Line Coding

Acknowledgments:

I would like to thank Wg Cdr (retd) Ramzan for his time and guidance which were very helpful in planning and preparing this lecture. I would also like to thank Dr. Ali Khayam and Mr. Saadat Iqbal for their help and support.

Most of the material for this lecture has been taken from "Digital Communications" 2nd Edition by P. M. Grant and Ian A. Glover.

Line Coding

Introduction:

Binary data can be transmitted using a number of different types of pulses. The choice of a particular pair of pulses to represent the symbols 1 and 0 is called Line Coding and the choice is generally made on the grounds of one or more of the following considerations:

- Presence or absence of a DC level.
- Power Spectral Density- particularly its value at 0 Hz.
- Bandwidth.
- BER performance (this particular aspect is not covered in this lecture).
- Transparency (i.e. the property that any arbitrary symbol, or bit, pattern can be transmitted and received).
- Ease of clock signal recovery for symbol synchronisation.
- Presence or absence of inherent error detection properties.

Line Coding

Introduction:

After line coding pulses may be filtered or otherwise shaped to further improve their properties: for example, their spectral efficiency and/ or immunity to intersymbol interference. .

Different Types of Line Coding

Unipolar Signalling

Unipolar signalling (also called on-off keying, OOK) is the type of line coding in which one binary symbol (representing a 0 for example) is represented by the absence of a pulse (i.e. a SPACE) and the other binary symbol (denoting a 1) is represented by the presence of a pulse (i.e. a MARK).

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

Unipolar Signalling

Unipolar Non-Return to Zero (NRZ):

In unipolar NRZ the duration of the MARK pulse ($\mathcal{T}$) is equal to the duration (T_o) of the symbol slot.

Unipolar Signalling

Unipolar Non-Return to Zero (NRZ):

In unipolar NRZ the duration of the MARK pulse ($\mathcal{T}$) is equal to the duration (T_o) of the symbol slot. (put figure here).

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" (explained later).
- 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.

Unipolar Signalling

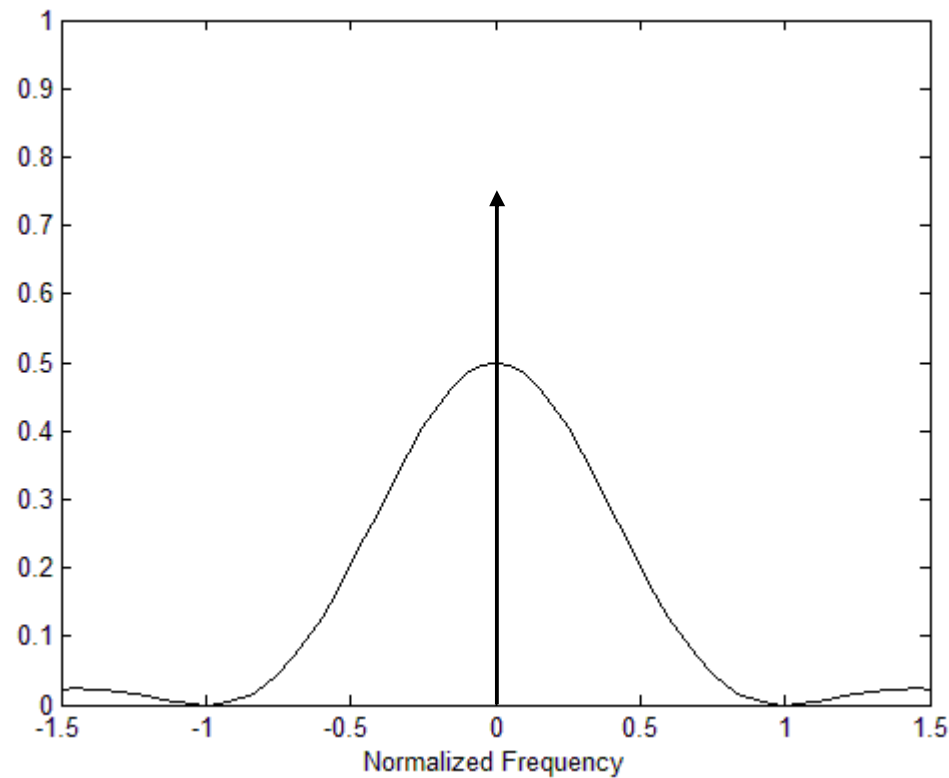**Unipolar Non-Return to Zero (NRZ):**

Figure. PSD of Unipolar NRZ

Unipolar Signalling

Unipolar Non-Return to Zero (NRZ):

When Unipolar NRZ signals are transmitted over links with either transformer or capacitor coupled (AC) repeaters, the DC level is removed converting them into a polar format.

The continuous part of the PSD is also non-zero at 0 Hz (i.e. contains low frequency components). This means that AC coupling will result in distortion of the transmitted pulse shapes. AC coupled transmission lines typically behave like high-pass RC filters and the distortion takes the form of an exponential decay of the signal amplitude after each transition. This effect is referred to as "**Signal Droop**" and is illustrated in figure below.
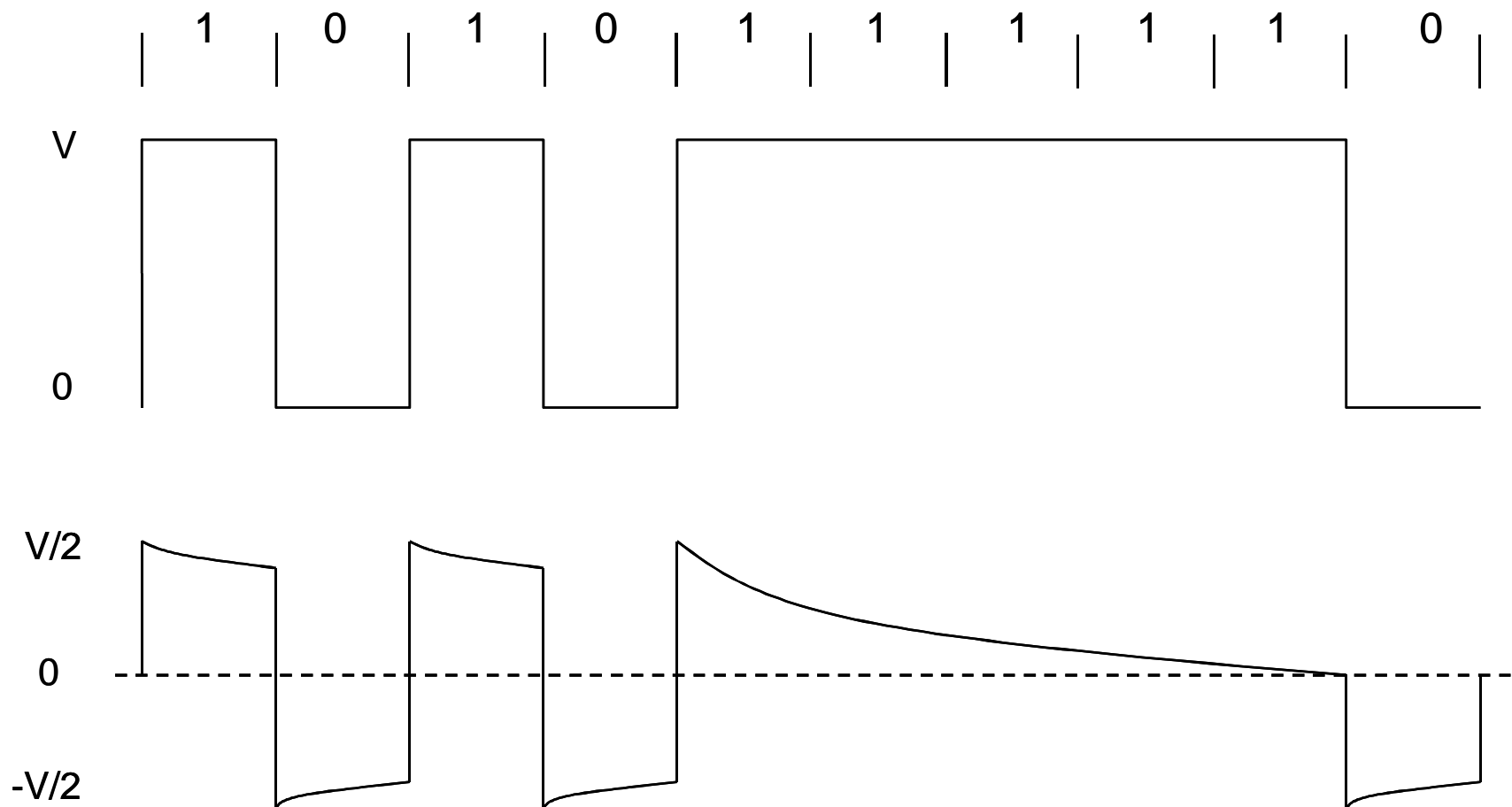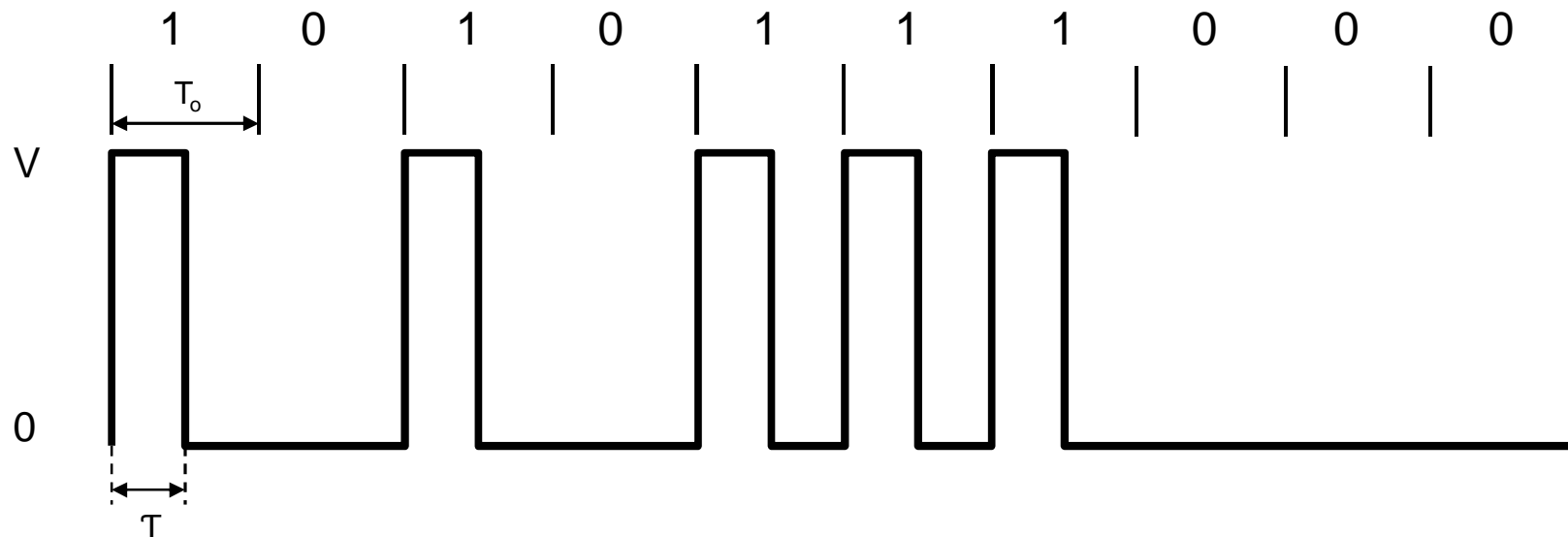
Unipolar Signalling

Figure Distortion (Signal Droop) due to AC coupling of unipolar NRZ signal
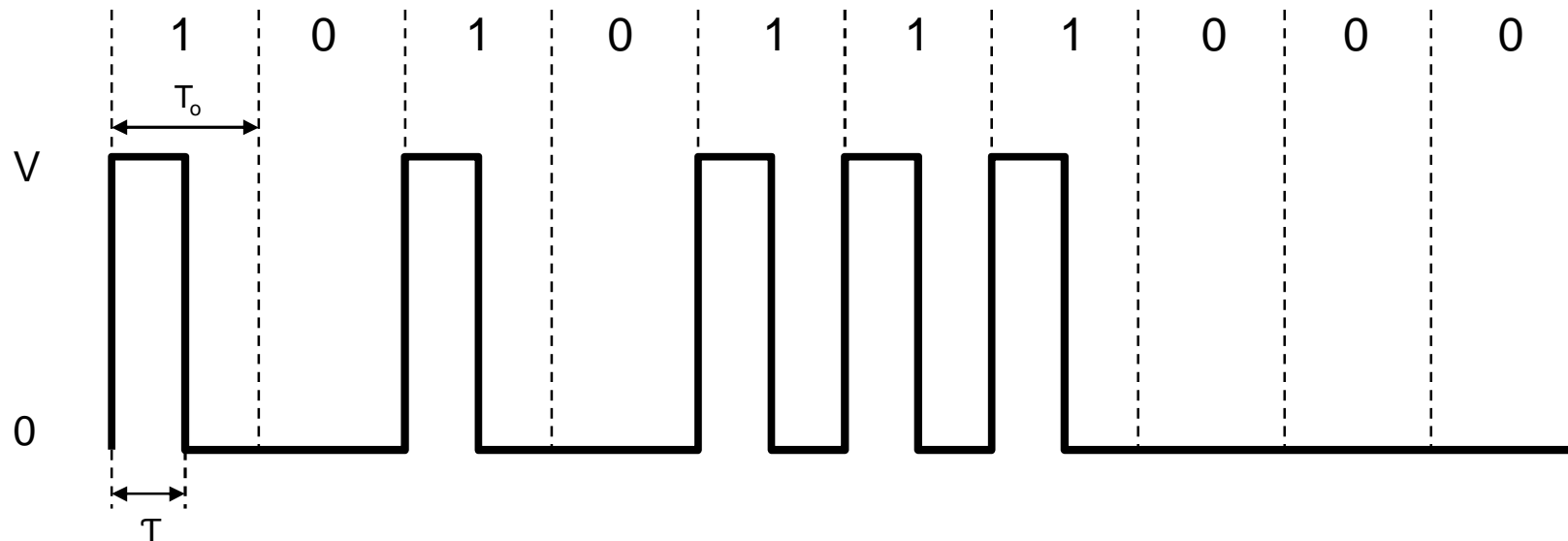
Unipolar Signalling

Return to Zero (RZ):

In unipolar RZ the duration of the MARK pulse (T) is **less** than the duration (T_o) of the symbol slot. Typically RZ pulses fill only the first half of the time slot, returning to zero for the second half.

Unipolar Signalling

Return to Zero (RZ):

In unipolar RZ the duration of the MARK pulse (T) is **less** than the duration (T_o) of the symbol slot. Typically RZ pulses fill only the first half of the time slot, returning to zero for the second half.

Unipolar Signalling

Unipolar Return to Zero (RZ):

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

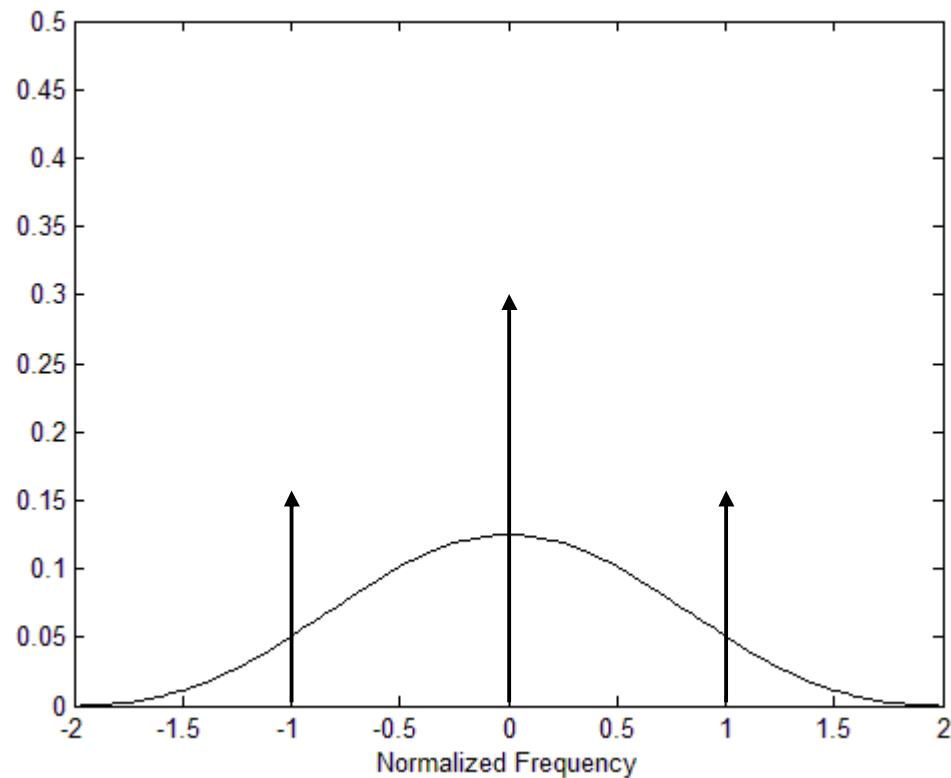# Unipolar Signalling

Unipolar Return to Zero (RZ):

Figure. PSD of Unipolar RZ

Unipolar Signalling

In conclusion it can be said that neither variety of unipolar signals is suitable for transmission over AC coupled lines.

Polar Signalling

In polar signalling a binary 1 is represented by a pulse $g_1(t)$ and a binary 0 by the opposite (or antipodal) pulse $g_0(t) = -g_1(t)$. Polar signalling also has NRZ and RZ forms.
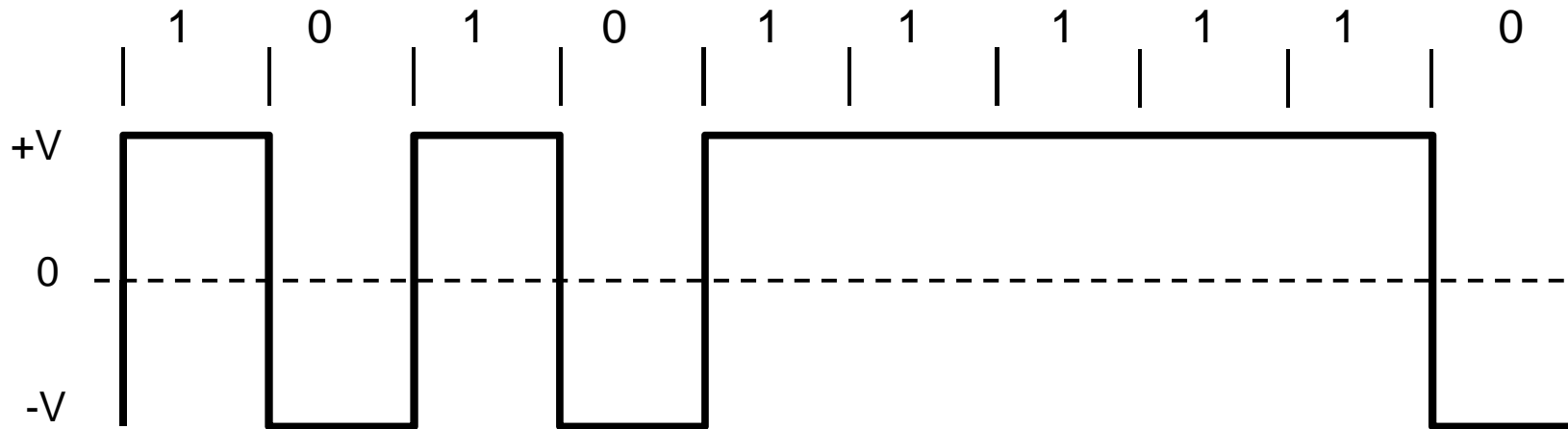

Figure. Polar NRZ

Polar Signalling

In polar signalling a binary 1 is represented by a pulse $g_1(t)$ and a binary 0 by the opposite (or antipodal) pulse $g_0(t) = -g_1(t)$. Polar signalling also has NRZ and RZ forms.
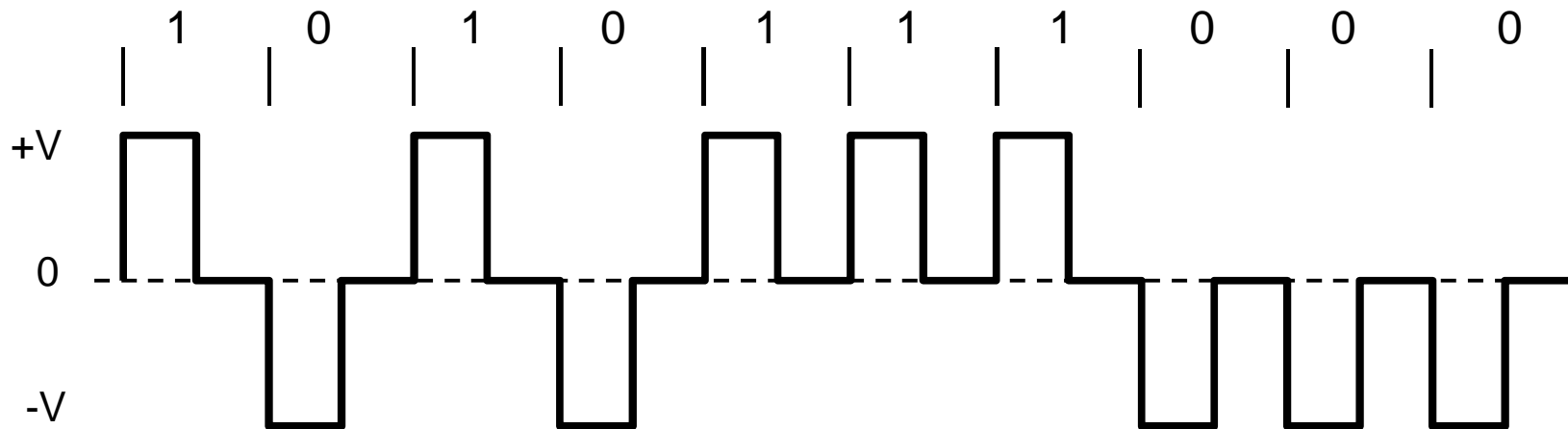

Figure. Polar RZ

Polar Signalling

PSD of Polar Signalling:

Polar NRZ and RZ have almost identical spectra to the Unipolar NRZ and RZ. However, due to the opposite polarity of the 1 and 0 symbols, neither contain any spectral lines.
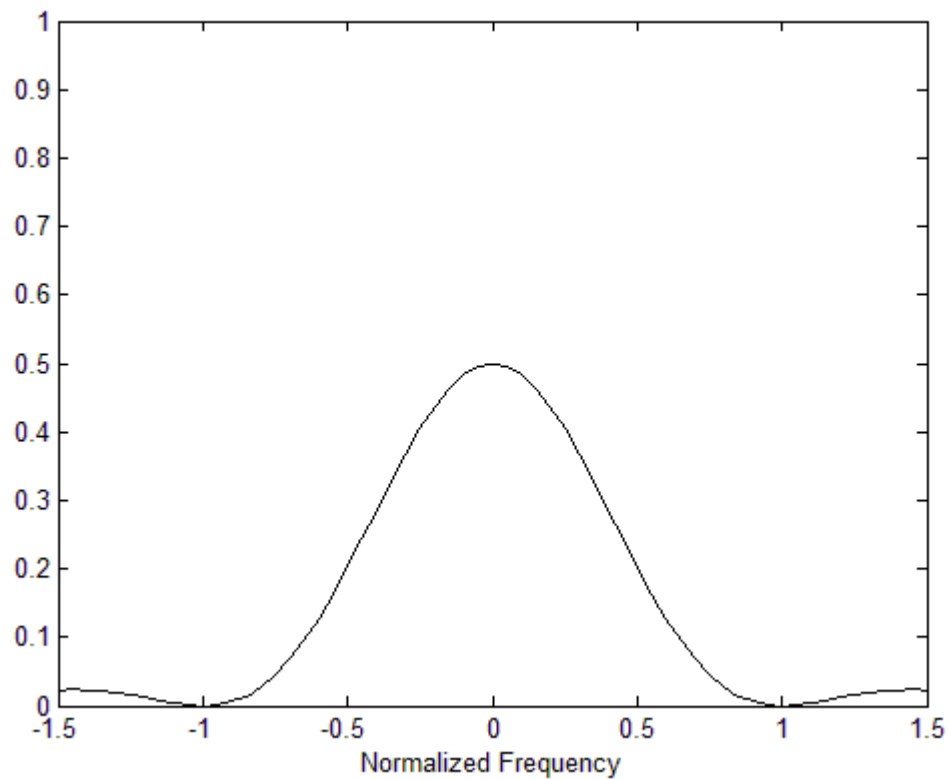

Figure. PSD of Polar NRZ

Polar Signalling

PSD of Polar Signalling:

Polar NRZ and RZ have almost identical spectra to the Unipolar NRZ and RZ. However, due to the opposite polarity of the 1 and 0 symbols, neither contain any spectral lines.
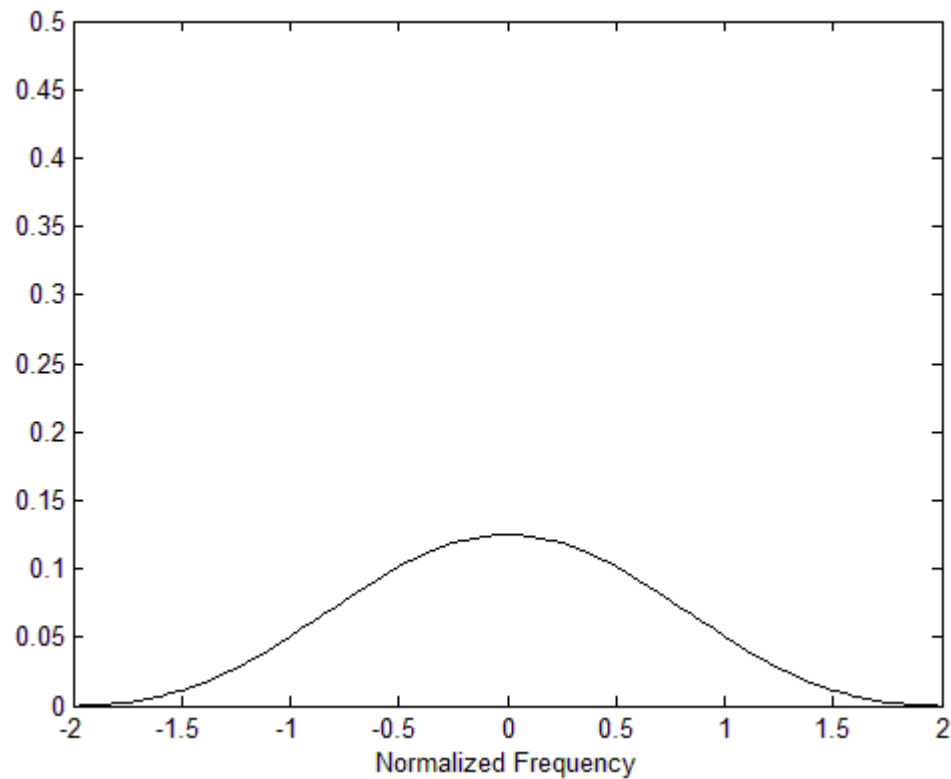

Figure. PSD of Polar RZ

Polar Signalling

Polar Non-Return to Zero (NRZ):

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.

Polar Signalling

Polar Return to Zero (RZ):

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 easy synchronisation. However, clock can be extracted by rectifying the received signal.

– Occupies twice as much bandwidth as Polar NRZ.

BiPolar Signalling

Bipolar Signalling is also called "alternate mark inversion" (AMI) uses three voltage levels (+V, 0, -V) to represent two binary symbols. Zeros, as in unipolar, are represented by the absence of a pulse and ones (or marks) are represented by alternating voltage levels of +V and –V.

Alternating the mark level voltage ensures that the bipolar spectrum has a null at DC And that signal droop on AC coupled lines is avoided.

The alternating mark voltage also gives bipolar signalling a single error detection capability.

Like the Unipolar and Polar cases, Bipolar also has NRZ and RZ variations.
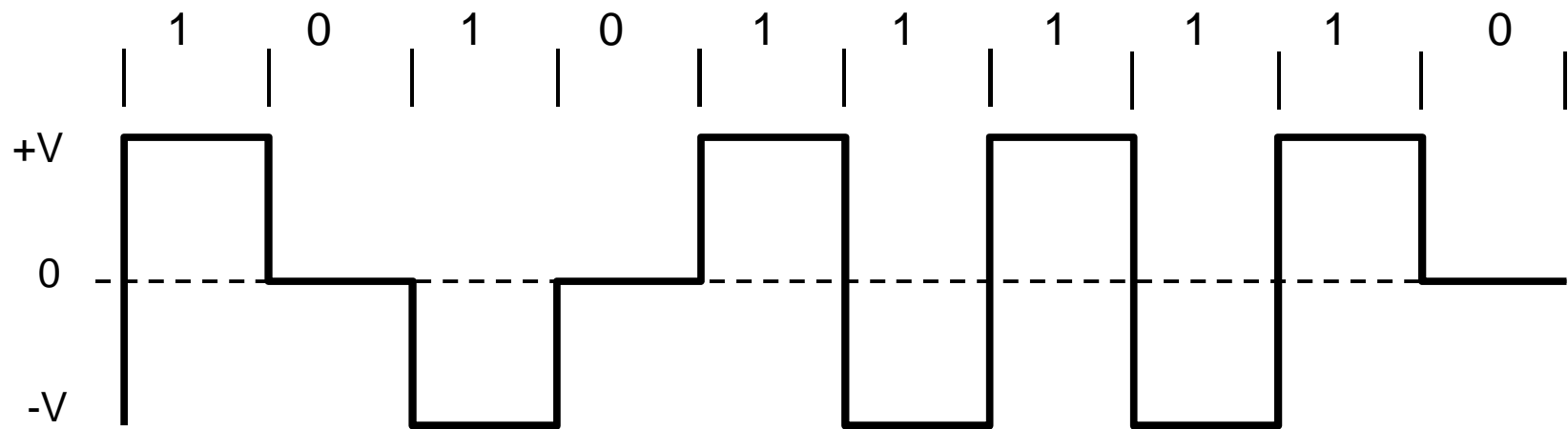
BiPolar Signalling

Figure. BiPolar NRZ

Polar Signalling
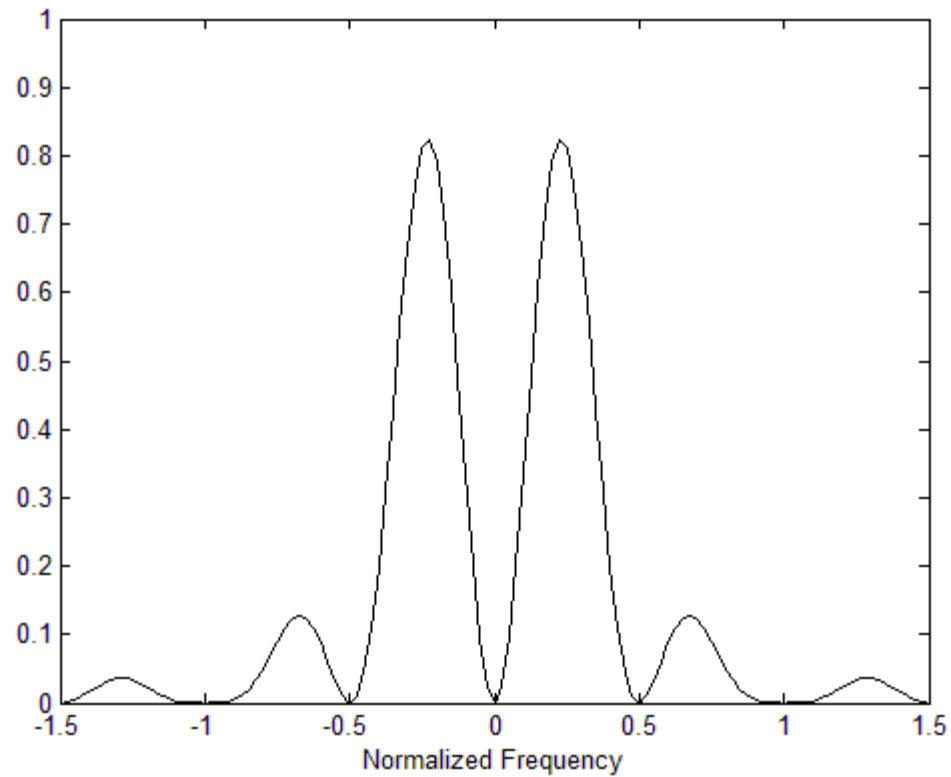
PSD of BiPolar/ AMI NRZ Signalling:

Figure. PSD of BiPolar NRZ

BiPolar Signalling

BiPolar / AMI NRZ:

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.
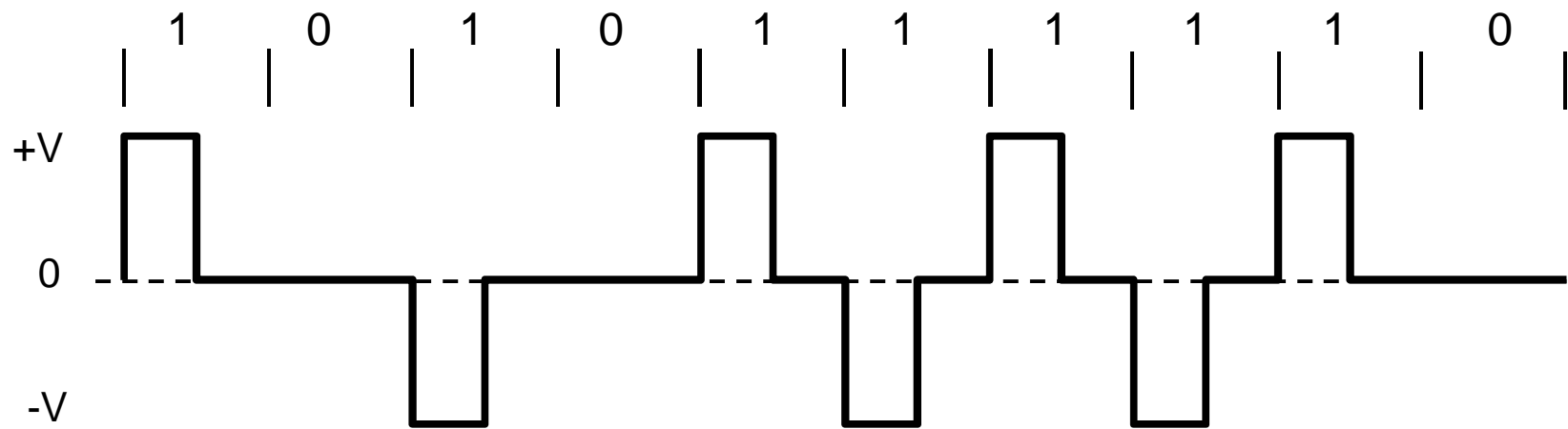- – Is not Transparent.

BiPolar Signalling

Figure. BiPolar RZ

Polar Signalling

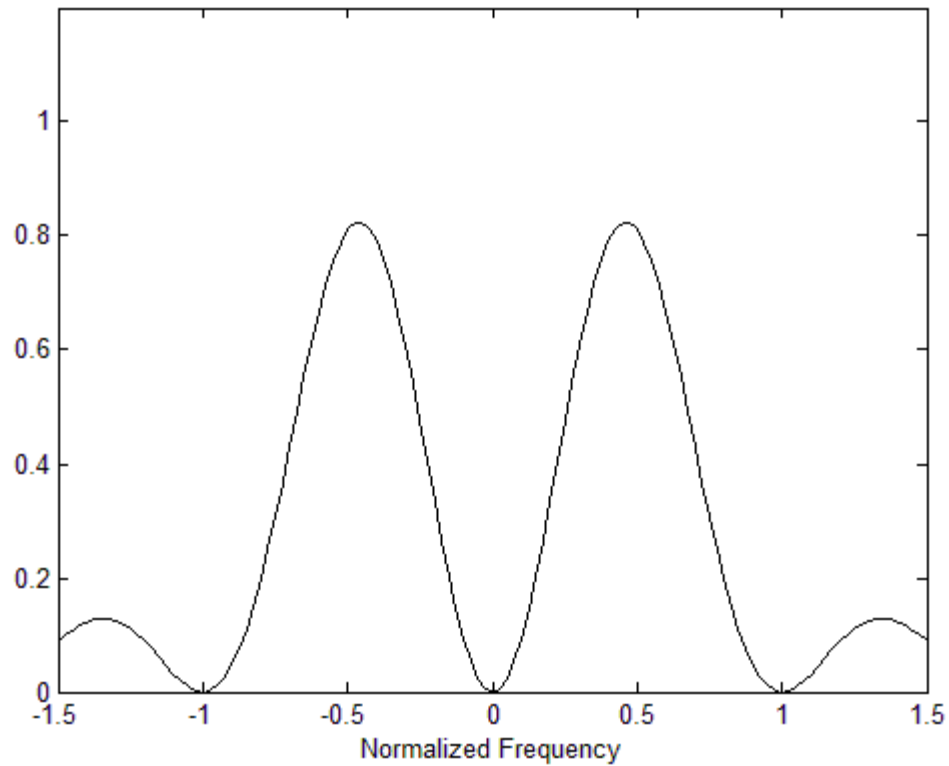**PSD of BiPolar/ AMI RZ Signalling:**

Figure. PSD of BiPolar RZ

BiPolar Signalling

BiPolar / AMI RZ:

Advantages:

- No DC component.

- Occupies less bandwidth than unipolar and polar RZ schemes.

- Does not suffer from signal droop (suitable for transmission over AC coupled lines).

- Possesses single error detection capability.

- Clock can be extracted by rectifying (a copy of) the received signal.

Disadvantages:

- Is not Transparent.

HDB*n* Signalling

HDB*n* is an enhancement of Bipolar Signalling. It overcomes the transparency problem encountered in Bipolar signalling. In HDB*n* systems when the number of continuous zeros exceeds *n* they are replaced by a special code.

The code recommended by the ITU-T for European PCM systems is HDB-3 (i.e. *n*=3).

In HDB-3 a string of 4 consecutive zeros are replaced by either **000V** or **B00V**.

Where,
       'B' conforms to the Alternate Mark Inversion Rule.
   'V' is a violation of the Alternate Mark Inversion Rule

HDB*n* Signalling

The reason for two different substitutions is to make consecutive Violation pulses alternate in polarity to avoid introduction of a DC component.

The substitution is chosen according to the following rules:
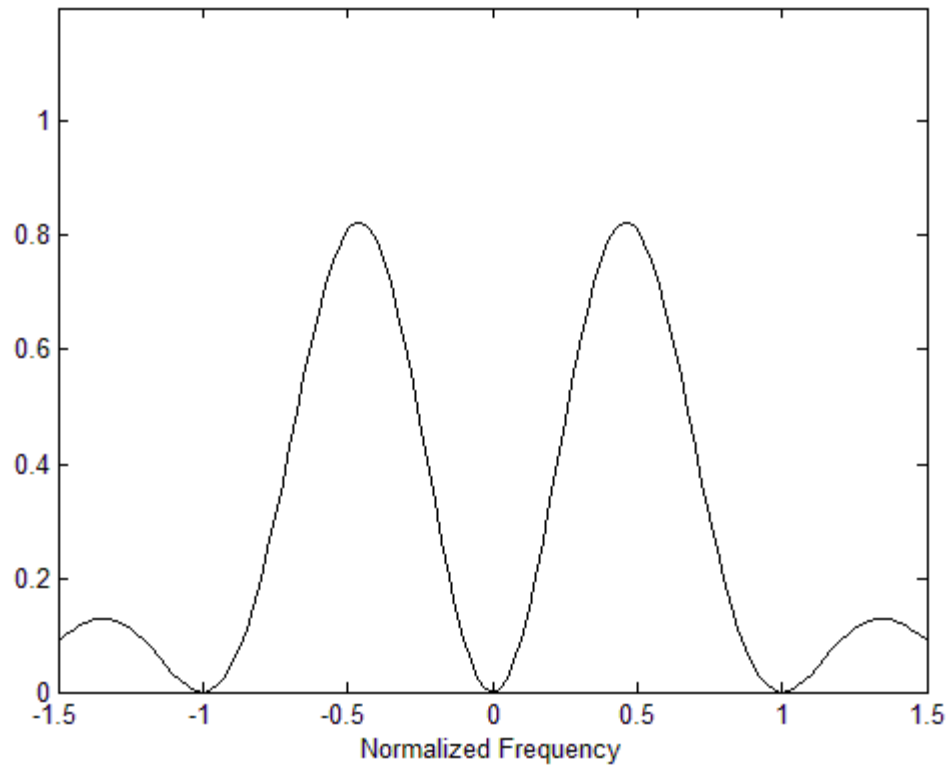
1.   If the number of nonzero pulses after the last substitution is odd, the substitution pattern will be **000V**.

2.   If the number of nonzero pulses after the last substitution is even, the substitution pattern will be **B00V**.

HDB*n* Signalling

1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0

B   0   0   V   0   0   0   V
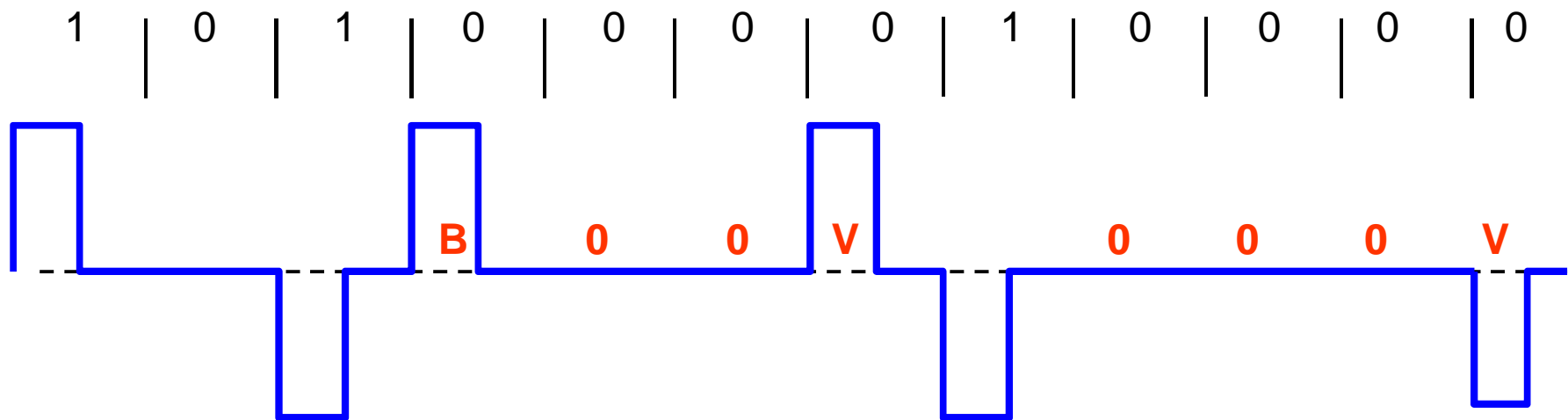
HDB*n* Signalling

PSD of HDB3 (RZ) Signalling:

The PSD of HDB3 (RZ) is similar to the PSD of Bipolar RZ.

Figure. PSD of HDB3 RZ

HDB*n* Signalling

HDB*n* RZ:

Advantages:

- No DC component.

- Occupies less bandwidth than unipolar and polar RZ schemes.

- Does not suffer from signal droop (suitable for transmission over AC coupled lines).

- Possesses single error detection capability.

- Clock can be extracted by rectifying (a copy of) the received signal.

- Is Transparent.

These characteristic make this scheme ideal for use in Wide Area Networks
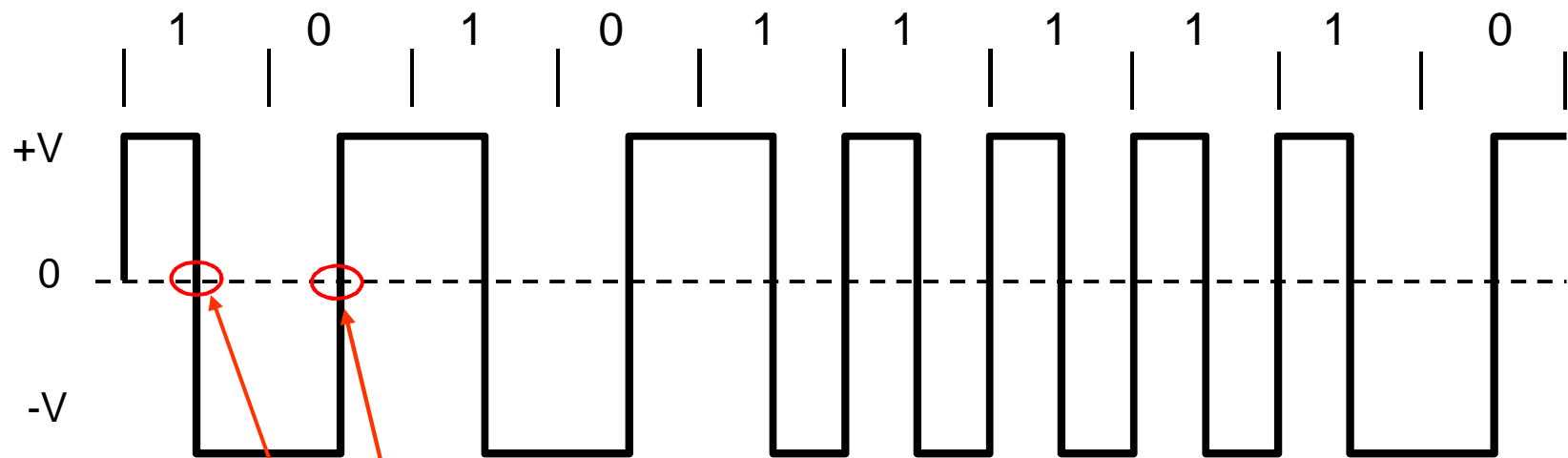
Manchester Signalling

In Manchester encoding , the duration of the bit is divided into two halves. The voltage remains at one level during the first half and moves to the other level during the second half.

A 'One' is +ve in 1st half and -ve in 2nd half.

A 'Zero' is -ve in 1st half and +ve in 2nd half.

Note: Some books use different conventions.

Manchester Signalling

Figure. Manchester Encoding.

Manchester Signalling
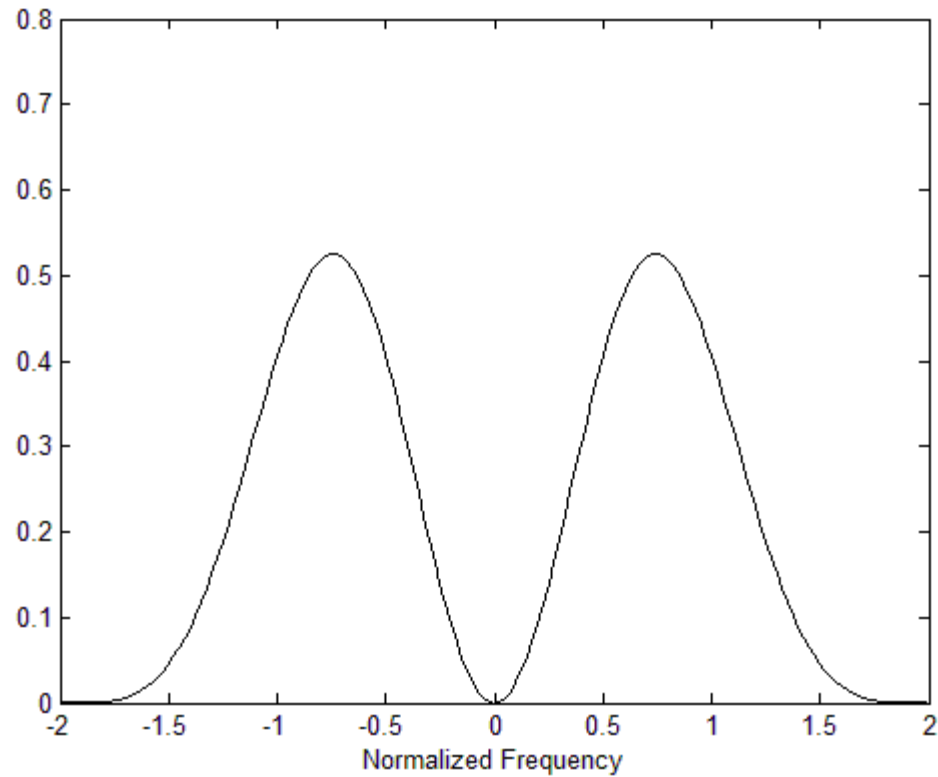
PSD of Manchester Signalling:

Figure. PSD of Manchester

Manchester Signalling

The transition at the centre of every bit interval is used for synchronization at the receiver.

Manchester encoding is called **self-synchronizing.** Synchronization at the receiving end can be achieved by locking on to the the transitions, which indicate the middle of the bits.

It is worth highlighting that the traditional synchronization technique used for unipolar, polar and bipolar schemes, which employs a narrow BPF to extract the clock signal cannot be used for synchronization in Manchester encoding. This is because the PSD of Manchester encoding does not include a spectral line/ impulse at symbol rate ($1/T_o$). Even rectification does not help.

Manchester Signalling

Manchester Signalling:

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

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

These characteristic make this scheme unsuitable for use in Wide Area Networks. However, it is widely used in Local Area Networks such as Ethernet and Token Ring.