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Shorting Pin Loaded S-shaped Patch Antenna for Multi-band Operation*

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Abstract: The multiband nature of the antenna is realized by loading shorting pin with S-shaped patch. Theoretical investigations were carried out using equivalent circuit concept. It is found that the antenna shows triple band characteristic with resonant frequencies at 3.4949 GHz, 4.3431 GHz and 5.2630 GHz with frequency band of 312.1 MHz (bandwidth 8.93 %), 388.9 MHz (bandwidth 8.95 %) and 636.4 MHz (bandwidth 12.09 %) respectively. The theoretical results are in good agreement with the simulated results.

Key Words: Microstrip patch antenna, Shorting pin, Multiband, Return loss, Radiation pattern

1. Introduction

The demand for application of microstrip antenna in various communication systems has been increasing rapidly due to its small size, low cost, lightweight, ease of integration with other microwave components. Microstrip antennas are also used in various applications that require both transmit and receive operations simultaneously. They have found most wide application in radar, satellite communications, wireless network, mobile communications and microwave sensors. Various techniques have been realized to achieve dual band characteristics of microstrip antenna such as connecting coaxial [1] or microstrip stubs [2] at the radiating edge, use of multi-resonator antennas [3], introducing slots parallel to the radiating edges of the patch [4], using multiple shorting pins located symmetrically with respect to the patch axes [5], etc. This solution does not allow a frequency ratio higher than 1.2. The frequency ratio from 1.3 to 3 has been realized by the simultaneous use of slots and short circuits [6]. In the present paper, an attempt has been made to realize multi-band behaviour of S-shaped patch antenna

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(SSPA) by loading two shorting pins located symmetrically with respect to the patch axes. The design of the proposed antenna is based on the philosophy of maximizing the current path for a given surface area to decrease the resonance frequency by shorting pin. In addition, superstrate (ε_{r2}=4.3) is loaded over the patch to protect the antenna from environmental hazards. The results obtained are compared with simulated results using Zeland IE3D Electromagnetic Simulator Version 14.05. The details of the theoretical investigations are given in the following sections.

2. Theoretical Considerations

Figure 1 shows the geometrical configuration of the proposed antenna. The lower S-shaped patch is like a rectangular patch of length L_p=15.6 mm and width W_p=22.2 mm with two identical notches incorporated in its radiating edges in such a way that one notch is in one radiating edge.

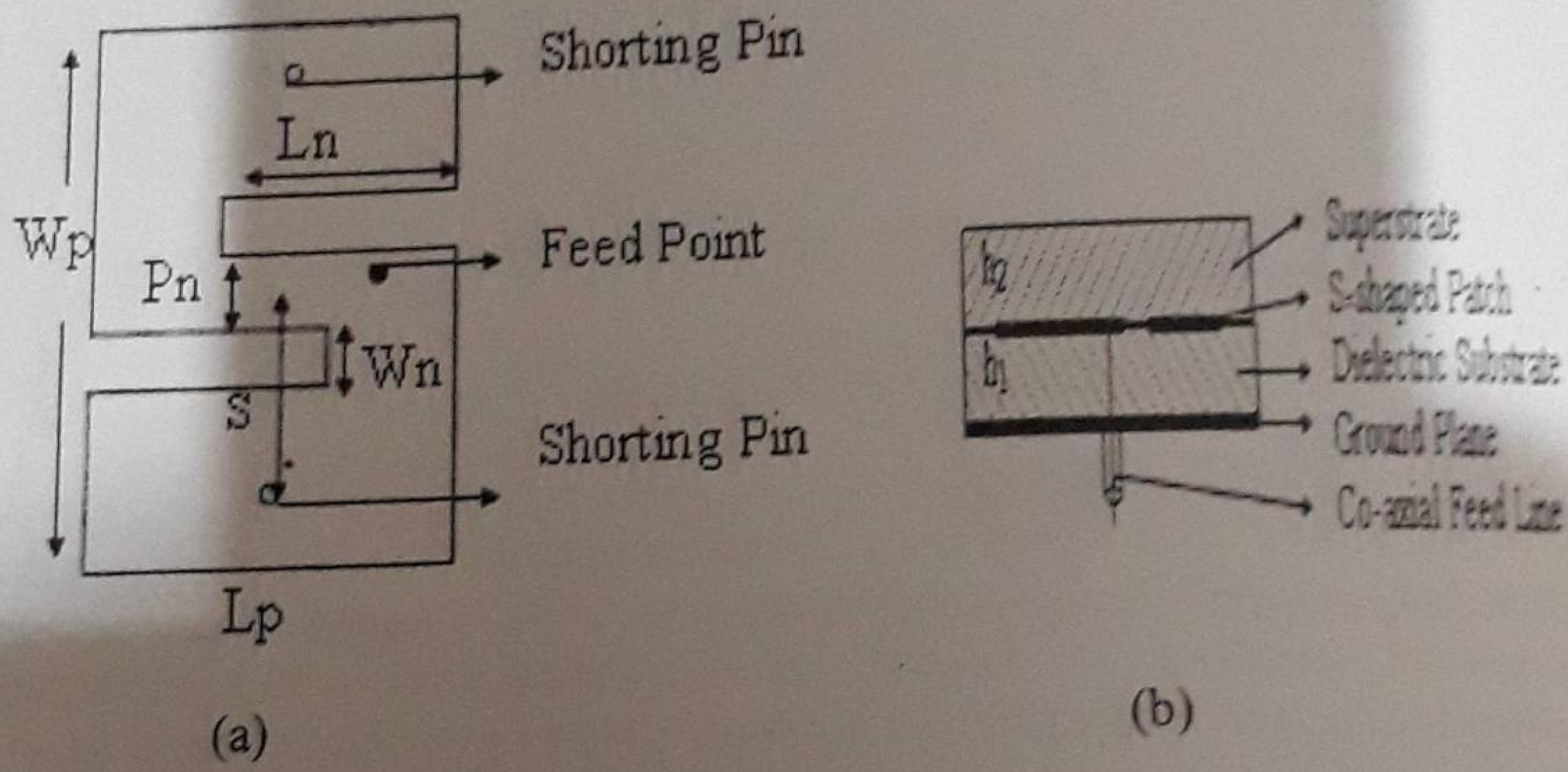
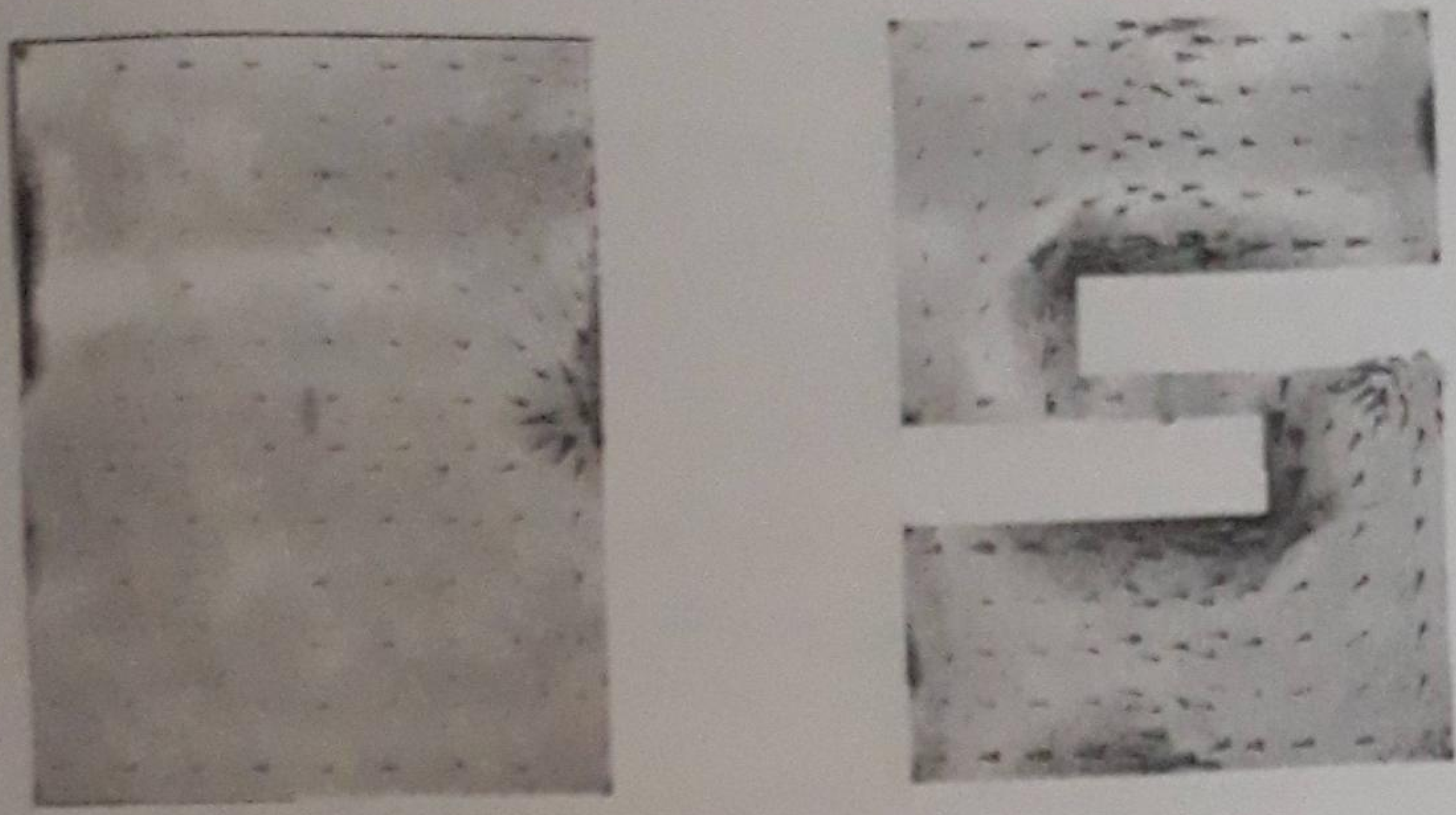


Figure 1 Geometrical configuration of the proposed antenna (a) Top view and (b) Side view

Each notch of length L_n=10.4 mm and width W_n=2.8 mm, is positioned symmetrically with respect the centre of the patch in such a way that P_n= 4.5 mm. The S-shaped patch is etched on a dielectric substrate of height h_1=5.0 mm and relative permittivity ε_{r1}=2.2. Two identical shorting pin of diameter 1.0 mm are loaded at two sides of the patch such that s = 8 mm for each pin. A coaxial probe of diameter 1.0 mm feeds the lower patch.



(a) (b)

Figure 2. Current distributions in (a) Simple rectangular patch and (b) S-shaped patch at 4.19 GHz

A simple patch antenna can be modeled as a simple LC resonant circuit[7]. The current flows from the feeding point to the top and bottom edges of the patch which is shown in Figure 2(a). L and C values are determined by these current paths. When two parallel notches are incorporated into the patch, it disturbs usual current path of the patch. The current has to flow around the notches and the length of the current is increased as shown in Figure 2(b). This effect can be modeled as an additional series inductance (ΔL)[8-12]. In the upper portion of the patch current covers longer path to reach top edge of the patch as compared to the current in the lower portion which reach bottom edge. Therefore, the values for additional inductance will be different for these two currents, these are ΔL_U and ΔL_L for upper and lower portion of the patch respectively. Therefore, the equivalent circuit for upper and lower portion of the patch can be modeled as shown in Figure 3 (b-c), where ΔC_U and ΔC_L are the additional capacitances due to upper and lower notches. These parts resonate with different frequencies. Thus due to effect of notches the resonance features of the patch change and SSPA acts as multi resonators to give multi-band characteristics.

For the simplicity in deriving impedance of S-shaped patch for which equivalent circuit is shown in Figure 3 (d), one can take

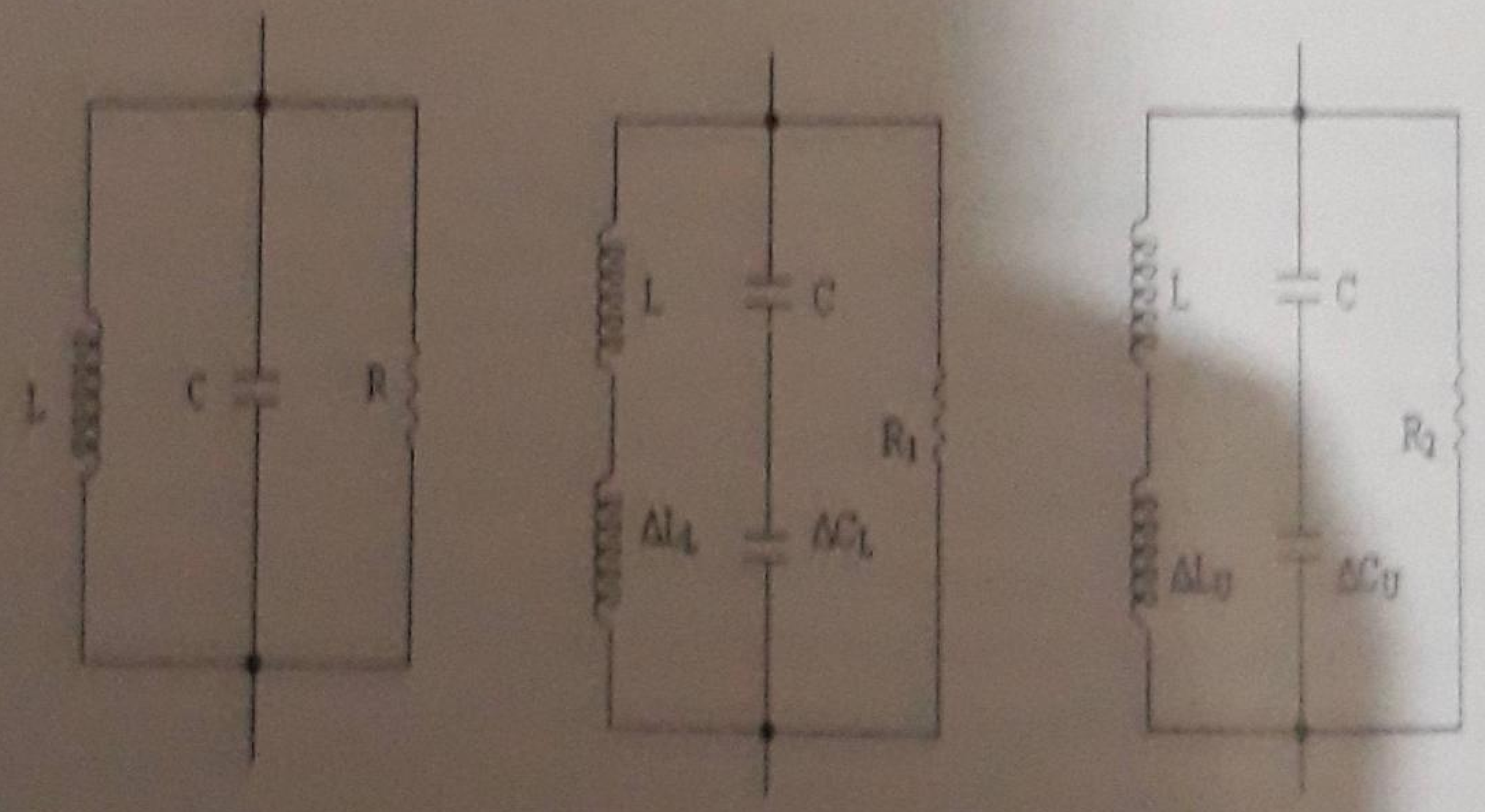
(1) $$Z_1 = \frac{j\omega(L + \Delta L_L)R_1}{R_1 - \omega^2(L + \Delta L_L)\left(\frac{C\Delta C_L}{C + \Delta C_L}\right)R_1 + j\omega(L + \Delta L_L)},$$

(2) $$Z_2 = \frac{j\omega LR}{R - \omega^2 LCR + j\omega L},$$

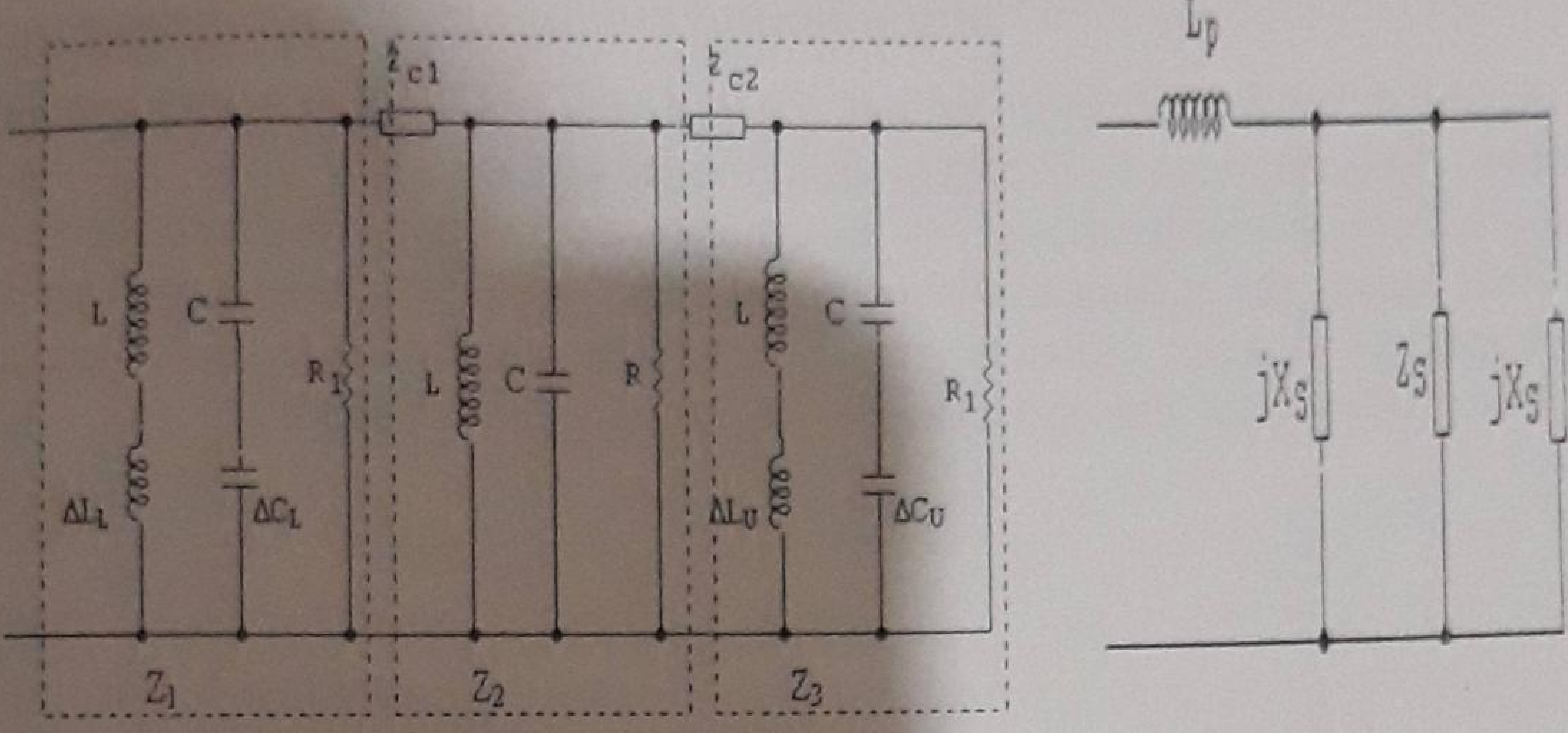
(3) $$Z_3 = \frac{j\omega(L + \Delta L_U)R_2}{R_2 - \omega^2(L + \Delta L_U)\left(\frac{C\Delta C_U}{C + \Delta C_U}\right)R_2 + j\omega(L + \Delta L_U)}.$$

Therefore, the impedance of S-shaped patch antenna can be derived as

(4) $$Z_{SPA} = \frac{Z_{C1}(Z_{C2} + Z_2 + Z_3) + Z_2(Z_{C2} + Z_3) + Z_1(Z_{C2} + Z_2 + Z_3)}{Z_1 Z_{C1}(Z_{C2} + Z_2 + Z_3) + Z_1 Z_2(Z_{C2} + Z_3)}.$$



(a) (b) (c)



(d) (e)

Figure 3. Equivalent circuits of (a) simple patch, (b) lower part of S-shaped patch, (c) upper part of S-shaped patch, (d) S-shaped patch and (e) shorted S-shaped patch

where Z_{C1} and Z_{C2} are the impedance due to mutual coupling of the two side resonators with the main patch resonator.

When shoring pins are loaded with the patch, reactive impedances due to each pins, are added parallel to the impedance of the patch. Thus the equivalent circuit of the shorting pin loaded S-shaped patch antenna can be given as shown in Figure 3 (e). The input impedance of the shorting pin loaded S-shaped patch antenna can be derived as

$$Z_{in} = j\omega L_p + \frac{jX_S Z_{SSPA}}{jX_S + 2Z_{SSPA}}, \quad (5)$$

where $X_S = j\omega L_S$; L_S and L_p are inductances due shorting pin and co-axial probe feed respectively.

The return loss value of the proposed antenna can be calculated as

$$RL = 20\log\frac{1+\Gamma}{1-\Gamma}, \quad (6)$$

where $\Gamma = \frac{Z_{in} - Z_0}{Z_{in} + Z_0}$ and Z_0 is the characteristic impedance of the coaxial feed (50 ohm).

3. Discussion of Results

Figure 4 show that shorting pin location (s) has crucial effect on the antenna performance. It is noted that the antenna shows three resonant frequencies. For small value of 's', antenna shows that only first resonance is matched but as the distance of shorting pin increases matching improves at two upper resonances. However, when's' becomes even larger, matching at second resonance further improves but degrades at third resonance.

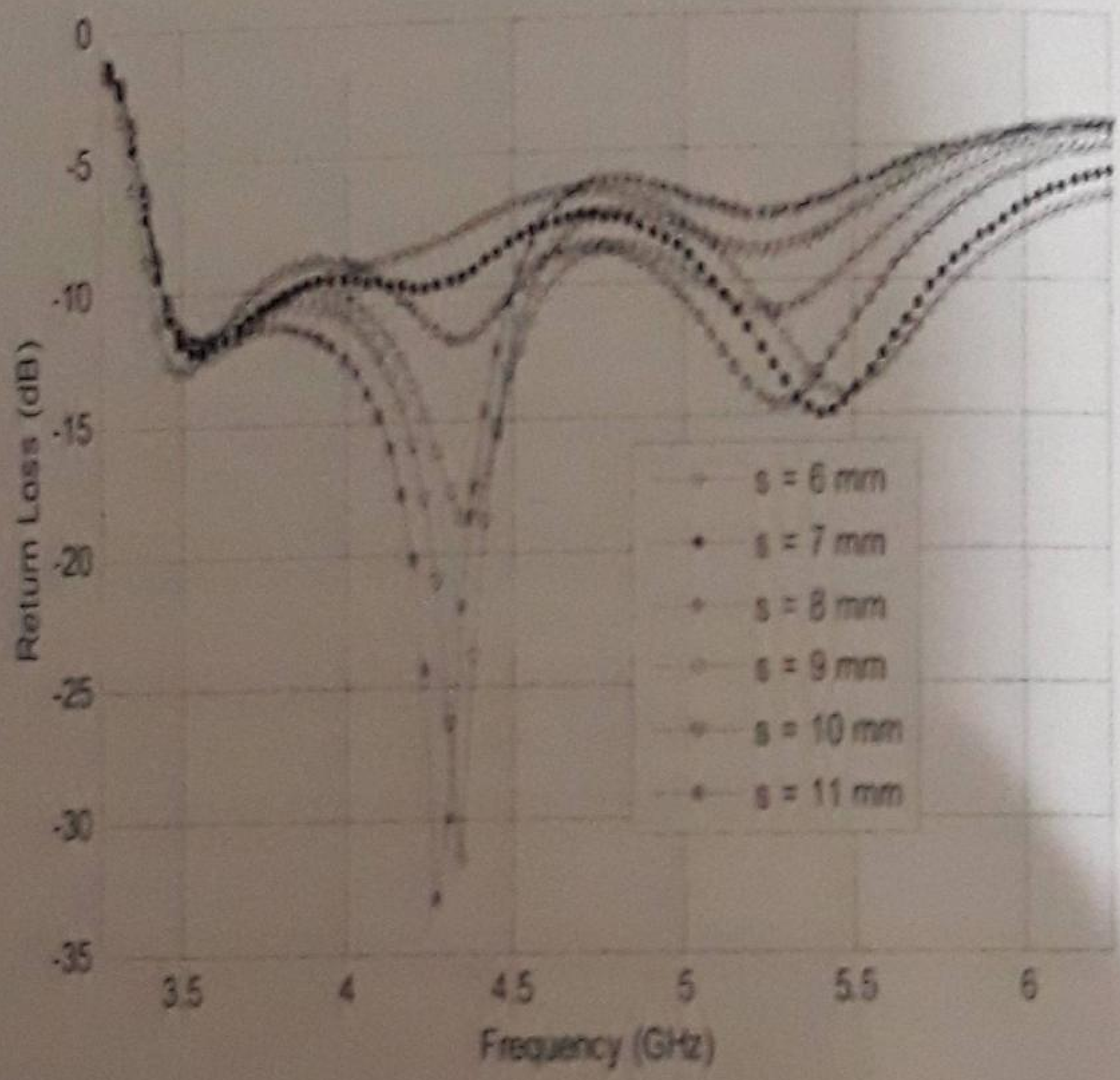


Figure 4. Variation of return loss with frequency at different shorting pin location (s)

The variation of return loss with frequency for the optimized antenna is shown in Fig. 5. It shows triple frequency band characteristic of the antenna. Theoretically, the three resonances appear at 3.4949 GHz, 4.3431 GHz and 5.2630 GHz respectively with frequency band of 312.1 MHz (bandwidth 8.93 %), 388.9 MHz (bandwidth 8.95 %) and 636.4 MHz (bandwidth 12.09 %). On the other hand, the simulated result shows resonances at 3.4303 GHz, 4.3429 GHz and 5.1980 GHz with operational frequency band of 300.7 MHz, 444.3 MHz and 619.6 MHz respectively. Thus the theoretical results are in good agreement with the simulated results. This proves the validity of the theoretical considerations.

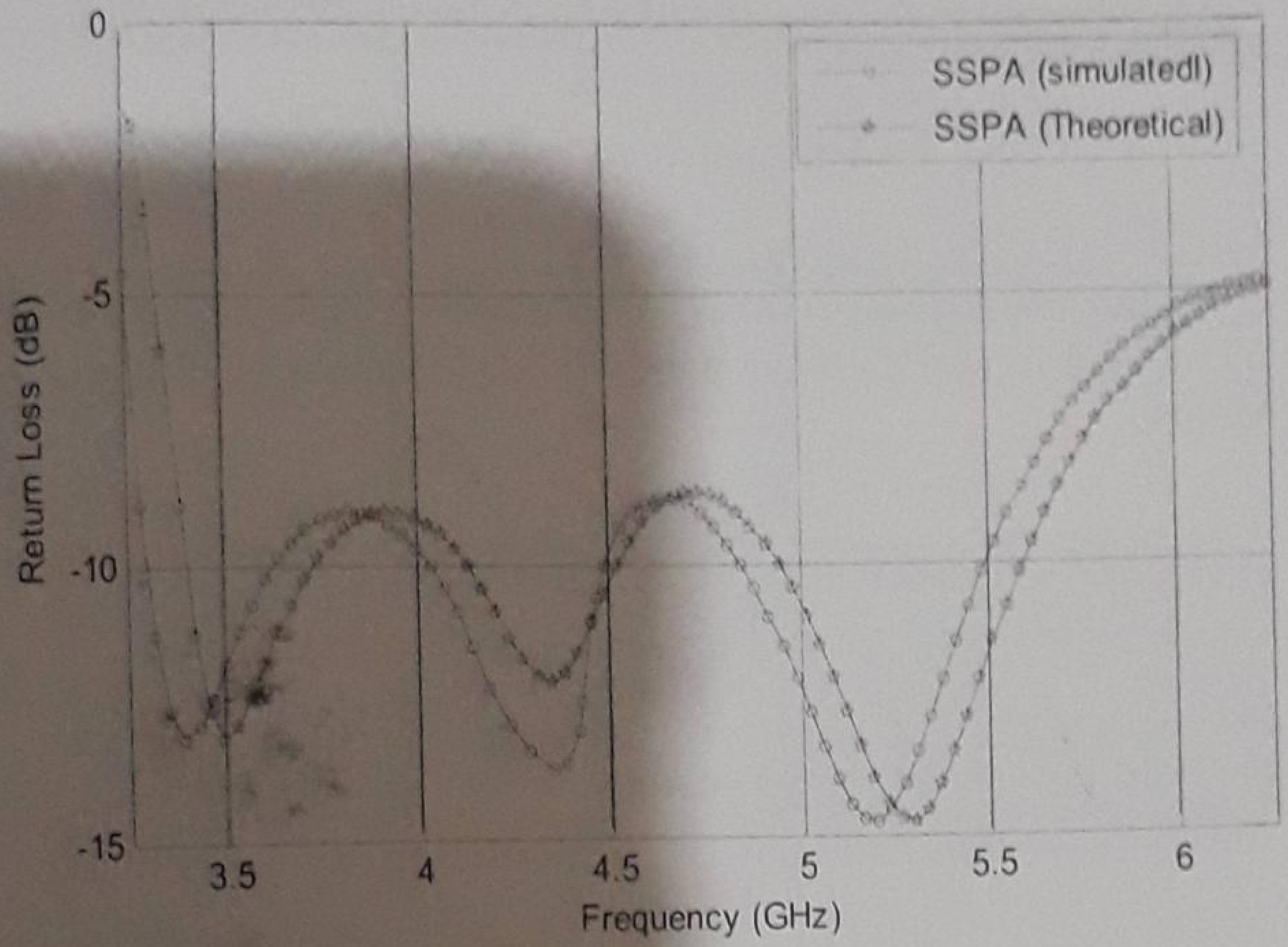


Figure 5. Variation of return loss with frequency for the optimized antenna

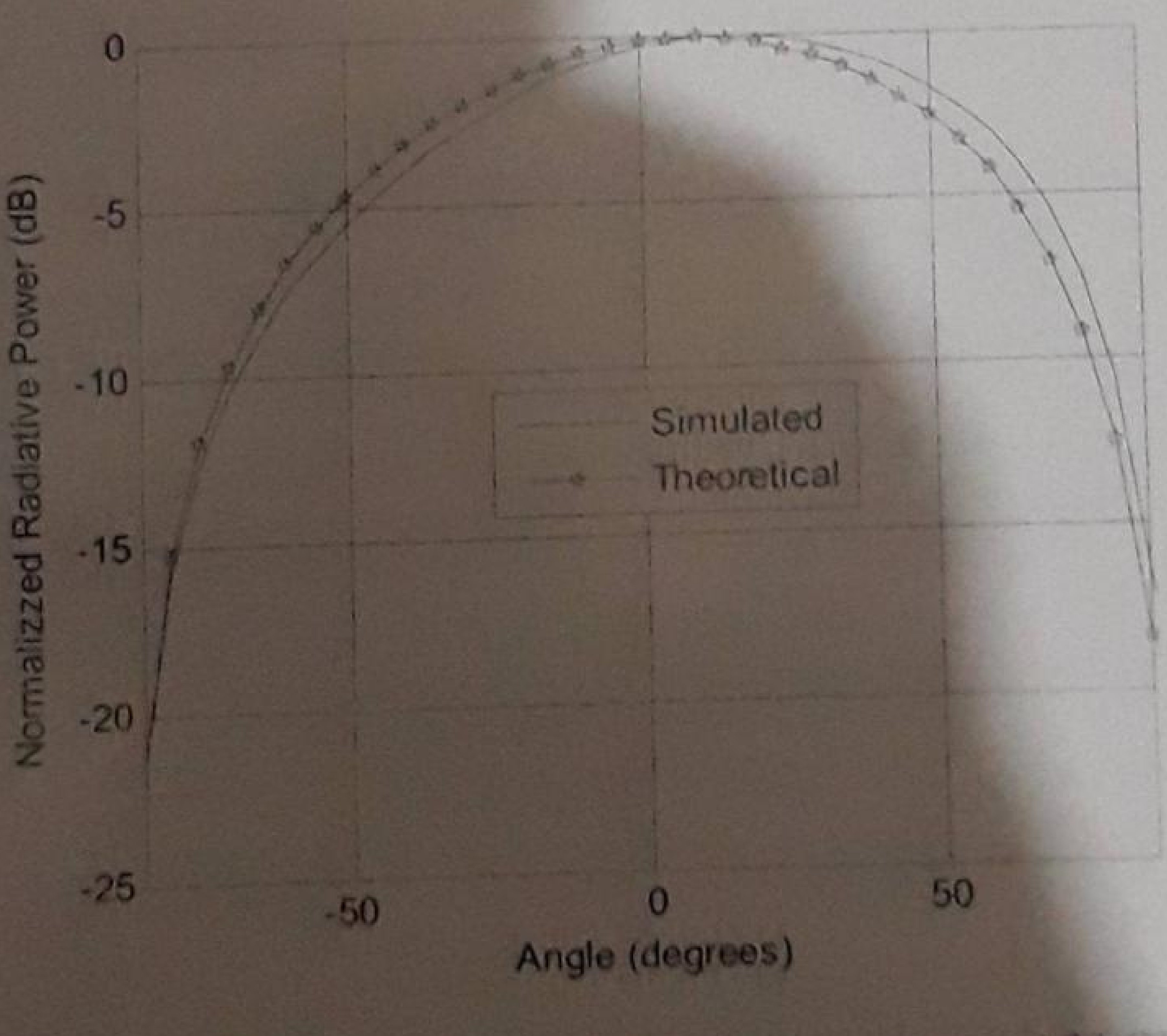


Figure 6. E-plane radiation pattern at frequency at 4.34 GHz

The E-plane radiation patterns of the antenna at frequency 4.34 GHz is shown in Figures 6. It is observed that the antenna shows 3-dB beam width of 68.42^0 4.34 GHz whereas simulated result shows 67.62^0 beam width. It is notable that the direction of maximum radiation shifts towards right from the broadside direction by 16^0.

4. Conclusions

It is, therefore, concluded that the antenna exhibits triple frequency band. This is due to the simultaneous effects of notches and shorting pins. The antenna can be used in wireless communication systems that require multi-band operations.

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