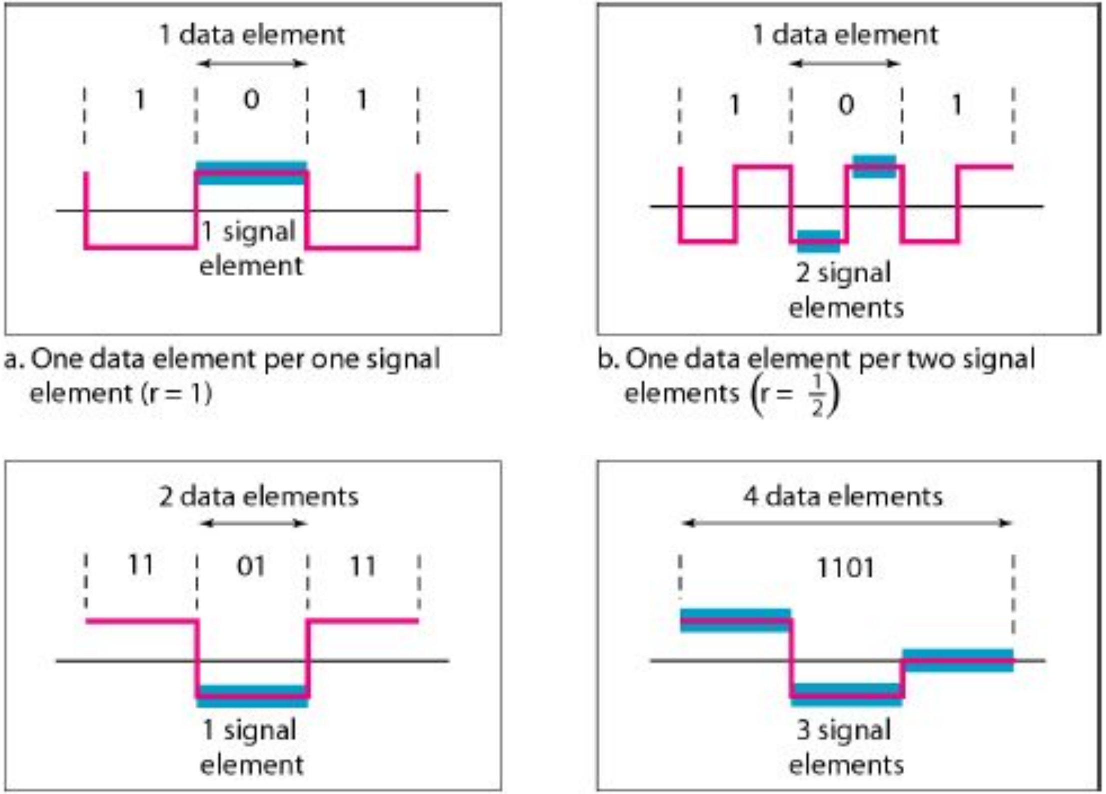
Signal element: what we send or the carrier

Ratio r is the number of data elements carried by each signal element.

Data element vs. signal element



Data element vs. signal element



a. One data element per one signal element ($r = 1$)

b. One data element per two signal elements $\left(r = \frac{1}{2}\right)$

c. Two data elements per one signal element ($r = 2$)

d. Four data elements per three signal elements $\left(r = \frac{4}{3}\right)$

Data and signal rate

- Data rate (N): number of data elements (bits) sent in 1 sec. Unit: bps.
- Signal rate (S): number of signal elements sent in 1 sec. Unit: Baud. Also known as baud rate, modulation rate or pulse rate.
- Goal: ?

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    - Increase in data rate: increases speed of data transmission.
    - Decrease in signal rate: decrease in bandwidth.

Relation between data and signal rate

We have the relation: S=N/r

This relationship not only depends on r but also on the data pattern. Three cases arise: best (min. signal rate), worst (max. Signal rate), average.

In data communication we consider average case, so,

$$S_{ave}=c*N*1/r$$

Where c represents case factor and c= ½ for the average case.

Example 4.1

A signal is carrying data in which one data element is encoded as one signal element ($r = 1$). If the bit rate is 100 kbps, what is the average value of the baud rate if c is between 0 and 1?

Solution

We assume that the average value of c is 1/2 . The baud rate is then

$$\boxed{S = c \times N \times \frac{1}{r} = \frac{1}{2} \times 100{,}000 \times \frac{1}{1} = 50{,}000 = 50 \text{ kbaud}}$$

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- So, we get $N_{max}=2*B*\log_2 L$.

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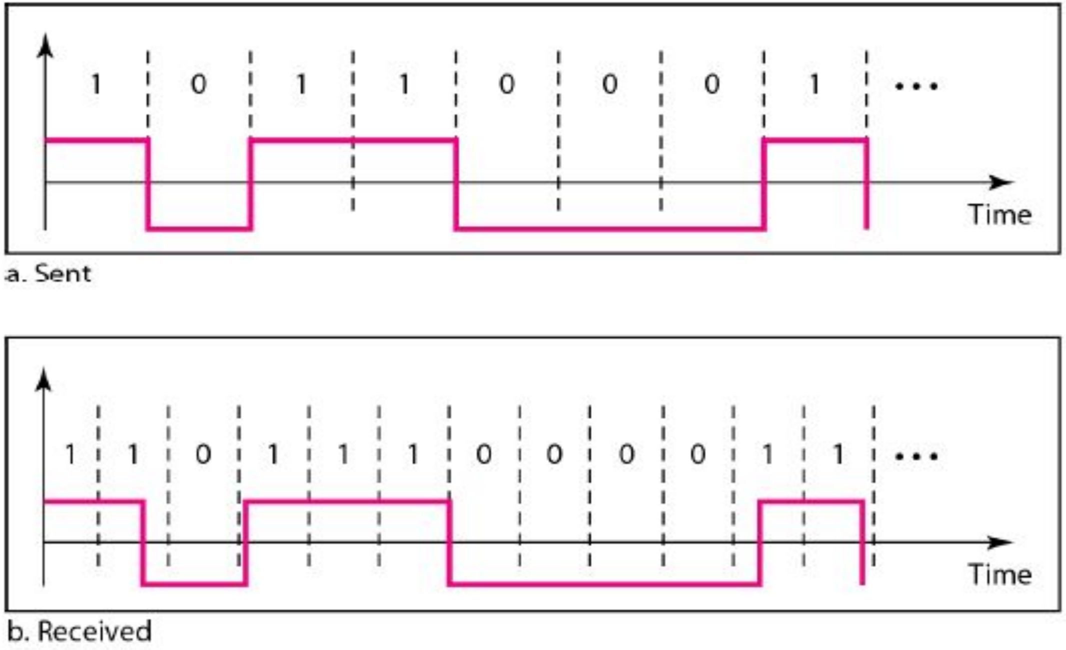
A long string of 0s or 1s can cause drift in baseline, i.e., baseline wandering and make it difficult for receiver to decode.

DC Component

- Equipments that contain transformer, capacitor block DC component leading to signal attenuation.
- Need an encoding which will not have DC component.

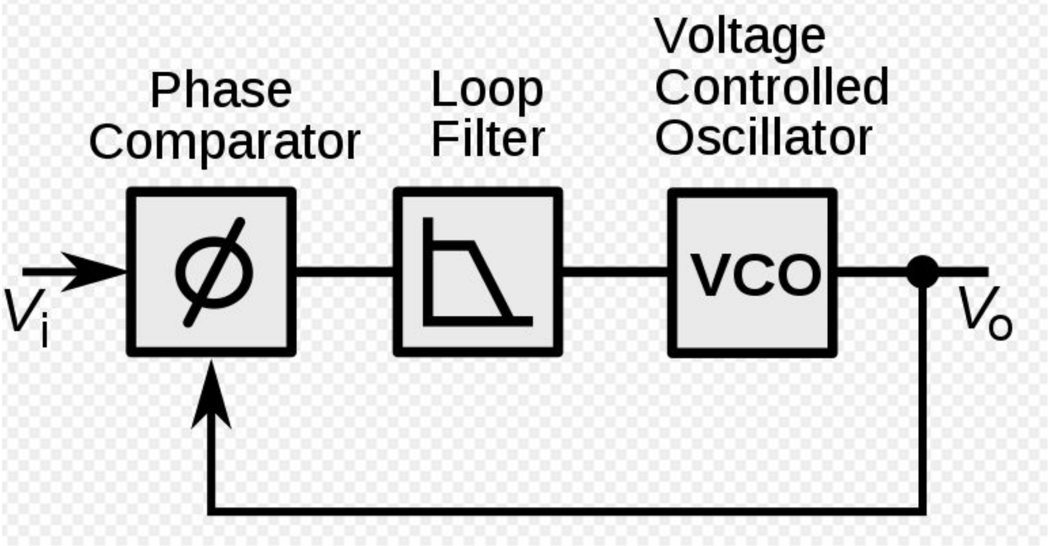
Synchronization

- To correctly interpret received signals, receiver's bit intervals must match the sender's bit intervals.



Synchronization solutions

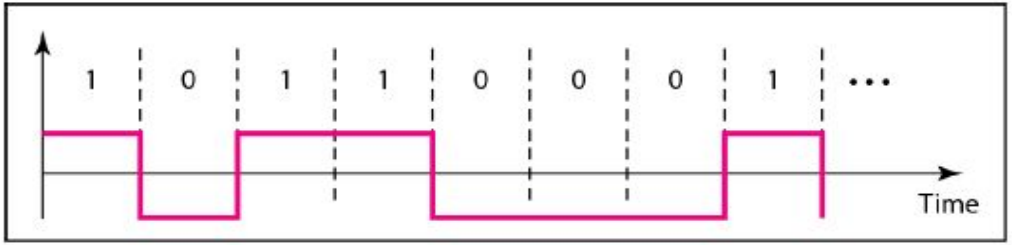
- Use a separate line to send clock to the receiver.
- Phase lock loop : Control system to generate O/P signal whose phase is related to I/P.



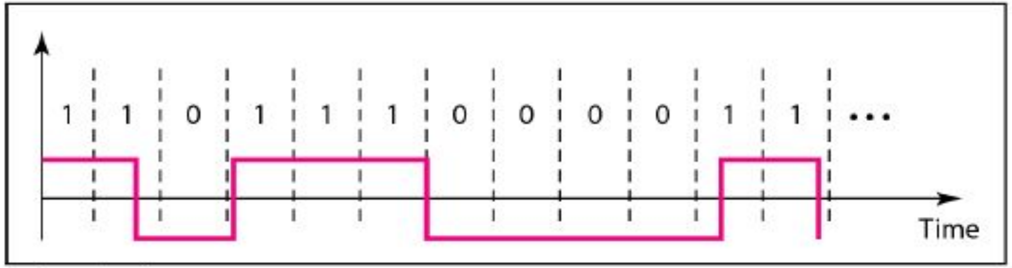
Source: https://en.wikipedia.org/wiki/File:Phase_locked_loop.svg

Synchronization solutions

- Self- synchronizing digital signal: digital signal which includes timing information. Achieved using more transitions in signals which alert user to the beginning, last, and middle of pulse.



a. Sent

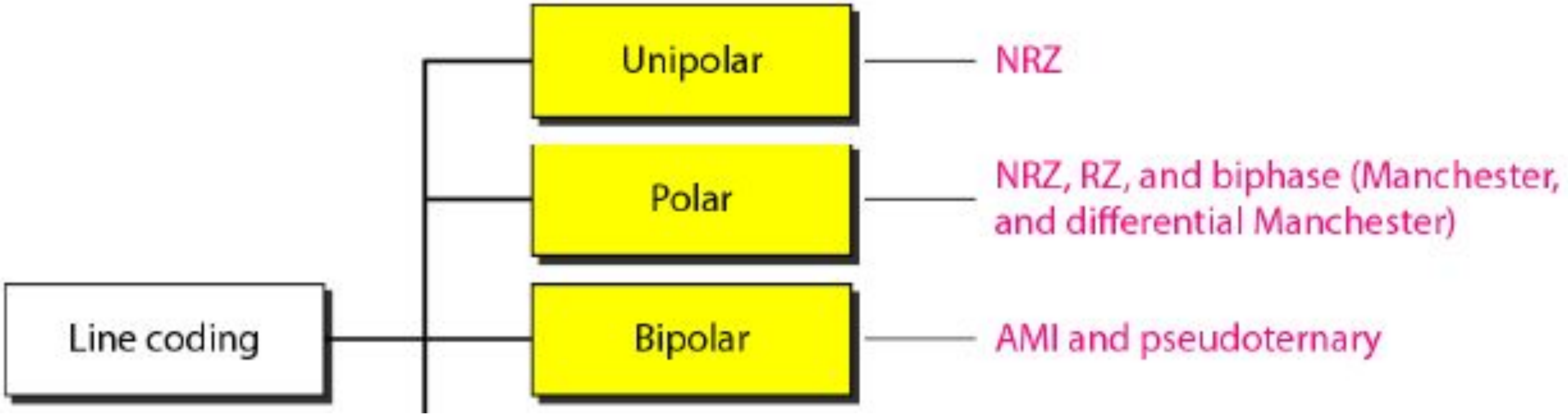


b. Received

Other features

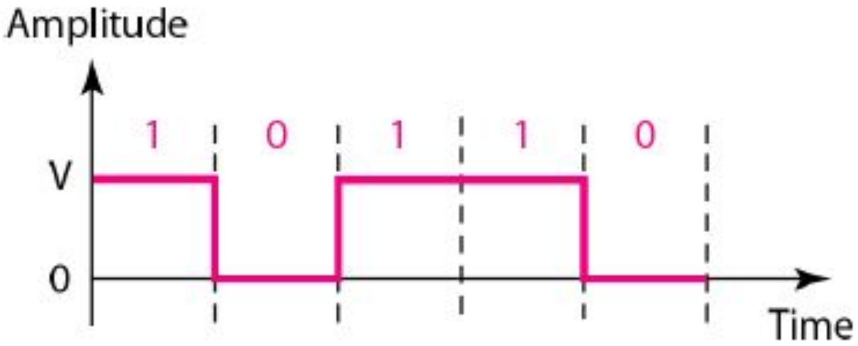
- Complex scheme means more cost. For example scheme with 4 signal levels is more difficult to interpret than the one with only two signal levels.
- Built-in error detection and immune to noise and interference.

Line encoding schemes



Unipolar

- All signal levels on one side of time axis either above or below.
- NRZ (Non return to zero) - signal does not return to zero for the entire signal element.



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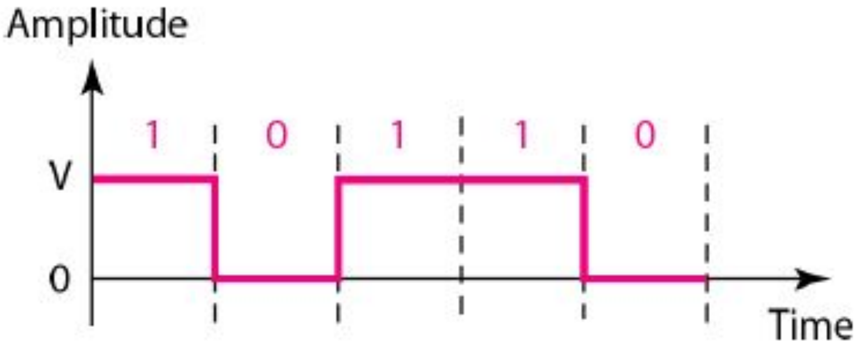

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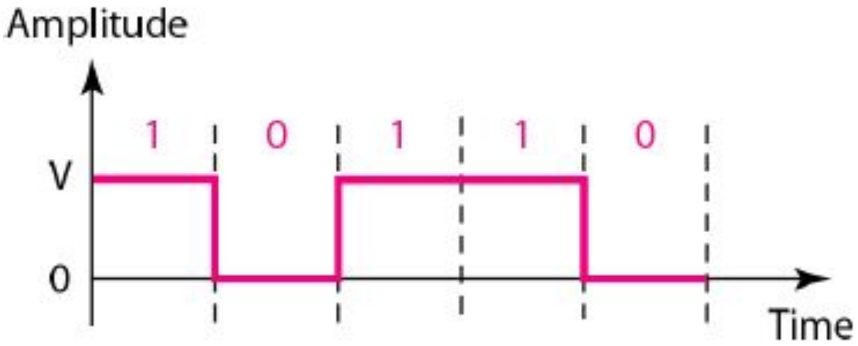

- Normalized power = 2A^2.
- Baseline wandering: sequence of 1s.
- DC component present.
- Loss of synchronization.
- Simple but obsolete.

Polar

- Voltage on both sides of time axis.
- Further types:
    - NRZ
        - NRZ-L
        - NRZ-I
    - RZ
    - Biphase
        - Manchester
        - Differential Manchester

NRZ (Non return to zero)

- NRZ- **L : LEVEL** of voltage determines the bit.
- NRZ- **I : INVERSION** or lack of inversion (or change in voltage level) determines the bit.
  - If there is no change bit is 0, else it is 1.

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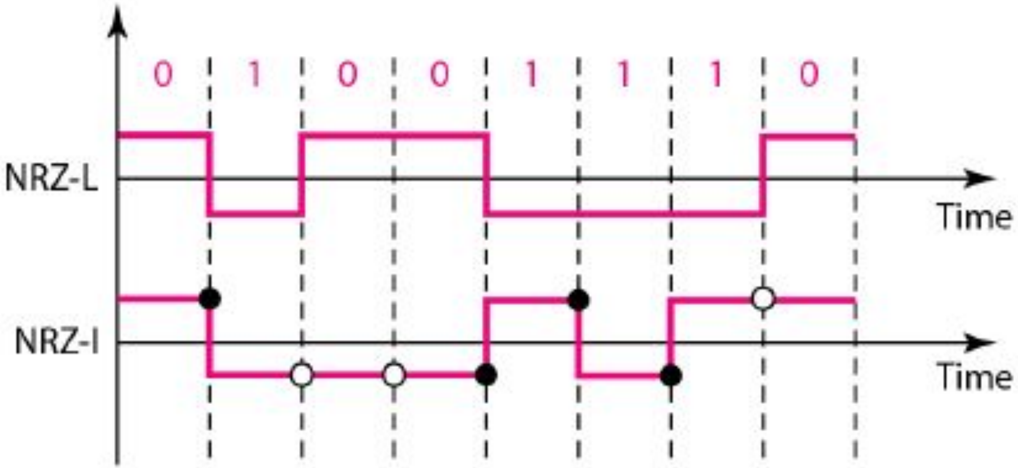

NRZ (Non return to zero)

- Baseline wandering:
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- DC Component:

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- Baseline wandering: in both but twice severe in NRZ-L.
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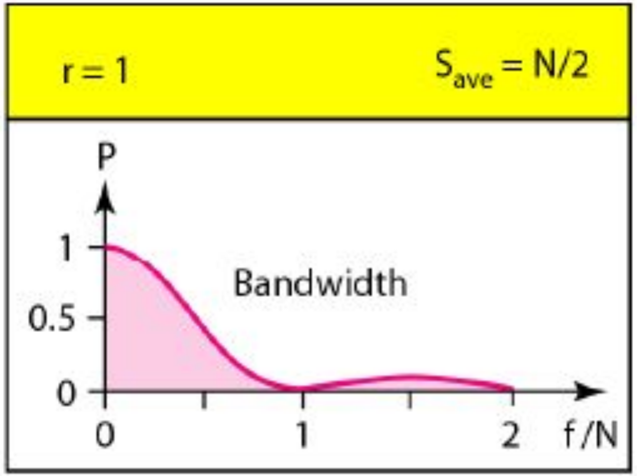
- Loss of synchronization: in both but for NRZ-I only long string of 0s is a problem.
- DC Component:

NRZ (Non return to zero)

- Baseline wandering: in both but twice severe in NRZ-L.
- Loss of synchronization: in both but for NRZ-I only long string of 0s is a problem.
- DC Component: carries high level of energy.

Although S_ave=N/2 energy is not evenly distributed.



RZ (Return to zero)

- Main problem in NRZ is lack of synchronization.
- Solution: Use three values +ve, -ve, and 0.
- Signal level changes not between the bits but during a bit.

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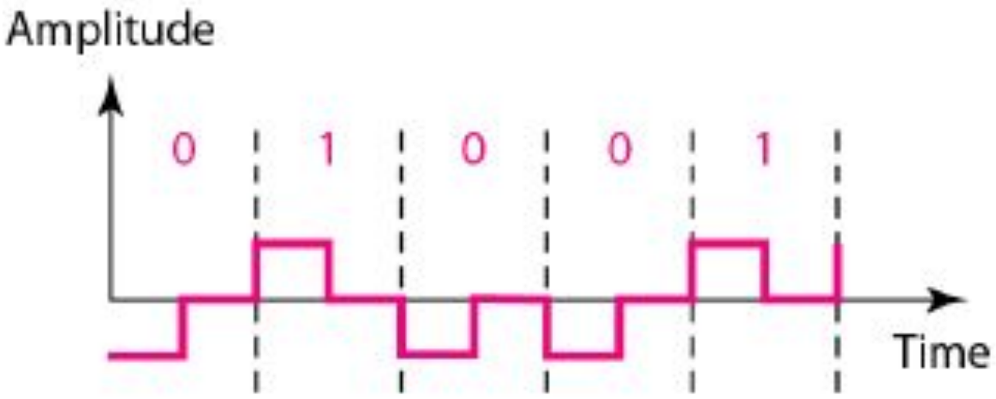


RZ (Return to zero)

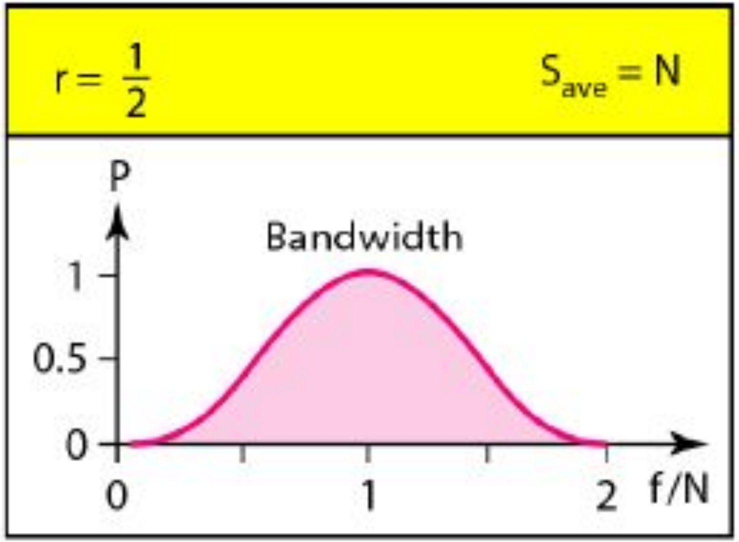
- DC component:
- Synchronization:
- Baseline wandering:

RZ (Return to zero)

- DC component: No
- Synchronization: Good
- Baseline wandering: Present

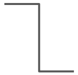
S_ave= N

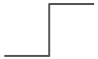
More Bandwidth



Biphase

- Combines the idea of RZ and NRZ.
- Manchester: RZ + NRZ-L
  - Divide duration of bit in two halves.
  - Voltage remains at one level; during one half and moves to other in second half.
- Example: Ethernet LAN
- G.E. Thomas: IEEE 802.3: opposite

1: 

0: 

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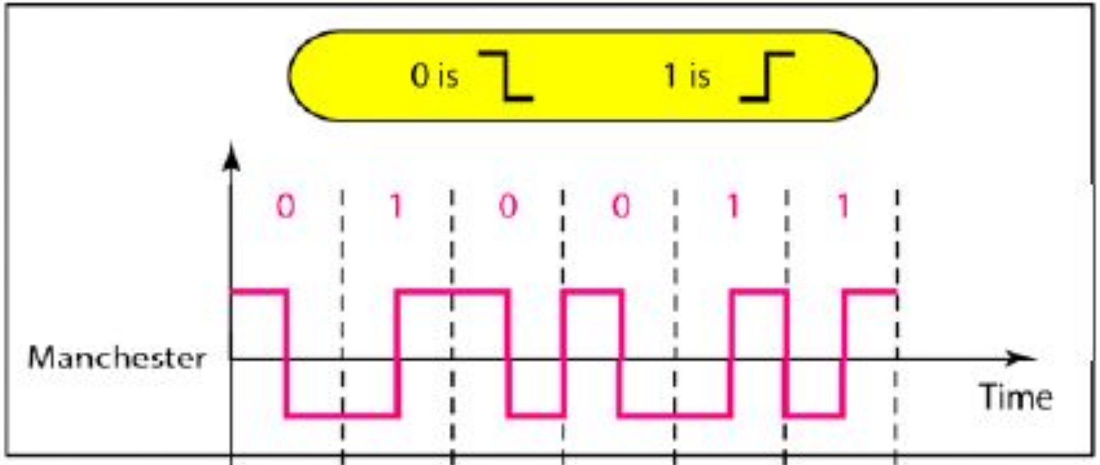

Biphase

- Differential Manchester: RZ + NRZ-I (complement)
  - Transition in the middle.
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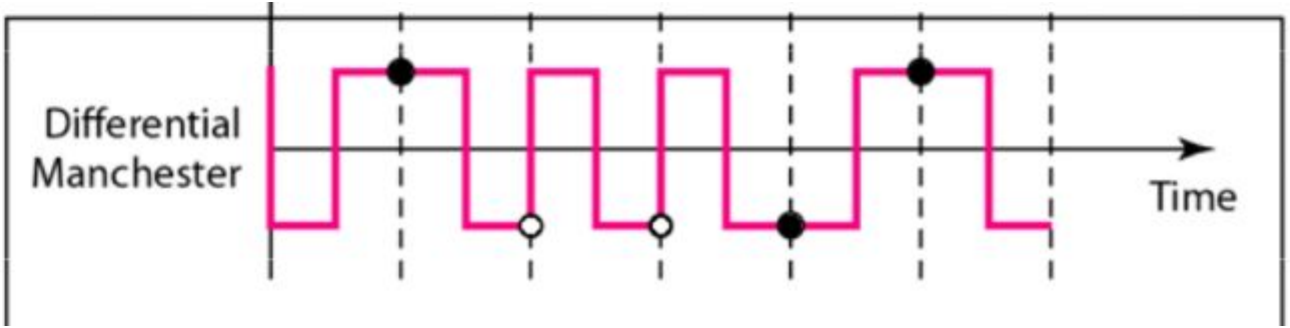
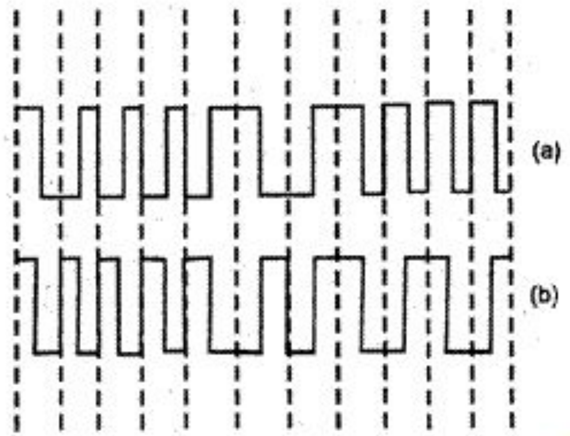


Q) In the waveform (a) given below, a bit stream is encoded by Manchester encoding scheme. The same bit stream is encoded in a different coding scheme in wave form (b). The bit stream and the coding scheme are



(A) 1000010111 and Differential Manchester respectively

(B) 0111101000 and Differential Manchester respectively

(C) 1000010111 and Integral Manchester respectively

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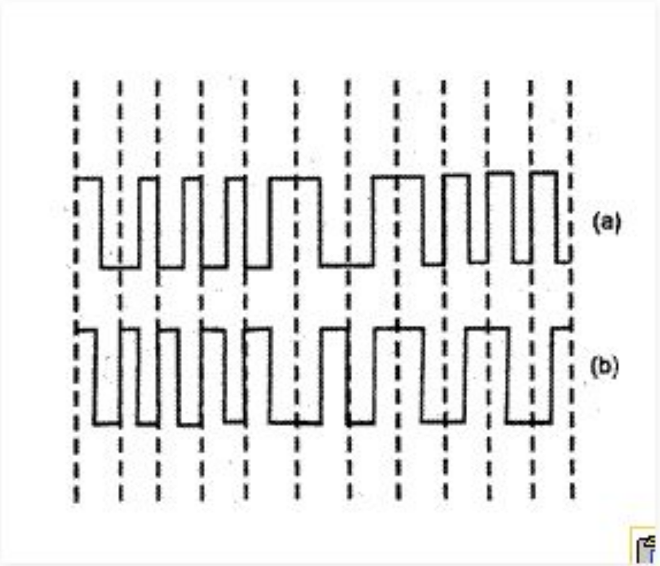

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Biphase

- Overcomes the problems of NRZ.
- No baseline wandering, DC component, and good synchronization.
- Drawback:

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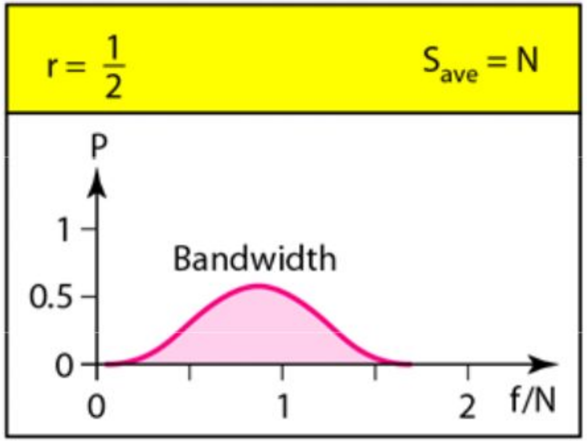
- No baseline wandering, DC component, and good synchronization.
- Drawback: Double bandwidth.



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(A) Half the baud rate.

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Bipolar (multilevel binary)

- Use three voltage levels: +ve, -ve and 0.
- Voltage level for one data element is at 0 while for the other it alternates between +ve and -ve.
- AMI (Alternate mark inversion): Neutral voltage represents 0 and 1 is represented by alternate +ve and -ve voltages.
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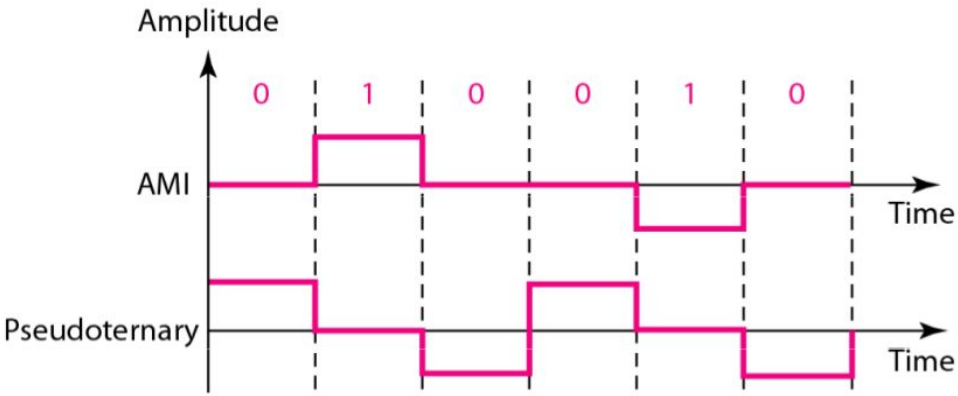
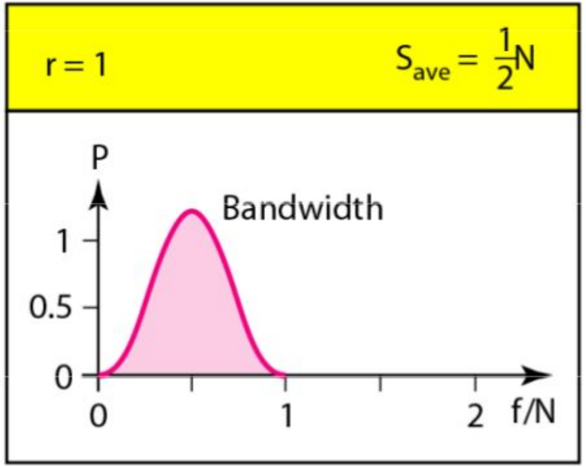


Bipolar (multilevel binary)

- Good alternative to NRZ as S_ave=N/2.
- DC component:

Bipolar (multilevel binary)

- Good alternative to NRZ as S_ave=N/2.
- DC component: No
- Synchronization: Only with long string of 0s.
- Example: Can be a good choice for long distance communication if the synchronization problem is solved.



Practical encoding schemes

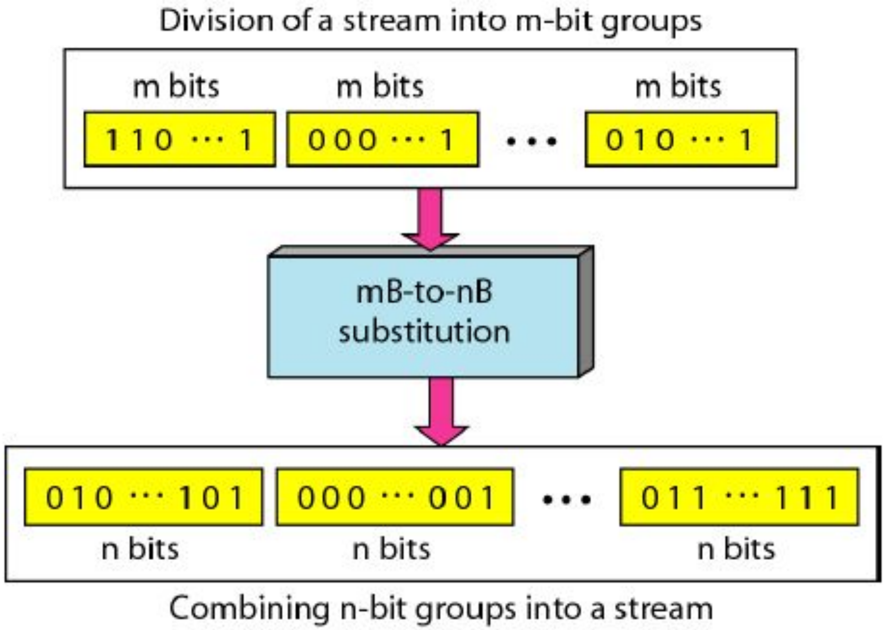
- Small Networks:
- Long-distance communication:

Practical encoding schemes

- Small Networks: **Biphase**
- Long-distance communication: **???**

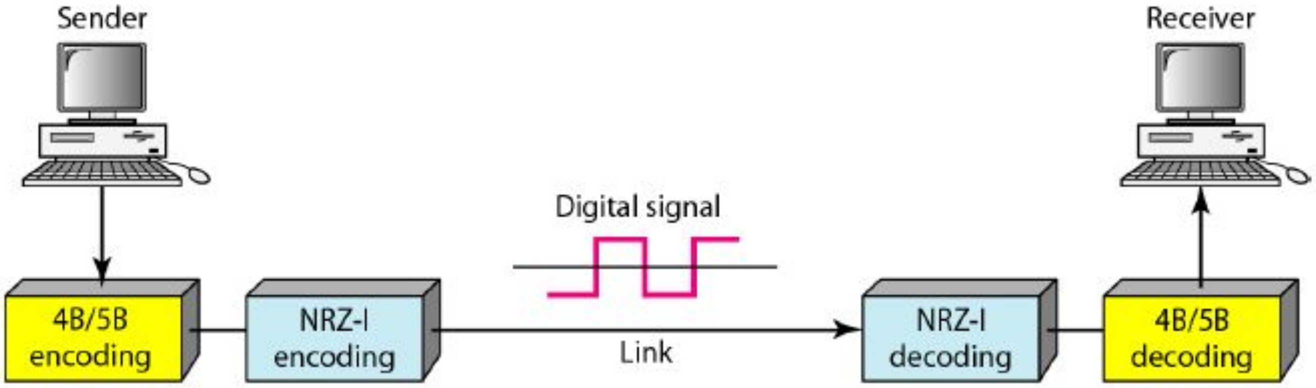
Block coding

- Provides redundancy and improves performance of line coding.
- We change a block of m bits into block of n bits, n>m. Also, known as mB/nB encoding.
- Three steps:
    - Division
    - Substitution
    - Combination
- Example: 4B/5B



Block coding

- Used in combination with NRZ-I which has good signal rate but synchronization problem due to long string of 0s.



Block coding

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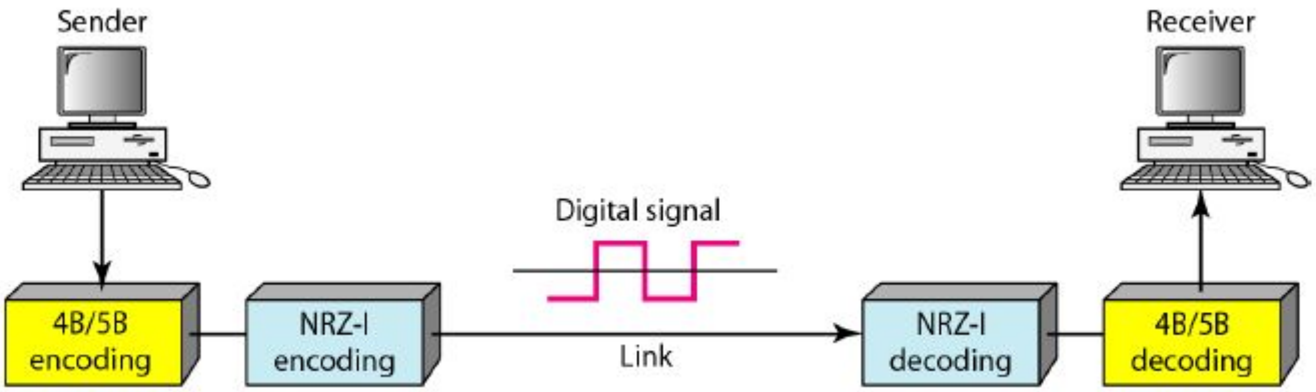
- 4B/5B changes data stream to avoid long string of 0s.



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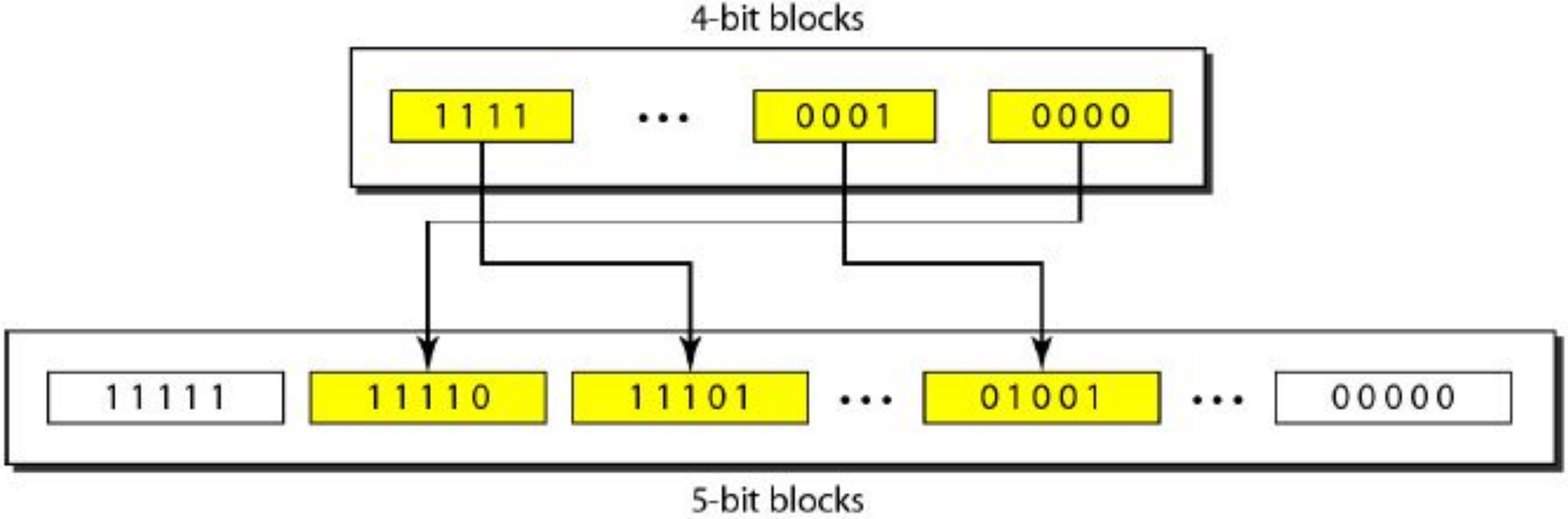
4-bit blocks
1111
• • •
0001
0000
11111
11110
11101
• • •
01001
• • •
00000
5-bit blocks

4B/5B coding

Data Sequence	Encoded Sequence
0000	11110
0001	01001
0010	10100
0011	10101
0100	01010
0101	01011
0110	01110
0111	01111
1000	10010
1001	10011
1010	10110
1011	10111
1100	11010
1101	11011
1110	11100
1111	11101

Scrambling

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  - Biphase is suitable for dedicated link between stations in LAN but not for long distance communication.
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- We need a technique that does not increase the bits and provide synchronization.
- Solution:

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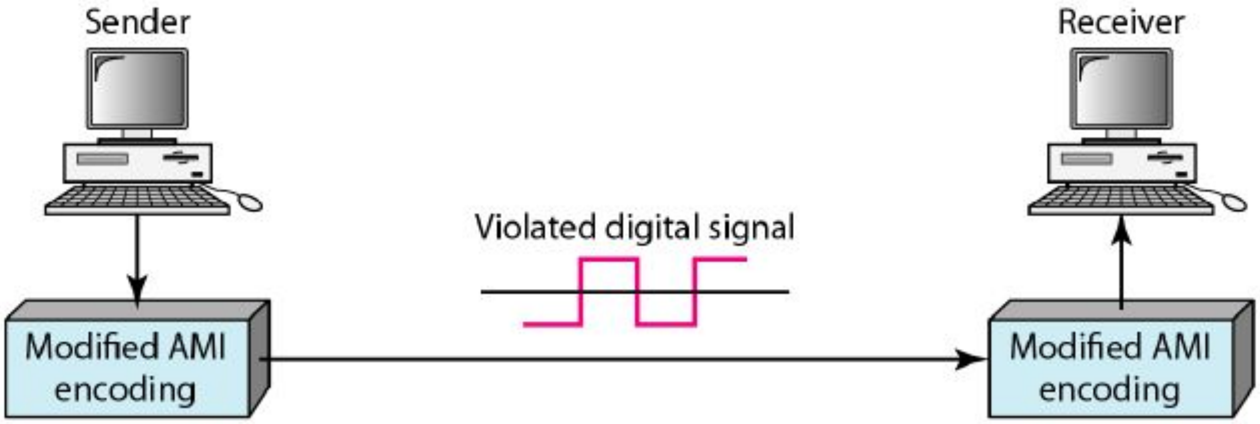
- Modify part of AMI rule (done at same time as encoding) - Scrambled AMI.

Scrambling


Sender
Receiver
Violated digital signal
Modified AMI encoding
Modified AMI encoding

B8ZS (Bipolar with 8 zero substitution)

- Replace 8 consecutive zeros by 000VB0VB.
- V - violation (voltage breaks AMI rule, same polarity as previous pulse)
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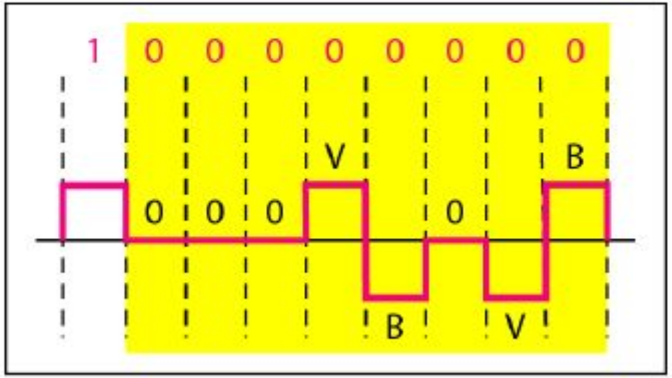
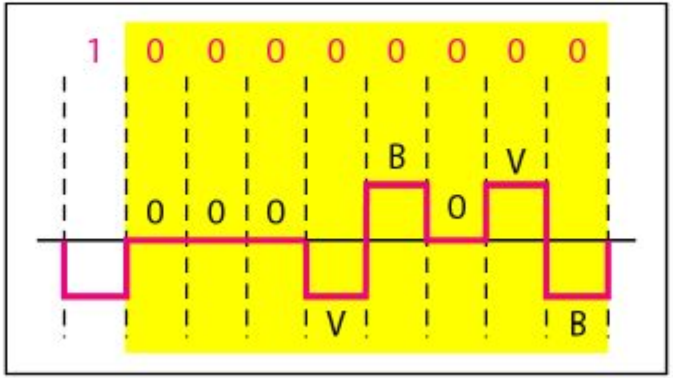


a. Previous level is positive.



b. Previous level is negative.

HDB3 (High density Bipolar 3 zero)

- In this 4 consecutive zeros are replaced by 000V or B00V to maintain even number of non-zero pulses after substitution.
- If no. of non-zero pulses after last substitution is
  - Odd - replace by 000V.
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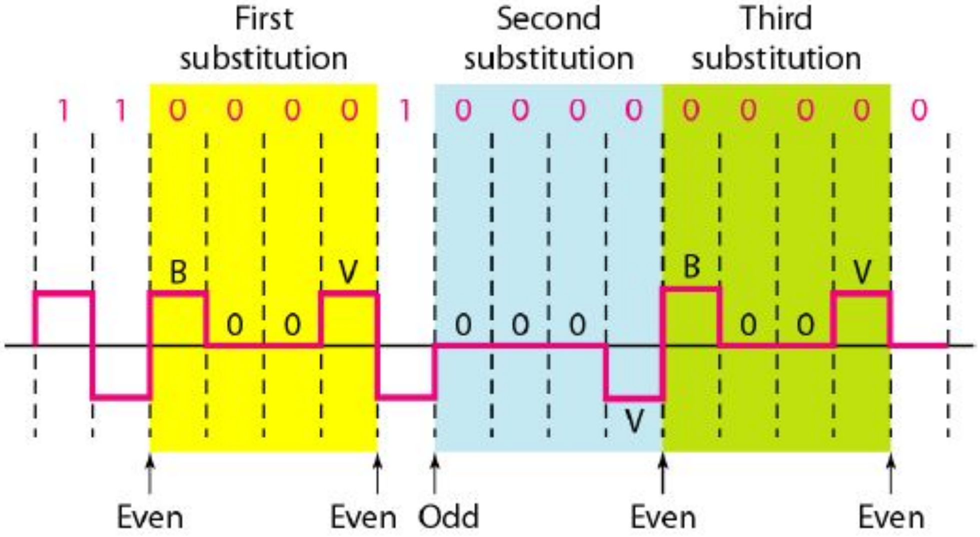

Practical encoding schemes

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- Long-distance communication: **Scrambling (Scrambled AMI)**

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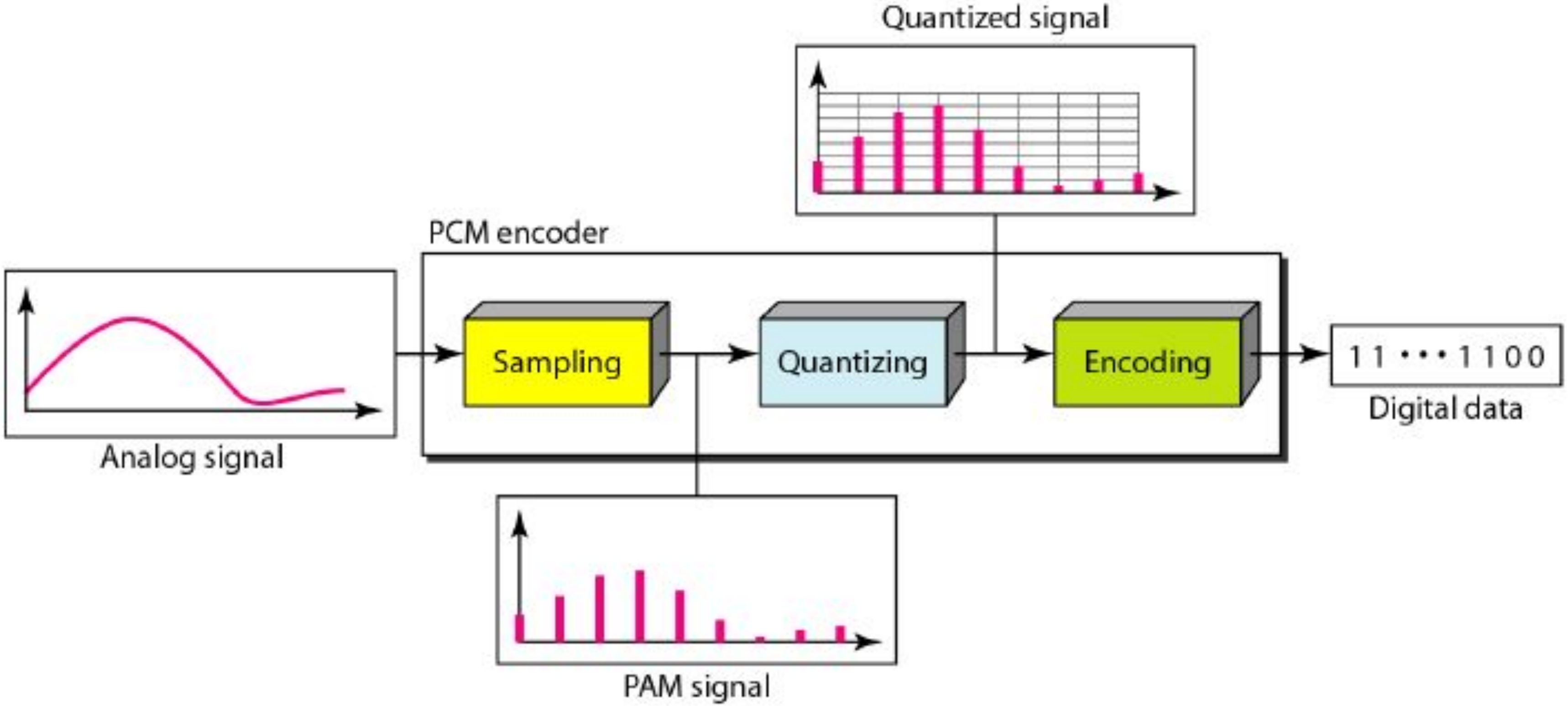
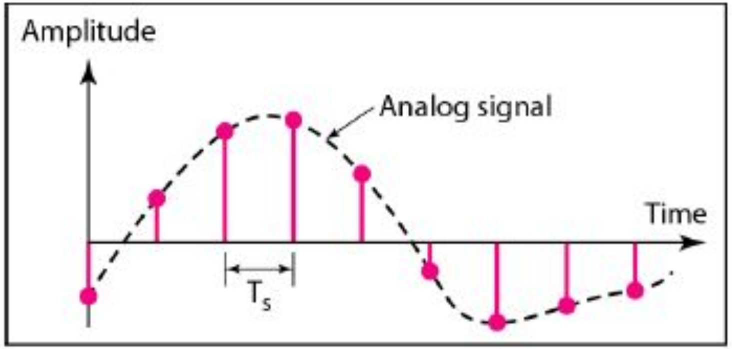
Digital	Digital	Encoding (Line encoding)
Analog	**Digital**	**Encoding (PCM, DM)**
Analog	Analog	Modulation (AM, FM, PM)
Digital	Analog	Modulation (Shift keying)

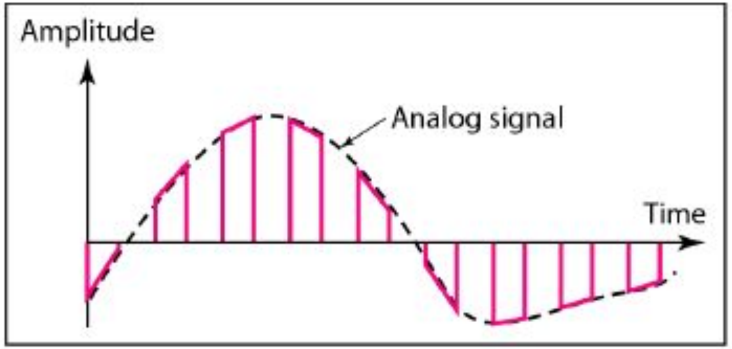
Pulse Code Modulation (PCM)



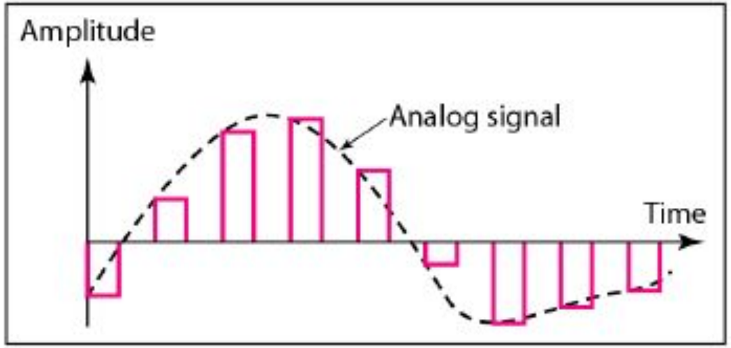
1.Sampling



a. Ideal sampling



b. Natural sampling

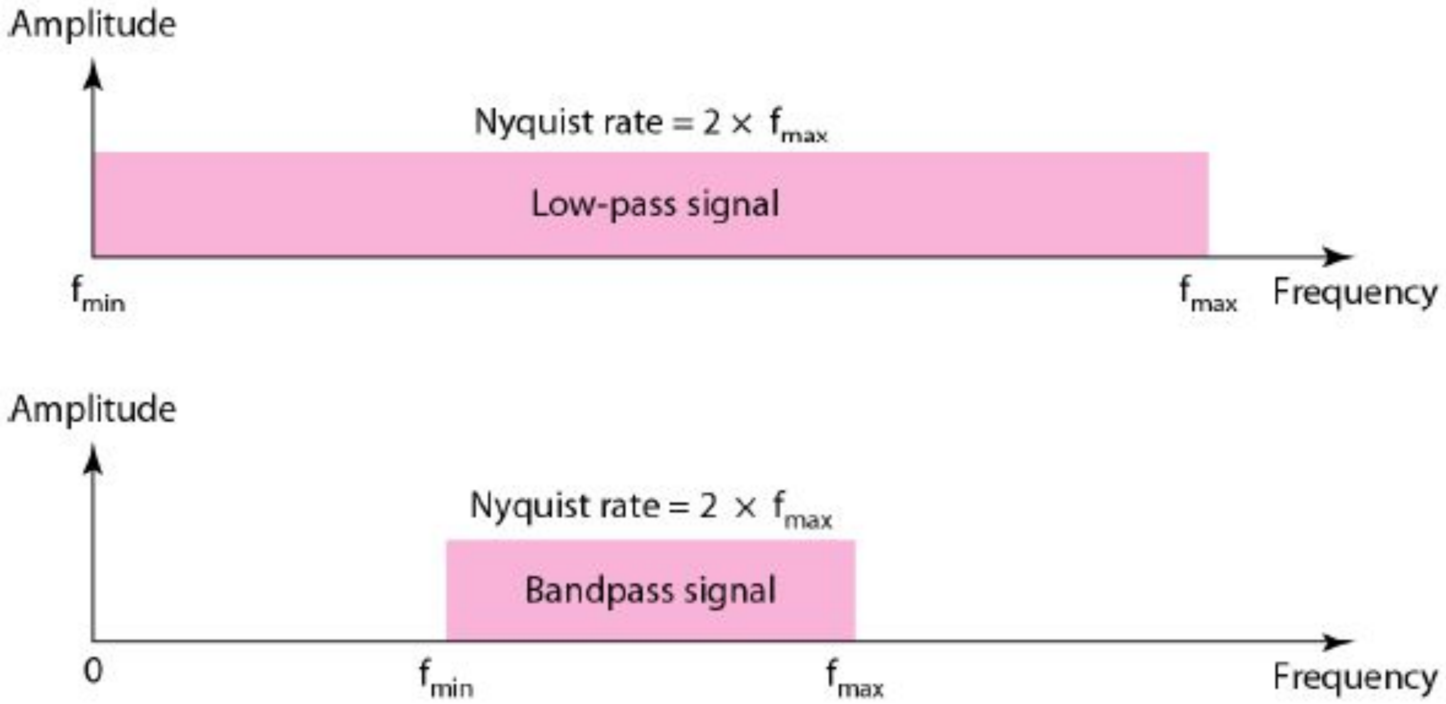


c. Flat-top sampling

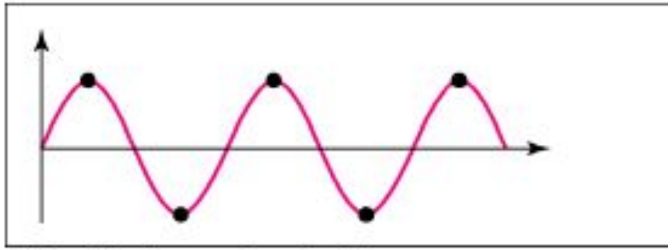
Nyquist Sampling Theorem

- To reproduce the original analog signal the sampling rate must be at least twice the highest frequency in the original signal.
- So, $f_s >= 2 f_m$
- Signal that needs to be sampled should be **bandlimited.**

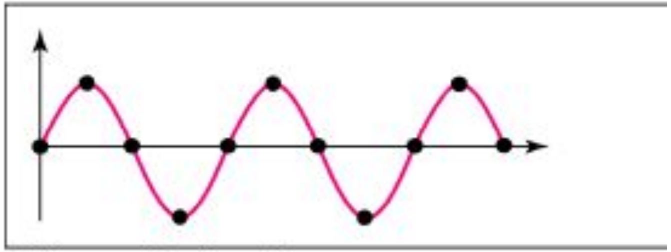
Nyquist’s rate for lowpass and bandpass signals



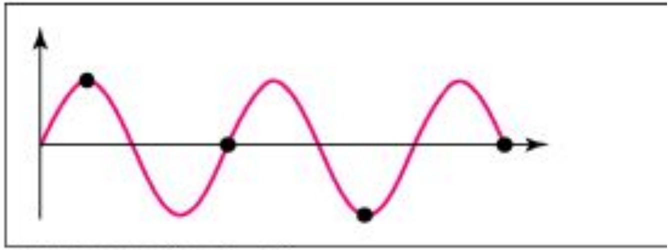
Sampled signal recovery at different sampling rates



a. Nyquist rate sampling: $f_s = 2f$

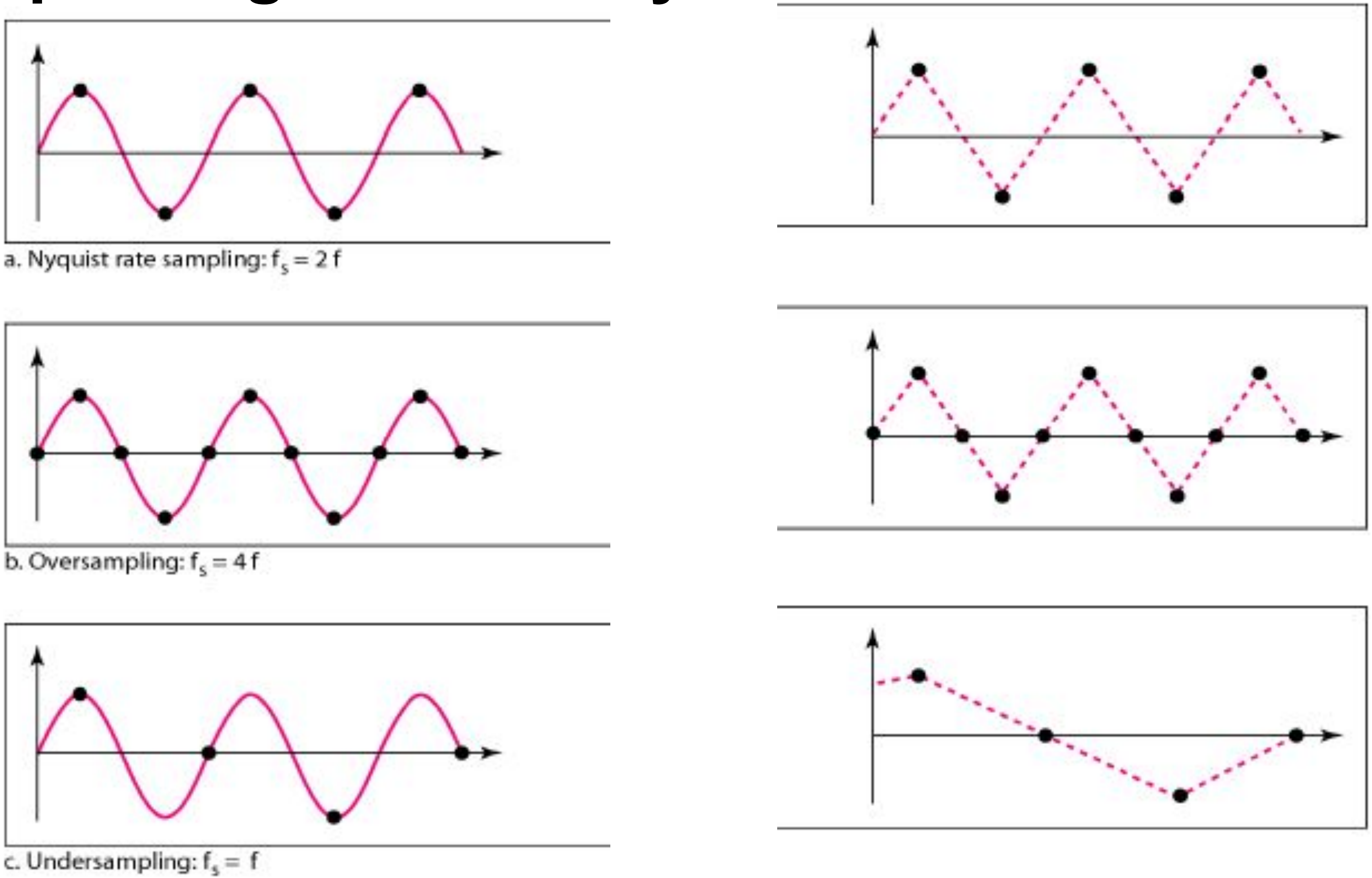


b. Oversampling: $f_s = 4f$



c. Undersampling: $f_s = f$

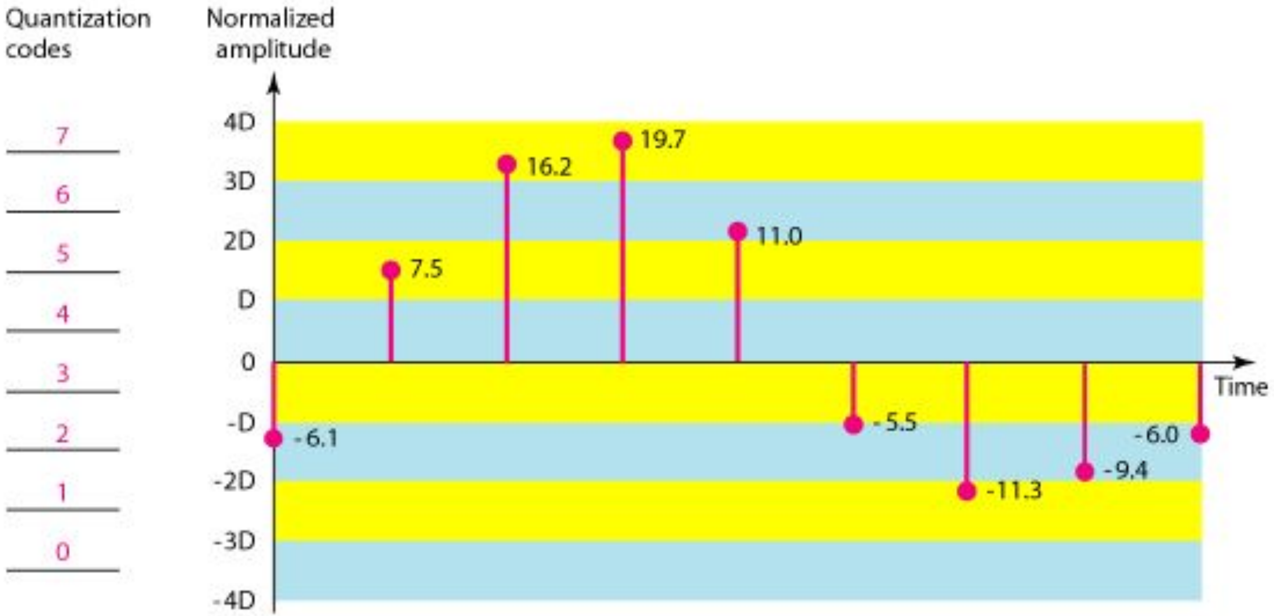
Sampled signal recovery at different sampling rates



Quantization

- Original signal is between V_min and V_max.
- Divide range in L zones, each of height Δ where Δ=V_max-V_min/L
- Assign quantised values from 0 to L-1 to mid-point of each zone.
- Approximate value of sampled amplitude to quantized value.

Quantization and encoding



Normalized PAM values	-1.22	1.50	3.24	3.94	2.20	-1.10	-2.26	-1.88	-1.20
Normalized quantized values	-1.50	1.50	3.50	3.50	2.50	-1.50	-2.50	-1.50	-1.50
Normalized error	-0.38	0	+0.26	-0.44	+0.30	-0.40	-0.24	+0.38	-0.30
Quantization code	2	5	7	7	6	2	1	2	2
Encoded words	010	101	111	111	110	010	001	010	010

Quantization Error

- Quantization error = Actual value - Quantized value
- ? <= Error <= ?

Quantization Error

- Quantization error = Actual value - Quantized value
- $-\Delta/2 \le \text{Error} \le \Delta/2$
- Quantization error changes SNR of signal which by Shannon capacity reduces the data capacity of channel.
- It has been proven that the contribution of Quantization error to SNR_{db} depends on quantization levels L or bits per sample $n_b = \log_2 L$.
- $SNR_{dB} = 6.02 n_b + 1.76$ dB

Q) A telephone subscriber line must have an SNR dB above 40. What is the minimum number of bits per sample?

Q) A telephone subscriber line must have an SNR dB above 40. What is the minimum number of bits per sample?

Solution

We can calculate the number of bits as

$$\boxed{\mathrm{SNR_{dB}} = 6.02n_b + 1.76 = 40 \longrightarrow n = 6.35}$$

Telephone companies usually assign 7 or 8 bits per sample.

Encoding

- Each sample is changed to n_b bit codeword based on quantization level.

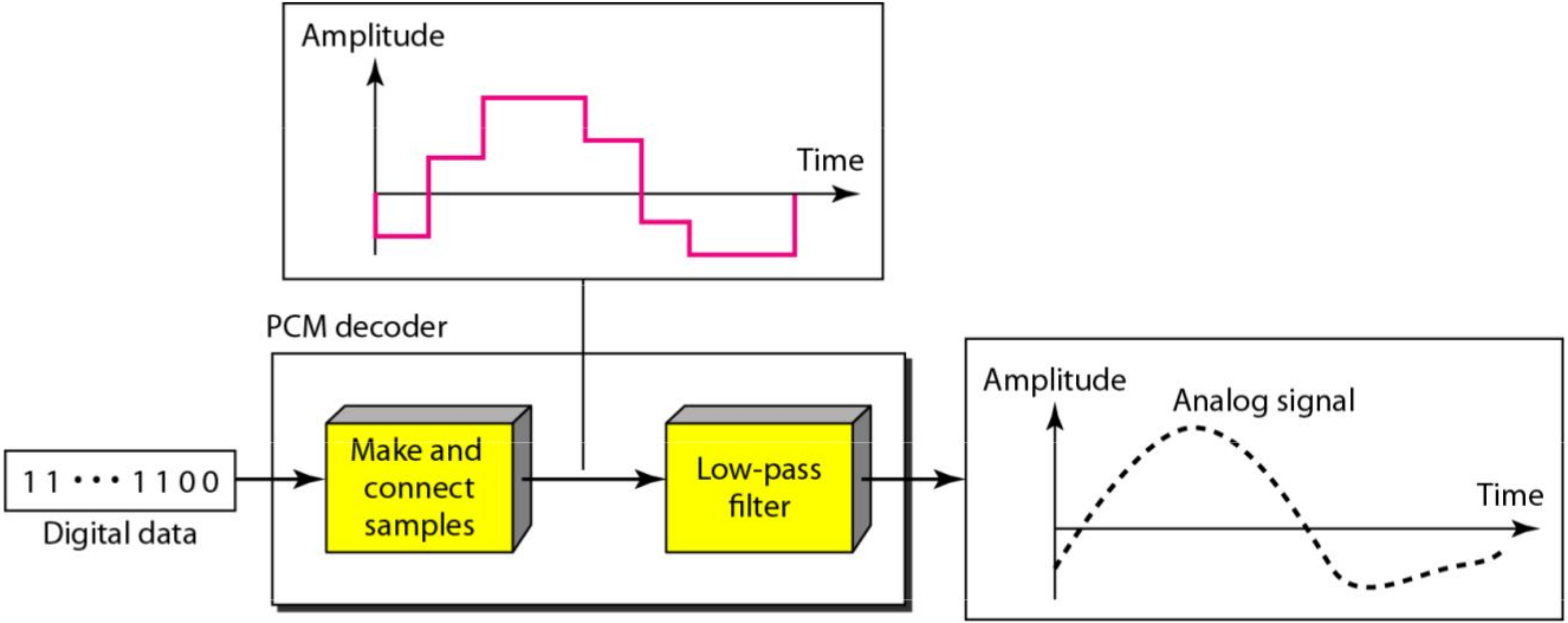
Encoding

- Each sample is changed to n_b bit codeword based on quantization level.
- Bit rate = sampling rate * no. of bits per sample

$$= f_s * n_b$$

- PCM used in PSTN (Public Switched Telephone Network).

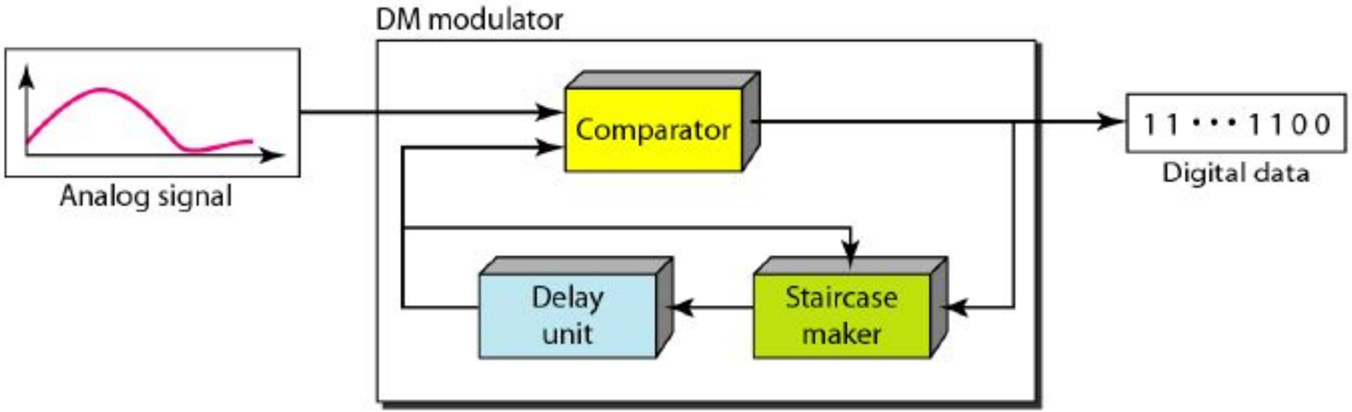
PCM Decoder


Amplitude
Time
PCM decoder
11 ••• 1100
Digital data
Make and connect samples
Low-pass filter
Amplitude
Analog signal
Time

Delta Modulation

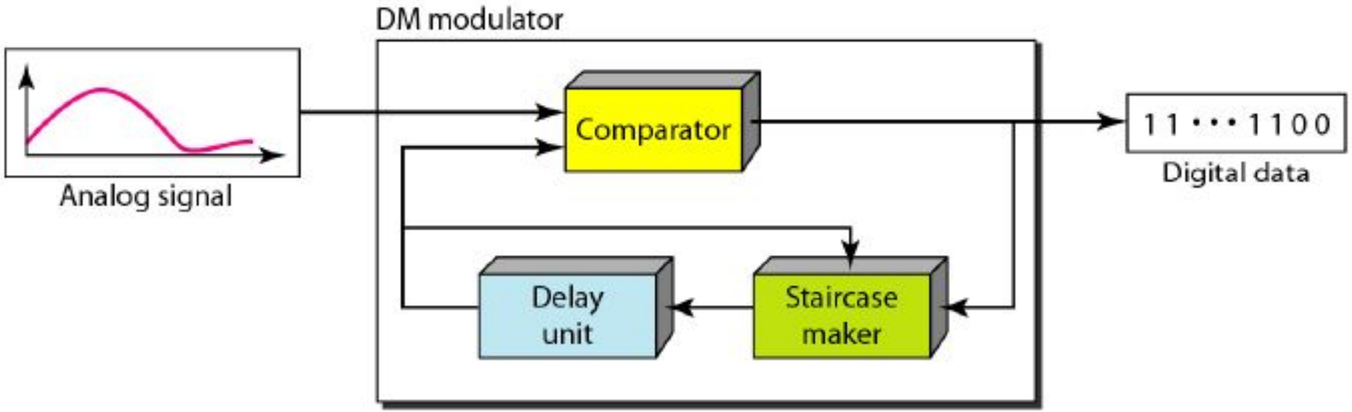
- PCM finds value of signal amplitude for each sample. However, for signals like voice which change slowly with time why not send the change than absolute value, i.e., difference between the consecutive samples : Differential PCM (DPCM).
- Special case: Delta Modulation wherein we send only one bit.
- Delta modulation finds the change from previous sample. If the difference is positive send 1 or else send 0.
- Used for long distance communication.

Delta Modulation

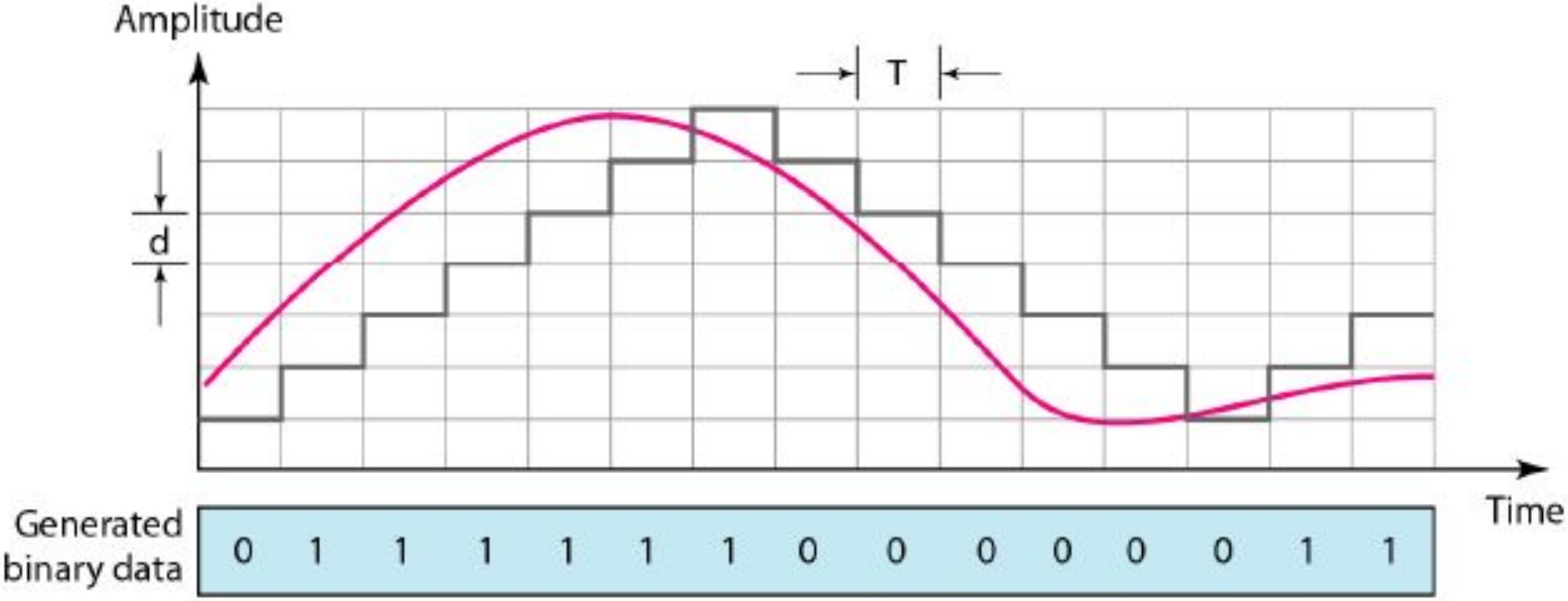


Delta Modulation

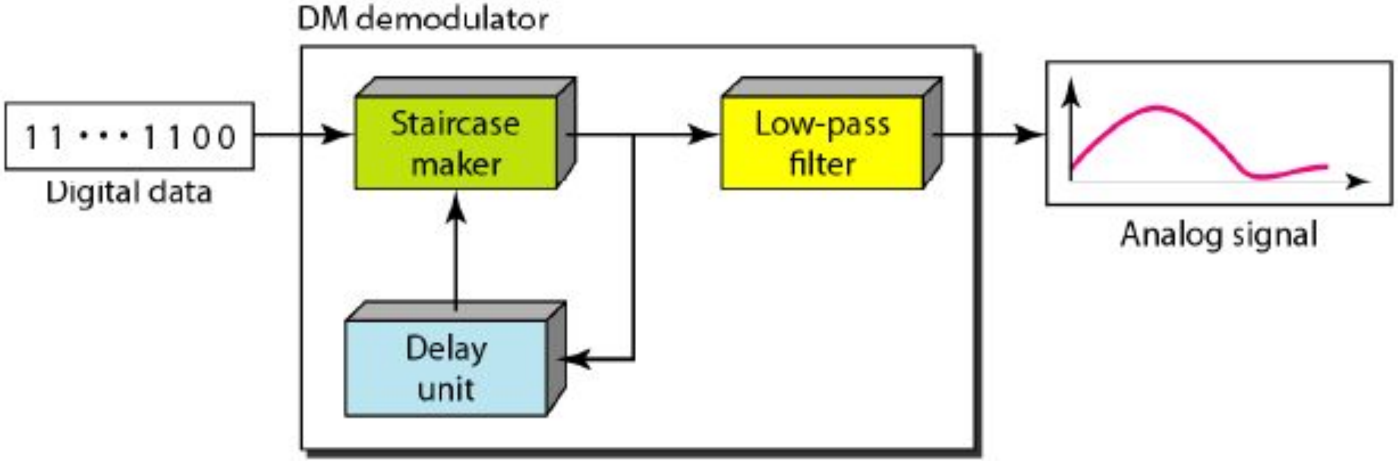
- Modulator at each sampling interval compares value of analog signal to last value of staircase, if amplitude of analog signal is larger, it takes a jump of +d and sends a 1, otherwise it takes a jump of -d and sends a 0.



Delta Modulation

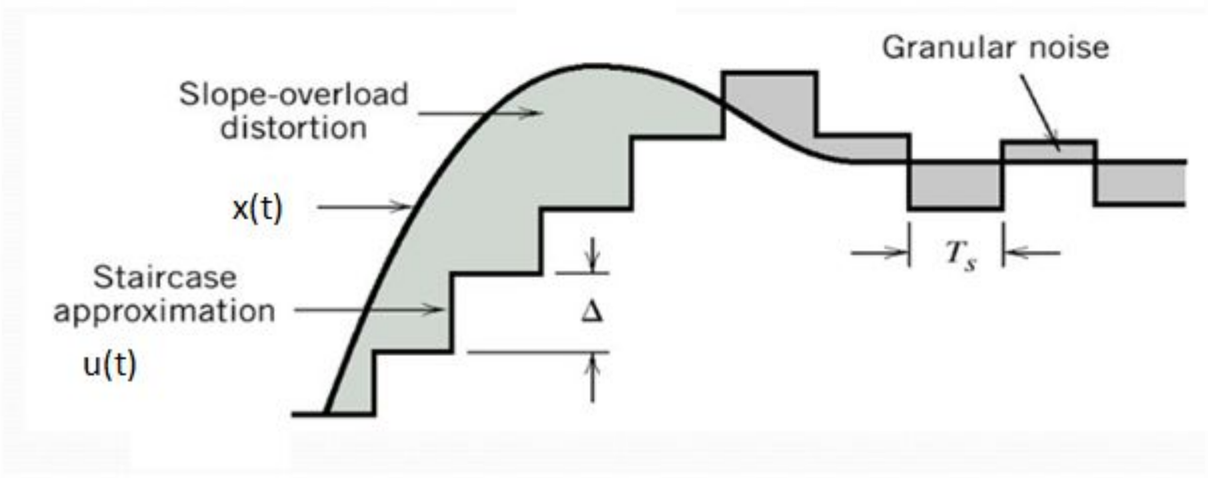


Delta demodulation



Issues with Delta Modulation

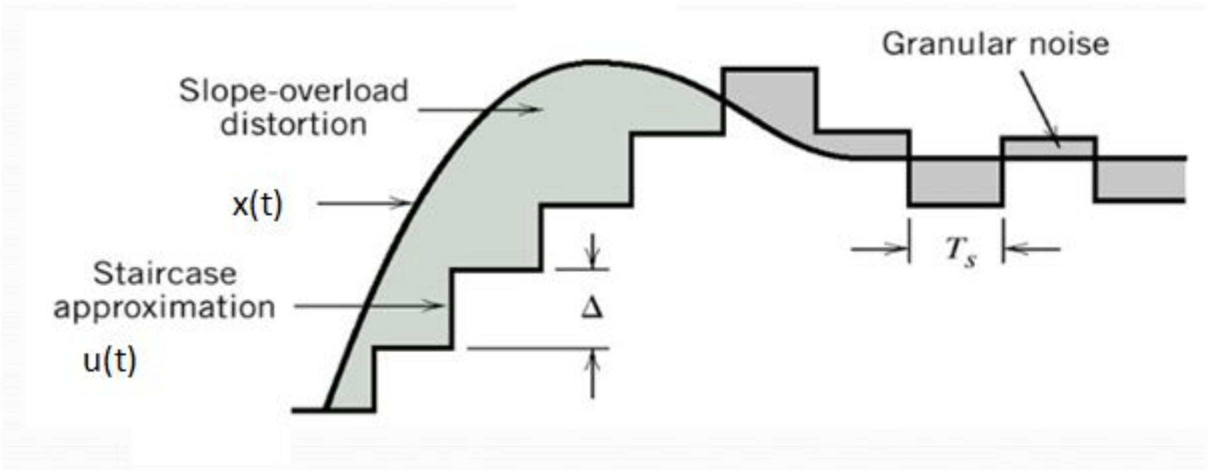
- Slope Overloading - steep slope. i.e., signal changes quickly.
- Granular noise - gradual slope, i.e, signal changes slowly.



Source: https://electronicspost.com/what-is-slope-overload-distortion-and-granular-noise-in-delta-modulation-and-how-it-is-removed-in-adm/

Issues with Delta Modulation

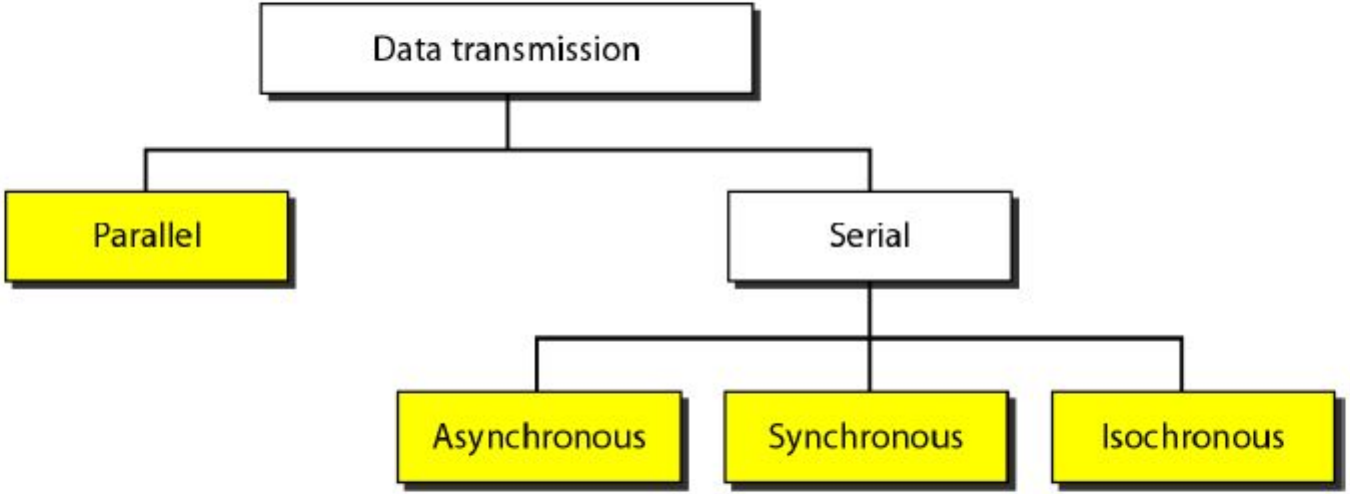
- Slope Overloading - steep slope. i.e., signal changes quickly.
- Granular noise - gradual slope, i.e, signal changes slowly.
- Solution: Adaptive delta modulation - change step size as the signal changes



Source: https://electronicspost.com/what-is-slope-overload-distortion-and-granular-noise-in-delta-modulation-and-how-it-is-removed-in-adm/

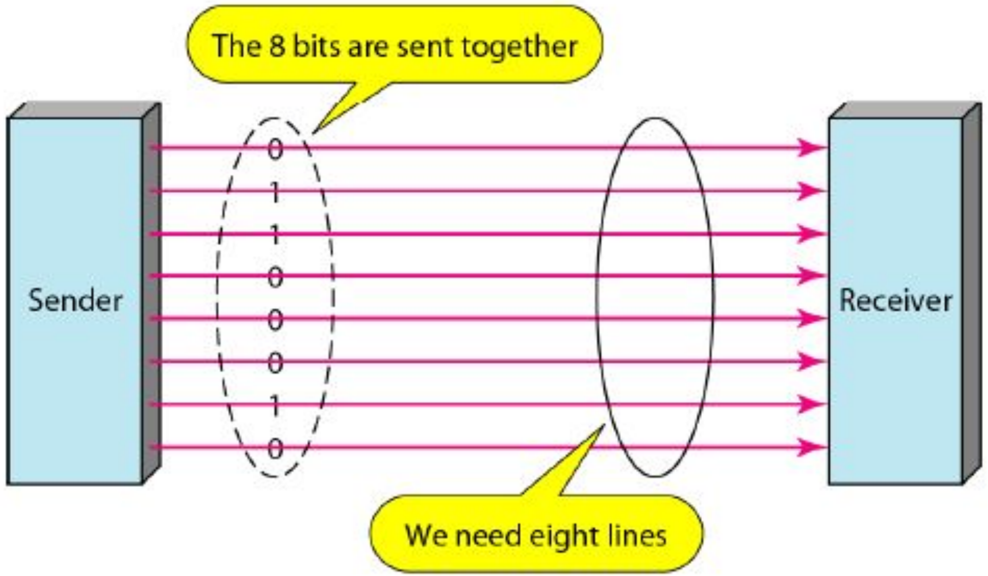
Transmission modes

- How to send data from one device to another?
- Send one bit at a time or a group of bits together.



Parallel Transmission

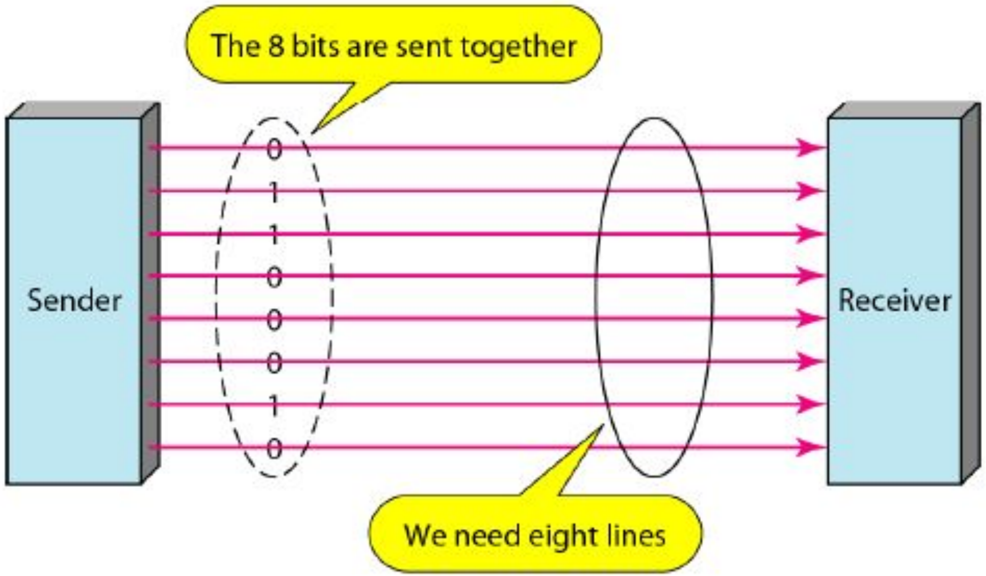
- Binary data organized into groups of n bits and then n bits are sent with each clock tick.
- n wires for n bits.



Parallel Transmission

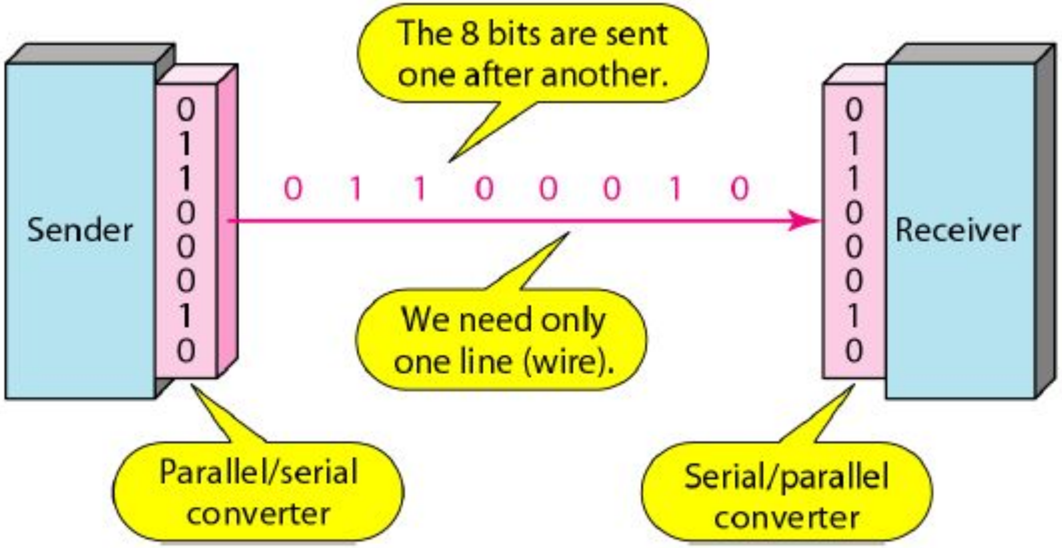
- Binary data organized into groups of n bits and then n bits are sent with each clock tick.
- n wires for n bits.
- Advantage: High speed
- Disadvantage: High cost,

  Limited to short distance.



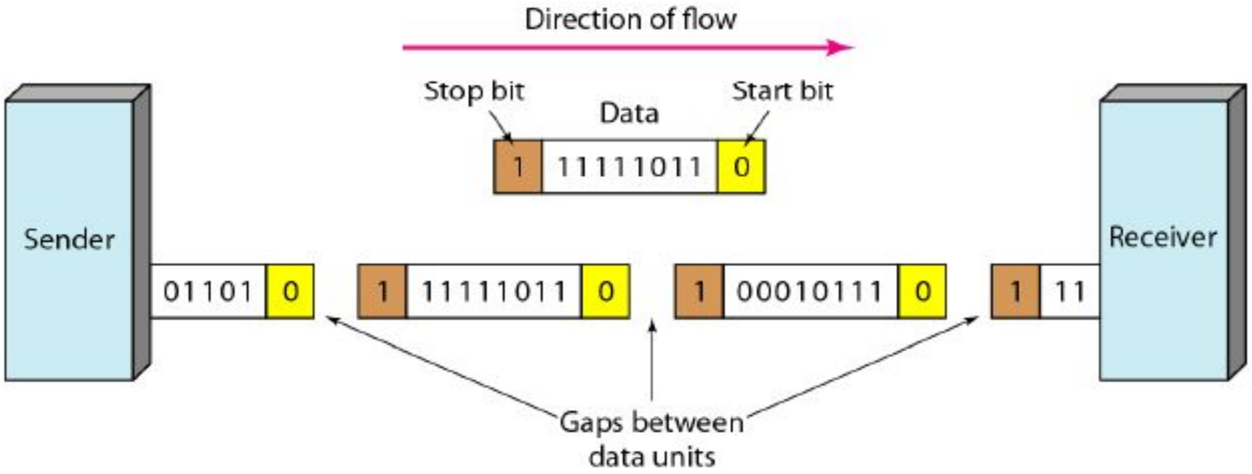
Serial Transmission

- Only one bit sent with a clock tick. Only one channel needed.



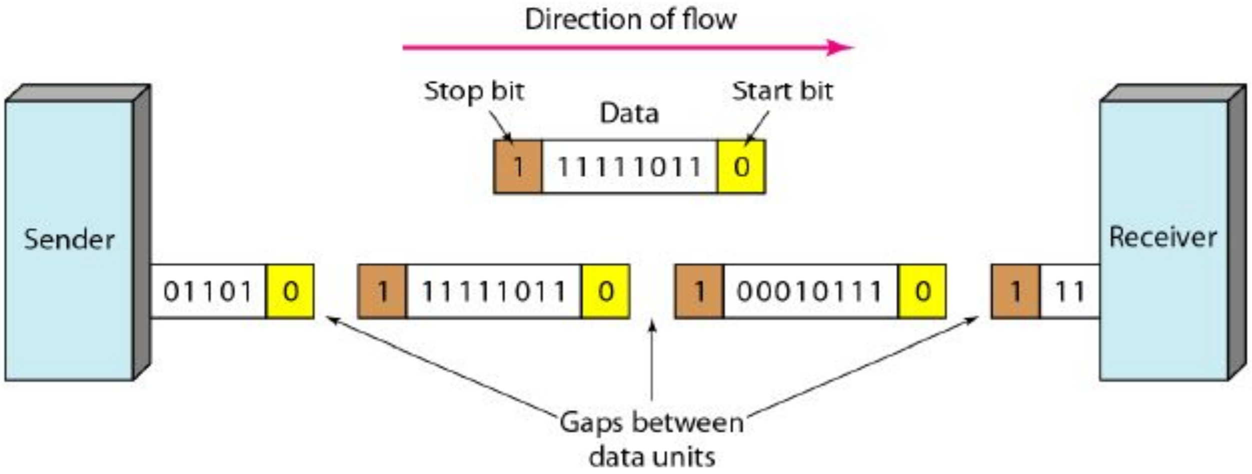
Asynchronous transmission

- Timing of signal is not important.
- Patterns used to recognize and group bit stream into bytes.
- To alert the receiver, add extra bit usually 0 as start bit and additional bits at the end as stop bits. In addition each byte is followed by a gap.
- Asynchronous only at byte level.



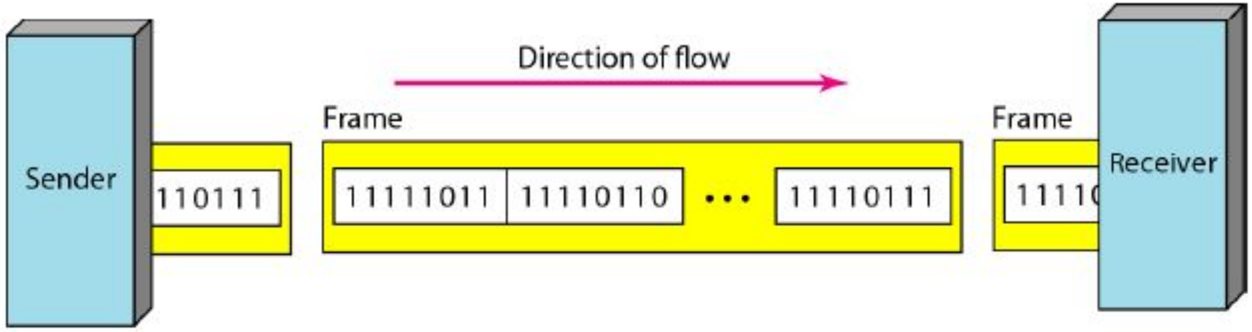
Asynchronous transmission

- Timing of signal is not important.
- Patterns used to recognize and group bit stream into bytes.
- To alert the receiver, add extra bit usually 0 as start bit and additional bits at the end as stop bits. In addition each byte is followed by a gap.
- Asynchronous only at byte level.
- Cheap and effective.
- Low speed.
- E.g., Keyboard - PC



Synchronous Transmission

- Bit stream combined into longer frames with multiple bytes and no gaps.
- Responsibility of receiver to group bits. Receiver counts bits and groups them.
- High accuracy of receiver required.
- Byte synchronization by data link layer.
- High speed
- E.g., PC-PC



Isochronous transmission

- For real time video, audio uneven delays between the frames are unacceptable.
- Need: synchronization not just between characters or frames but for the entire stream.
- Isochronous guarantees data arrives at fixed rate, i.e., transmission at regular intervals with fixed gap between the frames.

References

- Chapter 4 [BAF]
- Lecture 7, 8 [AP]
- **Note: Source of all images unless specified is [BAF] book.**