1

Encoding

Turning bits into signals for appropriate transmission

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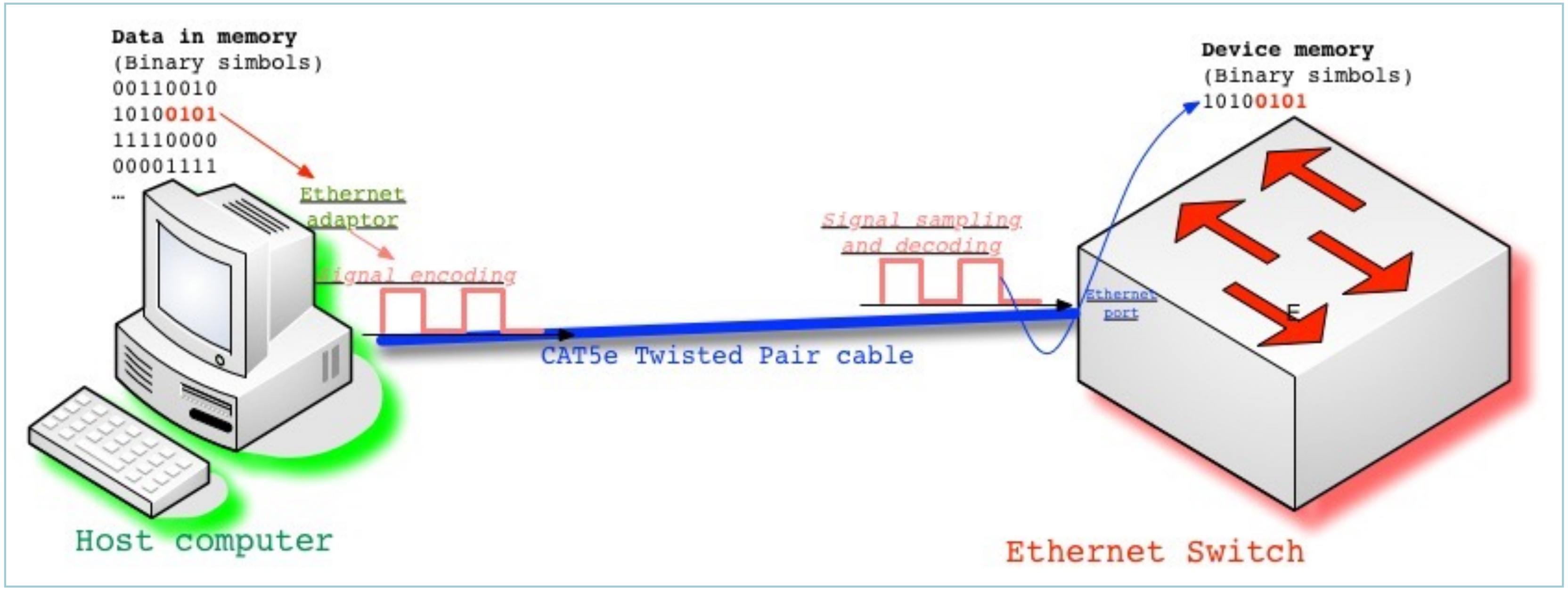
Line encoding: concept

- The data to be transmitted are stored in the host's memory
- Data bits must be translated into signals appropriate for the transmission media
  - There exist multiple ways of encoding a 0 bit and a 1 bit:
    - Line encoding techniques
  - An essential group signal waveforms is PCM:
    - Pulse Code Modulation



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Bit detection

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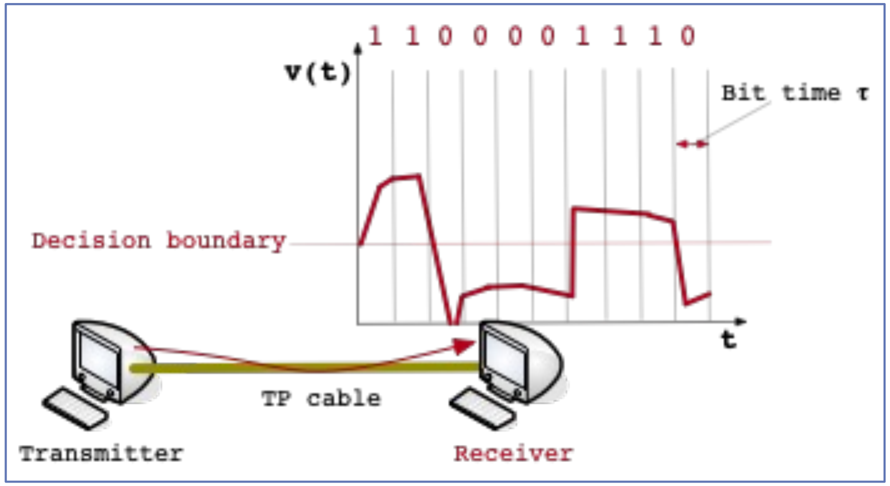
- Binary symbols 0 and 1 are assigned separate signals
- Usually, the voltage level of a signal that varies over time represents 0's and 1's
  - Level usually refers to the signal's voltage at each instant in time: v(t)
- Actually, signal level refers to a continuous range of voltages that is different from the range of voltages assigned to the other level
  - Distinguishing a high level from a low level reduces to establishing whether the signal's volatge is above or below a specific boundary: The decision boundary
  - Setting that boundary correctly is essential for the receiver's ability to correctly interpreting each received signal value
- The time dedicated to the reception of each bit is known as *bit time, τ*



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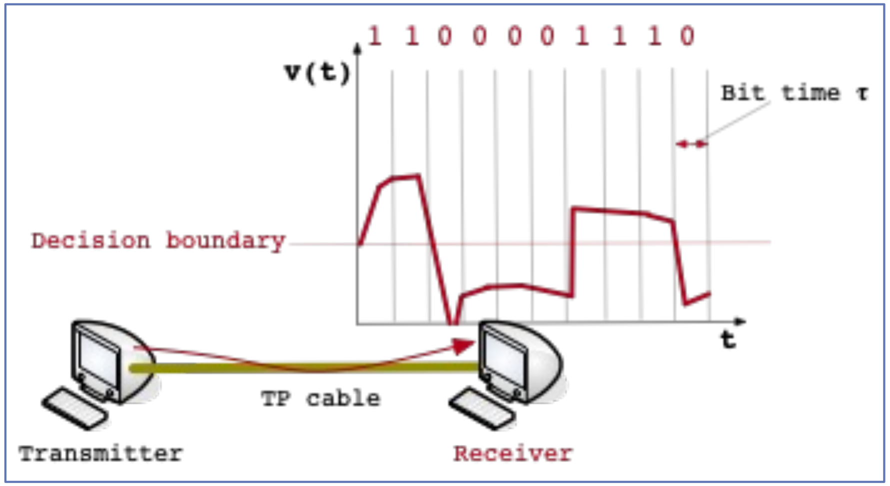
Encoding

- Translating bits into signals is known as encoding
- There exist **many** encoding schemes available
- All of them represent bits by using different **properties** of signals related with
  - Time t
  - Signal value v(t)
- NRZ-L
- NRZ-I
- Manchester
- In all cases, we pursue a detection technique that reliably returns the **correct bit value** (0 or 1)



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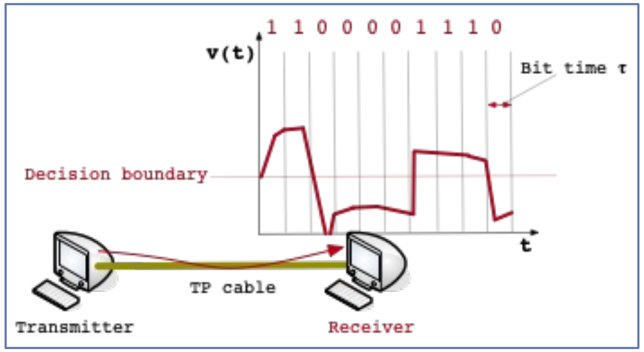
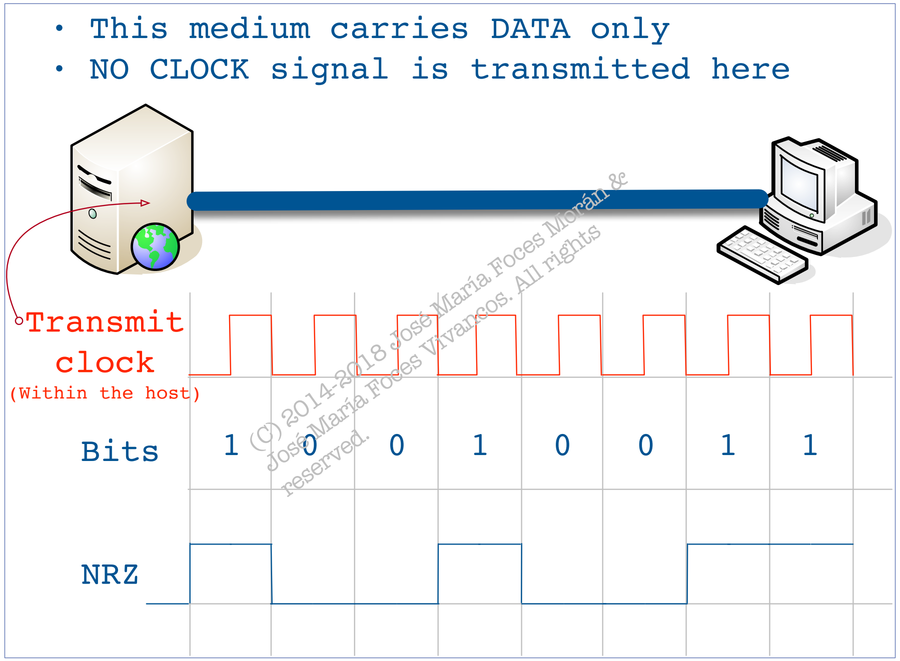
NRZ-L encoding (Non-Return to Zero Level)

- A binary 1 is assigned a level; a binary 0 is assigned the other level
  - Level usually refers to the signal's voltage at each instant in time: v(t)
  - Actually, signal level refers to a continuous range of voltages that is different from the range of voltages assigned to the other level
  - Distinguishing a high level from a low level reduces to establishing whether the signal's volatge is above or below a specific boundary
  - Setting that boundary correctly is essential for the receiver's ability to correctly interpreting each received signal value
  - Extensively used in the digital electronics lab





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Problems with NRZ-L

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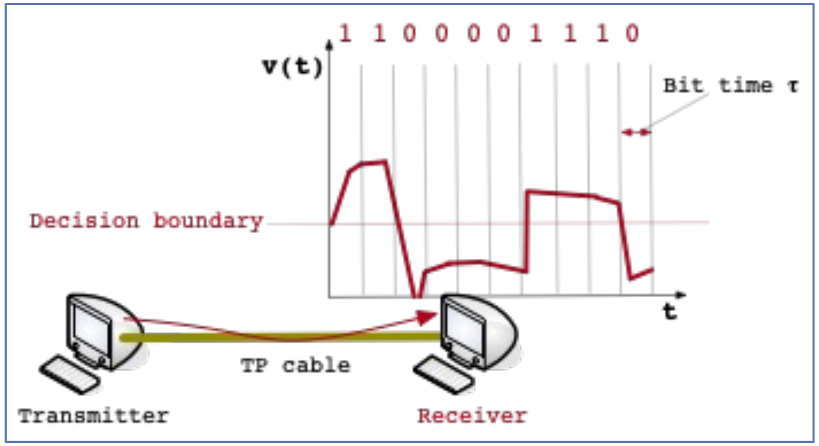
- Baseline wander
  - The **receiver keeps the average signal level** up until this moment
  - When a signal is significantly low than the average, it is interpreted as a low level, otherwise, it is interpreted as a high level
  - Too many consecutive 0's and 1's cause this average to bias, thereby making it more difficult to differentiate between the levels



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Problems with NRZ-L

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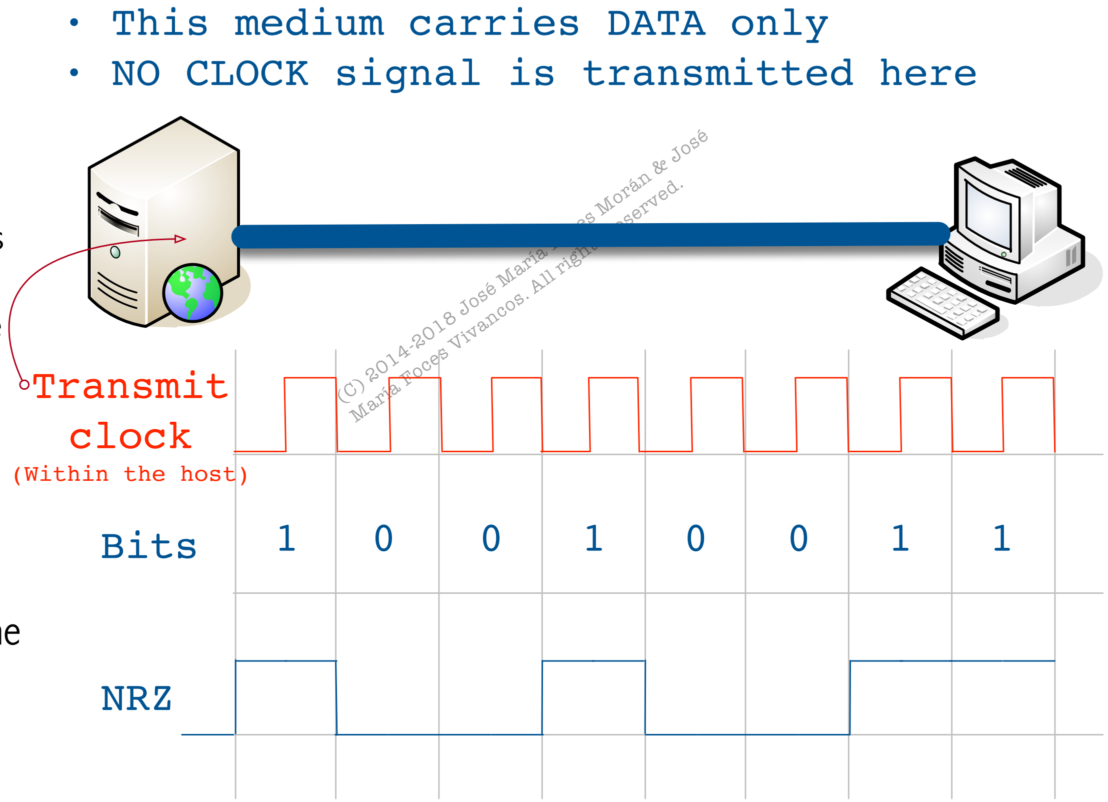
Clock recovery

- The transmitter sends symbols (0/1) at some transmission speed determined by an internal clock signal generated within the sender:
  - At every clock cycle, the sender transmits a new bit
  - In data communications, usually, the clock signal is not sent from sender to receiver
  - Then, how does the receiver become aware of the used transmission speed and of the clock edges that mark data (bits) as valid?
    - By having the transmitted signal carry the data alongside with frequent level changes which will help the receiver in recovering the clock signal used for transmission
- The receiver must be able to deduce the transmission speed from the signal containing the data
  - This entails frequent transitions from high to low and vice versa in the received data signal
  - This is known as clock recovery
  - Clock recovery yields a precise synchronization of sender and receiver



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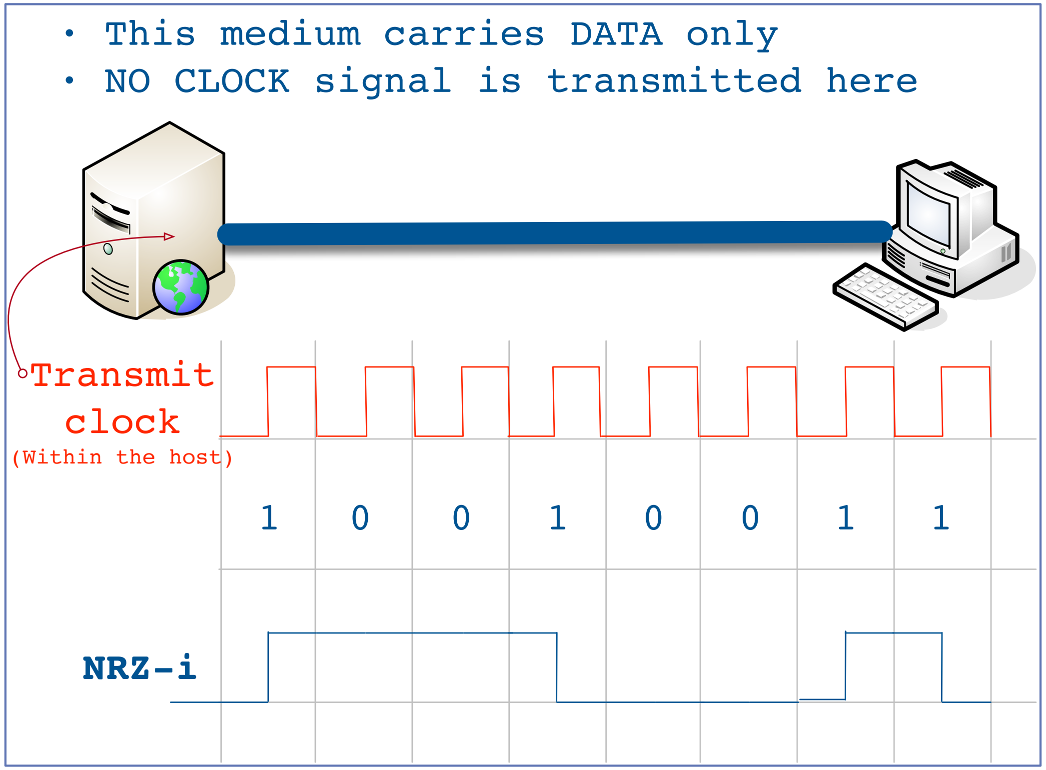
NRZ-i: a partial solution to NRZ

- A.K.A.: NRZ-M (Mark)
- Non Return to Zero Inverted
- Sender makes a transition from the current signal level to encode 1 and stays at the current signal level to encode a 0
- Solves for the consecutive 1's problem of NRZ



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Channel Encoding: 4B/5B

- It's a channel (block) encoding technique
- Performed by the transmitter before transmission, the sender inserts extra bits into bit stream so as to break up the long sequences of 0's
  - Every group of 4-bits of actual data are encoded into a 5-bit code which is transmitted to the receiver
  - 5-bit codes are selected in such a way that each one has
    - no more than one leading 0 (zero)
    - no more than two trailing 0's
    - `01100 Ok,` *`00111 Not ok, 11000 not ok`* …
  - No pair of 5-bit codes results in more than three consecutive 0's

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4B/5B table from Wikipedia

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Data (Hex)	Data (Binary)	4B5B code
0	0000	11110
1	0001	01001
2	0010	10100
3	0011	10101
4	0100	01010
5	0101	01011
6	0110	01110
7	0111	01111

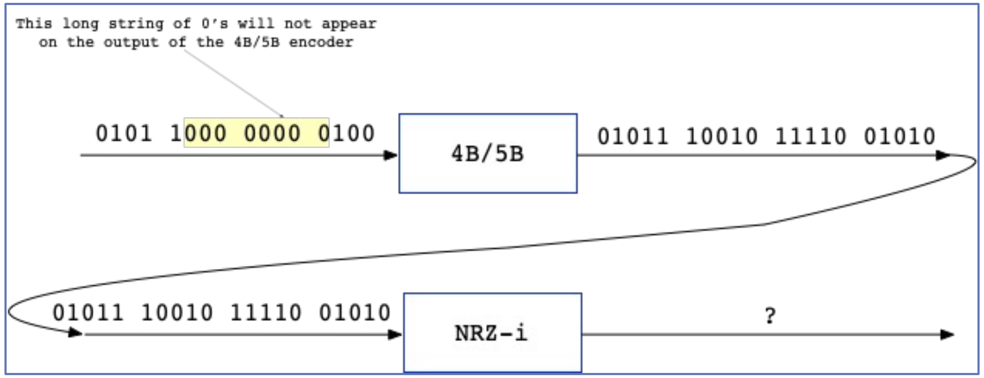
Data (Hex)	Data (Binary)	4B5B code
8	1000	10010
9	1001	10011
A	1010	10110
B	1011	10111
C	1100	11010
D	1101	11011
E	1110	11100
F	1111	11101

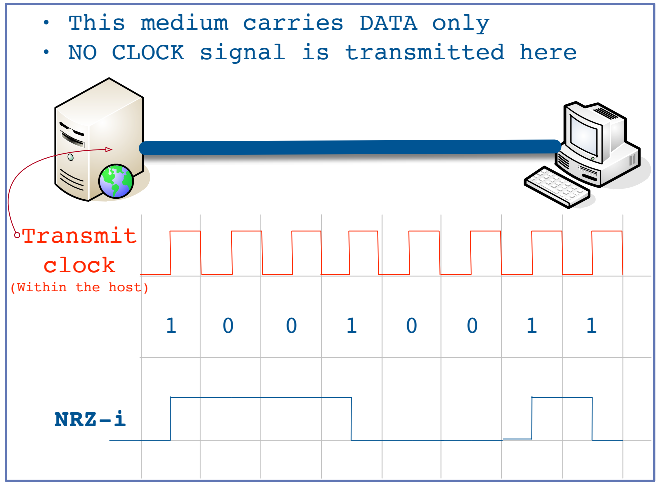
Symbol	4B5B code	Description
H	00100	Halt
I	111111	Idle
J	11000	Start #1
K	10001	Start #2
L	00110	Start #3
Q	00000	Quiet (loss of signal)
R	00111	Reset
S	11001	Set
T	01101	End (terminate)

Channel Encoding in the first place, then Line Encoding

- 4B/5B solves the problem of long sequences consecutive of 0's
- NRZI solves the problem of long sequences of consecutive 1's

- These encodings are used in tandem:
  - 4B/5B is applied first to the data to be transmitted
    - This is known as CHANNEL ENCODING
  - Then, the resulting bit stream is NRZI encoded
    - This is known as LINE ENCODING





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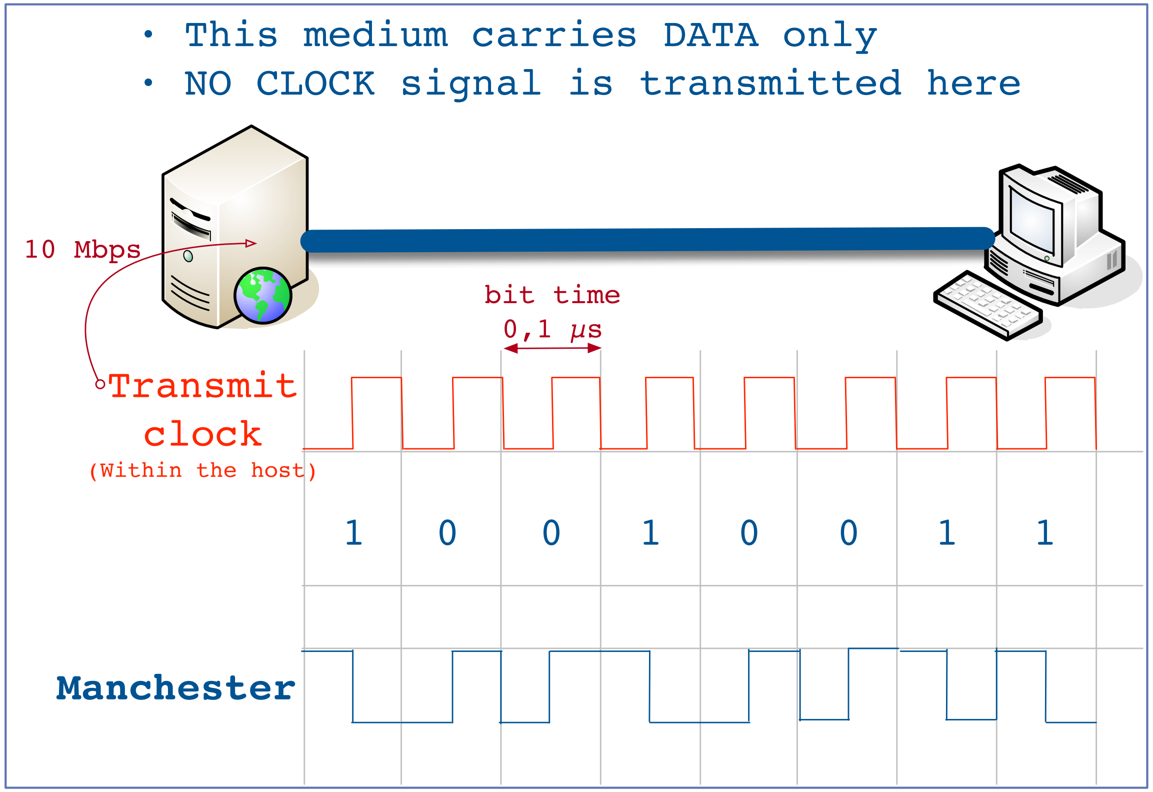
Manchester: complete solution to NRZ

- Strategy:
  - Merge the clock with signal by transmitting Ex-OR of the NRZ encoded data and the clock
  - Clock is an internal signal that alternates from low to high, a low/high pair is considered as one clock cycle
  - In Manchester encoding
    - 0: low→ high transition
    - 1: high→ low transition



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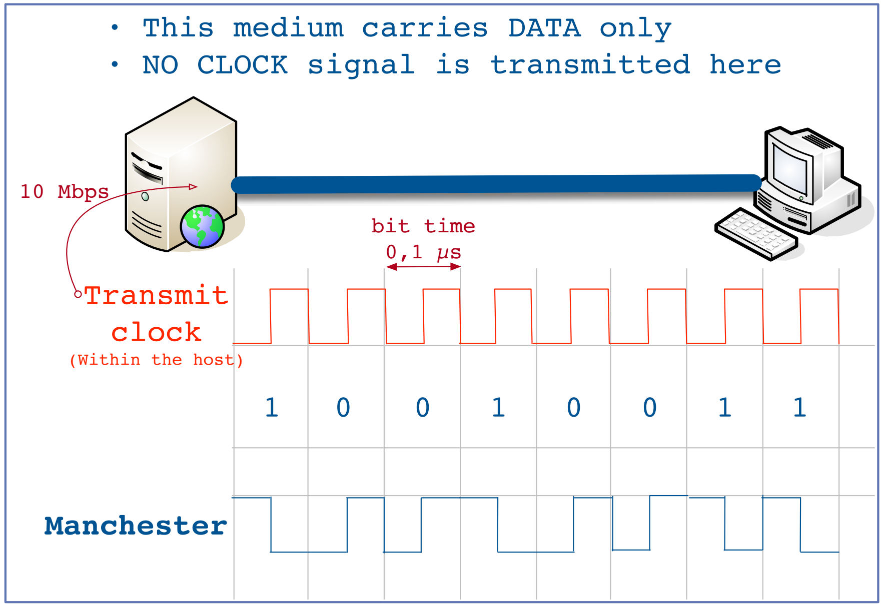
Manchester encoding problem

- Manchester doubles the rate of signal transitions present on the link
  - Which means the receiver has half of the time to detect each pulse of the signal
  - The rate at which the signal changes is called the link's **baud rate**
  - In Manchester the ***bit rate* is half the *baud rate***



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Communication theory, intro

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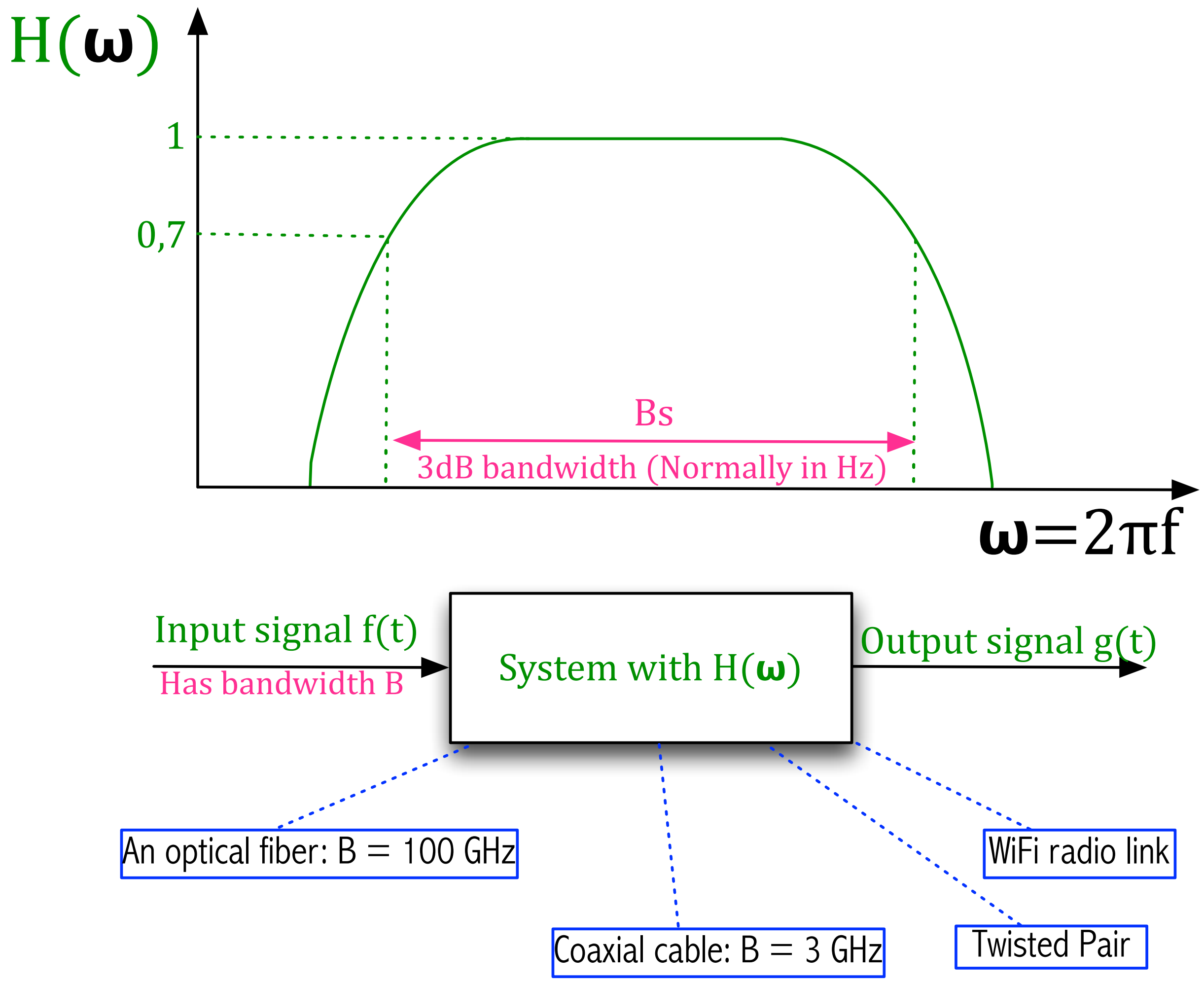
If link bandwidth is limited

- How can we determine our data **signal's bandwidth**?
- So that the link properly transmits it



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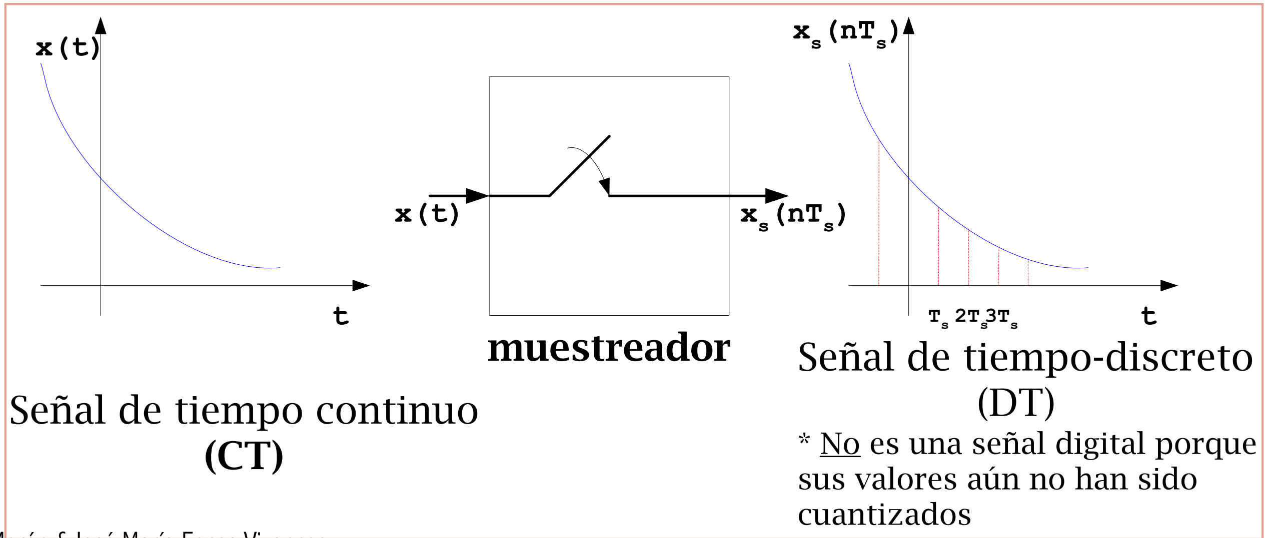
Communication theory: Nyquist's criterion

- If we want to recover a real signal from its samples:
  - The sampling process must be carried out **at least** at a speed twice the maximum significant frequency contained in the spectrum of the real signal
  - Otherwise, aliasing will occur: new frequency components will appear which will create distorsion
- If we sample the real signal at a frequency lower than twice its bandwidth, then reconstruction of of the original signal from its samples will be impossible.



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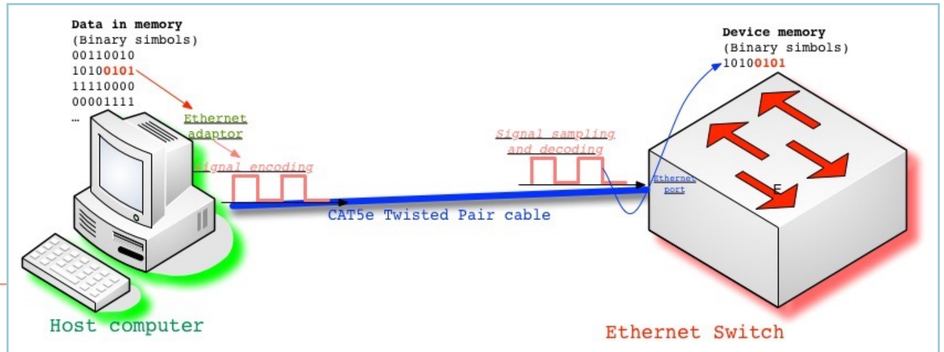
Communication theory: Shannon-Hartley Theorem

- Establishes an upper bound to the capacity of a channel in bps
- If we try to send information through a channel at a higher rate, on the receiving side, the probability of error in the estimation of the received symbols will be unbounded

  - Where B = 3300 – 300 = 3000Hz, S is the signal power, N the average noise.
  - The signal to noise ratio (S/N) is measured in decibels is related to dB = 10 x $\log_{10}$(S/N). If there is 30dB of noise then S/N = 1000.
  - Now C = 3000 x $\log_2$(1001) = 30kbps.
  - How can we get 56kbps?



$$C = B \cdot \log_2\left(1 + \frac{S}{n}\right) \quad bps$$

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Links

- All practical links rely on some sort of electromagnetic radiation propagating through a medium or, in some cases, through free space
- One way to characterize links, then, is by the medium they use
  - Typically copper wire in some form (as in Digital Subscriber Line (DSL) and coaxial cable),
  - Optical fiber (as in both commercial fiber-to-the home services and many long-distance links in the Internet's backbone), or
  - Air/free space (for wireless links)

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Links

- Another important link characteristic is the *frequency*
  - Measured in hertz, with which the electromagnetic waves oscillate
  - Electromagnetic waves propagate as the electric field generates a magnetic field that generates an electric field …

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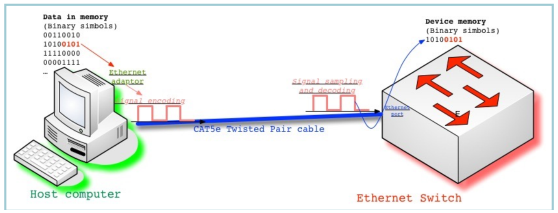
- Distance between the adjacent pair of maxima or minima of an electromagnetic wave measured in meters is called *wavelength:* $\lambda = v / f$
  - Speed of light divided by frequency gives the wavelength.
  - Frequency on a copper cable range from 300Hz to 3300Hz; Wavelength for 300Hz wave through copper is speed of light on a copper / frequency
  - $2/3 \times 3 \times 10^8 / 300 = 667 \times 10^3$ meters.
- Placing binary data on a signal is called *encoding*
- *Modulation* involves modifying the signals in terms of their frequency, amplitude, and phase
  - So that transmission over the physical medium is improved



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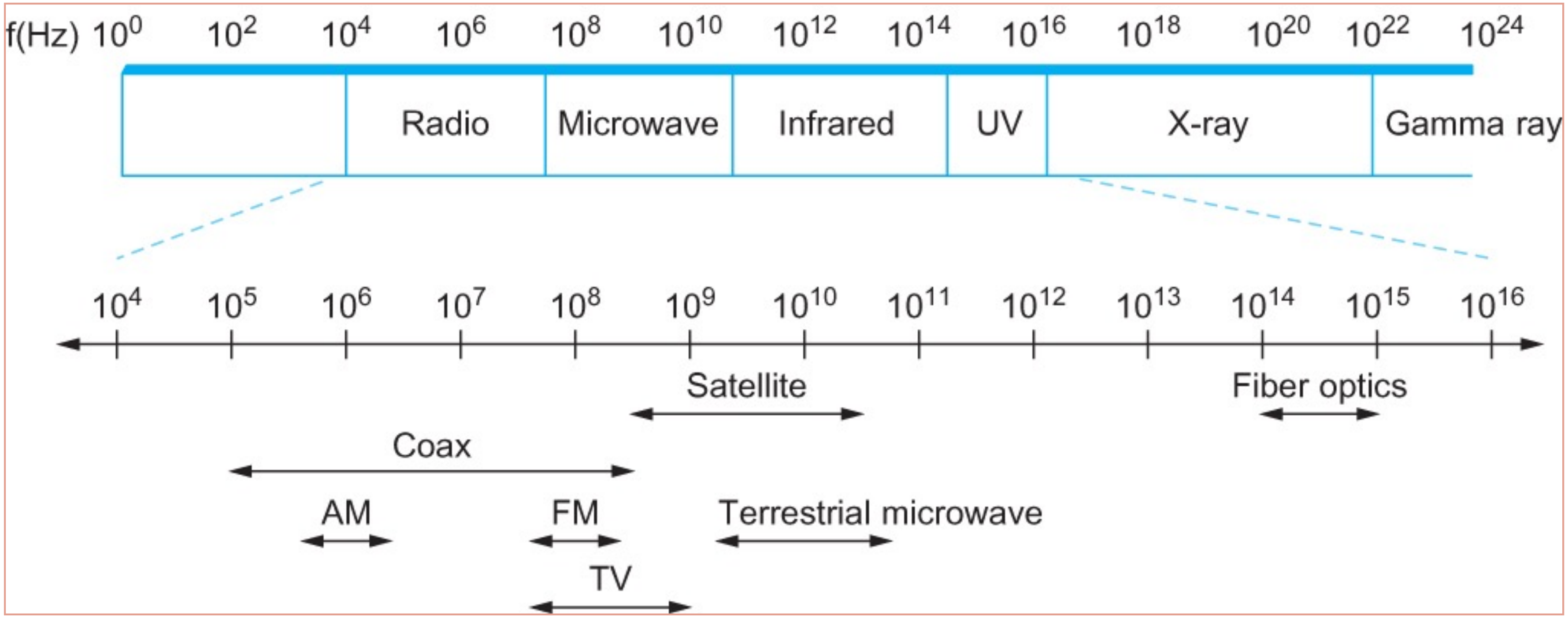

Electromagnetic spectrum

Links

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Service	Bandwidth (typical)
Dial-up	28–56 kbps
ISDN	64–128 kbps
DSL	128 kbps–100 Mbps
CATV (cable TV)	1–40 Mbps
FTTH (fibre to the home)	50 Mbps–1 Gbps

Common services available to connect your home