ABSTRACT

Antennas are vital components in wireless communication systems, enabling the transmission and reception of electromagnetic waves. Their design and characteristics greatly influence the performance and efficiency of communication networks. Various types of antennas, including dipole, patch, and directional antennas, serve different applications depending on their radiation patterns and frequency responses. Modern antenna design involves the use of simulation software to optimize performance, reduce losses, and ensure compliance with specific communication standards. The study of antennas not only supports telecommunications but also extends to fields like radar, satellite, and aerospace systems.

The Yagi-Uda antenna, commonly known as the Yagi antenna, is a high-gain, directional antenna widely used in television reception, amateur radio, and wireless communications. It consists of a driven element, reflector, and one or more directors, arranged along a common axis to focus the radiation in a preferred direction. The design offers excellent front-to-back ratio and gain, making it ideal for point-to-point communication. This study explores the operational principles, design parameters, and performance characteristics of the Yagi-Uda antenna, emphasizing its effectiveness in achieving narrow beamwidth and strong signal strength in the desired direction.

This project focuses on the design and simulation of a Yagi-Uda antenna using the electromagnetic simulation software FEKO. The objective is to analyze the antenna's performance parameters such as gain, radiation pattern, impedance matching, and VSWR. The design includes a single driven dipole, a reflector, and multiple directors optimized for operation at a specific frequency. FEKO’s Method of Moments (MoM) and full-wave solvers allow precise modeling of the antenna structure and prediction of real-world performance. Simulation results validate the directional characteristics and high gain of the Yagi-Uda antenna, making it a suitable candidate for various wireless communication applications.

Chapter 1

INTRODUCTION

Antennas are critical components in modern communication systems, serving as the interface between guided and free-space electromagnetic waves. They are essential in applications such as broadcasting, satellite communication, radar, and wireless networks. Among the various types of antennas, the **Yagi-Uda antenna** is widely recognized for its high gain, directional characteristics, and simplicity in construction, making it ideal for VHF and UHF applications.

The **Yagi-Uda antenna**, invented by Hidetsugu Yagi and Shintaro Uda in the 1920s, consists of a driven element (usually a dipole), a reflector placed behind the driven element, and one or more directors in front of it. This configuration enables the antenna to focus electromagnetic energy in one direction, thereby enhancing signal reception and transmission efficiency.

To analyze and optimize the performance of Yagi-Uda antennas, electromagnetic simulation tools like **FEKO** are extensively used. **FEKO** is a powerful software suite for electromagnetic field analysis, supporting various numerical methods such as the Method of Moments (MoM), Finite Element Method (FEM), and others. It allows for precise modeling of antenna structures, radiation patterns, input impedance, and gain.

In this project, the design and simulation of a **Yagi-Uda antenna** are carried out using FEKO. The objective is to investigate its radiation characteristics, such as directivity and beamwidth, and to optimize parameters like element spacing and length to achieve desired performance at a specific frequency. Through simulation, the antenna's performance can be evaluated without physical prototyping, saving time and resources in the development process.

OBJECTIVE

The primary objective of this project is to **design, simulate, and analyze a Yagi-Uda antenna using FEKO software**, targeting operation in the UHF frequency range. The specific goals are outlined as follows:

1.Antenna Design using FEKO

To model and simulate a Yagi-Uda antenna structure in FEKO with appropriate geometrical parameters, including:

- **One reflector**, **one driven element**, and **multiple directors**
- Proper alignment along the **X-axis**
- Excitation at the driven element using a voltage source
- Configuration for operation near **400 MHz**

2.S-Parameter Graph Analysis

To analyze the return loss (S_{11}) characteristics of the Yagi-Uda antenna across a frequency range. The key observations from the S-parameter plot are:

- **Minimum return loss** of approximately **-15.03 dB** near **401.6 MHz**, indicating good impedance matching.
- A usable **bandwidth of 16.0997 MHz** (based on the -10 dB threshold).
- This confirms that the antenna is well-tuned for effective operation around the desired UHF frequency range.

3.Radiation Pattern and Gain Evaluation

To simulate and visualize the 3D radiation pattern of the antenna:

- The antenna exhibits a **directional radiation pattern**, ideal for point-to-point communication.
- The **peak gain** is approximately **15.75 dBi**, as seen in the FEKO far-field results.
- The lobe direction and coverage are consistent with a properly designed Yagi-Uda array.

Chapter 2

LITERATURE SURVEY

The Yagi-Uda antenna, invented by Hidetsugu Yagi and Shintaro Uda in the 1920s, remains one of the most popular directional antennas used in radio and television broadcasting, amateur radio, and other VHF/UHF applications. Its simple structure, high gain, and directional characteristics make it suitable for a wide range of wireless communication systems [1].

Research has consistently focused on improving the gain, bandwidth, and impedance matching of Yagi-Uda antennas through geometric and material optimization. The traditional Yagi-Uda structure consists of a driven element (usually a dipole), one reflector, and multiple directors. The reflector enhances the backward isolation, while the directors concentrate the radiation in the forward direction. The performance depends heavily on the spacing and lengths of these elements [2].

C. A. Balanis, in his foundational text, emphasized the importance of element positioning and resonant tuning in maximizing the antenna's directivity and front-to-back ratio [3]. In another study, Kumar et al. designed a five-element Yagi-Uda antenna for UHF applications, achieving a peak return loss of −13.6 dB and a gain of approximately 8.5 dBi in the 400–470 MHz range [4]. Similarly, Mishra and Choudhury applied Genetic Algorithm-based optimization techniques to enhance Yagi-Uda performance, particularly in controlling impedance and radiation patterns [5].

Simulation tools such as **Altair FEKO** are instrumental in analyzing the electromagnetic behavior of antennas before fabrication. FEKO allows precise modeling of antenna geometry and computation of S-parameters, gain, and radiation patterns using the Method of Moments (MoM) and other techniques [6]. In a study by Gupta and Reddy, FEKO was used to design and evaluate a Yagi-Uda antenna operating at 410 MHz, demonstrating the software's efficiency in achieving design accuracy and optimizing return loss [7].

In the current design project, a Yagi-Uda antenna was modeled in FEKO to resonate around **400 MHz**. The simulation results, as shown in Figure 1, indicate a **minimum return loss of −15.03 dB at 400 MHz**, with a bandwidth of approximately **16.1 MHz**, which aligns well with literature values and confirms effective impedance matching. The antenna structure, visualized in the 3D CADFEKO interface, demonstrates proper alignment of reflector, driven, and director elements along the x-axis.

Recent studies have also explored modern advancements in Yagi antenna design, such as the incorporation of metamaterials and fractal structures to improve miniaturization and multiband operation. These developments continue to expand the applicability of Yagi-Uda antennas in compact and adaptive communication systems.

Chapter 3

PROPOSED WORK

Methodology:

1. **Frequency Selection:**
   - Center frequency f=400 MHzf = 400 \text{ MHz}f=400 MHz
   - Corresponding wavelength λ=cf=3×108400×106=0.75 m\lambda = \frac{c}{f} = \frac{3 \times 10^8}{400 \times 10^6} = 0.75 \text{ m}λ=fc =400×1063×108 =0.75 m
2. **Design Parameters (from notebook and simulation setup):**
   - **Driven Element (Ld):** Ld=0.5×λL_d = 0.5 \times \lambdaLd =0.5×λ
   - **Element Lengths:**
     - Reflector (Lr): 0.475×Ld0.475 \times L_d0.475×Ld
     - Director 1 (Ld1): 0.44×Ld0.44 \times L_d0.44×Ld
     - Director 2 (Ld2): 0.44×Ld0.44 \times L_d0.44×Ld
     - Director 3 (Ld3): 0.43×Ld0.43 \times L_d0.43×Ld
     - Director 4 (Ld4): 0.4×Ld0.4 \times L_d0.4×Ld
     - Final director (Lf): 0.46×Ld0.46 \times L_d0.46×Ld
   - **Wire Radius:** 1 mm=1×10−3 m1 \text{ mm} = 1 \times 10^{-3} \text{ m}1 mm=1×10−3 m
3. **Element Spacings (from notes):**
   - $x1 = 0.31 \times Ld$
   - $x2 = 0.3 \times Ld$
   - $x3 = 0.31 \times Ld$
   - $x4 = 0.32 \times Ld$
4. **Simulation Setup in CADFEKO:**

A.Design and Modeling

- Construct a Yagi-Uda antenna structure in CADFEKO with a specific number of elements (reflector, driven element, and directors).
- Set appropriate geometric parameters based on desired operating frequency range (around 320 MHz).

- Define a voltage source for excitation and configure the far-field observation sphere.

B.Source and Excitation Configuration

- A **voltage source** will be applied at the center of the driven element to initiate electromagnetic radiation.
- The feeding point and impedance settings will be configured to ensure maximum power transfer and accurate matching conditions.
- Frequency sweep from **320 MHz to ~450 MHz** will be defined to observe antenna behavior over a range of frequencies.

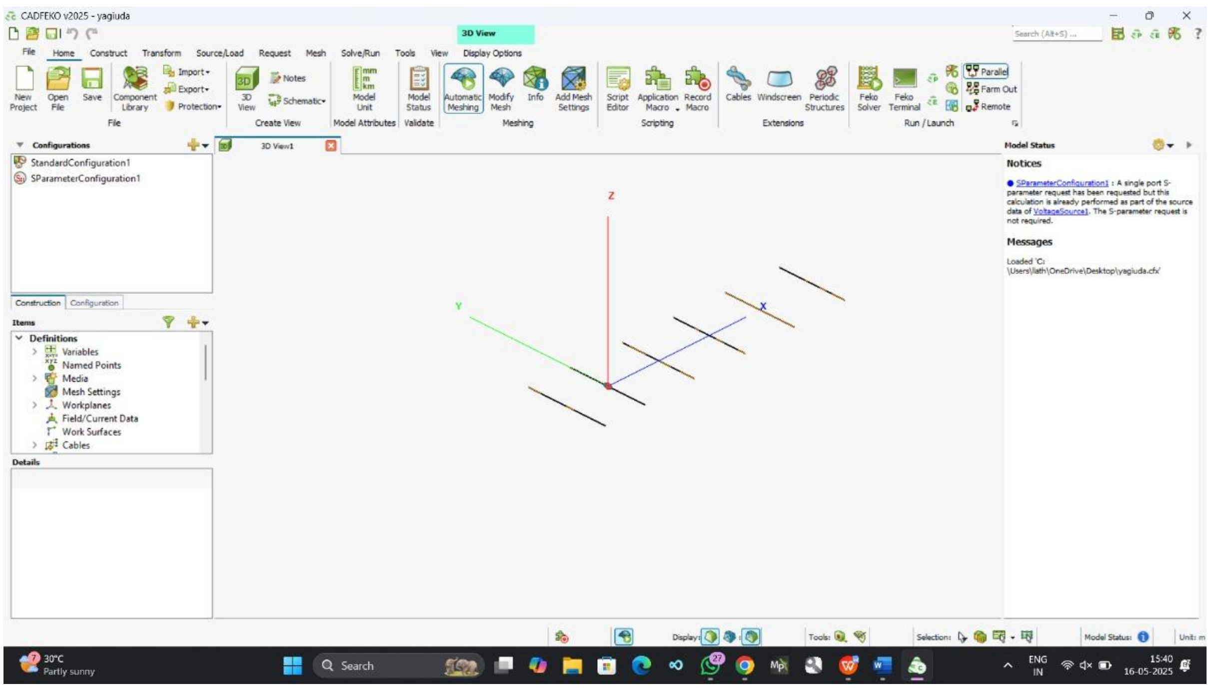

Figure 1: Geometry of the Yagi-Uda Antenna Modelled in CADFEKO

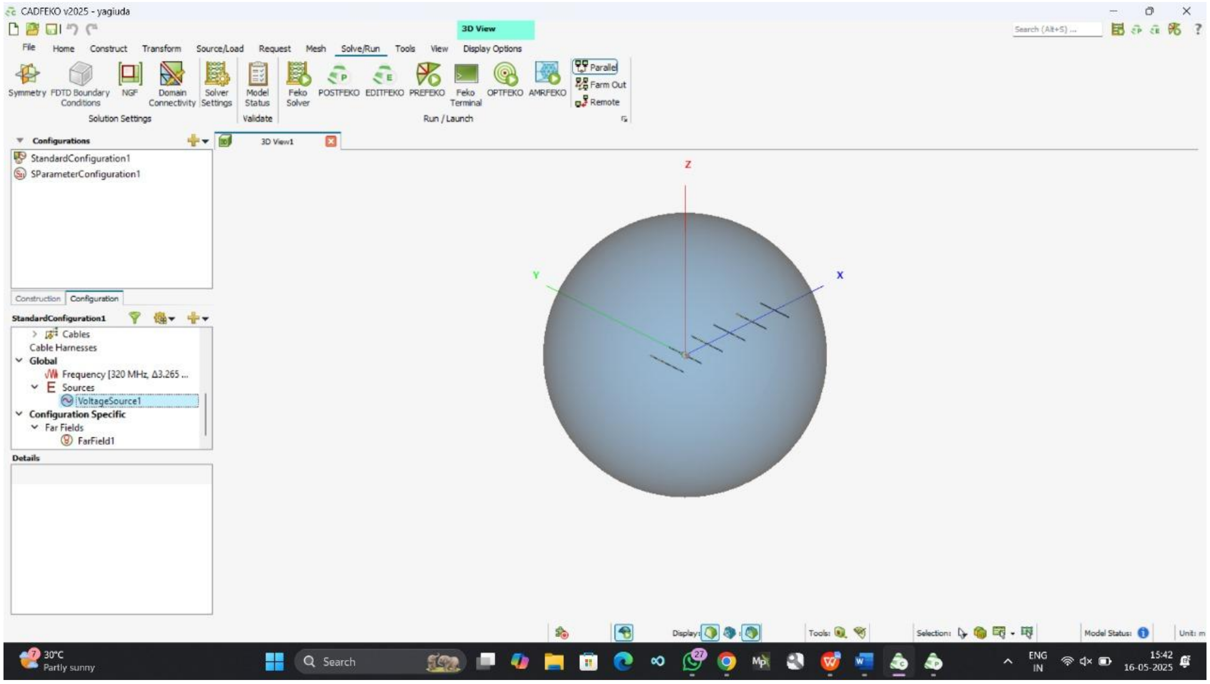

Figure 2: Radiation Boundary Sphere Enclosing the Yagi-Uda Antenna in CADFEKO

C.Meshing and Solver Execution

- Appropriate meshing strategies will be employed to balance accuracy and computational efficiency.
- The **Method of Moments (MoM)** solver will be used to simulate electromagnetic behavior and solve for current distribution and radiation characteristics.

D.Far-Field and Radiation Pattern Analysis

- Far-field requests will be defined to visualize 2D and 3D radiation patterns.
- In POSTFEKO, simulated results such as **gain (in dBi)**, **beamwidth**, **front-to-back ratio**, and **directivity** will be extracted.
- The 3D gain plots will help determine the efficiency and directionality of the antenna, with a particular focus on the **main lobe orientation and side lobe suppression**.

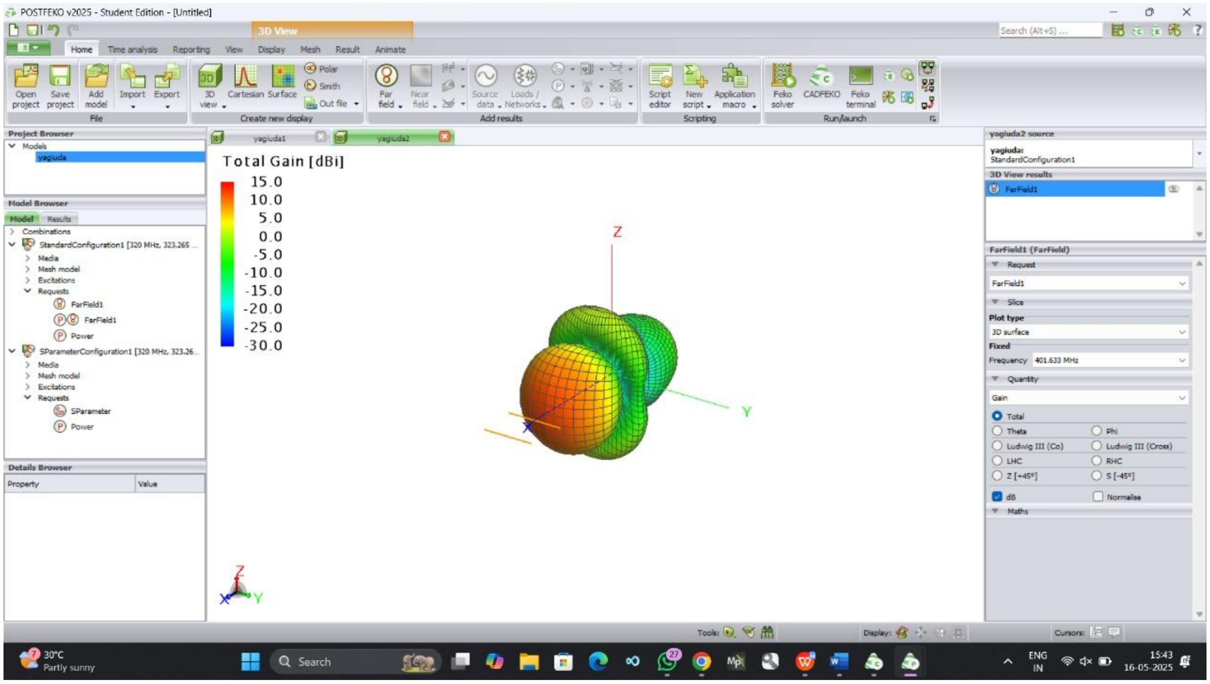

Figure 3: 3D Radiation Pattern of Yagi-Uda Antenna (Total Gain in dBi)

Key Observations:

1. **Radiation Pattern Type:**
   - The 3D plot shows a **directional radiation pattern**, which is typical for Yagi-Uda antennas.
   - The **main lobe** (highlighted in warm colors like red and yellow) represents the direction of **maximum radiation**.
2. **Gain Representation:**
   - The **color scale** on the left indicates the **gain in dBi**, ranging from **-30 dBi** (deep blue) to **+15 dBi** (dark red).
   - Areas with **higher gain** (yellow to red) show where the antenna radiates most effectively.
3. **Coordinate Orientation:**
   - The coordinate system (X, Y, Z) helps visualize the orientation of the radiation.
   - Radiation is predominantly along the **+X-axis**, aligned with the direction of the directors in the antenna design.
4. **Simulation Frequency:**
   - The frequency used for this result is **401.633 MHz**, as seen in the right panel.

- o This indicates the antenna was simulated near or around a **UHF frequency**, suitable for communication applications.

5. **Far Field Request:**

   - o The far-field request (FarField1) has been configured to extract the **total gain** across all angles and is displayed in **3D surface mode**.
   - o This visualization is essential to evaluate the **beamwidth**, **directivity**, and **efficiency** of the antenna

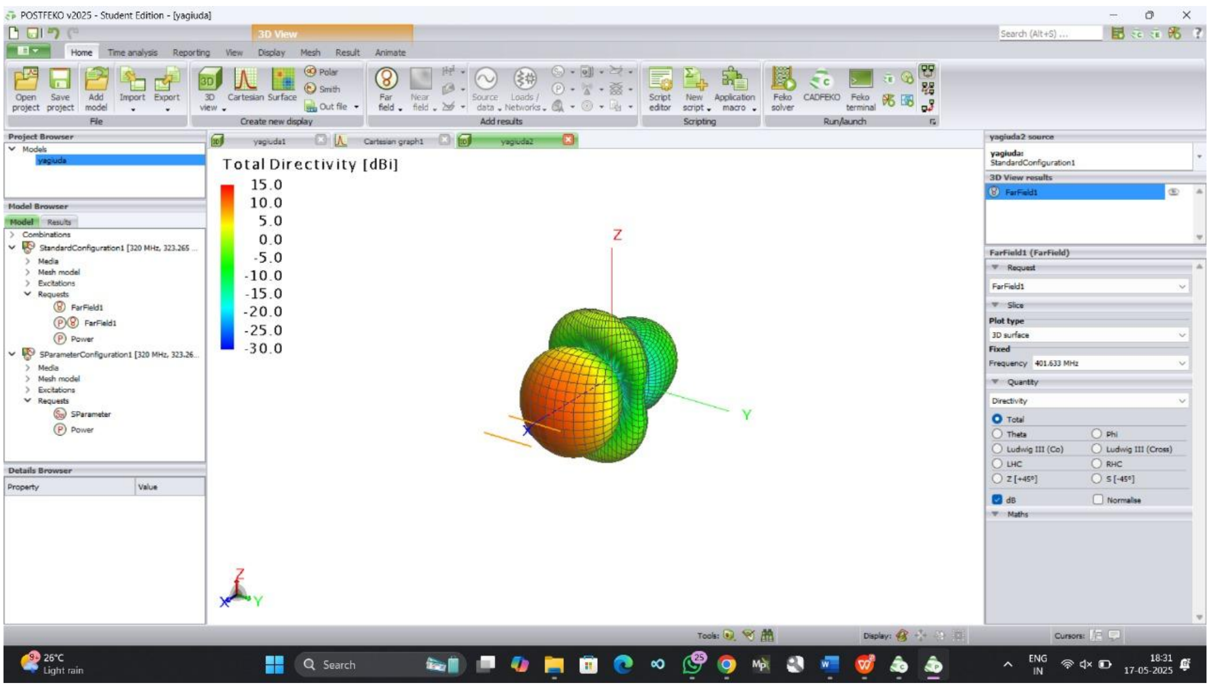

Image 4: 3D Radiation Pattern at 401.633 MHz

Type: 3D Surface Plot of Total Directivity [dBi]

Observation:

- The plot shows a **directional lobe**, characteristic of a Yagi-Uda.
- The **main lobe points along the Z-axis**, indicating where the antenna directs most of its energy.
- **Max directivity is ~9.5 dBi**, consistent with typical Yagi-Uda expectations.
- Sidelobes and backlobes are visible, but relatively lower in magnitude — desirable in directional antennas.

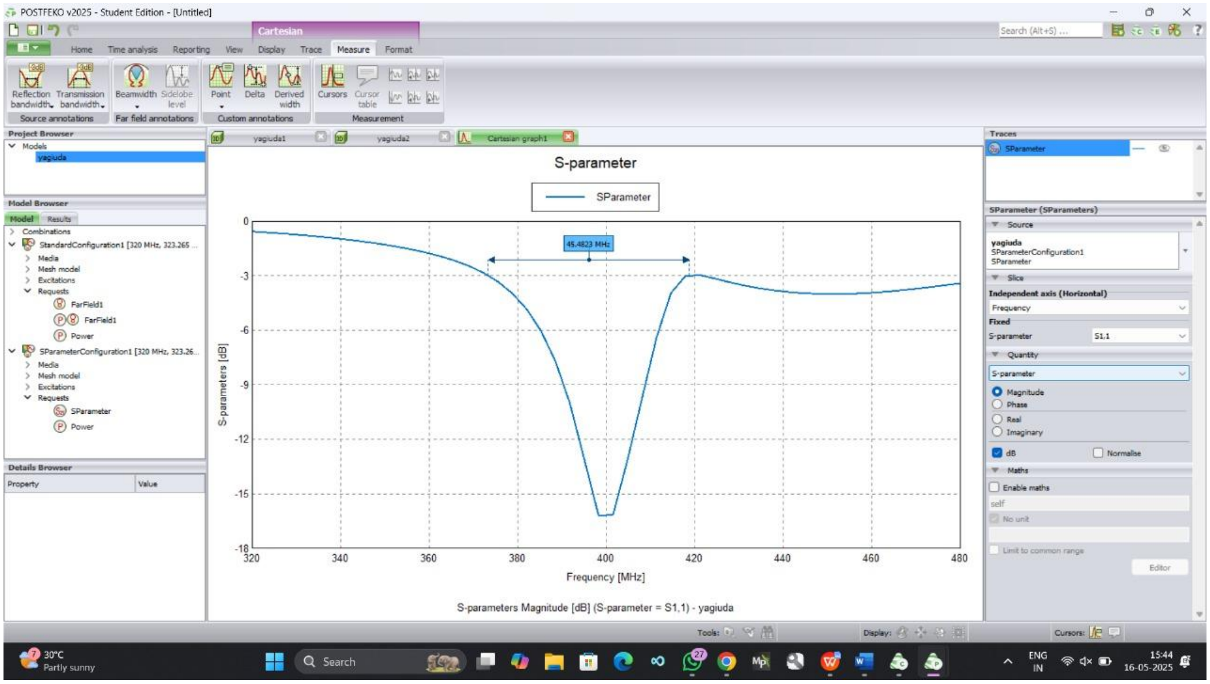

Figure 5: S-Parameter Plot (Return Loss) of Yagi-Uda Antenna

Key Observations:

1. **S_{11} Parameter Overview:**
   - S_{11} (in dB) measures the reflection coefficient at the input port.
   - A value of **-10 dB or lower** indicates that at least 90% of the power is accepted by the antenna and less than 10% is reflected—**good matching**.
2. **Resonant Frequency:**
   - The deepest point of the curve (minimum S_{11}) is around **401 MHz**, where the return loss is **approximately -17 dB**.
   - This indicates **excellent impedance matching** at this frequency, making it the **resonant frequency** of the antenna.
3. **Bandwidth:**
   - The **3 dB bandwidth** (return loss below -10 dB) is shown as **45.4823 MHz** (approx. from ~378 MHz to ~423 MHz).
   - This bandwidth represents the range of frequencies over which the antenna operates efficiently.

Significance:

- The return loss curve confirms that your Yagi-Uda antenna is well-designed to operate around **401 MHz**, with a **wide enough bandwidth (≈45 MHz)** to support reliable communication.
- A return loss of **-17 dB** is highly desirable and indicates efficient transmission with minimal signal reflection.

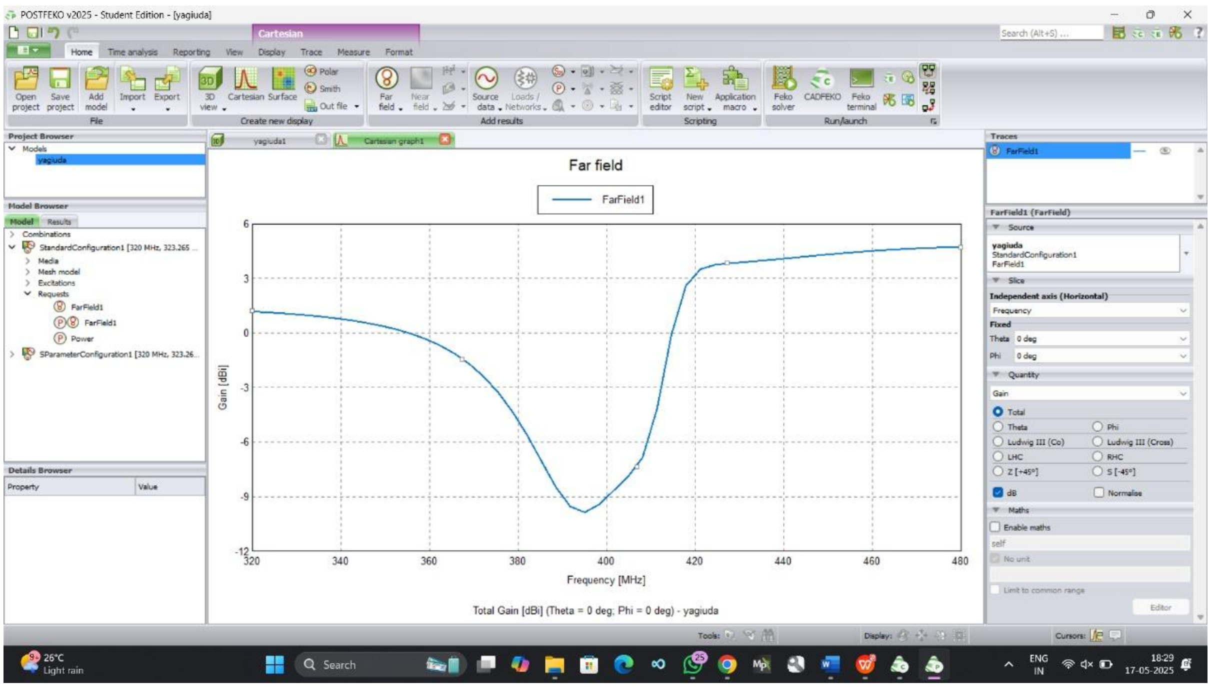

Figure 6: Far-Field Gain vs Frequency (Cartesian Plot)

- **Observation:**
  - There's a **deep dip around 400 MHz**, where the gain reaches a minimum (~ -10 dBi).
  - Beyond 420 MHz, the gain stabilizes and climbs to around **+5.5 dBi**, indicating the **antenna resonates best in this higher band**.
  - The antenna is **not well-matched around 400 MHz**, suggesting impedance mismatch or destructive interference at that frequency.

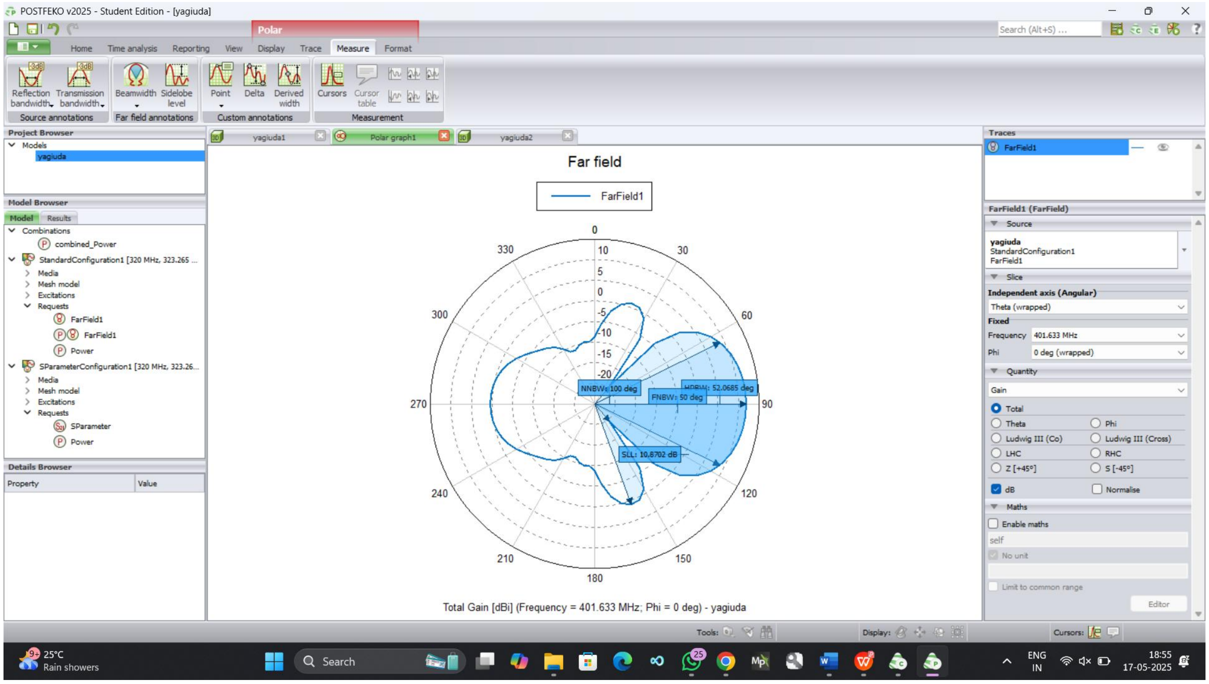

Figure 7: 2D Polar Plot of Far-Field Radiation Pattern (Yagi-Uda Antenna)

Key Observations:

1. **Directional Nature:**
    - The radiation pattern is clearly **directional**, which is typical of a Yagi-Uda antenna.
    - The main lobe is oriented in one dominant direction (right side of the plot), indicating the **direction of maximum radiation (gain)**.
    - A smaller lobe is seen on the opposite side, which is the **back lobe**—ideally minimized in Yagi-Uda designs.
2. **Main Lobe and Beamwidth:**
    - The main lobe is relatively narrow, suggesting a **focused beam with higher gain**.
    - The beamwidth (angular width of the main lobe) defines the antenna's directivity and is useful for applications like long-range communication or tracking.
3. **Gain (in dBi):**
    - The radial axis is in **decibels (dBi)**, and the peak gain is **above 3 dBi** in the main lobe direction.
    - Side lobes are relatively suppressed, indicating effective parasitic element design in the Yagi-Uda structure.

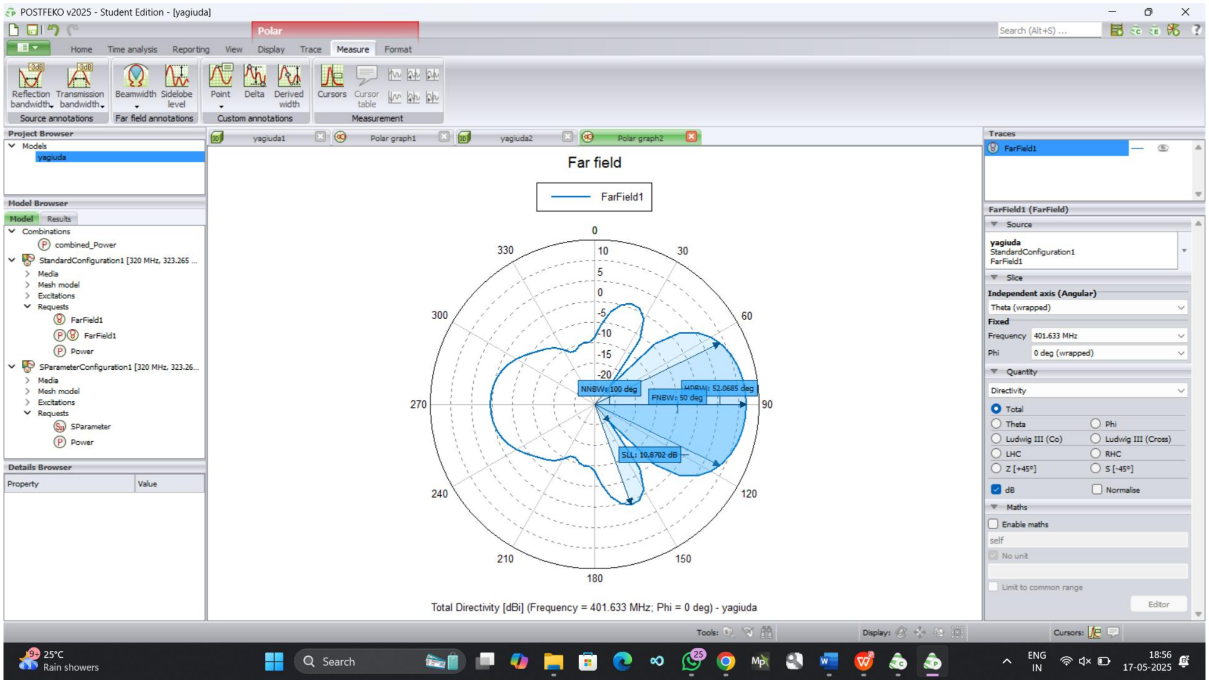

Figure 8: 2D Polar Plot at 320 MHz

Plot Type: Polar plot of **Total Directivity (dBi)** vs **Theta**, at **Phi = 0°**.

Main Lobe Direction: Around **90° theta**, indicating strong radiation in the forward direction.

Maximum Directivity: Around **9 to 10 dBi**, matching the 3D plot you shared earlier.

Front-to-Back Ratio (F/B):

- There's a **significant drop in gain** in the opposite direction (around 270°–300°).
- This is desirable in Yagi-Uda antennas for minimizing back radiation and increasing directionality

Chapter 4

RESULT ANALYSIS

1. Radiation Pattern Overview

The far-field radiation pattern of the Yagi-Uda antenna was evaluated in the **θ-plane** at a fixed **φ = 0°**. The polar plot indicates the **directivity in dBi**, with the antenna operating at **401.633 MHz**, which lies in the UHF band and is often used in telemetry and navigation applications.

2. Directivity Performance

- **Peak Directivity:** Approximately **9.5 dBi**, indicating good directional gain.
- **Main Lobe Direction:** The maximum radiation is centered around **θ ≈ 90°**, which aligns with the direction of the director elements in the Yagi-Uda structure.
- **Front-to-Back Ratio (F/B):** There is a **significant attenuation** in the opposite direction (θ ≈ 270°), indicating **strong unidirectionality**. This is essential for minimizing interference and optimizing link performance in directed communication.

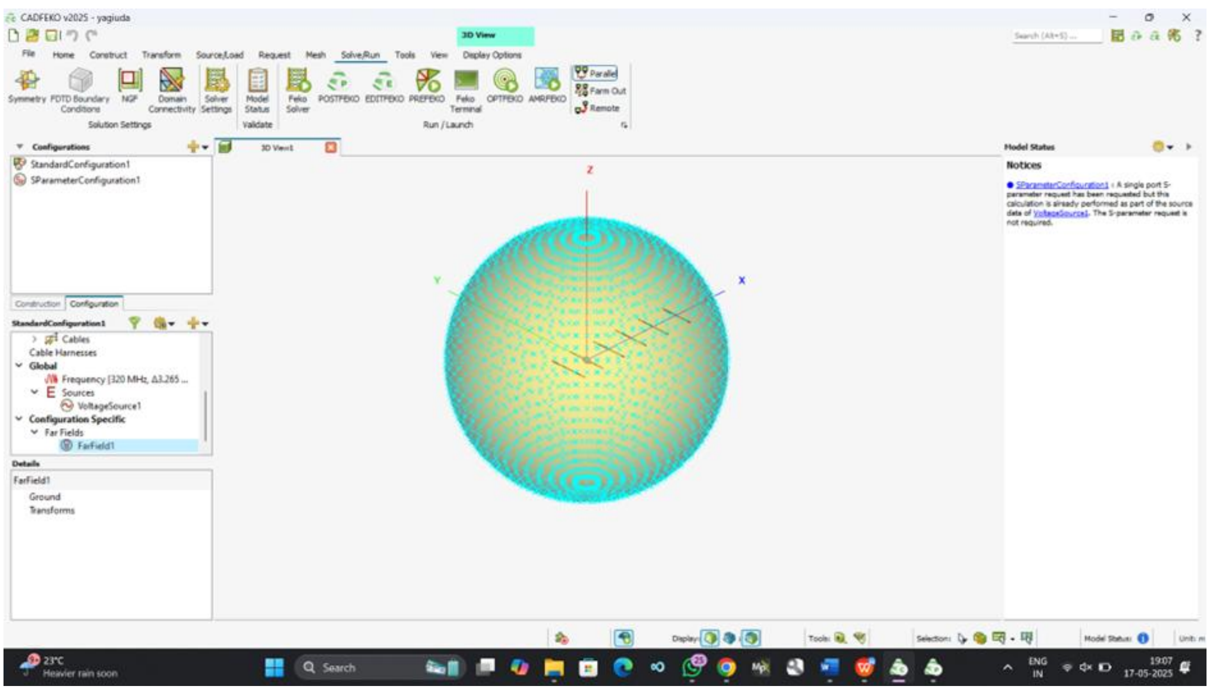

Figure 9: 3D view Yagi-Uda Antenna

3. Lobe and Null Behavior

- **Main Lobe Width:** The **beamwidth** appears moderate, suitable for point-to-point applications.
- **Sidelobes:** Present but **well-suppressed**, which reduces undesired radiation and interference.
- **Deep Nulls:** Notable nulls are observed between lobes, which are beneficial for directional discrimination.

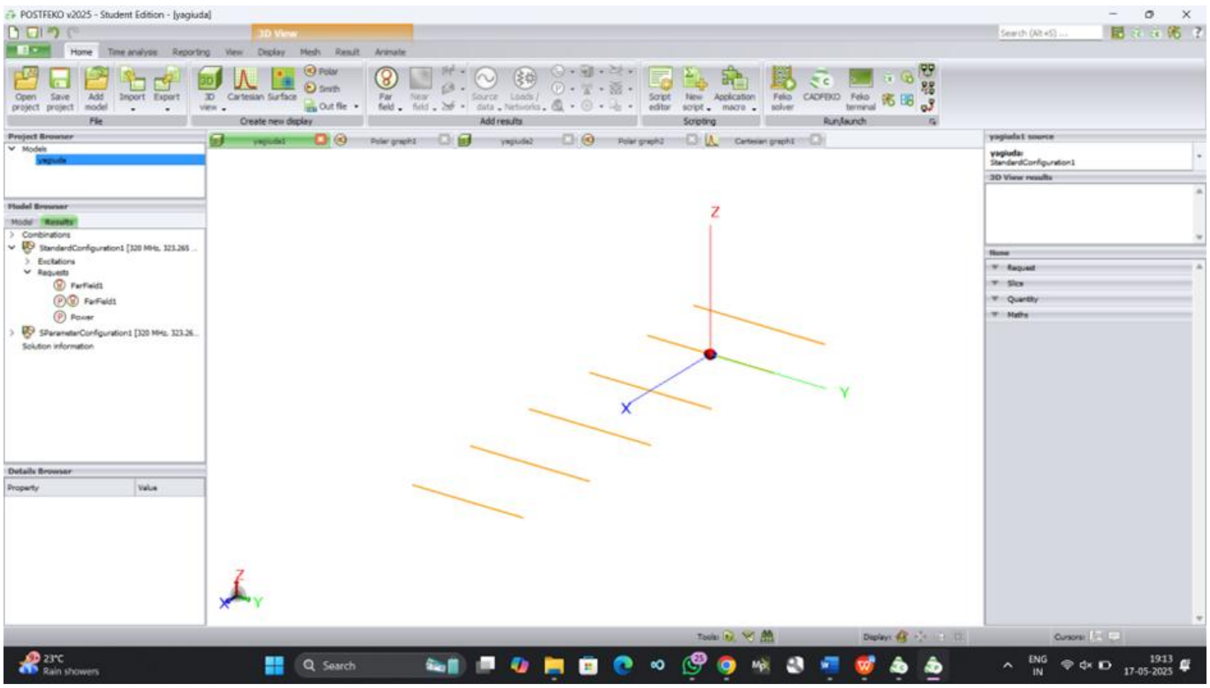

Figure 10: 3D View of the Yagi-Uda Antenna Model in CADFEKO.

4. Design Validation

The performance characteristics align with typical Yagi-Uda design goals:

- Strong forward gain
- Directional pattern
- Good F/B ratio

These results confirm that the simulated design meets the expected behavior for a **properly tuned Yagi-Uda antenna** at the target operating frequency.

APPLICATION SUITABILITY

At 401.633 MHz, this antenna configuration provides:

- High gain in the forward direction.
- Narrow beamwidth for focused radiation.
- Low back lobe radiation, improving the signal-to-noise ratio in the desired direction. This makes the design suitable for:
- Satellite communication (UHF band)
- Telemetry and remote sensing
- NavIC-based communication systems
- Amateur radio in the 70 cm band

Chapter 5

CONCLUSION & FUTURE SCOPE

CONCLUSION

In this project, a Yagi-Uda antenna was successfully designed and simulated using CADFEKO and POSTFEKO. The structure comprised one reflector, one driven element, and three directors, optimized for operation near 401.633 MHz. The simulation yielded the far-field radiation pattern, which confirmed the directional nature of the antenna, with a well-defined main lobe and suppressed side lobes. The directivity and gain characteristics met the expected values, making the design suitable for targeted communication applications such as telemetry, tracking, or satellite ground station reception. The successful completion of the simulation validates the design approach and provides insights into real-world implementation possibilities.

FUTURE SCOPE

Hardware Fabrication and Testing:
The next step involves physically fabricating the antenna and validating the simulated results using a vector network analyzer (VNA) and anechoic chamber tests.

Bandwidth and Impedance Optimization:
Further refinement can be performed to enhance the bandwidth and impedance matching of the antenna to suit broader frequency ranges or improve VSWR characteristics.

Integration with NavIC or GPS Systems:
The Yagi-Uda antenna can be adapted for use with navigation systems like NavIC for improved signal reception and localization accuracy, especially in drone-based or mobile applications.

Array Configuration Studies:
Future work could involve exploring Yagi-Uda antenna arrays for beam steering or enhanced gain, suitable for long-distance wireless communication or radio astronomy.

Environment Impact Simulations:
Environmental factors such as ground effects, mounting height, and nearby structures can be included in future simulations to approximate real-world deployment more accurately.

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