Module 3

Line Codes

Line Coding

- For the purposes of transmission, the symbols 0 and 1 should be converted to electrical waveforms. A number of waveform representations have been developed and are being currently used, each representation having its own specific applications.
- This representation is also called as **line coding** or **transmission coding**. The resulting waveforms are called line codes or transmission codes for the reason that they are used for *transmission* on a telephone *line*.

LINE CODING CHARACTERISTICS

The first approach converts digital data to digital signal, known as line coding, as shown in Fig.

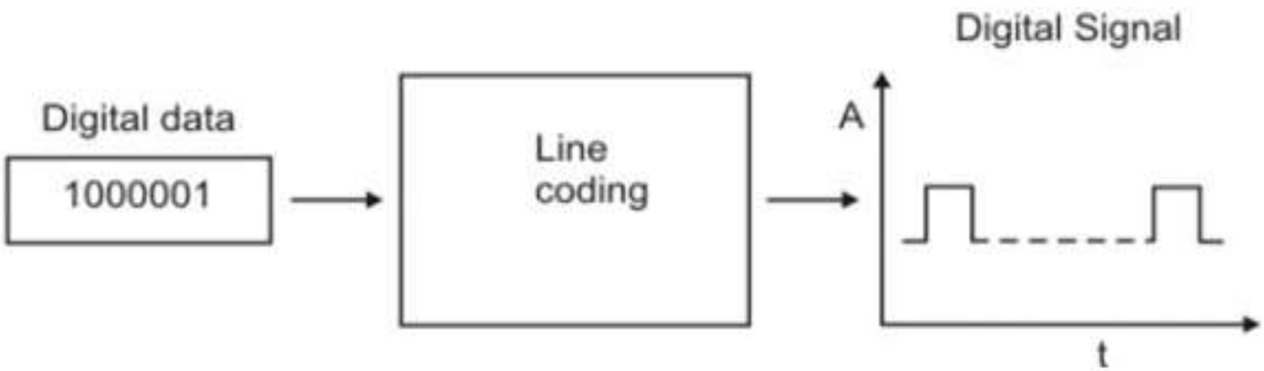


Fig: Line coding to convert digital data into digital signal

- **No of signal levels**: This refers to the number values allowed in a signal, known as s**ignal levels**, to represent data. Fig (a) shows two signal levels, whereas Fig(b) shows three signal levels to represent binary data.

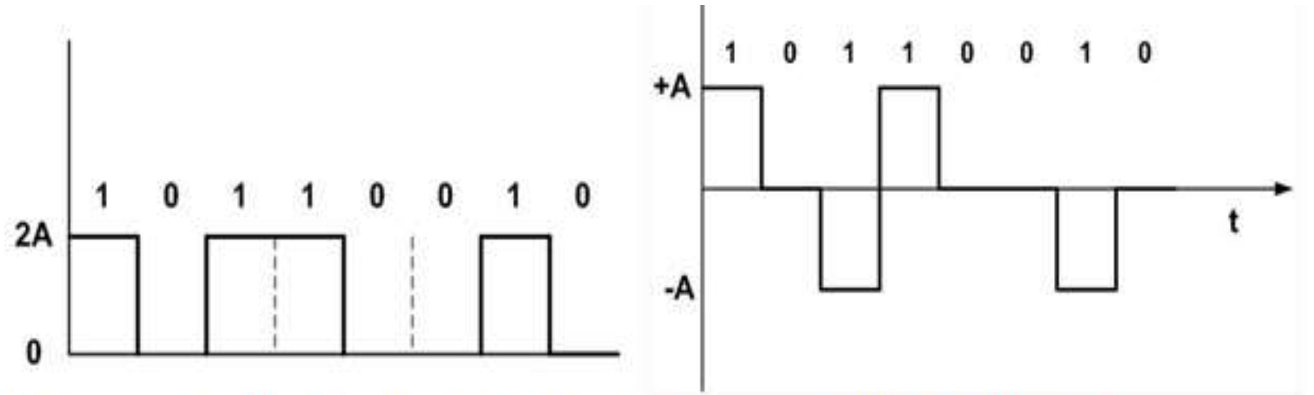


Fig (a) Signal with two voltage level Fig (b) Signal with three voltage level

Bit rate versus Baud rate:

- The **bit rate** represents the number of bits sent per second, whereas the **baud rate** defines the number of signal elements per second in the signal.
- Depending on the encoding technique used, baud rate may be more than or less than the data rate.

DC components:

- After line coding, the signal may have zero frequency component in the spectrum of the signal, which is known as the direct-current **(DC) component**.
- DC component in a signal is not desirable because the DC component does not pass through some components of a communication system such as a transformer.
- This leads to distortion of the signal and may create error at the output. The DC component also results in unwanted energy loss on the line.

Signal Spectrum:

- Different type of encoding technique leads to different spectrum of the signal.
- It is necessary to use suitable encoding technique to match with the medium so that the signal suffers minimum attenuation and distortion as it is transmitted through a medium.

Synchronization:

- To interpret the received signal correctly, the bit interval of the receiver should be exactly same or within certain limit of that of the transmitter. Any mismatch between the two may lead wrong interpretation of the received signal.
- Usually, clock is generated and synchronized from the received signal with the help of a special hardware known as Phase Lock Loop (PLL).
- However, this can be achieved if the received signal is self-synchronizing having frequent transitions (preferably, a minimum of one transition per bit interval) in the signal.

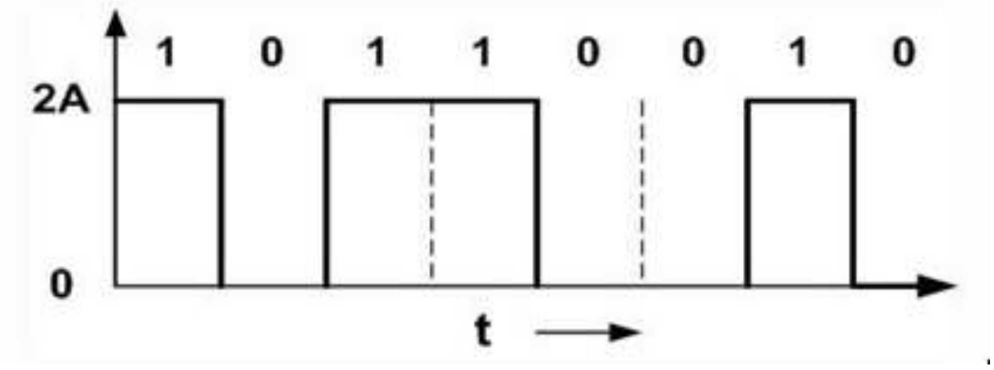
Cost of Implementation: It is desirable to keep the encoding technique simple enough such that it does not incur high cost of implementation.

Line coding formats

1) Unipolar NRZ and RZ
2) Polar NRZ and RZ
3) Bipolar NRZ and RZ
4) Manchester
5) Polar Quaternary codes
6)Differential encoding

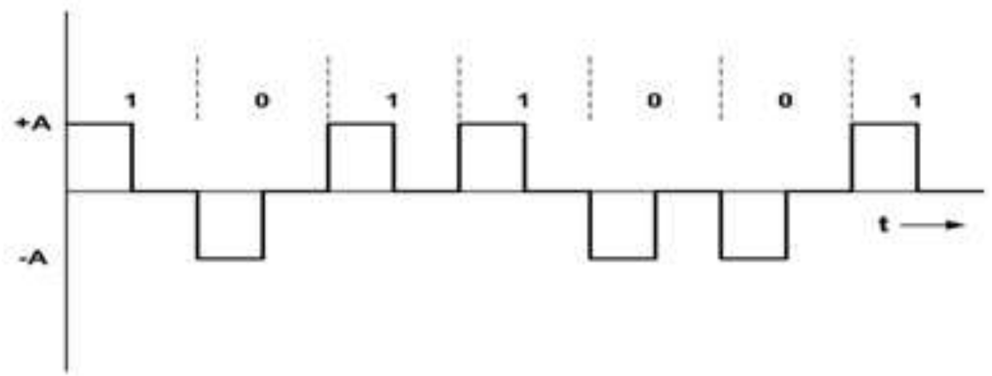
Unipolar format

- In the **Unipolar** format (also known as On-Off signaling), symbol 1 represented by transmitting a pulse, where as symbol 0 is represented by switching off the pulse. When the pulse occupies the full duration of a symbol, the unipolar format is said to be of the *non return-to-zero* (NRZ) type. When it occupies only a fraction (usually one-half) of the symbol duration, it is said to be of the *return-to-zero* (RZ) type. The unipolar format contains a DC component that is often undesirable.



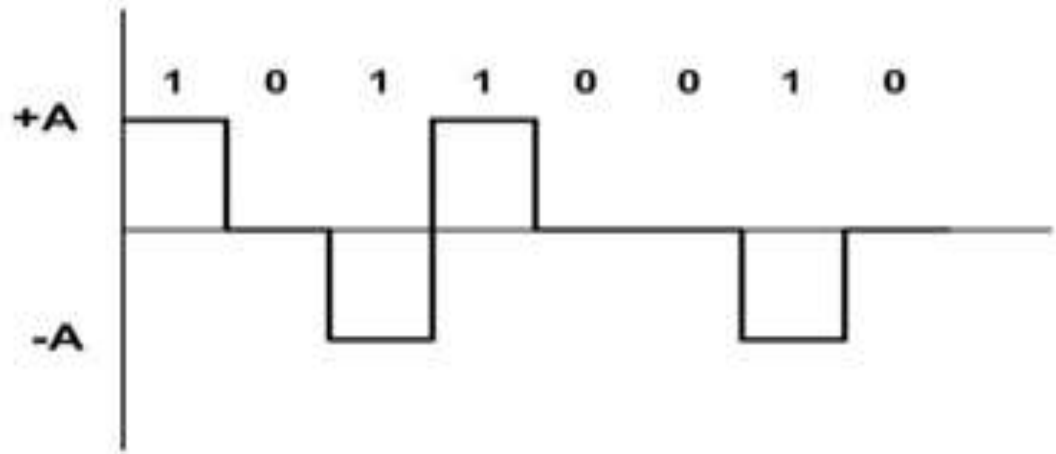
Polar format

In the *polar* format, a positive pulse is transmitted for symbol 1 and a negative pulse for symbol 0. It can be of the NRZ or RZ type. Unlike the unipolar waveform, a polar waveform has no dc component, provided that 0's and 1's in the input data occur in equal proportion.



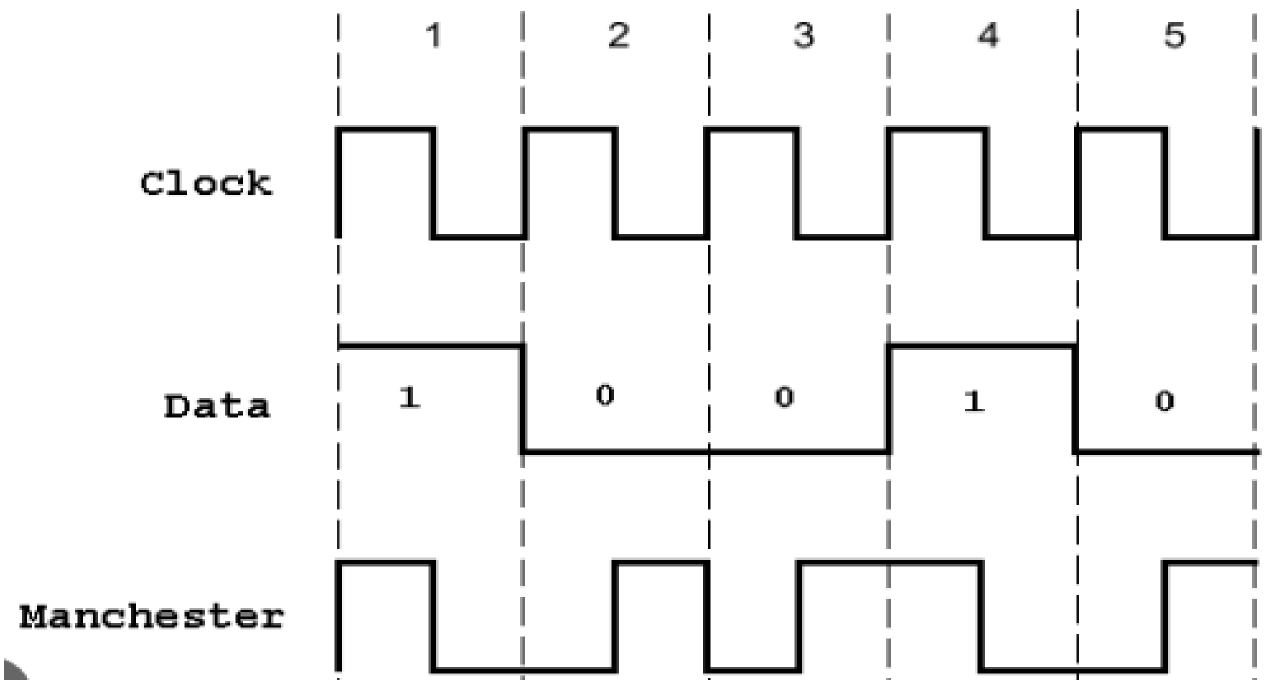
Bipolar format

- In the *bipolar* format (also known as *pseudo ternary* signaling or Alternate Mark Inversion, **AMI**), positive and negative pulses are used alternatively for the transmission of 1's (with the alternation taking place at every occurrence of a 1)and no pulses for the transmission of 0‘s.
- Again it can be of the NRZ or RZ type. Note that in this representation there are *three* levels: +1, 0, -1. An attractive feature of the bipolar format is the absence of a DC component, even if the input binary data contains large strings of 1's or 0's.
- The absence of DC permits transformer coupling during the course of long distance transmission. Also, the bipolar format eliminates ambiguity that may arise because of *polarity inversion* during the course of transmission. Because of these features, bipolar format is used in the commercial PCM telephony.


1 0 1 1 0 0 1 0
+A
-A

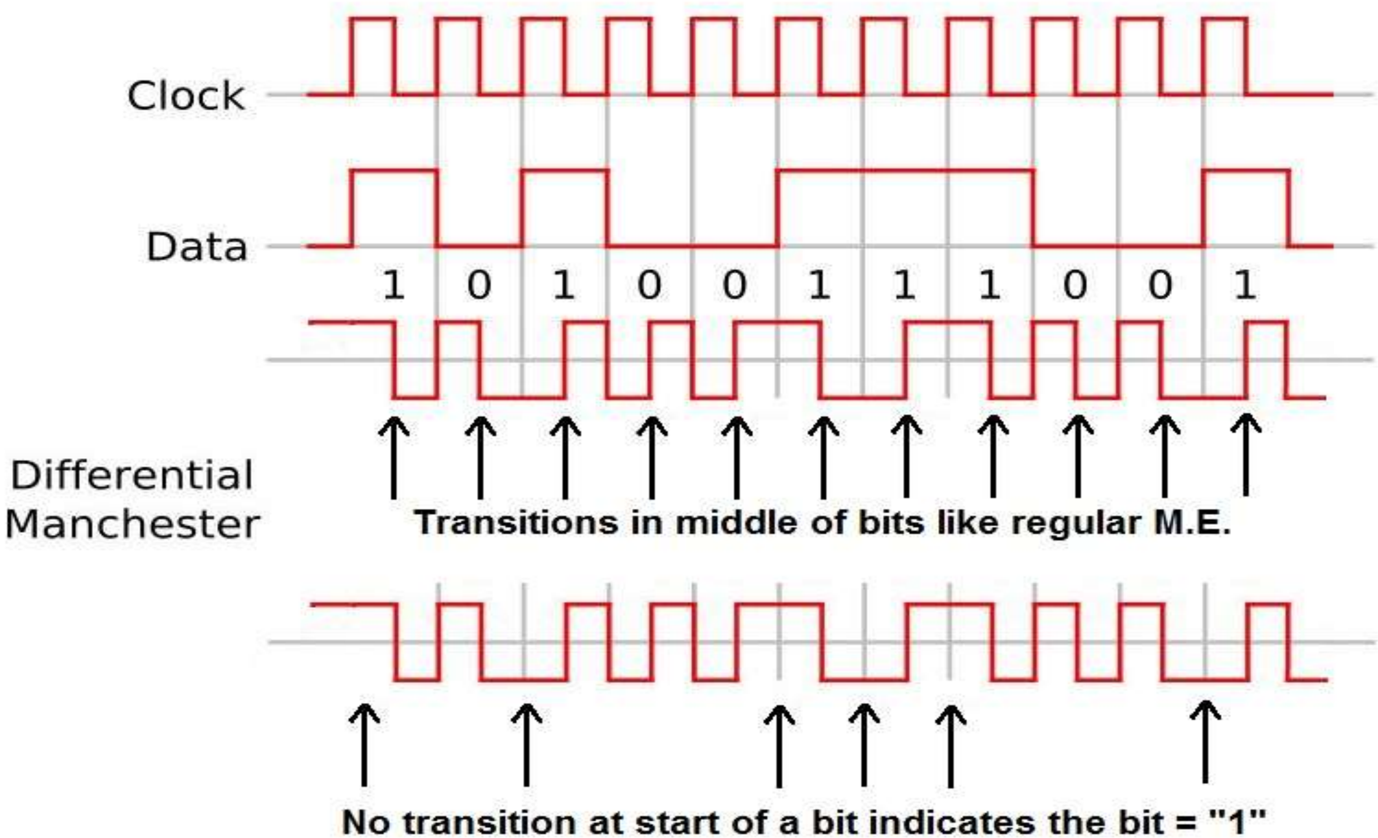
Manchester format

- In the *Manchester format* (also known as *bi-phase* or *split phase signaling*), symbol 1 is represented by transmitting a positive pulse for one-half of the symbol duration, followed by a negative pulse for the remaining half of the symbol duration; for symbol 0, these two pulses are transmitted in the reverse order.
- Clearly, this format has no DC component; moreover, it has a built in synchronization capability because there is a predictable transition during each bit interval.
- The disadvantage of the *Manchester format* is that it requires twice the bandwidth when compared to the NRZ unipolar, polar and bipolar formats.

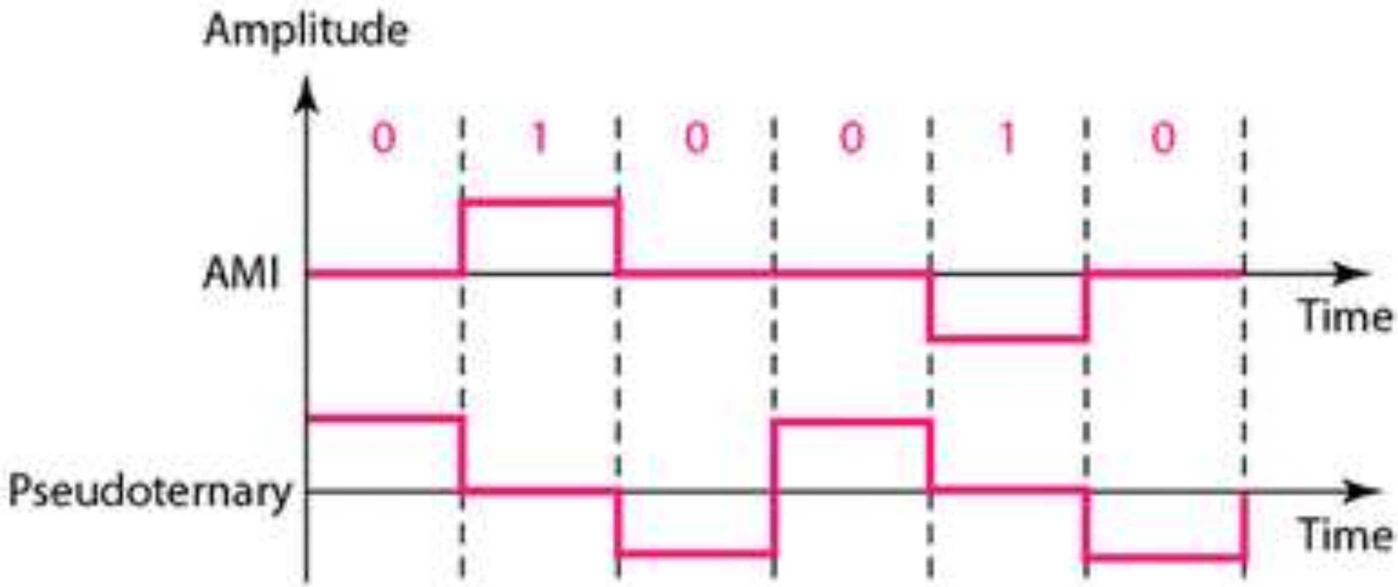

1
2
3
4
5
Clock
Data
1
0
0
1
0
Manchester

Differential Manchester

symbol 1 should come alternate and symbol 0 follows the previous level .



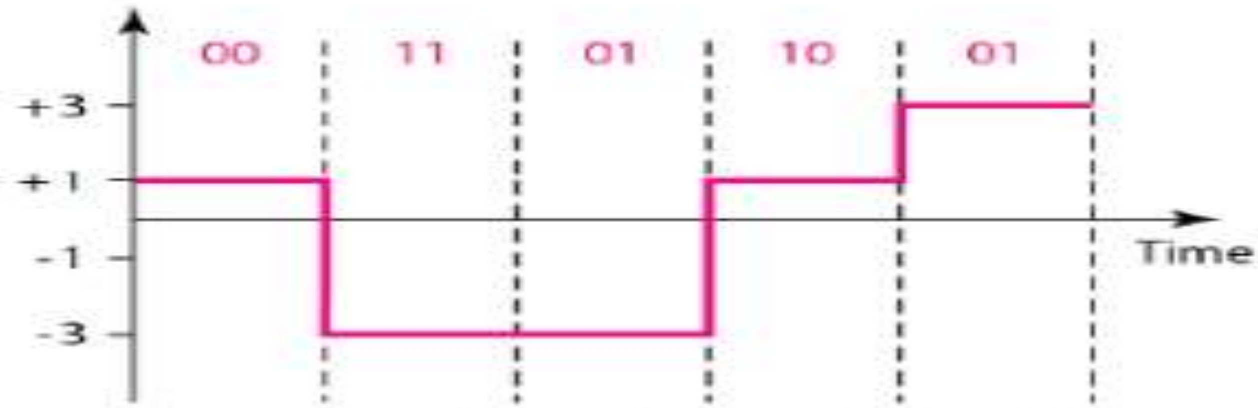
Pseudoternary



Polar Quaternary

	Previous level: positive	Previous level: negative
Next bits	Next level	Next level
00	+1	-1
01	+3	-3
10	-1	+1
11	-3	+3

Transition table



Assuming positive original level

Unipolar $A_k = \begin{cases} \text{Symbol } 1 = a \\ \text{Symbol } 0 = 0 \end{cases}$

Polar $A_k = \begin{cases} \text{Symbol } 1 = +a \\ \text{Symbol } 0 = -a \end{cases}$

Bipolar $A_k = \begin{cases} \text{Alternate Symbol } 1 \text{ takes} = +a, -a \\ \text{Symbol } 0 = 0 \end{cases}$

Manchester $A_k = \begin{cases} \text{Symbol } 1 = a \\ \text{Symbol } 0 = -a \end{cases}$

As A_k is discrete random variable, generated by random process X(t),

We can characterize random variable by its ensemble averaged auto correlation function given by

$R_A(n) = E\,[A_k.A_{k-n}]$,

A_k, A_{k-n} = amplitudes of k^{th} and $(k-n)^{th}$ symbol position

PSD & **auto correlation function** form **Fourier Transform pair** & hence auto correlation function tells us something about bandwidth requirement in frequency domain.

Hence PSD $S_x(f)$ of discrete PAM signal X(t).is given by

$$S_X(f) = \frac{1}{T}|V(f)|^2 \sum_{n=-\infty}^{\infty} R_A(n)\, e^{-j2\pi fnT}$$

Where V(f) is Fourier Transform of basic pulse V(t). V(f) & $R_A(n)$ depends on different line codes.

Power spectra of NRZ Unipolar

Consider unipolar form with symbol 1's and 0's with equal probability i.e.

$P(A_k=0) = ½$ and $P(A_k=1) = ½$

For n=0;

Probable values of $A_k.A_k = 0 \times 0$ & $a \times a$

$$=E [A_k.A_{k-0}]$$
$$= E[A_k^2] = 0^2 \times P [A_k=0] + a^2 \times P[A_k=1]$$
$$R_A(0) = a^2/2$$

If $n \neq 0$

$A_k.A_{k-n}$ will have four possibilities (adjacent bits)

0×0, $0 \times a$, $a \times 0$, $a \times a$ with probabilities ¼ each.

$$E[A_k.A_{k-n}] = 0 \times ¼ + 0 \times ¼ + 0 \times ¼ + a^2 / 4$$
$$= a^2 / 4$$

V(t) is rectangular pulse of unit amplitude, its Fourier Transform will be sinc function.

$V(f) = FT [V(t)] = T_b \, Sinc (fT_b)$ PSD is given by

$$V(f)=\int_{-\frac{T_b}{2}}^{\frac{T_b}{2}} v(t)e^{-j2\pi f t}\, d\, t$$

$$=\left[\frac{e^{-j2\pi ft}}{-j2\pi f}\right]$$

$$=\frac{1}{-\pi f}\left[\frac{e^{-j2\pi ft}-e^{+j2\pi ft}}{2j}\right]$$

$$=\frac{1}{\pi f}\left[\frac{e^{j\pi fT_b}-e^{-j\pi fT_b}}{2j}\right]$$

$$=\frac{\sin \pi f T_b}{\pi f} \, x \frac{T_b}{T_b}$$

$$V(f)=T_b \mathrm{sinc}(fT_b)$$

$$S_X(f) = \frac{1}{T}|V(f)|^2 \sum_{n=-\infty}^{\infty} R_A(n)\, e^{-j2\pi fnT}$$

substituting the values of V(f) and $R_A(n)$

$$S_X(f) = \frac{1}{T_b}\left[T_b^{\,2}\,\mathrm{Sinc}^2(fT_b)\right] \sum_{n=-\infty}^{\infty} R_A(n) e^{-j2\pi fnT_b}$$

$$= \left[T_b\,\mathrm{Sinc}^2(fT_b)\right]\left[R_A(0) + \sum_{\substack{n=-\infty \\ n\neq 0}}^{\infty} R_A(n) e^{-j2\pi fnT_b}\right]$$

$$=\left[T_b \, \mathrm{Sinc}^2(fT_b)\right]\left[\frac{a^2}{2}+\frac{a^2}{4}\sum_{\substack{n=-\infty \\ n\neq 0}}^{\infty} e^{-j2\pi\, fnT_b}\right]$$

$$=\frac{a^2}{4} T_b \, \mathrm{Sinc}^2(fT_b)+\frac{a^2}{4} T_b \, \mathrm{Sinc}^2(fT_b) \sum_{n=-\infty}^{\infty} e^{-j2\pi\, fn\, T_b}$$

using Poisson's formula

$$\sum_{n=-\infty}^{\infty} e^{-j2\pi\, fn\, T_b}=\frac{1}{T_b}\sum_{n=-\infty}^{\infty}\delta\left(f-\frac{n}{T_b}\right)$$

$$S_X(f)=\frac{a^2}{4} T_b \, \mathrm{Sinc}^2(fT_b)+\frac{a^2}{4} T_b \, \mathrm{Sinc}^2(fT_b)\,\frac{1}{T_b}\sum_{n=-\infty}^{\infty}\delta\left(f-\frac{n}{T_b}\right)$$

$\sum_{n=-\infty}^{\infty}\delta\left(f-\frac{n}{T_b}\right)$ is Dirac delta train which multiplies Sinc function which

has nulls at $\pm\frac{1}{T_b}, \pm\frac{2}{T_b}$ . . . .

As a result, $\mathrm{Sin}^2(fT_b).\sum_{n=-\infty}^{\infty}\delta(f-\frac{n}{T_b}) = \delta(f)$

Where $\delta(f)$ is delta function at f = 0,

Therefore

$$S_X(f) = \frac{a^2T_b}{4}\mathrm{Sin}^2(fT_b)+\frac{a^2}{4}\delta(f)$$

Power spectral Density of NRZ Polar format

Assuming, $P[A_k = +a] = P[A_k = -a] = \frac{1}{2}$ and 0's and 1's of the binary data sequence are statistically independent; it is easy to show,

$$R_A(n) = \begin{cases} a^2, & n = 0 \\ 0, & n \neq 0 \end{cases}$$

We know that the basic pulse v (t) is same for all the PAM formats; therefore, its Fourier transform will also remain same.
Hence,

$$P(f) = T_b \operatorname{sinc}(f T_b)$$

Thus the power spectral density (p s d) NRZ is given by, duration T_b

$$S_X(f) = a^2 T_b \operatorname{sinc}^2(f T_b)$$

Thus the power spectral density (p s d) RZ is given by, duration $T_b/2$

$$S_X(f) = a^2 \frac{T_b}{4} \operatorname{sinc}^2\left(\frac{f T_b}{2}\right)$$