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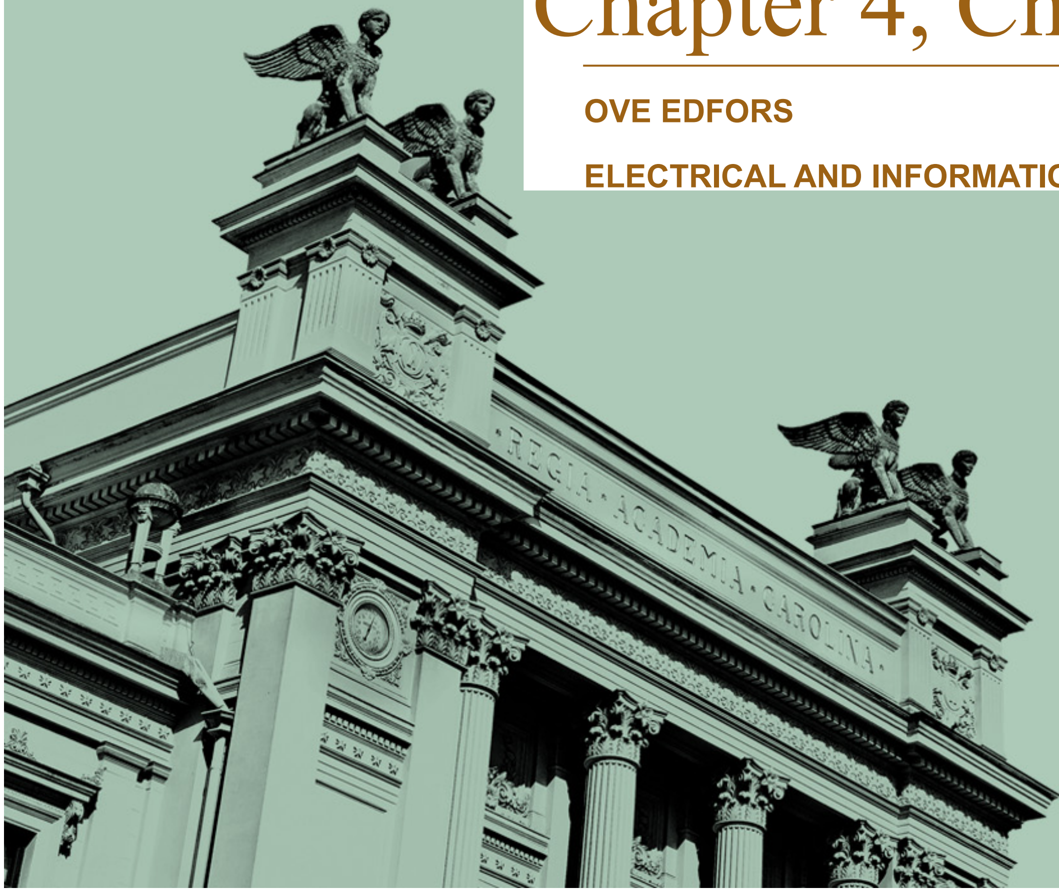
Information Transmission Chapter 4, Channels

OVE EDFORS

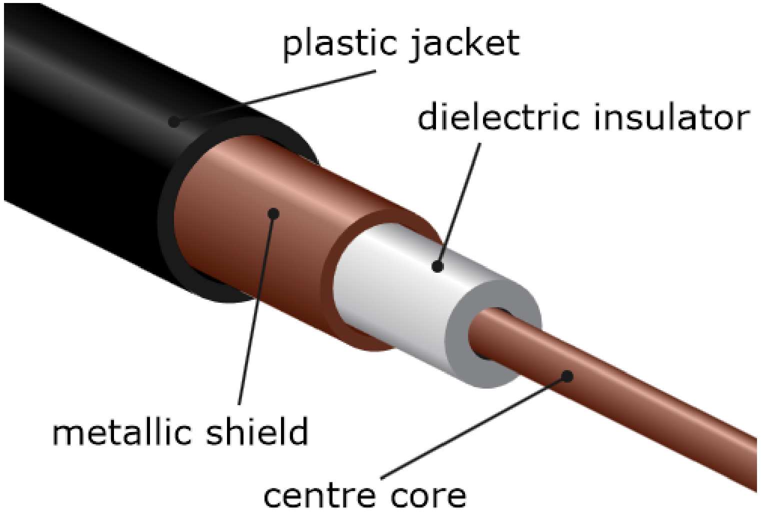
ELECTRICAL AND INFORMATION TECHNOLOGY



Learning outcomes

- After this lecture the student should
  - understand the basic properties of wired channels, such as cables and optical fibers,
  - know the basic properties of wireless channels, including propagation loss in free space and antenna gains,
  - understand how noise enters the system and how it is characterized,
  - understand the basic principles of how movements and multiple wireless propagation paths create Doppler effects and fading (variations in signal strength), and
  - be familiar with the principle of the magnetic recording channel (for storing data).

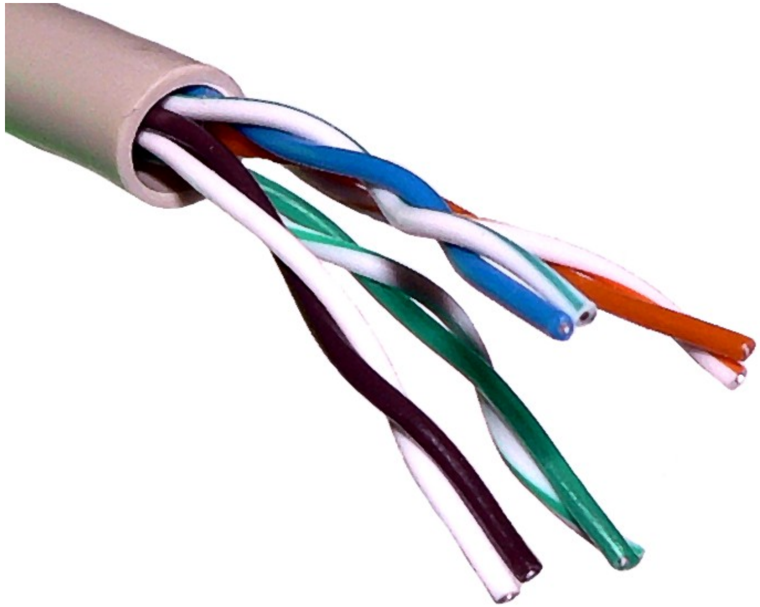
Wires, cables and fibers



» Coaxial cable

» Used for high frequency transmission

» Shielded and controlled properties



- Twisted pair
- Standard telephone line

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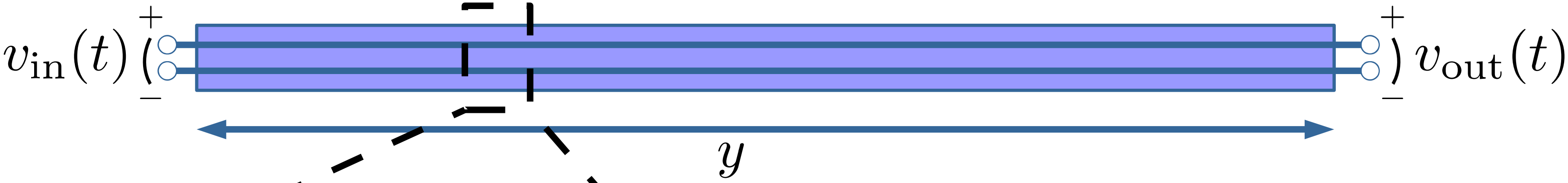
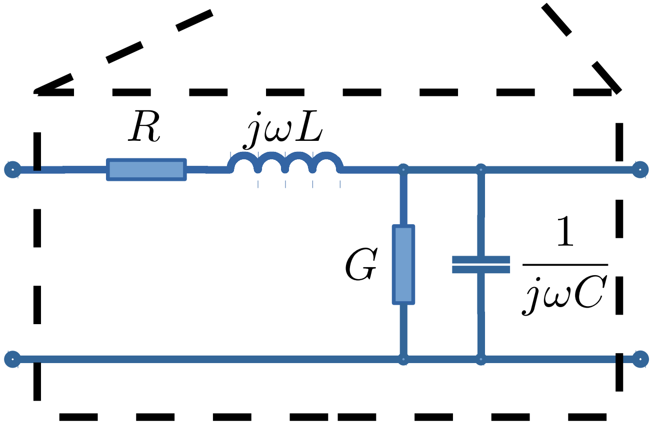
Model of a transmission line (wire)

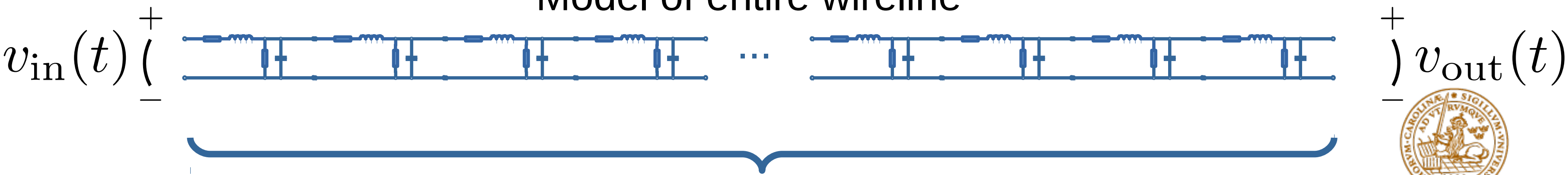




Model of short (unit length) section of line:

- R - resistive loss
- L - inductance from wires
- G - “short circuit” resistance
- C - capacitance between wires

Model of entire wireline



y unit length sections in series

Wires, cables and fibers

- Wires and cables have quite high attenuation

$v_{\mathrm{out}}(t)$ $v_{\mathrm{in}}(t)$

$$v(t) = V_0 e^{j\omega t} e^{-y\gamma} \text{ at distance } y$$

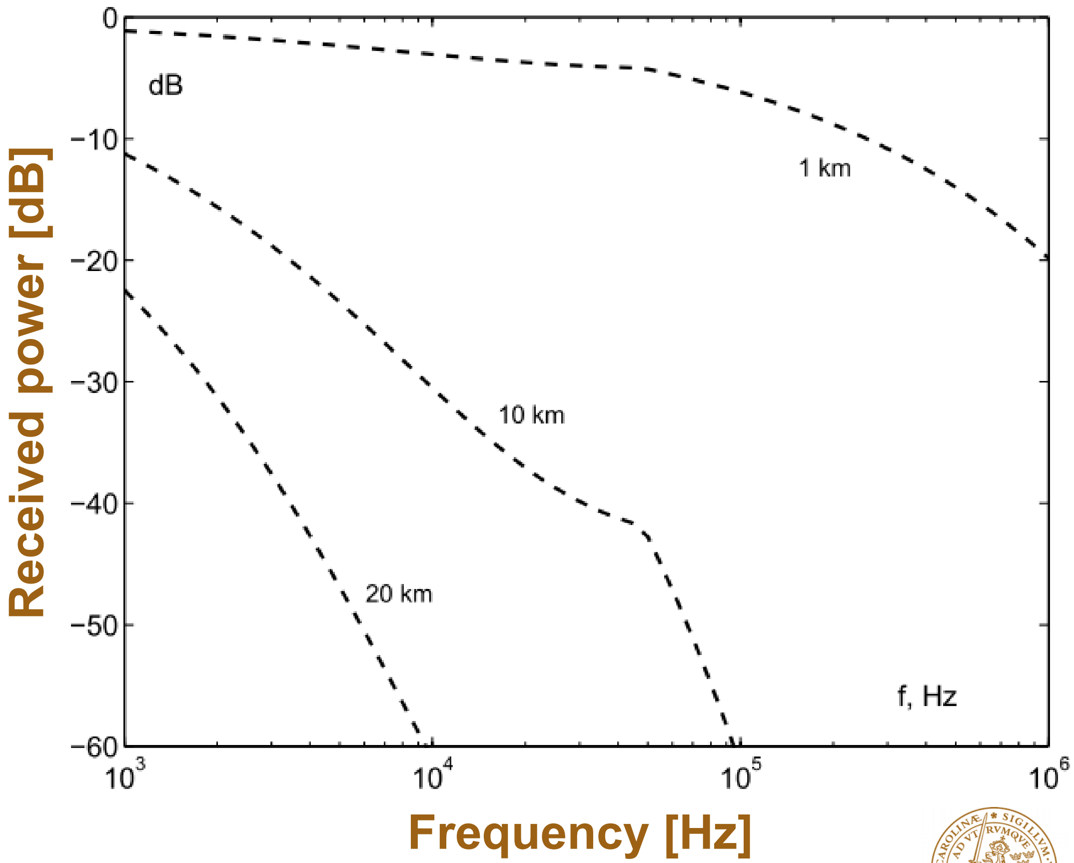
- Where the propagation constant is given by

$$\gamma(\omega) = \sqrt{(R(\omega) + j\omega L)(G + j\omega C)}, \quad \omega = 2\pi f$$

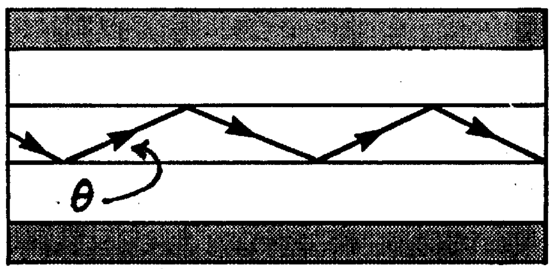
- Sinus in – sinus out, but with an attenuation and phase shift

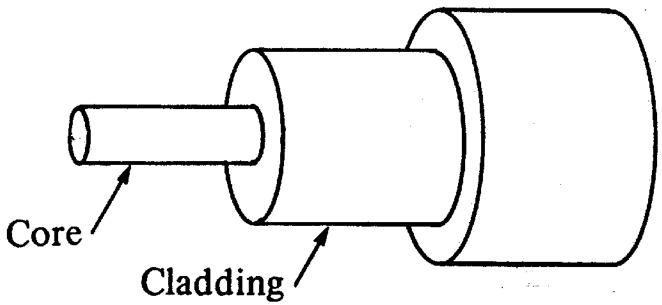
Attenuation of a wire pair (telephone line)

- For longer wire lengths the attenuation is huge at higher frequencies.
- They are already in place, so let's use them…



Propagation in a fiber





Fibers have low attenuation (< 0.5 dB/km).
Reflections inside the fiber lead to dispersion – the light pulse will Smear out in time.

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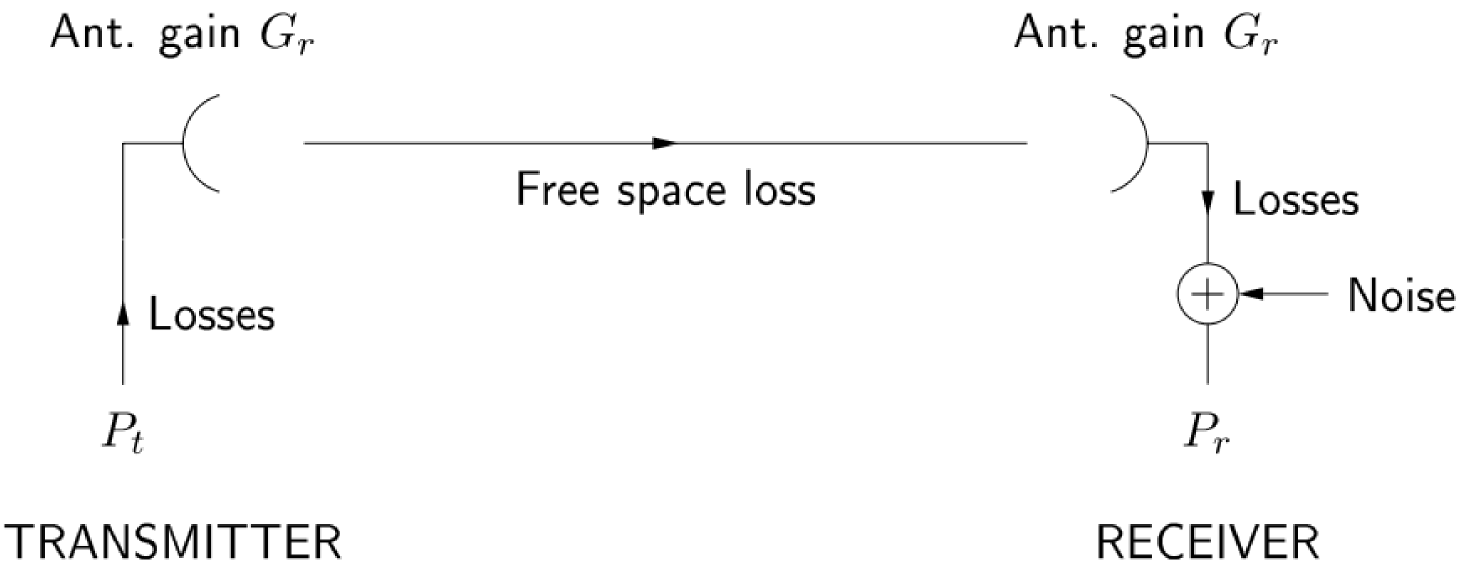
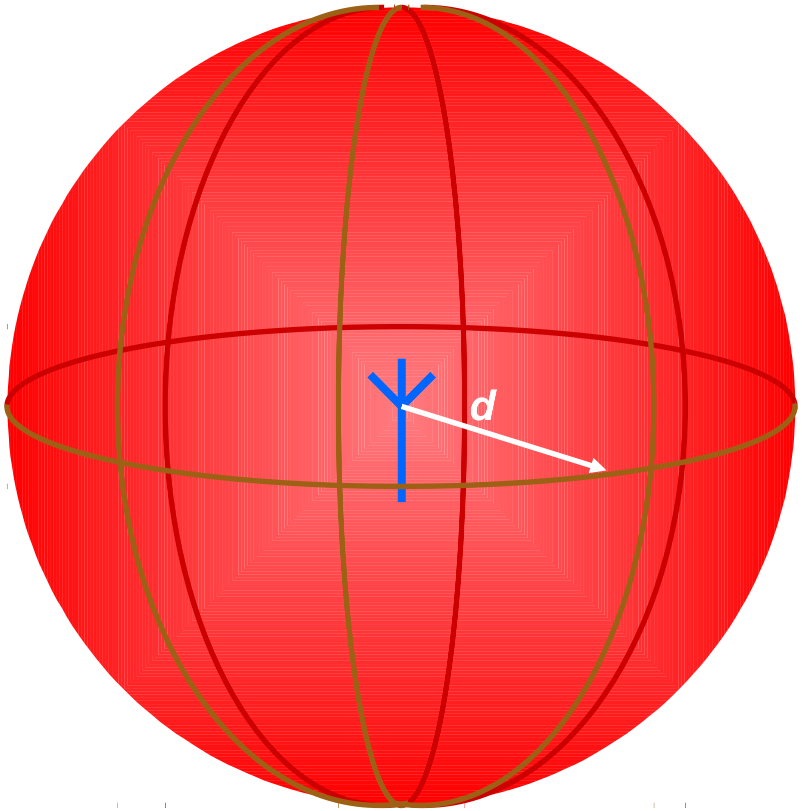
Radio Channels – Free space



Free-space loss



If we assume RX antenna to be isotropic:

$$P_{\mathrm{RX}}(d) = \left(\frac{\lambda}{4\pi d}\right)^2 P_{\mathrm{TX}}$$

Attenuation between two isotropic antennas in free space is (free-space loss):

$$L_{\mathrm{free}}(d) = \left(\frac{4\pi d}{\lambda}\right)^2$$

$$P_{\mathrm{RX}}(d) = \frac{1}{L_{\mathrm{free}}(d)} P_{\mathrm{TX}}$$

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Antenna gain

- An antenna will collect its power from an effective area *A*. The larger antenna the more power it will collect

$$G = \frac{4\pi A}{\lambda^2}$$

- Similarly, it will focus its transmit power in a certain direction where the power density then will be higher

Free-space loss, Friis' law

Received power, with antenna gains G_{TX} and G_{RX}:

$$P_{\mathrm{RX}}(d) = \frac{G_{\mathrm{RX}} G_{\mathrm{TX}}}{L_{\mathrm{free}}(d)} P_{\mathrm{TX}} = P_{\mathrm{TX}} \left(\frac{\lambda}{4\pi d} \right)^2 G_{\mathrm{RX}} G_{\mathrm{TX}}$$

⇔ If we write the expression in dB ...

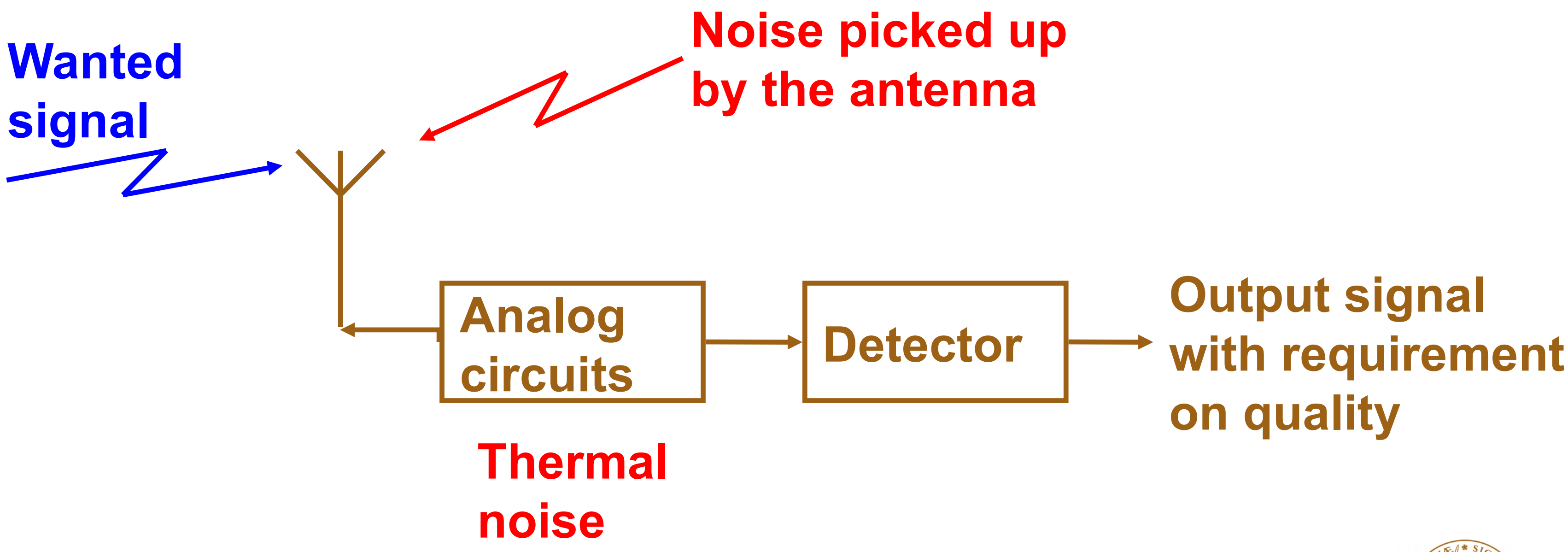
$$P_{\mathrm{RX|dB}}(d) = P_{\mathrm{TX|dB}} + G_{\mathrm{RX|dB}} - L_{\mathrm{free|dB}}(d) + G_{\mathrm{TX|dB}}$$

$$= P_{\mathrm{TX|dB}} + G_{\mathrm{RX|dB}} - 10 \log_{10} \left(\frac{4\pi d}{\lambda} \right)^2 + G_{\mathrm{TX|dB}}$$

In free space, the received power decays with distance at a rate = 20 dB/decade

Noise sources

The noise situation in a receiver depends on several noise sources



Receiver noise: Noise sources (1)

The power spectral density of a noise source is usually given in one of the following ways:

1) Directly [W/Hz]

2) Noise temperature [Kelvin]

$$kT_K \ [\mathrm{W/Hz}]$$

The power *N* of the noise is also determined by the bandwidth

$$N = kT_K B_m$$

Here *k* is Boltzmann's constant (1.38×10^{-23} W/Hz) and T_K is the is the temperature of the noise source in Kelvin.

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Distribution of the noise

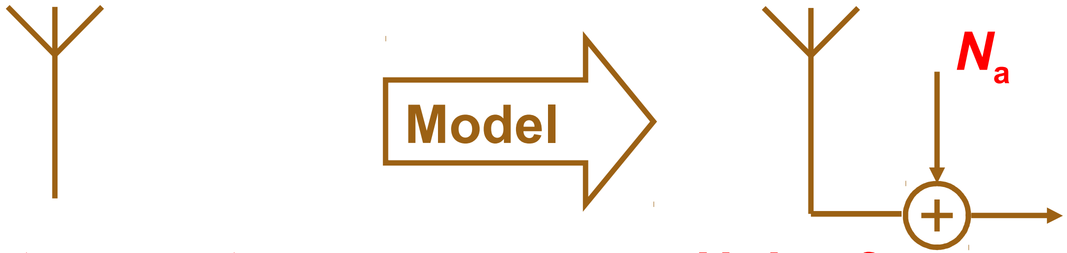
- The noise is most often assumed to have a Gaussian distribution

$$f(x) = \frac{1}{\sqrt{N\pi}} e^{-x^2/N}$$

- With this distribution it is possible to calculate the probability that a noise sample exceeds a certain level.

Receiver noise: Noise sources (2)

Antenna example



Noise temperature of antenna 1600 K

Noise free antenna

Power spectral density of antenna noise is

$$N_a = kT_a = 1.38 \times 10^{-23} \times 1600$$
$$= 2.21 \times 10^{-20}\ \mathrm{W/Hz} = -196.6\ \mathrm{dB[W/Hz]}$$

Multiply with bandwidth to get noise power

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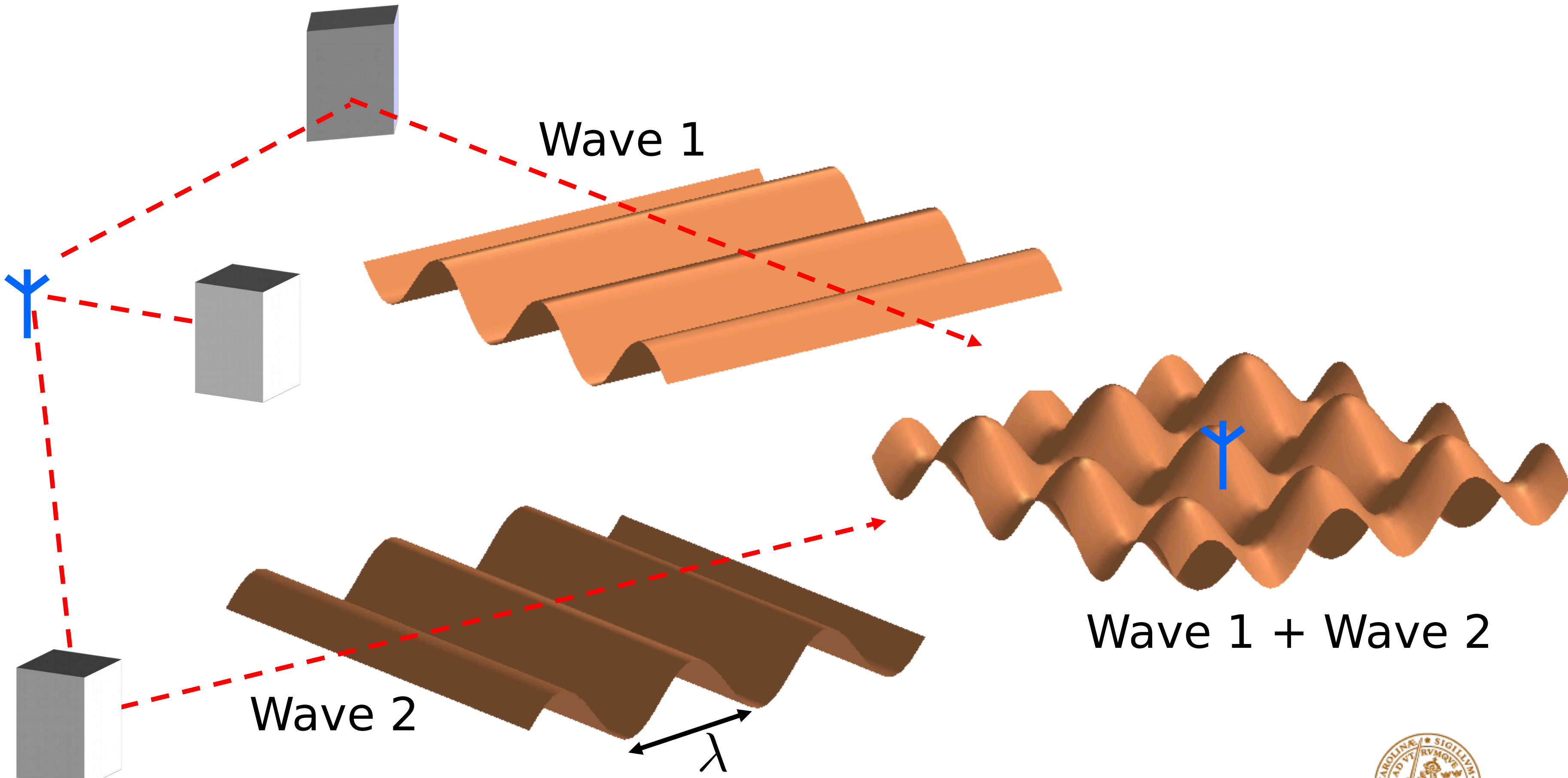
Multi-path propagation, Two waves



At least in this case, we can see that the interference pattern changes on the wavelength scale.

Small-scale fading

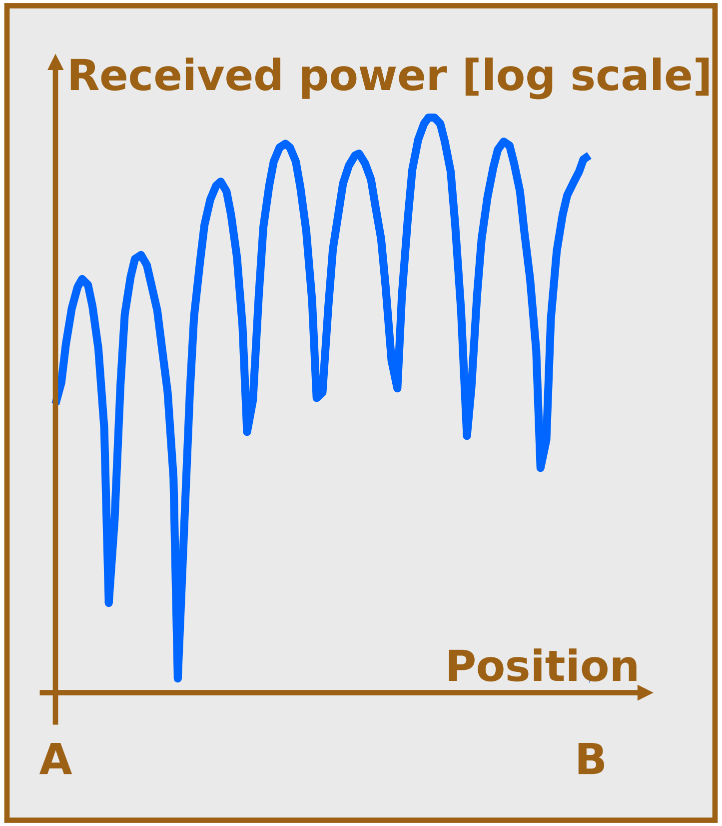
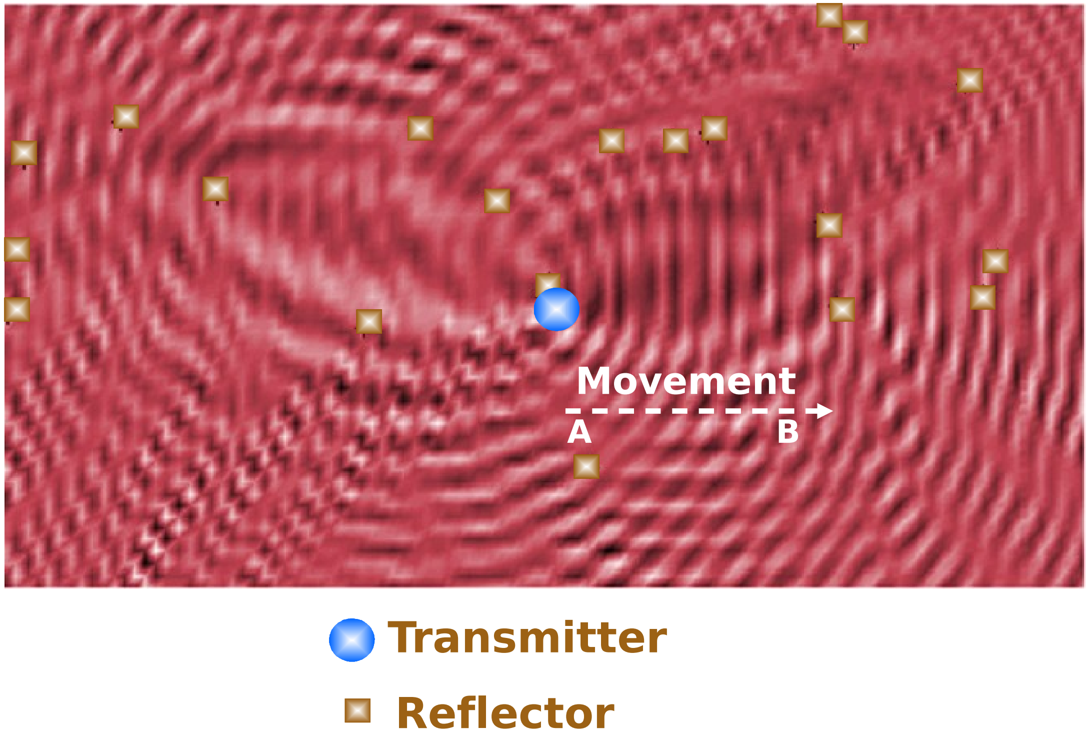
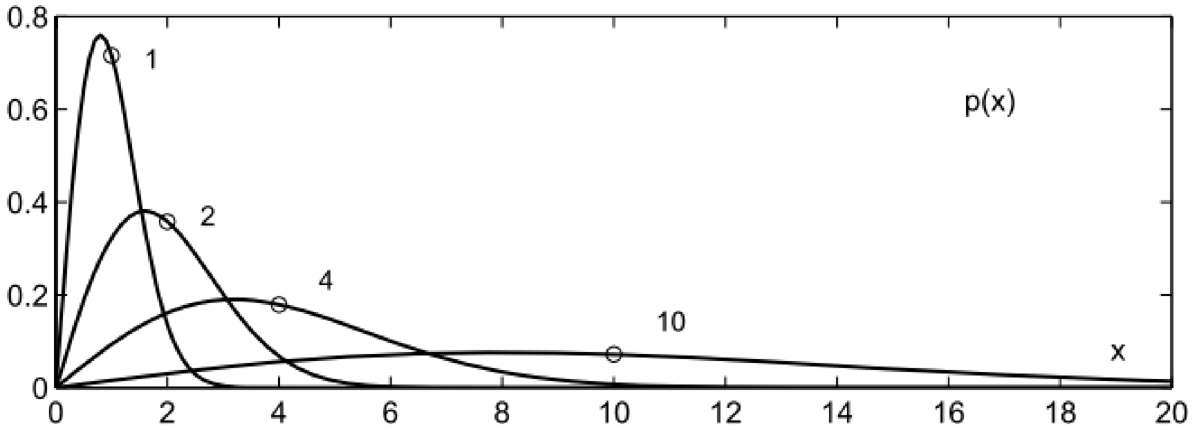


Illustration of interference pattern from above

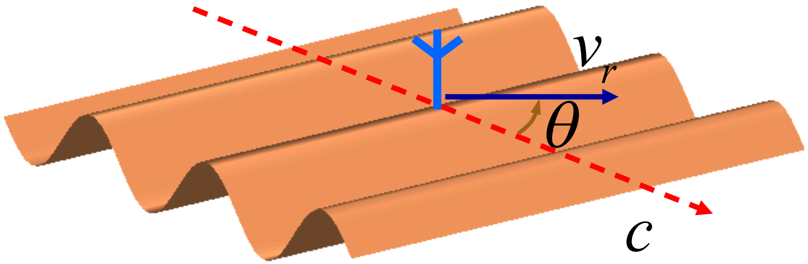


Small-scale fading - Rayleigh fading



$$p(x) = \begin{cases} \frac{x}{\rho} e^{-x^2/2\rho} & x > 0 \\ 0 & \text{otherwise} \end{cases}$$

Doppler shifts



Receiving antenna moves with speed v_r at an angle θ relative to the propagation direction of the incoming wave, which has frequency f_0.

Frequency of received signal:

$$f = f_0 + \nu$$

where the Doppler shift is

$$\nu = -f_0 \frac{v_r}{c} \cos(\theta)$$

The maximal Doppler shift is

$$\nu_{\max} = f_0 \frac{v}{c}$$

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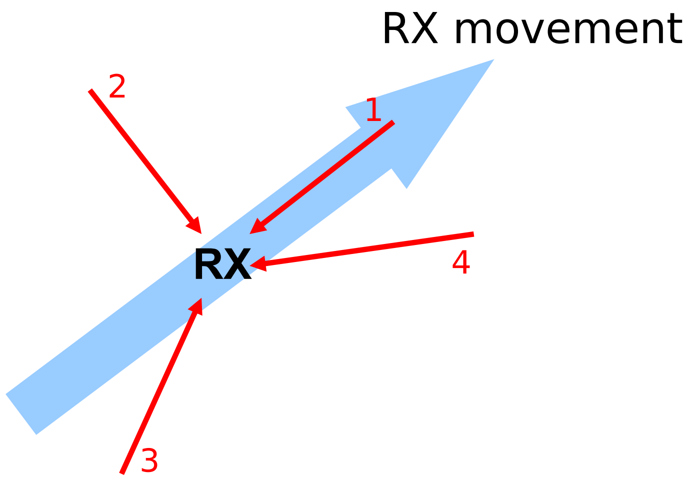
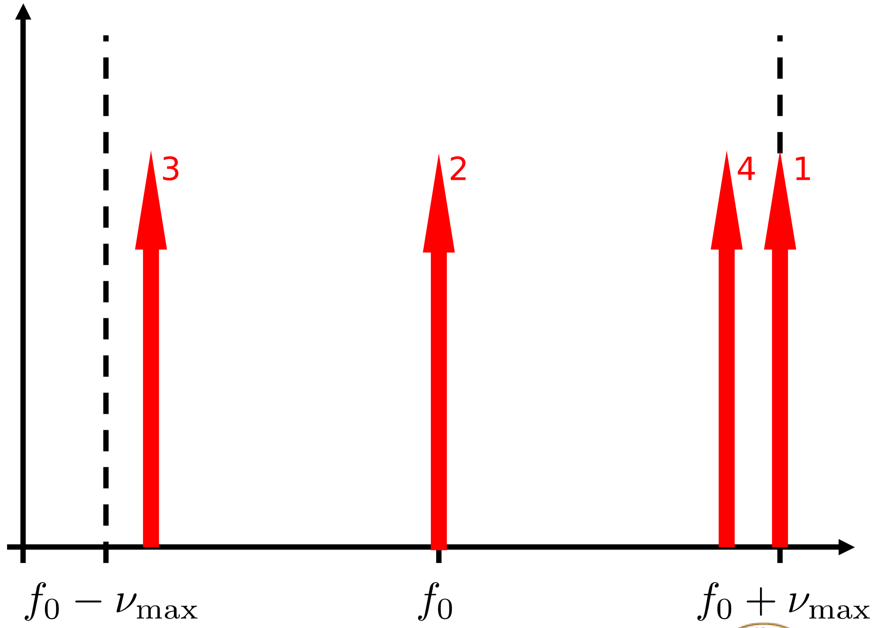
More than one incoming wave

Incoming waves from several directions
(relative to movement or RX)



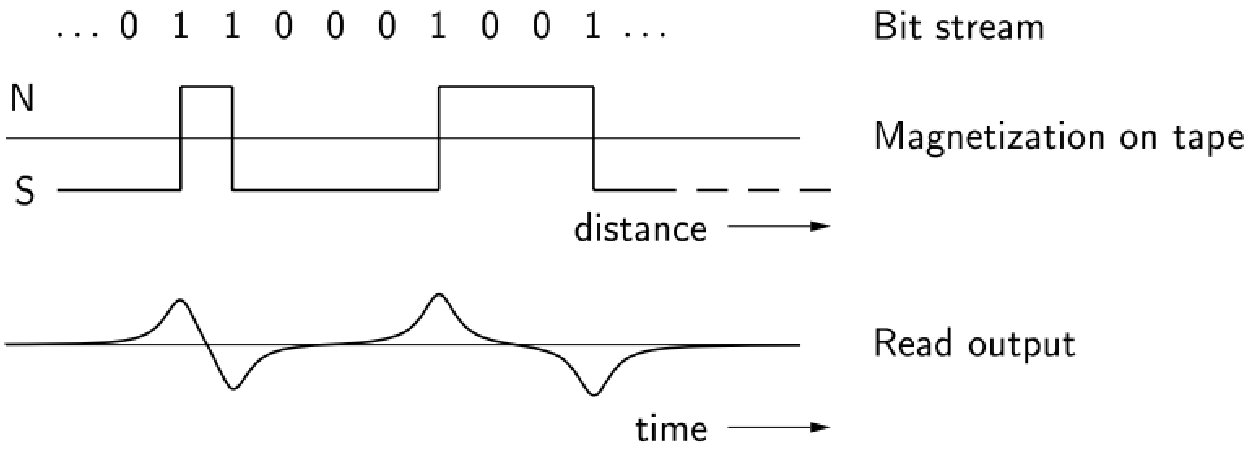
All waves of equal strength in this example, for simplicity.

Spectrum of received signal when a f_0 Hz signal is transmitted.



Magnetic recording

- Store magnetic field with different orientation



SUMMARY

- Wires, cables and fibers
  - Wirels and cables are LTI systems
  - Bandwidth of wires and cables depend on length
  - Coaxial cables can carry higher bandwidths than wires
  - Fibers have low attenuation
- Radio channels
  - Free-space propagation
  - Antenna gains
  - Friis' law
  - Noise properties and calculation
  - Multi-path propagation: Fading and Doppler shifts
- Magnetic recording
  - Storing messages by changing magnetization of tape (Transmitting to another time)

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