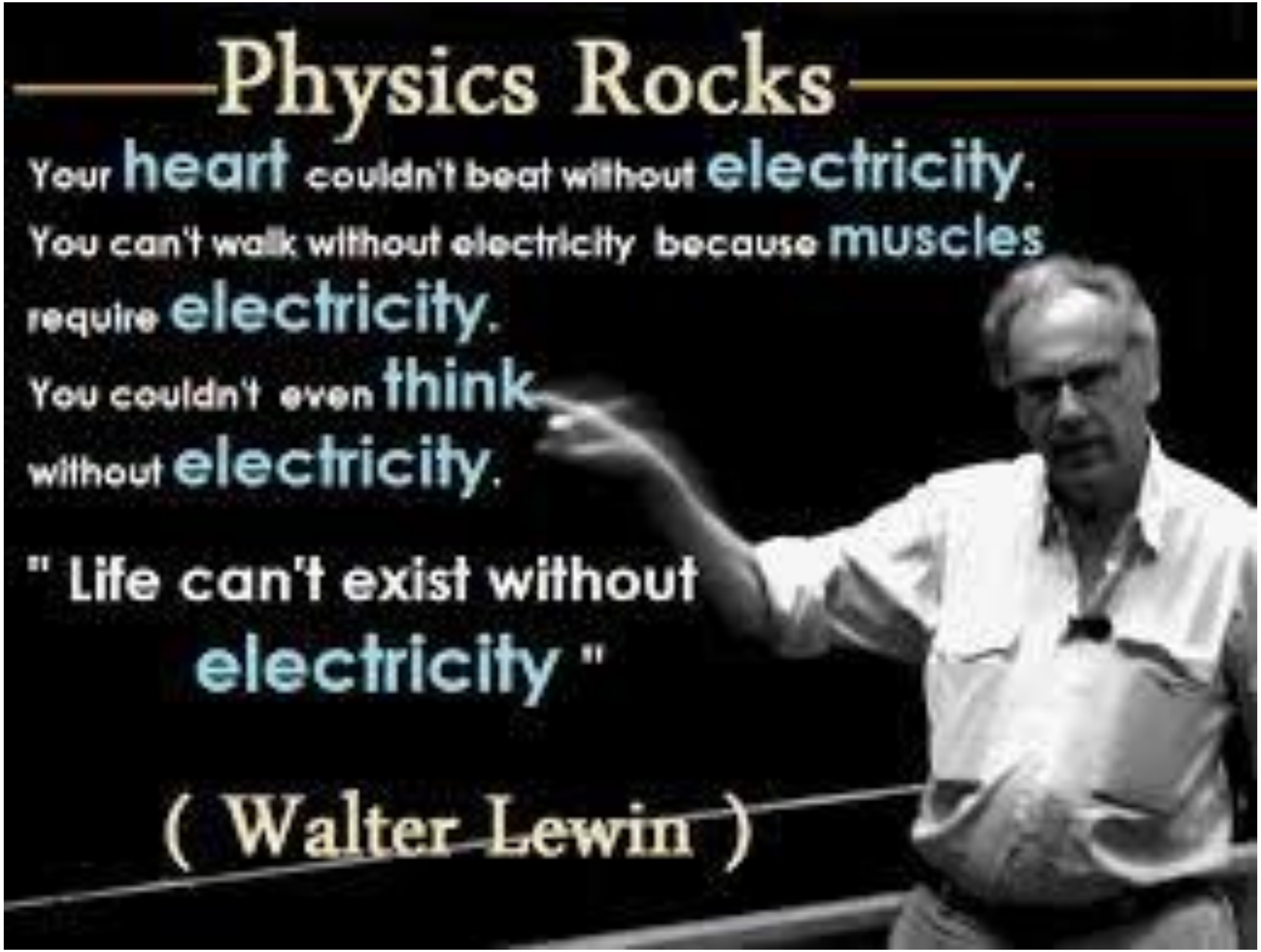
SOME PHYSICS OF SENSORS



Scientists made up the words radar, sonar and lidar. Each reflects a technology’s usefulness:

- Radar: ra(dio) d(etection) a(nd) r(anging)
- Sonar: so(und) na(vigation) (and) r(anging)
- Lidar: li(ght) d(etection) a(nd) r(anging)

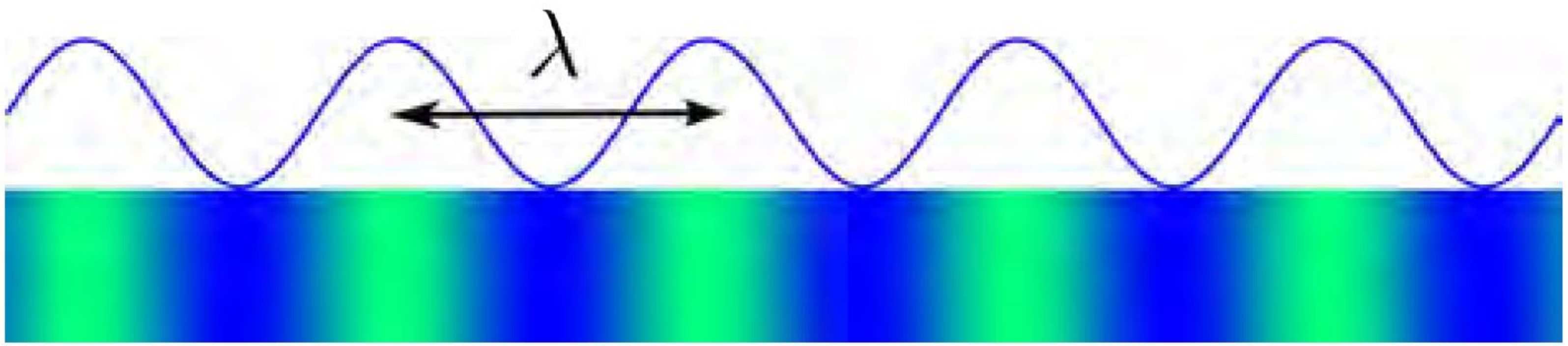


FIG. 2 A sound wave is a longitudal perturbation of pressure

- Wave period T [s]
- Frequency $f = 1/T$ [Hz]
- Sound speed c [m/s]
- Wavelength $\lambda = c/f$ [m]

https://www.uio.no/studier/emner/matnat/ifi/INF-GEO4310/h12/undervisningsmateriale/sonar_introduction_2012_compressed.pdf

The range to the target is then given as

$$R = \frac{c\tau}{2} \quad (12)$$

The sound velocity c has to be known to be able to map delay into space.

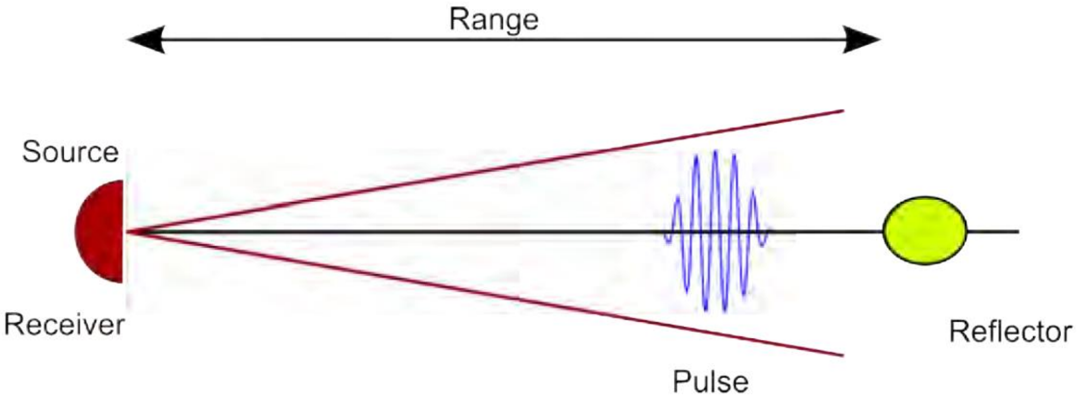


FIG. 14 Estimation of range.

The accuracy of which the range is estimated is related to the pulse length T_p for traditional pings (or gated CW pulses)

$$\delta R = \frac{cT_p}{2}. \quad (13)$$

This is equivalent to the *range resolution* defined as the minimum spacing two echoes can be seperated and still detected (see Fig. 15). A shorter pulse gives better range resolution. However, shorter pulses has less energy in the pulse, which again gives shorter propagation range.

A transducer (or antenna or loudspeaker) is directive if the size of the antenna is large compared to the wavelength. The directivity pattern generally contains a main lobe, with a *beamwidth* (or field of view)

$$\beta \approx \frac{\lambda}{D} \tag{16}$$

where D is the diameter (or length) of the antenna. This is shown in Fig. 16.

We note that the beamwidth is frequency dependent. Higher frequency gives narrower beam for a given antenna size. Or, conversely, higher frequency gives smaller antenna size for a given angular spread. This is the single most important reason to choose high frequencies in sonar imaging.

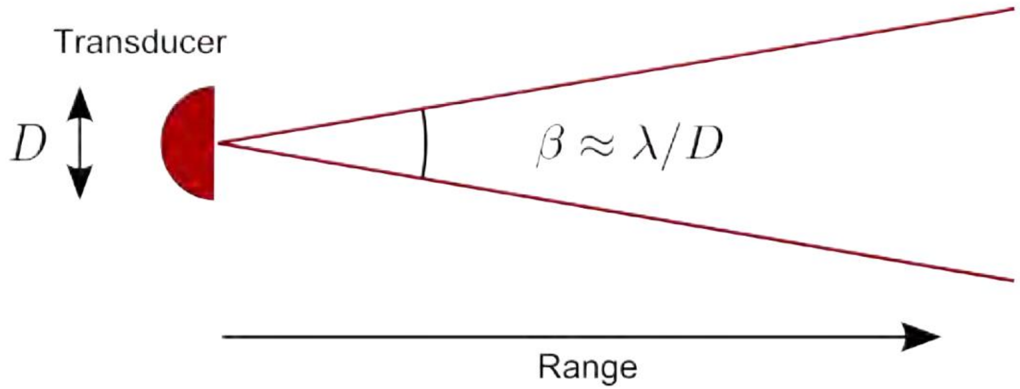


FIG. 16 Transducer directivity.

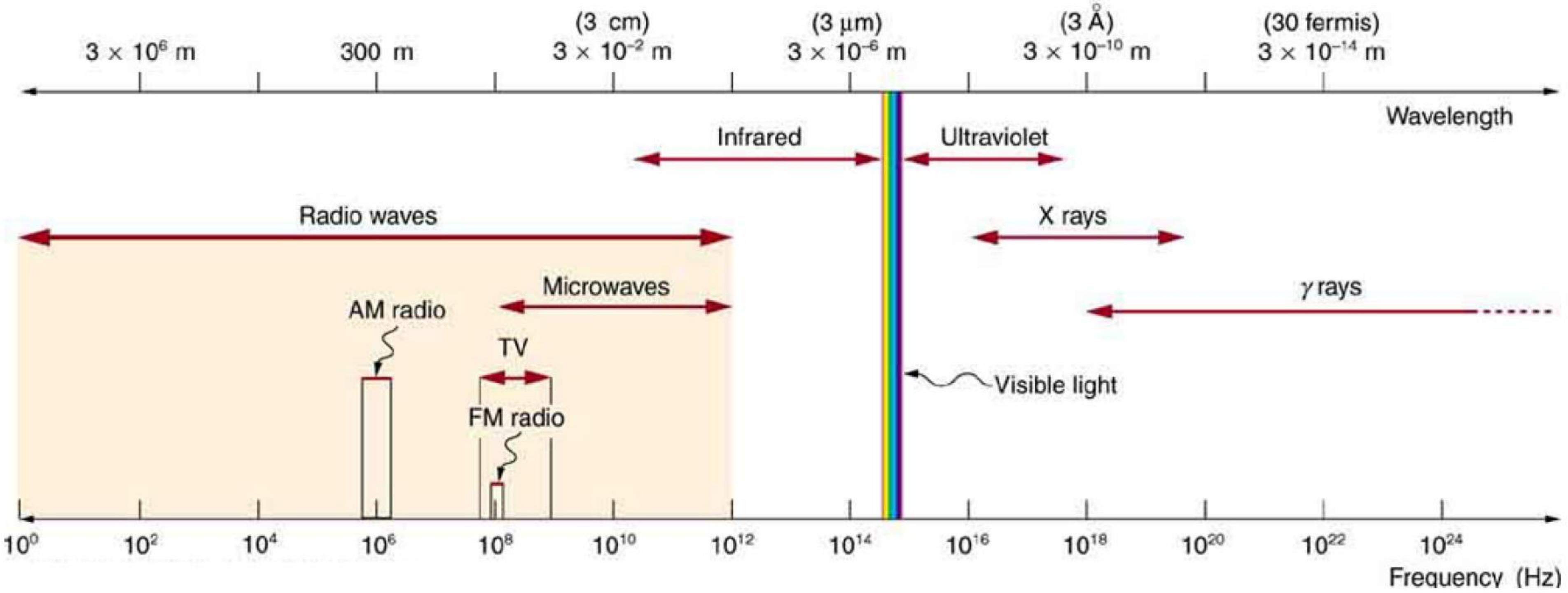


Figure 1. The electromagnetic spectrum, showing the major categories of electromagnetic waves. The range of frequencies and wavelengths is remarkable. The dividing line between some categories is distinct, whereas other categories overlap.

https://courses.lumenlearning.com/physics/chapter/24-3-the-electromagnetic-spectrum/

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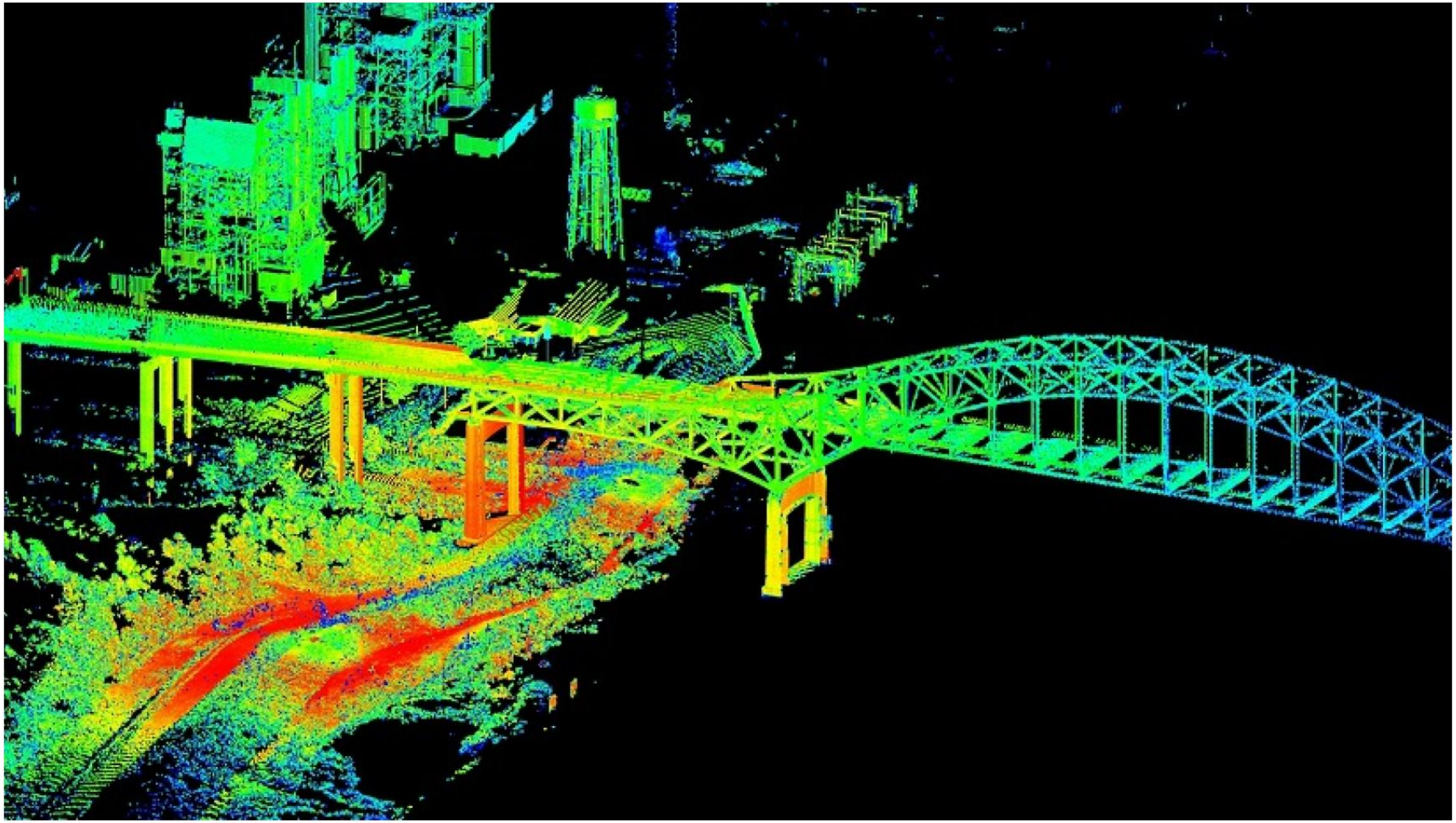
$c = f\lambda.$

- High-frequency electromagnetic waves are more energetic and are more able to penetrate than low-frequency waves.
- High-frequency electromagnetic waves can carry more information per unit time than low-frequency waves.
- The shorter the wavelength of any electromagnetic wave probing a material, the smaller the detail it is possible to resolve.

Note that there are exceptions to these rules of thumb.

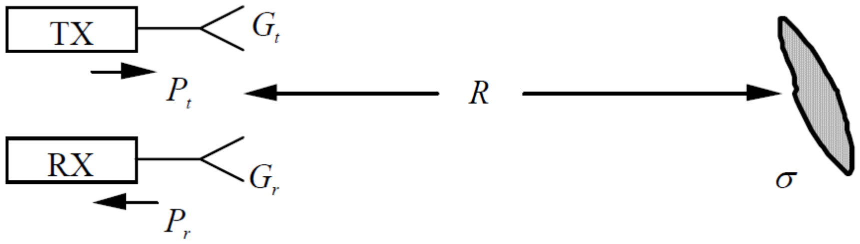


A 3-D lidar scan of the Interstate 510 bridge in New Orleans, La. The U.S. Geological Survey used lidar in parts of Louisiana, Mississippi and Alabama to map flooding after 2012's Hurricane Isaac.

Radar Range Equation

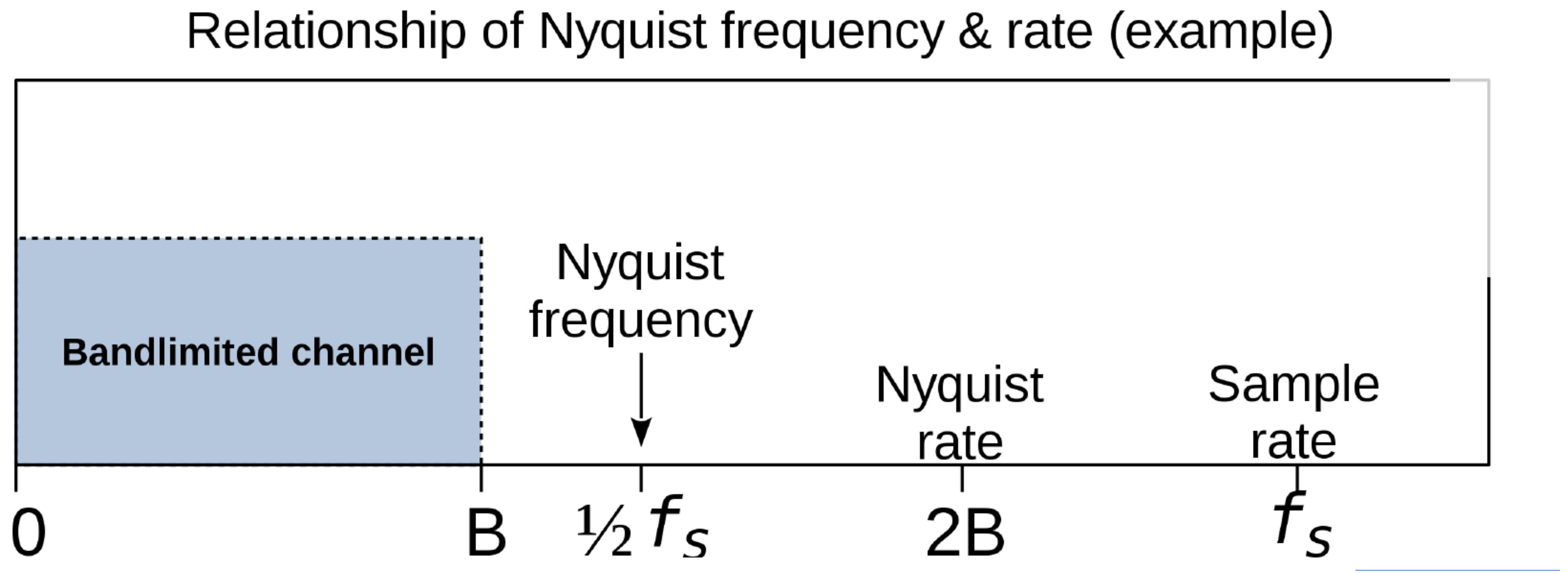
NAVAL POSTGRADUATE SCHOOL

- Quasi-monostatic



P_t = transmit power (W)
P_r = received power (W)
G_t = transmit antenna gain
G_r = receive antenna gain
σ = radar cross section (RCS, m^2)
A_{er} = effective aperture area of receive antenna

$$P_r = \frac{P_t G_t \sigma A_{er}}{(4\pi R^2)^2} = \frac{P_t G_t G_r \sigma \lambda^2}{(4\pi)^3 R^4}$$



Basic Sampling at 2x Highest Frequency in Band (B)

Nyquist Limit

The absolute limiting resolution of a sensor is determined by its Nyquist limit. This is defined as being one half of the sampling frequency, a.k.a **the number of pixels/mm** (Equation 3). For example, the Sony ICX285 is a monochrome CCD sensor with a horizontal active area of 9mm containing 1392 horizontal pixels each 6.45µm in size. This represents a horizontal sampling frequency of 155 pixels/mm (1392 pixels / 9mm = 1mm / 0.00645 mm/pixel = 155).

SPATIAL SAMPLING

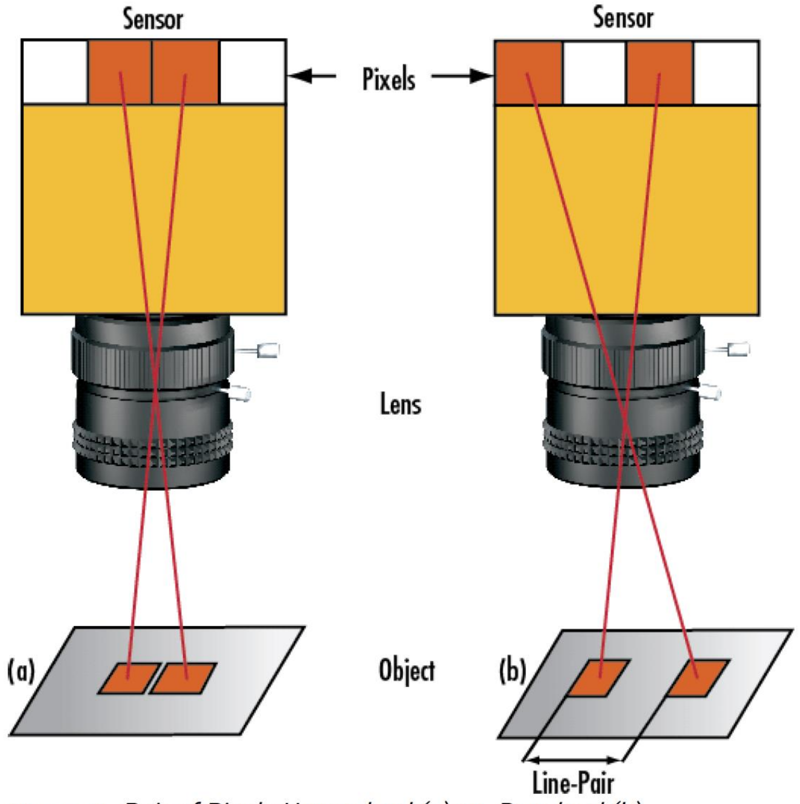


Figure 2: *Pair of Pixels Unresolved (a) vs. Resolved (b)*

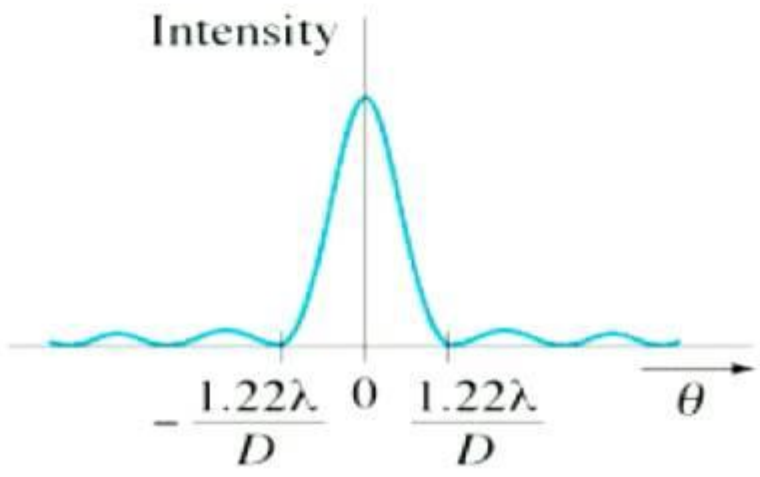
Lp = LinePairs

https://www.edmundoptics.com/knowledge-center/application-notes/imaging/camera-resolution-for-improved-imaging-system-performance/

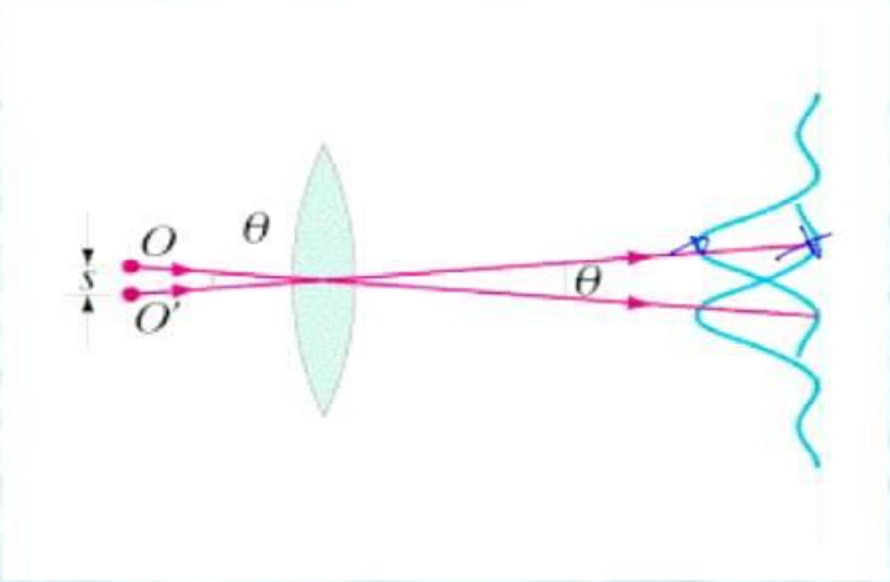
Rayleigh Criterion

$$\theta = \frac{1.22\lambda}{b}$$

θ = Angle of resolution (Rad)
λ = Wavelength (m)
b = Diameter of circular opening (m)
(Telescope aperture)



the bigger the aperture, the smaller the angle you can resolve.



Central maximum of one is over minimum of the other

Motocyle ?
Two Motocycles?
A car?