TD1 – Physical Properties of Transmission Media

1. Geometrical spreading

Typical values for parameters for submarine sonar, avionic radar and automotive lidar detection systems are given in the table below.

	Sonar	Radar	Lidar
Peak emitted power	1kW	250kW	50W
Minimal received power	1mW	10^{-12}W	1μW
Target cross section	10m²	25m²	1m²
Receiver cross section	1m²	4m²	0,01m²
Maximum range	2km	160km	180m

a) Assuming initially that in each case the emitter radiates isotropically with an emitted power P_0, obtain an expression for the average power per unit area at a distance R.

b) Assuming in each case that the target re-radiates this power isotropically, use the expression obtained in a) for both the outward trip towards the target and the return trip to the detector to obtain an expression for the received power on the detector based on the receiver cross section, A_r (effective detection area) and the target cross section, A_t (effective target area reflecting the incoming signal).

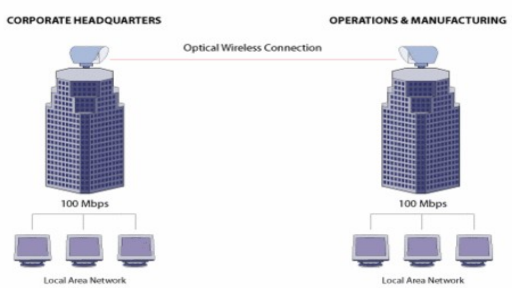
c) Apply this expression for each system (sonar, radar, lidar) to obtain a calculated maximum system range (assuming isotropic radiation) based on geometrical spreading considerations alone (ignore material absorption).

d) Compare the calculated ranges to the maximum ranges stated for each system in the above table. Explain any differences between the calculated ranges and stated maximal ranges and explain how the indicated ranges can be achieved.

2. Guided optical transmission vs Free-space optical transmission

To minimise optical spreading effects, in free-space optical transmission systems (typically used to transmit high data rates between buildings or quickly setup temporary high datarate transmission links), highly directive laser beams are used.

Free space optical communications



However, laser beams are not completely non-divergent and the beam diameter typically increases with propagation distance. This increase can be modelled using the Gaussian beam propagation expression given on page 20 of lecture C2.

a) Use the indicated expression to calculate the Gaussian beam radius on a receiver at a distance of 5km for a 2cm radius emitted beam at a wavelength of 1.55µm.

b) Assuming receiver collecting optics have a 10cm diameter, estimate the power loss factor due to Gaussian beam divergence (a very basic model based on surface area and a uniform disc shape light distribution is sufficient).

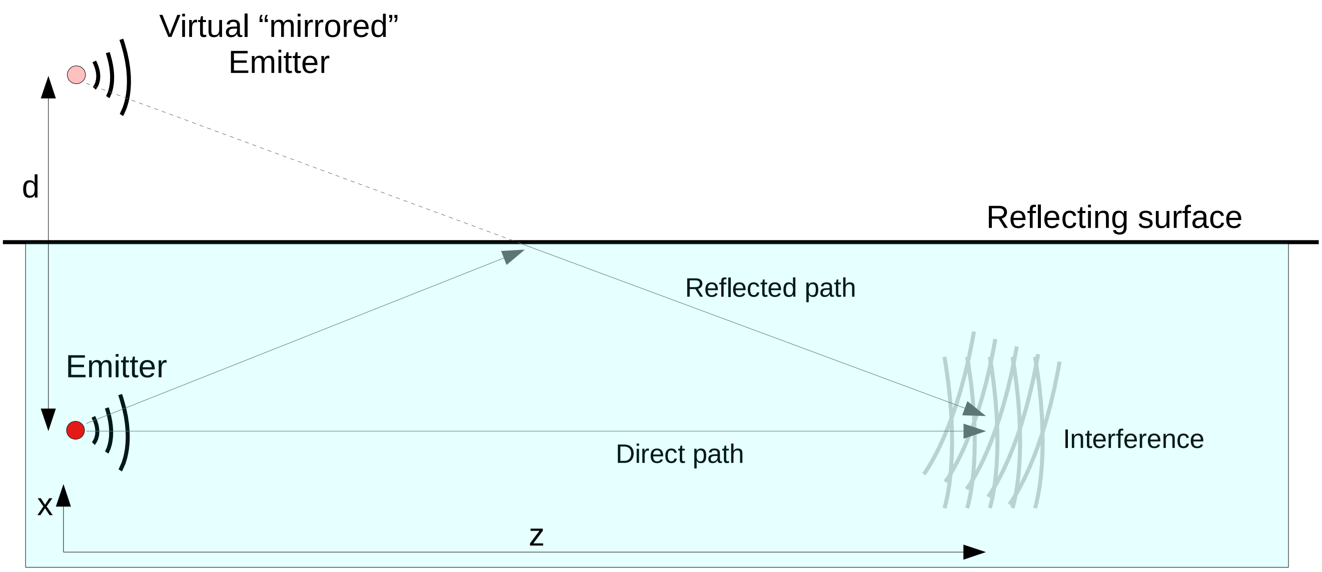
c) Calculate this power loss in dB

d) Compare this loss to the power loss over 5km in a single mode optical fibre waveguide with a loss of 0.18dB/km.

3. Fading and interference effects

Geometrical reflections from surfaces that appear smooth at the scale of the wavelength of a propagating signal can produce interference between direct ray paths and reflected paths. This interference can cause local variations (or fading) in the received signal power. Examples are the reflection of acoustic waves at the sea-air surface or the reflection of radio signals (e.g. WiFi) by metal clad buildings.

A simple but useful model for reflection by a plane surface is to consider that the reflection produces a second “mirrored” source and then to model the interference pattern produced by the superposition of the waves emitted by these two sources – see figure below.



This system is analogous to the well-known Lloyd's mirror or Young's slit experiment in optics in which the interference pattern intensity variation is given by:

$$I(x) \propto \cos^2\left(\frac{\pi d x}{\lambda z}\right)$$

where λ is the wavelength, d is the separation of the real and virtual sources, z and x are indicated in the figure and we assume the observation distance is much greater than the separation of the sources (z >> d).

a) Obtain an expression for the fading pitch (distance between two maxima in the detected intensity) in the x direction at a distance z.

b) Use this expression to obtain the fading pitch for the following three situations:

i. Sonar detection of an object at a distance of 500m using a sonar emitter immersed at a depth of 10m (surface ship mounted sonar) and operating at a wavelength of 5cm
ii. A pedestrian using a mobile phone (GSM frequency 1800MHz) at distance of 500m from the transmitter mast and 5m from a metal clad building.
iii. A vehicle mounted lidar system, operating at a wavelength of 1550nm positioned at a distance of 5m from a metal clad building used to detect an obstacle at a distance of 100m.

c) In each case indicate how and why interference induced fading effects are likely (or not) to disrupt device operation.

3. Range finding accuracy

Radar, Lidar and Sonar all use return "echo" signals to estimate the distance of a detected object based on the time difference between emission of the outgoing signal and the detection of the return echo. Variations in propagation speed in the transmission media can lead to uncertainty in the measured range.

Temperature, pressure and humidity variations produce changes in the refractive index of the atmosphere of approximately 0.02% at light wavelengths and 0.03% at radar wavelengths
Temperature, pressure and salinity variations in sea water produce changes in the propagation velocity (on average roughly 1500m/s) of approximately 3%.

Calculate the resulting uncertainty in range measurement for:

i. A Sonar detected underwater target at a distance of 1km
ii. A Lidar detected object at a distance of 200m
iii. A Radar detected object at a distance of 20km