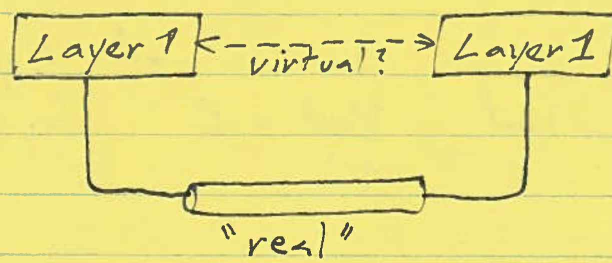
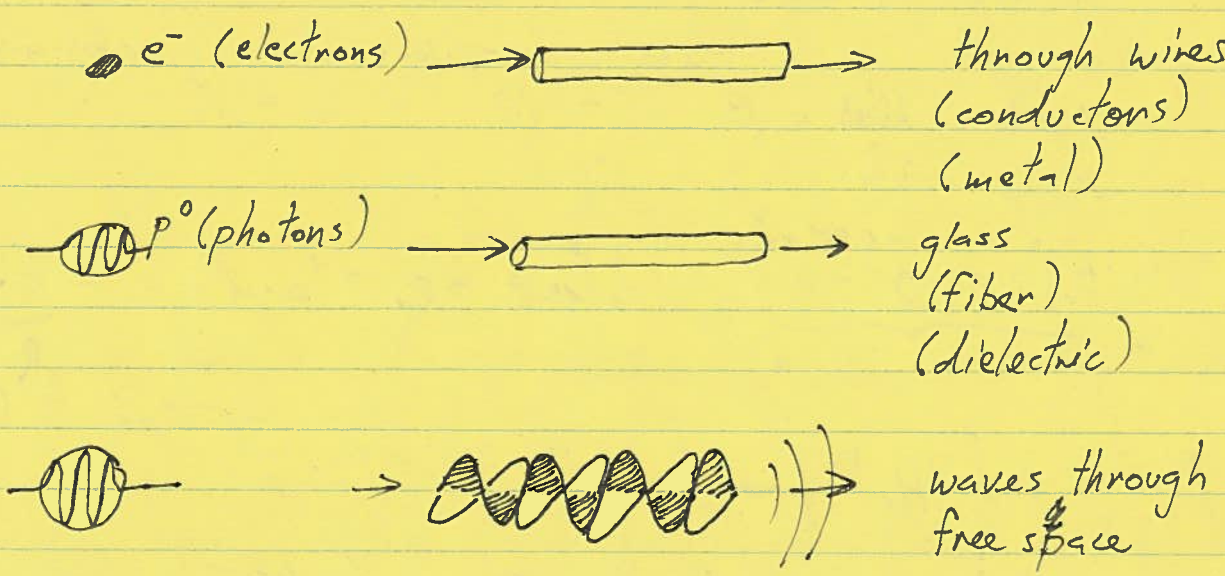
L8 Physical Media

8.1 Signal Particles

reminder of what we are talking about





8.2 Delay

- seen this before

$$t_{prop} = \frac{d}{v} \qquad v\big|_{free\ space} = c = 3\times10^8\ m/s$$

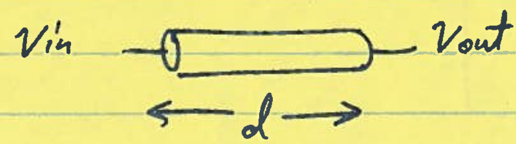
$$v\big|_{media} = \frac{c}{\sqrt{\epsilon_r}} \qquad \sqrt{\epsilon_r} = \frac{3}{2}$$

- what other problems do you expect from channels?

8.3 Attenuation

- signal comes in... but less of it comes out

Wires



$$\frac{V_{out}}{V_{in}} = e^{-\alpha d} \Big\} \text{ Exponential fn. distance}$$

- in terms of power?

$$\frac{P_{out}}{P_{in}} = \frac{V_{out}^2}{V_{in}^2} = e^{-2\alpha d} = 10^{-2 \cdot \log e \cdot \alpha \cdot d} = 10^{-2 \cdot 0.434 \cdot \alpha \cdot d}$$

$$\underbrace{|H_c|^2 = 10^{-0.869 \alpha d}}, \qquad |H_c|^2_{dB} = -8.69(\alpha \cdot d) = -\underbrace{k}_{[dB/m]} \cdot d$$

$$P_{in}\,[W] \longrightarrow \boxed{|H_c|^2} \longrightarrow P_{out} = P_{in} \cdot |H_c|^2 = P_{in} \cdot 10^{-0.869 \alpha d}$$

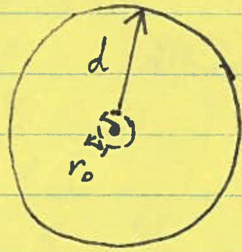
$$P_{in,\,dBm} = 10 \times \log\left(\frac{P_{in}}{10^{-3}}\right) \qquad P_{out,\,dBm} = P_{in,\,dBm} + (-0.869 \cdot \alpha \cdot d)$$

attenuation $|A_c|^2 = \dfrac{1}{|H_c|^2} = \dfrac{P_{in}}{P_{out}}$ $\qquad |A_c|^2_{dB} = k \cdot d$

$$P_{out} = \frac{P_{in}}{|A_c|^2}$$

$$P_{out}\big|_{dBm} = P_{in,\,dBm} - |A_c|^2_{dB}$$

Wireless



$$|H_c|^2 = \frac{P_{out}}{P_{in}} = \left(\frac{r_0}{d}\right)^2 = \left(\frac{r_0}{d}\right)^n \Bigg\} \text{ Power fn. of distance}$$

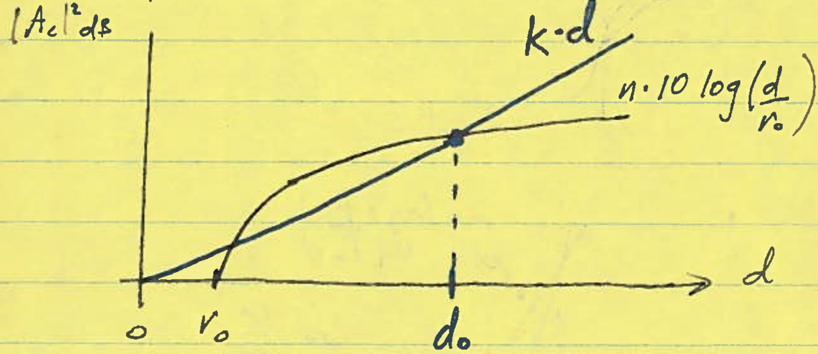
$$|H_c|^2_{dB} = \left|\frac{P_{out}}{P_{in}}\right|_{dB} = n \cdot 10 \cdot \log\left(\frac{r_0}{d}\right)$$

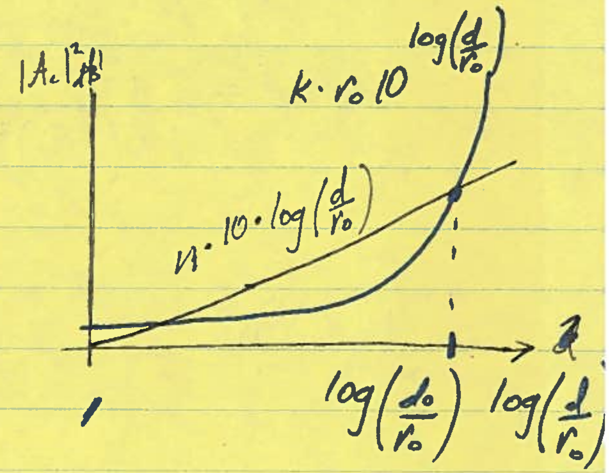
$$r_0 = \frac{\lambda}{4\pi} \qquad \lambda = \frac{c}{f} \qquad \therefore f = 3\times10^9,\ c = 3\times10^8$$

$$\lambda = 10\,\text{cm}$$

$$|A_c|^2 = \left(\frac{d}{r_0}\right)^n \qquad |A_c|^2_{dB} = n\cdot 10\cdot \log\left(\frac{d}{r_0}\right)$$

compare wired & wireless





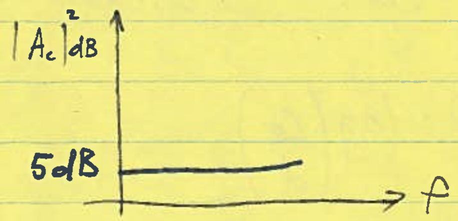
telephone

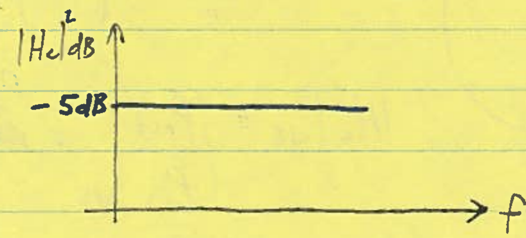
$$0.005\,\text{dB/m} \rightarrow k\cdot d_0 = n \times 10 \times \log\left(\frac{d_0 \times 4\pi}{\lambda_0}\right) \qquad \lambda_0 = 10\,\text{cm}$$

$$d_0 = 26.3\ \text{km}$$

8.4 Frequency Response

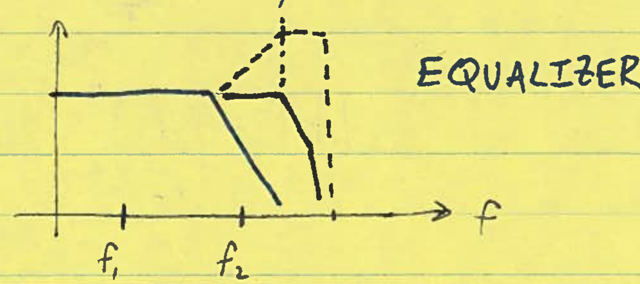
- "ideally" same attenuation over all frequencies





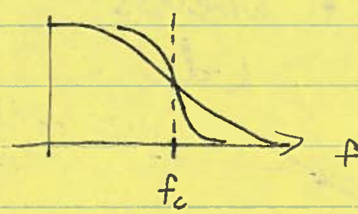
- in reality see variation with frequency

$$|H_c(f_1)|^2 \neq |H_c(f_2)|^2$$

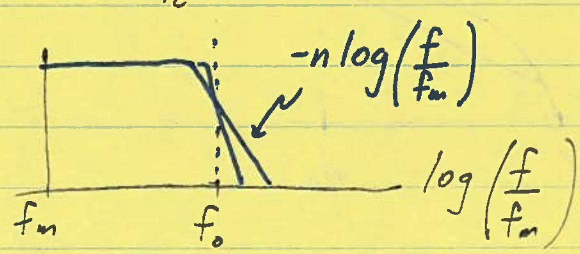


- a cause for distortion

$$|H_c(f)|^2 = \frac{1}{1+(f/f_c)^2}$$



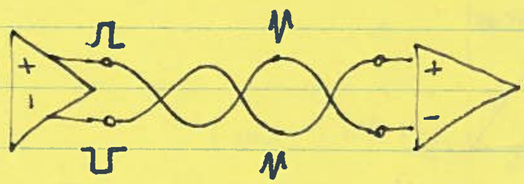
$$|H_c(f)|^2_{dB}$$



- lets look at some real wires

8.5 Twisted Pair

- ~~wood~~ wound wires ... UTP (unshielded twisted pair)

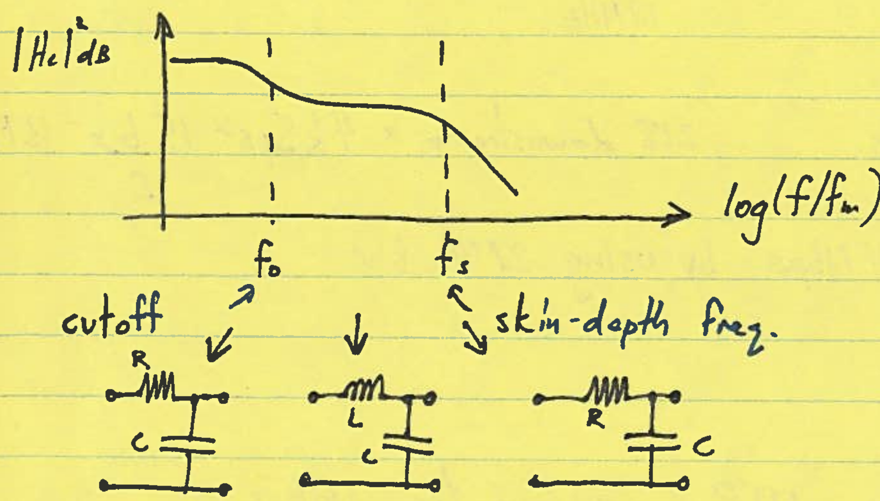


differential signal (limited interference to outside)

common-mode noise limited interference from outside

- a.k.a CAT 5 ... 4 UTPs bunched together

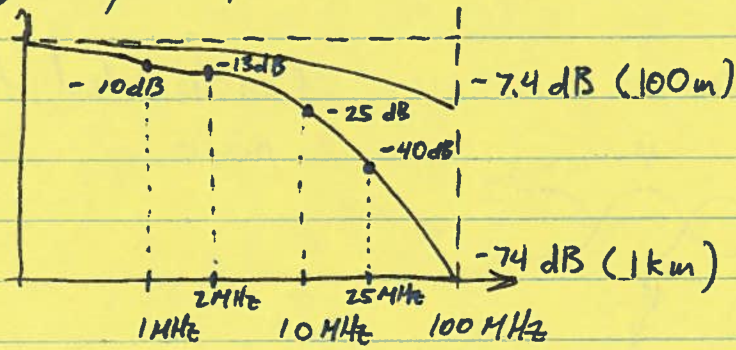
- frequency response



$$|H_c|^2 = \frac{1 + f/f_{o1}}{1 + f/f_o + f/f_s}$$

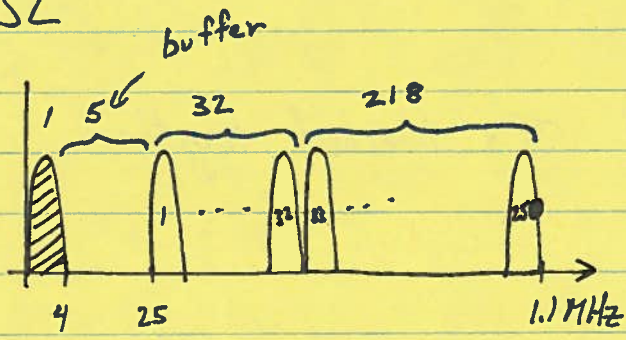
- for AWG 24 diam. = 0.511 mm $f_o \simeq 33$ kHz, $f_s \simeq 67$ kHz

- frequency response?



for $0 < f < 3\text{kHz}$ $\quad |H|^2 \geq -1.5\text{dB}$ @ 1km

8.6 ADSL

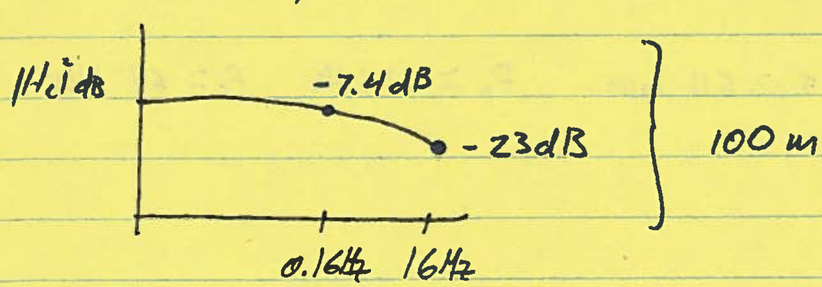


256 4-kHz channels $\qquad$ 218 downstream × 4 kSps × 15 $\frac{b}{s}$ = 13 Mbps

ADSL 2+ gets 24 Mbps by using 2MHz BW

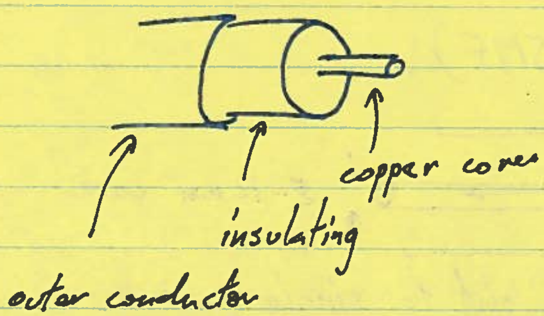
8.7 Ethernet

- A variety of uses UTP now up to 1Gbps



8.8 Coaxial Cable

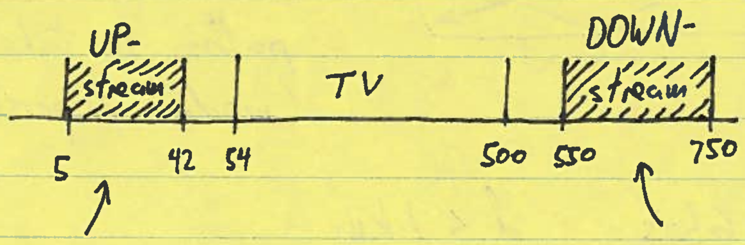
- a superior wire ... better shielding (EM confinement)



	UTP	Coax (2.6/9.5mm)
10 MHz	-25 dB	-5dB
100 MHz	-74 dB	-20dB

8.9 Cable Communications

- Cable modems



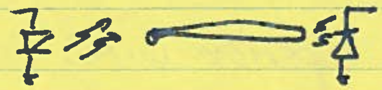
~18 2MHz channels
.5 - 4 Mbps/channel

~33 6 MHz channels
36 Mbps/channel

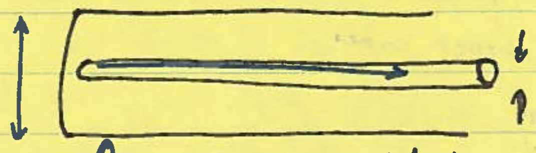
- ~ 500 - 2000 users per cable
  FDMA: 6 - MHz channels
  TDMA: Users get mini slots
  CDMA/ALOHA: Users share minislots & resources

8.10 Optical Fiber

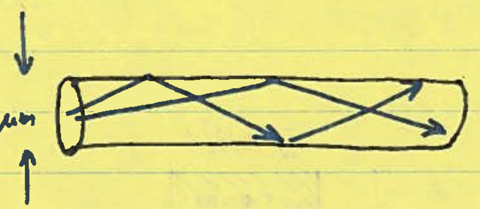
- shoot light through glass



- Single-Mode Fiber (SMF)



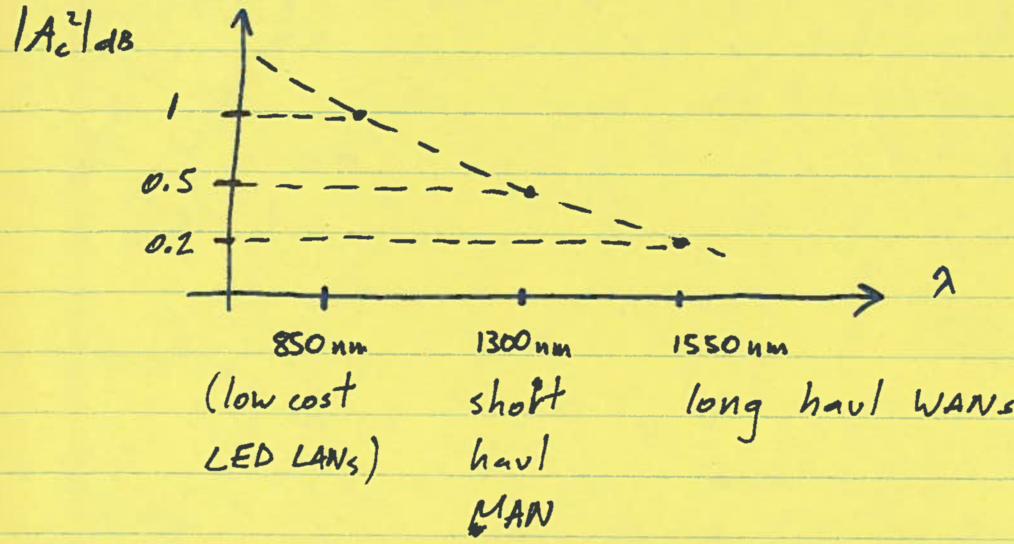
- used for long haul $R > 40$ Gbps $d > 100$ km
- EXPENSIVE
- Multi-Mode Fiber (MMF)



$R < 10$ Gbps $d < 1$ km

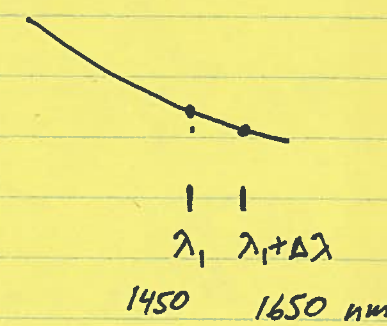
8.11 Optical Attenuation

UTP	@	100 MHz	−75 dB/km
Cable	@	100 MHz	−20 dB/km
Optical	@	1000 GHz	−0.2 dB/km



8.12 Optical Bandwidth

$$B = f_1 - f_2 = \frac{v}{\lambda_1} - \frac{v}{\lambda_1 + \Delta\lambda}$$



$$= \frac{v}{\lambda_1}\left(1 - \frac{\lambda_1}{\lambda_1 + \Delta\lambda}\right)$$

$$= \frac{v}{\lambda_1}\left(\frac{\Delta\lambda}{\lambda_1 + \Delta\lambda}\right) \approx \frac{v\,\Delta\lambda}{\lambda_1^2}$$

$$B = \frac{2\times10^8 \cdot 200\times10^{-9}}{(1450\times10^{-9})^2} = 19\text{ THz} = 19\times10^3\text{ GHz}$$

8.13 WDM, Coarse & Dense

→ don't bother with remaining optical