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# Descriptive study of the necessary equipment for the characterization of an antenna

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# Descriptive study of the necessary equipment for the characterization of an antenna

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***Abstract*—This descriptive study provides an examination of the fundamental equipment necessary for antenna characterization. The objective is to offer a comprehensive overview of essential tools for analyzing antenna performance. The research identifies critical equipment, approaches, and methods required for evaluating antenna features ,aiming to optimize design and functionality. To illustrate practical application, an example of antenna characterization is included, improving the credibility and applicability of the study's findings.**

***Index Terms*—anechoic chamber, RF absorber , VNA , Radiation pattern, VSWR , patch.**

## I. Introduction

Modern communication systems depend on antennas which act as the bridge between electromagnetic waves and electronic devices. A graphical representation of the relative distribution of the radiated power in space that the antenna will emit when a signal is fed into is called a radiation pattern [1]. Adding to it some other parameters that are very important to be known in order to identify the efficiency of the antenna across different applications. This paper examines the tools required for effective characterization of antennas. It is possible for researchers and engineers to gain more information regarding the behavior of an antenna by understanding how to measure certain parameters such as radiation pattern, input impedance and efficiency. The accurate characterization of antennas plays a vital role in their design and overall performance. This descriptive study seeks to outline major equipment needed for a comprehensive evaluation of antennas towards achieving developments in antenna technology and communication systems.

## II. Antenna characteristics

### A. Radiation pattern

The definition of an antenna pattern, also known as an antenna radiation pattern, is "a mathematical function or graphical representation of the radiation characteristics of an antenna as a function of spatial coordinates [2] ". The radiation pattern is often represented as a function of directional coordinates and calculated in the far-field region (that is, for $> 2D^2/\lambda$, where D is the maximum dimension of the antenna) [3]. Power flux density, radiation intensity, field strength, directivity, phase, and polarization are examples of radiation characteristics.

The radiation pattern (3D) can be seen as a description of the power radiated by the transmitting antenna. It displays the high, low, peak, and zero radiation locations as well as other radiation-related information.

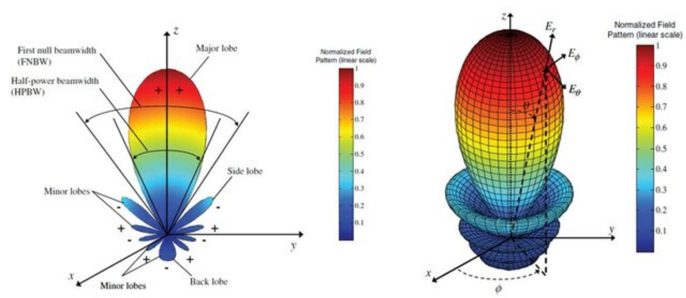



Fig. 1: 2D and 3D Radiation Pattern

We find 3 types of lobes in a pattern radiation representation:

- Main Lobe: Contains the maximum radiated energy and indicates the directivity of the antenna.
- Side Lobes: Represent areas where power is wasted, and minimizing them is crucial for performance improvement.
- Back Lobe: A minor lobe opposite to the main lobe, representing the wasted energy.

### B. Beamwidth

The antenna beamwidth refers to the angular extent of the primary lobe within the antenna's radiation pattern, representing the region where the majority of the emitted power is concentrated. This measurement is commonly taken at the angle between two points on either side of the main lobe, known as the half-power points or -3dB points, where the radiated power decreases to half of its peak value [4].

A narrower beamwidth characterizes a highly directional antenna, ideal for long-range communication purposes, while a wider beamwidth is preferable for short-range communication and broader coverage requirements. Various factors, including antenna type, design, orientation and operating frequency contribute to the variation in beamwidth.

### C. Voltage Standing Wave Ratio (VSWR)

VSWR holds significant importance as it evaluates the effectiveness of a radio antenna system. It signifies the proportion of energy that is reflected back to the transmitter upon signal

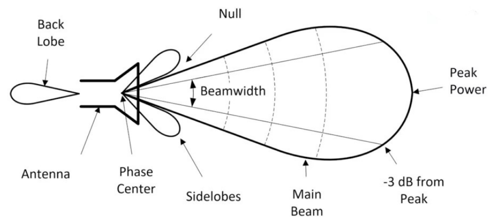



Fig. 2: Basic antenna parameters

transmission through the antenna. A high VSWR level indicates potential issues within the antenna and/or transmission line, as a considerable portion of energy is reflected rather than being radiated by the antenna [5]

In practical applications, minimizing VSWR is crucial to enhance system efficiency and ensure its stability. By reducing VSWR, the system can achieve better performance and mitigate potential losses associated with energy reflection.

### D. Polarization

Understanding polarization starts with the basics of electromagnetic waves. These waves consist of an electric field (E field) and a magnetic field (H field) that propagate in one direction. The E field and the H field are perpendicular to each other and perpendicular to the propagation direction of the plane wave.

Polarization refers to the plane of the electric field from the perspective of the signal transmitter: with horizontal polarization, the electric field moves laterally in the horizontal plane; with vertical polarization, the electric field swings up and down in the vertical plane. In order to transfer maximum power between a transmit and receive antenna, both of them must have the same spatial orientation, otherwise power transfer between the two antennas will be reduced which will reduce the system efficiency and performance [6]. There are three types of polarization: elliptical, circular, and linear. The electric field is said to be linearly polarized if the vector that represents it as a function of time at any given place in space always pointed in the direction of a line. Yet, the electric field is said to be elliptically polarized when it generally traces an ellipse. When transmit and receive antennas are both linearly polarized,the loss can be calculated using the equation 1 where $\phi$ is the difference in alignment angle between the two antennas.For $15°$, the loss is approximately 0.3 dB; for $30°$, the loss is 1.25 dB; for $45°$, the loss is 3 dB; and for $90°$, the loss is infinite [6].

$$\text{Loss (dB)} = 20 \log(\cos\phi) \tag{1}$$

### E. Input Impedence and efficiency

Antenna impedance is the impedance measured on the terminals of an antenna. This impedance may be decided because the ratio of voltage to cutting-edge on the antenna terminals. The ratio of suitable additives of electrical and magnetic fields at a factor additionally gift antenna impedance.

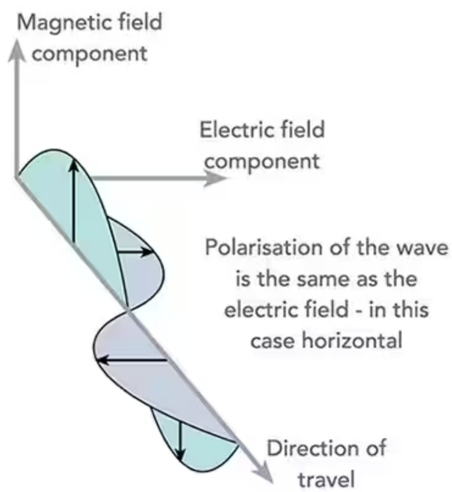



Fig. 3: An electromagnetic energy wave consists of E-field and horizontal-field components at right angles to each other.

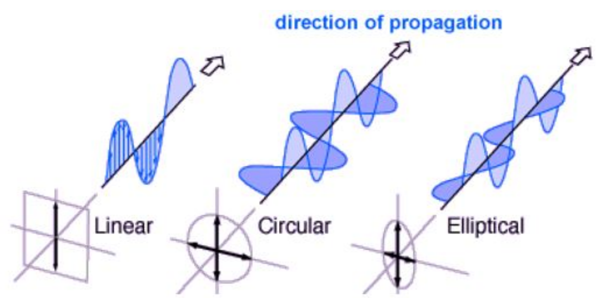



Fig. 4: antenna polarization types

Consider an antenna with terminals a and b with no load connected. The ratio of voltage to current at terminals a and b give the antenna impedance $Z_a$:

$$Z_a = R_a + jX_a \tag{2}$$

where $R_a$ is the resistance of the antenna and $X_a$ is the reactance of the antenna. The real part of the antenna $R_a$ is due to heat dissipation and radiation loss [7]. The antenna resistance $R_a$ can be resolved as : $R_a = R_l + R_r$. $R_l$ is the resistance of the antenna due to heat dissipation and $R_r$ is the resistance of the antenna depicting radiation loss. The radiation efficiency is also dependent on the radiation and loss antenna resistance

- Radiation efficiency

$$e(\%) = \frac{P_r}{P_r + P_l} \times 100 \tag{3}$$

$P_t = P_r + P_l$ : Total input power
$P_r$: Radiated power
$P_l$: Ohmic losses in the antenna

The energy that is stored in the near zone and surrounding the antenna is shown by the antenna reactance. An antenna experiences resonance when the electrical and magnetic energy it has accumulated are of identical magnitude. The antenna reactance is zero at resonance.

### F. Directivity and Gain

The power gain, often referred to simply as gain, is a crucial metric in assessing antenna performance, as it integrates both the antenna's directivity and electrical efficiency.

For a transmitting antenna, the gain reflects its effectiveness in converting input power into radio waves directed towards a specific direction.Conversely, for a receiving antenna, the gain signifies its ability to efficiently convert incoming radio waves from a specified direction into electrical power.

Directivity characterizes the focus of radiated power towards a specific direction, while Gain indicates the emphasis of input power towards a particular direction [8] .Gain is related to directivity with antenna efficiency factor as indicated in equation 4 where k is the dimensionless antenna efficiency factor $(0 \leq k \leq 1)$.

$$G = kD \tag{4}$$

Antenna Gain can be of two types:

- Power Gain (Gp) is defined as the proportion of radiation intensity observed in a particular direction relative to the average total input power.

$$G_p = \frac{4\pi U}{P_t} \tag{5}$$

- Directive Gain (Gd) is the proportion between the radiation intensity in a specific direction and the average power radiated overall.

$$G_d = \frac{4\pi U}{P_r} \tag{6}$$

U : radiation intensity (W/unit solid angle)

The maximum value of directive gain is the directivity D of the antenna and as the gain is related to directivity by an efficiency factor $e_r$, the directive gain is also related to the power gain by the same factor as equation 7 describes.

$$G_p = e_r G_d \tag{7}$$

The Friis Transmission Formula enables us to calculate the power $P_{\mathrm{r}}$ at the output of a receiving antenna received by a transmitting antenna with a transmitted power $P_{\mathrm{t}}$ over a distance $d$ in a free space environment ( figure 5). The Friis equation is given in linear values by the equation 8 and in dB by the equation 9.

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2 \tag{8}$$

Where:

- $P_{\mathrm{r}}$ is the received power (in watts, W),
- $P_{\mathrm{t}}$ is the transmitted power (in watts, W),
- $G_{\mathrm{r}}$ is the receiving antenna gain,
- $G_{\mathrm{t}}$ is the transmitting antenna gain,
- $\lambda$ is the wavelength of the signal (in meters, m),
- $d$ is the distance between the transmitting and receiving antennas (in meters, m).

$$P_r(dB) = P_t(dB) + G_t(dB) + G_r(dB) + 20\log_{10}\left(\frac{\lambda}{4\pi d}\right) \tag{9}$$

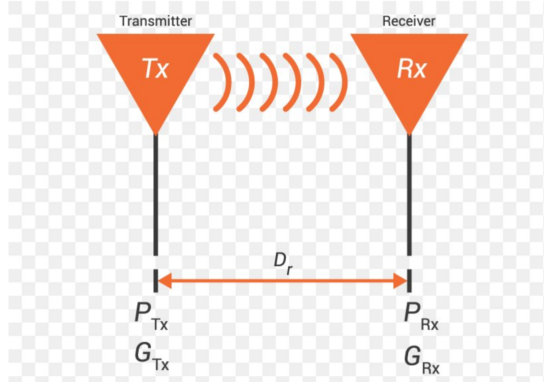



Fig. 5: Friis equation parameters

## III. Antenna measurements equipment

### A. Anechoic chamber

Anechoic chambers are specifically engineered spaces intended to absorb electromagnetic radiation reflections and reduce disruptive energy interferences from external sources. The term "an-echoic" denotes the absence of reflection.

The antenna testing setup within an anechoic chamber features surfaces covered with jagged triangles called RF absorbers, which effectively minimize reflections. This configuration ensures that the antenna testing environment remains free from unwanted echoes and disturbances.

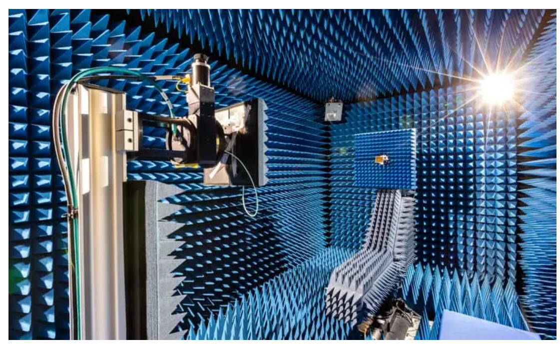


Fig. 6: Anechoic chamber

Most electromagnetic anechoic chambers utilize a standard microwave absorber, typically in the form of pyramidal structures. This absorber is composed of a solid carbon-loaded urethane foam infused with fire-retardant chemicals, either blended into the carbon solution or applied as a secondary treatment [9]. Among all known absorbers, the pyramidal variant shows superior broadband performance, functioning effectively at both normal and wide incidence angles. The modeling of microwave absorber is done with two main parameters which are the permittivity and permeability of the material [10]. Available in various thicknesses, this absorber enables chamber designers to tailor their selection to specific frequencies and angles of incidence.

### B. Reference Antenna

A reference antenna is one with established attributes such as radiation pattern, gain, and efficiency. Typically, dual-

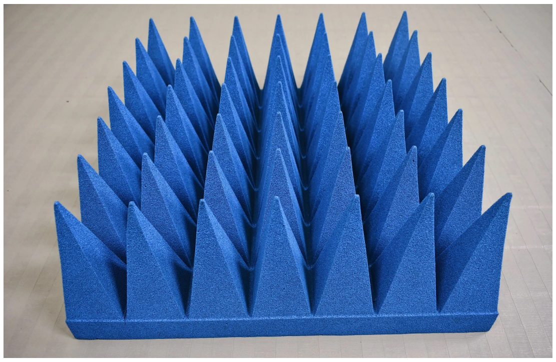


Fig. 7: pyramidal absorber

polarized horn antennas are utilized as reference antennas to measure both horizontal and vertical polarization. The reference antenna is coupled with a frequency(signal) generator which provides a stable signal with a known frequency.

### C. *Antenna under test*

An antenna whose characteristics are determined by antenna testing is called an antenna under test or test antenna. The antenna under test and an RF transmitter system are positioned at a known distance from a reference antenna. Additionally, a power meter is connected to the antenna under test for evaluation purposes.

### D. *Vector Network Analyzer VNA*

A Vector Network Analyzer (VNA) is an essential measurement tool for RF and microwave engineering, used to measure the scattering parameters (S-parameters) of high-frequency components, specially the antennas, filters and amplifiers. It measures antenna parameters such as input impedance, return loss, and VSWR (Voltage Standing Wave Ratio). Some VNAs can be used to test transmission performance and reflection case of electrical and optical devices up to 70GHz in bandwidth, including transmission power, transmission loss, transmission phase and group delay.

Before utilizing a Vector Network Analyzer (VNA) for antenna testing or any other measurement tasks, it is imperative to calibrate the instrument. Calibration ensures the accuracy and reliability of the measurements obtained from the VNA. Through calibration, systematic errors and imperfections in the measurement setup are accounted for and corrected, resulting in more precise and trustworthy results [11]. Calibration involves connecting known standards or calibration kits to the VNA and performing a series of measurements at various frequencies and power levels. These measurements serve as reference points for the VNA's internal calibration algorithms to adjust and compensate for any inherent deviations or inaccuracies in its measurements.

### E. *Signal Generator*

A signal generator is a tool designed to produce an electrical signal with a defined frequency. When utilizing a signal generator for antenna testing,we start by linking the generator

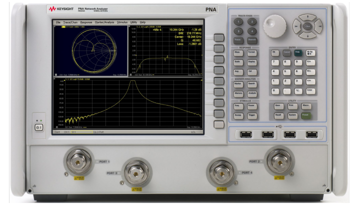


Fig. 8: A Vector Network Analyzer (VNA) [12]

to the antenna, then we configure the generator to the desired frequency. Proceed by transmitting a signal via the antenna and measure the signal's intensity at the transmission line's opposite end, employing instruments like an oscilloscope or a power meter. It's essential that the measured signal strength falls within the anticipated range to confirm the antenna's operational integrity.

Fig. 9: A signal Generator [13]

### F. *Power meter*

A power meter is a device used in antenna testing to measure the power received by the antenna under evaluation. It serves the purpose of determining the magnitude of the received power from the test signal. Typically, a power meter capable of measuring RF power is connected to the terminals of the test antenna using coaxial cables and connectors. The receiver system is typically designed to operate within a $50\Omega$ system.

The gain of the antenna under test can be derived from the signal amplitude measured at the receiver connected to the test antenna. By comparing the measurements obtained from the receiver and transmitter of the antenna under test, the efficiency of the antenna can be determined. This comparison provides insights into how effectively the antenna converts received RF power into usable electrical signals.

Fig. 10: A power meter [14]

### G. *Positioner*

The positioning system, also known as an antenna rotator or antenna azimuth/elevation system manages the alignment of the antenna under examination [15], it is programmed to rotate in a controlled manner, typically starting from 0 degrees and moving incrementally all the way to 360 degrees. At each specific angle at which the positioner stops, the power meter detects the received signal power.

The wattmeter and the positioner are connected to a computer, which records the received power data at each angle. A computer software processes this data to draw the radiation pattern of the antenna which is visualized in real-time on the computer screen.

Fig. 11: A positioner

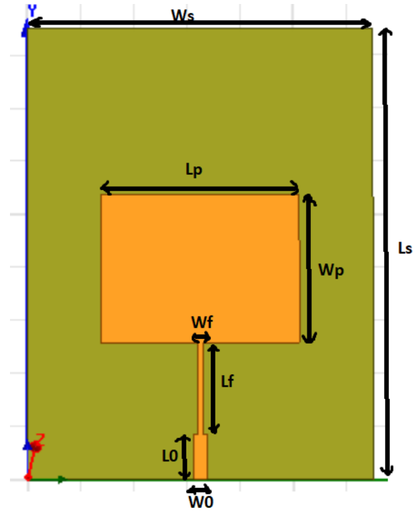



Fig. 12: Design of the MPA

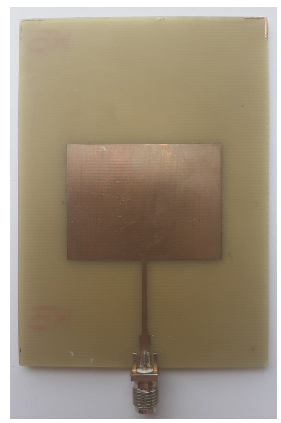


Fig. 13: Front view of the fabricated MPA

Fig. 14: Back view of the MPA

## IV. Antenna testing and results

A 2.4 GHz patch antenna was both simulated, its design is shown in figure 12 and its dimensions are detailed in the table below. Figures 13 and 14 present the fabricated Microstrip Patch Antenna (MPA). FR4 was used with a dielectric constant ($\epsilon_r$) of 4.3 and a substrate thickness ($h$) of 1.6 mm. The patch, feed, and ground thickness is 0.035 mm.

| Symbol | Dimension(mm) | Description |
|---|---|---|
| $W_s$ | 65 | Width of the substrate |
| $L_s$ | 85 | Length of the substrate |
| $W_p$ | 27.9 | Width of the patch |
| $L_p$ | 37.3 | Length of the patch |
| $W_f$ | 1 | Width of the feed line |
| $L_f$ | 17.2 | Length of the feed line |
| $W_0$ | 2.4 | Width of the junction |
| $L_0$ | 8.5 | Length of the junction |

TABLE I: Antenna Dimensions and Descriptions

### *A. The reflection coefficient and VSWR measurement*

First, we measure the reflection coefficient using a VNA. Before any measurement, The VNA must be calibrated using an electronic calibration kit in order to minimize noise and ensure reliable results. When it is red (figure 15), the VNA


Fig. 15: Calibration kit in OFF state.


Fig. 16: Calibration kit in ON state.

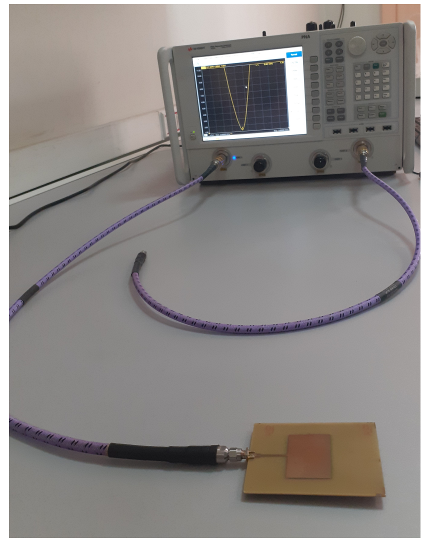


Fig. 17: The 2.4 GHz MPA measured using a VNA

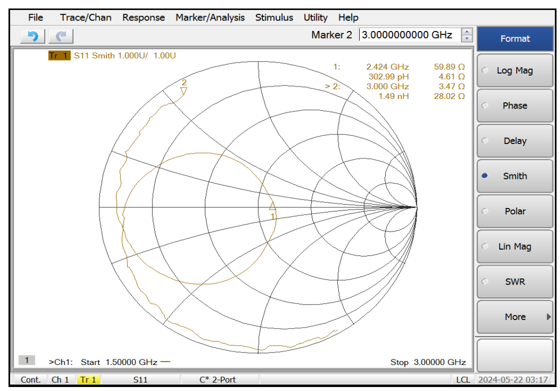
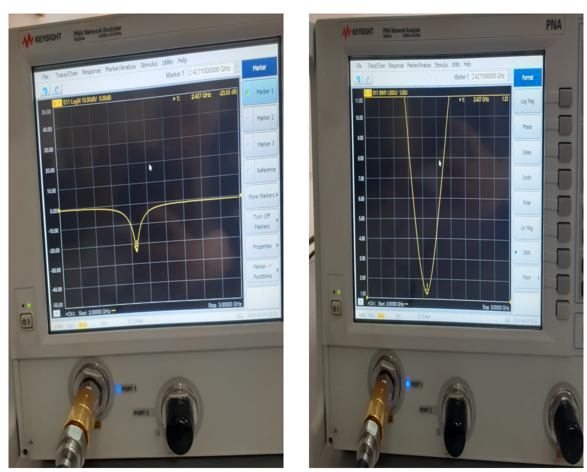



Fig. 18: The measured input impedence of the antenna

still contains noise. When it is green (figure 16), the VNA is ready to be used.

After calibrating the VNA, we proceed to measure the input impedence, the S11 and the VSWR of the antenna (figure 17). The figure 18 represents a smith chart which is a graphical tool used to visualize complex impedances. The horizontal axis represents the resistance, while the vertical axis represents the reactance. A perfect circle centered at the origin represents all possible impedances with a magnitude of 1 (or 0 dB). Marker 1 is located at 2.424 GHz, which is the resonant frequency of the patch antenna. The impedance at this point is 59.89Ω with a phase angle of 4.61° which means that the patch antenna has a good impedance match at its resonant frequency, but the impedance becomes mismatched at higher frequencies.
The figure 20 shows the S-parameter of the antenna. The minimum return loss is -20.99 dB with a bandwidth of 40 MHz (from 2.41– 2.45 GHz).
The figure 21 illustrates the comparison between the measured and simulated results which are almost equivalent.



a b

Fig. 19: VNA used to measure antenna's (a) S11 and (b) VSWR

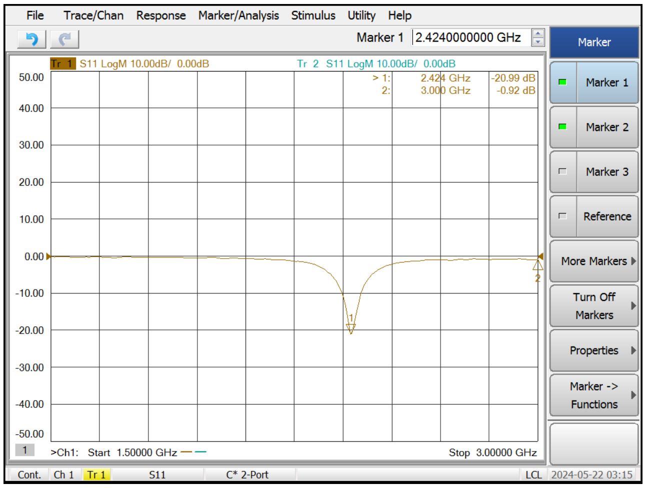



Fig. 20: S11 measured

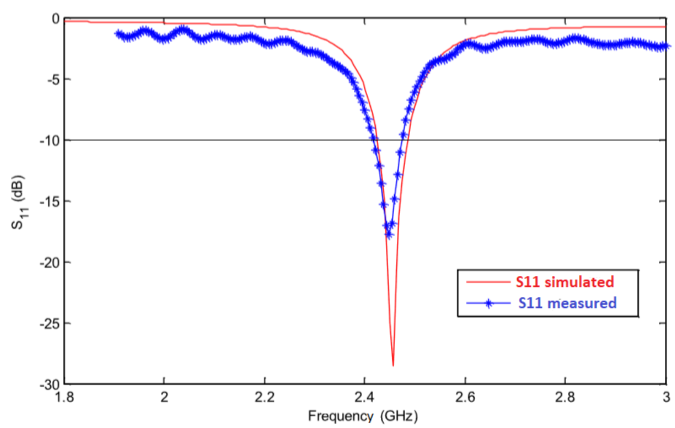



Fig. 21: Simulated Vs measured S11

The figure 22 below shows the Voltage Standing Wave Ratio (VSWR) versus frequency graph. Ideally, the VSWR value is between 1 and 2 which has been achieved for the resonance frequency (fr=2.424 GHz) and it is equal to 1.22.

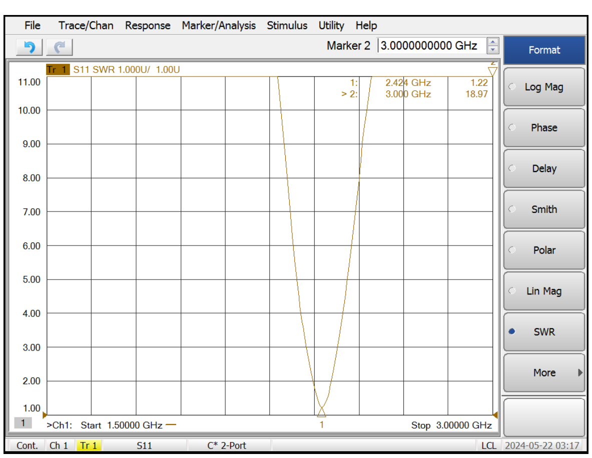



Fig. 22: VSWR measured

## B. *Gain and radiation patterns measurement*

We set up a measurement configuration within a semi-anechoic chamber, utilizing an ultra-wideband Yagi antenna with a reflector as the transmitting source (figure 23). The separation distance between the transmitting and receiving antennas "d" was set at $8\lambda$ to ensure optimal performance and minimize interference in the farfeild region. The transmitting antenna has a gain "$G_t$" of 14 dB at the frequency of 2.4 GHz and is connected to a frequency generator as shown in Figure 23. The frequency generator was set to operate at 2.4 GHz with a transmitted power "$P_t$" of 0 dBm (-30db). Utilizing a positioner, the received power is recorded every 10 degrees in both the E-plane and H-plane (figure 24). These recorded values are then employed to draw the radiation patterns for both planes, as presented in Figures 25 and 26 (the values in the X-axis present the received power in dbm). To calculate the gain of the antenna under test which has received power $P_r$ of -20dBm (-50dB) when the angle=0, we use the Friis transmission equation.

$$P_r(dB) = P_t(dB) + G_t(dB) + G_r(dB) + 20\log_{10}\left(\frac{\lambda}{4\pi d}\right)$$
$$\rightarrow G_r(dB) = P_r(dB) - P_t(dB) - G_t(dB) - 20\log_{10}\left(\frac{\lambda}{4\pi d}\right)$$
$$= -50 + 30 - 14 - 20\log_{10}\left(\frac{\lambda}{4\pi 8\lambda}\right) = 6dB$$

The gain of the 2.4Ghz patch antenna is 6dB.

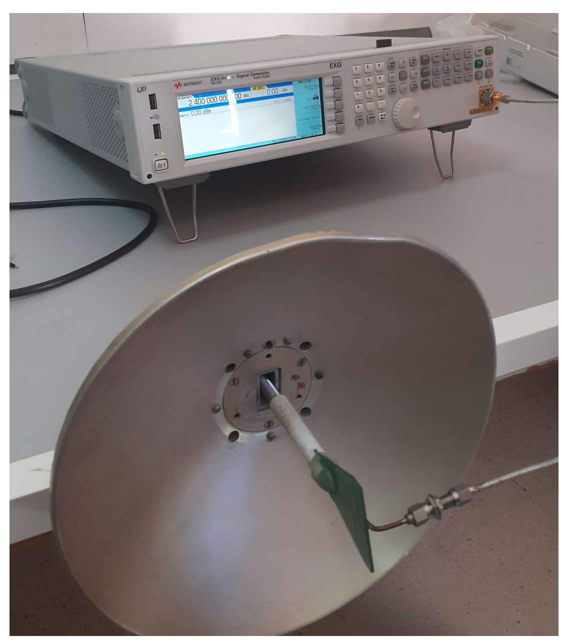
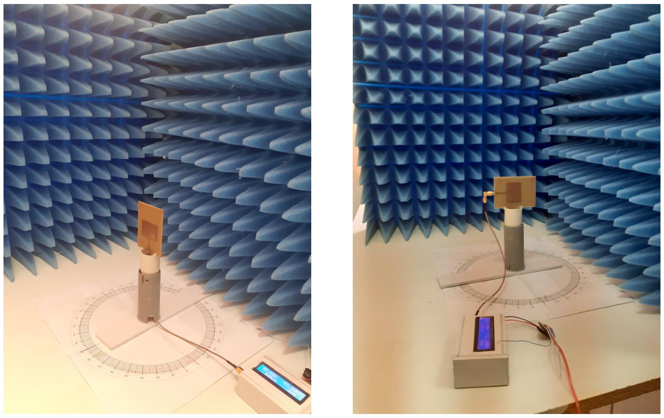


Fig. 23: Frequency generator set at 2.4Ghz linked with the transmission antenna



(a) H plan (b) E plan

Fig. 24: Receptive antenna in a semi anechoic chamber

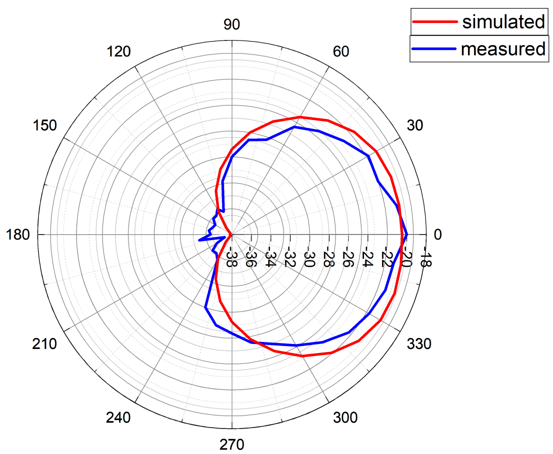



Fig. 25: Radiation pattern in E-plane

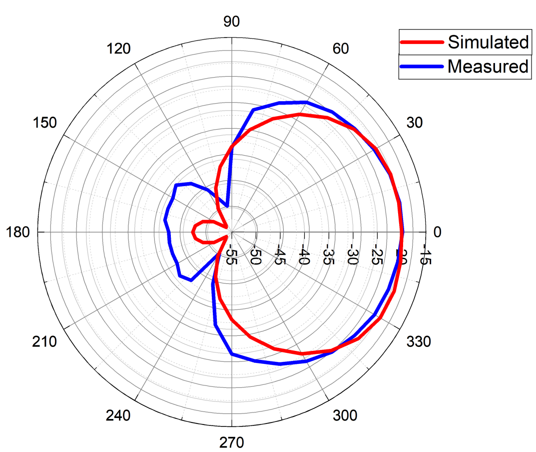



Fig. 26: Radiation pattern in H-plane

The measurement results closely match those of the simulation, the antenna's radiation pattern shows a large main lobe with a beamwidth of approximately 60 degrees. Comparing the H-plane and E-plane radiation patterns reveals that the 2.4 GHz rectangular patch antenna has a wider main lobe in the E-plane compared to the H-plane. This suggests that the antenna has a higher directivity in the direction of the patch length than in the direction of the patch width. The presence of the weak back lobe indicates that the antenna possesses a good directivity, which makes it well-suited for applications requiring directional transmission, such as local area networks, wireless sensor networks, and RF applications.

## V. Conclusion

This article has served as a concise guide to how to caracterise an antenna , equipping researchers with the necessary knowledge. We explored fundamental antenna characteristics, delved into essential measurement equipment like VNAs, signal generators, power meters, antenna positioners and finally, studied the process of testing a patch antenna within an anechoic chamber. This step-by-step approach empowers researchers with the tools and know-how to measure and analyze an antenna performance.

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