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EFFECT OF BACK REFLECTORS ON DIRECTIVITY OF RADIO ANTENNAS

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Contents

Keywords: Observational astronomy, astronomical methods, radio astronomy, radio wave propagation, reflection, interference, WiFi signal, antennas

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. Metal sheet (or) cardboard and aluminum foil
  d. 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

Reflectors play a vital role in radio antennas used in radio communication, radio telescopes, satellite tracking devices, and radars. Antennas employ various reflector shapes based on their application, such as the plane reflector, the parabolic reflector, the corner reflector, and the spherical reflector. Reflectors help increase the directionality, i.e., the antenna's sensitivity in preferred directions, and avoid radiation coming from undesired directions, such as from the ground or artificially generated interfering signals.

In this experiment, we will observe the effect of putting a plane reflector behind a transmitting antenna. Before proceeding, let us recall some basic principles relevant to this experiment. Let us imagine a radiating radio antenna and, for simplicity, consider initially only two waves; one traveling in the "forward" direction (towards an observer) and the other in the opposite (or "backward") direction. Suppose we place a conducting obstruction in the path of the wave traveling away from the observer. In that case, the wave will be reflected in another direction depending on the orientation of the reflector plane. Suppose the reflector plane is perpendicular to the signal propagation direction; in this case, the reflected wave will now travel back along the same path towards the source. This reflected wave will interfere with the direct (i.e., already "forward" traveling) wave, affecting the net wave amplitude observed by a distant observer. The net amplitude will depend on the relative phase-shift between the two contributors and their respective amplitudes. The signal's wavelength and the antenna-reflector distance will determine the relative phase difference, in addition to the wavelength-independent phase shift of 180 degrees due to reflection.

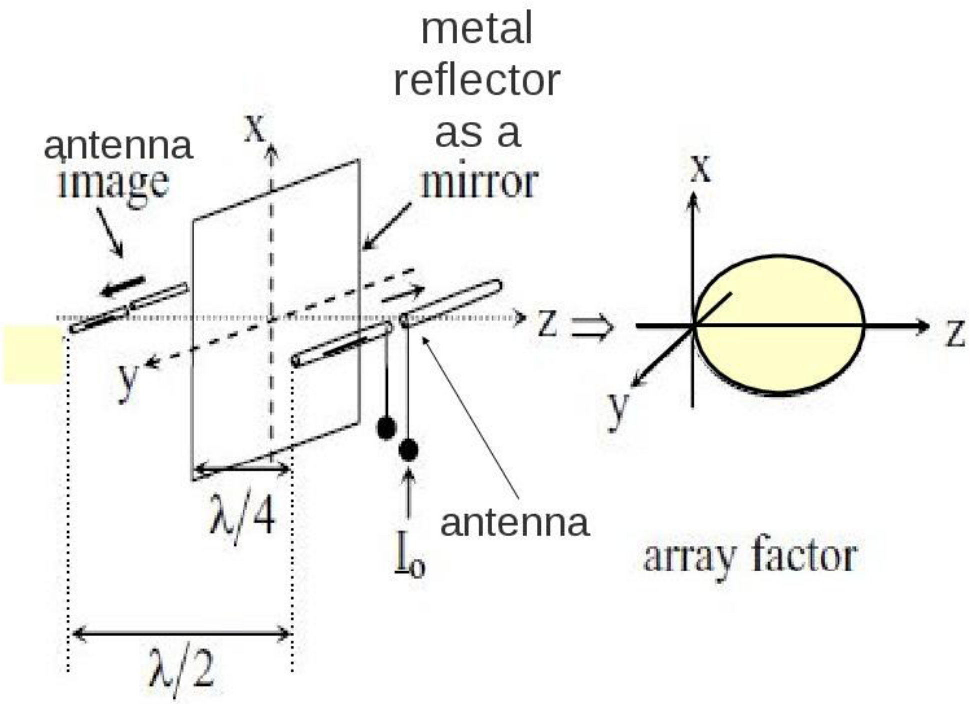

Figure 1.1: (Left) An illustration of the fundamental principle depicting the physical antenna and its 'image' behind the reflector. Note the opposite directions for the oscillating current indicated by the arrows close to the antenna and its image. The phase shift due to reflection is different from what one would expect from simply the path difference. (Right) The array factor plot for the configuration sketched on the left for an antenna-reflector separation equal to a quarter of the wavelength.

The concept can alternatively be illustrated as shown in Figure 1.1. The reflector acts as a 'radio mirror' forming a virtual image of the antenna behind the reflector at the same distance as the antenna-reflector separation. We can now understand the effect of reflection on the electromagnetic waves from a transmitter through this equivalent configuration of two identical radiators separated by twice the antenna-reflector distance (without the reflector). The only difference is that the currents flow in opposite directions in the two radiators to account for the 180-degree phase shift due to reflection.

The effect on the observed signal will now depend on the antenna-reflector separation and the viewing angle. One of the goals of this experiment is to determine the antenna-reflector separation for which the on-axis signal strength is maximum. However, it might be a valuable exercise for you to imagine the configuration explained above and predict the antenna-reflector separation, as a fraction or multiple of the wavelength, that will maximize the signal strength. With reference to the coordinates in Figure 1.1, one can choose a plane, say the X-Z plane, and determine the boost in signal strength along various directions in the plane. Figure 1.1 (right) includes a plot of such gain factor (or 'array factor') showing the qualitative angular variation. At distances large compared to the lengths of the antenna elements, the array factor will have rotational symmetry about the Z-axis. These results equivalently apply to receiving antennas used in radio astronomy, wherein appropriately placed reflectors help boost the signal available at the antenna feed.

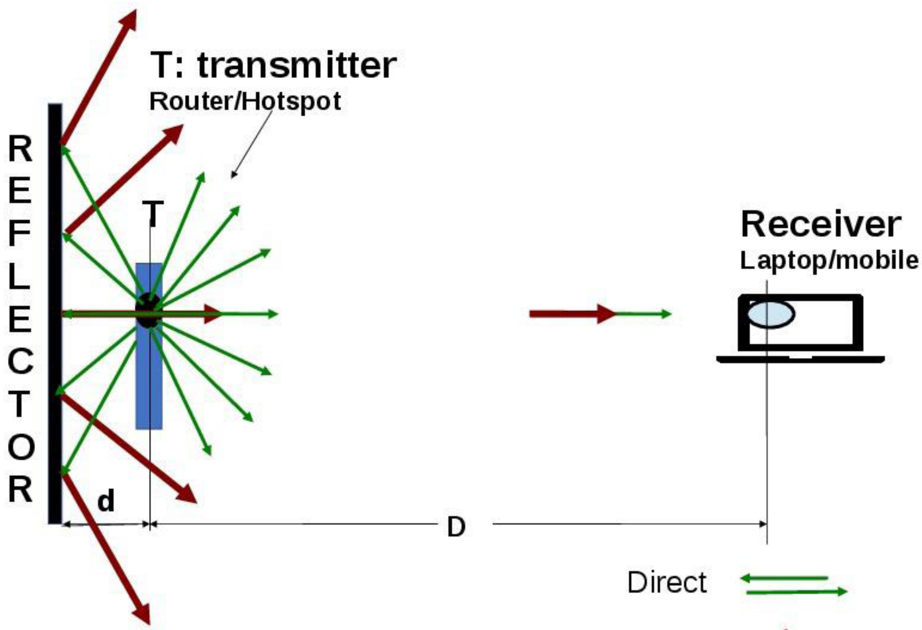

Figure 1.2: Left: A schematic of the corner reflector set-up illustrating the radio mirror principle on the left and a sample array factor plot on the right. The top-view of the setup is shown with a 90-degree corner reflector in blue, the antenna (S) oriented perpendicular to the figure plane along the X-axis, and the virtual antenna images (I1, I2, & I3) behind the reflectors. The filled circles and those marked with ' ' distinguish the 180-degrees phase-shifted current directions. Right: The sample array factor plot qualitatively shows the directivity in the Y-Z plane for antenna-reflectors separation of d = λ/4.

In an isotropically radiating antenna, placing a plane back reflector reflects the incident power in various directions. Suppose we place the reflector with its plane perpendicular to the line joining the source and the observer, as shown below in Figure 1.2; in that case, the received intensity of the signal can be significantly affected by changing the antenna-reflector distance. In this experiment, we will move the reflector to adjust the antenna-reflector distance.

A metal sheet placed behind the transmitter antenna will serve as a simple back reflector. Use any readily available plane metallic plate, provided it is larger than the antenna dimensions. If such a metal plate is unavailable, one can use aluminium foil pasted over a cardboard sheet as a reflector (see sample in Figure 1.3). The example in Figure 1.3-(a) shows a copper plate used as the reflector, and that in Figure 1.3-(b) has an aluminium foil wrapped on cardboard as the plane reflector. In both these examples, non-metallic supports hold the smartphone.

Figure 1.3: Two examples of metallic back reflectors, (a) metal plate and (b) aluminium foil, with transmitter phones on non-metallic supports.

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, $P_{dBm} = 10 \log(P)$.

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. Take a metallic plane reflector and place it behind the transmitter.

5. Change the antenna-reflector distance (d; see Figure 1.2) slowly and measure the power at the receiver. Change the antenna-reflector distance in intervals of 1 cm and take readings up to at least a meter. Pay attention to the maxima and minima in the received power.

6. Plot the graph of signal strength (dBm) versus reflector distance (cm or m) and fit an appropriate curve to the data. Check the residuals. Interpret the results.

7. When plotting the graph of power versus reflector distance (d), as shown in the sample plot in Figure 6.1, you will observe increase and decrease in power with distance. Compare the length scale of this variation to the wavelength at which the devices are operating and verify the constructive and destructive interference positions.

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, you may choose any tool/programming language such as Python, Matlab, Origin, Excel, etc.

5 | Observations

Transmitter–Receiver distance = ____________ cm.

Sr. No.	Transmitter–Reflector distance (cm)	Power (dBm)
1	1 cm	-32
2		
3		
4		
.		

6 | Results

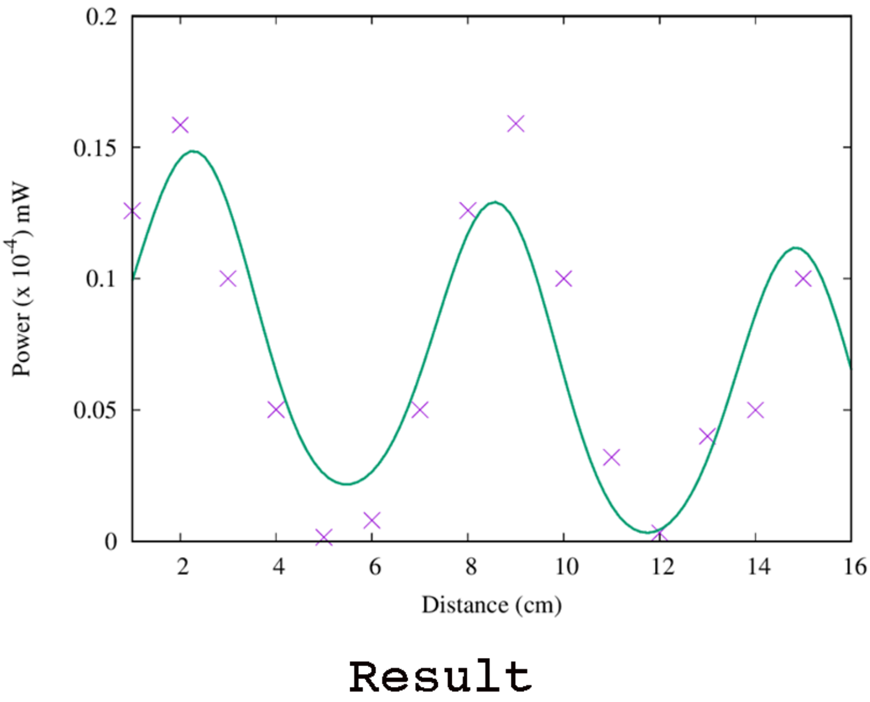

Figure 6.1: Sample plot of received power versus antenna-reflector distance (purple crosses), along with the best fit curve (green).

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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