Lecture 1: Introduction to Communication Systems

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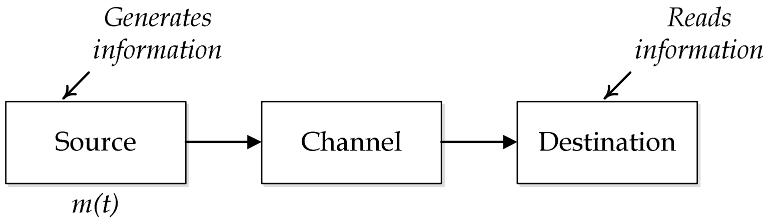
A Communication System

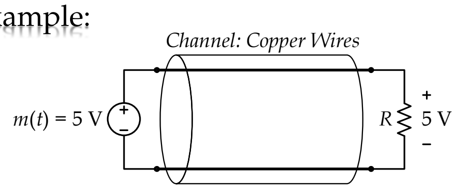
- Purpose of a communication system: Carry information from one point to another.
- A typical communication system consists of three main components:
  - Source
  - Channel
  - Destination

How to build it?

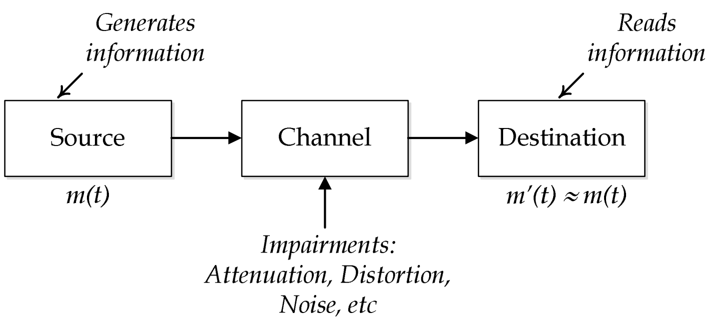
Three basic blocks:

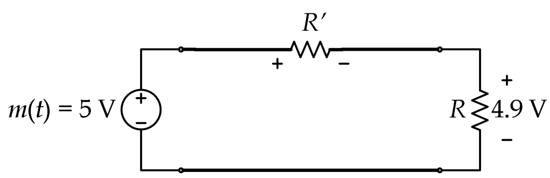


Simple example:



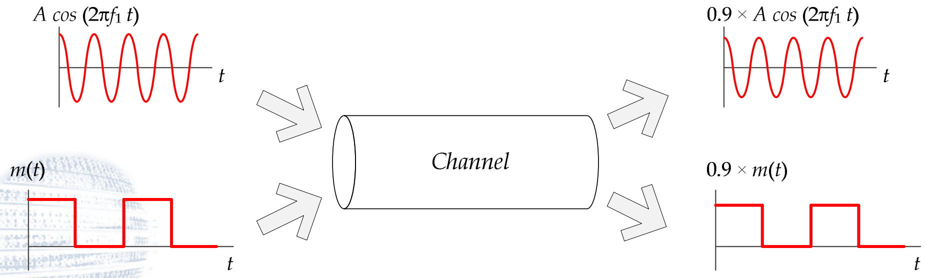
Channel Impairments





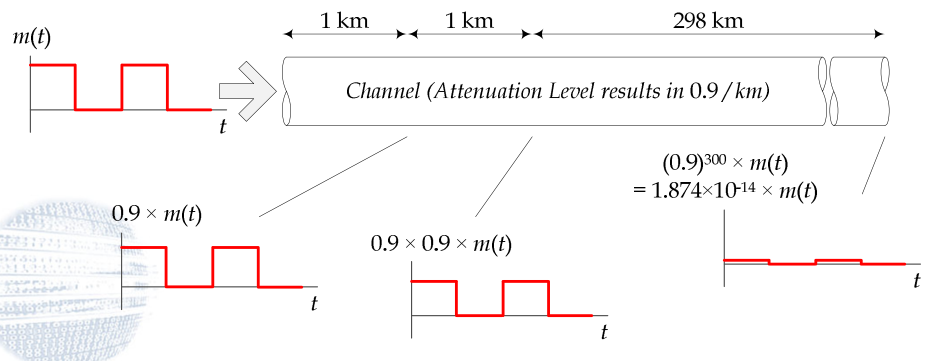
Channel Impairments

1. Attenuation: As the signal travels through the channel it loses some of its energy (*power*) as heat in the internal resistance of the channel. We say the signal is attenuated.



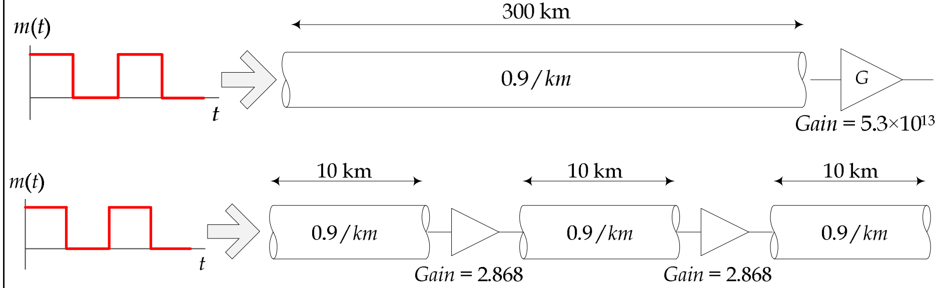
Attenuation

- Attenuation can be problematic for long distance communications (say cross-country).



Solutions to Attenuation

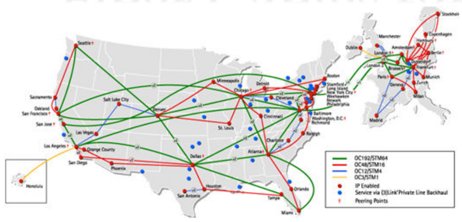
(a) Use Amplifiers:



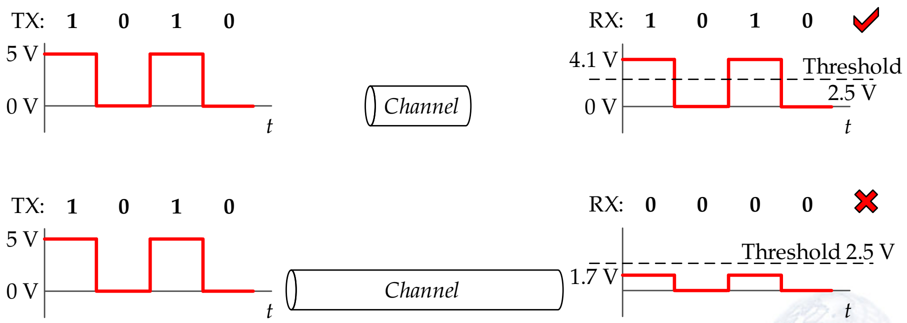
(b) Use channels with smaller attenuation levels (e.g., optical fiber) – such channels are usually more expensive.

(c) Digital signals are less susceptible to attenuation (because of threshold detection at the receiver).

Fiber Cables for Long Distance

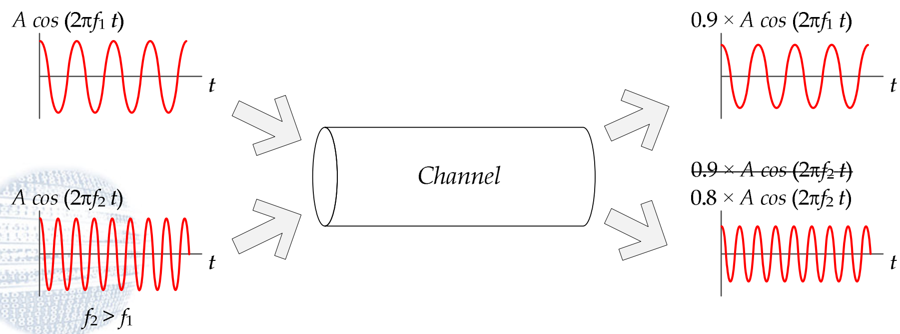


Digital: *Threshold Detection*

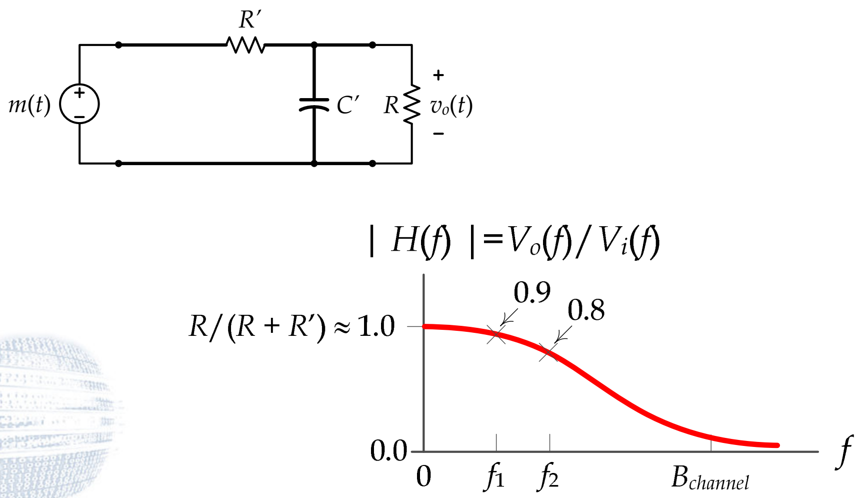


Channel Impairments

2. Linear Distortion: The channel *attenuation* changes according to the transmitted signal *frequency*. Usually higher frequencies are attenuated more. Hence, the channel acts as a LPF that attenuates high frequencies, thus distorting the signal. We say the channel is a filter that has finite (limited) *channel bandwidth*.



Linear Distortion: Cause



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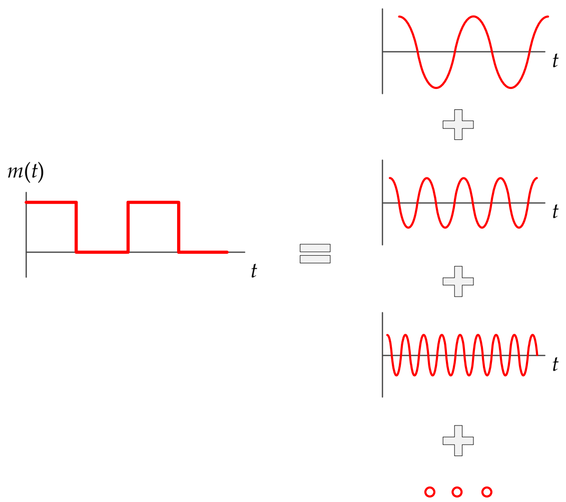
Linear Distortion: Effects



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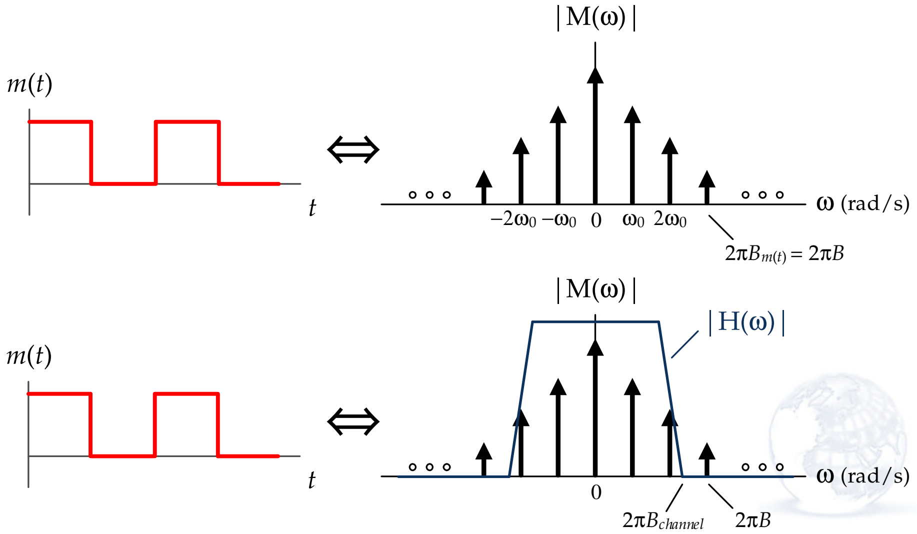
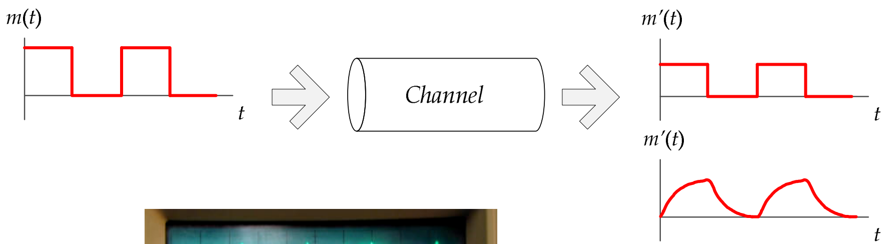
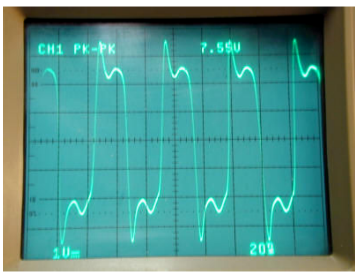
Linear Distortion: Effects



Linearly-Distorted Signals





Bandwidth vs. Bandwidth

- Channel Bandwidth $B_{channel}$:
  - A property of the channel.
  - You read it from the data sheet of the channel.
  - The *frequency* after which the channel presents very high attenuation.
- Signal Bandwidth $B_{m(t)} = B$:
  - A property of the signal.
  - You figure it out from the Fourier transform of the signal.
  - The *frequency* above which $m(t)$ has insignificant (negligible) harmonics.
- *Rule of thumb*: signal bandwidth should be less than or equal to channel bandwidth.

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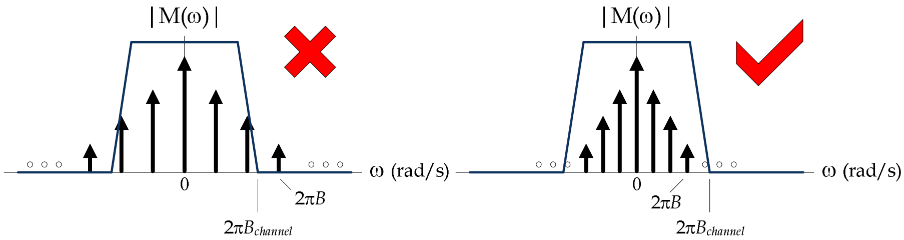
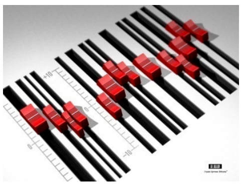
Solutions to Linear Distortion

(a) The message should **fit** in the channel bandwidth (either send at smaller data rate or use a better channel)



(b) Use an **Equalizer** at the receiver

(c) Pre-distortion at the transmitter



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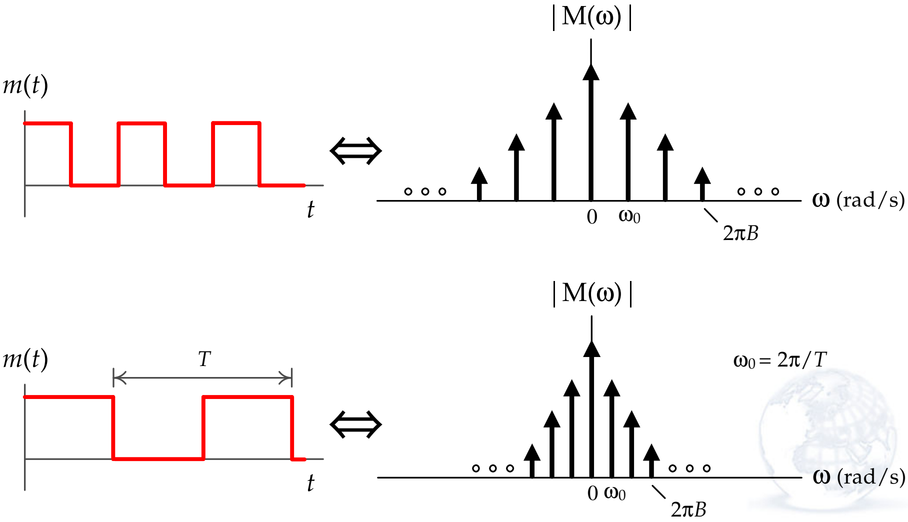
Fourier: Reciprocal Spreading



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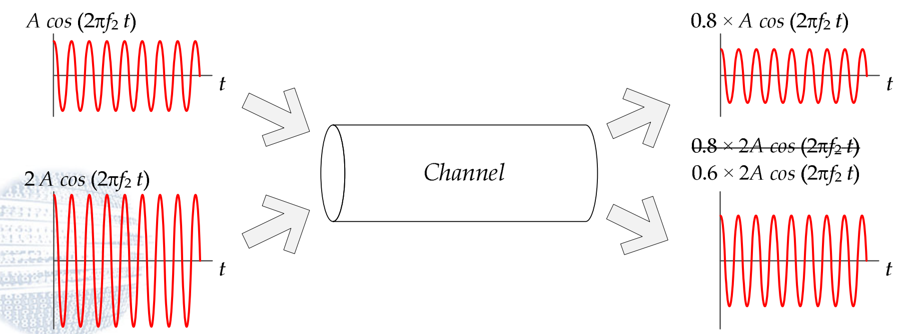
Channel Impairments

3. Non-Linear Distortion: The channel *attenuation* changes according to the transmitted signal *amplitude* and/or *phase*. Usually higher amplitudes are attenuated more. This causes distortion to the signal.



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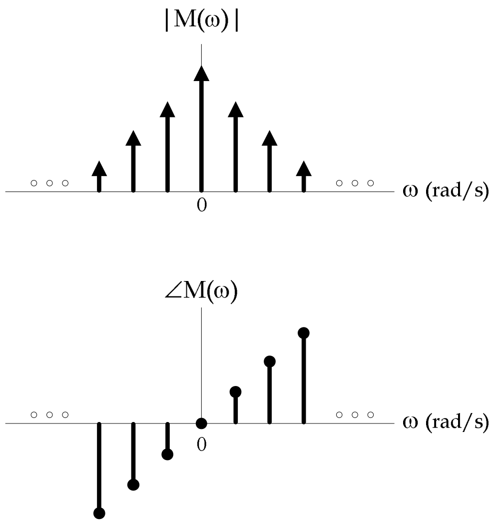
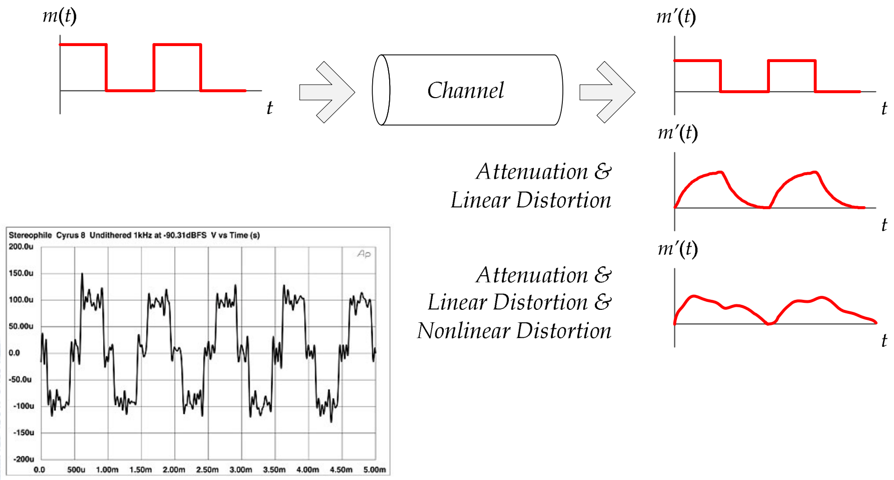
Fourier Transform *Again*!



Non-Linearly-Distorted Signals



Distorted signals are not desired!

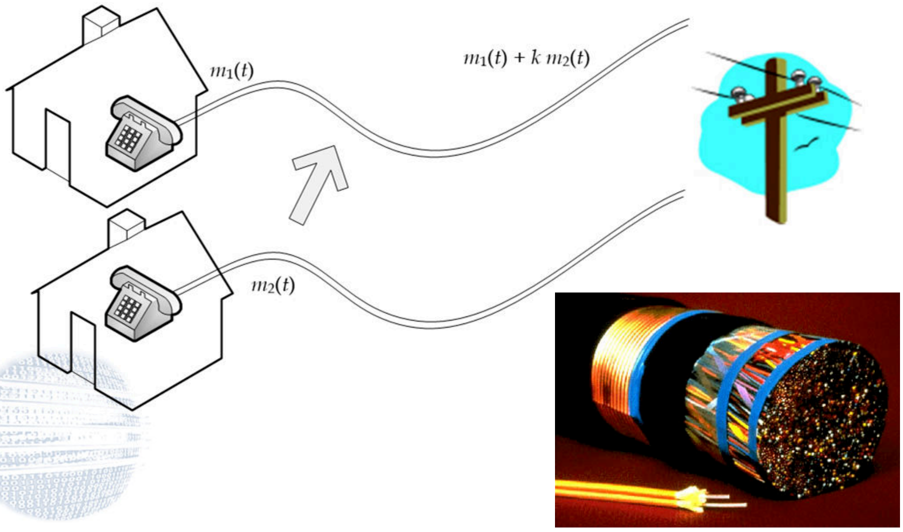
- Solutions to Non-Linear Distortion: Use an Equalizer at the receiver or Pre-distortion at the transmitter.

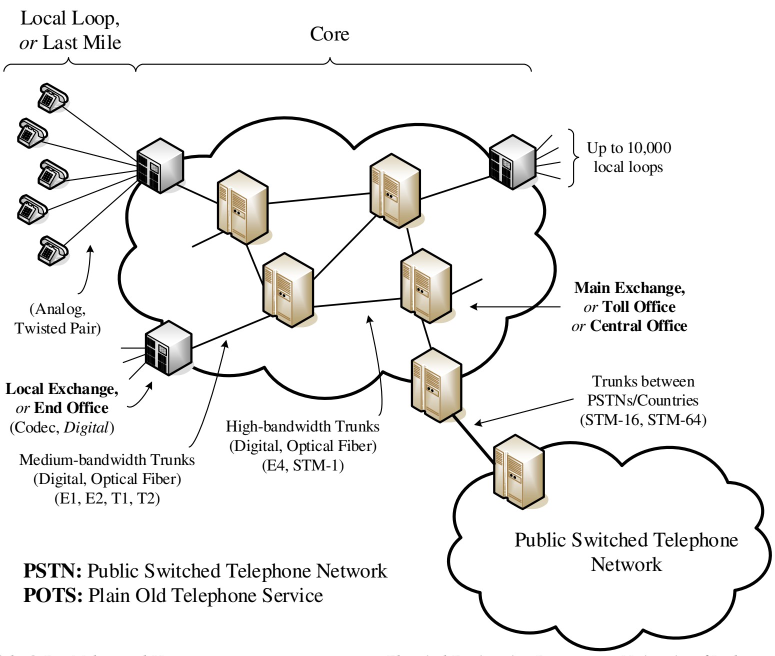
Channel Impairments

4. Noise: All the undesired signals (not part of the original signal) that are added by the channel. Noise is a random (*non-deterministic*) signal generated by external and internal sources.

- **External Sources:** interference from signals transmitted on nearby channels (crosstalk), interference generated by contact switches, automobile ignition radiation, fluorescent lights, natural noise from lightning, solar radiation, etc.

Example External Noise: Crosstalk

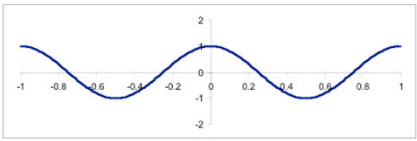




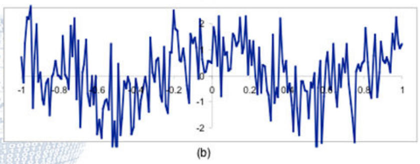
PSTN: Public Switched Telephone Network
POTS: Plain Old Telephone Service

Noise

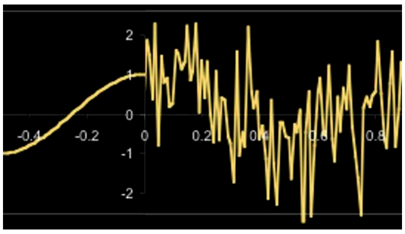
- **Internal Sources:** thermal noise (random motion of electrons in conductors, random diffusion and recombination of charged carriers in electronic devices).



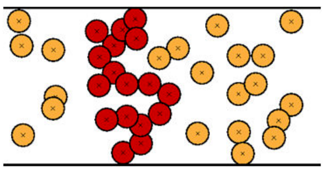
(a)



(b)



Moving Electrons

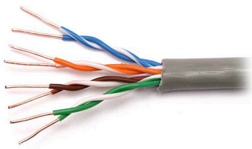


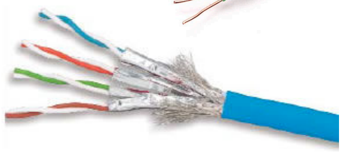
Noisy signals are not desired!

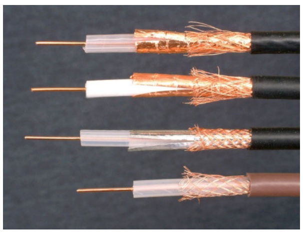
- The effects of external noise can be minimized or eliminated.
- The effects of internal noise can be minimized but never eliminated.

Solutions for *External* Noise

a) Shielding or twisting.
b) A different cable design (coax, fiber, wave guide).
c) Proper design of the whole system.
d) Using filters at the receiver side: BPF, LPF, notch filter.
e) Digital transmission (threshold detection, orthogonality, FEC, etc.)

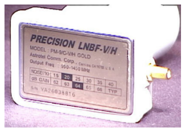




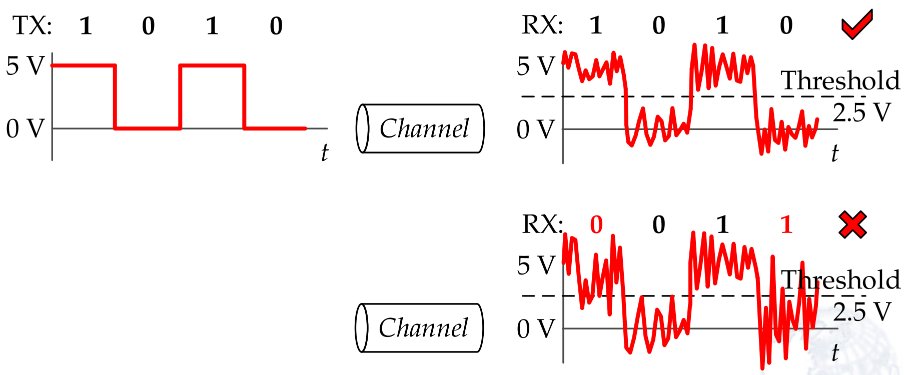


Solutions for *Internal* Noise

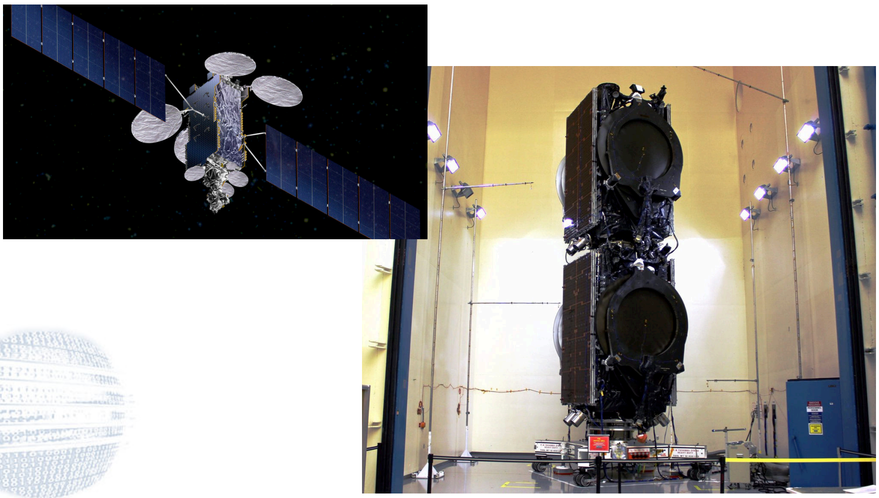
a) Cooling.
b) Using filters at the receiver side: BPF, LPF, notch filter.
c) Digital transmission (threshold detection, orthogonality, FEC, etc.)

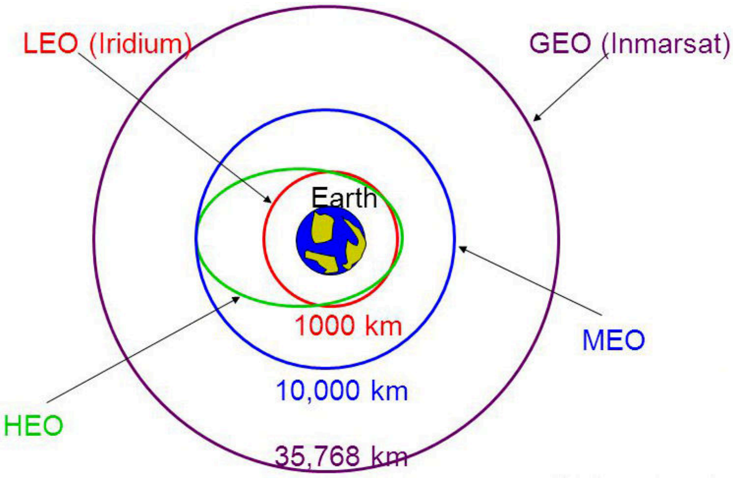
Threshold Detection vs. Noise



Satellite Systems

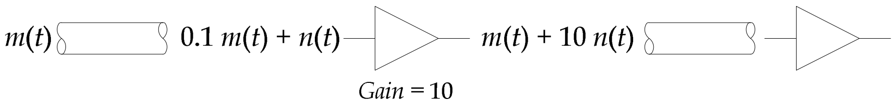


Satellite Orbits

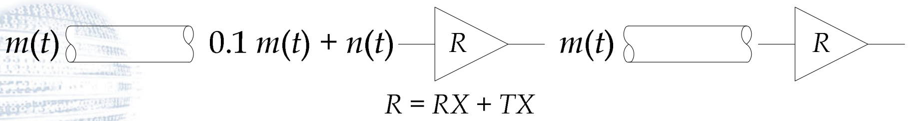


Impairments ALL Together

Attenuation + Noise:



We need new solutions: *Regenrators* (Digital Transmission)



Other Channel Impairments

5. **Fading**: Variable attenuation with time of day and receiver location (wireless systems).
6. **Doppler Shift**: Shift in the frequency of the transmitted signal. Shows up when we have a wireless channel and fast moving objects.
7. **Frequency-reuse interference**: Shows up in wireless systems when we re-use the same frequencies at multiple nearby locations to increase system capacity.
8. **Chromatic Dispersion**: Specific to optical fiber channels.

Shannon's Limit

$$C = B_{ch} \times \log_2(1 + SNR)$$

- C: Capacity of the channel in bits/second (bps)
- B_{ch}: Channel bandwidth (units of Hz)
- SNR: Signal-to-Noise Ratio (unitless)(*not* dB)

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