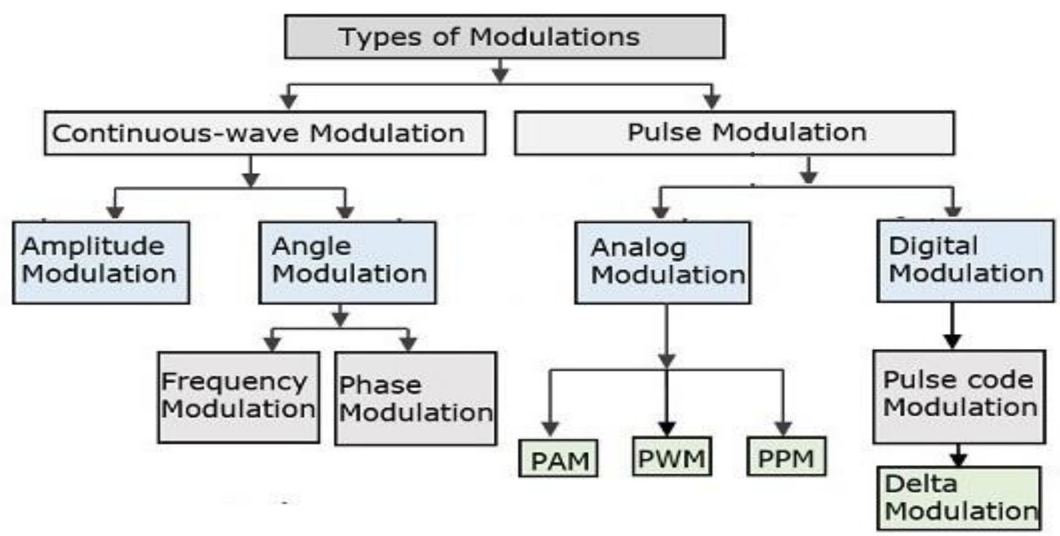
Lesson 5
Modulation and encoding
Voice Digitization
Topic objectives
By the end of the topic the learner should be able to:

i. Distinguish between PAM, PWM or PDM and PPM
ii. Distinguish between Pulse Code Modulation & Delta Modulation
iii. Describe factors that influence encoding schemes

3. **<u>Analog Data, Digital Signal</u>**
   Device used is a COde-DECoder <u>CODEC</u>

- Digitization
  — Conversion of analog data into digital data
  — Digital data can then be transmitted using NRZ-L
  — Digital data can then be transmitted using code other than NRZ-L
  — Digital data can then be converted to analog signal
  — Analog to digital conversion done using a CODEC
  — Pulse code modulation
  — Delta modulation



A. **Pulse Amplitude Modulation (PAM):**

In pulse amplitude modulation, the amplitude of regular interval of periodic pulses or electromagnetic pulses is varied in proposition to the sample of modulating signal or message signal. This is an analog type of modulation. These sample pulses can be transmitted directly using wired media or we can use a carrier signal for transmitting through wireless.

There are two types of pulse amplitude modulation based on signal polarity

1. Single polarity pulse amplitude modulation
2. Double polarity pulse amplitude modulation

In single polarity pulse amplitude modulation, there is fixed level of DC bias added to the message signal or modulating signal, so the output of modulating signal is always positive. In the double polarity pulse amplitude modulation, the output of modulating signal will have both positive and negative ends.

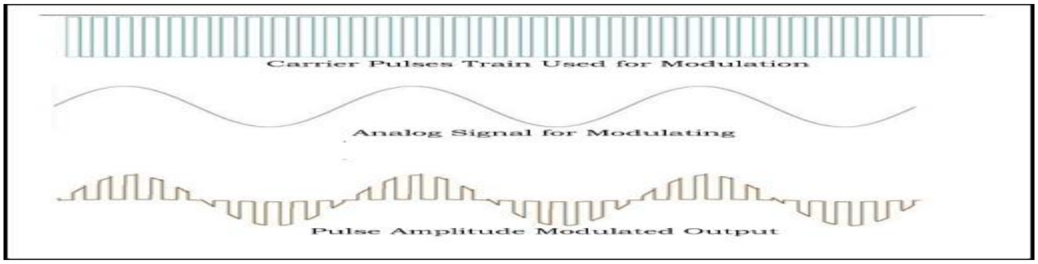


Fig 5.1 Double polarity pulse amplitude modulation

Advantages of Pulse Amplitude Modulation (PAM):

- It is the base for all digital modulation techniques and it is simple process for both modulation and demodulation technique.
- No complex circuitry is required for both transmission and reception. Transmitter and receiver circuitry is simple and easy to construct.
- PAM can generate other pulse modulation signals and can carry the message or information at same time.

Disadvantages of Pulse Amplitude Modulation (PAM):

- Bandwidth should be large for transmitting the pulse amplitude modulation signal. Due to Nyquist criteria also high bandwidth is required.
- The frequency varies according to the modulating signal or message signal. Due to these variations in the signal frequency, interferences will be there. So noise will be great. For PAM, noise immunity is less when compared to other modulation techniques. It is almost equal to amplitude modulation.
- Pulse amplitude signal varies, so power required for transmission will be more, peak power is also, even at receiving more power is required to receive the pulse amplitude signal.

Applications of Pulse Amplitude Modulation (PAM):

- It is mainly used in Ethernet which is type of computer network communication, we know that we can use Ethernet for connecting two systems and transfer data between the systems. Pulse amplitude modulation is used for Ethernet communications.
- It is also used for photo biology which is a study of photosynthesis.
- Used as electronic driver for LED lighting.
- Used in many micro controllers for generating the control signals etc.

B. **Pulse Duration Modulation (PDM) or Pulse Width Modulation (PWM):**

It is a type of analog modulation. In pulse width modulation or pulse duration modulation, the width of the pulse carrier is varied in accordance with the sample values of message signal or modulating signal or modulating voltage. In pulse width modulation, the amplitude is made constant and width of pulse and position of pulse is made proportional to the amplitude of the signal. We can vary the pulse width in three ways

1. By keeping the leading edge constant and vary the pulse width with respect to leading edge
2. By keeping the tailing constant.
3. By keeping the center of the pulse constant.

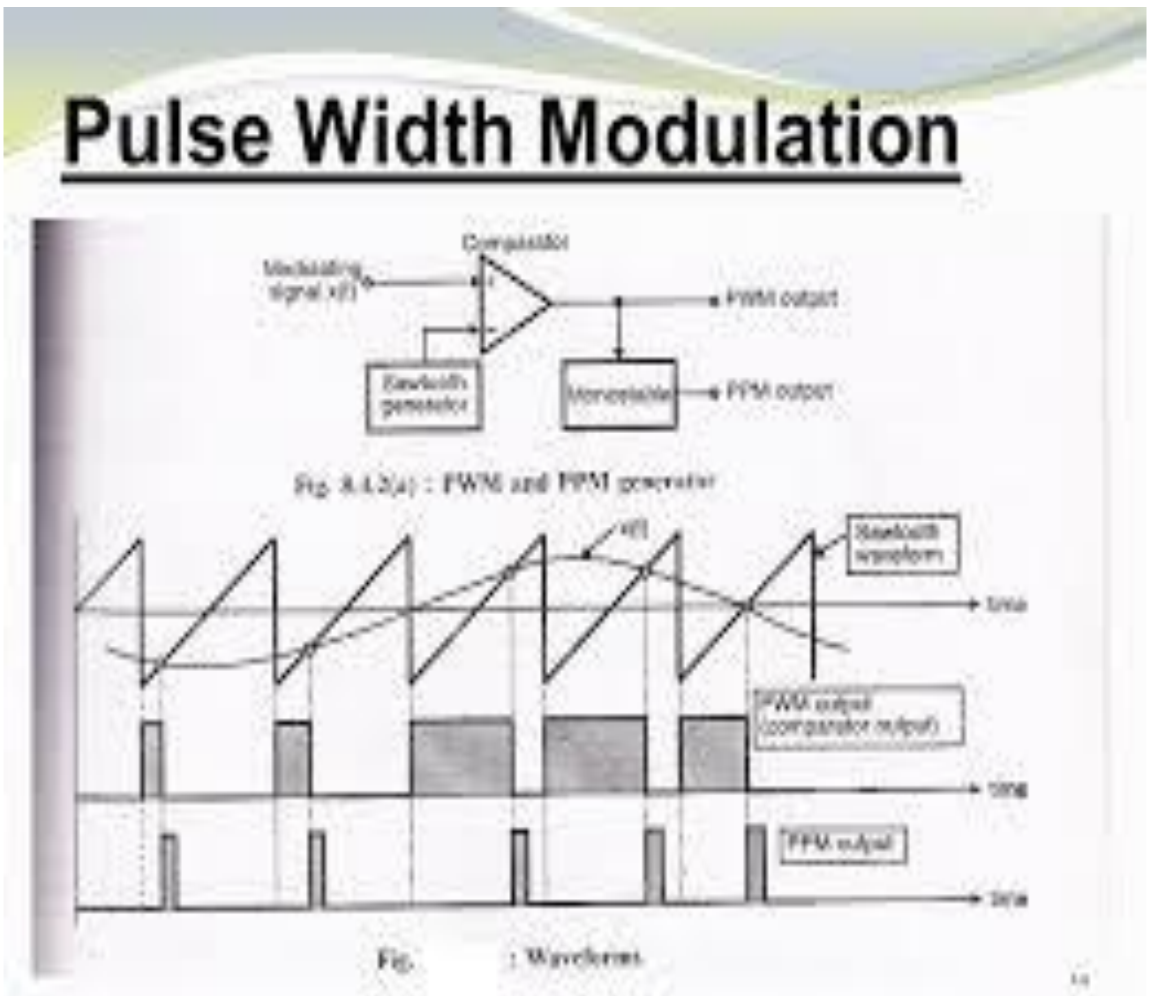


Fig 5.2 Pulse Width Modulation and Pulse Position Modulation

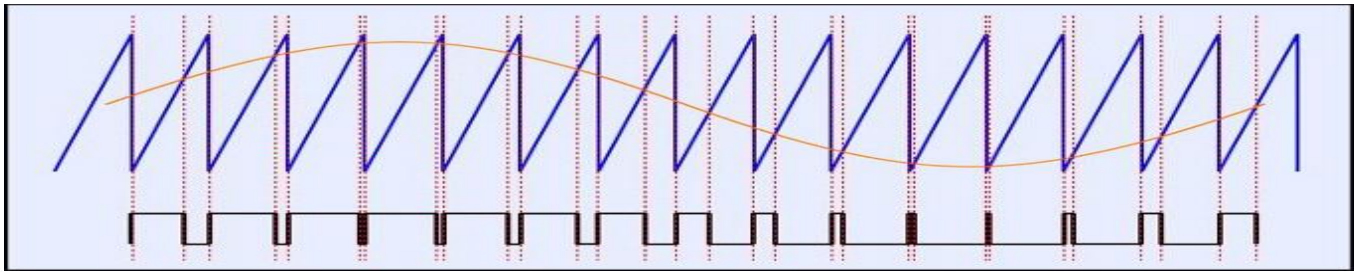


Fig 5.3 PWM or PDM diagram

Advantages of Pulse Width Modulation (PWM):

- Noise interference is less as amplitude has been made constant.
- Signal can be separated very easily at demodulation and noise can also be separated easily.
- Synchronization between transmitter and receiver is not required unlike pulse position modulation.

Disadvantages of Pulse Width Modulation (PWM):

- Power will be variable because of varying in width of pulse. Transmitter can handle the power even for maximum width of the pulse.
- Bandwidth should be large to use in communication, should be huge even when compared to the pulse amplitude modulation.

Applications of Pulse Width Modulation (PWM) Pulse Duration Modulation:

- PWM is used in telecommunication systems.
- PWM can be used to control the amount of power delivered to a load without incurring the losses. So, this can be used in power delivering systems.
- Audio effects and amplifications purposes also used.
- PWM signals are used to control the speed of the robot by controlling the motors.
- PWM is also used in robotics.
- Embedded applications.
- Analog and digital applications etc.

C. Pulse Position Modulation (PPM):

In the pulse position modulation, the position of each pulse in a signal by taking the reference signal is varied according to the sample value of message or modulating signal instantaneously. In the pulse position modulation technique that uses pulses of the same breath and height but is displaced in time from some base position according to the amplitude of the signal at the time of sampling. The position of pulse position modulation is easy when compared to other modulation. It requires pulse width generator and monostable multivibrator.

Pulse width generator is used for generating pulse width modulation signal which will help to trigger the monostable multivibrator, here trial edge of the PWM signal is used for triggering the monostable multivibrator. After triggering the monostable multivibrator, PWM signal is converted into pulse position modulation signal. For demodulation, it requires reference pulse generator, flip-flop and pulse width modulation demodulator.

Advantages of Pulse Position Modulation (PPM):

- Pulse position modulation has low noise interference when compared to PAM because amplitude and width of the pulses are made constant during modulation.
- Noise removal and separation is very easy in pulse position modulation.
- Very low power compared to other modulations due to constant pulse amplitude and width.

Disadvantages of Pulse Position Modulation (PPM):

- The synchronization between transmitter and receiver is required, which is not possible for every time and we need dedicated channel for it.
- Large bandwidth is required for transmission same as pulse amplitude modulation.
- A special equipment are required in this type of modulations.

Applications of Pulse Position Modulation (PPM):

- Used in non-coherent detection where a receiver does not need any Phase lock loop for tracking the phase of the carrier.
- Used in radio frequency (RF) communication.
- Also used in contactless smart card, high frequency, RFID (radio frequency ID) tags and etc.

D. Pulse Code Modulation (PCM)

Digitizing Analog Data

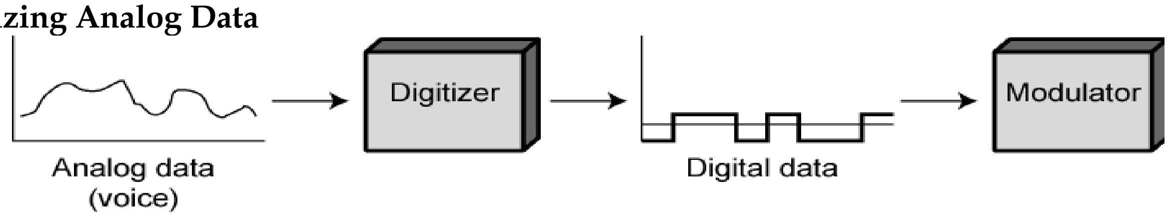


Fig 5.4 simple PCM diagram

- If a signal is sampled at regular intervals at a rate higher than twice the highest signal frequency, the samples contain all the information of the original signal — (Nyquist Sampling theorem)
- Voice data limited to below 4000Hz
- Require 8000 sample per second
- Analog samples (Pulse Amplitude Modulation, PAM)
- Each sample assigned digital value
- 4 bit system gives 16 levels

- Quantized
  - — Quantizing error or noise
  - — Approximations mean it is impossible to recover original exactly
- 8 bit sample gives 256 levels
- Quality comparable with analog transmission
- 8000 samples per second of 8 bits each gives 64kbps

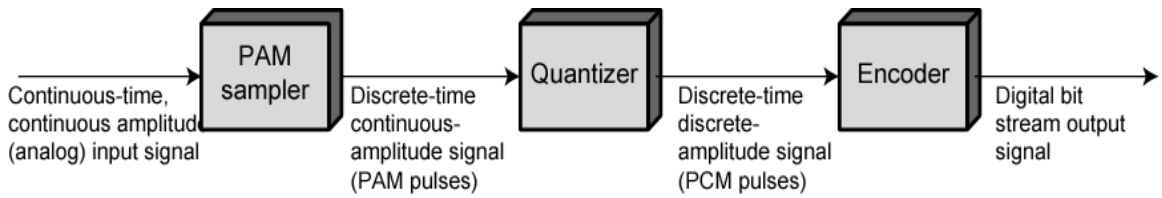


Fig 5. 5 PCM Block Diagram

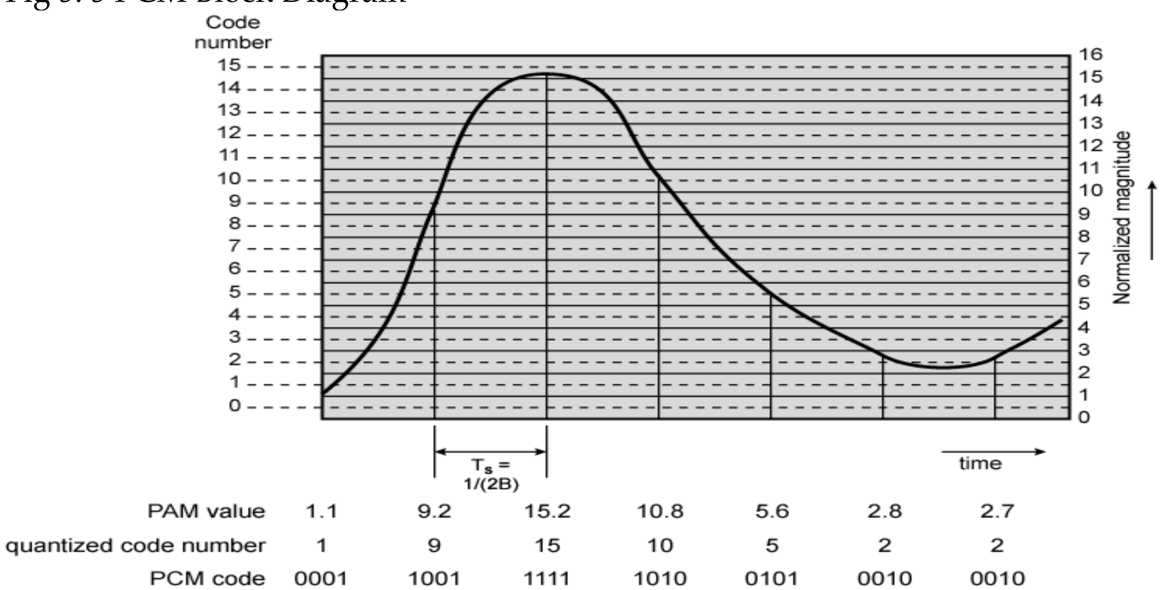


Fig 5.6 Voice Digitization using PCM

Digital modulation samples the information at regular time intervals.

- **Sampling Rate:** The sampling frequency must be at least double the highest frequency being sampled. (Nyquist).

- **Bit Rate:** This is the number of bits that have to be transmitted per second.
  If you need to sample speech, for tolerable quality the highest frequency is 3000Hz or 4000Hz for better mobile phone quality.
  The sampling rate would need to be double this at 6000 or 8000Hz.
  Eight bit samples give quite good quality so you would need 8 times 6000 or 8000.
  48000 bits per second would be the minimum acceptable rate and 64000 bits per second would be preferred.
  Using data compression techniques, fewer bits per second are needed.

Nonlinear Encoding

- Quantization levels not evenly spaced
- Reduces overall signal distortion
- Can also be done by companding (Compressing – Expanding)

Effect of Non-Linear Coding

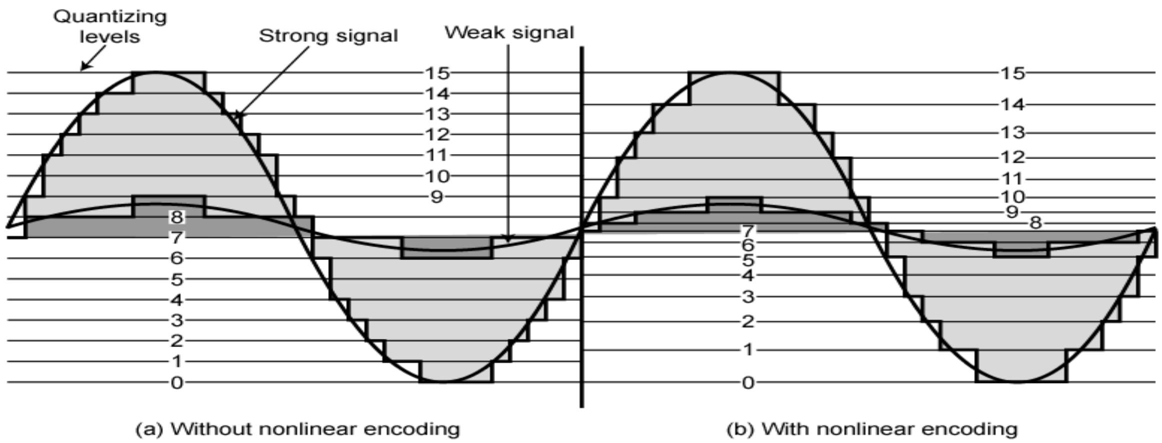


Fig 5.7 coding with and without nonlinear encoding (Companding/no Companding)

E. Delta Modulation

- Analog input is approximated by a staircase function
- Move up or down one level (δ) at each sample interval
- Binary behavior
    - — Function moves up or down at each sample interval

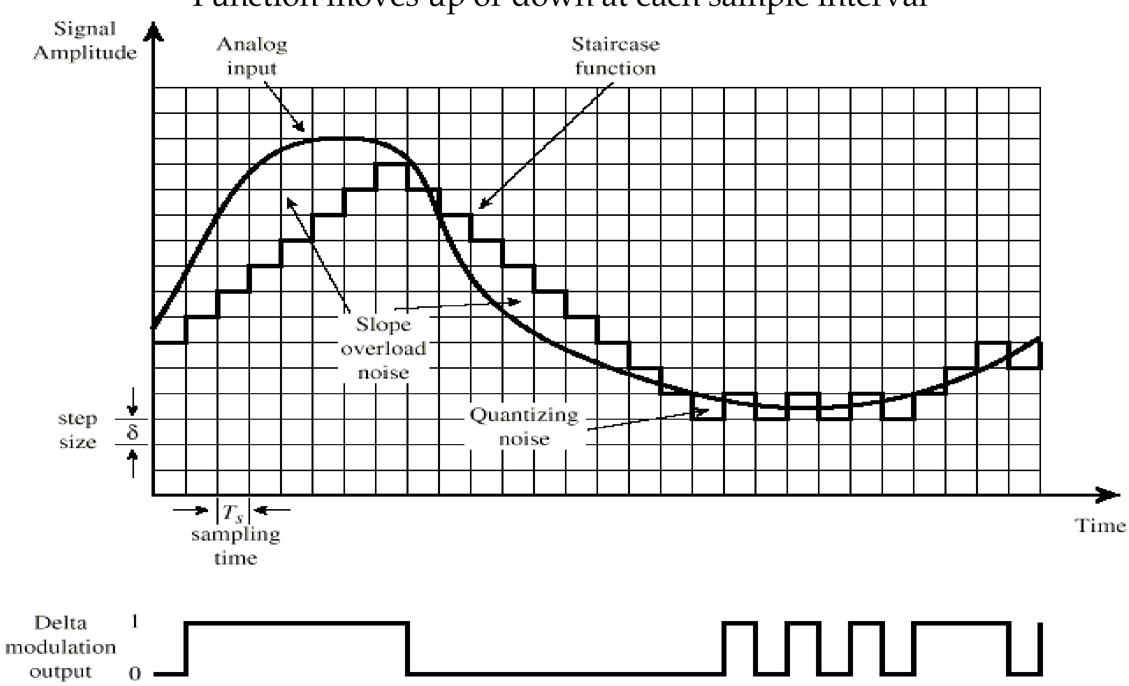


Fig 5.8 Delta Modulation

Delta modulation (DM or Δ-modulation) is an analog-to-digital and digital-to-analog signal conversion technique used for transmission of voice information where quality is not of primary importance. DM is the simplest form of differential pulse-code modulation (DPCM) where the difference between successive samples is encoded into n-bit data streams. In delta modulation, the transmitted data is reduced to a 1-bit data stream.

Its main features are:

- The analog signal is approximated with a series of segments
- each segment of the approximated signal is compared to the original analog wave to determine the increase or decrease in relative amplitude
- The decision process for establishing the state of successive bits is determined by this comparison
- Only the change of information is sent, that is, only an increase or decrease of the signal amplitude from the previous sample is sent whereas a no-change condition causes the modulated signal to remain at the same 0 or 1 state of the previous sample.

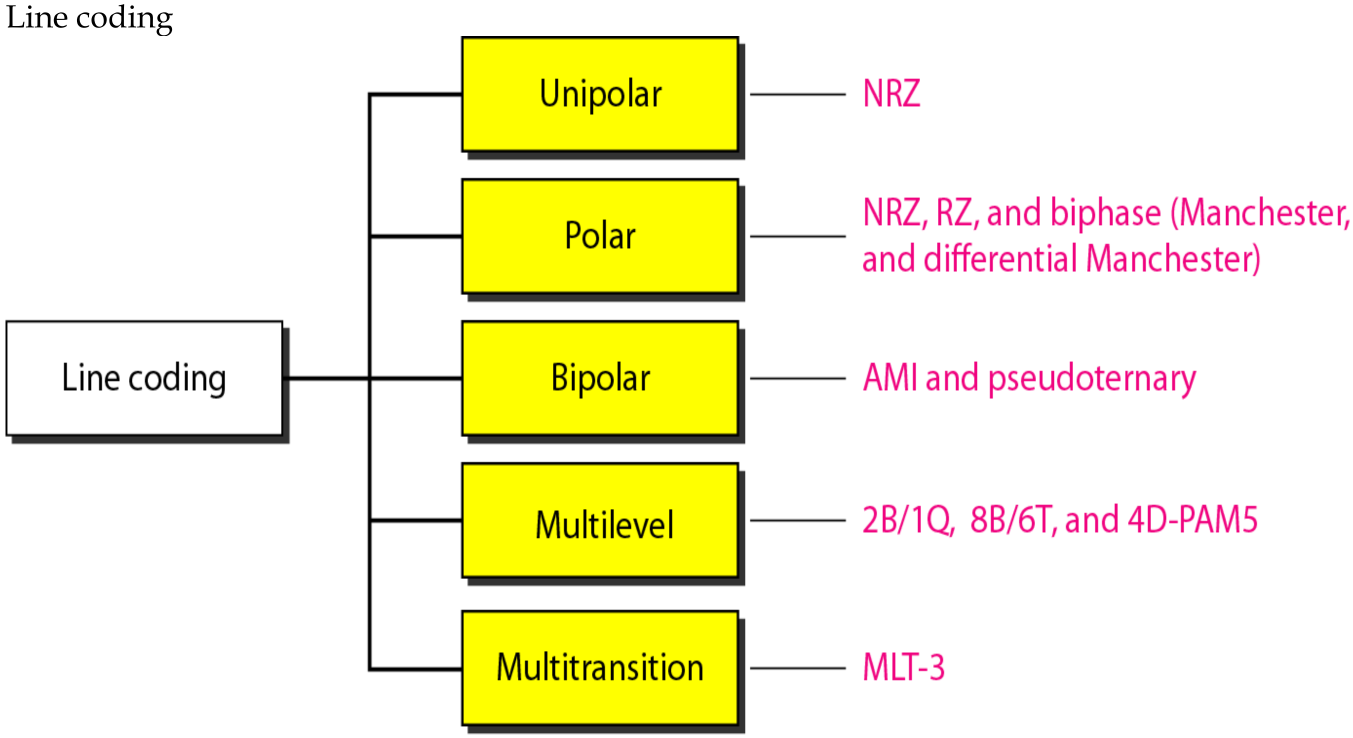
To achieve high signal-to-noise ratio, delta modulation must use over - sampling techniques, that is, the analog signal is sampled at a rate several times higher than the Nyquist rate.

Derived forms of delta modulation are continuously variable slope delta modulation, and differential modulation. The Differential Pulse Code Modulation is the super set of DM.

4. **Digital data – Digital Channel (line coding) digital baseband Modulation**

Device used is a Digital Transceiver

Line coding



Encoding Schemes

- No return to Zero-Level (NRZ-L)
- Non-return to Zero Inverted (NRZI)
- Bipolar -AMI
- Pseudoternary
- Manchester
- Differential Manchester
- B8ZS
- HDB3

Non-return to Zero-Level (NRZ-L)

- Two different voltages for 0 and 1 bits
- Voltage constant during bit interval
    - no transition I.e. no return to zero voltage
- e.g. Absence of voltage for zero, constant positive voltage for one
- More often, negative voltage for one value and positive for the other
- This is NRZ-L

Non-return to Zero Inverted

- Non-return to zero inverted on ones
- Constant voltage pulse for duration of bit
- Data encoded as presence or absence of signal transition at beginning of bit time
- Transition (low to high or high to low) denotes a binary 1
- No transition denotes binary 0
- An example of differential encoding

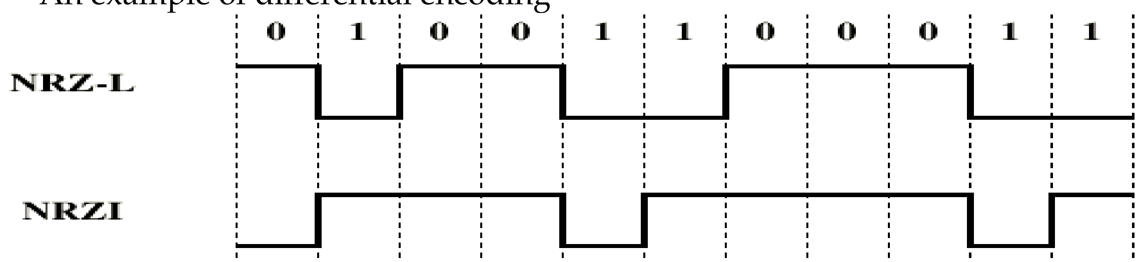


Fig 5.9 Comparing NRZ-l to NRZ-I

Differential Encoding

- Data represented by changes rather than levels
- More reliable detection of transition rather than level
- In complex transmission layouts it is easy to lose sense of polarity

NRZ pros and cons

- Pros
    - Easy to engineer
    - Make good use of bandwidth
- Cons
    - dc component
    - Lack of synchronization capability
- Used for magnetic recording
- Not often used for signal transmission

Bipolar

- Use more than two levels
- Bipolar-AMI
  - — zero represented by no line signal
  - — one represented by positive or negative pulse
  - — one pulses alternate in polarity
  - — No loss of sync if a long string of ones (zeros still a problem)
  - — No net dc component
  - — Lower bandwidth
  - — Easy error detection

Pseudoternary

- One represented by absence of line signal
- Zero represented by alternating positive and negative
- No advantage or disadvantage over bipolar-AMI

0	1	0	0	1	1	0	0	0	1	1

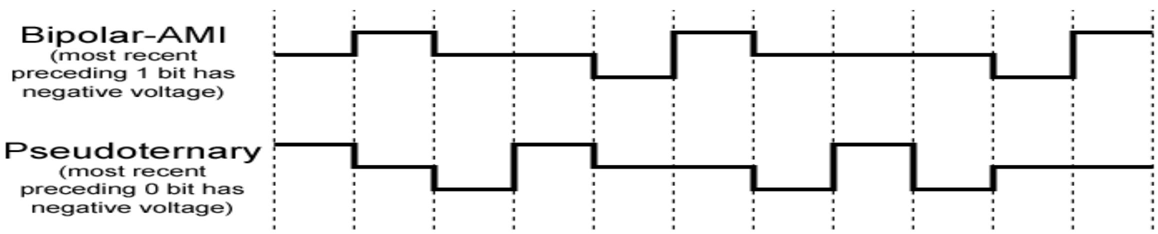


Fig 5.10 Comparison between Bipolar AMI to Pseudoternary

Trade Off for Bipolar

- Not as efficient as NRZ
  - — Each signal element only represents one bit
  - — In a 3 level system could represent $\log_2 3 = 1.58$ bits
  - — Receiver must distinguish between three levels (+A, -A, 0)
  - — Requires approx. 3dB more signal power for same probability of bit error

Bi-phase

- Manchester
  - — Transition in middle of each bit period
  - — Transition serves as clock and data
  - — Low to high represents one
  - — High to low represents zero
  - — Used by IEEE 802.3
- Differential Manchester
  - — Mid-bit transition is clocking only
  - — Transition at start of a bit period represents zero
  - — No transition at start of a bit period represents one
  - — Note: this is a differential encoding scheme
  - — Used by IEEE 802.5

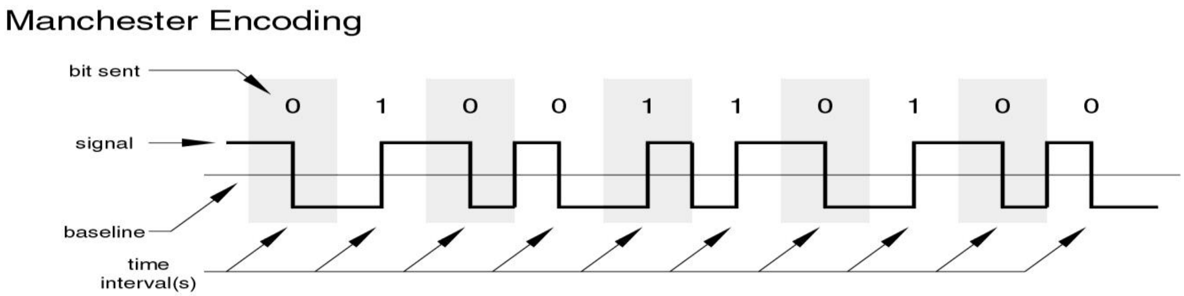


Fig 5.11 Manchester encoding

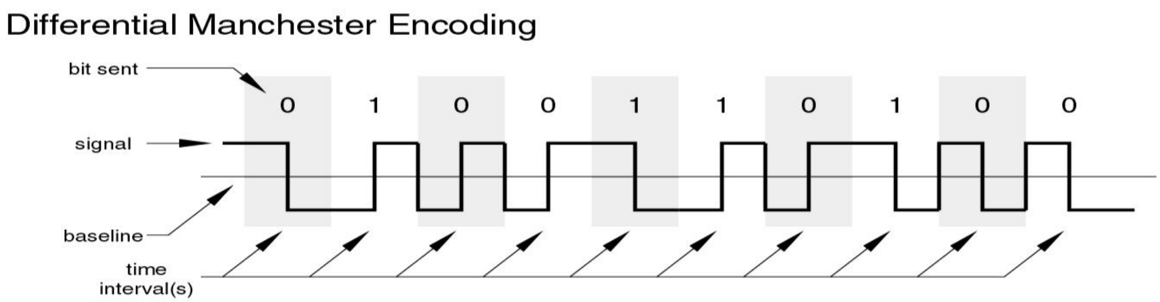


Fig 5.12 Differential Manchester encoding

Bi-phase Pros and Cons

- Con
  - At least one transition per bit time and possibly two
  - Maximum modulation rate is twice NRZ
  - Requires more bandwidth
- Pros
  - Synchronization on mid bit transition (self-clocking)
  - No dc component
  - Error detection
    - Absence of expected transition

Scrambling

- Use scrambling to replace sequences that would produce constant voltage
- Filling sequence
  - Must produce enough transitions to sync
  - Must be recognized by receiver and replace with original
  - Same length as original
- No dc component
- No long sequences of zero level line signal
- No reduction in data rate
- Error detection capability

B8ZS

- Bipolar With 8 Zeros Substitution
- Based on bipolar-AMI
- If octet of all zeros and last voltage pulse preceding was positive encode as 000+-0-+
- If 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

HDB3

- High Density Bipolar 3 Zeros
- Based on bipolar-AMI
- String of four zeros replaced with one or two pulses

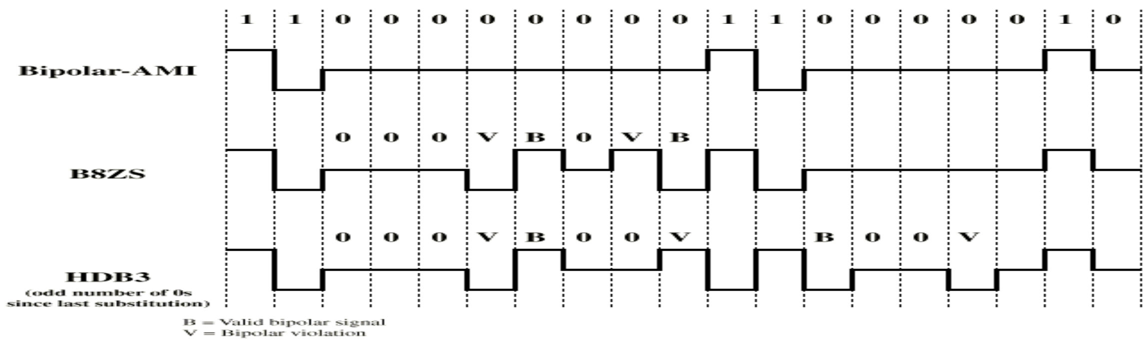


Fig 5.12 B8ZS and HDB3 Synchronization Codes (scrambling)

After line coding, the signal is put through a "physical channel", either a "transmission medium" or "data storage medium". Sometimes the characteristics of 2 very different-seeming channels are similar enough that the same line code is used for them. The most common physical channels are:

- The line-coded signal can directly be put on a transmission line, in the form of variations of the voltage or current (often using differential signaling).
- The line-coded signal (the "baseband signal") is further modulated to create the
- "RF signal" that can be sent through free space.
- The line-coded signal can be used to turn on and off a light in Free Space Optics, most commonly infrared remote control.

Unfortunately, most long-distance communication channels cannot transport a DC component. There are 2 ways of eliminating the DC component:

- Requires synchronization
- Error detection

Summary:

- Each bit is transmitted in a fixed time (the "period").
- A **0** is expressed by a low-to-high transition, a **1** by high-to-low transition (according to G.E. Thomas' convention -- in the IEEE 802.3 convention, the reverse is true).
- The transitions which signify **0** or **1** occur at the midpoint of a period.
- Transitions at the start of a period are overhead and don't signify data.

Manchester code always has a transition at the middle of each bit period and may (depending on the information to be transmitted) have a transition at the start of the period also. The direction of the mid-bit transition indicates the data. Transitions at the period boundaries do not carry information. They exist only to place the signal in the correct state to allow the mid-bit transition. Although this allows the signal to be self-clocking, it doubles the bandwidth requirement compared to NRZ coding schemes.

Differential Manchester encoding

Another layer of complexity in many new systems is multiplexing. Two principal types of multiplexing (or “multiple access”) are TDMA (Time Division Multiple Access) and CDMA (Code Division Multiple Access).
These are two different ways to add diversity to signals allowing different signals to be separated from one another

Summary of line coding schemes

Category	*Scheme*	*Bandwidth (average)*	*Characteristics*
Unipolar	NRZ	$B = N/2$	Costly, no self-synchronization if long 0s or 1s, DC
Unipolar	NRZ-L	$B = N/2$	No self-synchronization if long 0s or 1s, DC
	NRZ-I	$B = N/2$	No self-synchronization for long 0s, DC
	Biphase	$B = N$	Self-synchronization, no DC, high bandwidth
Bipolar	AMI	$B = N/2$	No self-synchronization for long 0s, DC
Multilevel	2B1Q	$B = N/4$	No self-synchronization for long same double bits
	8B6T	$B = 3N/4$	Self-synchronization, no DC
	4D-PAM5	$B = N/8$	Self-synchronization, no DC
Multiline	MLT-3	$B = N/3$	No self-synchronization for long 0s

William Stallings Data and Computer Communications 7th Edition Chapter 5

Signal Encoding Techniques

https://www.google.co.ke/?gws_rd=ssl#q=data+encoding+in+computer+networks

http://www.electronicshub.org/modulation-and-different-types-of-modulation/