Information Transmission
Chapter 4, Channels

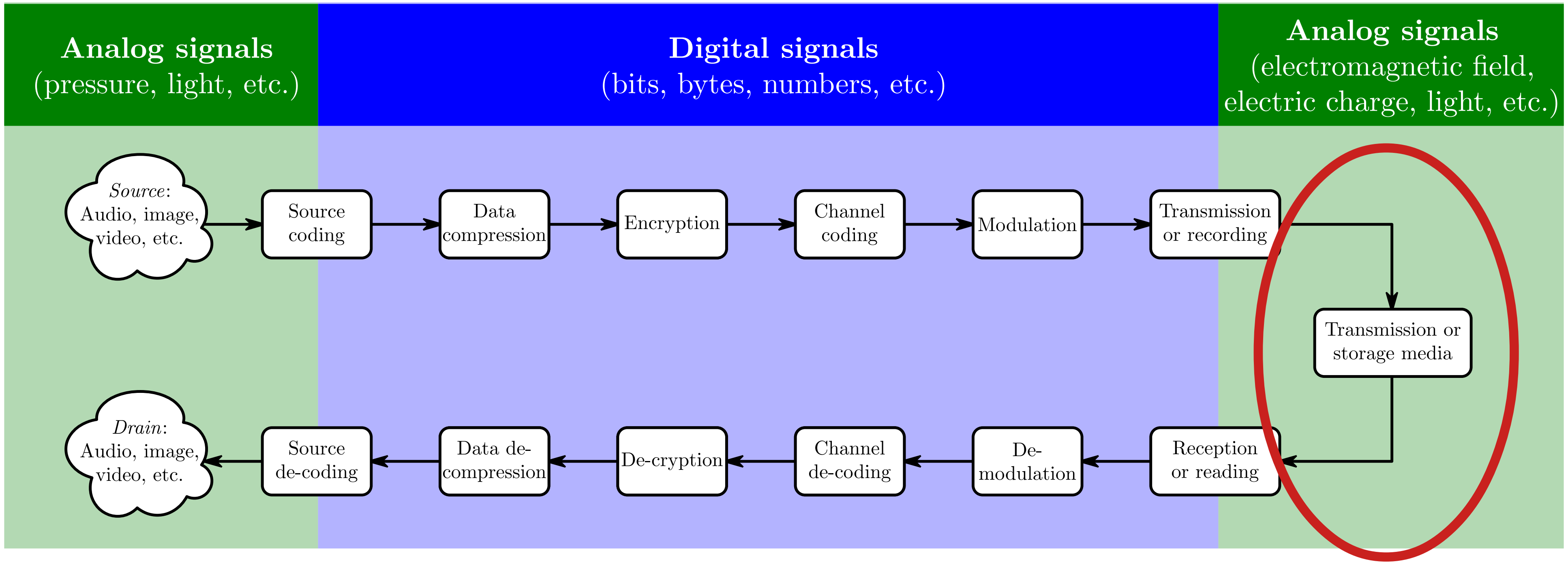
OVE EDFORS

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).

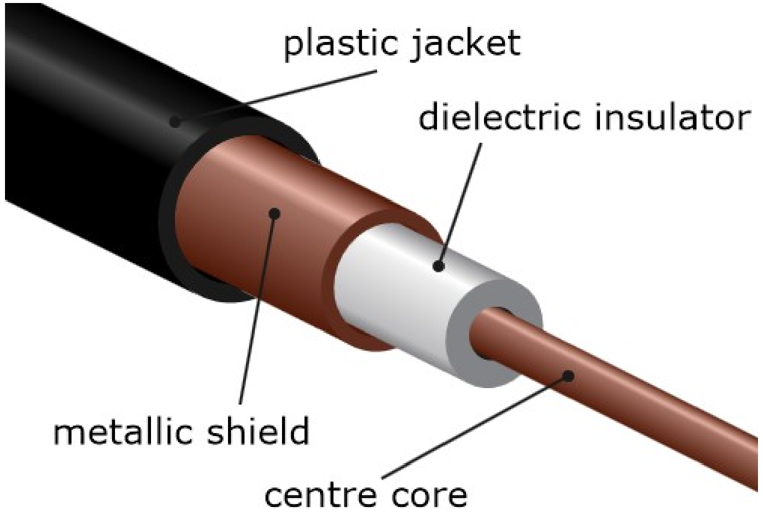
Where are we in the BIG PICTURE?



Lecture relates to pages 105–117 in textbook.

Models of transmission and storage media.

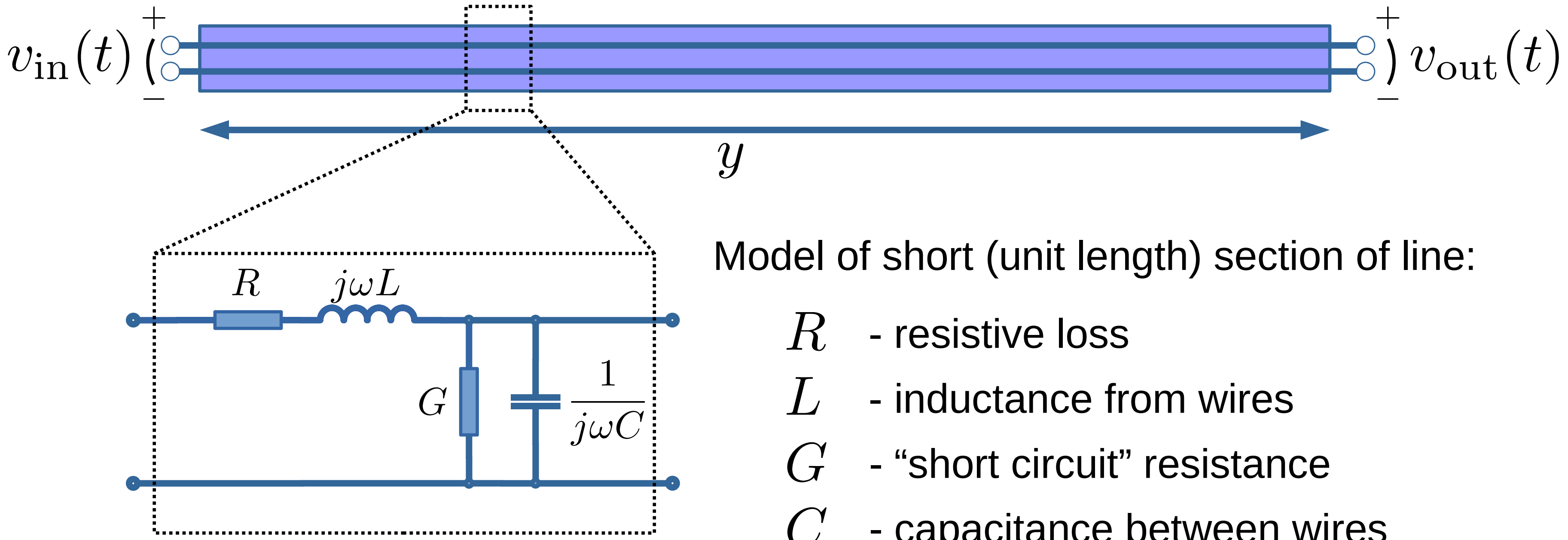
Wires, cables and fibers



- Coaxial cable
- Used for high frequency transmission
- Shielded and controlled properties

- Twisted pair
- Standard telephone line

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

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

- Where the propagation “constant” is given by

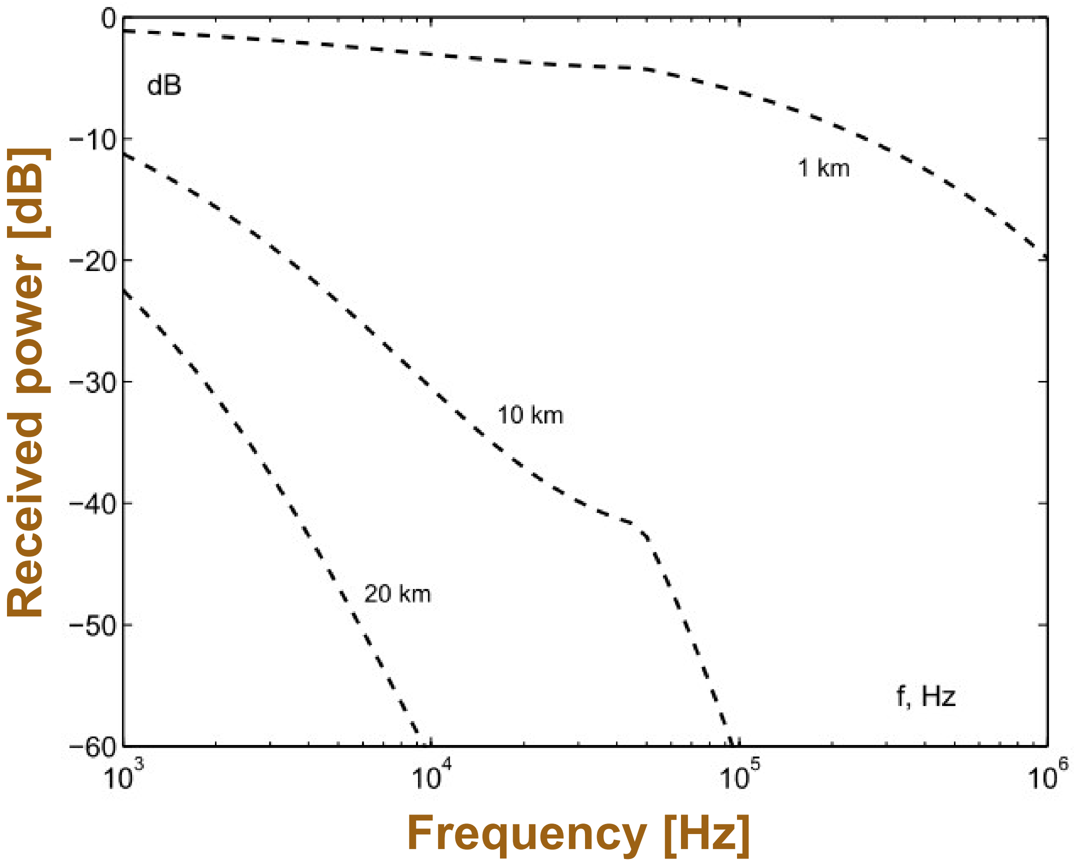
$$\gamma(\omega) = \sqrt{(R(\omega) + j\omega L)(G + j\omega C)}, \quad \omega = 2\pi f$$

- Sinusoid in – sinusoid out, but with an attenuation and a phase shift

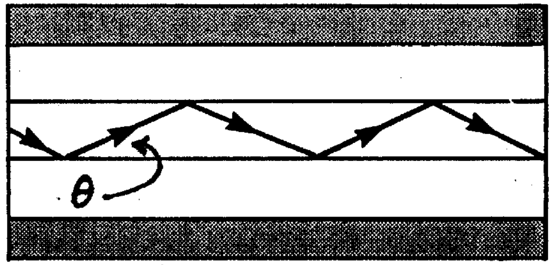
NOTE: Due to something called the *skin effect*, the resistance R is frequency dependent at high frequencies, so that $R(\omega) \approx K_0\sqrt{\omega}$

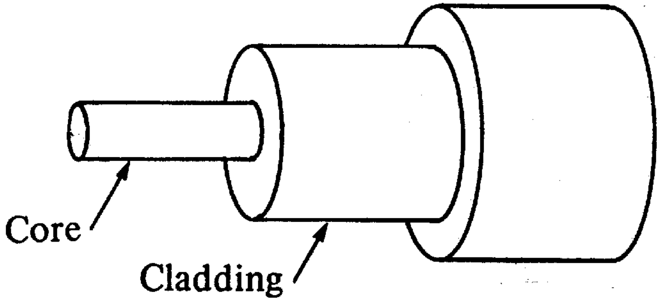
Attenuation of a wire pair (phone line)

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



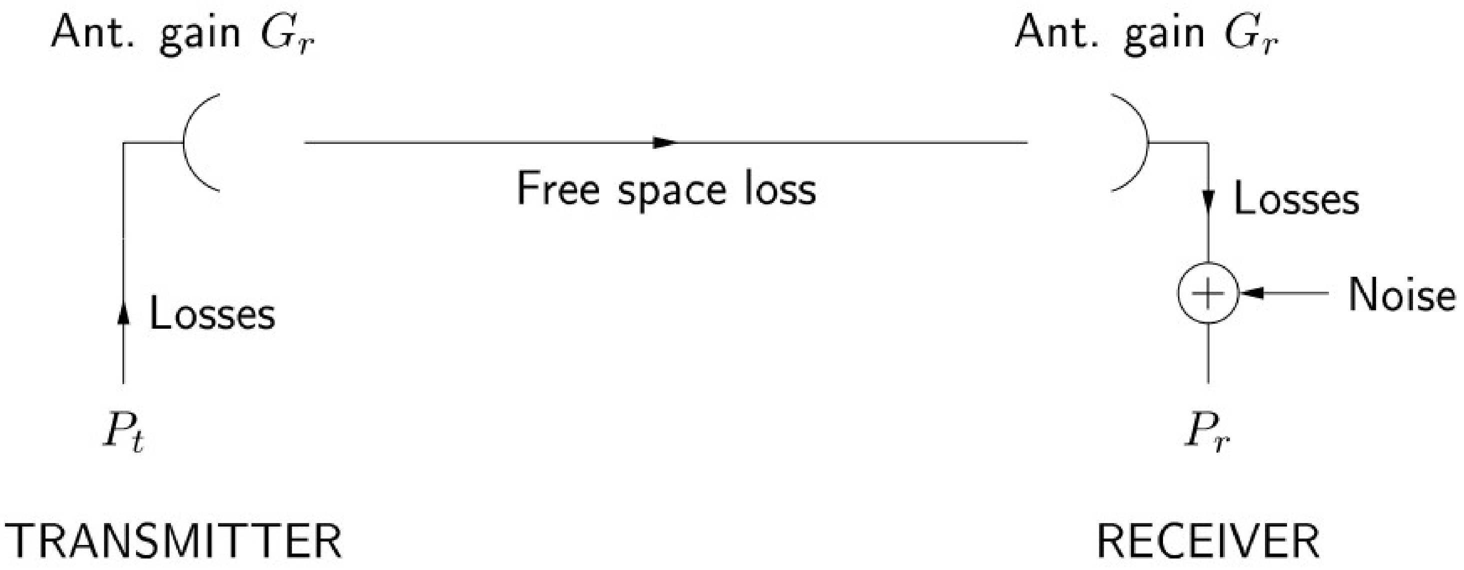
Propagation in a fiber





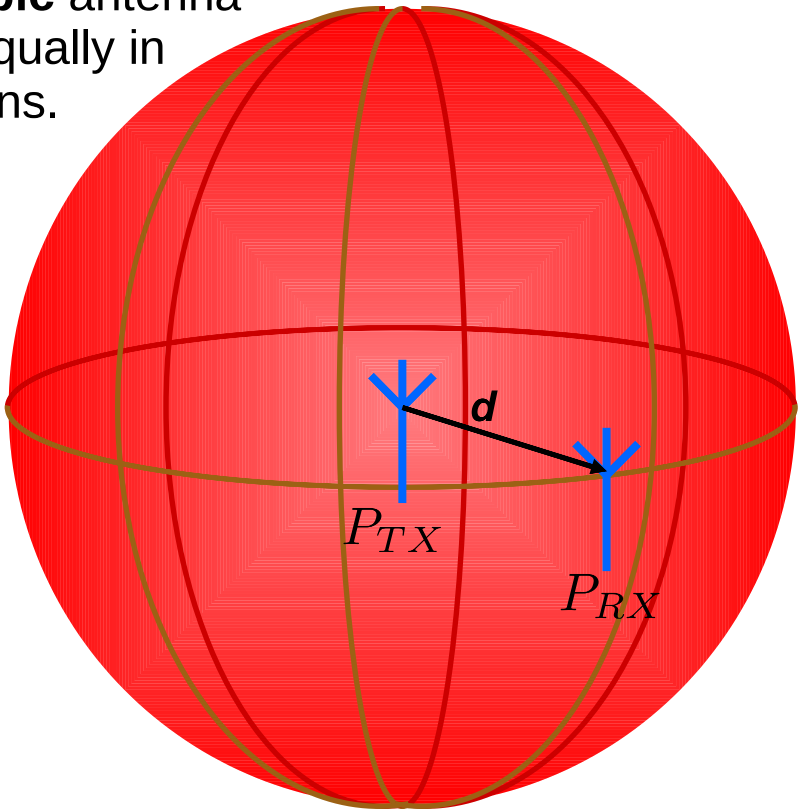
Fibers have low attenuation (< 0.5 dB/km).
Reflections inside the fiber lead to dispersion – the light pulse will
Smear out in time.

Radio Channels – Free space



Free-space loss

An **isotropic** antenna radiates equally in all directions.



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):

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

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

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}:

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

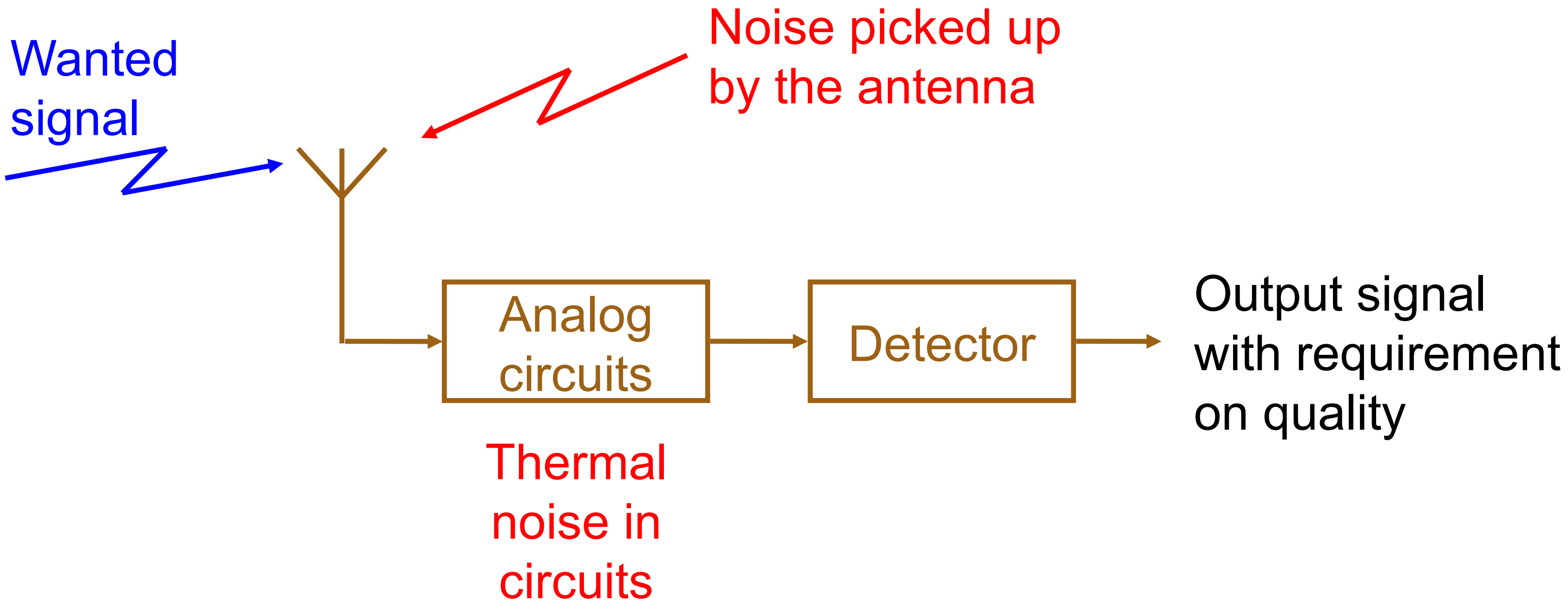
If we write the expression in dB ...

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

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

Noise sources

The total noise situation in a receiver depends on several noise sources



Receiver noise: Noise sources (1)

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

1) Directly [W/Hz]

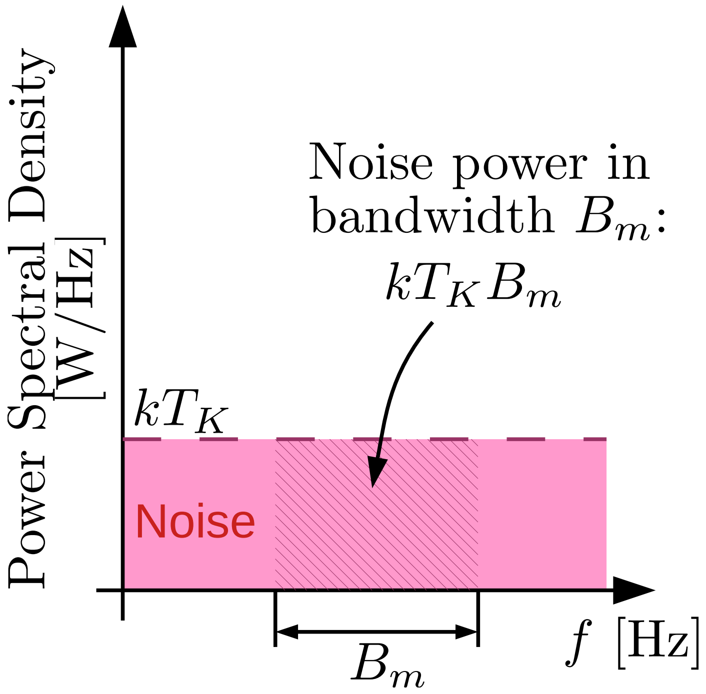
2) Noise temperature [Kelvin]

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

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

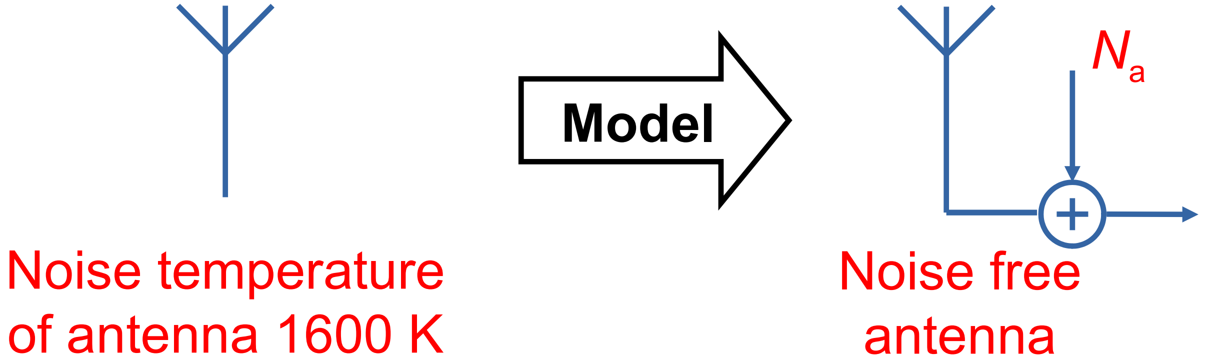
$$N = kT_K B_m$$

Here *k* is Boltzmann’s constant (1.38x10^{-23} W/Hz) and T_K is the is the temperature of the noise source in Kelvin.



Receiver noise: Noise sources (2)

Antenna example



Power spectral density of antenna noise is

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

Multiply with bandwidth to get noise power

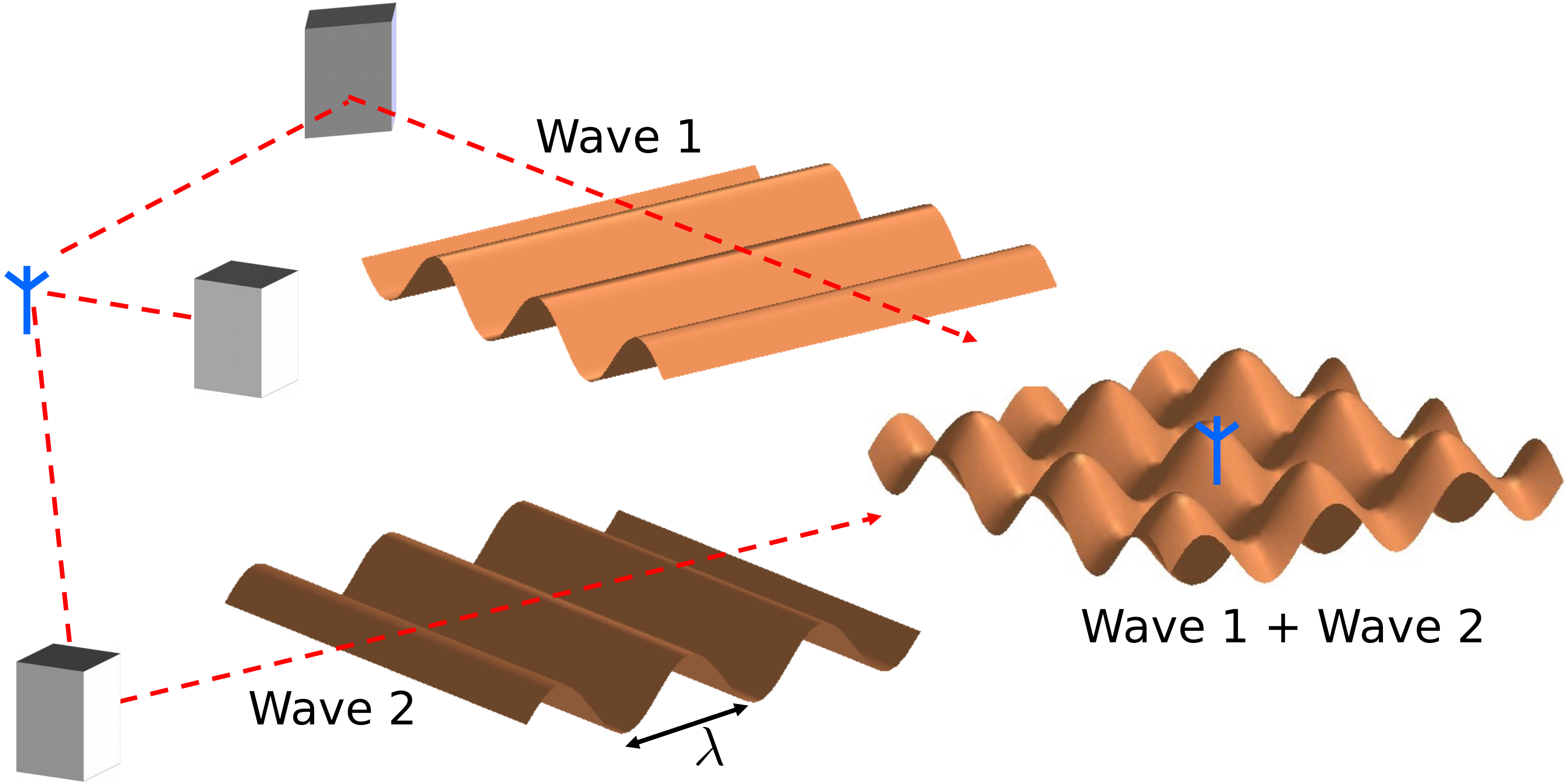
Distribution of the noise

- 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.

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

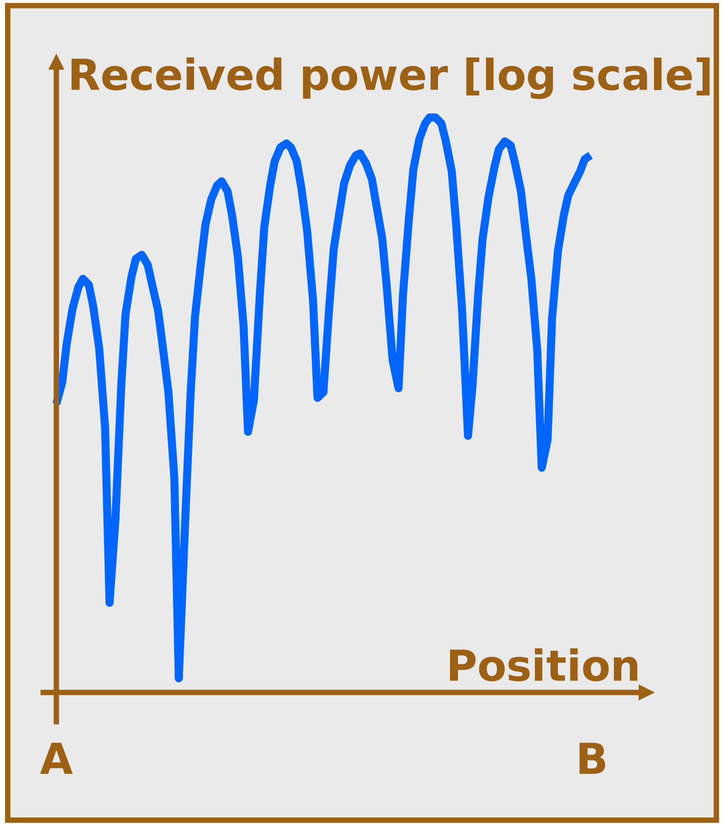
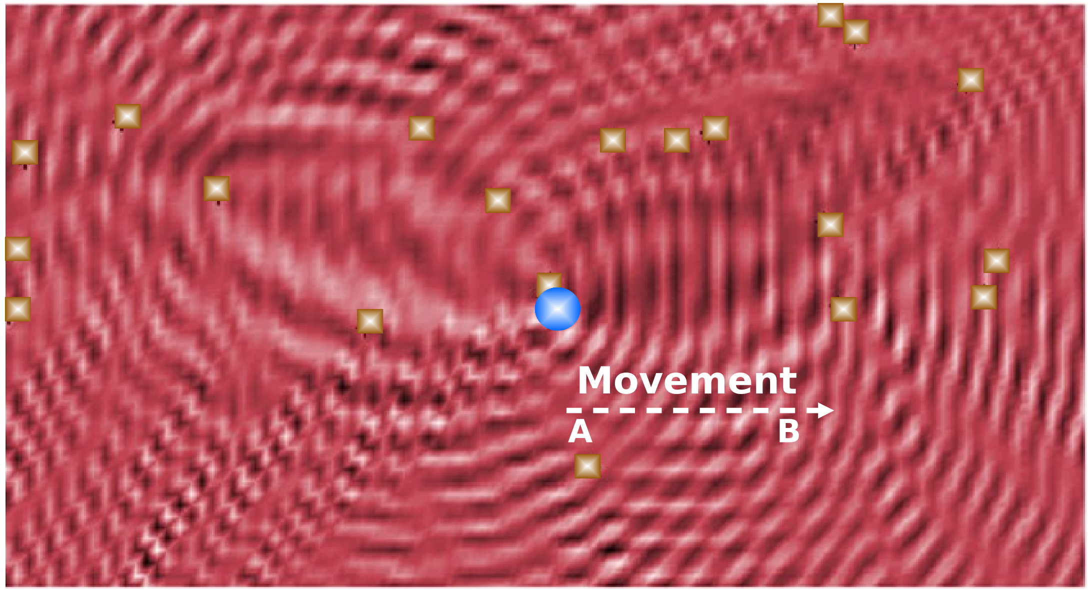


Illustration of interference pattern from above

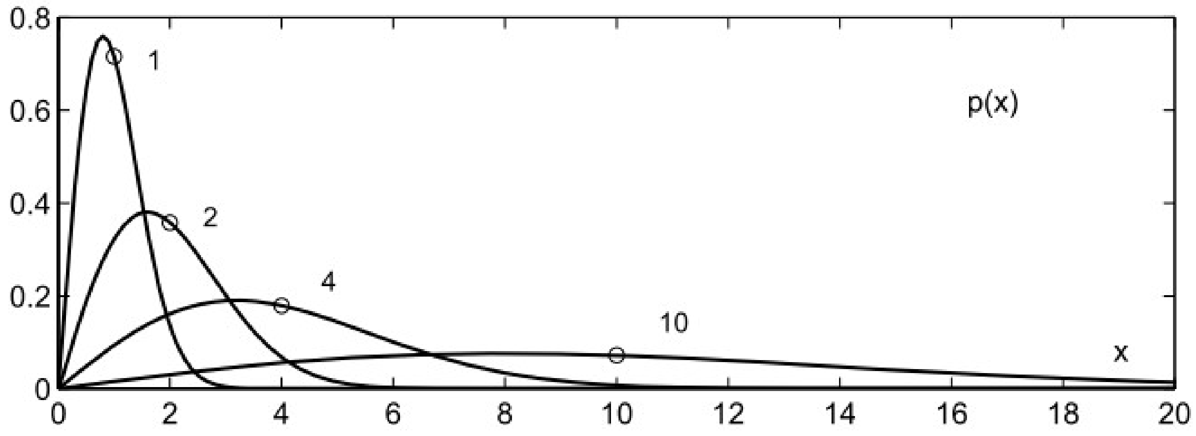


● Transmitter

▨ Reflector

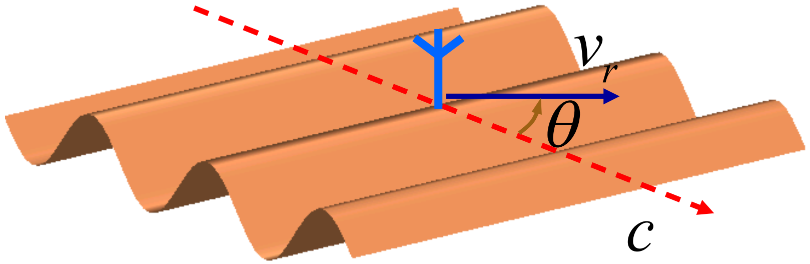
Small-scale fading - Rayleigh fading

Amplitude distribution when mean amplitude is 1, 2, 4, and 10.



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

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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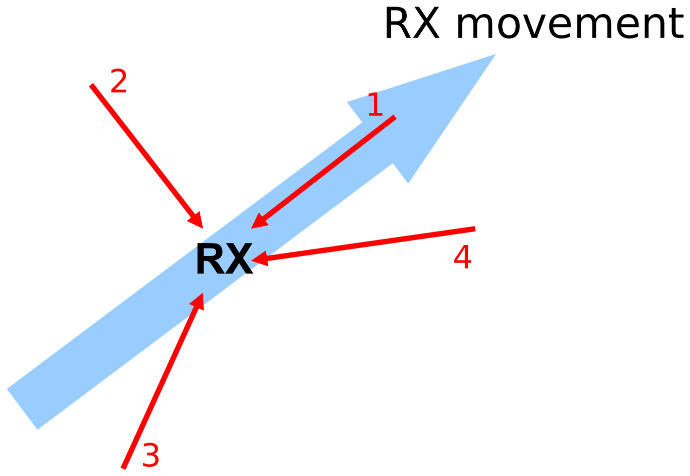
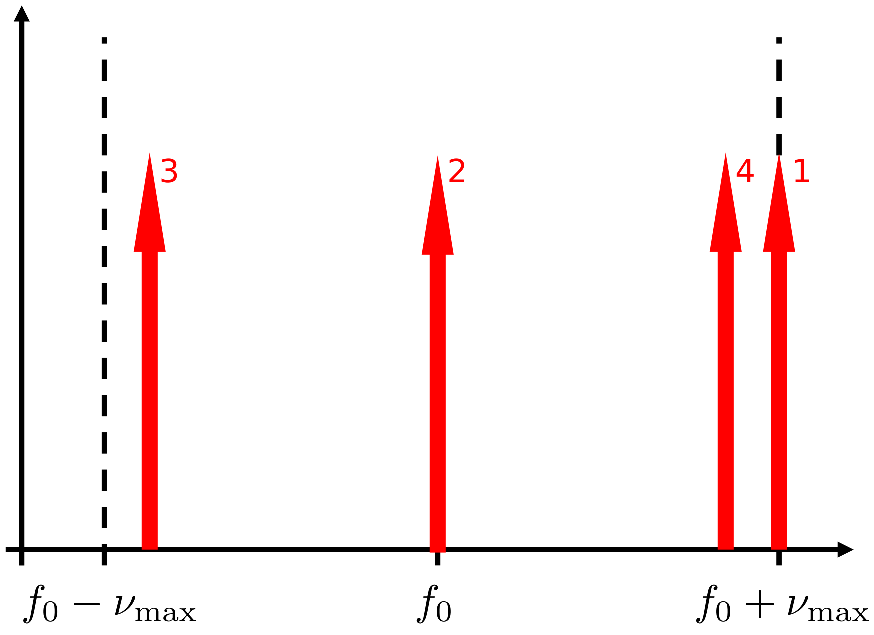
More than one incoming wave

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



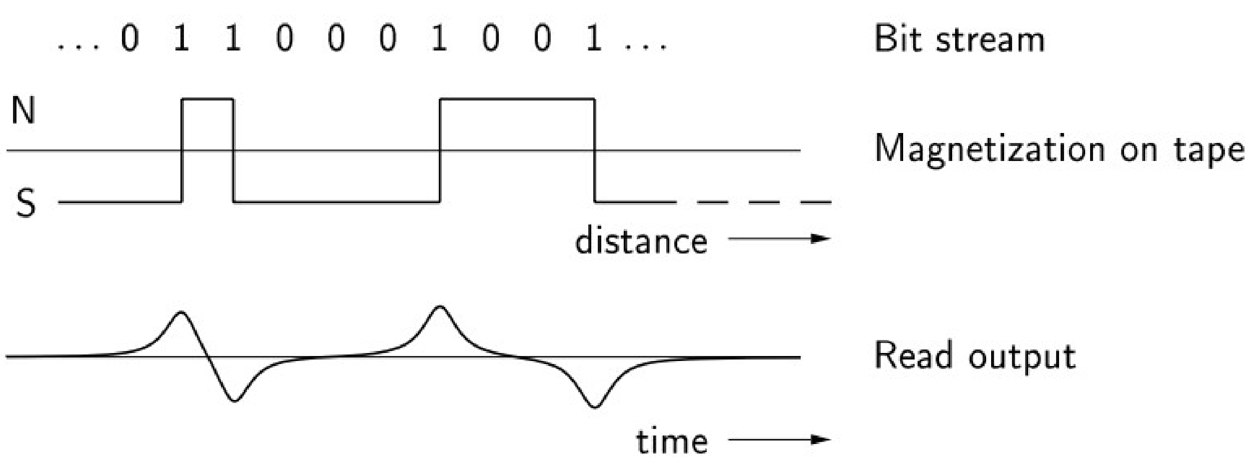
All waves of equal strength in this example, for simplicity.

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



Magnetic recording

- Store magnetic field with different orientation



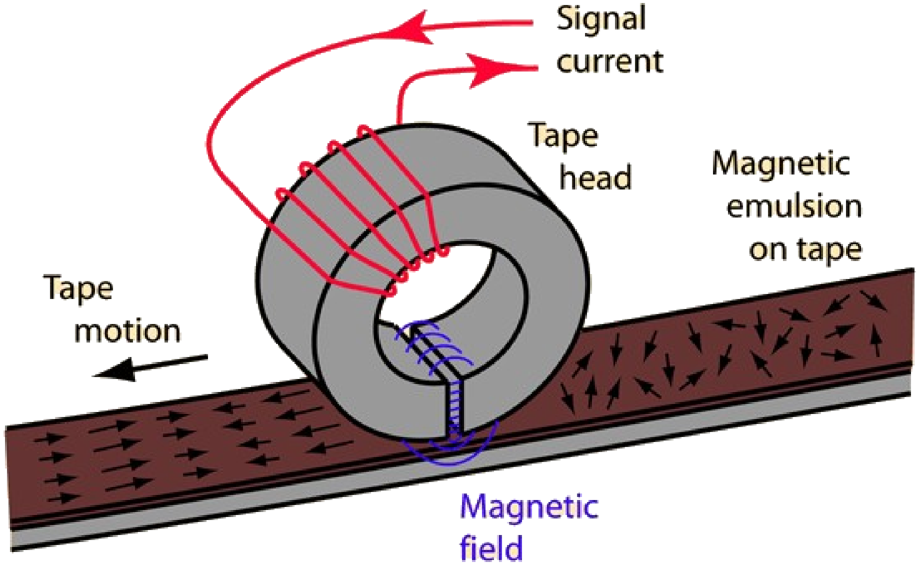


Figure source: http://hyperphysics.phy-astr.gsu.edu

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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