10EC61

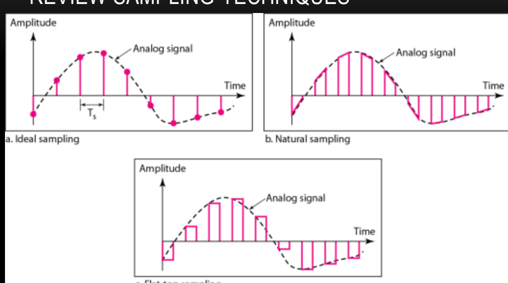
DIGITAL COMMUNICATION

UNIT 3

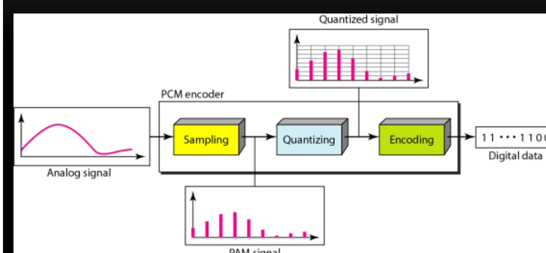
OUTLINE

- Waveform coding techniques (continued), DPCM, DM, applications.
- Base-Band Shaping for Data Transmission
- Discrete PAM signals, power spectra of discrete PAM signals.

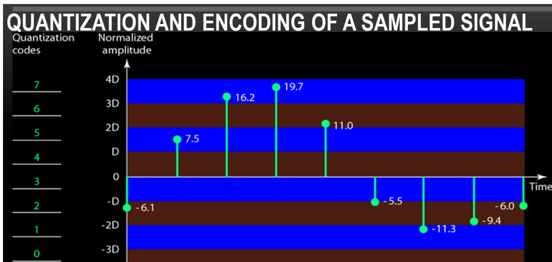
REVIEW-SAMPLING TECHNIQUES



REVIEW- PCM TRANSMITTER



QUANTIZATION AND ENCODING OF A SAMPLED SIGNAL



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

REDUNDANCY IN PULSE CODE MODULATION

REDUNDANCY IN PCM….

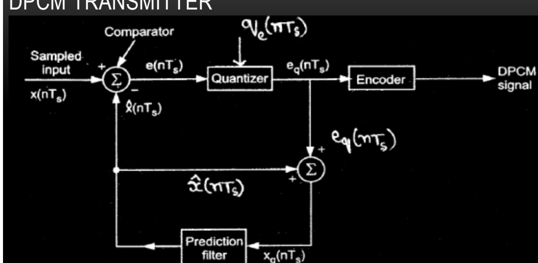
- Each sample is encoded independently of other samples.
- Samples of signals are highly correlated
  - Signal doesn't change fast
  - We are taking the samples above Nyquist rate
- Correlated samples, when encoded, results in redundant information
- If the redundancy is removed before encoding, efficiency of the coded signal can be increased.

The redundancy can be eliminated by using DPCM

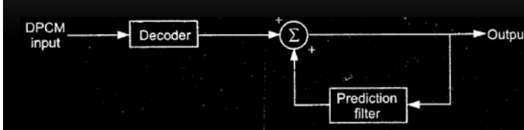
DPCM

- Differential pulse code modulation (DPCM) is procedure of converting analog to digital signal
  - analog signal is sampled and then difference between actual sample value and its predicted value is quantized and then encoded forming digital value.
    - predicted value is based on previous sample or samples
    - difference between samples can be interpreted as prediction error
  - DPCM code words represent differences between samples unlike PCM where code words represented a sample value.

DPCM TRANSMITTER



DPCM RECEIVER



PREDICTION GAIN (G_P)

- The output signal-to-quantization noise ratio of a signal coder is defined as

$$(SNR)_0 = \frac{\sigma_X^2}{\sigma_Q^2} \quad \text{-------------(1)}$$

- where σ_x^2 is the variance of the signal x(nTs) and σ_Q^2 is the variance of the quantization error q(nTs). Then

$$(SNR)_0 = \left(\frac{\sigma_X^2}{\sigma_E^2}\right)\left(\frac{\sigma_E^2}{\sigma_Q^2}\right) = G_p\,(SNR)_p \quad \text{------------(2)}$$

- where σ_E^2 is the variance of the prediction error e(nTs) and $(SNR)_P$ is the prediction error-to-quantization noise ratio, defined by

$$(SNR)_p = \frac{\sigma_E^2}{\sigma_Q^2} \quad \text{----------------(3)}$$

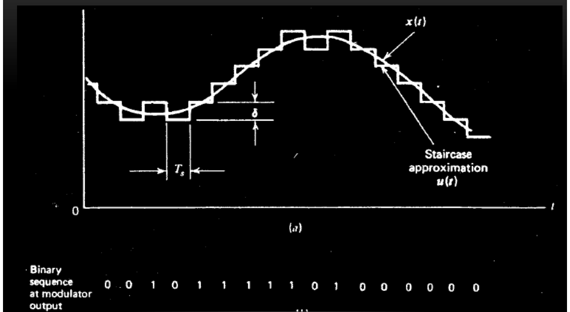
- The Prediction gain Gp is defined as

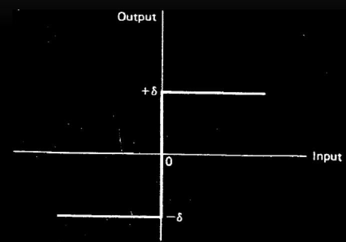
$$G_p = \frac{\sigma_X^2}{\sigma_E^2} \quad \text{----------------(4)}$$

DELTA MODULATION

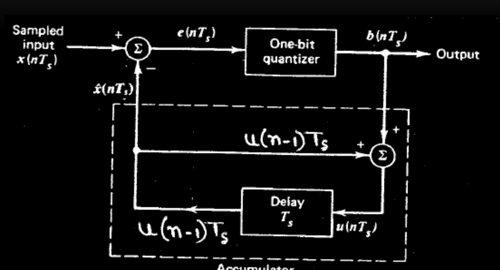
- If the sampling interval 'Ts' in DPCM is reduced considerably, i.e. if we sample a band limited signal at a rate much faster than the Nyquist sampling rate, the adjacent samples should have higher correlation
- The sample-to-sample amplitude difference will usually be very small.
- So, one may even think of only 1-bit quantization of the difference signal.
- The principle of Delta Modulation (DM) is based on this premise.
- Delta modulation is also viewed as a 1-bit DPCM scheme.
- The 1-bit quantizer is equivalent to a two-level comparator

DELTA MODULATION





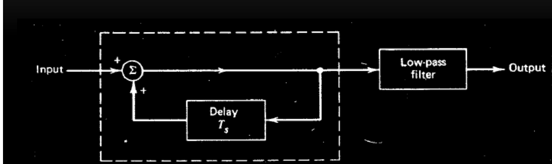
DM TRANSMITTER



FEATURES OF DELTA MODULATION

- No effective prediction unit – the prediction unit of a DPCM coder is eliminated and replaced by a single-unit delay element.
- A 1-bit quantizer with two levels is used.
- The quantizer output simply indicates whether the present input sample is more or less compared to its accumulated approximation.
- Output of the delay unit changes in small steps.
- The accumulator unit goes on adding the quantizer output with the previous accumulated version
- Performance of the Delta Modulation scheme is dependent on the sampling rate.

DM RECEIVER

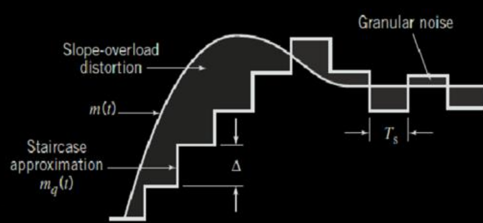


ADVANTAGES OF DM

- DM transmits only on bit for one sample. Thus the signalling rate and transmission channel bandwidth is quite small for DM.
- Overall complexity of a delta modulator-demodulator is less compared to DPCM as the predictor unit is absent in DM.
- One –bit code word for the o/p, which eliminates the need for word framing.

DRAWBACKS OF DM

- Two types of quantization error
  - Slope-overload distortion
  - Granular Noise



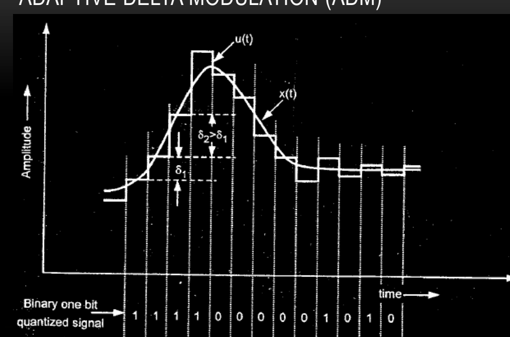
SLOPE-OVERLOAD DISTORTION

- if the input signal amplitude changes fast, the step by-step accumulation process may not catch up with the rate of change
- This happens initially when the demodulator starts operation from cold-start but is usually of negligible effect for speech.
- However, if this phenomenon occurs frequently the quality of the received signal suffers.
  - The received signal is said to suffer from slope-overload distortion.
- An intuitive remedy for this problem is to increase the step-size δ but that approach has another serious problem (granular noise)

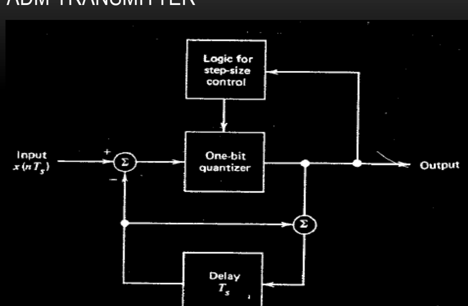
GRANULAR NOISE

- If the step-size is made arbitrarily large to avoid slope-overload distortion, it may lead to 'granular noise'.
- Imagine that the input speech signal is fluctuating but very close to zero over limited time duration.
- During such moments, delta modulator is likely to produce a fairly long sequence of 101010…., reflecting that the accumulator output is close but alternating around the input signal.
- This phenomenon is manifested at the output of the delta demodulator as a small but perceptible noisy background.
- This is known as 'granular noise'.
- Larger step-size increases the granular noise while smaller step size increases the degree of slope-overload distortion.

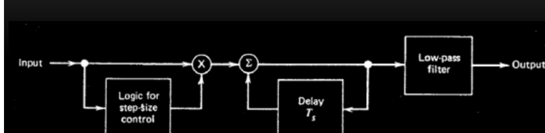
ADAPTIVE DELTA MODULATION (ADM)



ADM TRANSMITTER



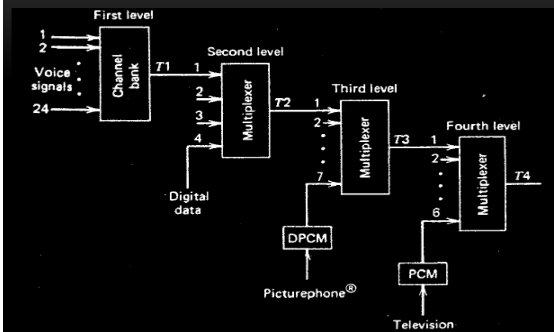
ADM RECEIVER



ADVANTAGES OF ADM

- SNR is better than ordinary delta modulation because of the reduction in the slope overload distortion and granular noise
- Utilization of bandwidth is better than DM

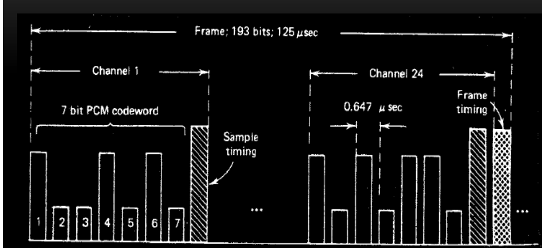
DIGITAL HIERARCHY (T1 TO T4 CARRIER SYSTEM)



PICTURE PHONE

- Bell Picturephone. It's Skype, 1964-style.

T1 FRAME



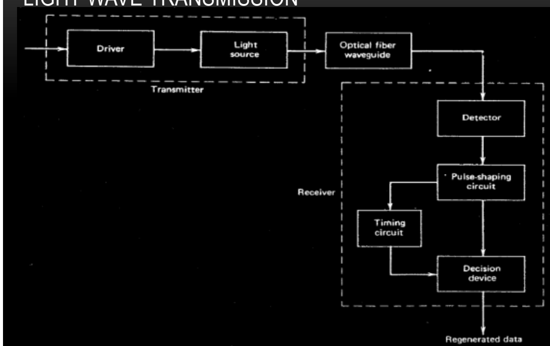
T1 TRANSMISSION RATE

Step	What Happens	Calculation
1	The eight-bit digital samples created by PCM (for voice signals only) are grouped into the 24 discrete timeslots created by TDM. Each group of 24 time-slots is called a T1 frame.	24 samples x 8 bits per sample 192 information bits per frame
2	A framing bit is added to mark the end of one frame and the beginning of the next.	192 information bits + 1 framing bit 193 total bits per frame
3	T1 frames are transmitted at the rate of 8,000 per second.	8,000 samples x 193 total bits 1,544,000 bits per second (1.544 Mb/s)

T1 FRAME

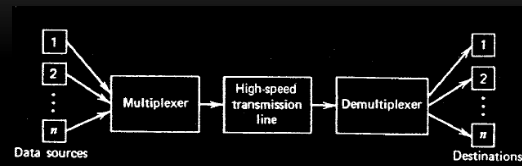
- In T1, the eight-bit digital samples created in the PCM step (for voice traffic only) are grouped into the 24 discrete DS0 timeslots created by TDM.
- Each group of 24 timeslots is called a T1 frame.
- Since each timeslot contains eight bits, the number of information bits within each frame totals 192 (24 x 8).
- Additionally, a 193rd bit is added to mark the end of one frame and the beginning of the next.
- Appropriately enough, this added bit is called the framing bit.
- Since the DS0 signals are sampled 8,000 times per second, it means that 8,000 192-bit information frames are created during that period.
- Total: 1.536 Mb/s. At 8,000 samples per second, framing bits are created at the rate of 8 kb/s.
- Result: a single 1.544 Mb/s signal known as digital signal-level one (DS1). See Table 1 on how to calculate the 1.544 Mb/s rate.

LIGHT WAVE TRANSMISSION



Optical fiber link.

DIGITAL MULTIPLEXERS



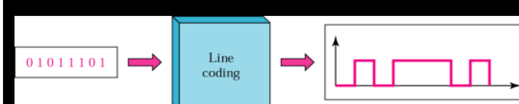
Conceptual diagram of multiplexing–demultiplexing.

Line Coding

Introduction:

•Binary Data: Pulses

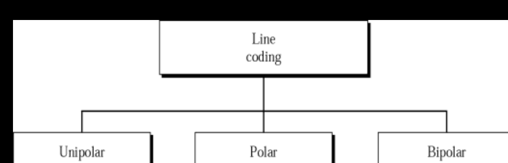
•Line Coding: A pair of pulses to represent symbols 1 and 0



Properties of Line Coding:

- Transmission Bandwidth: as small as possible
- Power Efficiency: As small as possible for given BW and probability of error
- Error Detection and Correction capability: Ex: Bipolar
- Favorable power spectral density: dc=0
- Adequate timing content: Extract timing from pulses
- Transparency: Prevent long strings of 0s or 1s

TYPES OF LINE CODING:



Unipolar Signaling:

•On-Off keying ie OOK

•Pulse 0: Absence of pulse

•Pulse1 : Presence of pulse

There are two common variations of unipolar signalling:
1. Non-Return to Zero (NRZ)
2. Return to Zero (RZ)

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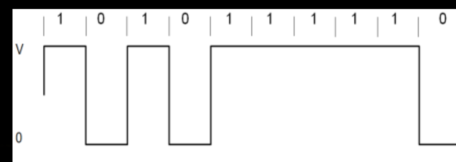
Unipolar Non-Return to Zero (NRZ):

•Duration of the MARK pulse (T) is equal to the duration (T_o) of the symbol slot.



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Advantages:
•Simplicity in implementation
• Doesn't require a lot of bandwidth for transmission.

Disadvantages:
•Presence of DC level (indicated by spectral line at 0 Hz).
•Contains low frequency components. Causes "Signal Droop"
•Does not have any error correction capability.
•Does not posses any clocking component for ease of synchronisation.
•Is not Transparent. Long string of zeros causes loss of synchronisation.

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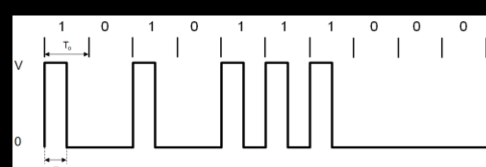
Unipolar Return to Zero (RZ):

•MARK pulse (T) is **less** than the duration (T_o) of the symbol slot.
•Fills only the first half of the time slot, returning to zero for the second half.



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Advantages:

•Simplicity in implementation.
•Presence of a spectral line at symbol rate which can be used as symbol timing clock signal.

Disadvantages:

•Presence of DC level (indicated by spectral line at 0 Hz).
•Continuous part is non-zero at 0 Hz. Causes "Signal Droop".
•Does not have any error correction capability.
•Occupies twice as much bandwidth as Unipolar NRZ.
•Is not Transparent

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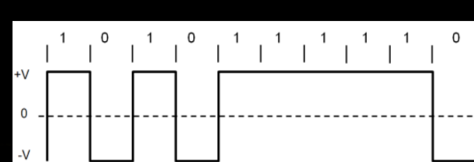
Polar Signalling:
•Polar RZ
•Polar NRZ

Polar NRZ:
•A binary 1 is represented by a pulse $g_1(t)$
•A binary 0 by the opposite (or antipodal) pulse $g_0(t) = -g_1(t)$.



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Advantages:
•Simplicity in implementation.
•No DC component.

Disadvantages:
•Continuous part is non-zero at 0 Hz. Causes "Signal Droop".
•Does not have any error correction capability.
•Does not posses any clocking component for ease of synchronisation.
•Is not transparent.

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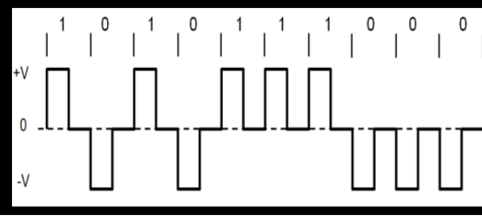
Polar RZ:

•A binary 1: A pulse $g_1(t)$
•A binary 0: The opposite (or antipodal) pulse $g_0(t) = -g_1(t)$.
•Fills only the first half of the time slot, returning to zero for the second half.



Advantages:
•Simplicity in implementation.
•No DC component.

Disadvantages:
•Continuous part is non-zero at 0 Hz. Causes "Signal Droop".
•Does not have any error correction capability.
•Occupies twice as much bandwidth as Polar NRZ.

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Bipolar Signalling:

•Alternate mark inversion (AMI)

•Uses three voltage levels (+V, 0, -V)

•0: Absence of a pulse

•1: Alternating voltage levels of +V and –V

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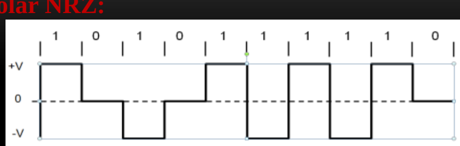
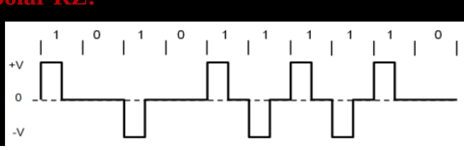
Bipolar NRZ:



Bipolar RZ:



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Advantages:
•No DC component.
•Occupies less bandwidth than unipolar and polar NRZ schemes.
•Does not suffer from signal droop (suitable for transmission over AC coupled lines).
•Possesses single error detection capability.

Disadvantages:
•Does not posses any clocking component for ease of synchronisation.
•Is not Transparent.

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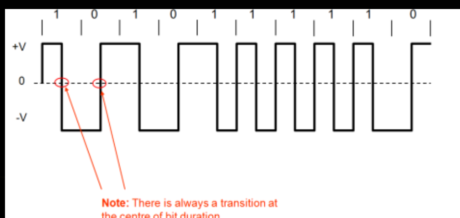
Manchester Signalling:

- The duration of the bit is divided into two halves
- A 'One' is +ve in 1st half and -ve in 2nd half.
- A 'Zero' is -ve in 1st half and +ve in 2nd half.



Advantages:

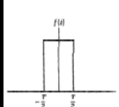
- No DC component.
- Does not suffer from signal droop (suitable for transmission over AC coupled lines).
- Easy to synchronise.
- Is Transparent.

Disadvantages:

- Because of the greater number of transitions it occupies a significantly large bandwidth.
- Does not have error detection capability.

Power Spectral Density:

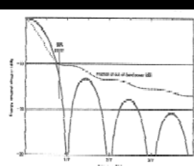
- The function which gives distribution of power of a signal at various frequencies in frequency domain.
- PSD is the Fourier Transform of autocorrelation
- Rectangular pulse and its spectrum



$$f(t) = \begin{cases} 1 & |t| \le \frac{T}{2} \\ 0 & \text{otherwise} \end{cases}$$

$$F(w) = (T)\frac{\sin(wT/2)}{wT/2}$$

where w = radian frequency $2\pi f$,
T = duation of a signal interval.



PSD Derivation:

- We now need to derive the time autocorrelation of a power signal x(t)

$$R_x(\tau) = \lim_{T_p\to\infty} \frac{1}{T_p}\int_{-T_p/2}^{T_p/2} x(t)x(t+\tau)dt$$

- Since x(t) consists of impulses, $R_x(\tau)$ is found by

$$R_x(\tau) = \frac{1}{T}\sum_{n=-\infty}^{\infty} R_n\delta(\tau - nT)$$

where $R_n = \lim_{N\to\infty} \frac{1}{N}\sum_k a_k a_{k+n}$

- Recognizing $R_n = R_{-n}$ for real signals, we have

$$S_x(w) = \frac{1}{T}\left(R_0 + 2\sum_{n=1}^{\infty} R_n \cos nwT\right)$$

- Since the pulse filter has the spectrum of $F(w) \leftrightarrow f(t)$, we have

$$\begin{aligned} S_y(w) &= |F(w)|^2 S_x(w) \\ &= |F(w)|^2\left(\sum_{n=-\infty}^{\infty} R_n e^{-jnwT_b}\right) \\ &= \frac{|F(w)|^2}{T}\left(R_0 + 2\sum_{n=1}^{\infty} R_n \cos nwT\right) \end{aligned}$$

- Now, we can use this to find the PSD of various line codes.

PSD of Polar Signalling:

- In polar signalling,
  - Binary "1" is transmitted by a pulse f(t)
  - Binary "0" is transmitted by a pulse –f(t)
- In this case, a_k is equally likely to be 1 or -1 and a_k^2 is always 1.

$$R_0 = \lim_{N\to\infty} \frac{1}{N}\sum_k a_k^2 = \lim_{N\to\infty} \frac{1}{N}(N) = 1$$

Where, There are N pulses and $a_k^2 = 1$ for each one.
The summation on the right-hand side of the above equation is N.

- Moreover, both a_k and a_{k+1} are either 1 or -1. So, $a_k a_{k+1}$ is either 1 or -1.

They are equally likely to be 1 or -1 on the average, out of N terms the product $a_k a_{k+1}$ is equal to 1 for N/2 terms and is equal to -1 for the remaining N/2 terms.

$$R_1 = \lim_{N\to\infty} \frac{1}{N}\left[\frac{N}{2}(1) + \frac{N}{2}(-1)\right] = 0$$

$$R_n = 0 \qquad n \ge 1$$

$$S_y(w) = \frac{|F(w)|^2}{T}R_0 = \frac{|F(w)|^2}{T}$$

$$S_y(w) = \frac{T}{2}\text{sinc}^2\left(\frac{wT}{2}\right)$$

PSD of Bipolar Signalling:

• To calculate the PSD, we have

$$R_n = \lim_{N\to\infty} \frac{1}{N}\sum_k a_k a_{k+n} \qquad R_0 = \lim_{N\to\infty} \frac{1}{N}\sum_k a_k^2$$

• On the average, half of the a_k's are 0, and the remaining half are either 1 or -1, with $a_k^2=1$. Therefore,

$$R_0 = \lim_{N\to\infty} \frac{1}{N}\left[\frac{N}{2}(\pm1)^2 + \frac{N}{2}(0)^2\right] = \frac{1}{2}$$

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• To compute R1, we consider the pulse strength product $a_k a_{k+1}$.

-Four possible equally likely sequences of two bits:11,10,01,00.
-Since bit 0 encoded by no puls $(a_k=0)$, the product $a_k a_{k+1}=0$ for the last three of these sequences. This means that, on the average, 3N/4 combinations have $a_k a_{k+1}=0$ and only N/4 combinations have non zero $a_k a_{k+1}$. Because of the bipolar rule, the bit sequence 11 can only be encoded by two consecutive pulse of opposite polarities. This means the product $a_k a_{k+1} = -1$ for the N/4 combinations.

$$R_1 = \lim_{N\to\infty} \frac{1}{N}\left[\frac{N}{4}(-1) + \frac{N}{4}(0)\right] = -\frac{1}{4}$$

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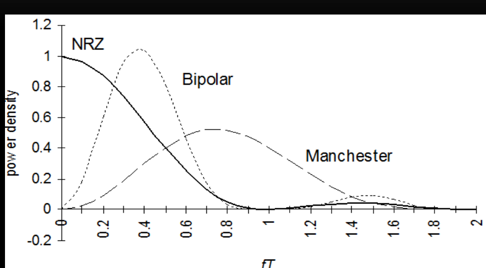
PSD of Lines Codes:



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Comparison of Line Codes:

Sr. No.	Parameters	Polar RZ	Polar NRZ	AMI	Manchester
1	Transmission of DC component	YES	YES	NO	NO
2	Signaling Rate	1/Tb	1/Tb	1/Tb	1/Tb
3	Noise Immunity	LOW	LOW	HIGH	HIGH
4	Synchronizing Capability	Poor	Poor	Very Good	Very Good
5	Bandwidth Required	1/Tb	1/2Tb	1/2Tb	1/Tb
6	Crosstalk	HIGH	HIGH	LOW	LOW

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