INDIAN INSTITUTE OF TECHNOLOGY- KHARAGPUR

Design Laboratory

Problem 2- Assignment

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Roll No- 20EC63R06

Spring-2021

DESIGN OF A TWO-ELEMENT ARRAY ANTENNA

Design of a microstrip patch antenna with microstrip feed:

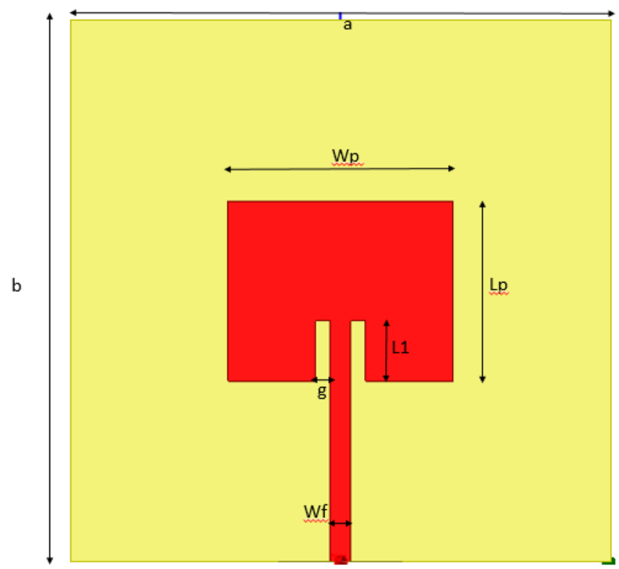

Fig.1. Layout of microstrip patch antenna

Fig.1 shows the top view of the designed microstrip patch antenna. Wave ports are not visible as they are in the orthogonal plane. Radiation box's visibility is turned off. Plots have been plotted with the help of MATLAB

- **Components:**
  - Metal: **Copper**
    - Conductivity: 58000000 Siemens/m
    - Relative Permittivity (εr): 1
  - Substrate: **Rogers RO4003C**
    - Relative Permittivity (εr): 3.55
    - Dielectric Loss Tangent ($tan\delta$): 0.0027

- **Design Specifications:**

    - a = 30mm
    - b = 30mm
    - h = 0.508mm (Substrate thickness)
    - t = 0.017mm (Metal thickness)
    - Lp = 9.9072mm
    - Wp = 12.384mm
    - W_f = 1.1363mm
    - g = 0.8mm
    - L_1 = 3.3024mm

- **Design Criteria:**

    - Frequency of Operation: 7.8 GHz

- **Results:**

    - **Magnitude Plot of S11 Parameter**

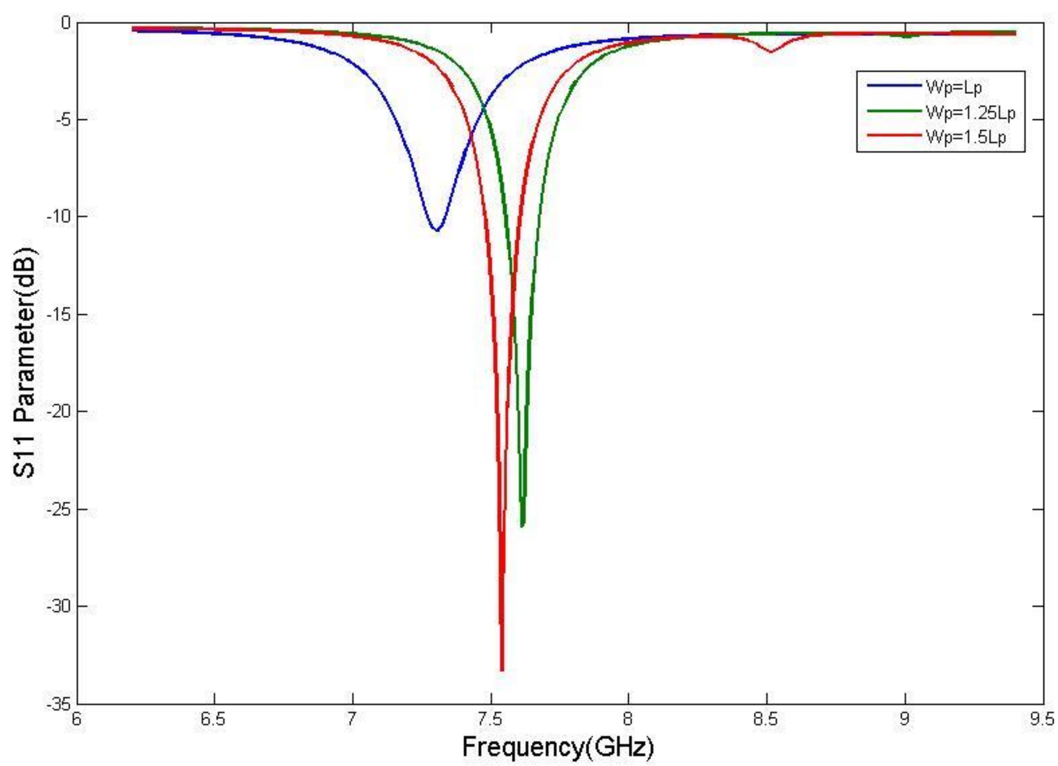

Fig.2. Magnitude Plot of S11 Parameters

- **Group delay plots**

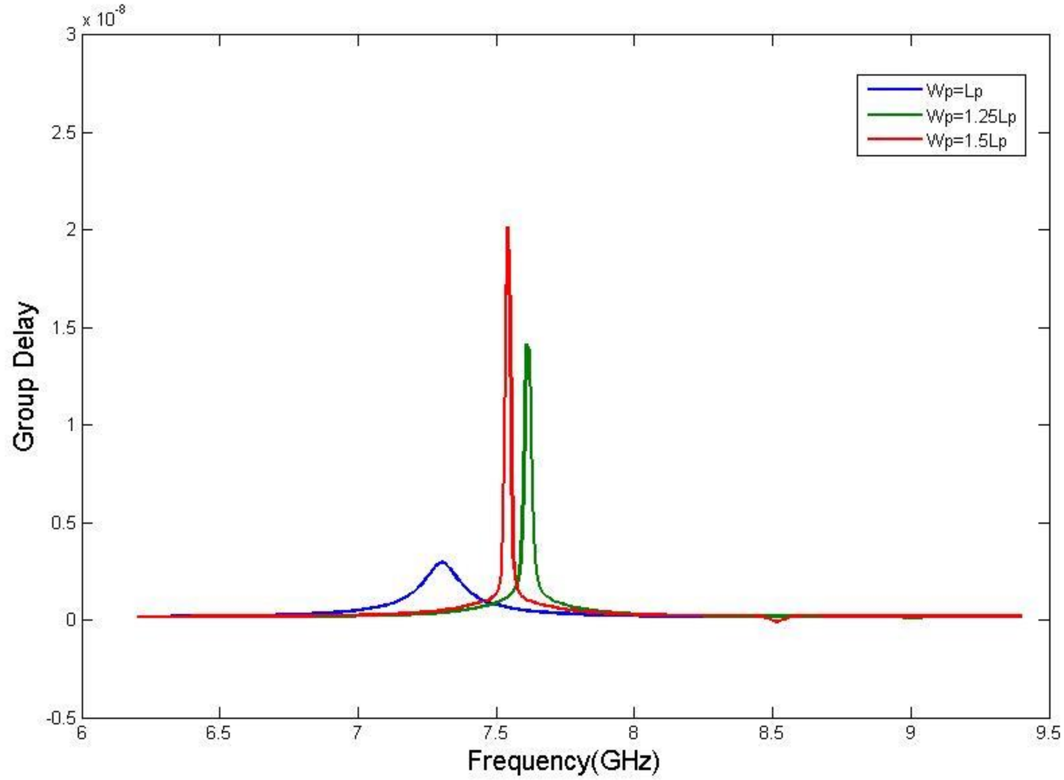

Fig.2. Group delay for different conditions of the width of the patch

- **Far-Field 3D Polar Plot of the patch antenna**

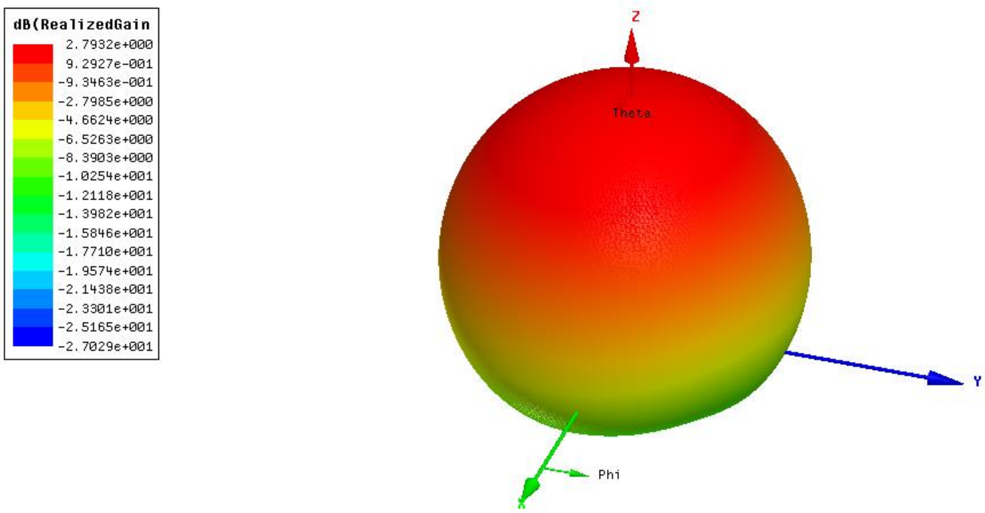

Fig.3. 3D Polar plot of patch antenna at 7.8 GHz

- **2D Realized Gain in E and H plane**

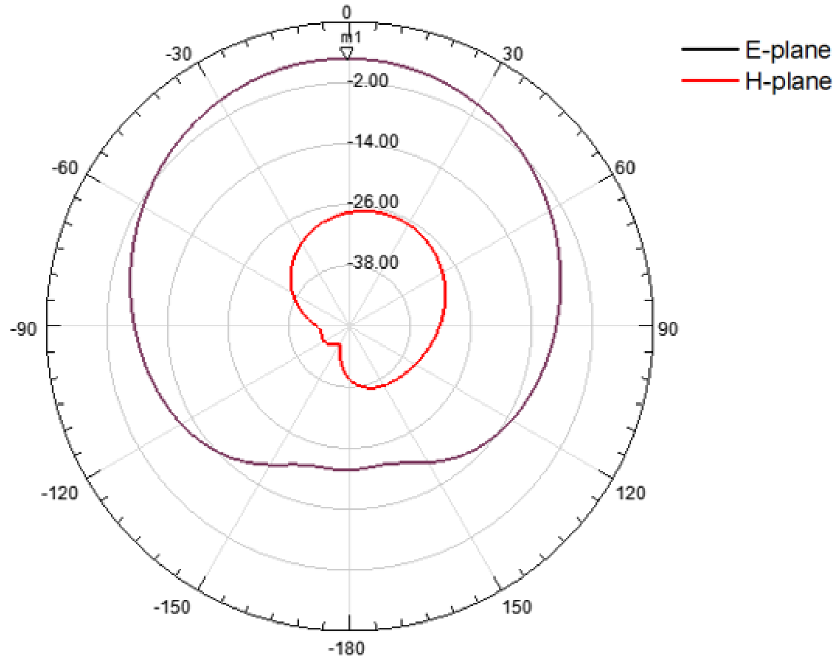

Fig.4. Realized gain of patch antenna at E and H Plane

- **Co and Cross Polarization in H plane**

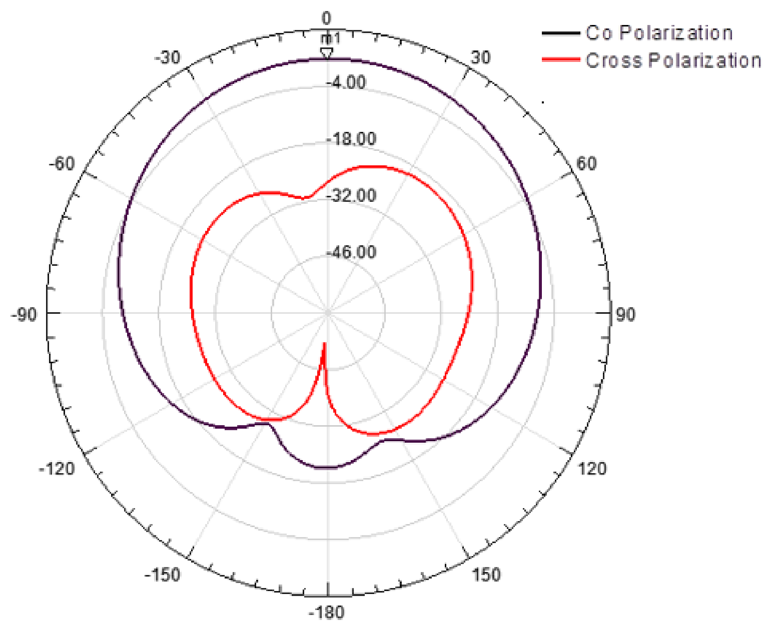

Fig. 5. 2D realized gain for microstrip patch antenna for co and cross-polarization in H-plane

- **Vector Electric at the surface of the patch antenna**

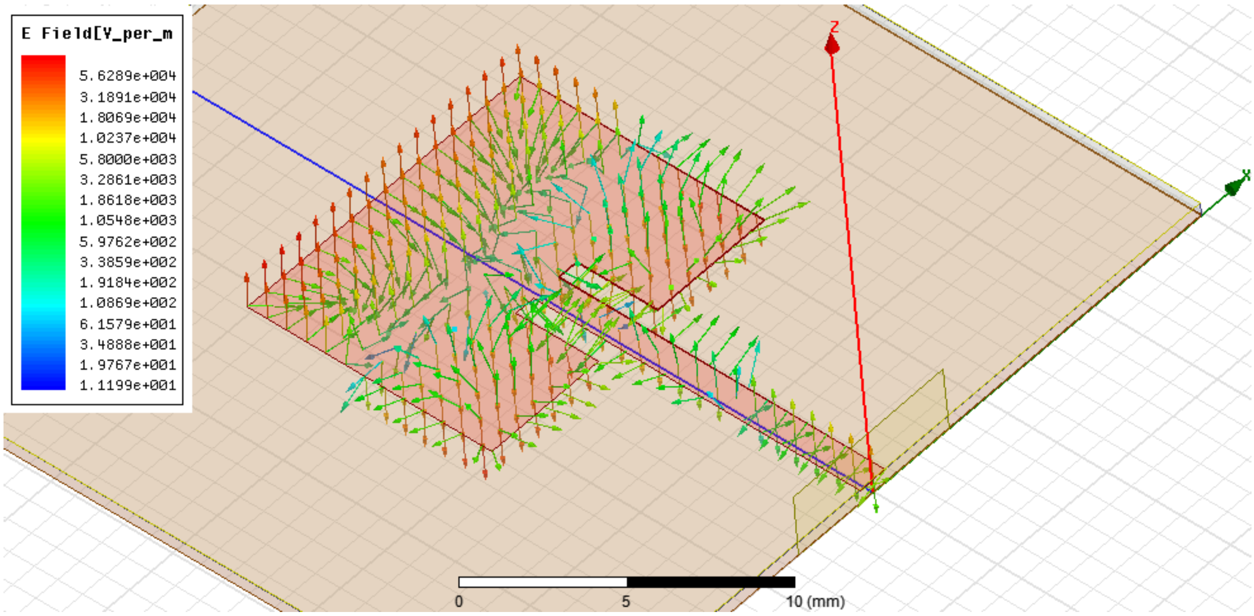

Fig.6. Vector electric field of microstrip patch antenna at 7.8 GHz

- **<u>Calculations</u>**

- **Design:**
  - length of the antenna $L \approx \lambda_g/2$
  - $W = 1.2L\text{-}1.3L$
  - $g = 0.5\text{-}1$ mm
  - $L_1 \approx L/3$
  - The ground plane of the antenna should be at least $3L \times 3L$.

- The highest delay is at the resonant frequency of the patch. Thus the group delay is at the operating frequency is 1.4×10^{-8}

- If the resonant frequency is f_1 then to transform it to f_0, multiply L by f_1/f_0. Optimize L_1 for best input matching.

- The 10 dB matching Bandwidth is 1.67 % at the Operating frequency of 7.8 GHz

- The maximum gain of 2.766 dB is observed and the 3 dB beamwidth is nearly 78 degrees as shown in Fig.

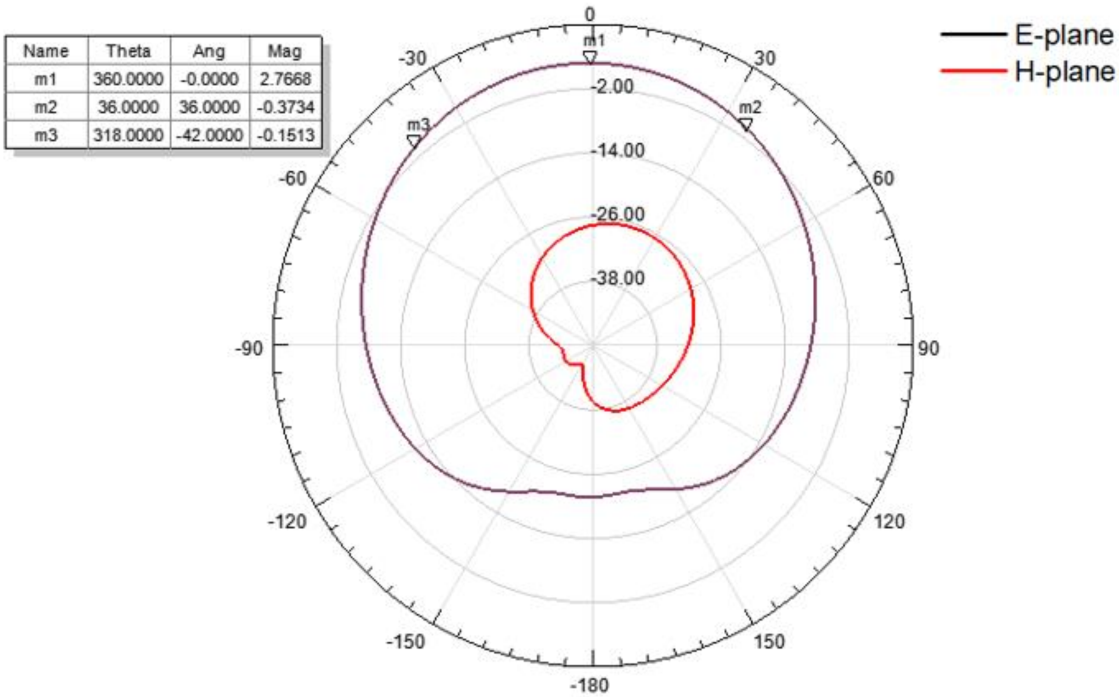

Fig 7. Realized Gain and -3dB Beamwidth for patch antenna.

- **<u>Conclusion</u>**

- A microstrip patch antenna is designed on a Rogers RO4003C substrate having dielectric constant 3.55 and dielectric loss tangent 0.0027 using HFSS and its characteristics are studied through Fig.2. Fig.2 shows the magnitude of the reflection coefficient of the patch antenna over 6-9.5 GHz band.

- The reflection curve remains below -25 dB indicating good matching at the resonant frequency 7.8 GHz. The 10 dB bandwidth of the antenna is found to be 1.67% for the operating frequency of 7.8 GHz.

- Fig.3 and Fig.4 show the 3D polar plot and the 2D radiation pattern of the microstrip patch antenna respectively at 7.8 GHz. A broadside gain of 2.7668 dB at the resonant frequency is observed here.

- The matching was not obtained at the first time of the simulation. By optimizing the length of the patch we obtained a dip at the centre frequency.

- To obtain promising matching the gap and the L3 were tuned such that the dip at the centre frequency of the magnitude plot can be below -25dB.

- The plots of E and H plane also showed the results that were expected. The maximum realized gain was obtained at the broad side of the patch antenna.

- The length of the patch antenna was checked for various lengths such that:

    - Wp = Lp. The matching was not obtained right at the centre frequency of 7.8 GHz. Also, the peak of group delay wasn't satisfactory.
    - Wp = 1.25Lp. The matching was satisfactory by getting a dip near the centre frequency. The peak of the group delay was found to be satisfactory at the centre frequency.
    - Wp = 1.5Lp. The matching was up to the mark. The group delay was also excellent. However, it deviated from the centre frequency.

- The magnitude of the co polarization was greater than the cross-polarization. However, the magnitude of the cross-polarization also had a significant value.

- The realized gain vs frequency curve shows that it stays maximum at the centre frequency and starts decreasing for the rest of the bandwidth, away from the centre frequency.

- The vector electric field was plotted and since we can see from the fig. 6 that the field follows the pattern of TM mode.

Design Of T Junction:

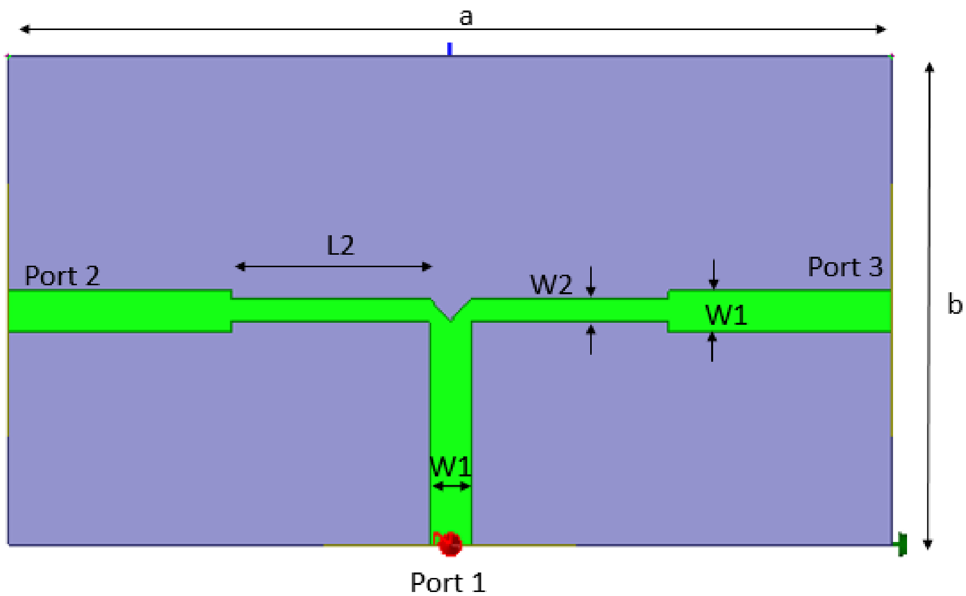

Fig. 8: Layout of T Junction

- **Components:**

  - Metal: **Copper**
    - Conductivity: 58000000 Siemens/m
    - Relative Permittivity (εr): 1

  - Substrate: **Rogers RO4003**
    - Relative Permittivity **(**εr): 3.55
    - Dielectric Loss Tangent ($tan\delta$): 0.0027

- **Design Specifications:**

  - a = 23.785mm
  - b = 13.136mm
  - h = 0.508mm (Substrate thickness)
  - t = 0.017mm (Metal thickness)
  - W_1 = 1.1363mm
  - W_2 = 0.6199mm
  - L_2 = 5.8929mm

- **Design Criteria:**

  - Operating Frequency: 7.8 GHz

- **Results:**

- **Magnitude Plot of S parameters of the T junction:**

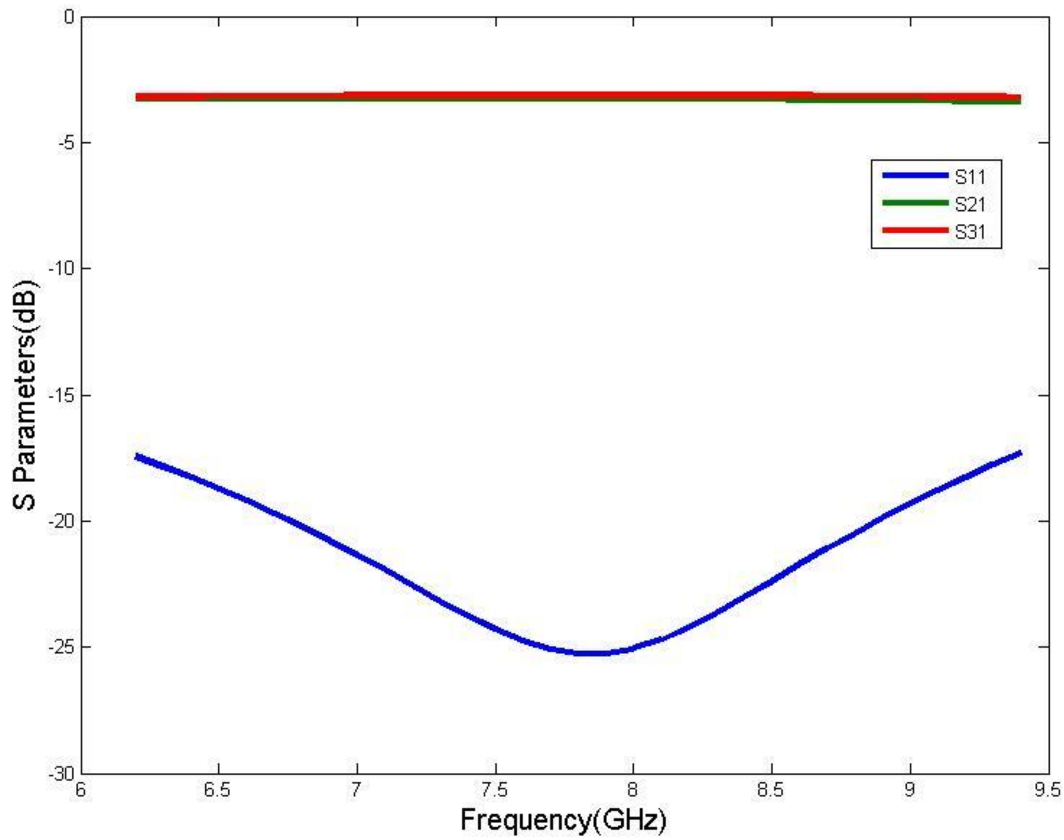

Fig. 9. Magnitude plot for the simulated S parameters of the T junction

- **Calculations**

- **Design:**
  - Length of the quarter-wave transformer $L2 \approx \lambda g/4$
  - Characteristics impedance of the quarter-wave transformer is 70.71 Ω

- The microstrip lines at all three ports are 50Ω line. The 50Ω line of the input port is divided equally to 100Ω line at the junction. To match these lines to 50Ω line of port 2 or port 3, we have used a quarter-wave transformer of length λ/4 and line impedance

$$Z_{quarter} = \sqrt{50 \times 100} = 70.71\Omega$$

Conclusion

- A T junction is designed on a Rogers RO4003C substrate having dielectric constant 3.55 and dielectric loss tangent 0.0027 using HFSS as shown in Fig. 8 and its characteristics are studied through Fig. 9. Fig.9 shows the magnitude of reflection and transmission coefficients of the T junction over 6-9.5 GHz band.

- The reflection curve remains below -25 dB indicating good matching throughout the band and the transmission coefficients remain nearly at -3 dB mark.

- Ideally, the transmission through the T junction is supposed to be at -3 dB as the power transmitted through the junction should be equally divided in the two arms of the junction.

- Due to a low value of the loss tangent of Rogers RO4003C substrate, the Loss seems to be less enough at the port 2 and port 3. However, the transmission coefficients at both of these ports give nearly -3dB as expected theoretically.

Design of the two-element array antenna:

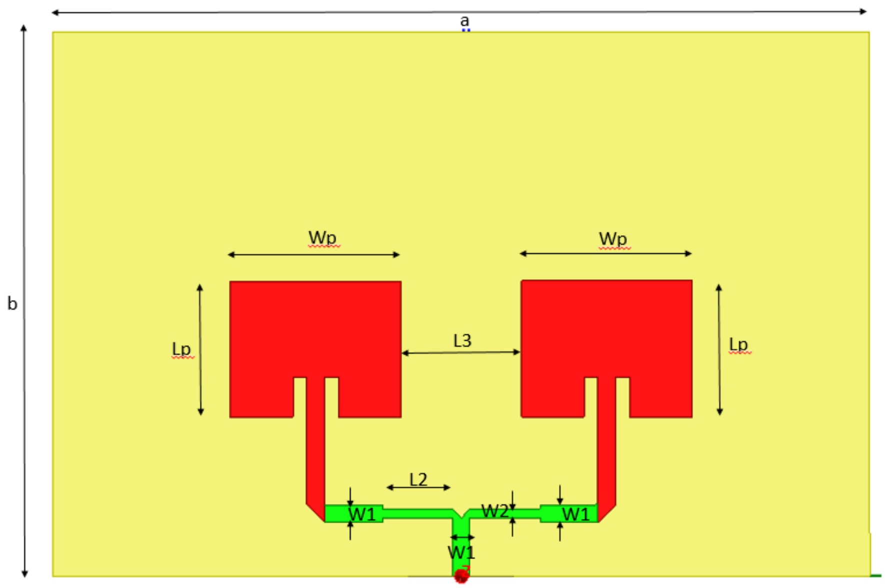

Fig.10. Layout of Two element array antenna

Fig.1 shows the top view of the designed microstrip patch antenna. Wave ports are not visible as they are in the orthogonal plane. Radiation box's visibility is turned off. Plots have been plotted with the help of MATLAB

Components:

- Metal: **Copper**
  - Conductivity: 58000000 Siemens/m
  - Relative Permittivity (εr): 1
- Substrate: **Rogers RO4003C**
  - Relative Permittivity (εr): 3.55
  - Dielectric Loss Tangent ($tan\delta$): 0.0027

Design Specifications:

- a = 52.808mm
- b = 35.205mm
- h = 0.508mm (Substrate thickness)

- t = 0.017mm (Metal thickness)
- Lp = 8.801mm
- Wp = 11.001mm
- W_f = 1.1363mm
- L_f = 6.801mm
- g = 0.9mm
- W_1 = 1.1363mm
- W_2 = 0.6199mm
- L_2 = 5.0929mm
- L_3 = 6.6815mm

Design Criteria:

- Frequency of Operation: 7.8 GHz

Results:

- **Magnitude Plot of S11 Parameter**

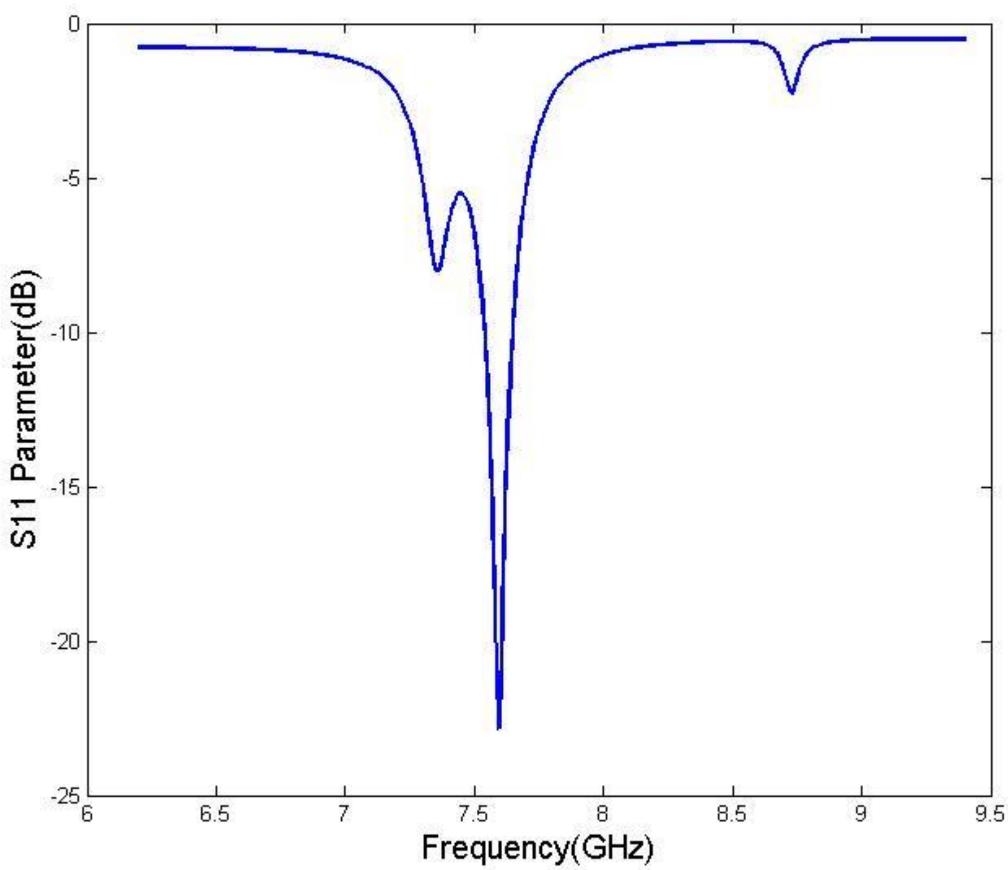

Fig. 11. Magnitude Plot of S11 Parameter

- **Group Delay plot**

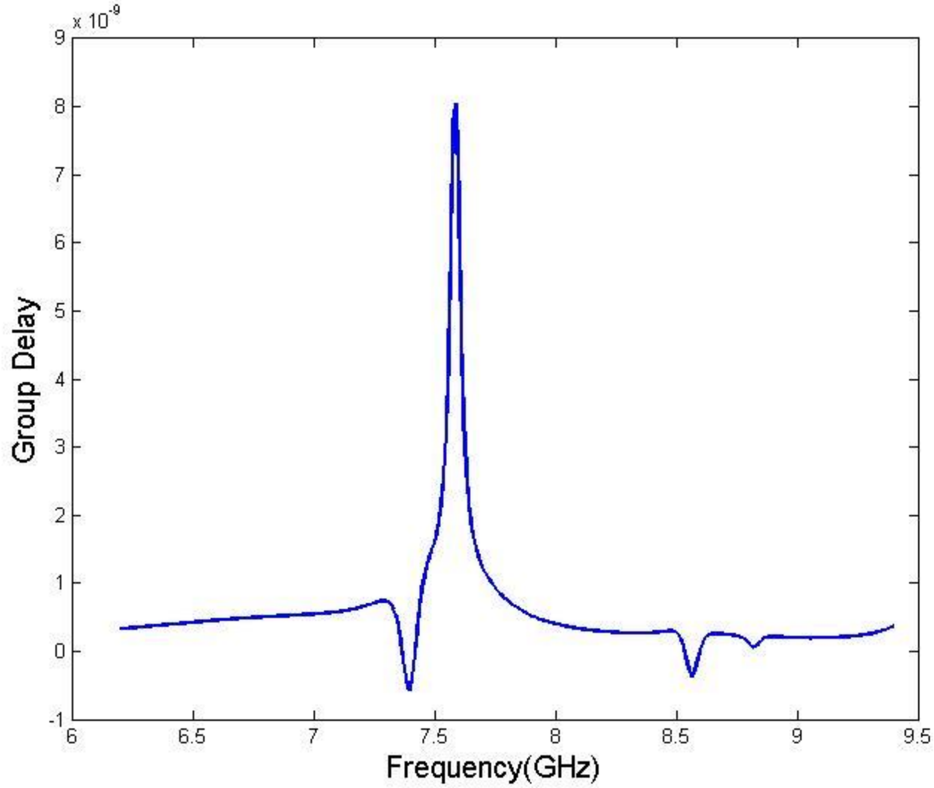

Fig. 12. Group Delay plot of the two-element array antenna.

- **Far-Field 3D Polar Plot of the two-element array antenna**

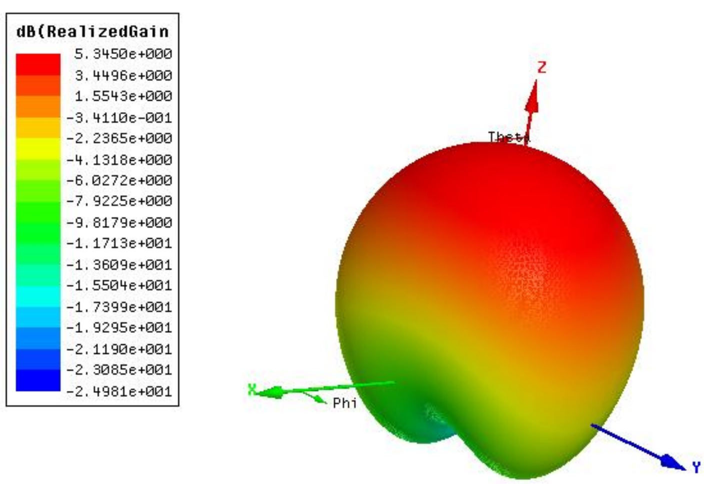

Fig. 13. 3D Polar plot of two-element array antenna at 7.8 GHz

2D Realized Gain in E and H plane

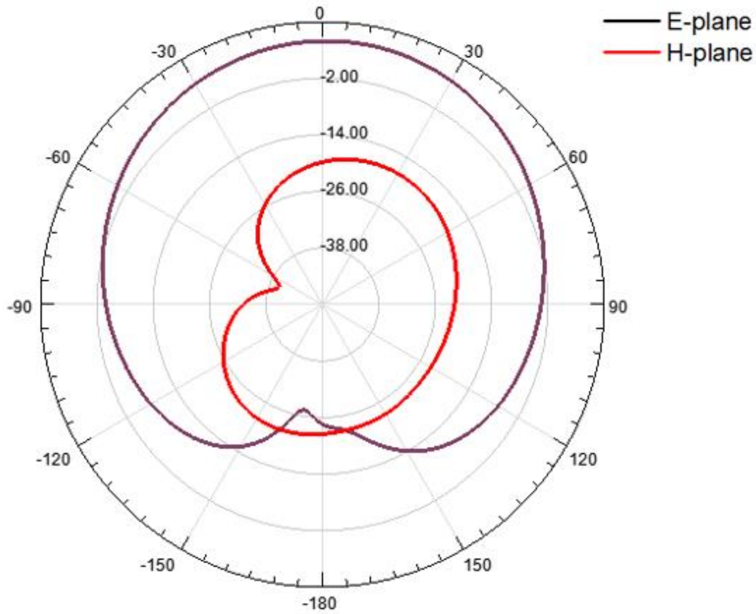

Fig. 14. Realized gain of two-element array antenna at E and H Plane

Co and Cross Polarization in H plane

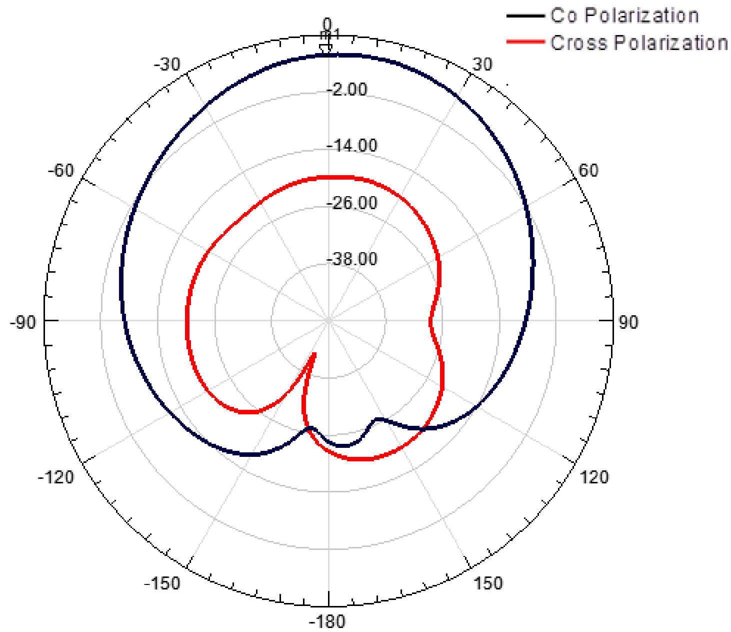

Fig. 15. 2D realized gain for two-element array antenna for co and cross-polarization in H-plane

- **Vector Electric at the surface of the patch antenna**

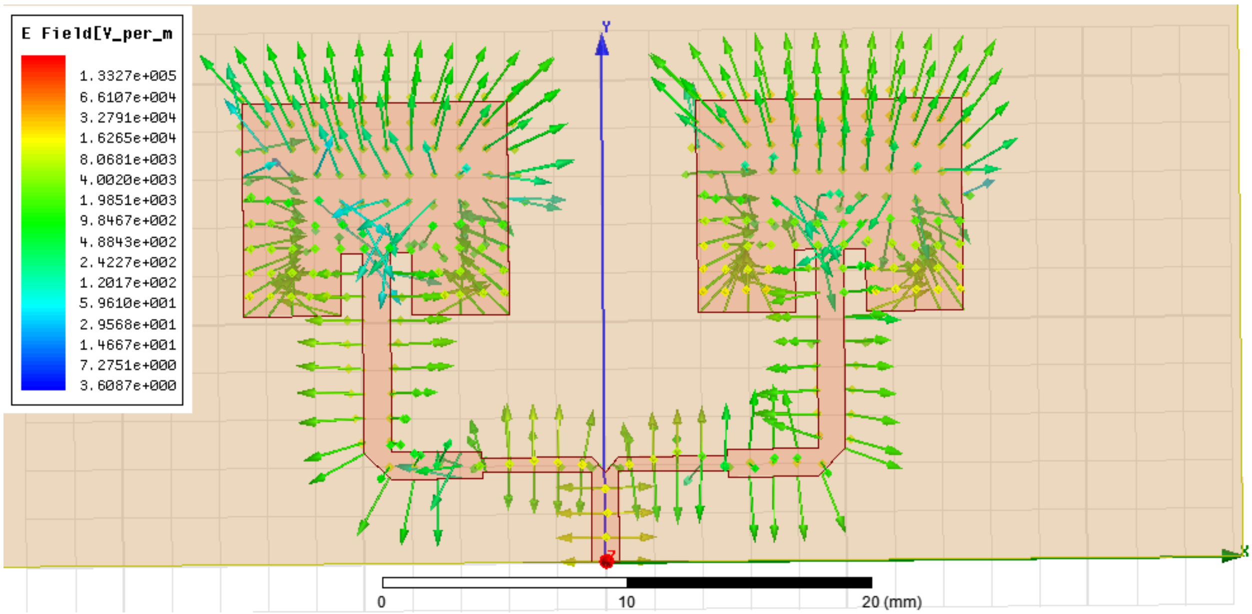

Fig. 16. Vector electric field of two-element array antenna at 7.8 GHz

Calculations

- **Design:**
  - The patch antenna designed above was used along with the T-junction both at port 2 and port 3.
  - The distance between the two patch antennas $L_3 = 1.1L$
  - The quarter-wave transformer converts the impedance at the patch side into 100Ω which is in parallel combination to another transformed impedance of 100Ω.
  - The equivalent impedance of the parallel combination gives 50Ω which matches with the 50 Ω feed line.

- The highest delay is at the resonant frequency of the patch. Thus the group delay is at the operating frequency is 8.05×10^{-9}

- The 10 dB matching Bandwidth is 1.79 % at the Operating frequency of 7.8 GHz.

- The realized gain of 5.345 dB is observed in the simulation with a -3dB bandwidth of 43 degrees.

Conclusion

- A two-element array patch antenna is designed on Rogers RO4003C substrate having dielectric constant 3.55 and dielectric loss tangent 0.0027 using HFSS and its characteristics are studied through Fig. 11. Fig. 11 shows the magnitude of the reflection coefficient of the patch antenna over 6-9.5 GHz band.

- The reflection curve remains near -25 dB indicating good matching at the resonant frequency 7.8 GHz. The 10 dB bandwidth of the antenna is found to be 1.79% for the operating frequency of 7.8 GHz.

- Fig.3 and Fig.4 show the 3D polar plot and the 2D radiation pattern of the microstrip patch antenna respectively at 7.8 GHz. A broadside gain of 5.345 dB at the resonant frequency is observed here.

- The matching was not obtained at the first time of the simulation. By optimizing the length of the patch we obtained a dip at the centre frequency.

- To obtain promising matching the gap and the L3 were tuned such that the dip at the centre frequency of the magnitude plot can be below -25dB.

- The plots of E and H plane also showed the results that were expected. The maximum realized gain was obtained at the broad side of the patch antenna.

- The magnitude of the co polarization was greater than the cross-polarization. However, the magnitude of the cross-polarization also had a significant value.

- The realized gain vs frequency curve shows that it stays maximum at the centre frequency and starts decreasing for the rest of the bandwidth, away from the centre frequency.

- The vector electric field was plotted and since we can see from the fig. 6 that the field follows the pattern of TM mode.