Predicting the Weather by Watching Airplanes

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Outline

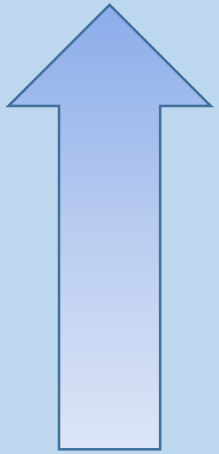
- The importance of measuring humidity distributions in the lower atmosphere (troposphere).
- Insights of how ADSB radio wave transmissions could be used to achieve this by using refractive techniques and radio wave interferometry.
- Discussion of initial relative humidity refraction tests.
- Further work and ideas.

Humidity

- Humidity is an indicator of how much water vapour is present within the air.

- Relative Humidity (RH) is a measure, in %, of how close the air is to being fully saturated:

RH = 100% → Fully Saturated

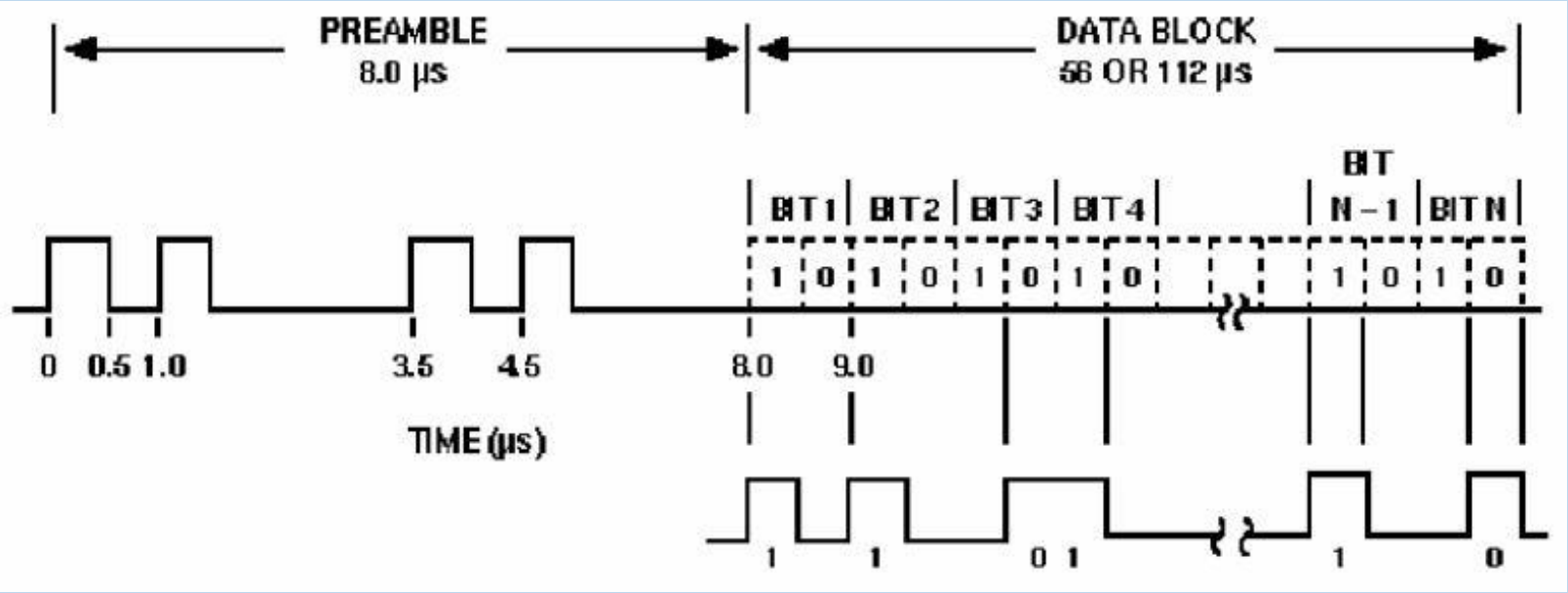


RH = 0% → Completely Dry

- It is an important indicator to weather forecasting e.g. a higher RH means more likelihood of rain.

ADSB

Automatic **D**ependent **S**urveillance **B**roadcast



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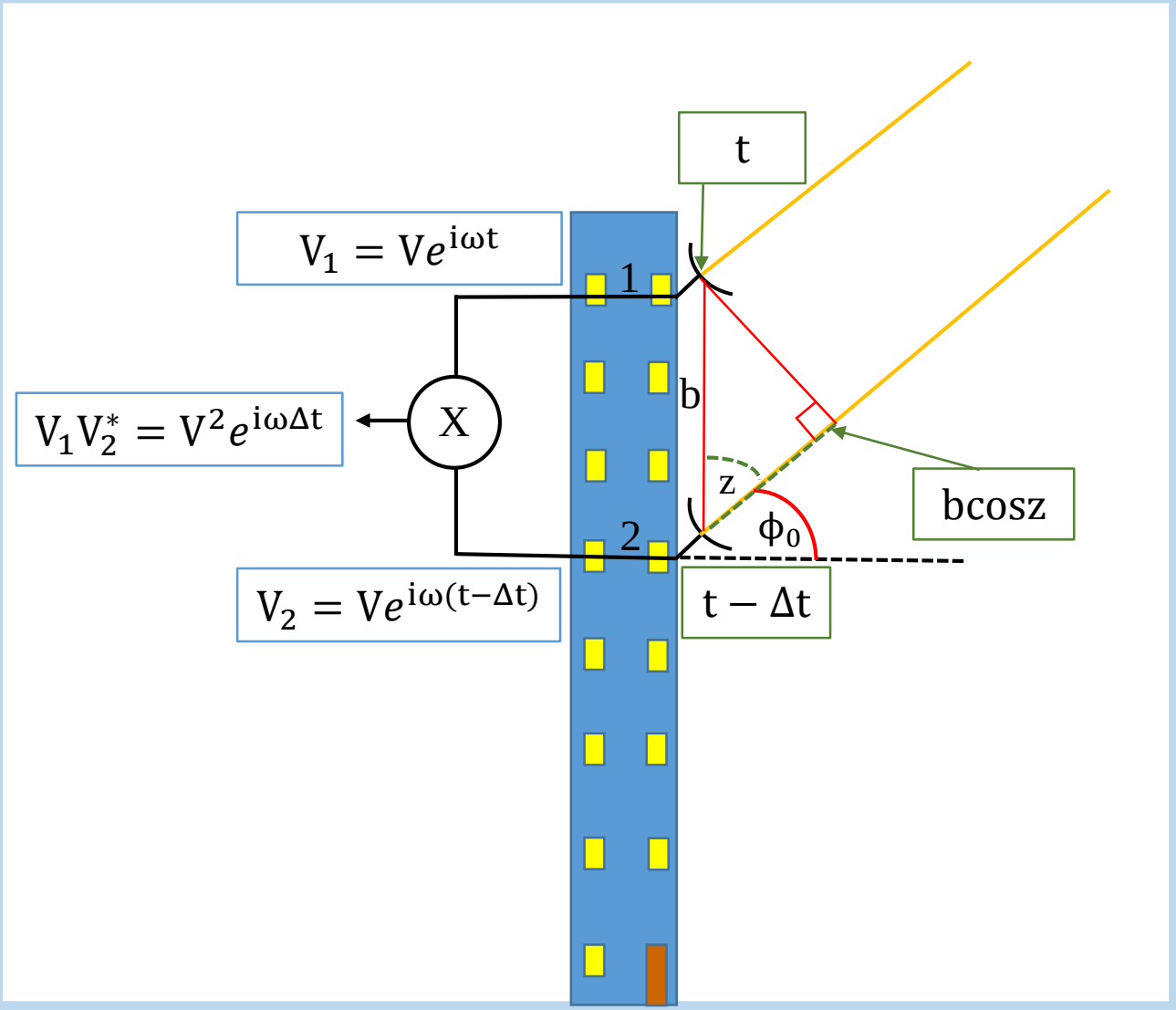
- 1090MHz radio wave → oscillates at 10^{-9}s!
- Characteristic 8.0µs preamble (for synchronisation) & 56 or 112µs data block
- 1 Bit per µs
- Pulse transmitted in 1st or 2nd half of bit


t
$V_1 = Ve^{i\omega t}$
1
b
$V_1V_2^* = V^2e^{i\omega\Delta t}$
X
z
ϕ_0
bcosz
2
$V_2 = Ve^{i\omega(t-\Delta t)}$
$t - \Delta t$

Radio Interferometry

- Two radio interferometers are located on floors four and seven of the Physics building.

- The baseline gap, b ~ 10m

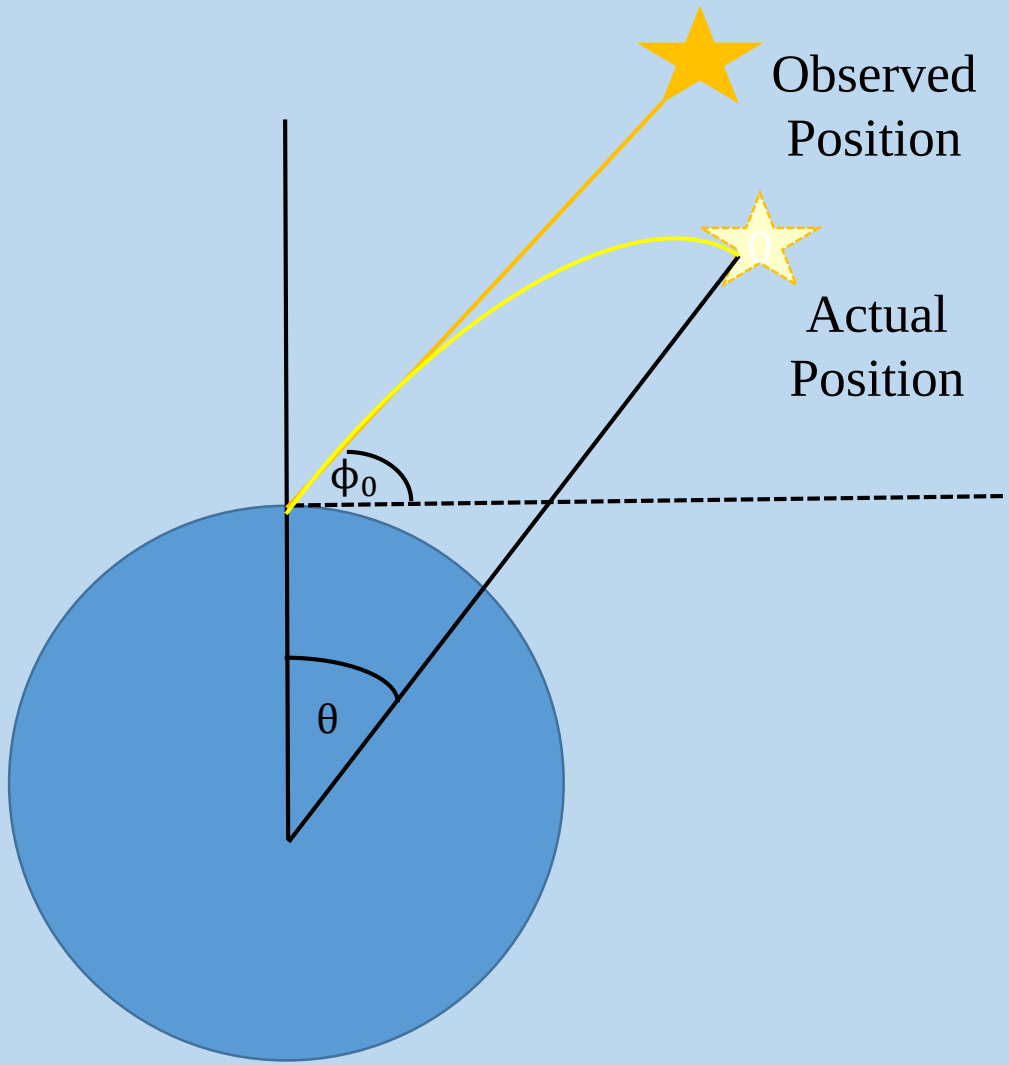
- ADSB signals from a source is received and the conjugate product $V_1 V_2^*$ is taken to obtain;

  - the time average voltage: $\frac{V^2}{2}$

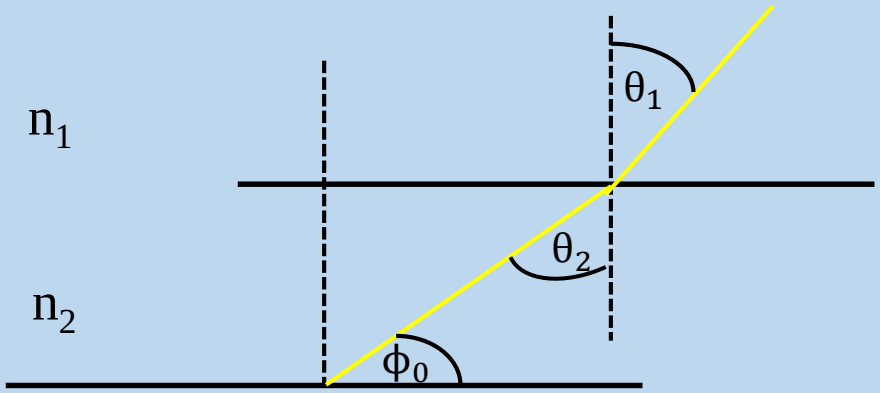
  - the phase: $\phi = \omega\Delta t = 2\pi\frac{b}{\lambda}\cos z$

Refraction

- The more refracted the ray, the smaller its path distance for each increment in θ.



- Due to Snell's law, one would expected more refraction as the observed angle ϕ_0 becomes smaller.



$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

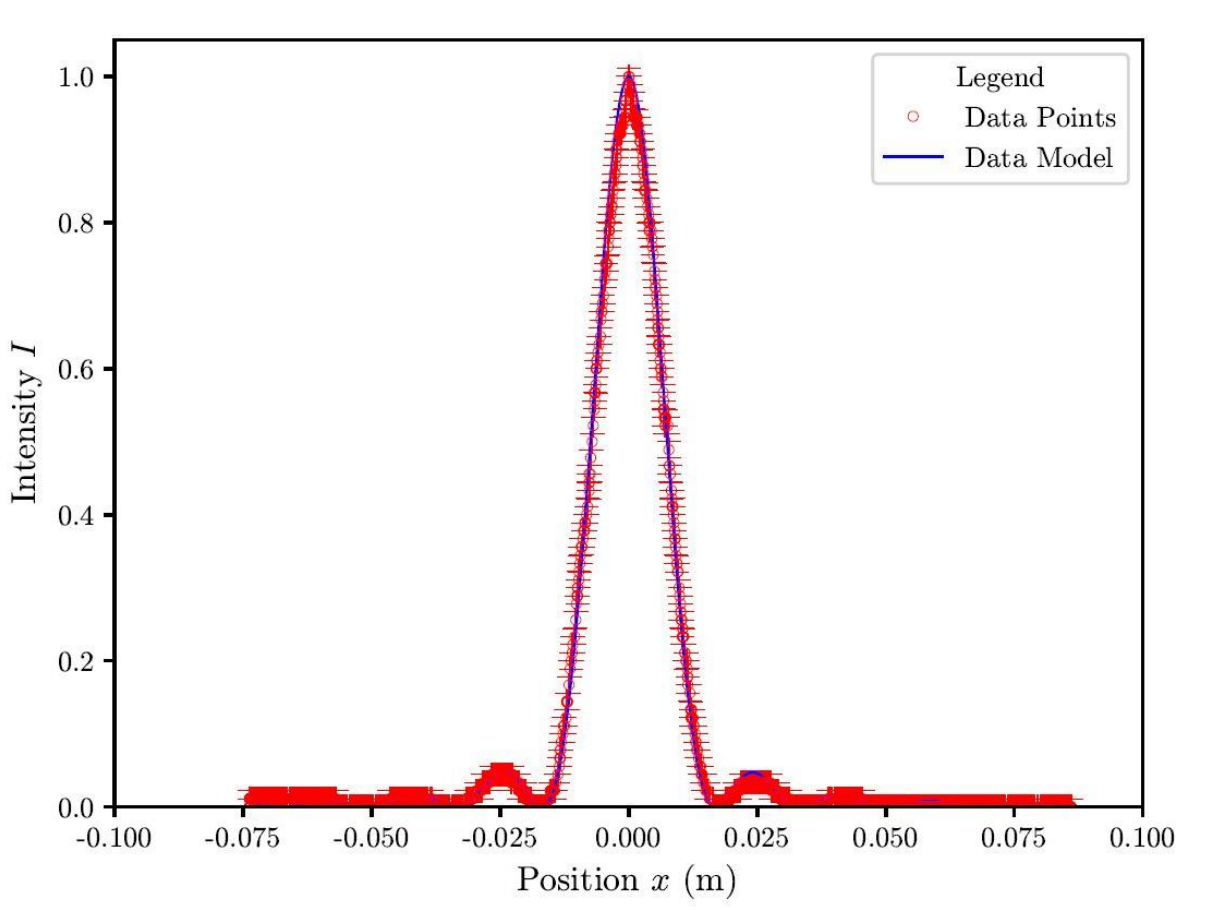
$$\rightarrow n_1 \sin\theta_1 = n_2 \left(\frac{\pi}{2} - \phi_0\right)$$

$$\rightarrow n_1 \sin\theta_1 = n_2 \cos\phi_0$$

Single Slit Diffraction

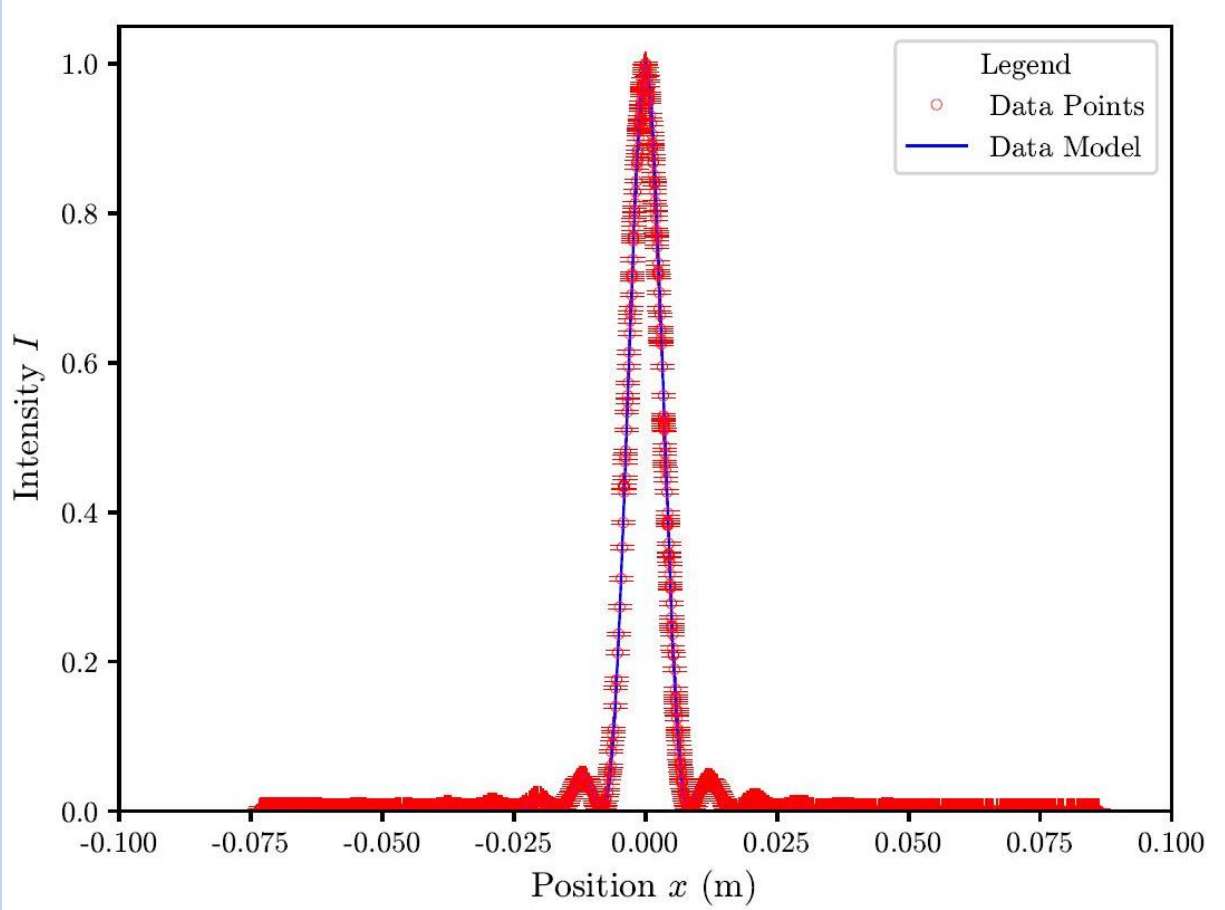
$$I \approx I_0 \frac{\sin^2\left(\frac{\pi a}{L} \cdot \frac{x}{\lambda}\right)}{\left(\frac{\pi a}{L} \cdot \frac{x}{\lambda}\right)^2}$$

1.0mm Aperture, a = 0.02mm



Experimental Value: $\lambda = 674 \pm 1$ nm

1.0mm Aperture, a = 0.04mm



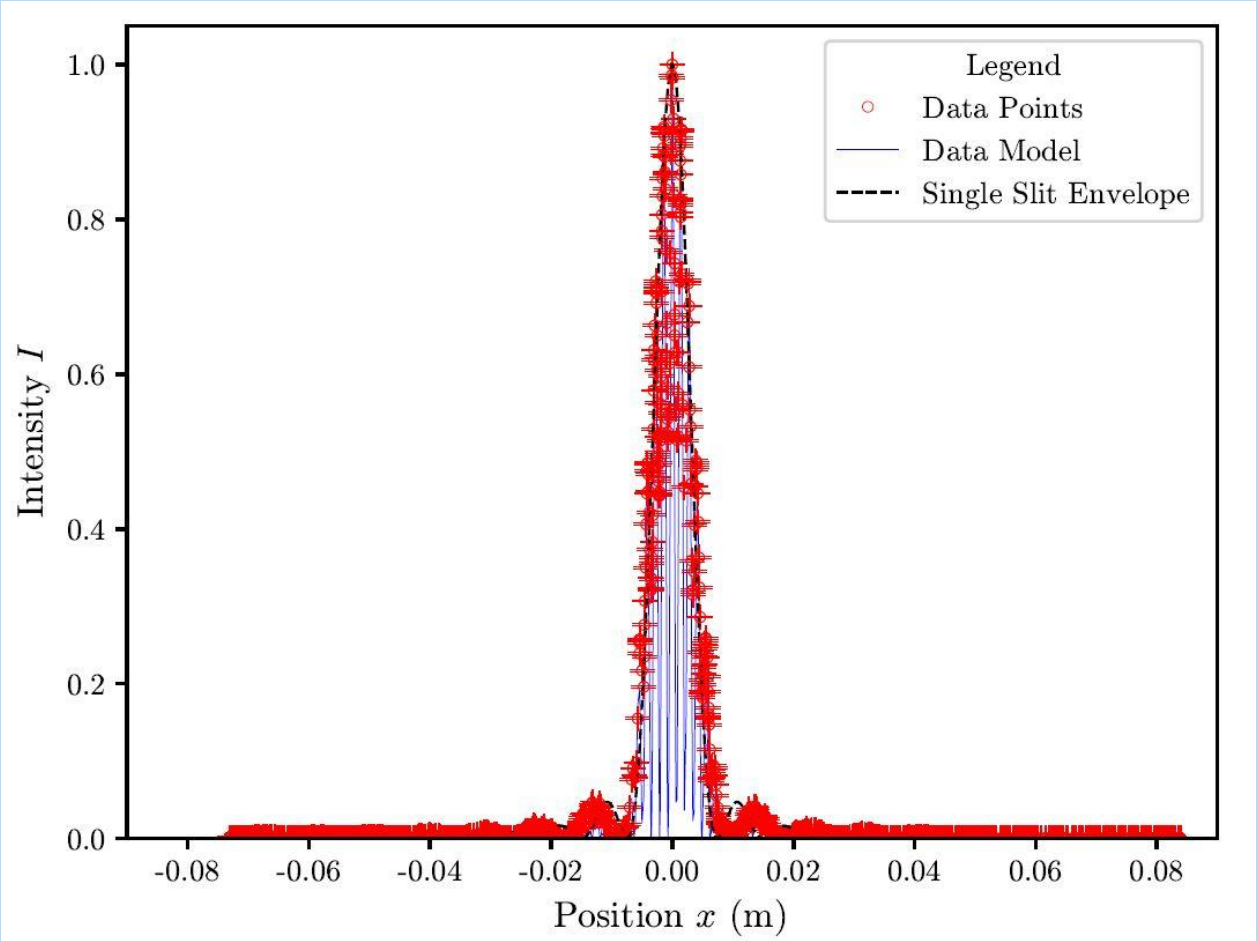
Experimental Value: $\lambda = 662 \pm 1$ nm

Known Value[3]: $\lambda = 650 \pm 10$ nm

Double Slit Diffraction

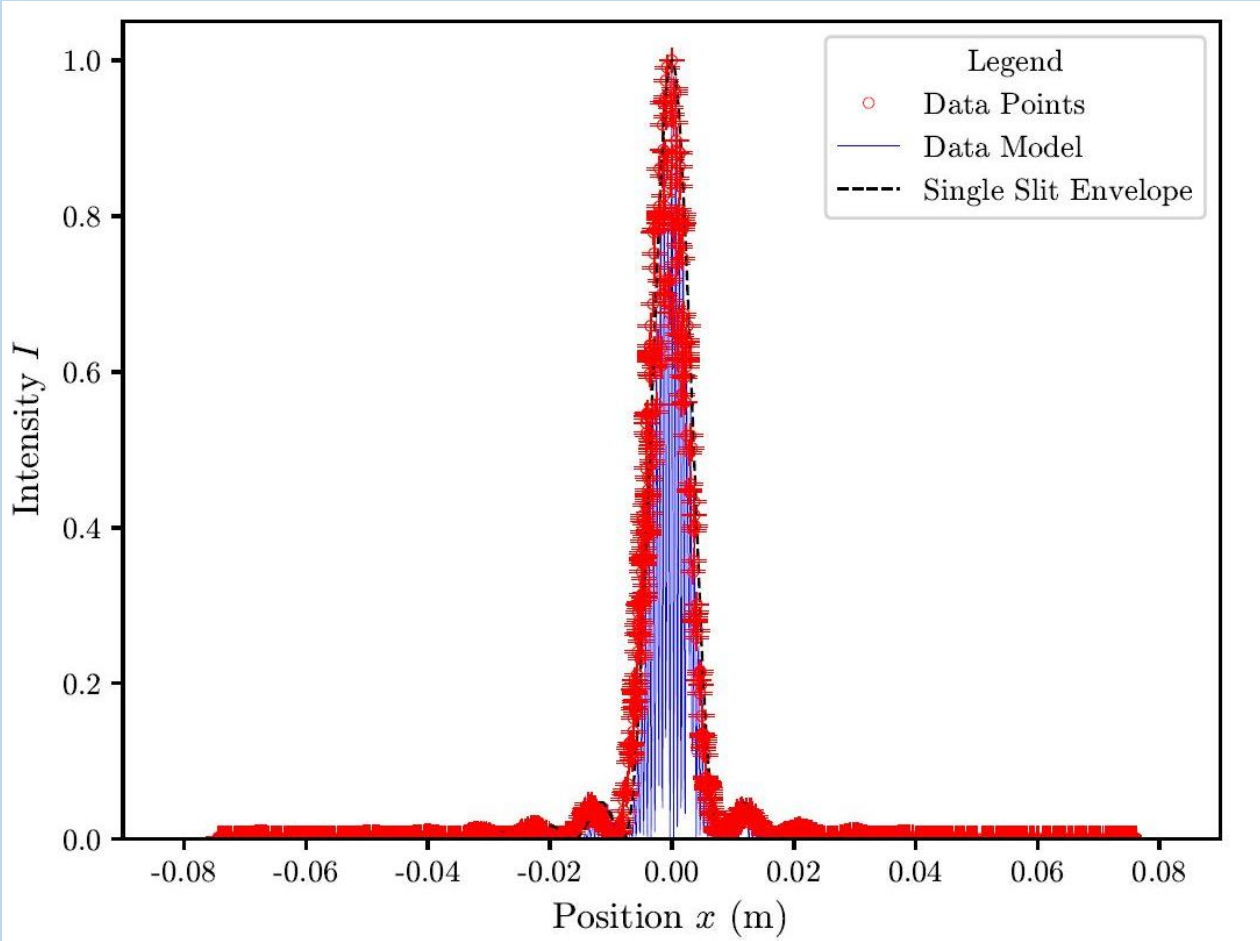
$$I \approx I_0 \frac{\sin^2\left(\frac{\pi a}{L}\cdot\frac{x}{\lambda}\right)}{\left(\frac{\pi a}{L}\cdot\frac{x}{\lambda}\right)^2}\cos^2\left(\frac{\pi d}{L}\cdot\frac{x}{\lambda}\right)$$

1.0mm Aperture, a = 0.04mm and d = 0.25mm



Experimental Value: $\lambda = 698 \pm 2$ nm

1.0mm Aperture, a = 0.04mm and d = 0.5mm

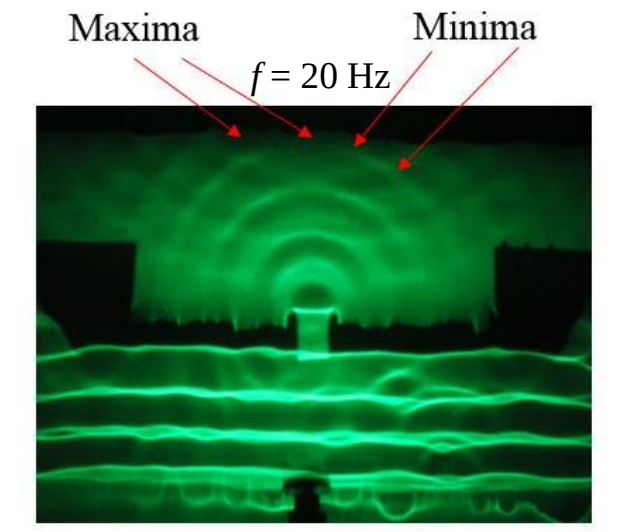


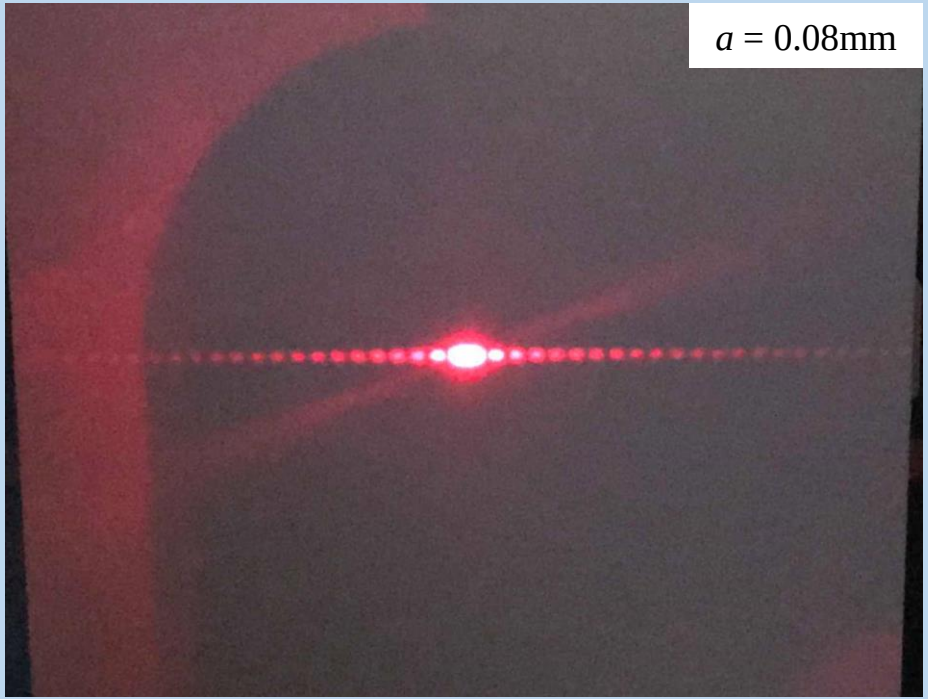
Experimental Value: $\lambda = 617 \pm 1$ nm

Known Value[3]: $\lambda = 650 \pm 10$ nm

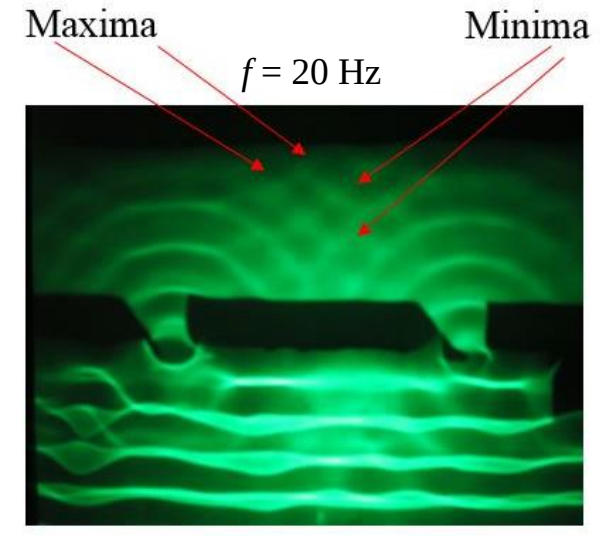
Interference of Mechanical & EM Waves

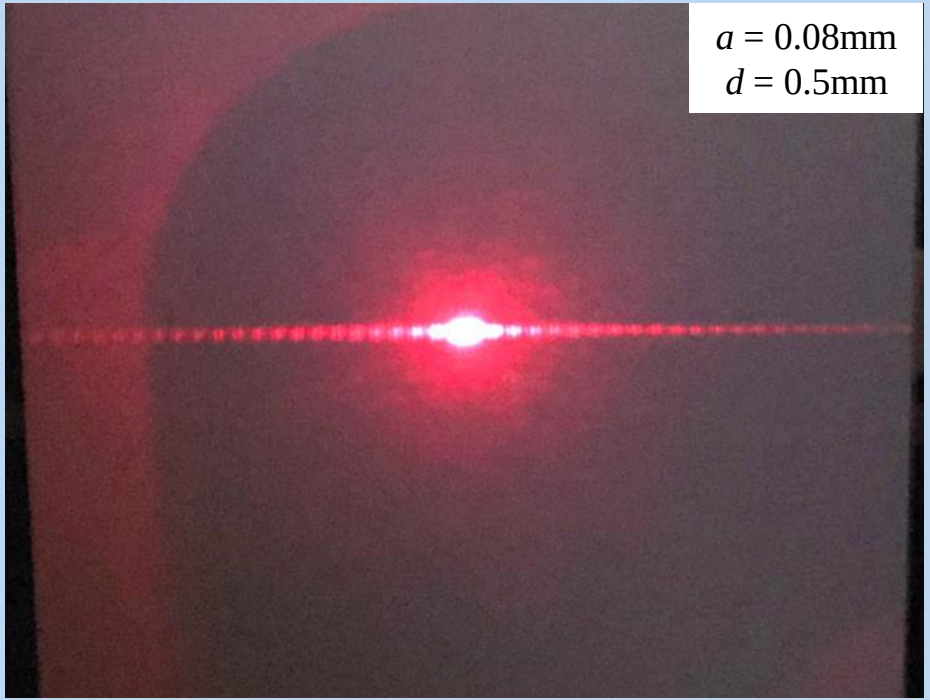
Single Slit Interference





Double Slit Interference





Summary

- Water waves nicely demonstrate various properties of (mechanical) waves and water wave speed has been shown to vary with depth.

- Using diffraction and interference of EM waves has been shown to determine the wavelength of a light source.

- Mechanical and Electromagnetic interference patterns show strong similarities.

References

- [1] Barber N.F, *Water Waves*, 1st Edition, Chapter 3, pages 36 - 55, 1969.
- [2]College of Engineering, Mathematics and Physical Sciences, University of Exeter, PHY2026, *Diffraction and Interference Worksheet* (Accessed 8th February 2019).
- [3] *Red Diode Laser – Basic Optics - OS-8525A* https://www.pasco.com/prodCatalog/OS/OS-8525_red-diode-laser-basic-optics/index.cfm?fbclid=IwAR3gzuNSAoumEZpwYZQO6tX3j1nLhTtLYklX5U6V6HHw5xyHKdszO1ID00I (Accessed 15th March 2019).

ADSB - Extended

- Characteristic 8.0μs preamble = 8 bits

- Data Block construction:

➢5 bit Downlink Format e.g. 17 ADSB

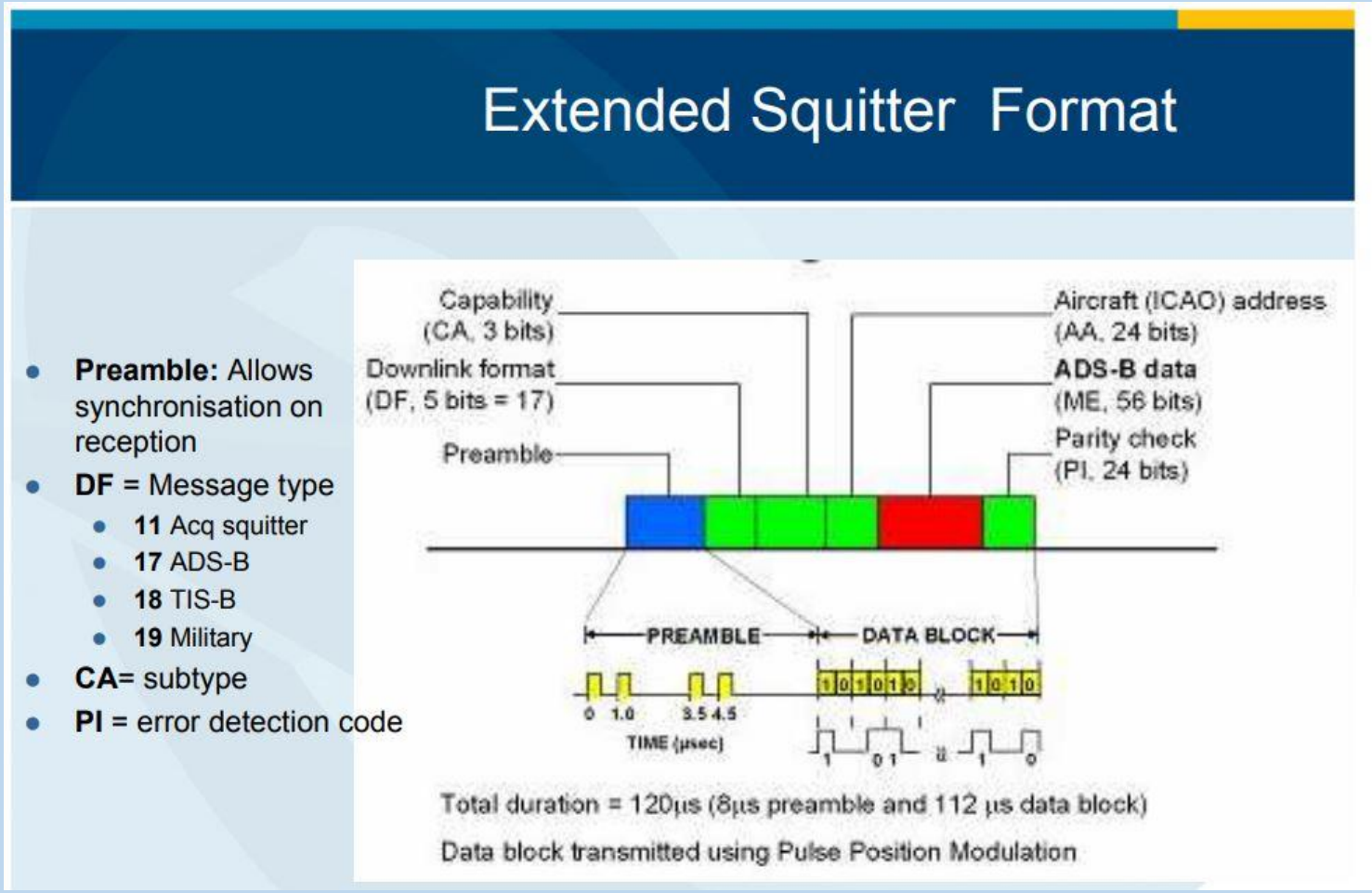
➢3 bits Capability (additional identifier)

➢24 bit ICAO (International Civil Aviation Organization) address – unique ID & registration of aircraft

➢56 bit ADSB data

➢24 bit parity check (to check if message has been received without error)

- Total of 120 μs



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