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VERIFYING THE INVERSE SQUARE LAW USING WIFI SIGNALS

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Prerequisites: Interferometry, electromagnetic wave propagation, reflection, and antenna basics

Materials:

- **Hardware:**
  a. A transmitter: Smartphone with hot-spot or WiFi router
  b. A receiver: Laptop/smartphone or any other similar portable device that can be connected to WiFi and has provision to show WiFi signal strength
  c. Distance measurement tape/ruler

- **Software:**
  Based on the device used as the receiver, install one of the following software/apps:
  a. Mac OS/ Linux/Unix: Wireshark – Download Wireshark
  b. Windows OS: Vistumbler – Vistumbler - Open Source WiFi scanner and channel scanner for windows
  c. Linux Ubuntu: Python notebook to read and record WiFi signal strength – https://github.com/nrciucaa/WifiSignal
  d. Android OS: WiFi Analyzer – WiFi Analyzer - Apps on Google Play

  The installation process of these software can be found by following the link: Software/Apps/Codes_Wifi_experiments
  We conducted this experiment initially for the Radio Astronomy Winter School 2020 (RAWS2020). The recordings relating to the experiment are available in the following YouTube playlist: Radio Astronomy Winter School 2020 playlist

1 | Introduction

The inverse square law states that the intensity of radiation received at a distance from a point source will decrease inversely proportional to the square of the distance. Figure 1.1 illustrates this geometric dilution of intensity. The flux density or the intensity of the radiation received at a distance 'r' is the source strength 'S' divided by the area of a sphere with radius 'r'. Alternatively, if the intensity radiated by an isotropic source integrated over a unit area sphere is I0, then the intensity I(r), seen at a distance r from the source, is given by

$$I(r) = \frac{I_0}{4 \pi r^2}$$

where $4\pi r^2$ is the area of a sphere of radius r.

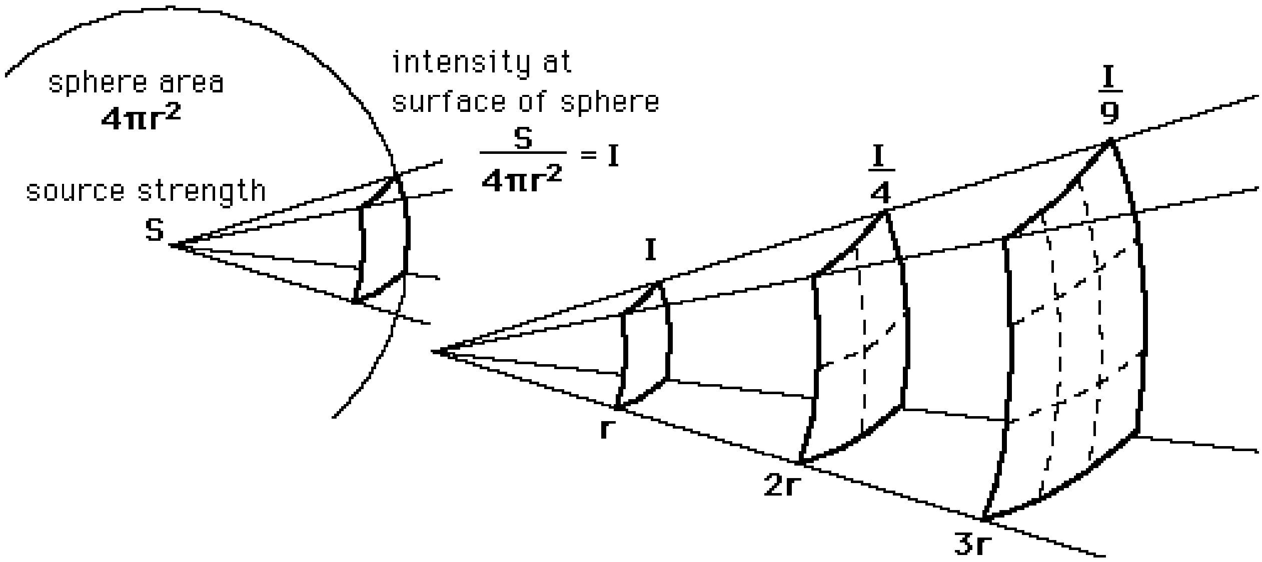

Figure 1.1: A geometric illustration of the reduction in intensity with distance

Intensities associated with entities other than the electromagnetic field, such as electric field, sound, gravitational field, and other centrally emitted, spatially conserved quantities undergo this geometric dilution with increasing distance.

The inverse square law followed by electromagnetic waves can be examined through a simple experiment using radio waves. For this purpose, we will require a suitable transmitter of radio waves and a portable and compatible receiver capable of measuring the intensity of the radio signal received at different distances from the transmitter. We will use WiFi signals, noting the broader accessibility of the two devices needed, one for transmitting radio signals and the other for receiving them. One can use a WiFi router or WiFi hotspot-enabled devices such as smartphones/tablets/laptops as the transmitter. Similarly, one can use a WiFi-capable smartphone, tablet, or laptop with suitable WiFi signal measuring software/tool installed as a portable receiver. The basic setup for the experiment is schematically shown in Figure 1.2.

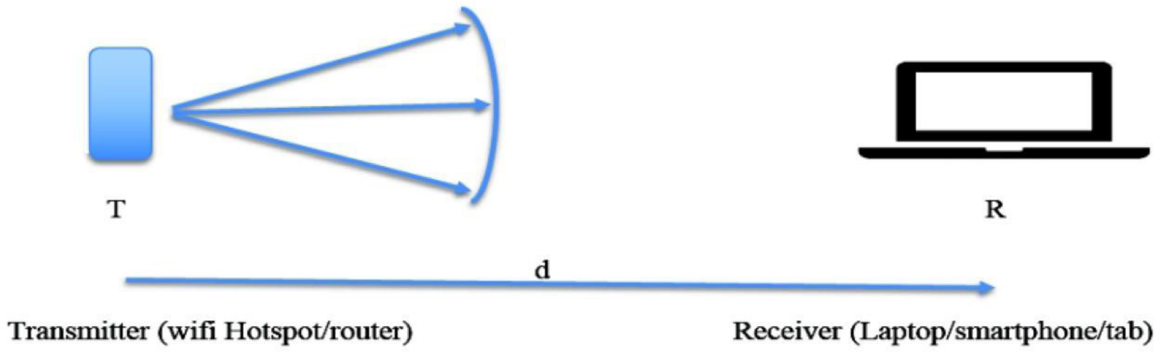

Figure 1.2: A schematic showing the basic setup and wave propagation

2 | Experiment setup

1. The line of sight between the transmitter and the receiver must be clear and free of any human/ animal movements across the sightline to avoid any undesired reflection or absorption of the signal.

2. Reduce the possibility of significant reflections (from surrounding walls, ground, roof, furniture, and other objects and structures) that will unavoidably interfere and contaminate the direct signal. For best results, carry out this experiment in outdoor/open-ground areas or carefully reduce the possible reflections in any indoor setup (and note down the potential sources of contamination). In either case, to minimize the adverse effect of ground reflections, it is advisable to keep the transmitter and receiver devices above a certain height (>50 cm) from the ground, using non-metallic supports (see an illustrative arrangement in Figure 1.3).

3. If using a smartphone as a receiver, turn off its data connection to reduce the power fluctuations due to data transfers. Similarly, keep the smartphone in airplane mode to avoid fluctuations in the radiated power due to data transfers and other WiFi activities. For routers, remove the external network connection.

4. The WiFi devices may provide an option to operate at about 2.4 GHz or 5 GHz (each with a few MHz of bandwidth). The central frequency is slightly different for every WiFi device, depending on the band in use. One can select the operating frequency based on the compatibility of the receiving device.

5. Determine the physical location of the WiFi antennas in your devices for accurately measuring distances and ensuring that the corresponding sightline remains clear. The accuracy in distance measurements becomes more critical at smaller distances (in the near field of radiators/receptors) where the signal intensity may deviate from the law that governs its far-field behavior.

6. Finally, equip the receiver with the appropriate software/application to measure the received WiFi power by following the details/links given under the 'software' section above. The software will enable viewing the signal strength in dBm and transmitter device information such as the operating frequency and bandwidth. Power expressed in dBm is ten times the log (to the base 10) of the power P in milli-watts, PdBm = 10 log(P).

Figure 2.1: An example of transmitter/receiver locations relative to floor and walls

3 | Procedure

1. Ensure the router is on or create a WiFi hot-spot on the mobile phone.
2. Connect your receiver (laptop/smart-phone) to the WiFi.
3. Disconnect the mobile phone or router from the internet. Put the mobile phone in Flight Mode or disconnect router network input.
4. Move the receiver slowly, changing the transmitter-receiver distance ('d' in Figure 1.2 and 1.3) and measure the power at the receiver. Change the transmitter-receiver distance and take at least 10 measurements.
5. Plot the graph of log power (or signal strength in dBm) versus log distance (d), as shown in the sample plot in Figure 1.4.
6. Fit an appropriate model curve, check residuals, and estimate best-fit model parameters.
7. Interpret the results.

4 | Tips

1. Keep your mobile phone and laptop charged.
2. The WiFi power detector device might take a few seconds to settle down on a value. Please do not disturb the receiving setup during this time and allow sufficient time for the reading to settle down to its minimum fluctuation level.

3. Depending on the device, the lowest signal strength that can be measured reliably could be between -80 dBm to -95 dBm; hence avoid measurements below about -80 dBm (limiting the maximum distance).

4. For plotting, pick any tool/programming language such as Python, Matlab, Origin, Excel, etc.

5 | Observations

Sr. No.	Transmitter–Receiver distance (cm)	Power (dBm)
1	5 cm	-10 dBm
2		
3		
4		
.		

6 | Results

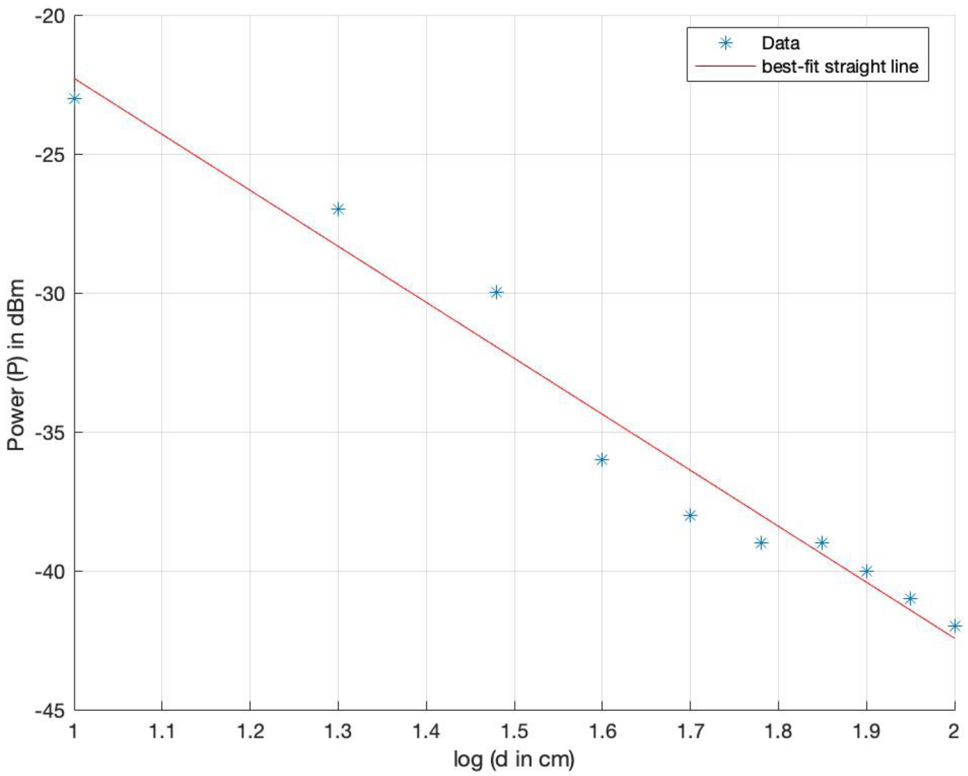

Figure 6.1: Sample plot of Wifi power 'P' vs transmitter-receiver distance 'd'. The best fit line to the data is also shown

7 | References

1. https://www.education.com/science-fair/article/wifi-signals/

2. https://www.sciencebuddies.org/science-fair-projects/project-ideas/CompSci_p047/computer-science/what-materials-can-block-a-wifi-signal

8 | Acknowledgements

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