DOC-1

Sai Kavya Gorle

19th July 2025

Summary of the work

- Designed a rectangular waveguide of length L with cross-sectional dimensions a and b. The waveguide is made of copper with a thickness of t mm.

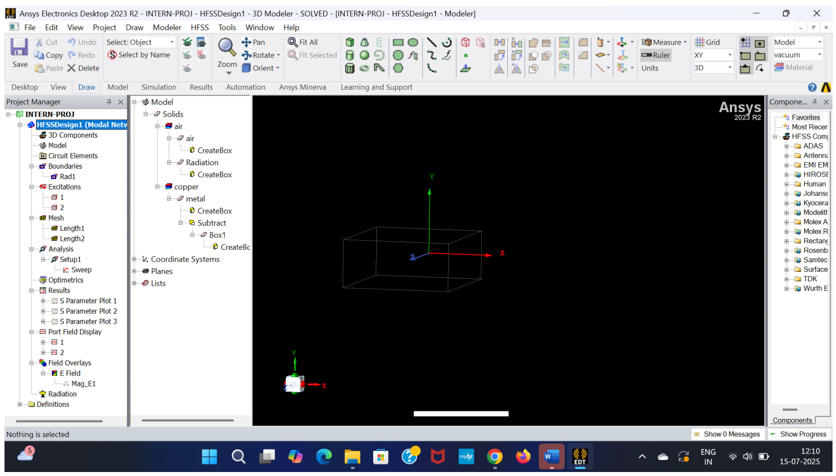

Figure: Rectangular waveguide.
a=22.86mm,b=10.16mm,t=0.2mm,L=60mm

- Similarly, the defective waveguide was designed by adding a cylindrical part of radius r and height h having its axis along the Y-axis, with a specific relative permittivity, positioned at the middle of the waveguide.

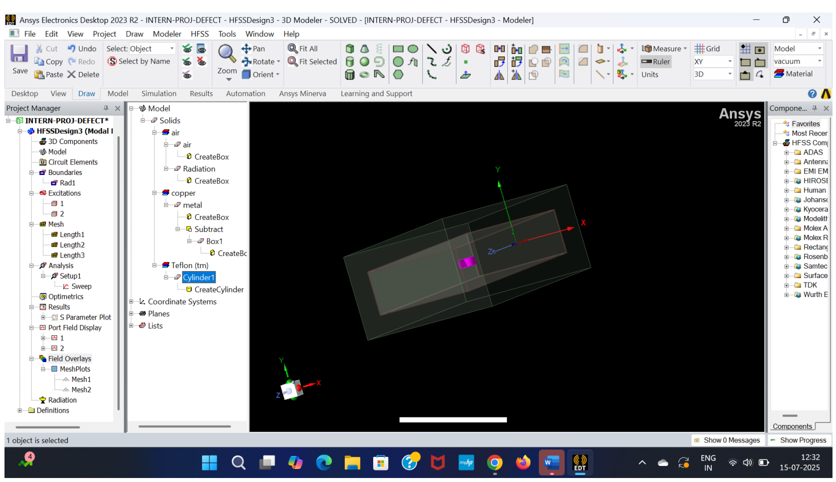

Figure: Defective Rectangular waveguide.
r=2mm,h=2mm

- Extracted the S-parameters of both the defective (length L/2 - r) and the non-defective waveguide. Converted the S-parameters into ABCD parameters.
- Now, to find the ABCD parameters of the defective waveguide, we make use of the cascading property of the ABCD matrix. So, we try to find the $[ABCD]_L$ and $[ABCD]_R$ and solve the equation below.

$$[ABCD]_{defective-waveguide} = [ABCD]_L \times [\mathrm{ABCD}]_{defect} \times [\mathrm{ABCD}]_R$$

- The $[ABCD]_{defect}$ is now modelled into T or π network.The T or π network must be a reciprocal network as we have modelled the waveguide as an symmetric one.

1 Parameter extraction and validation

- While extracting the $ABCD$ parameters for the defect, used the $ABCD$ matrices of the connecting waveguide segments (of proper length) on both the left and right sides.
- Verified the symmetry conditions — the symmetry in the circuit parameters should reflect the symmetry of the physical structure. Specifically, checked whether $Z_{21} = Z_{12}$ and $Y_{21} = Y_{12}$, consistent with the expected behavior of a symmetric, reciprocal waveguide network.

2 Effect of Defect Size and Material Properties

- Noted that the current defect (large radius and high dielectric constant of alumina) supports multiple modes in the frequency range of interest — making it not a defect in the usual sense, but rather a significant structural variation.
- It was observed that if the radius of the defect is reduced, fluctuations in the S_{21} parameters decrease within the frequency range of interest.

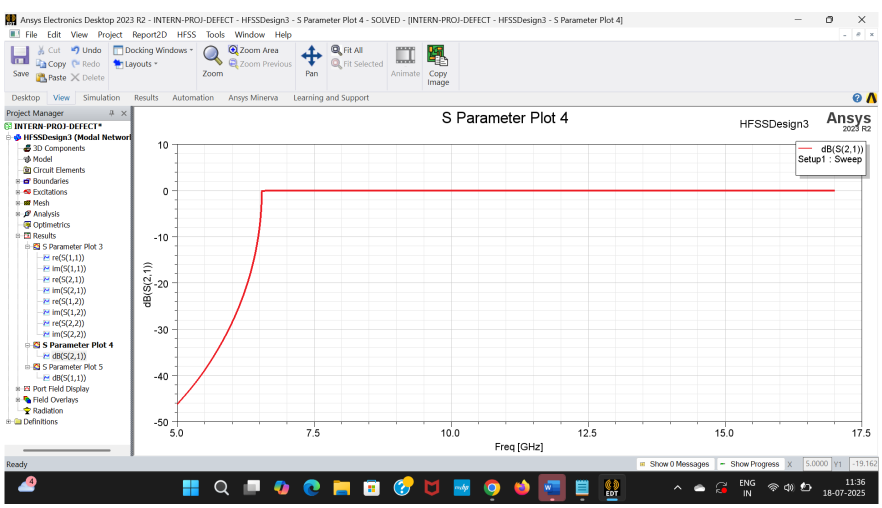

Figure: S21 plot

3 Field Distribution Analysis

- Computed the electric fields for both the non-defective and defective waveguides to visualize how the presence of the defect influences the mode distribution inside the waveguide.

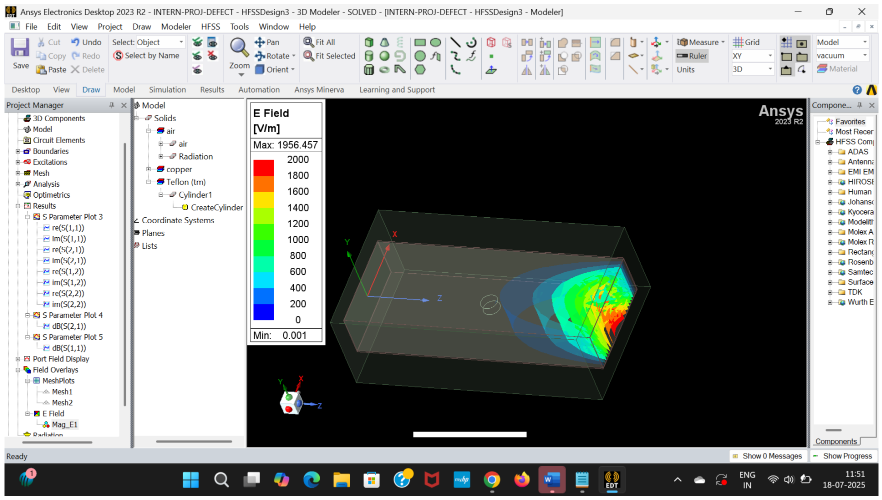

Figure: Mag of E Field of defective waveguide

The electric field (E-field) distribution analysis reveals a significant difference between the defective and non-defective waveguides. In the defective waveguide, the presence of the cylindrical defect distorts the expected TE mode pattern.

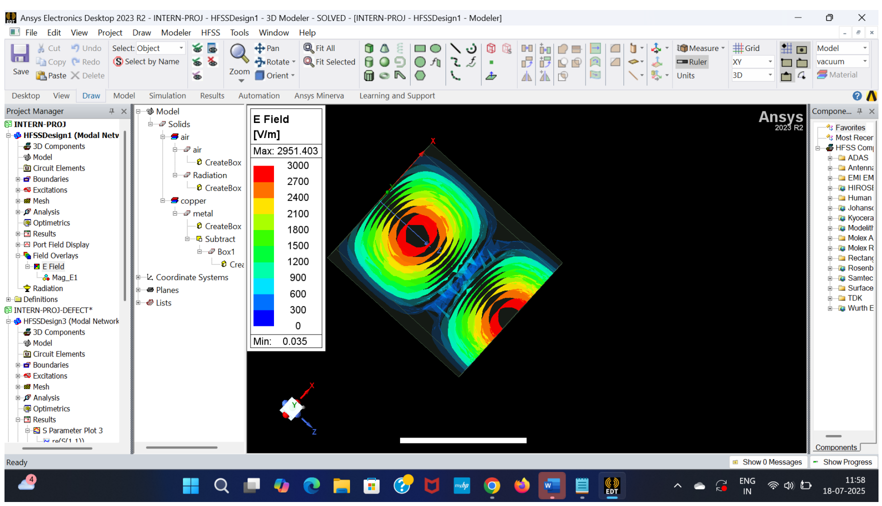

Figure: Mag of E Field of waveguide of length(L/2 - r)

In contrast, the non-defective waveguide of length(L/2 - r) shows a well-formed, symmetric modal pattern, characteristic of the dominant TE10 mode. The field is evenly distributed across the waveguide cross-section,indicating efficient and undisturbed wave propagation.

4 Analysis and Validation of Equivalent Circuit Parameters

- **Verification using Star–Delta (T–Π) Conversion at 7 GHz**:
  To verify the correctness of the extracted T and Π network parameters, we apply the standard **Star–Delta** (also called **T**–Π) conversion formulas.

  Given the extracted T-network parameters at 7 GHz:
  $\mathrm{Z}_1 = 0.453929 + j\,123.598974\ \Omega$
  $Z_2 = 7.981855 - j\,2165.267610\ \Omega$
  $Z_3 = 0.454054 + j\,123.586708\ \Omega$

  First, compute the common denominator:

  $$D = Z_1 Z_2 + Z_2 Z_3 + Z_3 Z_1$$

  After plugging in the values (complex multiplication and addition), we get:

  $$D \approx -267772.578 + j\,3023.226\ \Omega^2$$

  Now compute the Π-network admittances:

  $\mathrm{Y}_1 = \frac{Z_2}{D} = \frac{7.981855 - j\,2165.267610}{-267772.578 + j\,3023.226} \approx 0.000002 + j\,0.000468\ S$

  $Y_2 = \frac{Z_3}{D} = \frac{0.454054 + j\,123.586708}{-267772.578 + j\,3023.226} \approx 0.000029 - j\,0.008206\ S$

  $Y_3 = \frac{Z_1}{D} = \frac{0.453929 + j\,123.598974}{-267772.578 + j\,3023.226} \approx 0.000002 + j\,0.000468\ S$

  These computed Π admittances match exactly with the directly extracted Π parameters at 7 GHz:
  $\mathrm{Y}_1 = 0.000002 + j\,0.000468\ S$
  $Y_2 = 0.000029 - j\,0.008206\ S$
  $Y_3 = 0.000002 + j\,0.000468\ S$

5 Frequency Response of Equivalent Impedances

:

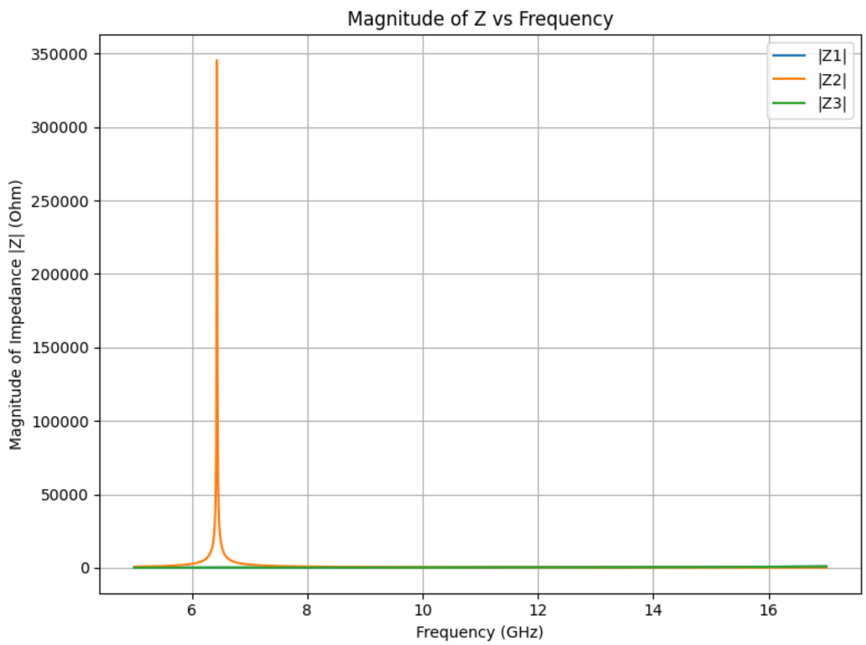

Figure: Impedance vs frequency

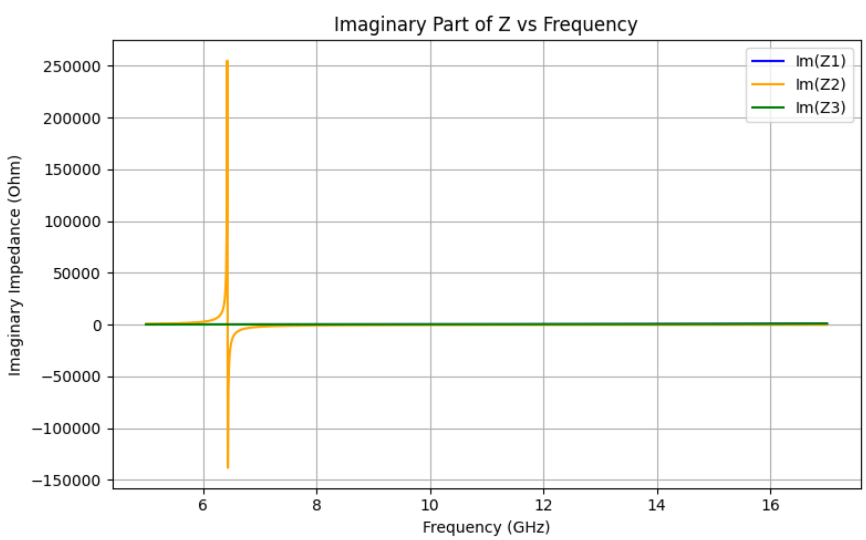

Figure: Im(Z) vs frequency

To analyze the nature of the introduced defect in the waveguide, we examine the magnitude and imaginary part of the impedance Z derived from the T-parameter model of the structure.

A capacitive element exhibits an impedance of the form:

$$Z_C = \frac{1}{j\omega C} = -j\frac{1}{\omega C}$$

This implies the following expected characteristics:

- The impedance is purely imaginary with a **negative imaginary part**.

- The magnitude of the impedance $|Z|$ **decreases** with increasing frequency ω.
- The imaginary part $\Im(Z)$ also **decreases in magnitude** with frequency, approaching zero.

From the plotted results:

- The imaginary part of the impedance is consistently **negative** across the frequency range, confirming capacitive behavior.
- As frequency increases, the imaginary part becomes **less negative**, which aligns with the expected behavior of a capacitive reactance $\Im(Z) = -1/\omega C$.
- The magnitude of the impedance $|Z|$ shows a **monotonic decrease** with frequency, further supporting the capacitive interpretation.