LINE CODING

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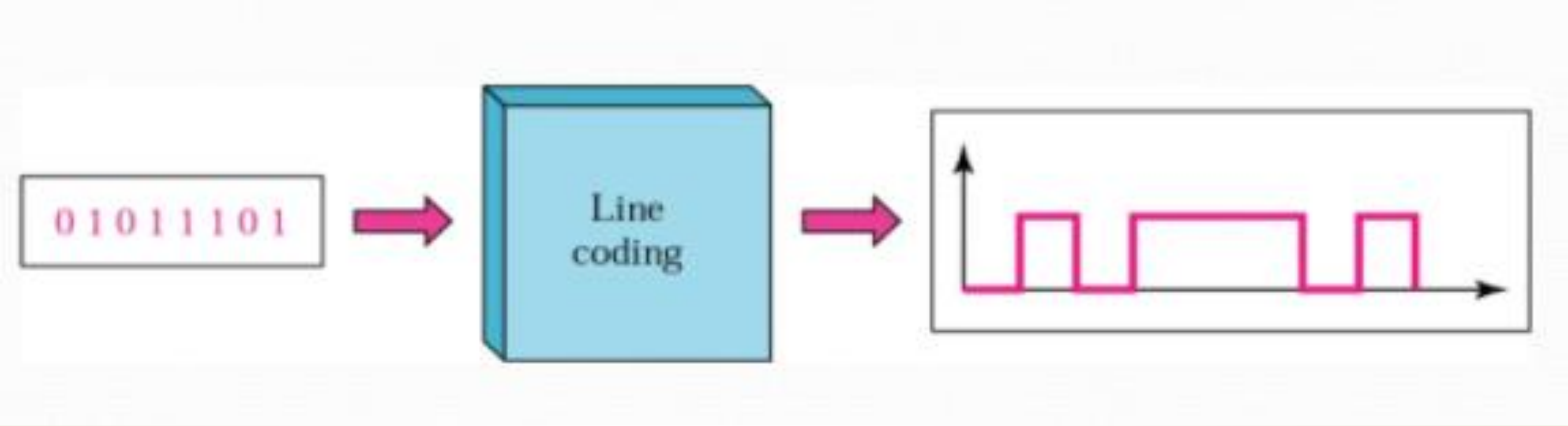
Digital to digital conversion (Line Coding)

- **Converting a sequence of data bits** (text, numeric, audio, or video) into a **digital signal, at the sender**, then recovering the original bit sequence from the signal, at the destination.



- There are many different line coding techniques**, ranging in complexity from very basic unipolar schemes** in which the **presence or absence of a voltage** is used to represent a binary one or a binary zero, to **highly sophisticated multilevel schemes** in which different signal amplitudes are used, each representing a unique grouping of binary digits.

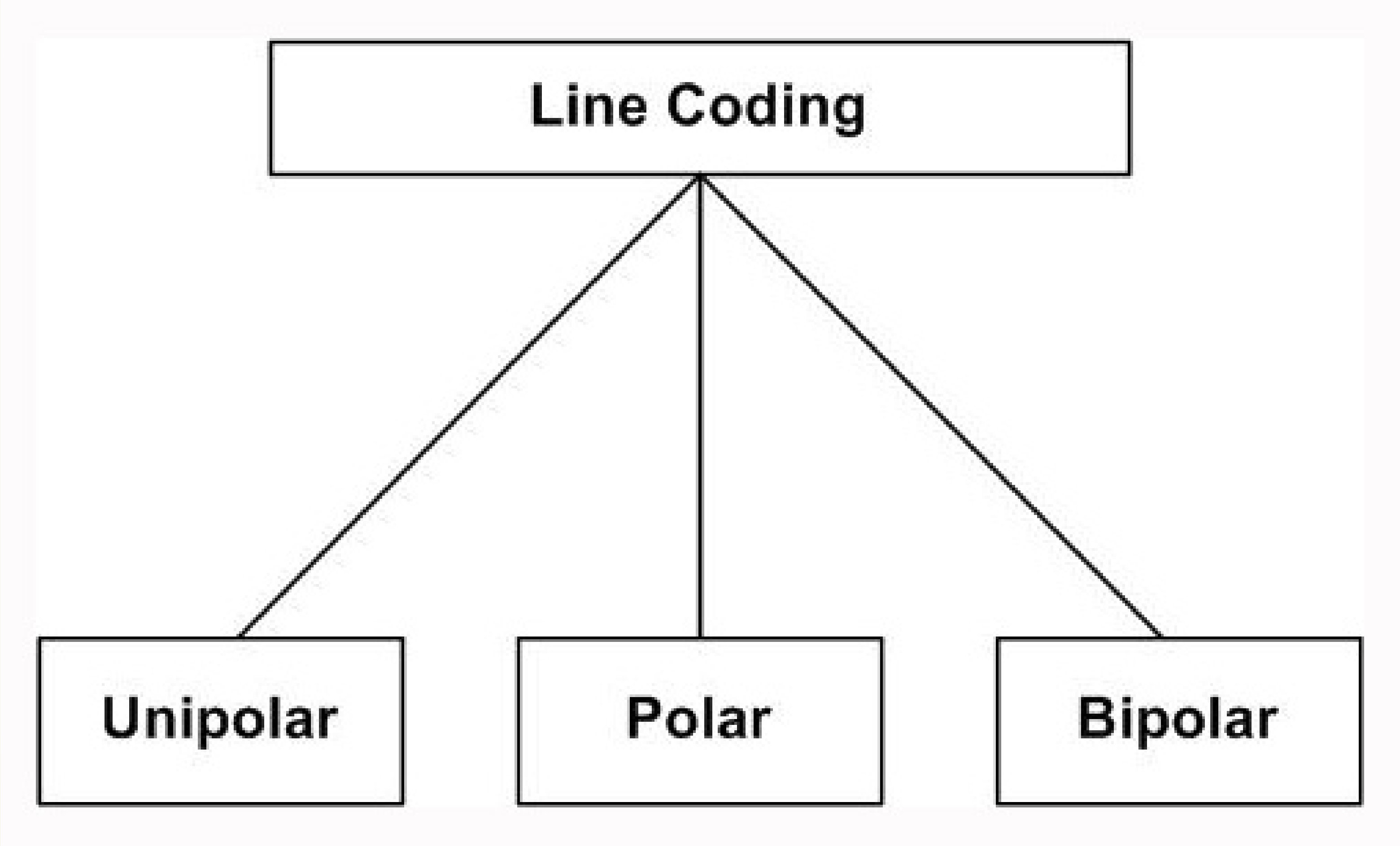
- The simplest line coding schemes are generally only used **for relatively low-speed asynchronous transmission,** in which data is sent in small independent blocks, and the receiver can resynchronise itself with the transmitter at the start of each incoming block.
- **For high speed synchronous applications** in which much larger blocks of information are transmitted, timing becomes far more critical, as do **factors such as noise and the potential presence in a signal of a net DC componen**t.
- The one thing that all line **coding schemes have in common is that they modify signal levels in some way in order to represent digital data.** In wired channels consisting of twisted-pair or coaxial cables, the line code **manipulates voltage or current levels** in order to generate electrical pulses that represent data values.
- In **optical fiber channels**, it represents the **data values by modifying the intensity of pulses of light.**

Properties (general characteristics) of Line Coding

- ***Minimal complexity*** - complex line coding schemes require sophisticated electronic circuitry in the transmitter to encode the digital data for transmission, and in the receiver to decode the incoming signal. The **complexity of the line coding scheme should therefore be kept to a minimum in order to reduce the cost and complexity** of transmitter and receiver hardware.
- ***Embedded clock signal*** - in most applications, it is impractical to provide a separate timing circuit between a transmitter and a receiver to maintain synchronization. **Since timing is absolutely critical for the reliable transmission of large amounts of data at high signaling rates, the timing information must be embedded in the signal itself** so that the receiver can extract the clock signal from the incoming bit stream.
- ***DC-balanced*** - if the data to be sent includes long strings of ones or zeros, **a zero-frequency DC component can develop in the transmitted signal**. This can lead to signal distortion at the receiver, especially if transmission elements are AC coupled, because the DC part of the signal will be blocked by transformers and capacitors. Energy will also be lost on the transmission line due to the wires being heated up by the direct current. **The line coding scheme should therefore be *DC-balanced***.
- ***Bandwidth limited*** - there are several reasons for wanting to limit the bandwidth of a baseband signal, not least of which **is to maximize the data signaling rate that can be used on a channel with limited bandwidth**. Another reason is that **higher frequencies tend to generate more electromagnetic radiation**, and are thus more likely to create crosstalk and interference.

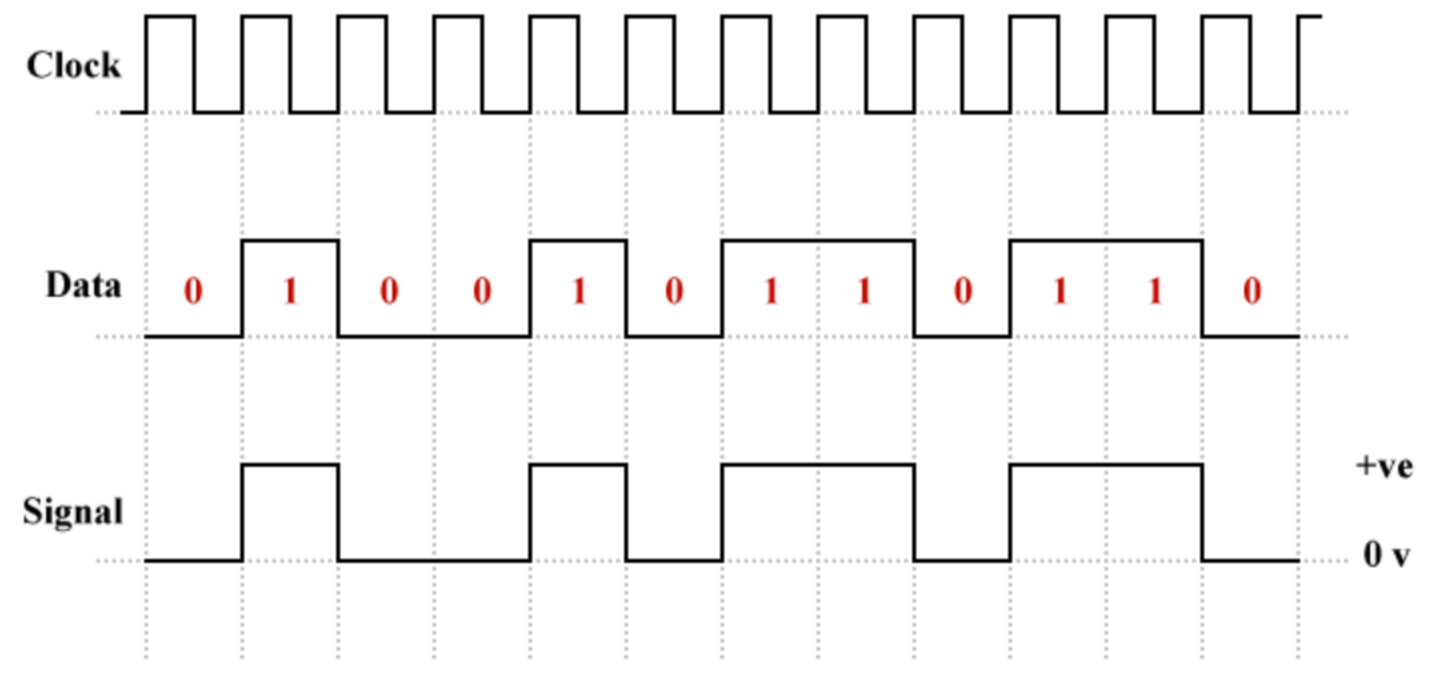
- ***Power efficiency*** - the transmitted signal power should be as low as possible for the required data rate and probability of error in order to make the most efficient use of power and minimize the amount of electromagnetic noise on the transmission line.
- ***Target spectral density*** - the *power spectral density* (PSD) is the distribution of power over the frequencies that make up the signal. The PSD of the transmitted signal should be compatible with the communication channel's frequency response. If the signal bandwidth (i.e. the frequency interval that contains most of the signal's power) is greater than that of the channel, the higher frequencies will be cut off, causing the signal to spread out in the time domain. This phenomenon is known as *pulse-spreading*, and can cause *inter symbol interference* (ISI), making it difficult for the receiver to decode the incoming signal correctly.
- ***Avoidance of baseline wandering*** - the **average signal-power at the receiver is used as a baseline reference against which the value of incoming data elements is determined**. The baseline may drift up or down over time if long strings of ones or zeros are transmitted, making it difficult for the receiver to decode the incoming signal correctly. **Most line coding schemes are designed to prevent this from happening.**
- ***Noise tolerance*** - the degree to which noise is a problem depends on the type of transmission medium over which the signal is being sent. Some line coding schemes are inherently more tolerant of noise than others, and thus present a better choice in noisy environments. *Baseline wandering* (see above) can also have an adverse effect on noise tolerance, since it can cause the receiver's detection threshold to drift closer to the noise floor.
- ***Error detection and correction*** - some line coding schemes have limited error detection and correction capabilities built right into the line coding scheme itself. Errors can also be avoided if there is enough timing information embedded in the signal to enable the receiver to sample the incoming signal at the right time intervals.

Three basic categories of line coding techniques



Unipolar - NRZ (non return to zero) No signal return to zero level at the mid of bit

In a unipolar signaling scheme, **all non-zero signaling elements have the same polarity** - **either they are all positive or they are all negative**. It is analogous to a **simple on-off keying scheme in which the presence of a voltage pulse signifies a binary one and the absence of a pulse signifies a binary zero**. It is also the simplest kind of line-code we will encounter. The **oldest unipolar line coding schemes are *non-return-to-zero* (NRZ) schemes in which the signal does not return to zero in the middle of the bit time.** A positive voltage represents a binary one, and a zero voltage represents a binary zero



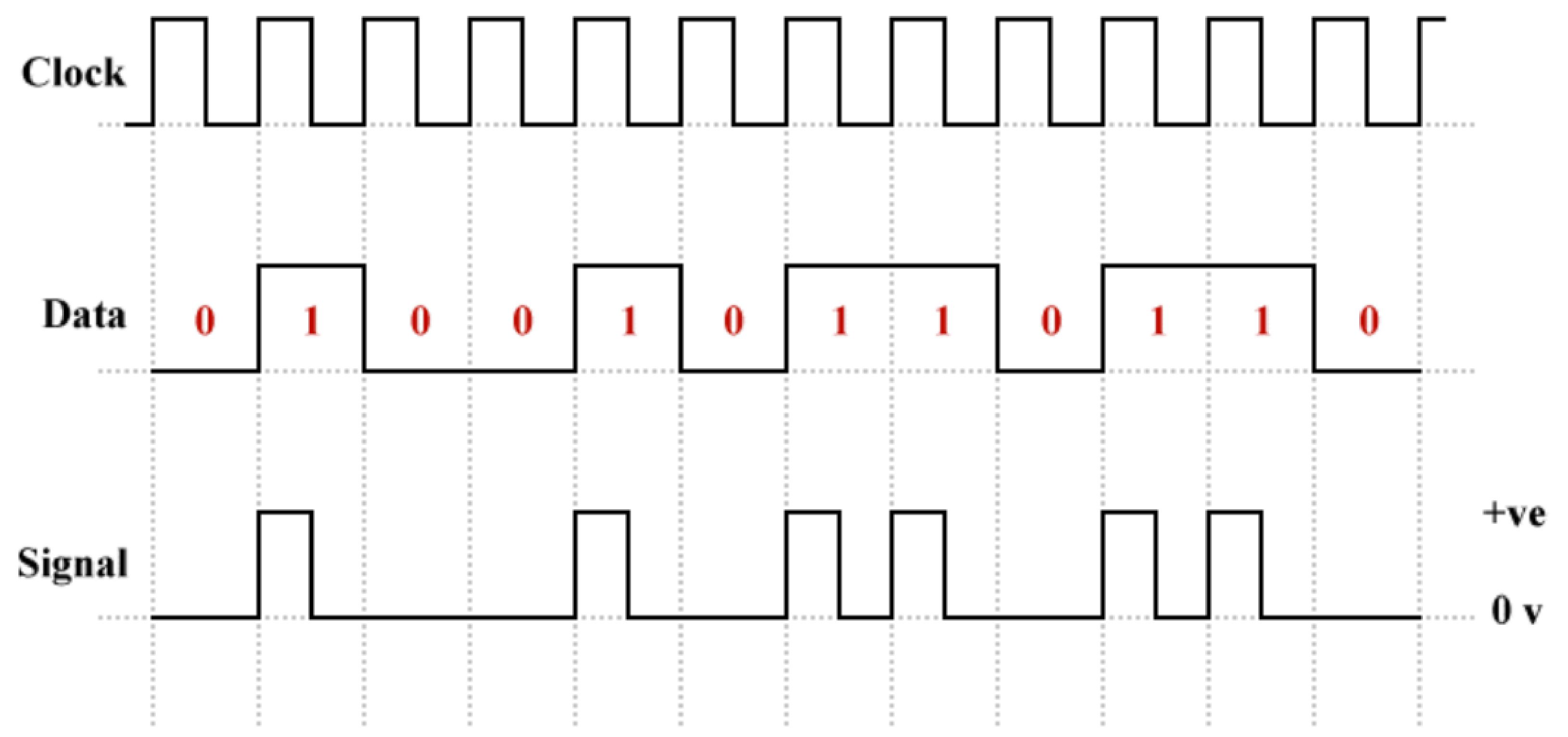
An example of unipolar non-return-to-zero (NRZ) line coding

- **The advantages of unipolar NRZ are:**
- Simple to implement.
- Requires relatively low bandwidth

- **The disadvantages of unipolar NRZ are:**
- **There is a significant DC component,** which means that **power is wasted due to heating of the wires in the transmission line**. It also means that channel links must be DC-coupled, because AC-coupled links will reject the signal's DC component.
- There is no mechanism for embedding a clock signal into the line code**. Long sequences of ones or zeros can cause loss of synchronization** at the receiver due to the absence of voltage transitions.

Unipolar – RZ (Return to zero) signal return to zero level at the mid of bit

There is also a ***return-to-zero*** **(RZ) version of unipolar line coding** in which the ***logic high*** **(binary one) signal voltage returns to zero half way through the bit time**.



An example of unipolar return-to-zero (RZ) line coding

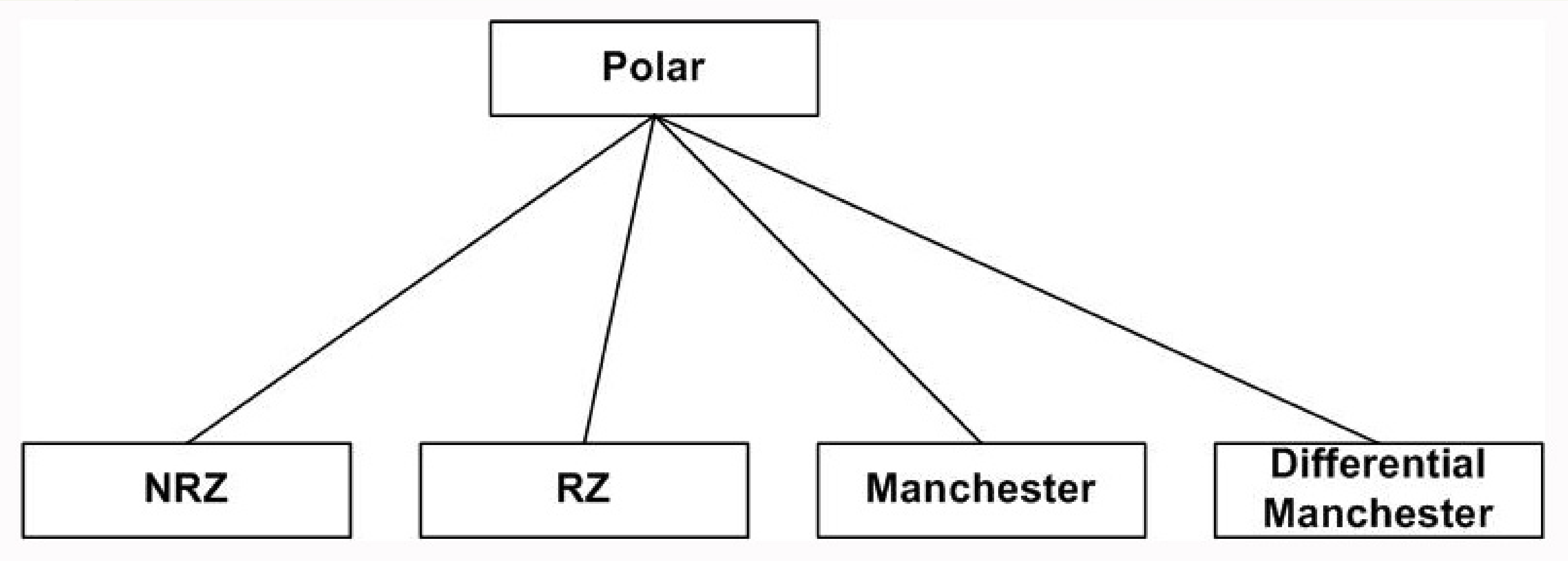
- **The advantages of unipolar NRZ are:**
- Simple to implement.
- The additional transitions can help to maintain synchronisation.
- The DC component is half that of unipolar NRZ.

- **The disadvantages of unipolar NRZ are:**
- Requires twice as much bandwidth as unipolar NRZ.
- Long sequences of zeros can still cause loss of synchronisation at the receiver.
- There is still a significant DC component, so some power is still wasted and AC coupling is still a problem.

In addition to their other disadvantages, neither unipolar NRZ nor unipolar RZ include any error detection or correction capability.

Polar

Polar encoding technique uses **two voltage levels** – one **positive** and the other one **negative. Basically,** Four different encoding schemes shown in the Figure.



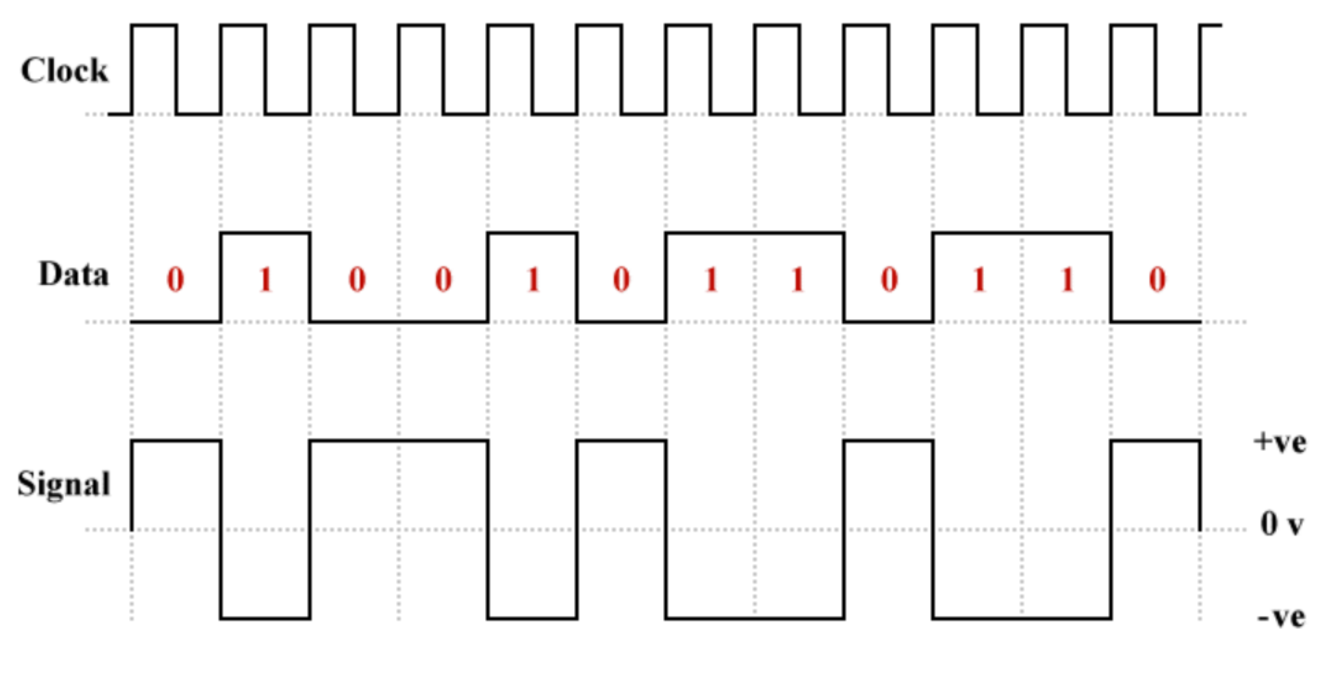
Polar line coding schemes use both positive and negative voltage levels to represent binary values.

Like the unipolar line coding schemes described above, polar signaling has both NRZ and RZ versions.

For polar line coding, however, there are two different kinds of NRZ scheme.

NRZ-level (NRZ-L)

Here, the **voltage level determines the value of a bit.** Typically, ***logic low* (binary zero) is represented by a positive voltage** while ***logic high* (binary one) is represented by a negative voltage**



An example of polar NRZ-level (NRZ-L) line coding

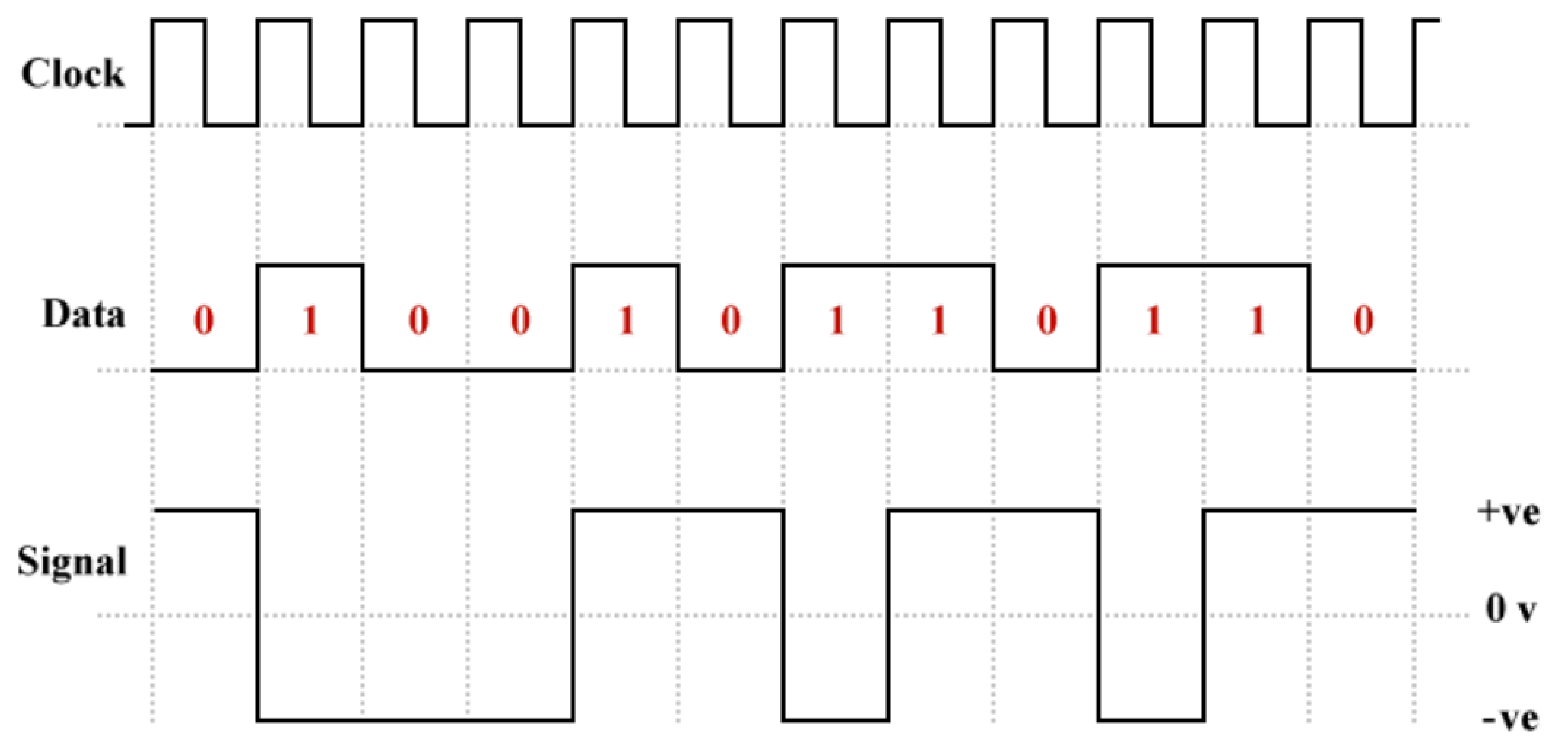
NRZ – L

1 = low level (-ve Voltage)

0 = high level (+ve Voltage)

NRZ-invert (NRZ-I)

- Here, the value of a bit is determined by the **presence or absence of a transition from a positive voltage to a negative voltage**, or **vice versa**.
- **A transition signals that the next bit is a logic high (binary one),** while **no transition signals a logic low (binary zero).**



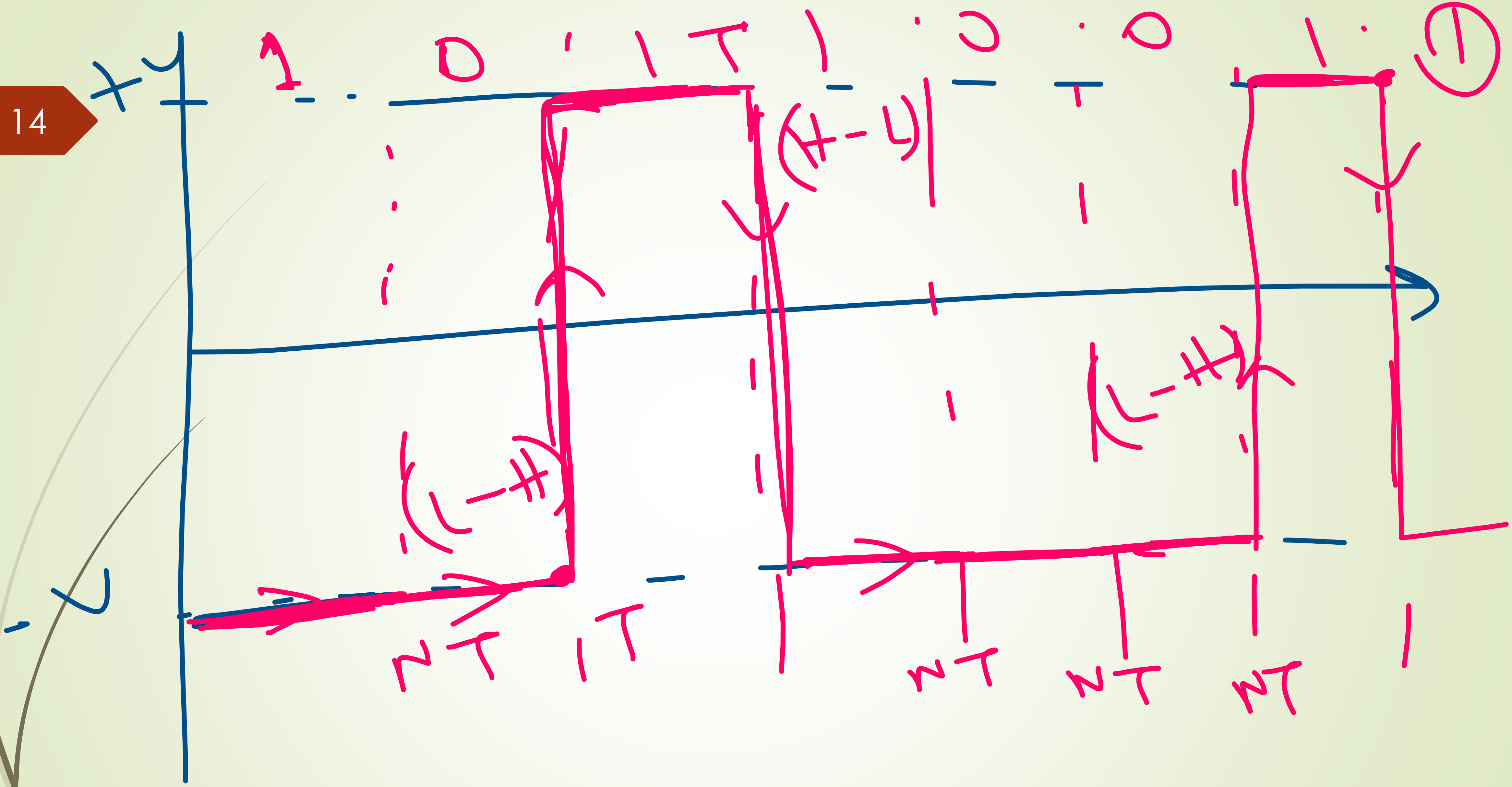
An example of polar NRZ-invert (NRZ-I) line coding

NRZ – I

• For each 1 in the bit sequence, the signal level is inverted.

• A transition from one voltage level to the other represents a 1.

No transition in o bit.


+V
-V
1
0
1
1
0
0
1
(H-L)
(L-H)
(L-H)
NT
IT
NT
NT
NT

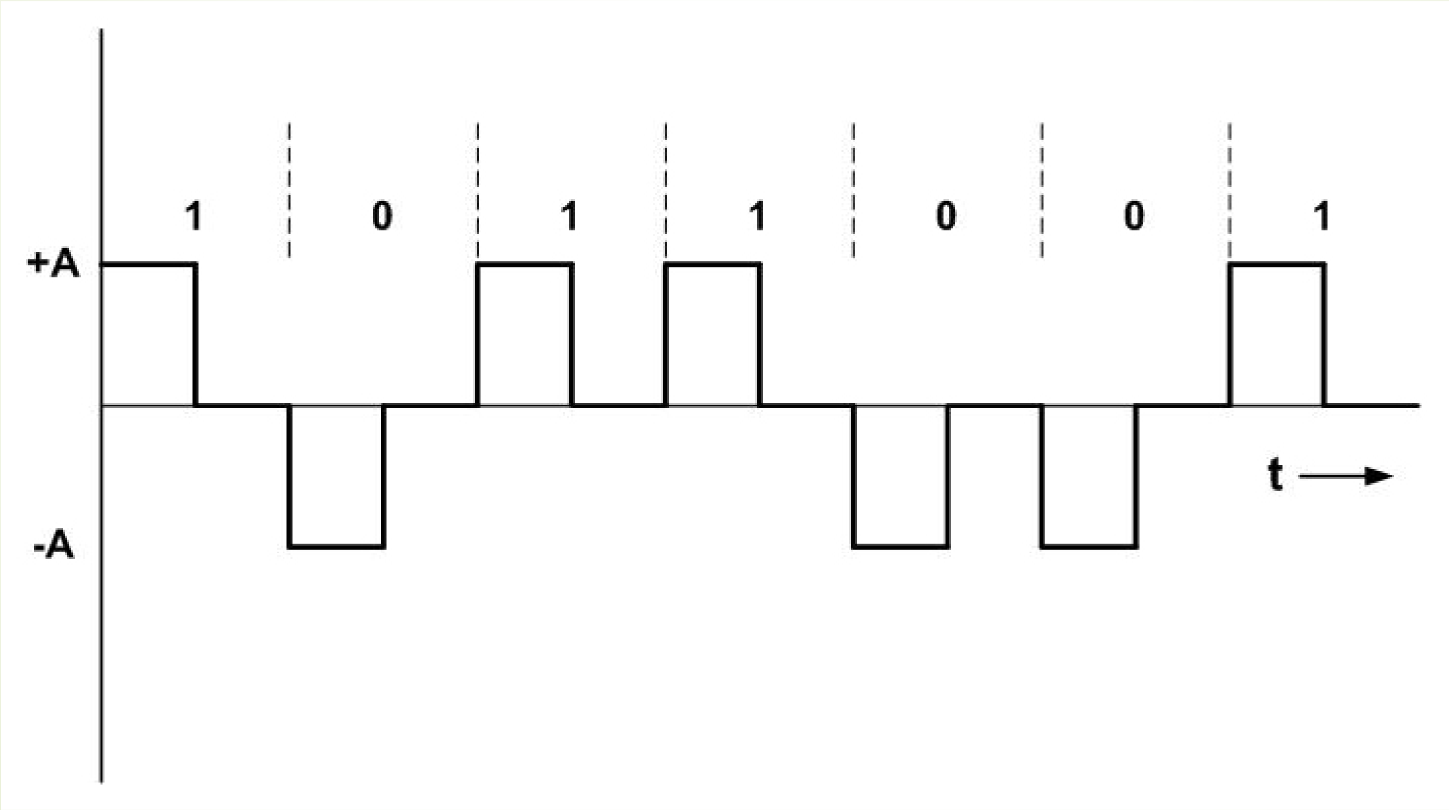
- **The advantages of unipolar NRZ are:**
- Relatively simple to implement.
- Requires relatively low bandwidth.

- **The disadvantages of unipolar NRZ are:**
- Neither polar-NRZ-L nor polar NRZ-I are DC balanced, although the DC component will be negligible for polar NRZ-L if the number of ones and zeros is approximately the same.
- There is no mechanism for embedding a clock signal into the line code. Long sequences of zeros can cause loss of synchronisation at the receiver in both polar NRZ-L and polar NRZ-I due to the absence of voltage transitions, and for long sequences of ones in Polar NRZ-L for the same reason.
- Baseline wandering (see above) is a problem for both polar NRZ-L and polar NRZ-I when long sequences of zeros occur. The effect is twice as likely to occur in polar NRZ-L, where long sequences of ones can also cause baseline wandering.

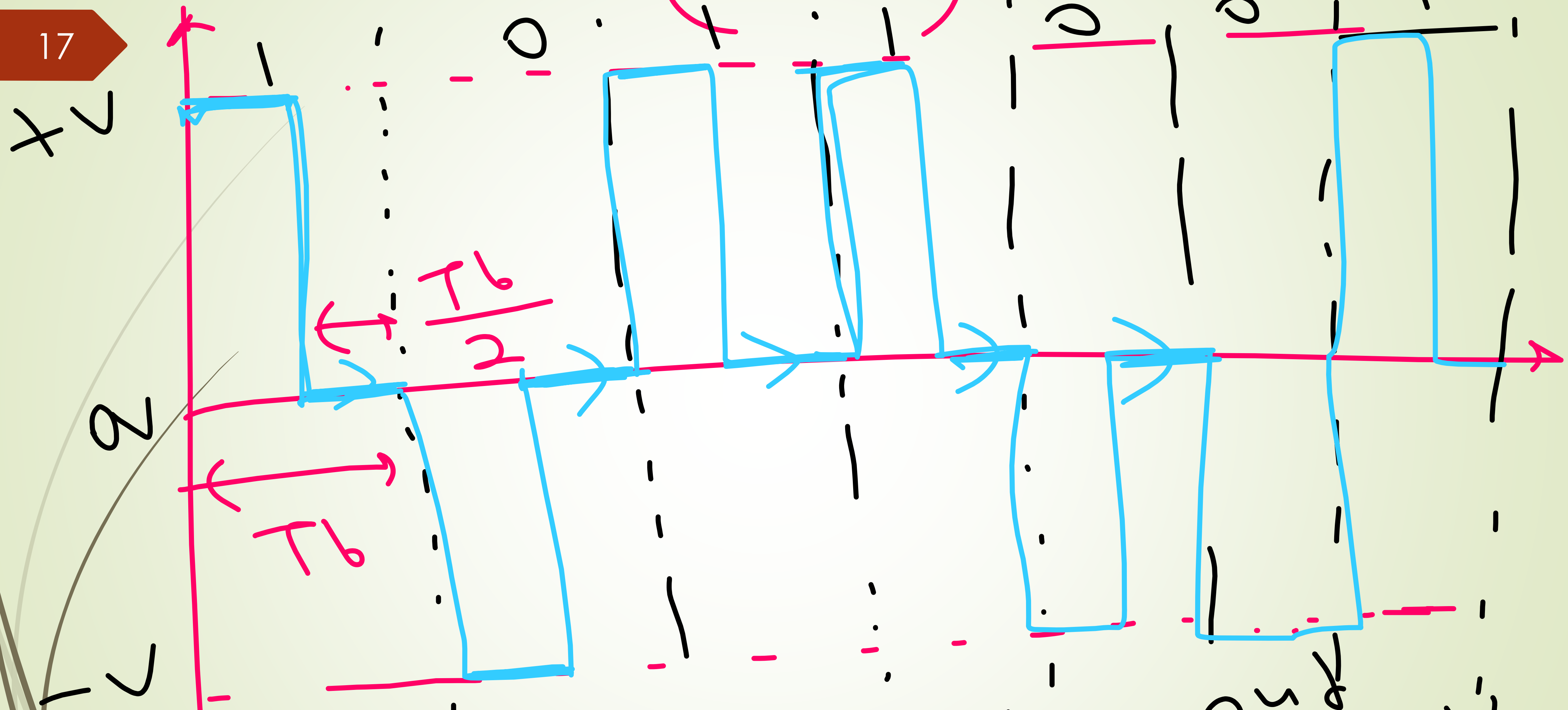
In addition to their other disadvantages, neither unipolar NRZ nor unipolar RZ include any error detection or correction capability.

Polar Return to Zero - RZ

- Polar RZ is the **return-to-zero form of polar line coding**. Some of the problems relating to polar NRZ line coding schemes are mitigated here through the use of three signaling levels.
- It is still the case that (typically) **logic low is represented by a negative voltage** and **logic high is represented by a positive voltage**, but in both cases the signal level returns to zero half way through the bit time and stays there until the next bit is transmitted



polar (R-Z)



① → 1st half (+V) → 2nd → 0V

0 → " " (−V) → 0

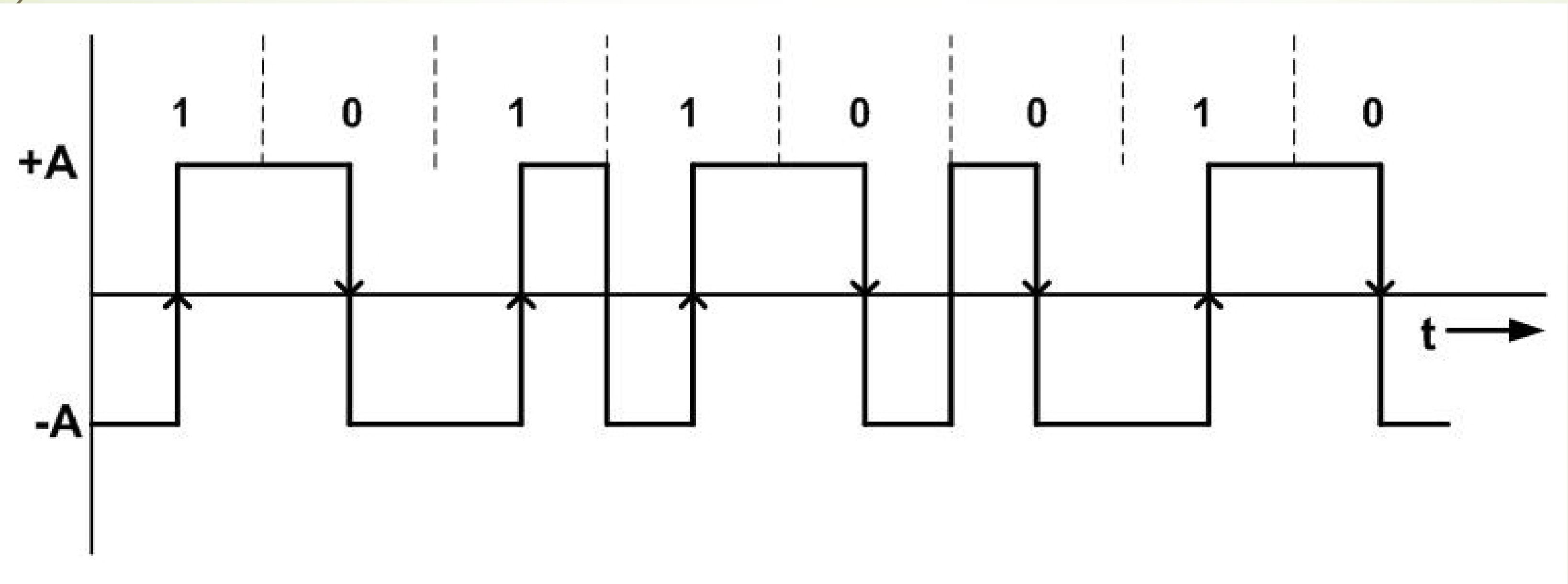
- **The advantages:**
- Relatively easy to implement.
- Uses less power than polar NRZ-L or polar NRZ-I.
- Transitions in the middle of each bit time enable the receiver to re-synchronise itself.

- **The disadvantages:**
- Greater complexity than polar NRZ-L or polar NRZ-I.
- Not DC balanced, although the DC component will be negligible if the number of ones and zeros is approximately the same.
- Requires twice as much bandwidth as either polar NRZ-L or polar NRZ-I.

Manchester

In the standard Manchester coding **there is a transition at the middle of each bit period**. A **binary 1 corresponds to a *low-to-high transition*** and a **binary 0 to a *high-to-low transition* in the middle**.

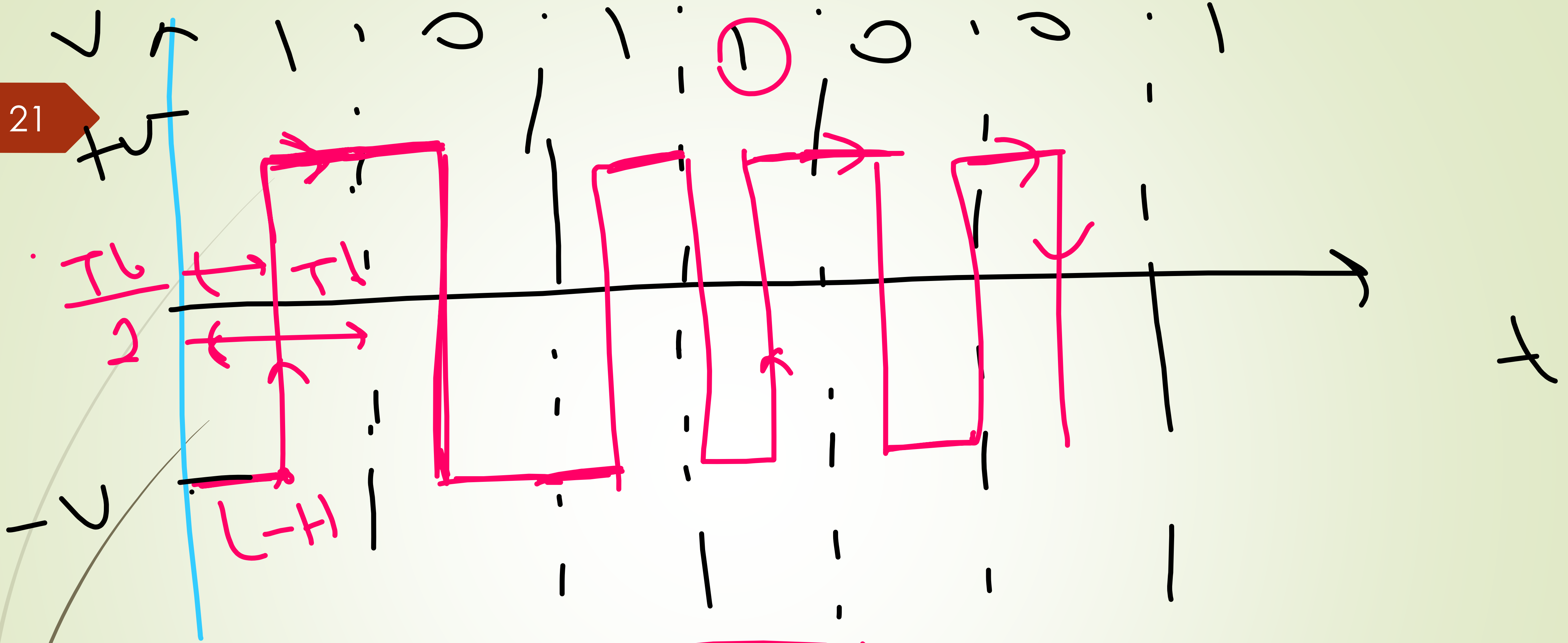
Manchester encoding is somewhat **combination of the RZ (transition at the middle of the bit) and NRZ-L schemes**. The duration of the bit is divided into two halves. The voltage remains at one level during the first half and moves to the other level in the second half. The transition at the middle of the bit provides synchronization.



- Because each bit consists of both a positive and a negative pulse, Manchester encoding is sometimes referred to as bi-phase encoding. As you can see from the illustration, for each pair of consecutive zeros or consecutive ones, an additional transition is required at the boundary between the two bits to maintain the correct sequence of transitions.

- There are similarities between Manchester encoding and both polar NRZ-L and polar RZ. Both polar NRZ-L and Manchester use two signal voltage levels, and both schemes feature a direct relationship between voltage state and logic state. The main difference is that polar NRZ-L uses a negative voltage to represent binary one and a positive voltage to represent binary zero, whereas Manchester uses a positive-to-negative transition to represent binary one and a negative-to-positive transition to represent binary zero.

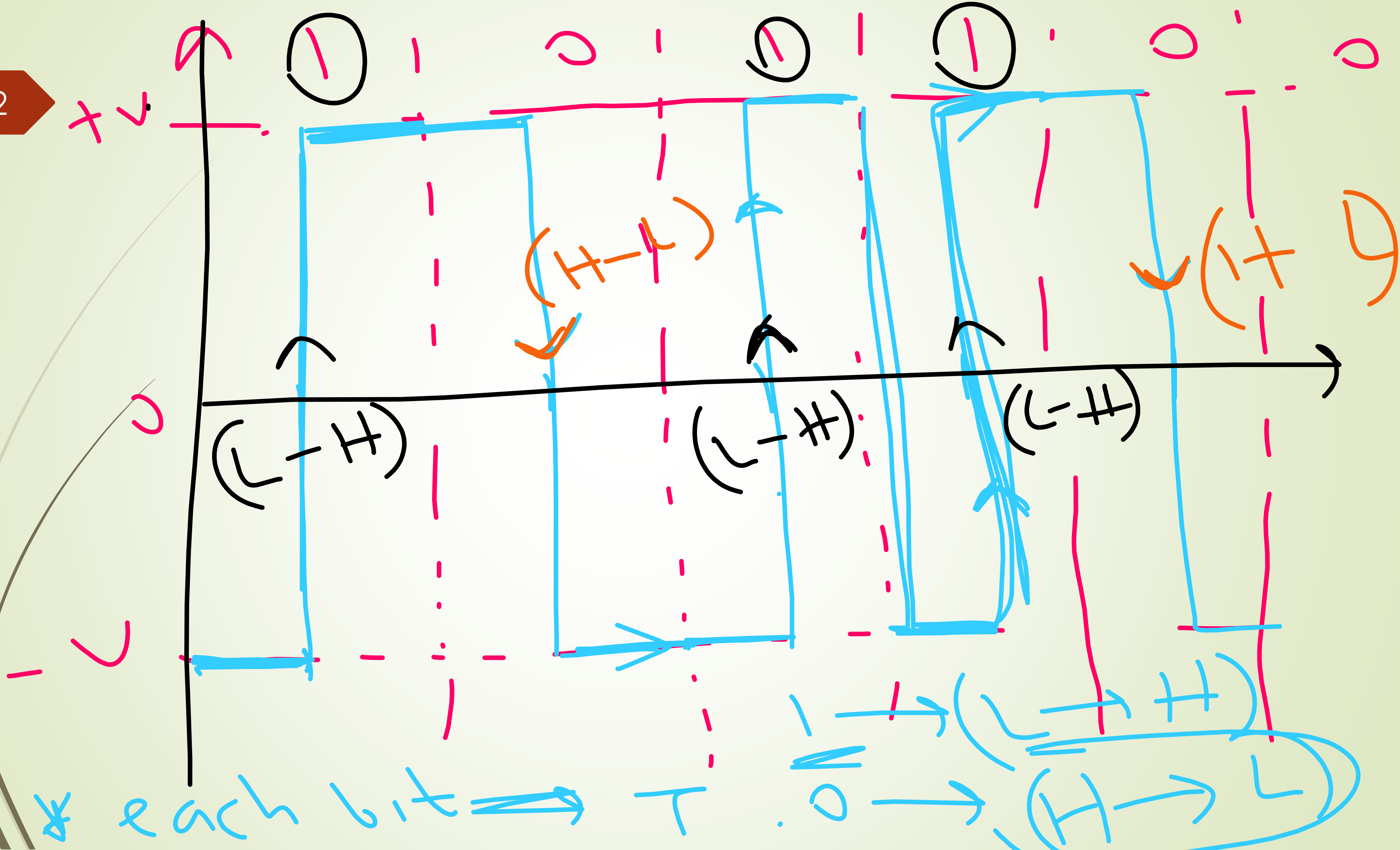
- Like polar RZ, Manchester encoding has a transition in the middle of every bit time. The main difference here is that, whereas the transitions in polar RZ all go from either positive or negative to zero volts, the transitions in Manchester go from positive to negative or from negative to positive. Note that there are actually two versions of Manchester encoding. The original scheme is as per the illustration above, and follows the convention first described by G. E. Thomas.



binary (1), L → H

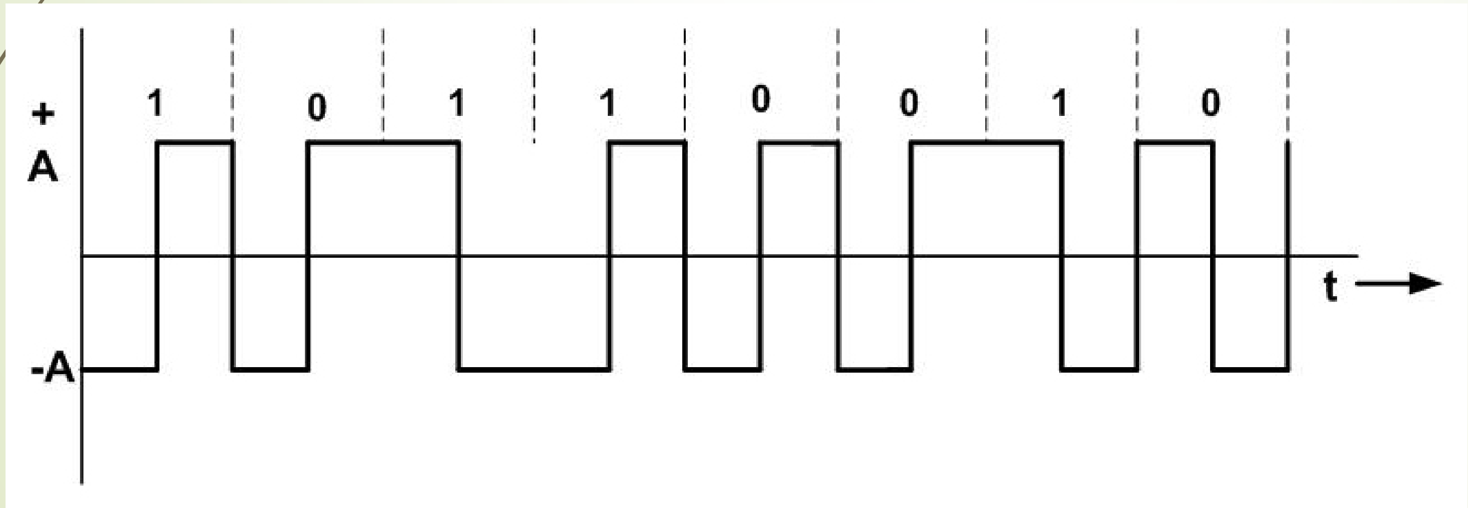
" 0 : H → L

⇒ middle of each bit (Transit


1 0 1 1 0
+v
0
-v
(L-H)
(H-L)
(L-H)
(L-H)
* each bit → T
1 → (L → H)
. 0 → (H → L)

Differential Manchester

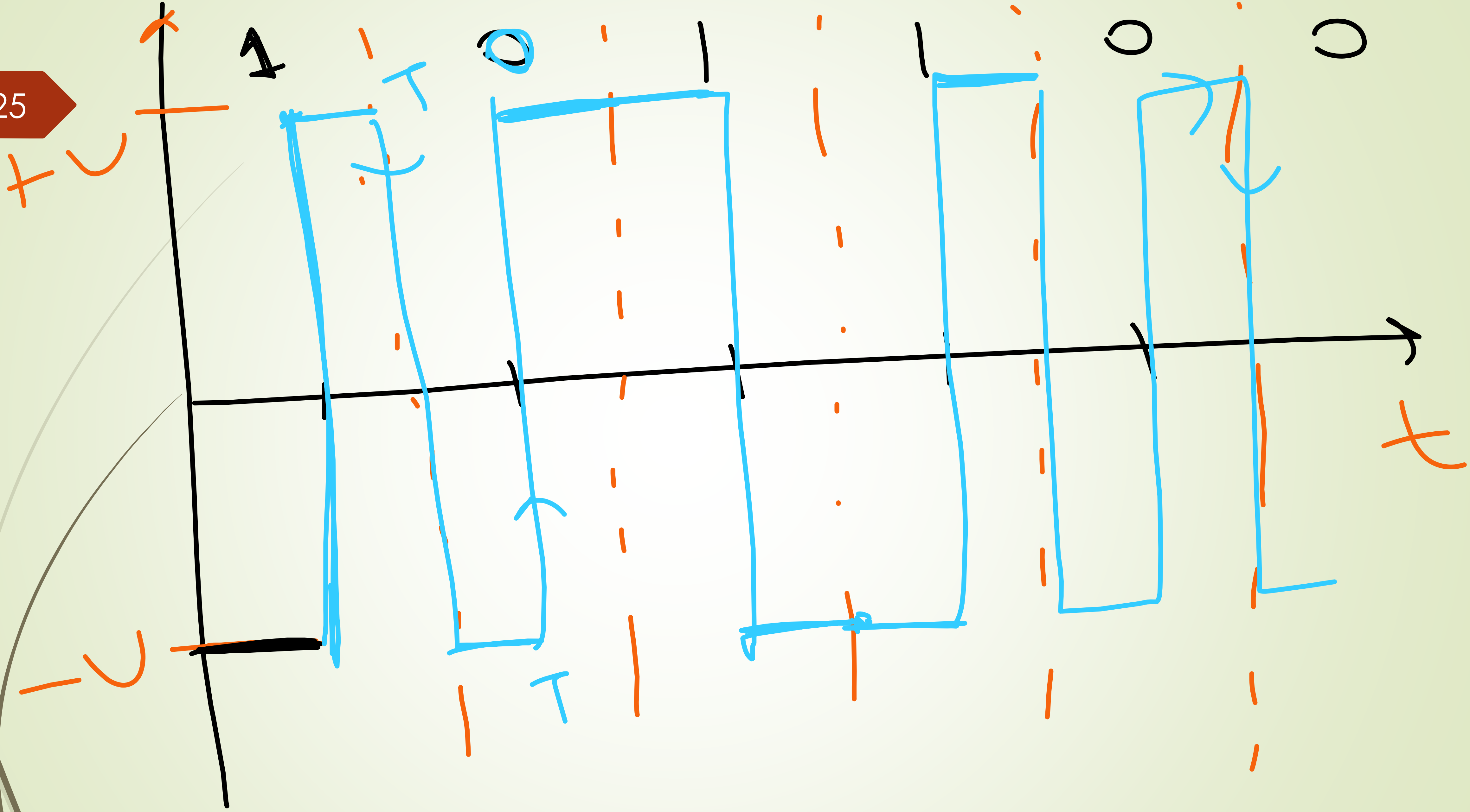
- In Differential Manchester, inversion in the middle of each bit is used for synchronization. **The encoding of a 0 is represented by the presence of a transition both at the beginning and at the middle** and 1 is represented by a **transition only in the middle of the bit period.**
- Differential Manchester is somewhat combination of the **RZ and NRZ-I schemes.** There is always a transition at the middle of the bit but the bit values are determined at the beginning of the bit. **If the next bit is 0, there is a transition, if the next bit is 1, there is no transition.**



ث man

ث 0 → ت at (begining + middle)

ث 1 → T - at middle

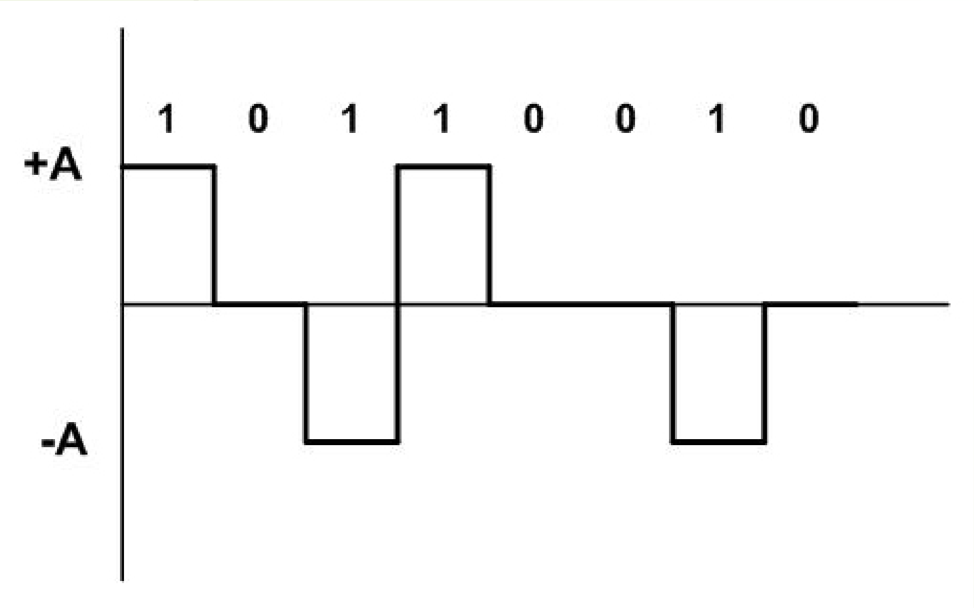

1
0
1
1
0
0
+U
−U
t
T
T

The Manchester scheme overcomes several problems associated with NRZ-L, and differential Manchester overcomes several problems associated with NRZ-I as there is **no baseline wandering** and **no DC component because each bit has a positive and negative voltage contribution**.

- Only limitation is that the minimum bandwidth of Manchester and differential Manchester is twice that of NRZ.

Bipolar

Bipolar AMI **(Alternate mark Inversion)** uses three voltage levels. Unlike in RZ, the zero level is used to represent a 0 and a binary 1's are represented by alternating positive and negative voltages.



The bipolar scheme is an alternative to NRZ. This scheme has the same signal rate as NRZ, but there is no DC component as one bit is represented by voltage zero and other alternates every time.