Sensitivity in Ring Interferometers

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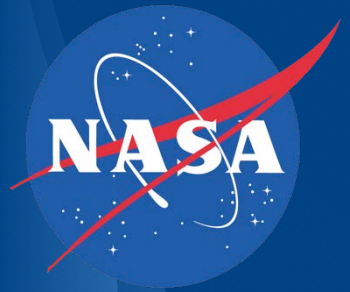


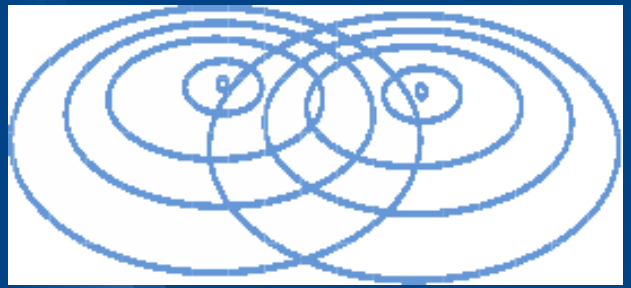
Objectives

- to research the wave property of matter to understand interferometry

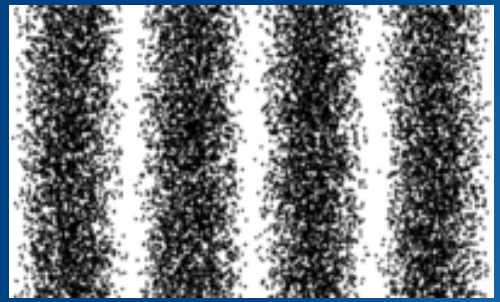
- to simulate a ring interferometer in MatLab and understand how changing variables affects its sensitivity

Outline

- Matter behaving as a wave
- What is Interferometry?
- Atom Interferometer
- Sagnac Effect
- Changing variables of a ring interferometer in Matlab (Research)



Thierry Dugnolle. "Wave Particle Duality." *Wikipedia*. Wikimedia Foundation, n.d. Web. 23 July 2015.

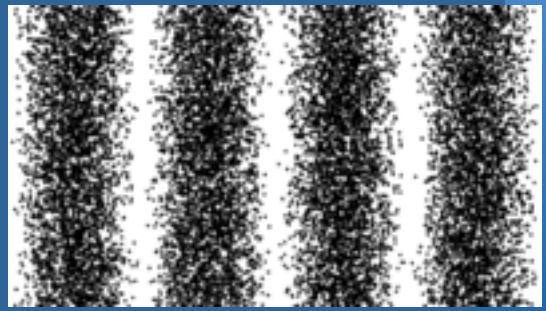


Thierry Dugnolle. "Wave Particle Duality." *Wikipedia*. Wikimedia Foundation, n.d. Web. 23 July 2015.

"The Physics Classroom." *The Physics Classroom*. N.p., n.d. Web. 27 July 2015.

Matter as Waves

- Matter behaves as a wave as well.
- Matter is subject to interference and can be used in interferometry because of this
- Large objects have very small waves and particles have relatively large waves.
- This is illustrated by the De Broglie finding $\lambda = \frac{h}{mv}$
- This equation shows that the wave length, λ , is equal to Planck's constant, h ,divided by the momentum of a particle's object, mv.

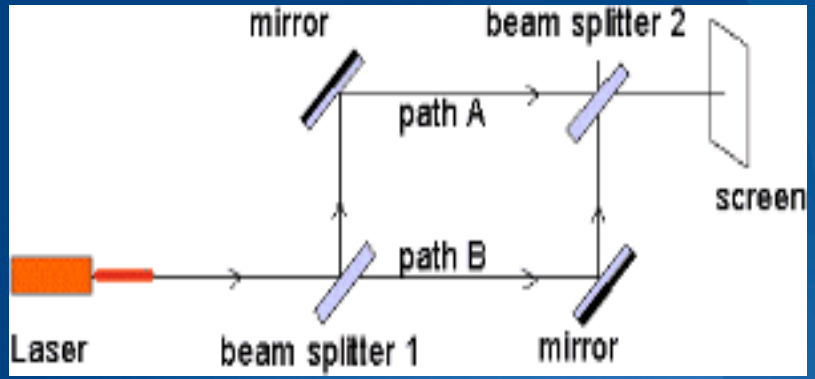


Thierry Dugnolle. "Wave Particle Duality." *Wikipedia*. Wikimedia Foundation, n.d. Web. 23 July 2015.

Interferometer Set-Up

- **Vary in arrangement**
- **Most consist of:**
  - A source that emits a wave
  - Beam splitter- Splits wave
  - Mirrors- to reflect and redirect waves
  - Detectors to observe interference patterns if one is made

Mach- Zehnder Interferometer

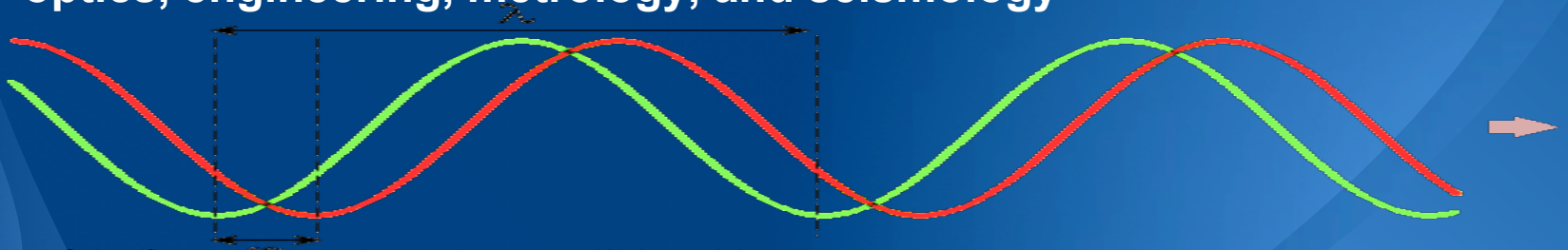


Thierry Dugnolle. "Wave Particle Duality." *Wikipedia*. Wikimedia Foundation, n.d. Web. 23 July 2015.

Uses of Interferometry

- **Could be used to make precise measurements in displacement by employing the idea of wave or atom interference**
- **Could be also used to measure infinitesimal disturbances.**
- **Used in many different fields such as astronomy, fiber optics, engineering, metrology, and seismology**

Fringe Pattern. Digital image. *Davidson*. N.p., n.d. Web. 24 July 2015.

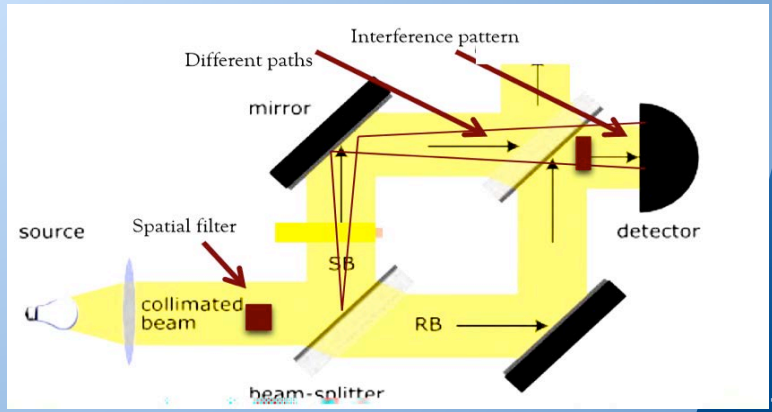


Scientificamerican.org. N.p., 26 Aug. 2009. Web. 21 July 2015.

Atom Interferometer

- Uses the waves that atoms have, also known as matter waves or De Broglie waves.
- Better than optical interferometers in that DeBroglie wavelengths are much smaller than optical wavelength, thus making the interferometer more sensitive.
- Uses the principle of phase shift.

Mach-Zender Interferometer



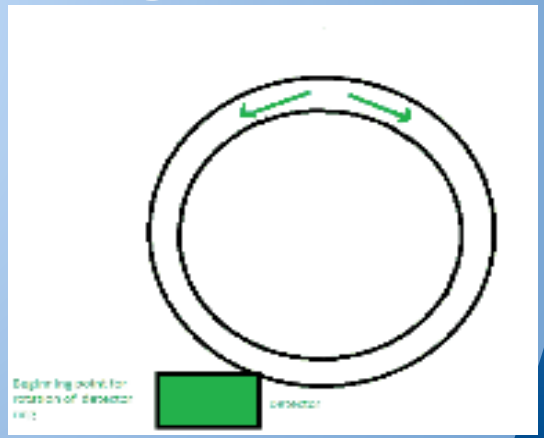
"What Is This a Picture Of?" *Wolfram: Computation Meets Knowledge*. N.p., n.d. Web. 16 July 2015.

Sagnac Effect

- Works with a beam of atom waves travelling around a ring
- Difference in path length is caused by rotating one ring in favor of the direction of a beam (in case of ring interferometer)
- Difference in path length causes phase shift which leads to interference pattern.

$$\theta_S = \frac{2\pi M \Omega A}{\hbar}$$

Sagnac Effect



Matlab Research

Important to know that we will be dealing with multiple rings.

Distance between each ring is the same.

Matlab Research (Visual Perspective)

- Investigating Changes in sensitivity of ring interferometer when the distance between rings,kd, is increased/decreased
- Investigating Changes in sensitivity of ring interferometer when the number of rings, N, is increased/decreased

Increasing the number of rings

Increasing the distance between a given set of rings

Matlab Research (Mathematical Perspective)

- **The first derivative of Transmission probability of the interferometer , $T(kL, \theta_s)$, is positively correlated to the sensitivity.**

$$T(kL, \theta_s) = \frac{1}{1 + C(kL, \theta_s) U_{N-1}^2(\epsilon)}$$

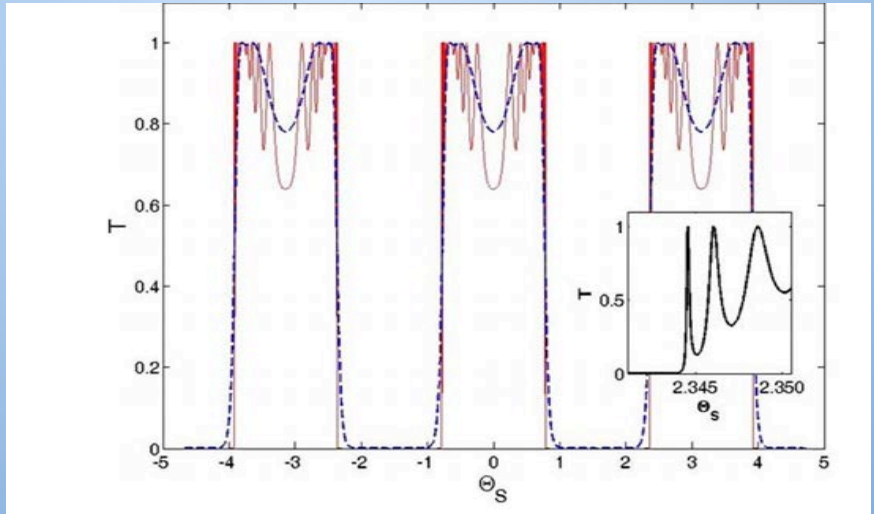
We will input the number of rings in $U_{N-1}^2(\epsilon)$.

$$\epsilon = \frac{cos(kL)cos(kd)}{cos(\theta_s)} + \frac{sin(kd)4sin^2(\theta_s) - 5sin^2(kL)}{4cos(\theta_s)sin(kL)}$$

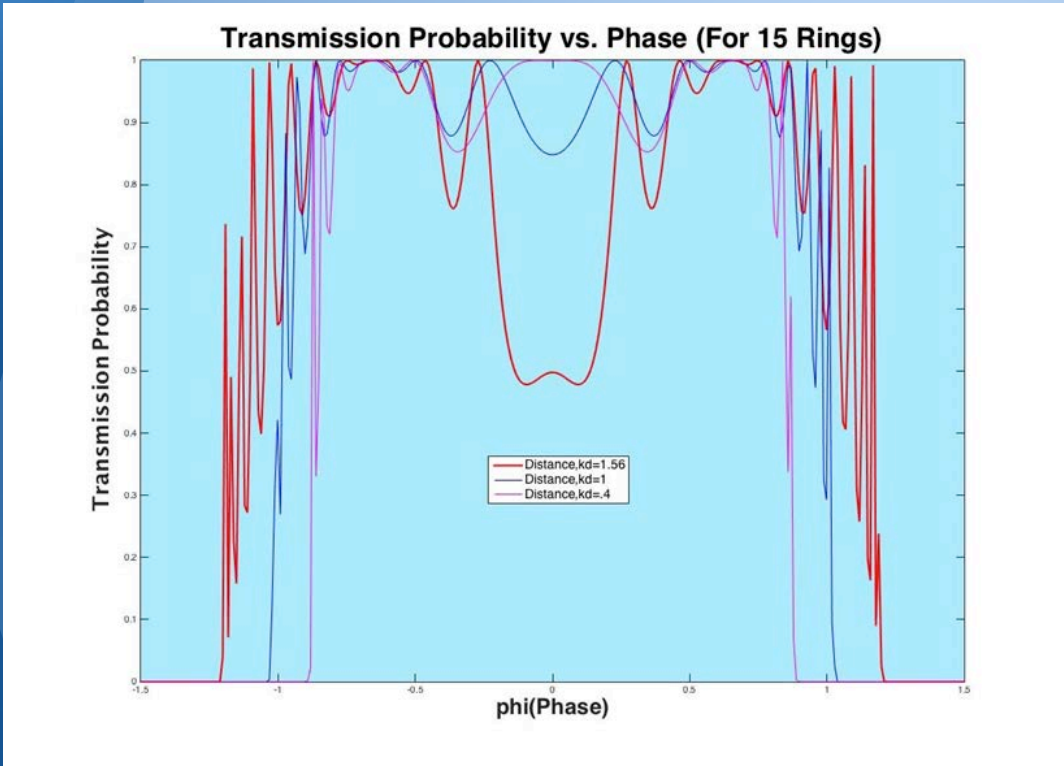
We will input the value of distance,kd, between a set of rings.

Point

- We learn that the greatest sensitivity occurs when the first derivative of the transmission probability is the greatest (dT/dPhi).
- We find that the greatest derivative always is on the leading edge of the oscillation point when the transmission probability transitions from 0 to the oscillation period for any combination of distance between rings or number of rings.

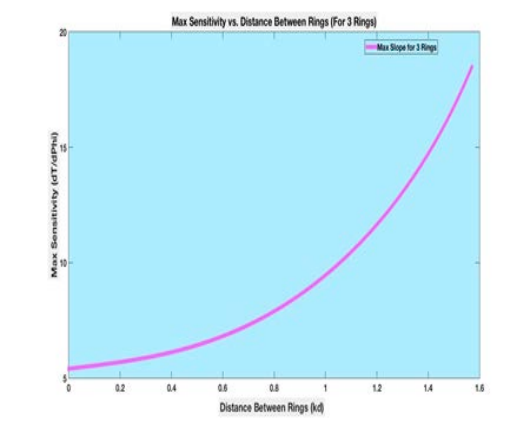


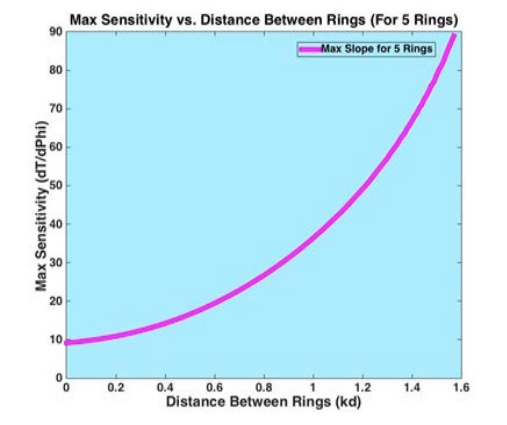
Relationship Between Sensitivity and Phase

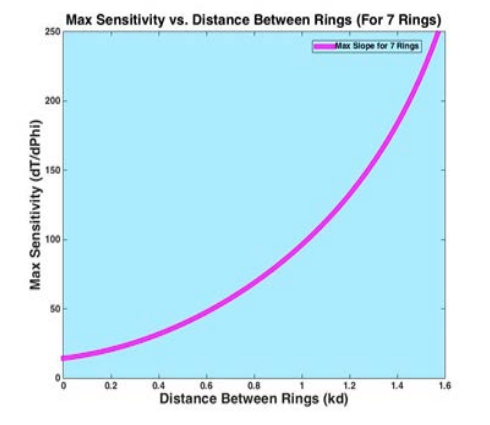


- This plot illustrates the broadening of the transmission and the narrowing of the stop gap as the distance between rings is increased.
- We learn that these two variables are nonlinearly proportional.

Relationship Between Distance and Sensitivity



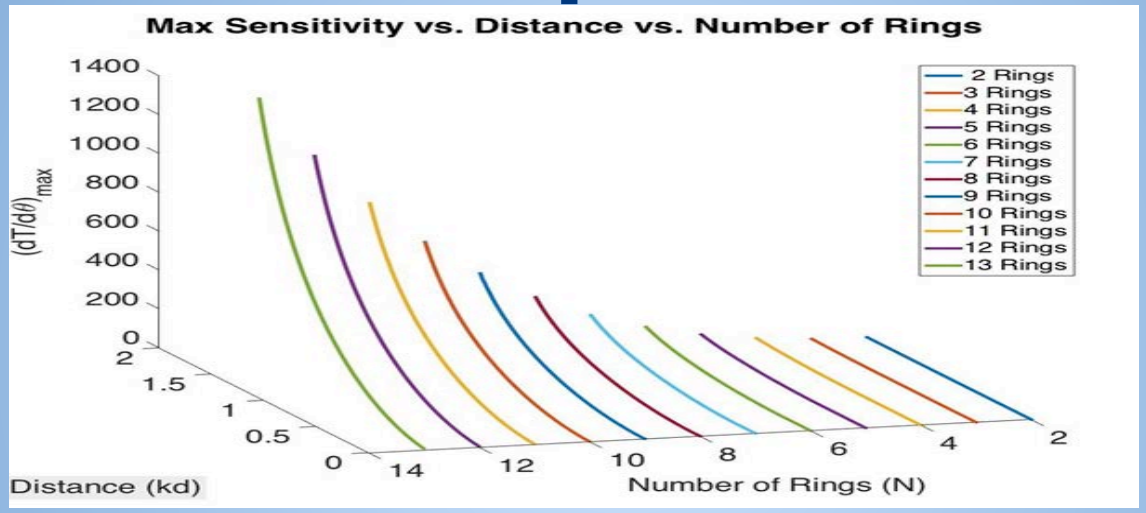




We found that distance is nonlinearly proportional the maximum sensitivity of the interferometer for any number of rings.

The pictures are above from left to right illustrate this effect for 3 rings, 5 rings, and 7 rings respectively.

Intuitive Representation



- **We can also observe that the sensitivity of the Ring Interferometer grows as the number of rings grow.**
- **Knowing these trends is advantageous in the construction of a very sensitive ring interferometer.**

Why is this important to you?

We can make smartphones and devices more sensitive and open up the range of uses.

We can make satellites use these interferometers to take higher resolution pictures.

Iphone 6+. Digital image. *IPhone*. Apple, n.d. Web. 29 July 2015. <Apple.com>.

Satellite. Digital image. *Communications*. N.p., 29 July 2015. Web. <telephone-europe.com>.

Next Steps

- **Fit Max Slope Vs Kd to quantify behavior**
- **Extend current analysis to 50 rings**
- **Generalize model to transfer matrices so that inter-ring sizes can be individually modified and combined with non-uniform array geometries**
- **Include effects of velocity broadening of incident atomic waves**

References

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