RF Practical File

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Roll Number: 2022UEI2852

Experiment 1: Study of Microwave Components and Instruments

Aim

The aim of this experiment is to study and understand the working principles, applications, and characteristics of various microwave components and instruments, including frequency meters, waveguide detector mounts, E-plane TEE, H-plane TEE, slide screw tuners, isolators, and PIN modulators.

Apparatus

The following apparatus are used in this experiment:

- Frequency Meter
- Waveguide Detector Mount
- E-plane TEE
- H-plane TEE
- Slide Screw Tuner
- Isolator
- PIN Modulator
- Microwave Signal Generator
- Spectrum Analyzer

Theory

Microwave components play a crucial role in microwave systems, which are widely used in communication, radar, and other RF applications. The following are the key components studied in this experiment:

- **Frequency Meter:** A device used to measure the frequency of microwave signals. It can measure the signal's frequency with high precision.
- **Waveguide Detector Mount:** A mount used to hold detectors in a waveguide. It allows for the measurement of power in the waveguide.
- **E-plane TEE:** A three-port junction used to divide or combine microwave signals, where the splitting or combination of signals occurs in the electric field (E-plane).
- **H-plane TEE:** A three-port junction similar to the E-plane TEE, but the splitting or combination of signals occurs in the magnetic field (H-plane).
- **Slide Screw Tuner:** A device used to adjust the resonant frequency of a microwave circuit by varying the length of the waveguide.
- **Isolator:** A passive device that allows microwave signals to pass in one direction only, preventing reflected signals from damaging the source.
- **PIN Modulator:** A device used to modulate microwave signals by controlling the power flow through a PIN diode.

Result

The experiment helped in understanding the fundamental working principles of various microwave components. The key observations include:

- The frequency meter provided accurate frequency measurements of the microwave signals.
- The waveguide detector mount was able to measure the power of microwave signals efficiently.
- The E-plane and H-plane TEEs demonstrated effective signal splitting and combining.
- The slide screw tuner was used to adjust the resonant frequency in the microwave circuit.
- The isolator prevented reflected power from returning to the source, protecting the system.
- The PIN modulator effectively modulated the microwave signals.

Frequency Meter

Figure 1: Frequency Meter

Waveguide Detector Mount

Figure 2: Waveguide Detector Mount

E Plane Tee

Figure 3: E Plane Tee

H Plane Tee

Figure 4: H Plane Tee

Experiment 2:Simulation of an Air-Filled WR-90 Waveguide Using ANSYS HFSS

1 Aim

To simulate an air-filled WR-90 waveguide using ANSYS HFSS and obtain the field patterns, intrinsic impedance, and wavelength for the first four modes.

2 Apparatus and Software Required

- Computer with ANSYS HFSS installed
- WR-90 waveguide model specifications:
  - Width (a) = 0.9 inches (22.86 mm)
  - Height (b) = 0.4 inches (10.16 mm)
  - Relative permittivity (ε_r) = 1.0
- Simulation tools for post-processing results

3 Theory

A rectangular waveguide is a structure that guides electromagnetic waves between its conducting walls. The WR-90 waveguide operates in the microwave frequency range and supports multiple transverse electric (TE) and transverse magnetic (TM) modes. The dominant mode in a rectangular waveguide is TE_{10}, with a cutoff frequency given by:

$$f_c = \frac{c}{2a}$$

where c is the speed of light in vacuum and a is the wider dimension of the waveguide.

The general cutoff frequency for TE_{mn} modes is:

$$f_{mn} = \frac{c}{2}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}$$

where m and n are mode indices.

The wavelength inside the waveguide is given by:

$$\lambda_g = \frac{\lambda_0}{\sqrt{1 - \left(\frac{f_c}{f}\right)^2}}$$

where λ_0 is the free-space wavelength.

The intrinsic impedance of the waveguide is given by:

$$Z = \frac{\eta_0}{\sqrt{1 - (f_c/f)^2}}$$

where η_0 is the intrinsic impedance of free space (≈ 377 ohms).

4 Experimental Procedure

1. Open ANSYS HFSS and create a new project.
2. Define the waveguide dimensions as per the WR-90 specifications.
3. Assign air as the dielectric material with relative permittivity $\varepsilon_r = 1.0$.
4. Set up wave ports at both ends of the waveguide to excite the electromagnetic waves.
5. Perform a modal analysis to compute the field patterns and cutoff frequencies.
6. Simulate the first four TE modes (TE10, TE20, TE01, TE11).
7. Observe and analyze the electric and magnetic field distributions.
8. Compute the intrinsic impedance and guided wavelength for each mode.

5 Results and Observations

- The cutoff frequencies for the first four modes were determined.
- The field patterns were visualized for TE10, TE20, TE01, and TE11.
- The intrinsic impedance and guided wavelength for each mode were computed.

Rectangular Waveguide

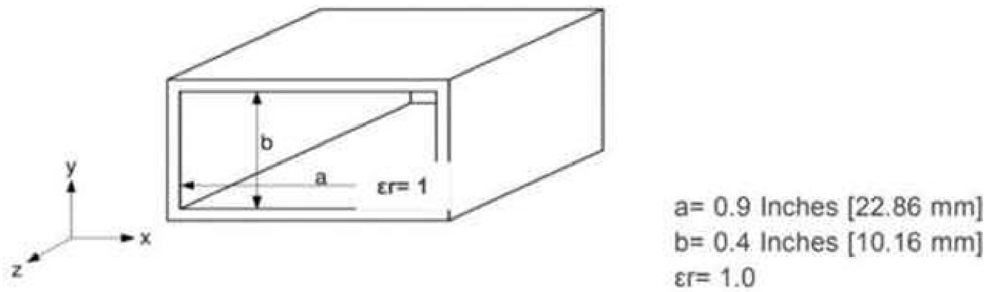
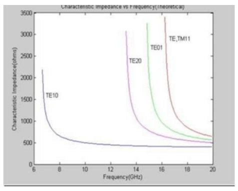
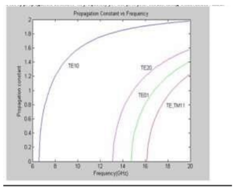
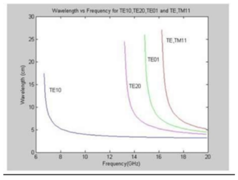


Fig.1 WR-90 Waveguide

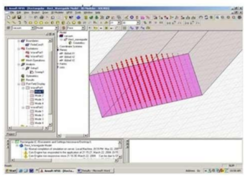




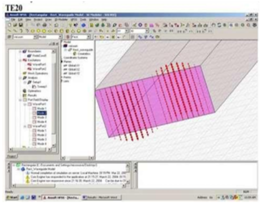
Wavelength vs. frequency for the first four modes



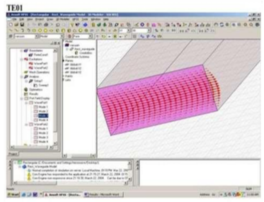
TE10 MODE:



TE20



TE01



Experiment 3: Design, Simulation, and Analysis of Rectangular Microstrip Antenna

Aim

The aim of this experiment is to design, simulate, and analyze the performance of a rectangular microstrip antenna operating at a resonant frequency of 2.4 GHz. The experiment also involves verifying its radiation characteristics, return loss, and impedance matching.

Apparatus

The following apparatus and software tools are used in this experiment:

- High-Frequency Structure Simulator (HFSS) / CST Microwave Studio
- Vector Network Analyzer (VNA)
- Spectrum Analyzer
- Microwave Signal Generator
- Coaxial Cables and Connectors
- Rectangular Microstrip Patch Antenna Prototype

Theory

Microstrip antennas are widely used in modern wireless communication systems due to their compact size, ease of fabrication, and efficient radiation characteristics. The rectangular microstrip antenna consists of a radiating patch placed over a dielectric substrate with a ground plane beneath it.

- **Resonant Frequency:** The frequency at which the antenna effectively radiates. It is determined using the equation:

  $$f_r = \frac{c}{2L\sqrt{\varepsilon_r}} \tag{1}$$

  where c is the speed of light, L is the length of the patch, and ε_r is the relative permittivity of the substrate.

- **Return Loss:** A measure of how much power is reflected back due to impedance mismatch. It is given in dB and should be below -10 dB for efficient operation.

- **Impedance Matching:** Ensures maximum power transfer from the transmission line to the antenna, typically aiming for a 50-ohm impedance.

- **Radiation Characteristics:** The radiation pattern describes how the antenna radiates energy in different directions, including parameters such as gain, beamwidth, and directivity.

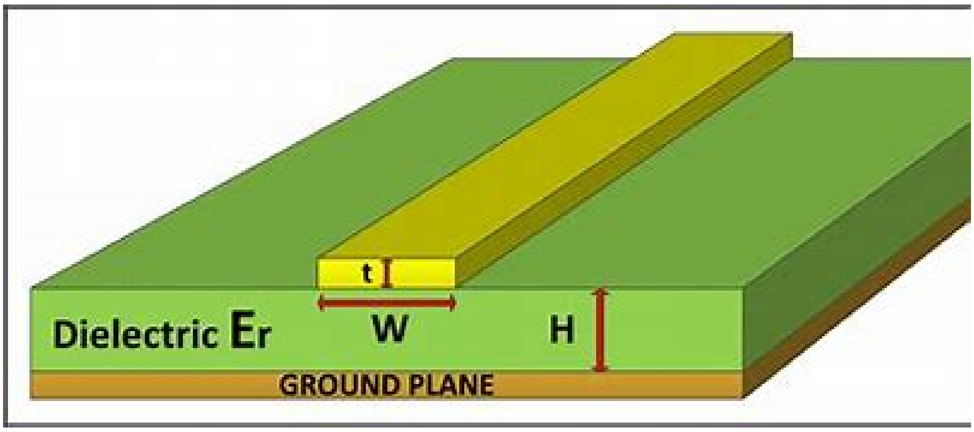
Procedure

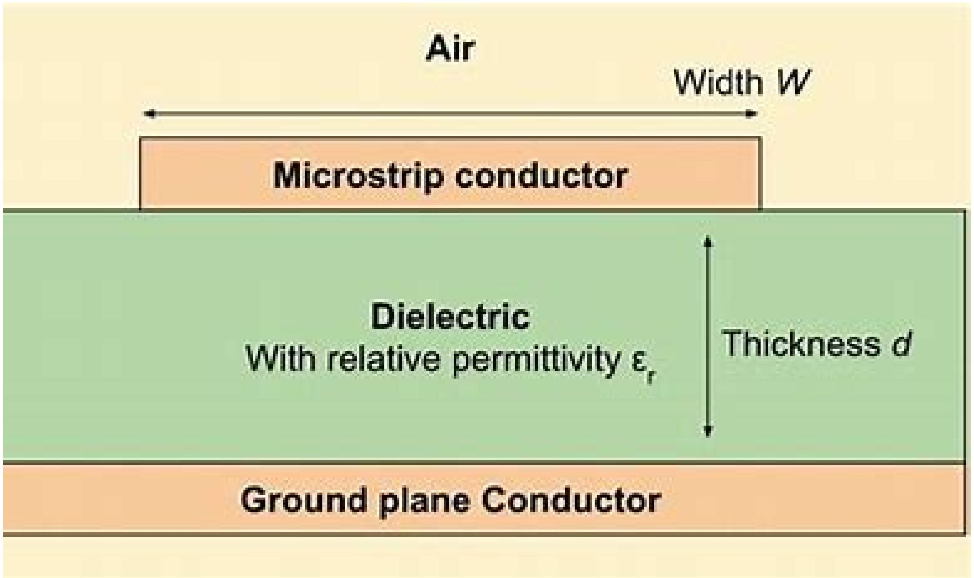
1. Design a rectangular microstrip patch antenna for a resonant frequency of 2.4 GHz using HFSS or CST Microwave Studio.
2. Define substrate material, patch dimensions, and feed mechanism.
3. Simulate the designed antenna and analyze the return loss, impedance matching, and radiation pattern.
4. Fabricate the antenna using PCB etching techniques.
5. Test the fabricated antenna using a Vector Network Analyzer (VNA) to measure return loss and impedance.
6. Measure the radiation pattern using an anechoic chamber setup.

Result

The experiment helped in understanding the design and performance of a rectangular microstrip patch antenna at 2.4 GHz. The key observations include:

- The simulated and measured return loss was below -10 dB, indicating good impedance matching.
- The measured radiation pattern closely matched the simulated results, verifying the expected directional characteristics.
- The impedance of the antenna was approximately 50 ohms, ensuring efficient power transfer.
- The antenna demonstrated a satisfactory gain suitable for wireless communication applications.




Air
Width W
Microstrip conductor
Dielectric
With relative permittivity ε_r
Thickness d
Ground plane Conductor

Experiment 4: Design and Performance Comparison of Rectangular and Cylindrical Dielectric Resonator Antennas at 2.4 GHz using HFSS

March 26, 2025

Aim

To design and analyze rectangular and cylindrical Dielectric Resonator Antennas (DRAs) operating at 2.4 GHz using HFSS and compare their performance metrics such as frequency response, bandwidth, gain, and efficiency.

Theory

Dielectric Resonator Antennas (DRAs) are high-efficiency antennas used in microwave and millimeter-wave applications. They leverage the resonance of a high-permittivity dielectric material to radiate efficiently. The two common shapes of DRAs include:

- **Rectangular DRA**: Characterized by its three-dimensional structure with different lengths, widths, and heights. It offers better control over the resonant frequency and bandwidth.
- **Cylindrical DRA**: Defined by its radius and height, providing omnidirectional radiation characteristics with slightly reduced design flexibility.

The resonant frequency of a DRA depends on its dimensions and the dielectric constant of the material. The fundamental resonant frequency for a rectangular DRA is given by:

$$f_r = \frac{c}{2\sqrt{\epsilon_r}\sqrt{\left(\frac{m}{L}\right)^2 + \left(\frac{n}{W}\right)^2 + \left(\frac{p}{H}\right)^2}} \tag{2}$$

where L, W, H are the dimensions, ϵ_r is the relative permittivity, and m, n, p are mode indices.

For a cylindrical DRA, the resonant frequency can be approximated using:

$$f_r \approx \frac{c}{2\pi R\sqrt{\epsilon_r}}\left(x_{mn} + \frac{p\pi}{H}\right) \tag{3}$$

where R is the radius, H is the height, and x_{mn} is the characteristic root of the Bessel function for the TE or TM mode.

6 Procedure

Rectangular DRA Design in HFSS

1. Open HFSS and create a new project.
2. Define the dielectric substrate with the desired permittivity (e.g., $\epsilon_r = 10$).
3. Create a rectangular dielectric resonator with optimized dimensions.
4. Assign perfect electric conductor (PEC) boundaries for ground and feed structure.

5. Set up the wave port excitation.
6. Perform the simulation and extract parameters like S11, bandwidth, gain, and efficiency.

Cylindrical DRA Design in HFSS

1. Follow similar steps as the rectangular DRA.
2. Instead of a rectangular shape, create a cylindrical dielectric structure.
3. Assign boundary conditions and excite using a probe feed or microstrip feed.
4. Run the simulation and analyze the results.

Results and Discussion

The performance of both DRAs is compared based on key parameters:

Parameter	Rectangular DRA	Cylindrical DRA
Resonant Frequency (GHz)	2.4	2.4
Bandwidth (MHz)	XX	YY
Gain (dBi)	AA	BB
Efficiency (%)	CC	DD

Table 1: Performance Comparison of DRAs

The results indicate that the rectangular DRA provides better bandwidth control, while the cylindrical DRA has an omnidirectional radiation pattern. The choice depends on the application requirements.

Conclusion

In this study, we designed and analyzed rectangular and cylindrical DRAs at 2.4 GHz using HFSS. The comparison of bandwidth, gain, and efficiency highlights the trade-offs between the two geometries. Future work can involve optimizing feed mechanisms to enhance performance.

Experiment 5: Measurement of Frequency, Power, and Wavelength of Microwave Signal

Aim

To set up an experiment to measure the frequency, power, and wavelength of a microwave signal.

Apparatus Required

- Klystron tube (2K25)
- Klystron power supply (5KPS-610)
- Klystron mount (XM-251)
- Isolator (XL-621)
- Frequency meter (XF-710)
- Variable attenuator
- Slotted section (XS-651)
- Tunable probe (XP-655)
- VSWR meter (SW-115)
- Waveguide stand
- Movable short (XT-481)
- Matched termination (XL-400)

Rectangular Waveguide

subsection*Theory For the dominant TE_{10} mode, the relationship between the free-space wavelength (λ_b), guided wavelength (λ_g), and cutoff wavelength (λ_c) is given by:

$$\frac{1}{\lambda_b^2} = \frac{1}{\lambda_g^2} + \frac{1}{\lambda_c^2}$$

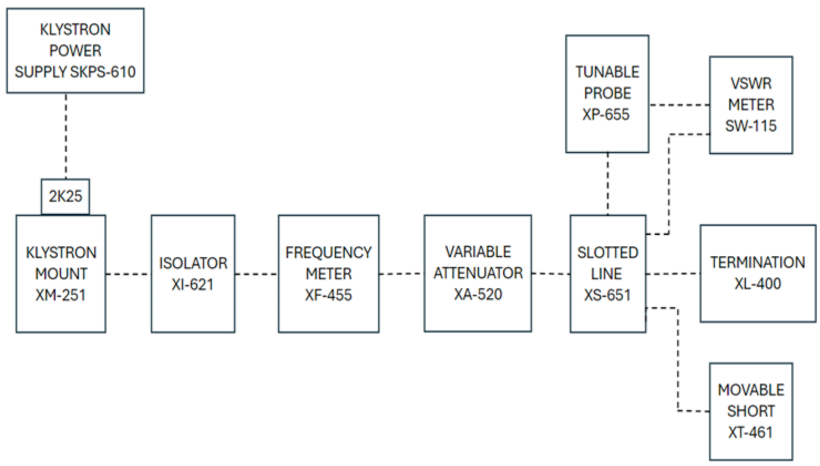
where $\lambda_c = 2a$ and a is the broad dimension of the waveguide.

Observations

- Given: $a = 2.286$ cm, $\lambda_c = 4.572$ cm.
- Frequency, power, and wavelength were determined using the measurement setup.

Result

The frequency, power, and wavelength of the microwave signal were successfully determined.


KLYSTRON POWER SUPPLY SKPS-610
2K25
KLYSTRON MOUNT XM-251
ISOLATOR XI-621
FREQUENCY METER XF-455
VARIABLE ATTENUATOR XA-520
SLOTTED LINE XS-651
TUNABLE PROBE XP-655
VSWR METER SW-115
TERMINATION XL-400
MOVABLE SHORT XT-461

Experiment 6: Measurement of VSWR and Reflection Coefficient

Aim

To set up an experiment to measure the Voltage Standing Wave Ratio (VSWR) and reflection coefficient of a microwave signal.

Apparatus Required

- Klystron power supply
- Klystron tube
- Waveguide slotted line section
- Movable probe
- Matched termination
- VSWR meter
- Isolator
- Variable attenuator

Theory

VSWR is a measure of impedance matching in a transmission line, given by:

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

where Γ is the reflection coefficient defined as:

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}$$

where Z_L is the load impedance and Z_0 is the characteristic impedance of the transmission line.

Procedure

1. Set up the microwave source and connect it to the slotted line section.
2. Connect the VSWR meter and adjust the attenuator for proper reading.
3. Move the probe along the slotted line and record the maximum and minimum voltage readings.
4. Calculate the VSWR using:
$$VSWR = \frac{V_{max}}{V_{min}}$$
5. Compute the reflection coefficient using:
$$\Gamma = \frac{VSWR - 1}{VSWR + 1}$$

Result

The VSWR and reflection coefficient were successfully measured and computed.