Physical Layer

Lecture 3 Physical Media and Attenuation

The physical layer is about communication between adjacent nodes.
→ What signals do we send?
→ How do we deal with distortion?

Say A is sending a message to B.
(binary: $0 \to 0V$, $1 \to 5V$)

Ideally, B would receive exactly what A sends.
What could go wrong?
→ There could be $\underbrace{\text{magnetic flux}}_{\text{due to currents between other people talking}}$ through the circuit, $\underbrace{\text{messing up}}_{\text{emf} \propto \frac{dB}{dt}}$ the voltages.

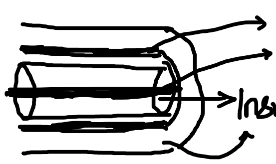
"Cross-talk"

How to fix?
- Reduce area of loop.
- Twisted-pair.  reduces flux. If done well, eliminates most cross-talk

  CAT-3 cables have 10 Mbps over 100m.
  CAT-5 cables have 100 Mbps over 100m.
  CAT-6 cables have 1 Gbps over 100m.
  10 Gbps over 50m.

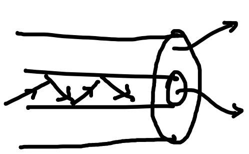
- Ethernet connectors have many wires coming in.
  (8 wires — 4 twisted pairs)

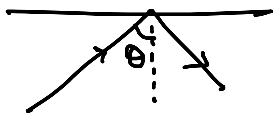
- Co-axial cables have a layer of shielding / insulation.



(0.2 in) ThinNet Coax give 100 Mbps over 200m
(0.4 in) ThickNet Coax give 100 Mbps over 500m

- Optic fibres allow very high data rate. They use $\underbrace{\text{light rays}}_{\text{fired from laser.}}$ instead of electric signals, thus reducing attenuation.





$\theta \geq \sin^{-1}\left(\frac{n_2}{n_1}\right)$

If it allows multiple angles to pass through (modes), it is called multi-mode fibre.

They are not the best because different modes can overlap. In single-mode fibre, only one mode passes through.

↳ Reduce diameter or increase refractive index

More expensive.

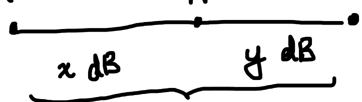
Say A transmits amplitude A_{in} and B receives amplitude A_2.

The attenuation, measured in dB, is equal to

$$\underbrace{10 \log_{10}\left(\frac{P_{in}}{P_{out}}\right)}_{\text{Powers}} = 20 \log_{10}\left(\frac{A_{in}}{A_{out}}\right).$$

It is usually measured in dB/1000 ft.

Note that it is additive over distance.



$(x+y)$ dB attenuation total

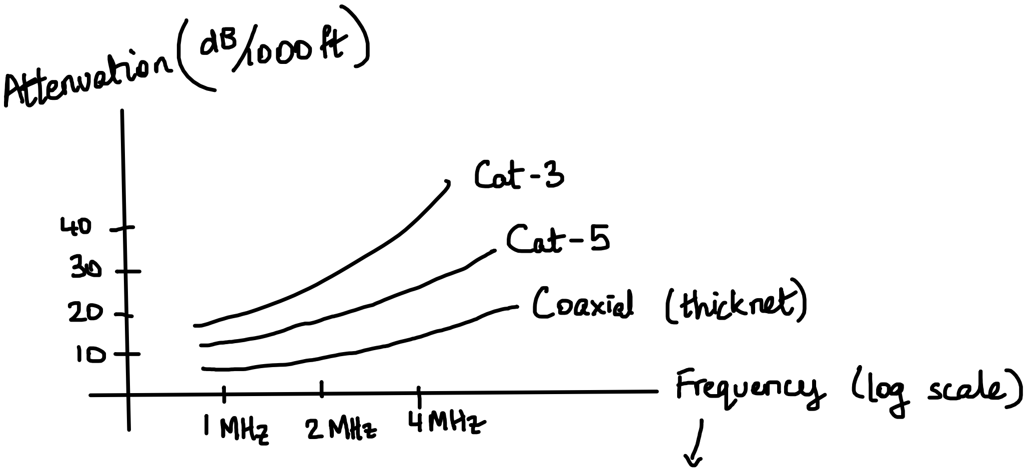
$$\left(\frac{A_{out}}{A_{in}}\right) = \left(\frac{A_{out}}{A'}\right) \cdot \left(\frac{A'}{A_{in}}\right)$$

If P goes to P/2, attenuation is ~ 3dB.

We also measure absolute power in dBm, dBW.

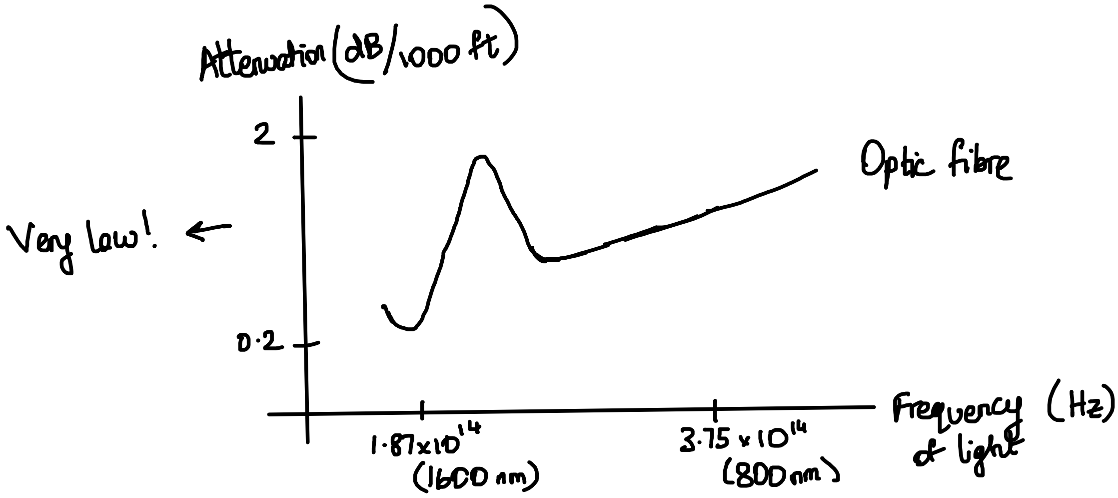
Suppose power P.

$$10 \log_{10}\left(\frac{P}{1\,mW}\right) \longrightarrow \text{Power in dBm.}$$

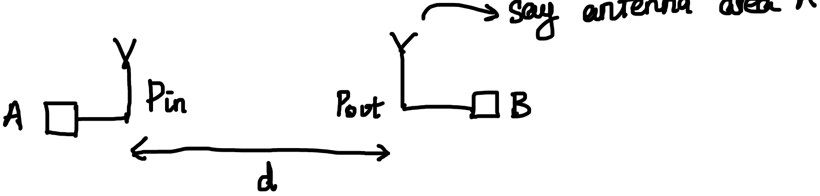


Influences inductance and capacitance

Freq ↑, Attenuation ↑



Say A and B are communicating wirelessly. A sends signals via antenna.



If power is spread isotropically in all directions

$$P_{out} \propto \frac{P_{in} \cdot A}{d^2}$$

↳ Huge power loss with distance.

In real life, it's even worse at d^α for some $2 < \alpha < 5$.

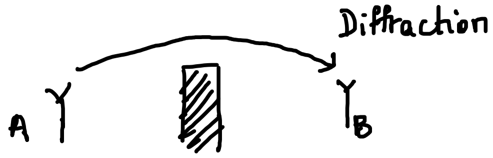
To solve this, we sometimes use directional antennas. (dish antennas for example)

Nowadays, we use MIMO (multiple-input and multiple-output) or more recently, massive MIMO.

In the wireless case, we could have

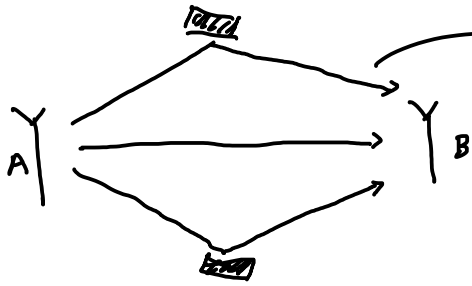
→ Interference (counterpart of cross-talk)

→ Obstructions



(Not a problem if line of sight)

→ Multipath (counterpart of multimode)



This arrives later and might have significant phase difference.

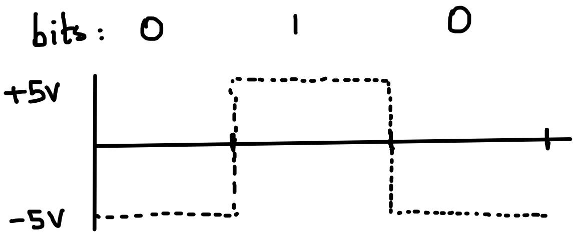
Lecture 4

Given a set of bits, we have to convert them into signals. How?

Wired situation.

We use line coding.

- Non-return to zero (NRZ)



→ Negative voltage.

(+5V when 1 and -5V when 0)

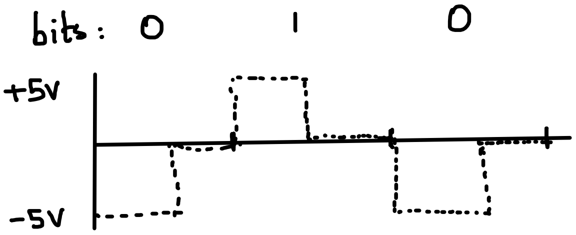
Issues with NRZ:

- Clock recovery - 001100 and 010 are essentially the same. How would we get the actual clock duration of the sender? The clock may be slightly slower/faster due to imperfections and may also have "drift".
  ↳ getting even slower/faster with time
  We are unable to recover the clock from the signal.

- Baseline wander - Instead of being exactly -5 and +5, there may be some offset. The DC offset is the average of the two offsets - the "new 0". This leads to errors other than the usual errors itself.

If we use a high pass filter, it partially resolves it. However, if there is a long string of 0s or 1s, it gets messed up.

- Return to Zero (RZ)

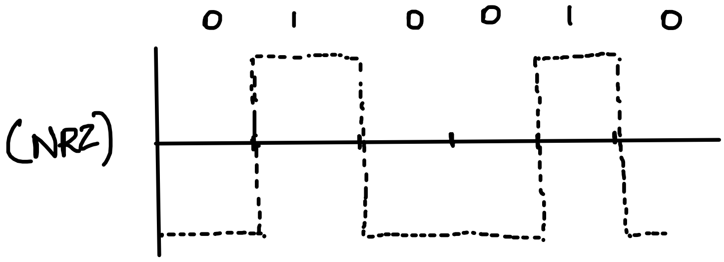


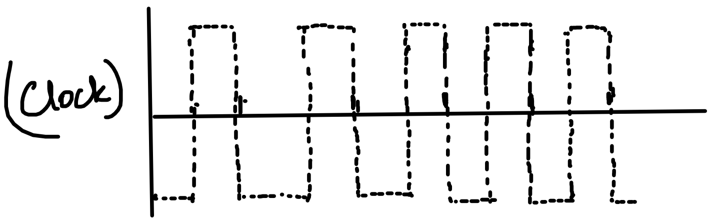
(Return to 0 at the middle of each bit)

We never have a constant signal for a long time, so high pass filters can remove baseline wander.
However, the issue is that we now have three levels.

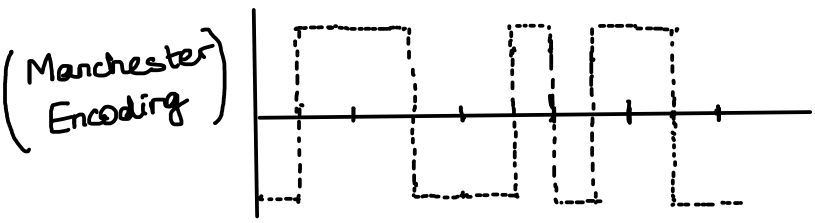
- Manchester Coding (802.3 IEEE)
  ↳ standard for ethernet

This is what is used usually.
We start with NRZ.





We then XOR the two.



The regular transitions eliminate the issue of clock recovery.
Like RZ, we can use a high pass filter to eliminate baseline wander.
(but only two voltage levels)

Note that the encoding of a 0 has a positive transition
1 has a negative transition

We can recognize the bit if we know where it starts.

1. We need to know where each bit begins.
2. We mustn't mess up the polarity.

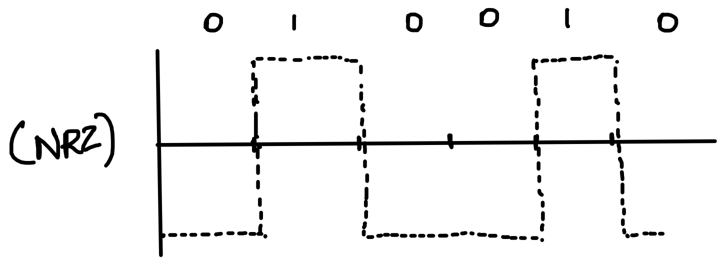
To do 1, we use a known signal known as the preamble to synchronize. Before the actual message, we insert this special signal. It can be thought of as a physical layer header.

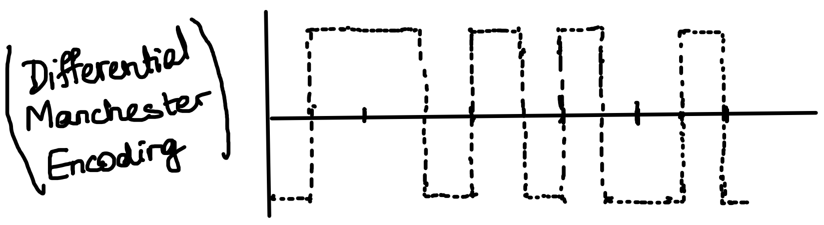
- Differential Manchester Encoding (802.5 IEEE)

It is used in token ring LANs (see. DLL)

For a 0, the first half is opposite of the last half of the previous bit.
1, the first half is equal to the last half of the previous bit.

Within each bit, there is a clock-like signal.





This has the advantages of Manchester encoding and further, the polarity issue is now gone.
(just see if it inverts or stays the same)

- **4B/5B Encoding:**

Recall that in NRZ, we run into issues if the same bit occurs multiple times.

What if we manually change it once in a while?

What this does is that for an input of 4 bits, it gives out 5 bits. For example,

$$\left.\begin{array}{ccc} 0000 & \rightarrow & 01010 \\ 1000 & \rightarrow & 10010 \\ & \vdots & \end{array}\right\} 2^4 \text{ such things.}$$

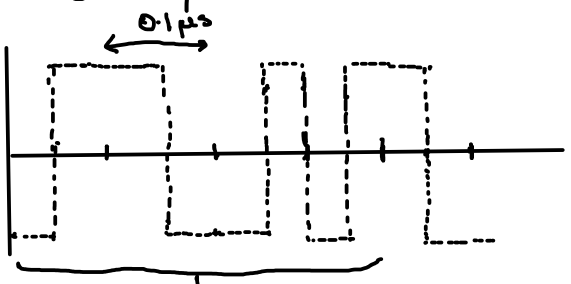
This ensures that there are atmost 3 consecutive 0s/1s in the encoded bit string.

This is disadvantageous because there is some degree of redundancy.

Baud Rate:

Recall that the bit rate is the maximum possible number of bits transferred per second.

The Baud rate is the maximum allowable number of symbol changes made to the transmission medium per second.



for example, 5 symbol changes

Worst case, one change every 0.05 μs

$\downarrow$

Baud rate = 2×10^7 symbols s^{-1}

In some sense, Baud rate captures what potential we can use the medium to

The allowable frequency range is related.

↳ recall that as freq.↑, attenuation↑.

An allowable signal should have most of the Fourier transform contained within the allowable frequencies.

Observe that in Manchester, Baud rate > bit rate and twice as much

in NRZ, Baud rate = bit rate.