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EFFECT OF CORNER REFLECTOR ON DIRECTIVITY OF RADIO ANTENNAS

Ashish Mhaske, Jameer Manur, and Prakash Arumugasamy
Astronomy Centre for Educators,
Inter-University Centre for Astronomy and Astrophysics

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Contents

Keywords: Observational astronomy, astronomical methods, radio astronomy, radio wave propagation, 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. 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

A corner reflector is a particular type of reflector among other types such as a plane reflector, parabolic reflector, and spherical reflector used to improve the directivity of an antenna. This kind of antenna-reflector combination is used in communication systems as well as in radio telescopes. The corner reflector increases the antenna directionality, i.e. the response of the antenna is selectively improved in certain directions, and helps in avoiding radiation towards (or coming from) other directions. In the astronomy context, the directions to be avoided would include those towards the ground or any man-made sources of interfering radiation.

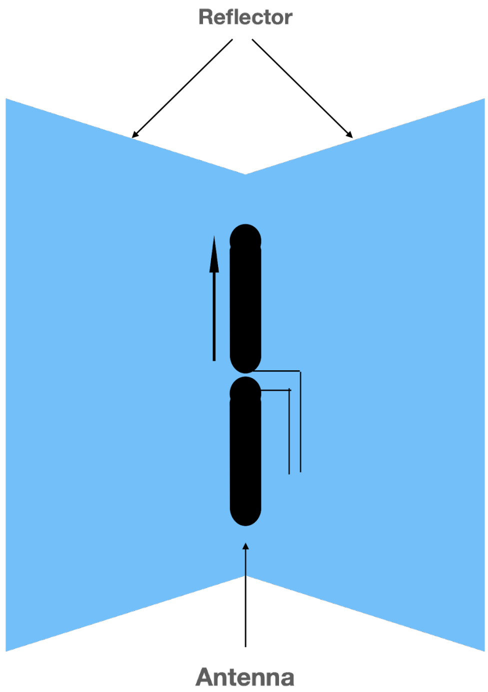

Figure 1.1: An illustration of the simple corner reflector antenna setup

In another similar experiment [IUCAA-ACE/radio/Exp002], we examined the effect of a plane back reflector on an antenna's directivity. In the case of a plane reflector behind a radiating radio antenna, we considered, for simplicity, initially only two waves; one travelling in the "forward" direction (towards an observer) and the other in the opposite (or "backwards") direction, where the latter is reflected by the a conducting obstruction in its path. The wave direction on reflection depends on the orientation of the reflector plane, and when the latter is perpendicular to the signal propagation direction, the reflected wave would travel "back" along the same path towards the source, and will interfere with the direct (i.e., already "forward" travelling) wave. The net wave amplitude, for a distant observer, depends on the relative phase-shift between the two contributors and their respective amplitudes. The signal wavelength and the antenna-reflector distance determine the relative phase difference, in addition to the wavelength-invdependent phase shift of 180 degrees due to reflection.

In the present experiment, we consider a corner reflector, made of two plane reflectors perpendicular to each other, and a radio antenna placed in the corner at an equal distance from the two reflectors. Now a combined effect of the direct wave and reflected waves from both the surfaces, as a result of interference dictated by the relative phase differences, will determine what a distant observer will see. The signal strength in a given direction will thus be a function of the location of the antenna relative to the reflecting surfaces, and wavelength.

The concept can alternatively be illustrated as shown in Figure 1.2. The reflectors act as 'radio mirrors' forming virtual images of the antenna behind the reflectors. There will be three virtual images for a 90-degree corner made of two plane reflectors, two behind the reflector planes and one behind the corner. The principle is similar to how regular mirrors forming a corner will produce multiple images of an object placed within the corner. The images behind the reflectors will be separated from the antenna by twice the antenna to reflector plane separation and the image behind the corner will be twice the antenna-corner separation from the antenna. We can now understand the effect of reflection on the electromagnetic waves from a transmitter through this equivalent configuration of four identical radiators forming a square array. The difference, however, will be that the currents in the two radiators, corresponding to images behind the reflector planes, will be opposite to the original antenna current direction to account for the 180-degree phase shift due to reflection. The current flow in the radiator behind the corner, which is technically an image of the image, will have a current direction identical to the original antenna.

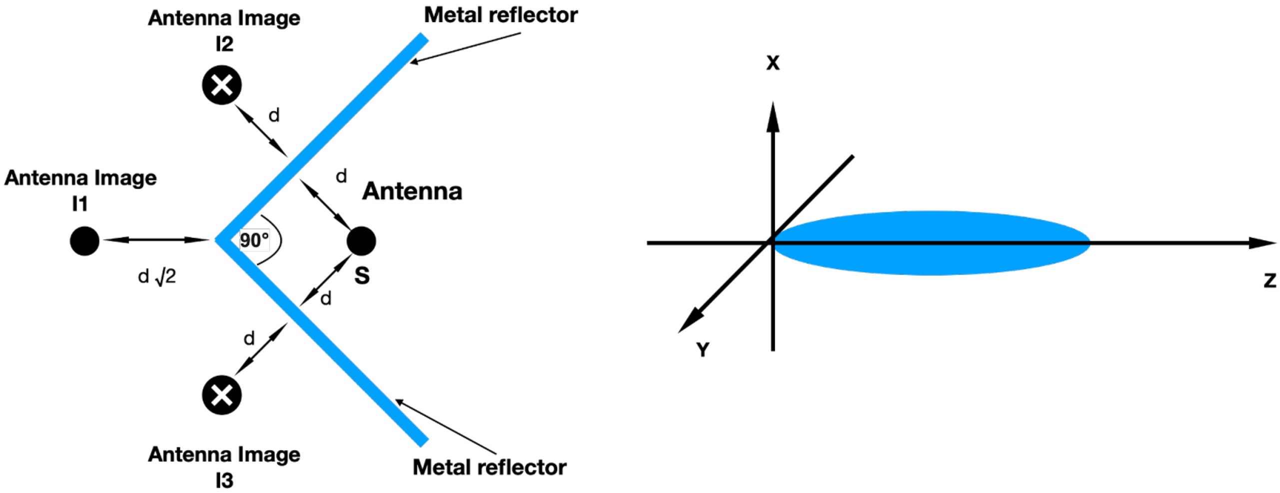

Figure 1.2: Left: A schematic of the corner reflector set-up illustrating the radio mirror principle on the left and a sample array factor plot on the right. The top-view of the setup is shown with a 90-degree corner reflector in blue, the antenna (S) oriented perpendicular to the figure plane along 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 = $\lambda/4$.

As we have already appreciated, the effect of the corner reflector on the observed signal will now depend on the antenna position within the corner and the viewing angle. One of the goals of this experiment is to determine the antenna separation from the two reflector planes (marked ‘d’ in Figure 1.2) for which the on-axis (along the line joining the corner and the antenna) signal strength is maximum. With reference to the coordinates in Figure 1.2, one can choose a plane, say the X-Z plane, and determine the boost in signal strength along various directions in the plane. Figure 1.2 (right) includes a plot of such a gain factor (or ‘array factor’) showing the qualitative angular variation and the implied noticeable enhancement in directivity. Unlike the plane back reflector, the array factor will not have rotational symmetry about the Z-axis. Moreover, the new parameter in the setup, the angle of the corner, will determine the number of side lobes in the array factor. These results equivalently apply to receiving antennas used in radio astronomy, wherein appropriately placed reflectors help boost the signal available at the antenna feed.

In an isotropically radiating antenna, when we place two plane reflectors at an angle and the antenna at the “center”, the power incident on the reflectors is reflected back in a range of directions depending on the angle of incidence. For the reflector-antenna setup shown in Figures 1.3 & 1.4, we will determine the change in signal strength on- and off-axis by shifting the receiver alone to arrange viewing at different angles.

Two metal sheets forming a corner behind the transmitter antenna will serve as a simple corner reflector for our purposes. Use any readily available plane metallic plates, provided it is larger than the antenna dimensions. If such metal plates are not available, one can use aluminium foil pasted over two cardboard sheets to make a corner reflector (see example in Figure 1.4). The example in Figure 1.4

uses aluminium foil-wrapped cardboard as the plane reflectors. Two insulating pieces of Polystyrene (Thermocol sheet piece) are used to support the radiator (Smartphone).

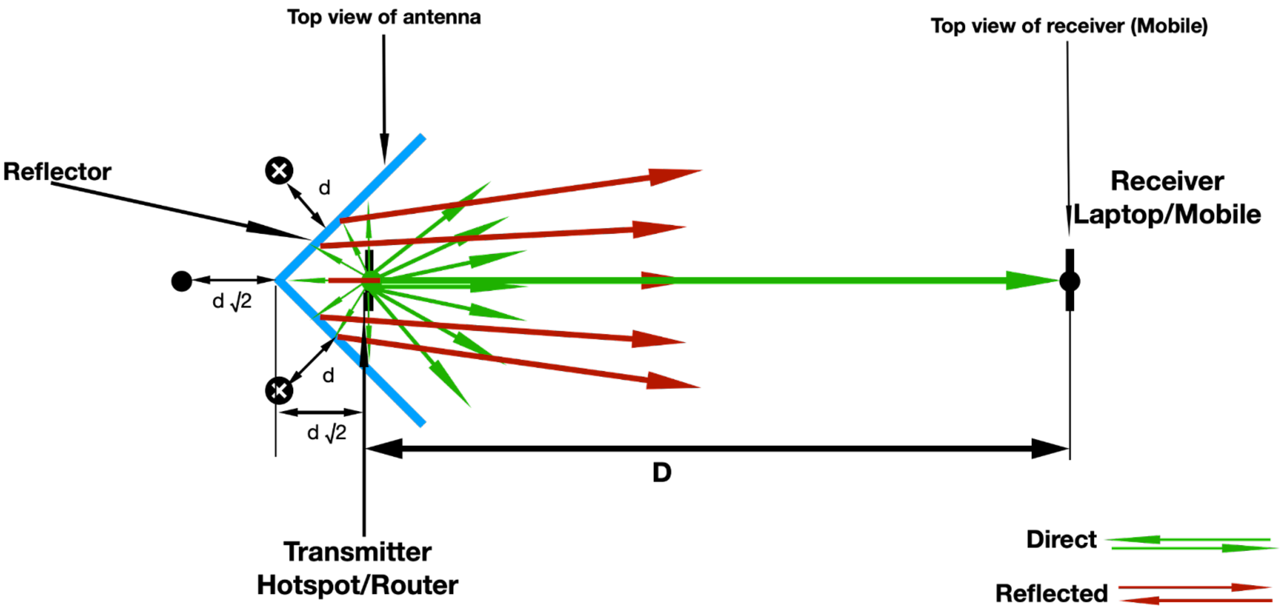

Figure 1.3: An illustration of the basic setup showing sample ray directions. The effect of the corner reflector can be observed at the receiver end when you vary the distance (d) between the reflector and the transmitter (smartphone) while keeping the distance (D) between the transmitter and the receiver fixed. The angular distribution of power at the receiver plane can be determined by moving the receiver off-axis through various angles.

Figure 1.4: Set-up of Corner reflector antenna with the radiator (Smartphone) at the centre

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 1.4).

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 aeroplane 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 behaviour.

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 your router is on, or create a WiFi hotspot on the mobile phone.

2. Connect your receiving device (laptop/smart-phone) to the hotspot/WiFi.

3. Disconnect the mobile phone or router from data/internet. Put the mobile phone in Flight Mode or disconnect router network input.

4. Take a metallic corner reflector and place it behind the transmitter.

5. Make sure that initially the corner, radiator, and receiver are aligned. Now, change the distance between the reflector and the transmitter (d) slowly and measure the power at the receiver. For an on-axis receiver, you will get the maximum power when the antenna is at a distance of quarter wavelength from the reflectors.

6. Keeping the distance between the corner reflector and the receiver (D) the same, move the receiver off-axis on both sides and note down the power.

7. Plot angle (θ in degrees) versus power (in dBm) to see the radiation pattern on a polar graph. Choose a maximum angle according to where the signal strength drops to its lowest value.

8. 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 set up 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.	Angle (θ)	Power (dBm)
1	0^0	-10
2	10^0	-20
3		
4		
.		

6 | Results

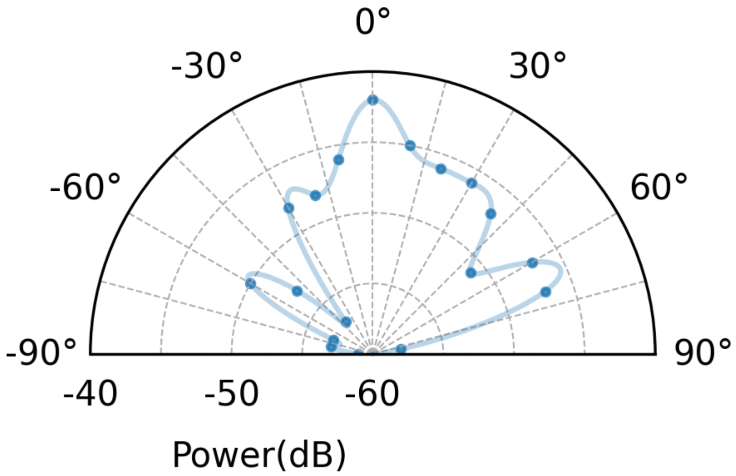

Figure 6.1: Sample plot of Wifi power P vs Azimuthal angle θ

7 | References

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

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