Line Coding: (Baseband Modulation).

- The digital output of a source encoder is converted (or coded) into some waveforms for the suitable transmission over the channels. This process is called line coding or transmission coding.

- This is mainly used for baseband (low pass) transmission hence also known as Baseband modulation.
$(0 \le f \le f_m)$

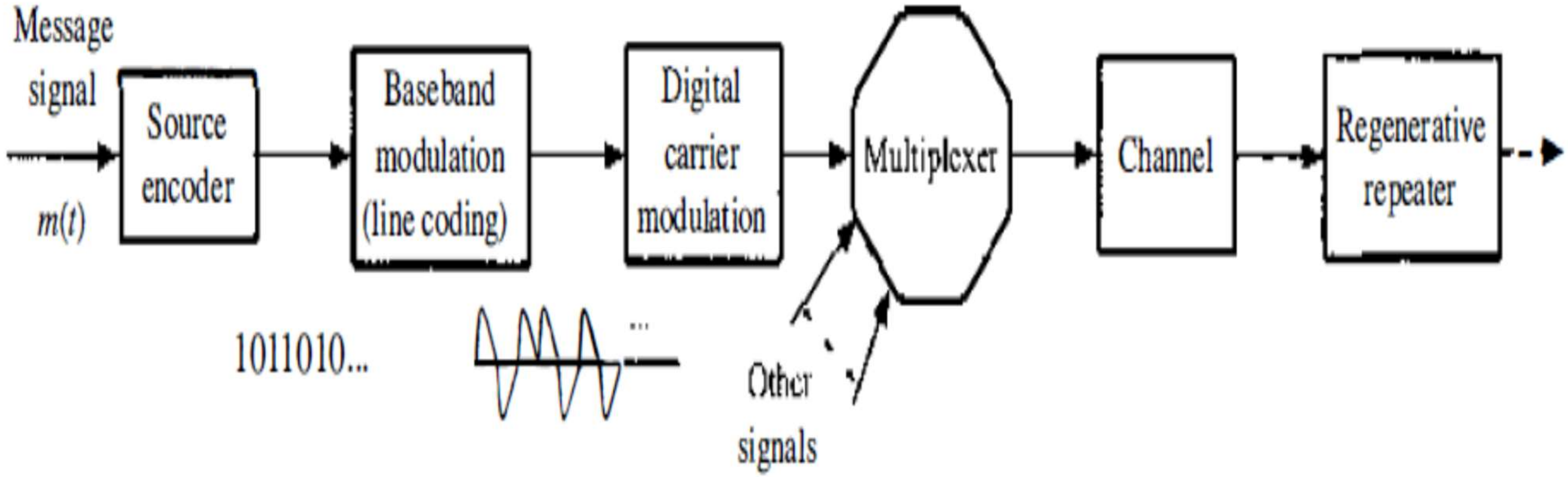


Figure : Fundamental building blocks of digital communication systems.

Review: Energy and Power Signals

- An energy signal $x(t)$ has $0 < E < \infty$ for average energy

$$E = \int_{-\infty}^{\infty} |x(t)|^2 dt$$

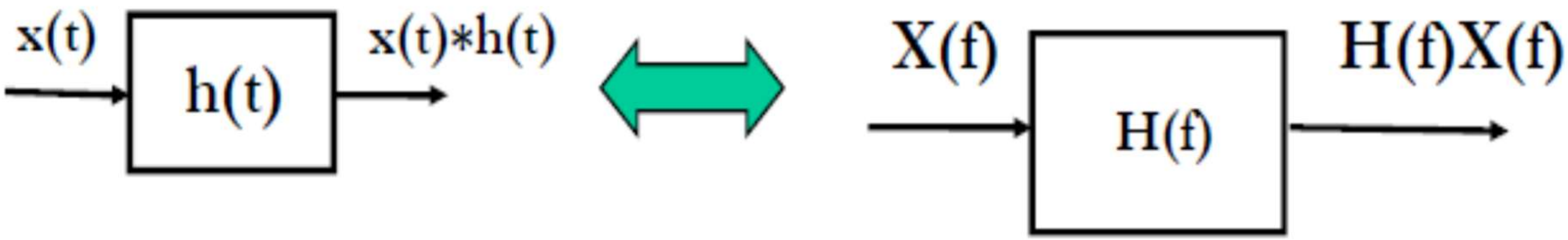
- A power signal $x(t)$ has $0 < P < \infty$ for average power

$$P = \lim_{T \to \infty} \frac{1}{2T} \int_{-T}^{T} |x(t)|^2 dt$$

- Can think of average power as average energy/time.
- An energy signal has zero average power.
- A power signal has infinite average energy.
- Power signals are generally not integrable so don't necessarily have a Fourier transform.
- We use power spectral density to characterize power signals that don't have a Fourier transform.

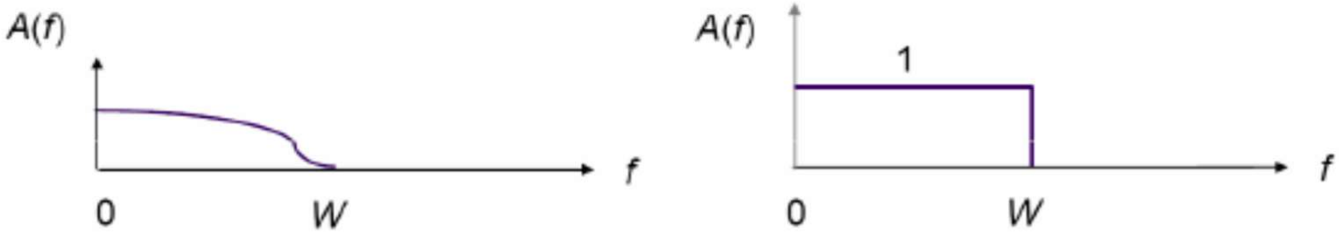
Review: Time-Invariant Systems

- Linear Time-Invariant Systems
- System Impulse Response: h(t)
- Filtering as Convolution in Time
- Frequency Response: $H(f)=|H(f)|e^{j\angle H(f)}$



Pulse Transmission over a Channel

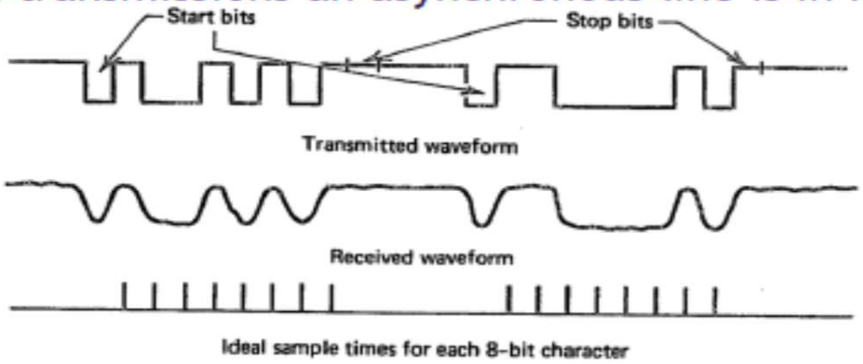
(a) Low-pass and idealized low-pass channel



(b) Maximum pulse transmission rate is 2W pulses/second

Asynchronous vs Synchronous Transmission

- Asynchronous transmission: Separate transmissions of groups of bits or characters
  - The sample clock is reestablished for each reception
  - Between transmissions an asynchronous line is in idle state.



- Synchronous transmission: Digital signals are sent continuously at a constant rate
  - The sample clock is established and maintained throughout entire time.

Maximum Signaling Rate

- The percentage of total spectrum power is important measure
- A major result for digital transmissin pertains to the maximum rate at which pulses can be transmitted over a channel.
- If a channel has bandwidth W, then the narrowest pulse that can be transmitted over the channel has duration $T=1/(2W)$ seconds.
- Thus, the maximum rate at which pulses can be transmitted through the channel is given by
  - $R_{max}=2\times W$ pulses/second.

Desirable Properties of the Line Codes :

1). **Transmission Bandwidth**: should be as small as possible, so that we can approach minimum theoratical bandwidth required.

$BW = \frac{f_b}{2}$, $f_b \rightarrow$ transmission rate b/s.

2). **Power efficiency** :- For a given bandwidth and error detection rate, the transmission power should be as low as possible.

3). **Favorable power spectral density** :- It is desirable to have zero power spectral density (PSD) at $f=0$ (dc Null). because ac coupling and transformers are often used at the repeaters The transformers have very poor (frequency) response at low frequency. Low frequency (or dc) also cause DC wonder. (Shift in dc Level)

4). <u>Error detection and Correction capability</u>: It is desirable to detect and preferably correct the bit errors caused due to channel noise.

5). <u>Adequate Timing content</u>: It should be possible to extract time or clock information from the transmitted signal itself. Clock time is used for synchronization purpose.

6). Transparency: A code is transparent if coded data for every possible sequence can be received faithfully. (without any ambiguity).

- A line code in which bit pattern (and hence corresponding assigned pulse pattern for 1's & 0's) does not affect the accuracy of clock timing information is said to be transparent.
- The RZ polar scheme (where each bit is transmitted by some non zero pulse) is transparent, where as the on-off and bipolar are nontransparent.

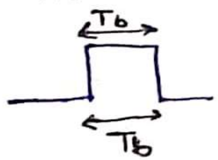
Classification of Line codes :

Classification of line codes (baseband modulation) can be understood interms of (pulse duration and amplitude levels).

1). Based of pulse duration

- RZ (Return to zero), where each pulse width is half to that of bit duration.
  also, called Half-width pulse.

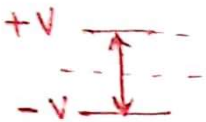
- NRZ (Non return to zero).
  - Each pulse is of full bit duration.
  also called, Full-width pulse



2). Based on amplitude level

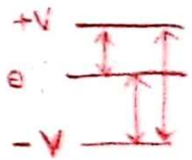
ON-OFF (Unipolar) : where 1's represented by $p(t)$ $(+V)$ and 0's represented by zero voltage level. (no pulse)

Polar : where 1's represented by $p(t)$ and 0's represented by $-p(t)$.



Bipolar : where 0's represented by no pulse. 1's represend by $+p(t)$ or $-p(t)$ depending upon previous 1's

Pseudoternary
$+p(t), 0, -p(t)$



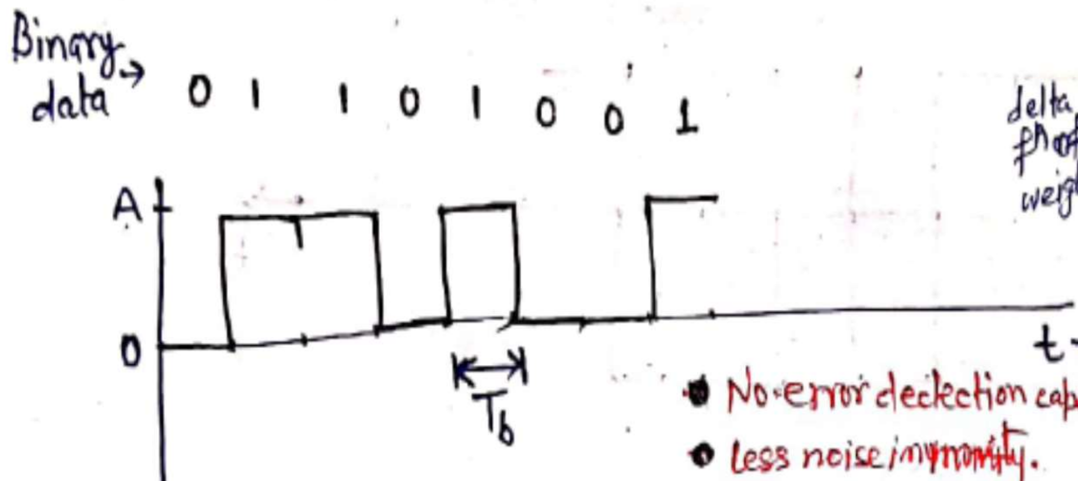
3). Based on memory or memoryless :-

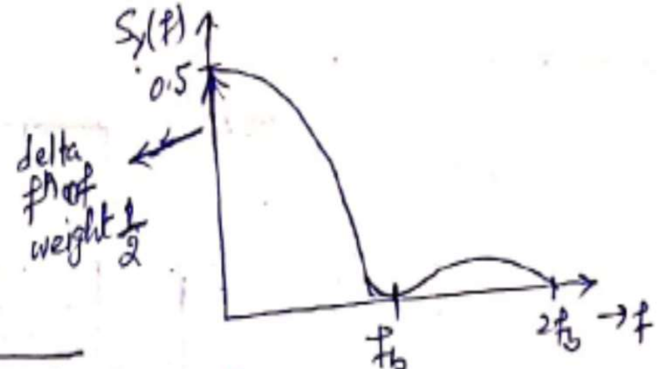
With Memory : If the polarity of pulse (+p(t) or −p(t)) depends on the polarity of earlier pulse ; ∴ Then the line code or baseband modulation scheme is called with memory modulation.
(eg: AMI, HDBn Signalling)
& Duo-binary signalling

Memoryless : If the polarity of current pulse does not depend upon the polarity of previous pulse assigned. Then the above scheme does not require memory and hence can be said memoryless baseband modulation / line coding.
(eg: on-off (RZ), on-off (NRZ), polar (RZ), polar (NRZ).)

1). ON-OFF (unipolar) non return-to-zero (NRZ) signalling:-

- In this line code symbol 1 is represented by transmitting a pulse of amplitude A for the full duration (T_b) of the symbol, and symbol 0 is represented by zero valtage level. (switching off the pulse).

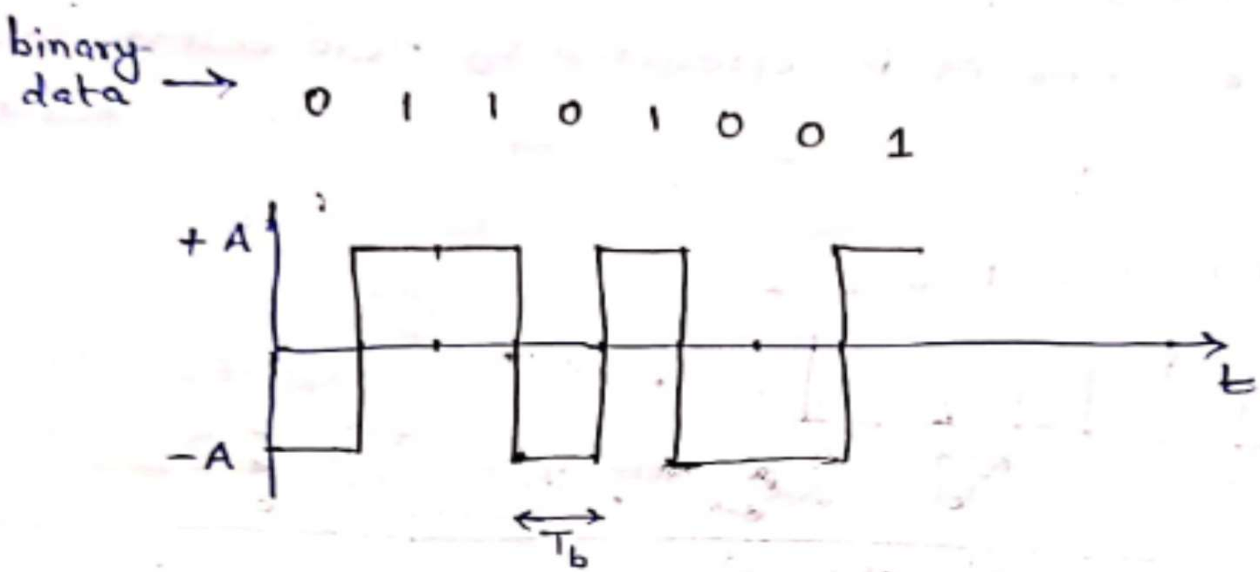




- No error dedection capability
- Less noise immunity.
- No DC Null
- Not Transparent
- Required BW = f_b

2). Polar non return to zero (NRZ) Signalling:

- In this line code, symbols 1 and 0 are represented by transmitting pulse of amplitudes +A and -A respectively.



PSD.

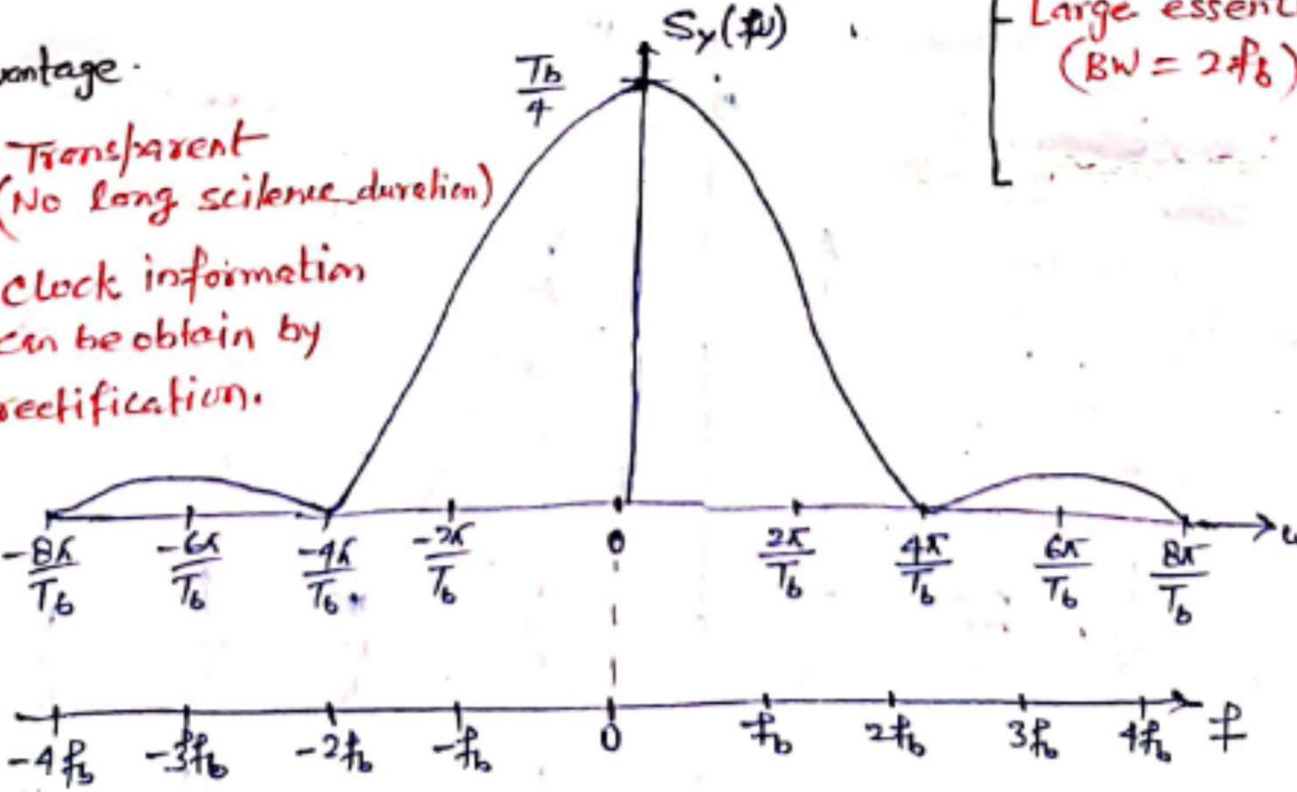
$$\boxed{S_y(f) = \frac{T_b}{4}\,\mathrm{Sinc}^2\left(\frac{\pi f T_b}{2}\right)}$$

disadvantage

- No error dedection correction capability
- No DC Null
- Large essential BW (BW = $2f_b$)

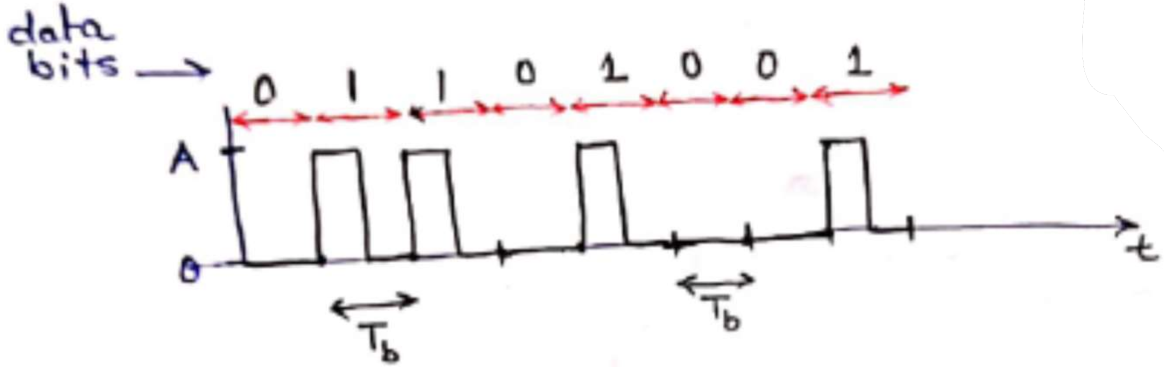
Advantage.

- Transparent (No long scilence duretion)
- clock information can be oblain by rectification.



3). ON-OFF (Unipolar) Return-to-zero (RZ) Signalling:

- In this line code, symbol 1 is represented by a rectangular pulse of Amplitude A and half-width duration, and symbol 0 is represented by transmitting No. pulse.



4). Bipolar return-to-zero (BRZ) signalling (AMI).

- In this scheme Half ~~pulse~~ width. pulse is used. (with memory).
- A symbol 0 is represented by zero voltage level. (Pseudo ternary)
& symbol 1 is represented by +A & -A alternatively.
- It is also known as Alternate mark inversion (AMI) signaling.
- This is a class of <u>With memory</u> line coding (baseband modulation).

$x(t) \longrightarrow \boxed{h(t)=p(t)} \longrightarrow y(t).$

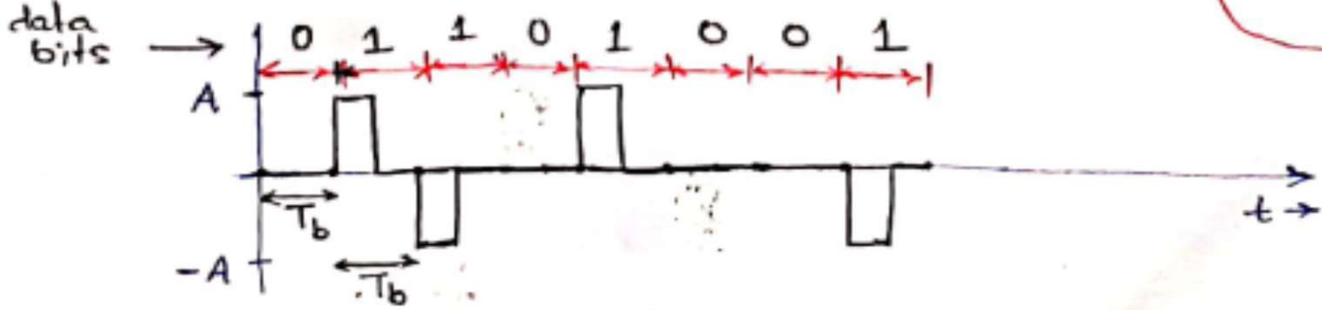
$$S_y(\omega) = |p(\omega)|^2 \cdot S_x(\omega)$$

$$= \frac{|p(\omega)|^2}{2T_b}\left(1-\cos\omega T_b\right)$$

$$S_y(\omega) = \frac{|p(\omega)|^2}{2T_b} \sin^2\left(\frac{\omega T_b}{2}\right)$$

PSD.

$$\boxed{S_y(\omega) = \frac{T_b}{4}\,\mathrm{sinc}^2\left(\frac{\omega T_b}{4\pi}\right)\sin^2\left(\frac{\omega T_b}{2}\right)}$$

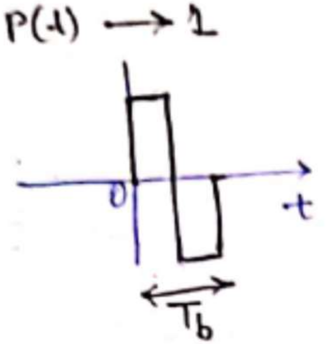


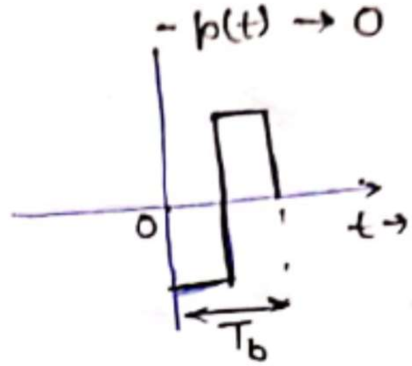
Advantages:
- spectrum has a dc. null
- BW not excessive, $BW = f_b$
- detect upto single error
- Semitransparent
- Clock recovery by rectification.

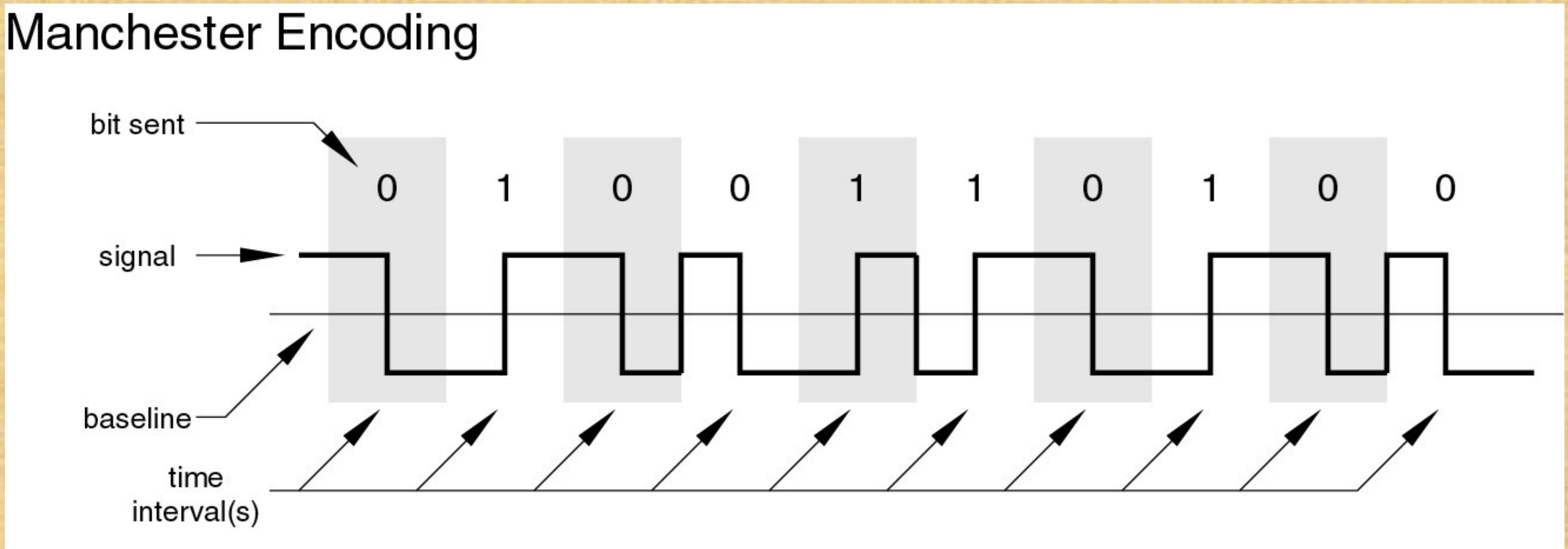
Disadvantage: Requires twice as much power as a polar signal (for similar noise performance to polar) needs. This is because bipolar detection is essentially equivalent to ON-OFF signalling from the detection point of view. One distinguishes between +A or −A from 0 rather than between ±A.

5). Split-phase (Manchester Code) (Twinned-binary).

In this method of signaling, symbol 1 is represented by a positive pulse of amplite A followed by a negative pulse of amplite -A, with both pulse being Half-width pulse.







This is widely used in wired ethernet. Also common in RF, particularly in low power near field RF (NFRF) devices.

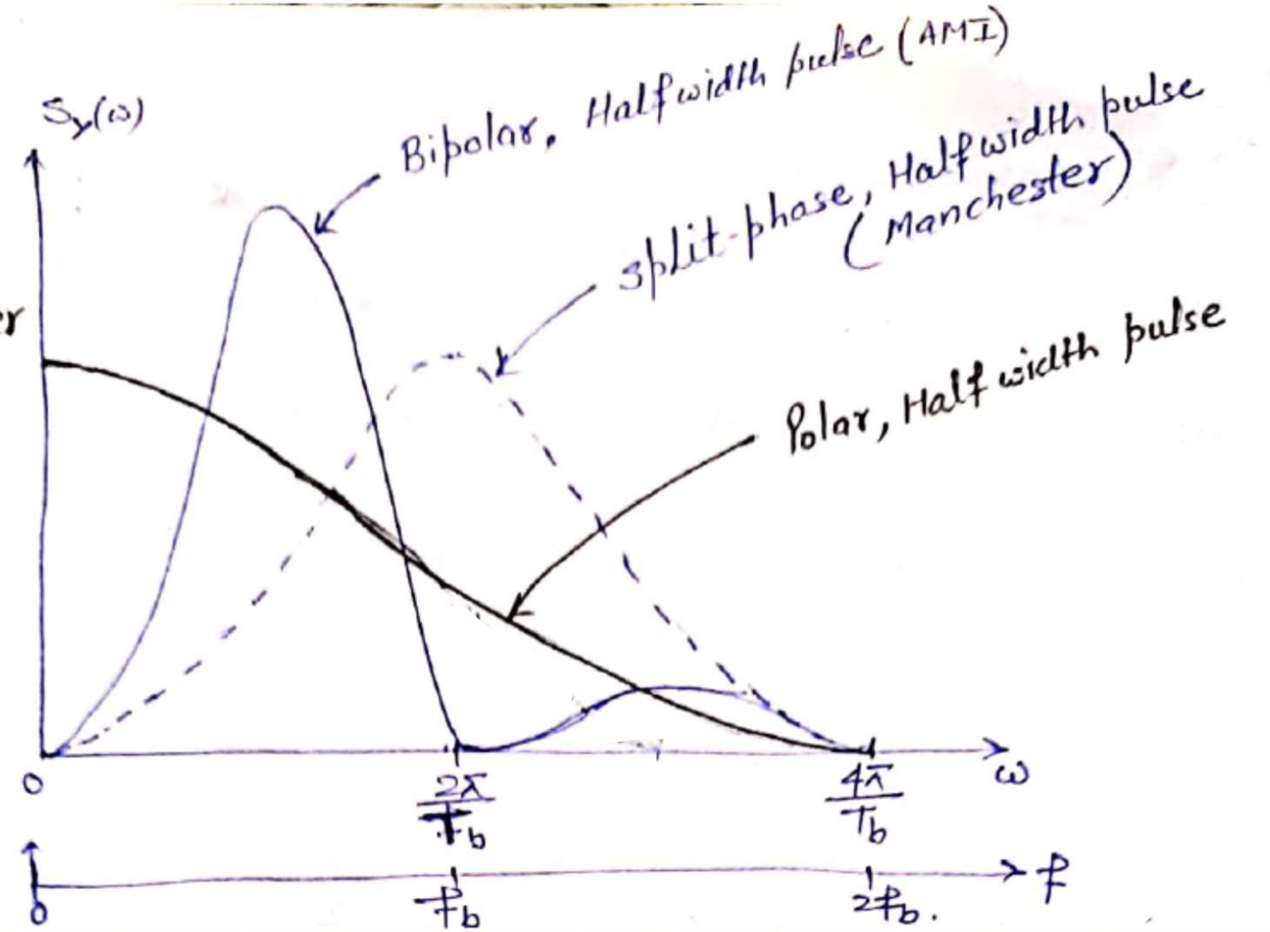
- The main advantage of this code is.
    - DC Null irrespective of signal statistics.
    - Transparent
    - clock recovery possible.
- Bandwidth is twice that of bipolar.,

$BW = 2f_b$. (four time the theoretical minimum, $BW_{min} = \frac{f_b}{2}$)

$$\boxed{S_y(\omega) = T_b \sin^2\left(\frac{\omega T_b}{4\pi}\right) \sin^2\left(\frac{\omega T_b}{4}\right)} = \frac{|P(\omega)|^2}{T_b}$$

Figure:

PSD of bipolar, polar, and Manchester signalings.
(Half width pulse)
(Normalized for equal power.).



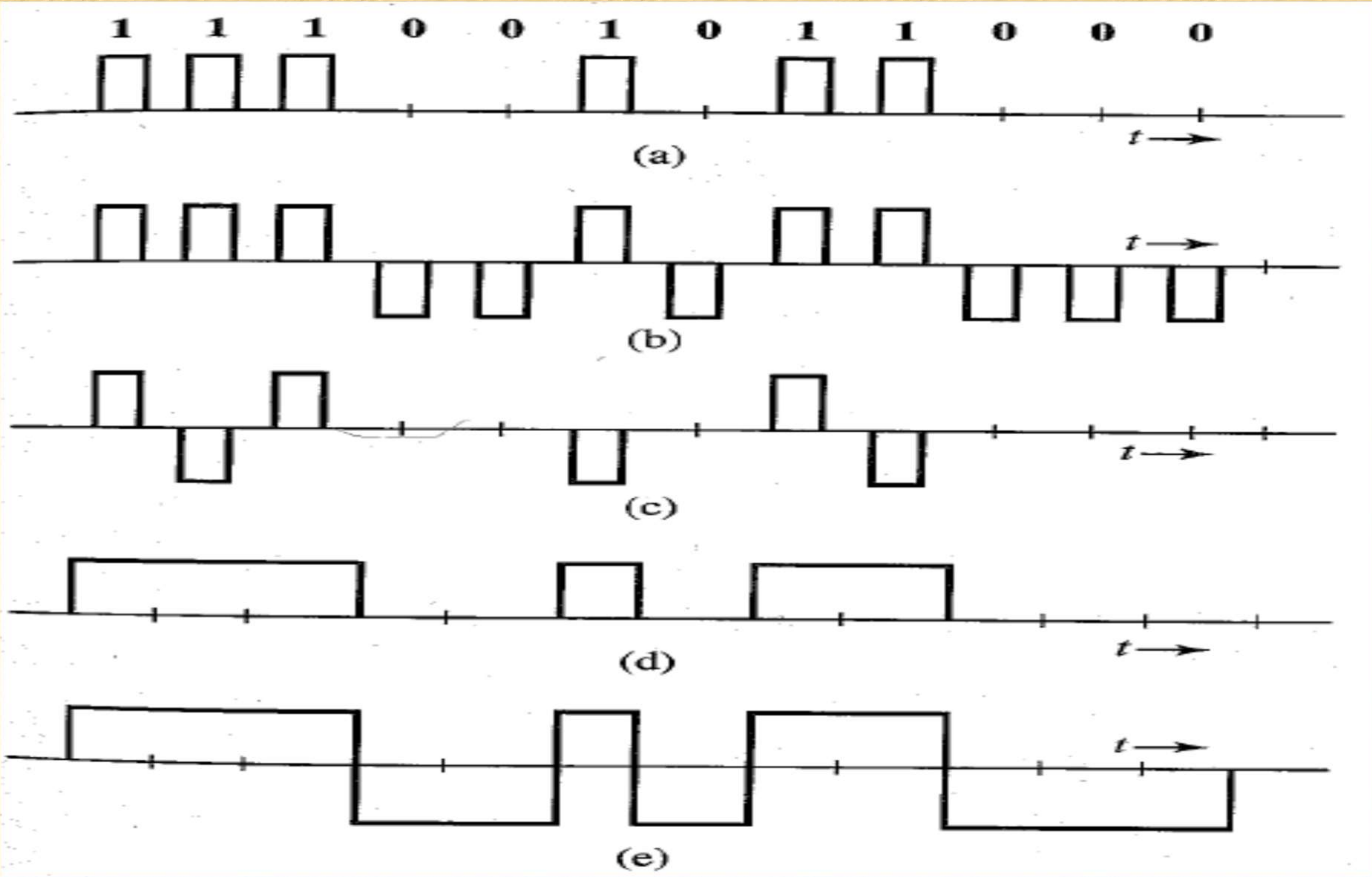
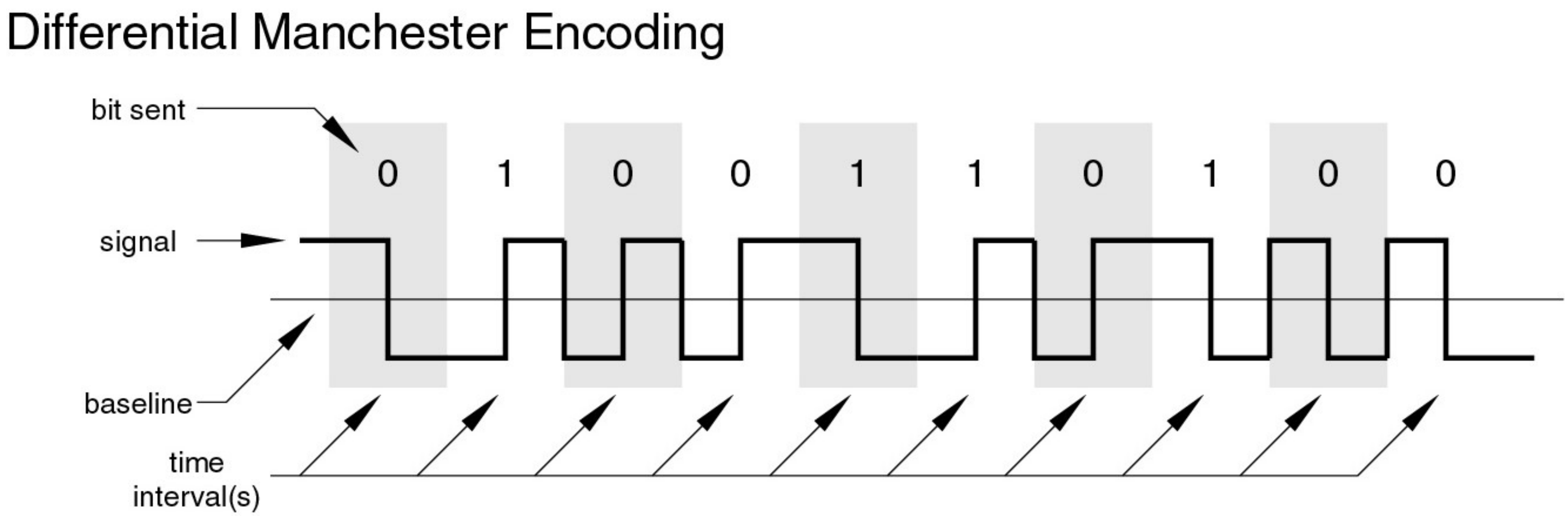


Figure : Some line code examples (a) On-off (RZ) (b) Polar (RZ) (c) Bipolar (RZ) (d) On-off (NRZ) (e) Polar (NRZ)

Differential Manchester Encoding



- Transition at start of a bit period represents zero
- No transition at start of a bit period represents one

- With Memory, DC Null, Clock Recovery, Error detection,
- Large BW.

(7) High-Density Bipolar (HDBN) Signaling

- The HDB scheme is an ITU (formerly CCITT) standard.
- With memory scheme.
- In this scheme the problem of nontransparency (no pulse) in bipolar signaling is eliminated by adding pulse when the number consecutive 0's exceeds N.
- The most important of the HDB code is HDB_3 format.

- In HDB3 $(N=3)$ when $\underline{\overset{(3+1=4)}{4} \text{ consecutive 0's occurs}}$, the group of 4 zeros is replaced by one of the special N+1 binary digit sequences.

- To increase the timing content of the signal, the sequences are choosen to include some binary 1's.

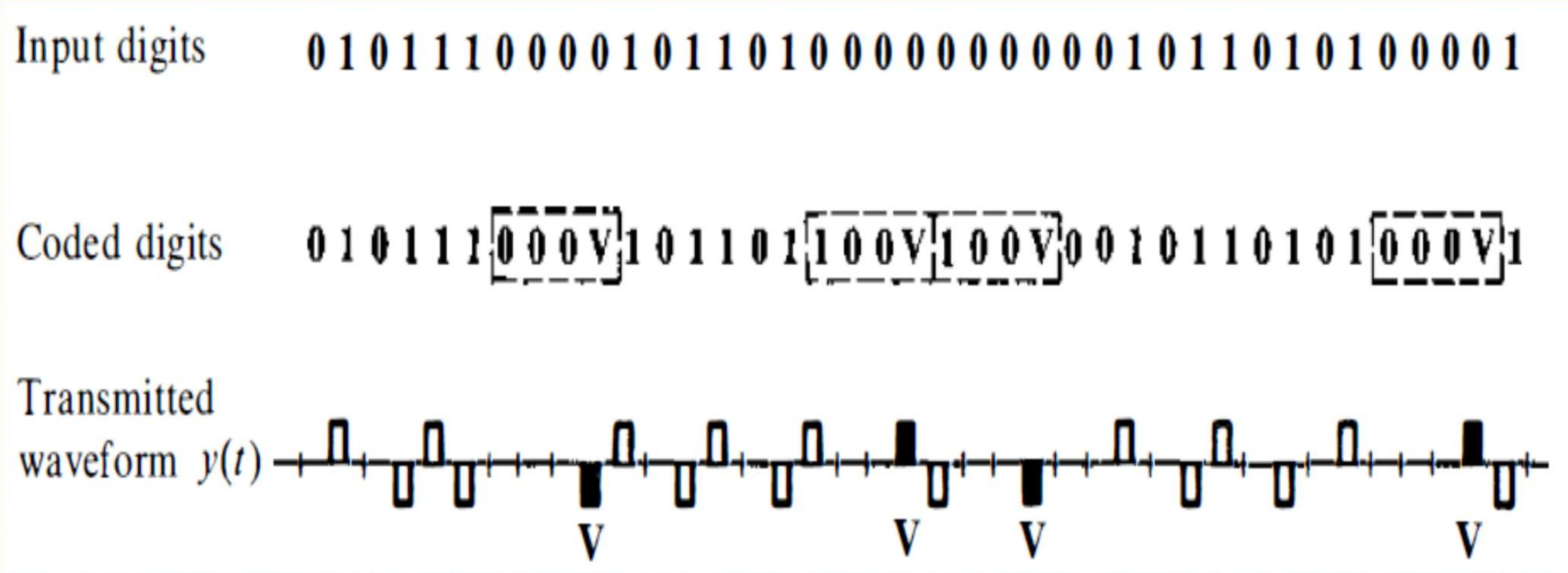
- The 1's included deliberately violet the bipolar rule for easy identification of the substituted sequence.

- In HDB3 coding, for example, the special sequence used as <u>000V</u> and <u>BOOV</u>, where <u>B = 1, confirms (follows) bipolar rule</u> & <u>V = 1, voilets bipolar rule.</u>

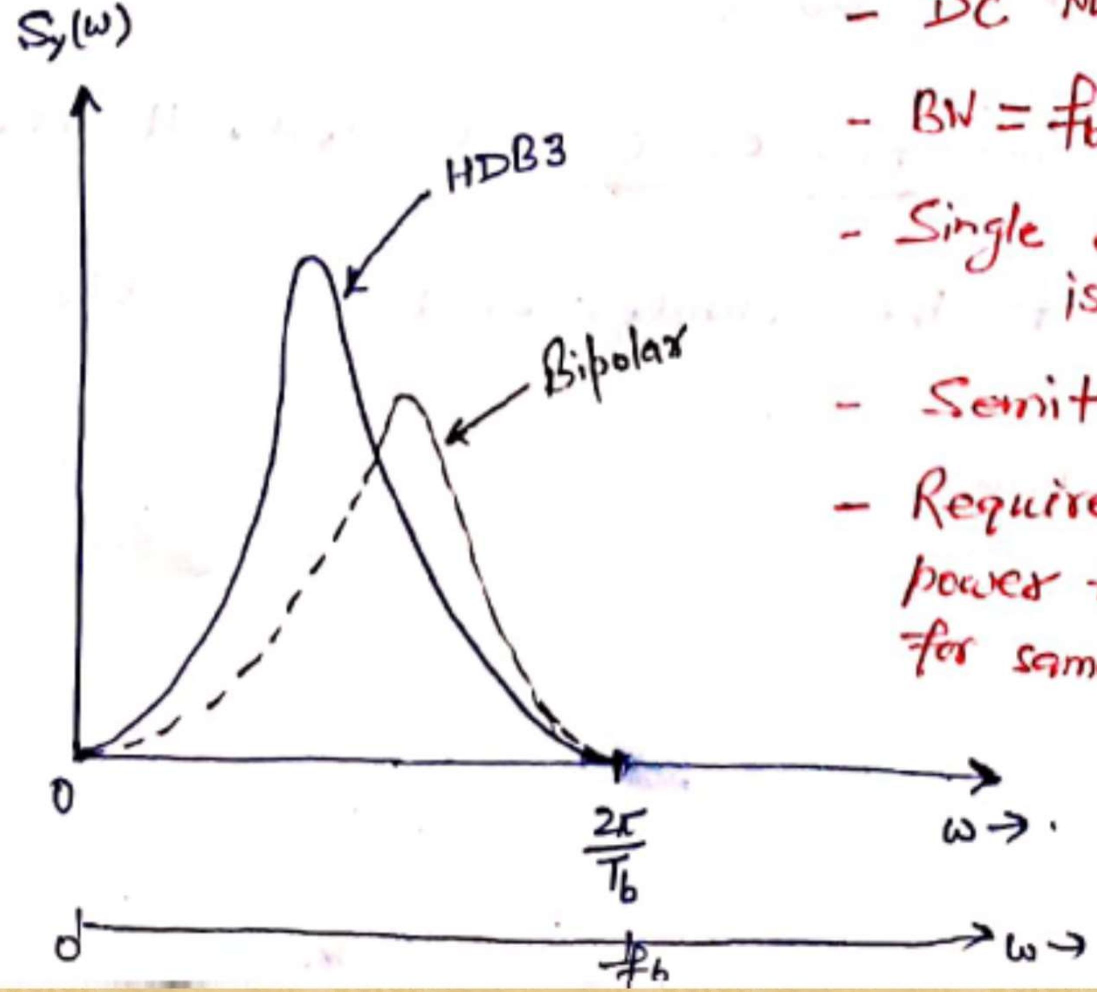
- The choice of sequence 000V or BOOV is made in such a way so that consecutive V pulses alternate signs to <u>avoid dc wonder</u> and <u>maintain the dc Null in PSD.</u>

- The sequence B00V be used when there are an even number of 1's following the last special sequence.
- Sequence 000V be used when there are odd number of 1's following the last special sequence.
- The decoder has to check two things – the bipolar voilations and the number of 0's preceding each voilations to determine if the previous 1 is also a substitution (B00V).
- In sequence B00V both B&V are encoded by the same pulse.
- HDB signaling retains error detecting capability. for single error.

HDB3



0000→ 000V or 100V
Odd 1's → 000V
Even 1's → 100V
V→ Violation of polarity



- DC Null
- $BW = f_b$
- Single error detection is possible
- Semitransparent
- Requires 3db more power than polar for same noise immunity.

(8) Binary with N zero substitution (BNZS) Signaling :

- If. N zeros occur. in succession, they are replaced, by one of the two special sequence containing some 1's to increase timing content.
- There are deliberate bipolar voilations just as in HDBN.

- In Binary with eight-zero substitution (B8ZS), eight zero's length sequence is replaced by the pattern 000VB0VB. It is used in DS1 signal of digital telephony hyrarchy.

Voilets bipolar rule

follows bipolar rule

- in Binary with 6 zero substitution (B6ZS) code, a string of six-zeros is replaced with 0VB0VB.

- B6ZS code is used in DS2 signal.

- The B3ZS code is slightly more complex than others. here either BOV or OOV is used. The choice being made so that the number of B pulses b/w consecutive V pulses is odd.

Applications of Line Coding

- NRZ encoding: RS232 based protocols
- Manchester encoding: Ethernet networks
- Differential Manchester encoding: token-ring networks
- NRZ-Inverted encoding: Fiber Distributed Data Interface (FDDI)