Measuring the power-pattern of a horn antenna

Team Members

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1 Introduction

Antennas are at the heart of every wireless communication system, be it your phone, a satellite, or a radar. One of the most important ways to understand an antenna's performance is by looking at its power radiation pattern. This pattern shows how much power the antenna sends out in different directions, and it's key to knowing how well it focuses energy, how wide its beam is, and whether it might cause interference where you don't want it.
In this project, we focused on studying the power pattern of a horn antenna, which is a common directional antenna used in microwave and radar systems. The goal was to see how the antenna behaves across different directions and frequencies and how factors like polarization affect its performance. Understanding this is important not just for academic purposes, but also for real-world applications like satellite links, antenna design, and wireless communication setups where directional control really matters. Our objective is to measure and analyze the power pattern of a standard Horn antenna across a frequency range of 1 GHz to 4 GHz. We focus on two principal planes, i.e., the E-plane and the H-plane, and examine both co-polarized and cross-polarized configurations. To achieve this, we set up a controlled experiment using a horn antenna as the transmitter and a dipole antenna as the receiver. The horn antenna was rotated 360 degrees in the horizontal plane, and the received power at the dipole antenna was recorded at regular angular intervals for each frequency step of 0.01 GHz.
The purpose of this experiment is twofold: firstly, to experimentally validate theoretical predictions of horn antenna radiation patterns; and secondly, to develop a deeper understanding of polarization effects and directional characteristics of antennas in practical scenarios. Such knowledge is vital for applications in radar, satellite communication, and RF design, where antenna performance directly affects system reliability and efficiency.

2 Theory

1. Antenna Fundamentals

An antenna is a passive device that converts electromagnetic radiation in space into electrical currents in conductors or vice versa, depending on whether it is being used for receiving or for transmitting, respectively. Radio telescopes are receiving antennas, and radar telescopes are also transmitting antennas. It is often easier to calculate the properties of transmitting antennas and to measure the properties of receiving antennas. Fortunately, most characteristics of a transmitting antenna (e.g., its radiation pattern) are unchanged when that antenna is used for receiving, so any analysis of a transmitting antenna can be applied to a receiving antenna used in radio astronomy, and any measurement of a receiving antenna can be applied to that antenna when used for transmitting.

2. Power Pattern

The power pattern of an antenna describes how its radiated power varies with direction. In practice, one measures the power density in the far field over all angles and then normalizes it so that the maximum is unity. This "normalized power pattern" shows the main beam where most power is sent or received, as well as any side lobes present.

3. E Plane and H Plane

The E-plane and H-plane are fundamental concepts in antenna theory and waveguide systems, defining the orientation of electric and magnetic fields relative to an antenna's radiation pattern and are specifically used in the study and design of antennas, waveguides, and other microwave devices. They serve as reference planes for analyzing the orientation and polarization of electromagnetic fields radiated or received by these devices.

a. E-Plane

The E-plane (electric field plane) contains the electric field vector and the direction of maximum radiation from the antenna. This plane is crucial for determining the polarization or orientation of the radio wave. In linearly polarized dipoles, the E-plane coincides with the dipole.

b. H-Plane

The H-plane is the plane that contains the magnetic field vector and the direction of maximum radiation. It is always orthogonal (90 degrees apart) to the E-plane. For a similarly polarized dipole, the H-plane is perpendicular to the dipole.

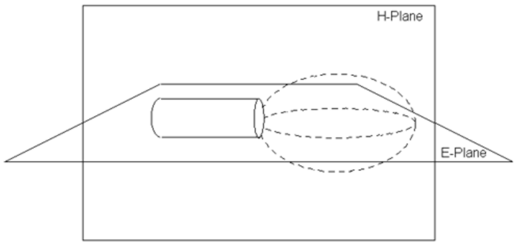

Figure 1: E-Plane and H-Plane of a horizontally polarized antenna(Source: Wikipedia)

Polarization Configurations

Co-polarization (co-pol) and cross-polarization (cross-pol) in the context of E-plane and H-plane describe the alignment of electromagnetic fields relative to an antenna's intended polarization. Co-pol refers to the polarization aligned with the antenna's dominant electric field component (E-plane), while cross-pol represents the orthogonal polarization (H-plane). The received power is highest when the antenna is aligned with the co-polarization direction, and it is lowest when the antenna is oriented in the cross-polarization direction.
In the experiment performed, we have gathered the power pattern data in 4 configurations.
E-plane-co: The E-plane is in the same plane as the Dipole antenna and in the co-pol configuration.
E-plane-cross: The E-plane is in the same plane as the Dipole antenna and in the cross-pol configuration.
H-plane-co: The E-plane is orthogonal to the Dipole antenna and in the co-pol configuration.
H-plane-cross: The E-plane is orthogonal to the Dipole antenna and in the cross-pol configuration.

3 Experimental Setup and Equipment:

1. Anechoic Chamber

An anechoic chamber absorbs electromagnetic waves, creating a reflection-free environment for antenna measurements. Its walls, ceiling, and floor are lined with RF-absorbing materials in pyramidal shapes.

- Effective for frequencies above 300 MHz (Cadence Design Systems).
- Eliminates interference and reflections for accurate measurements.

The chamber ensures precise measurement of the horn antenna's radiation pattern by minimizing reflections.

2. Horn Antenna

A horn antenna, a directional device with a flared waveguide, converts electrical signals into electromagnetic waves, used in microwave and satellite communications.

- Operates in 1–18 GHz, frequencies experiment-dependent.
- Connected to VNA Port 1 via an amplifier.

It transmits waves to measure its power pattern, critical for radar and wireless applications.

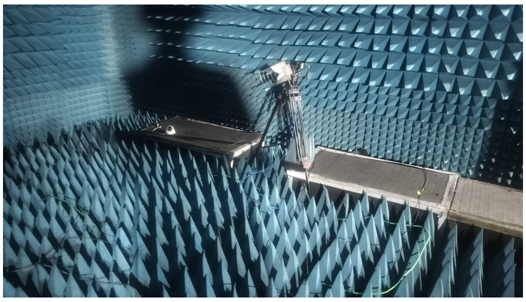

Figure 2: Horn Antenna inside an Anechoic Chamber

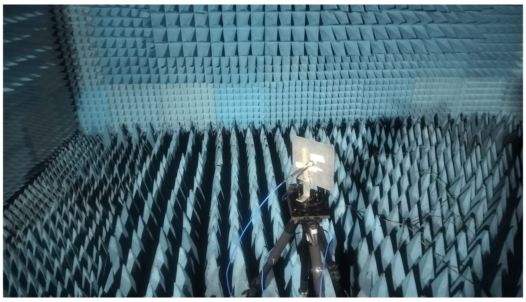

Figure 3: Dipole Antenna inside an Anechoic Chamber

3. Dipole Antenna

A dipole antenna, with two symmetric conductive elements, has a well-characterized radiation pattern, ideal as a reference antenna.

- Half-wave dipole, tuned to the horn's frequency.
- Omnidirectional in the plane perpendicular to its axis.
- Connected to VNA Port 2.

It receives the horn's signal for radiation pattern calculation.

4. Vector Network Analyzer (VNA)

A two-port VNA measures scattering parameters (S-parameters), capturing magnitude and phase.

- Port 1 for transmission, Port 2 for reception.
- Measures S21 in dB as $10 \log_{10}(|S_{21}|^2)$.
- Displays real-time S21 on a monitor.
- Controlled by MATLAB for frequency sweeps.

Port 1 transmits to the horn via an amplifier, Port 2 receives from the dipole, with S21 processed by MATLAB.

5. Amplifier

An amplifier boosts signal power, powered by a DC supply.

- RF power amplifier, matched to experiment's frequency range.
- Connected between VNA Port 1 and horn antenna.

It ensures the horn transmits a strong signal, compensating for VNA limitations.

6. Motor Controller

The motor controller manages antenna positioning with two channels, each controlling a motor.

- One channel for horn, one for dipole.
- Rotates antennas in azimuth and elevation planes.
- Operated via MATLAB commands.

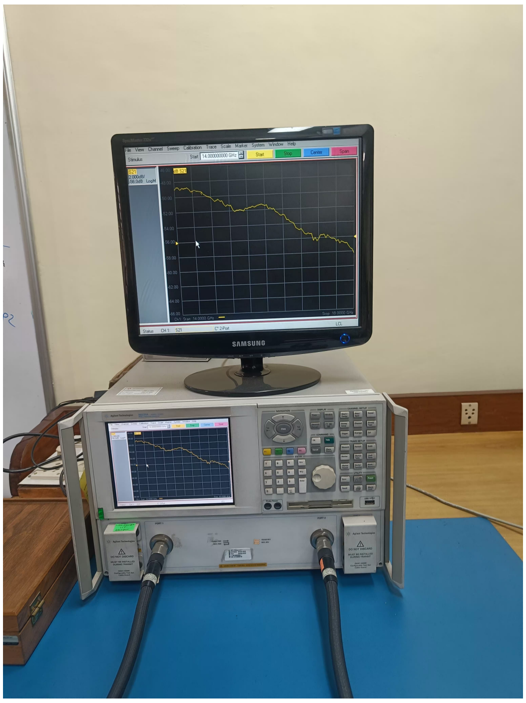

Figure 4: Vector Network Analyzer

Figure 5: Amplifier

It rotates antennas to measure the power pattern, enabling S21 data collection.

Figure 6: Motor Controller

4 Experimental Procedure

The setup measures E-plane co-polarized, E-plane cross-polarized, H-plane co-polarized, and H-plane cross-polarized radiation patterns as follows:

1. Setup Initialization

- Connect horn to VNA Port 1 via amplifier, dipole to Port 2.
- Position antennas in the anechoic chamber at far-field distance.
- Connect motor controller for azimuth (H-plane) and elevation (E-plane) rotation.
- Calibrate VNA for cable losses, amplifier gain, and connector mismatches.
- Configure MATLAB to interface with VNA and motor controller.

2. Polarization Configuration

- Align dipole with horn's polarization for co-pol (e.g., both vertical).
- Rotate dipole 90° for cross-pol (e.g., dipole horizontal).
- Repeat for E-plane and H-plane orientations.

3. Signal Transmission

- VNA generates amplified signal to horn, which radiates waves.

4. Signal Reception

- Dipole receives signal, sent to VNA Port 2.

5. S21 Measurement

- VNA calculates S21 in dB, displayed and recorded by MATLAB.

6. Antenna Rotation

- MATLAB rotates antennas:
- E-plane: Elevation (-90° to 90°), azimuth fixed.
- H-plane: Azimuth (0° to 360°), elevation fixed.
- Measure S21 for co-pol and cross-pol.

7. Data Collection

- Repeat steps 3–6, collecting S21 for:
- E-plane co-pol, cross-pol; H-plane co-pol, cross-pol.
- MATLAB stores S21 versus angle dataset.

8. Data Analysis

- MATLAB generates 2D/3D S21 plots for E-plane and H-plane co-pol and cross-pol.
- Analyze for gain, directivity, and polarization purity.

5 Results and Discussion:

The radiation patterns of a horn antenna were measured in an anechoic chamber across four cases: E-plane co-polarized, E-plane cross-polarized, H-plane co-polarized, and H-plane cross-polarized. Measurements were conducted over a frequency range of 1 GHz to 4 GHz, with data recorded at angular increments of 5° from 0° to 360°. Polar contour plots were generated for each case, with the E-plane co-polarized pattern at 1.6 GHz highlighted due to its maximum observed response.

a. E-plane Co-polarized Radiation Pattern at 1.6 GHz

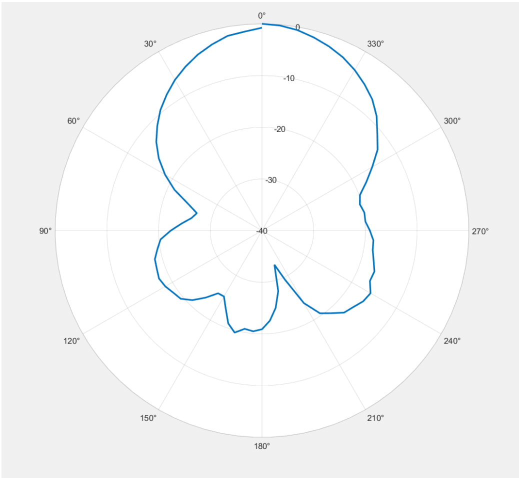

Figure 7: Power Pattern at 1.6 GHz

At 1.6 GHz the E-plane co-polar pattern exhibits a broad main lobe centered at 0° with a half-power beam width of roughly 60° (±30°) and a –10 dB width extending to about ±45° (total ≈ 90°). The first nulls occur near ±95°, plunging below –35 dB, and the deepest back-lobe null at 180° reaches nearly –40 dB—yielding a front-to-back ratio of about 40 dB. Primary side lobes just beyond the nulls sit in the –15 to –20 dB range. A pronounced secondary lobe between 180° and 210° peaks around –5 to –10 dB (likely from edge diffraction or support-structure scattering), and a smaller rise between 240° and 270° appears at –20 to –25 dB.

As frequency increases from 1 GHz to 4 GHz, the main lobe narrows roughly in inverse proportion to wavelength—HPBW shrinks from about 80–90° at 1 GHz to 20–25° at 4 GHz—while side-lobe levels decrease and null depths deepen thanks to the horn's growing electrical aperture and stabilized phase center. To capture sharp nulls and low side-lobes accurately, angular sampling should use steps of 1° or finer, and chamber reflections must be minimized with thorough absorber coverage and non-reflective fixtures.

b. E-plane Cross-polarized Radiation Pattern at 1.6 GHz

The E-plane cross-polarized radiation pattern at 1.6 GHz, derived from the provided polar plot, exhibits an irregular, roughly kidney-shaped curve with notable amplitude variations across the angular range. Starting at 0°, the pattern begins near -10 dB, indicating a moderate cross-polarized signal. It fluctuates between 0° and 60°, with minor dips and rises, stabilizing briefly near -10 dB. Around 90°, the pattern dips sharply toward -30 dB, marking the onset of a significant reduction in signal strength. The deepest null occurs between 90° and 150°, reaching approximately -40 dB around 120° to 150°, indicating minimal cross-polarized radiation in this region. From 150° to 180°, the pattern rises to about -20 dB. Between 180° and 210°, it hovers around -20 dB to -30 dB with slight fluctuations. From 210° to 270°, the pattern gradually increases, peaking near -10 dB between 240° and 270°, suggesting a directional lobe. From 270° to 330°, it fluctuates mildly, with a slight dip near 300°, before returning to -10 dB at 360°.

The pattern's asymmetry highlights a directional cross-polarized response, with the main lobe oriented between 240° and 300°, where amplitudes approach -10 dB. The pronounced null between 120° and 150° aligns with expected cross-polarized behavior. Across the 1–4 GHz range, cross-polarized levels remain 20–30 dB below the co-polarized main lobe, confirming effective polarization isolation.

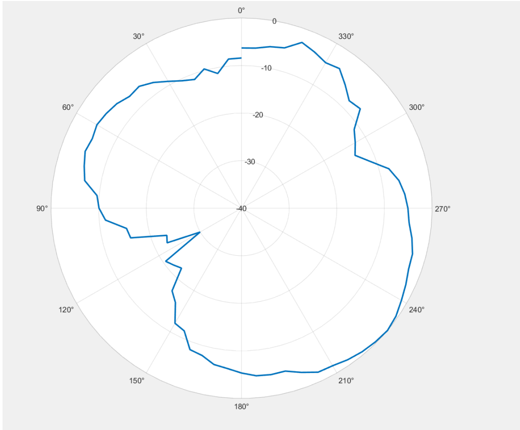

Figure 8: Power Pattern at 1.6GHz

c. H-plane Co-polarized Radiation Pattern at 1.6 GHz

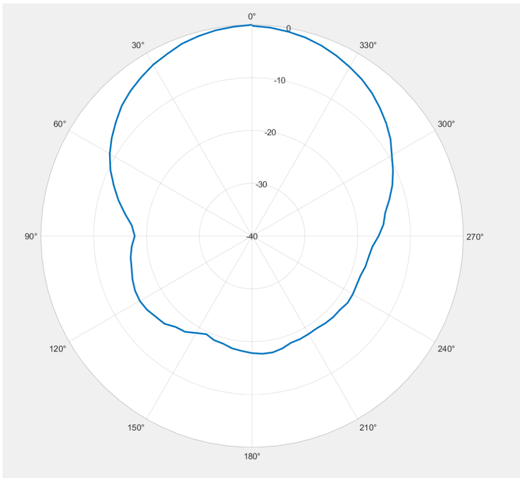

Figure 9: Power Pattern at 1.6 GHz

The H-plane co-polarized pattern at 1.6 GHz exhibits a directional behavior with a prominent main lobe and distinct nulls. Starting at 0° (aligned with 360°), the gain is near 0 dB, indicating strong radiation in the forward direction. The gain remains high (close to 0 dB) from 0° to 30° and 330° to 360°, forming the main lobe. As the angle increases from 30° to 90°, the gain decreases gradually, reaching approximately -10 dB around 60° and -20 dB near 90°.

A significant null appears between 90° and 150°, where the gain drops sharply to -30 dB to -40 dB, with the deepest point around 120° to 150°. This indicates minimal radiation in these directions. From 150° to 180°, the gain recovers to around -20 dB, and between 180° and 210°, a secondary lobe emerges, peaking at -10 dB to 0 dB. The gain dips again to -20 dB between 210° and 240°, then rises to -10 dB from 240° to 270°. From 270° to 330°, the gain fluctuates mildly, dipping slightly around 300° before returning to 0 dB at 360°.

The pattern is asymmetrical, featuring a strong main lobe near 0°, a secondary lobe around 180°-210°, and deep nulls separating these regions. This suggests a directional antenna with preferred radiation directions and suppressed radiation in specific angular zones.

d. H-plane Cross-polarized Radiation Pattern at 1.6 GHz

The H-plane cross-polarized radiation pattern at 1.6 GHz displays several notable characteristics. It features a multi-lobed structure, with prominent peaks near 0° and 180°, where the gain reaches approximately -10 dB, indicating significant cross-polarized radiation along the main axis. The pattern also exhibits deep nulls between 60°-120° and 240°-300°, where the gain drops sharply to between -30 dB and -40 dB, marking directions of minimal cross-polarization. Additionally, the pattern has an irregular shape, particularly noticeable between 180° and 240°, which may suggest interference or design-specific influences. The gain range spans from -10 dB at the peaks to -40 dB at the nulls, reflecting a 30 dB dynamic range. Finally, the pattern shows symmetry about the 0°-180° axis, with comparable lobes and nulls on either side.

The H-plane cross-polarized radiation pattern at 1.6 GHz reveals an irregular, multi-lobed shape with maximum gain around -10 dB (occasionally nearing 0 dB) and minimums at -40 dB. Main lobes appear at 0° and 180°, with deep nulls between 60°-120° and 240°-300°. While the antenna achieves good polarization isolation in some directions, the

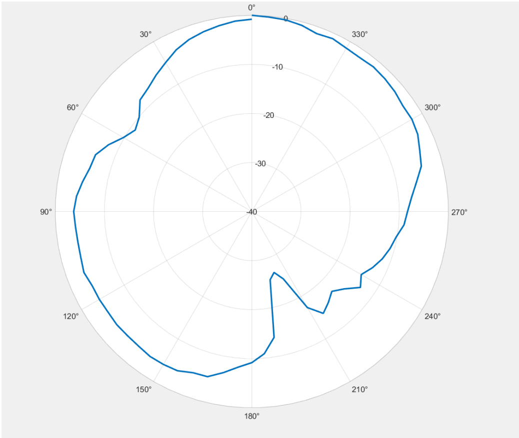

Figure 10: Power Pattern at 1.6GHz

relatively high cross-polarization along the main axis (-10 dB) suggests potential limitations for applications demanding strict polarization control.

6 Conclusions

In this experiment, we mapped the far-field power pattern of a standard horn antenna in both its principal planes (E- and H-planes) under co- and cross-polarized conditions across 1–4 GHz using an anechoic chamber and a VNA-driven dipole receiver. At 1.6 GHz, the E-plane co-polar pattern exhibited a broad main lobe of roughly 60° half-power beam-width, deep first nulls near ±95° and a front-to-back ratio around 40 dB, while its cross-polar levels lay some 20–30 dB below the main lobe. The H-plane showed a similarly directional main beam with distinct nulls and secondary lobes. As the frequency rose from 1 GHz to 4 GHz, the beam narrowed from about 80–90° to 20–25°, side-lobe amplitudes fell, and null depths deepened—behaviors consistent with increased electrical aperture and ideal aperture efficiency.

7 References

1. Essential Radio Astronomy
2. E-plane and H-plane
3. MATLAB code for Power Pattern