Frequency Reconfigurable Patch Antenna for L band Applications

Sanjeev Kumar, Rohit Khandekar, Priyanka Tupe-Waghmare

Abstract: A novel design of a Frequency Reconfigurable patch antenna which has applications in the L-Band, namely, radars, GPS, telecommunication system and aircraft surveillance is presented in this paper. The antenna having dimensions of 34.45mm x 45.64mm has been designed using Ansys HFSS. It is a microstrip line inset fed patch antenna with square concentric rings as Defected Ground Structure (DGS) and FR-4 as the substrate. Two PIN diodes, BAR 63-02V, have been used on the ground plane to carry out switching in the frequency domain. The simulated results depict the frequency shift from 1.612 MHz to 1.815 MHz for different combinations of PIN diodes while keeping the radiation patterns intact. The simulated $S_{11}$ values are well below the –10dB value in all the four combinations. The average impedance bandwidth obtained is 400 MHz. The measured results on the fabricated antenna using Vector Network Analyzer are in close approximation to the simulated results.

Keywords- Inset patch, PIN diodes, DGS, and Square ring slots.

I. INTRODUCTION

L-band is an IEEE defined range of frequencies from 1 GHz to 2GHz in the radio spectrum. L band is prominently used for Global Positioning System (GPS), Satellite communications, Aircraft surveillance, Telecommunication and for Radars. As the L band ranges from 1 to 2 GHz, it has a small bandwidth and therefore, L band is majorly used in Tracking systems and Fleet management.

Patch antennas have gained much attention due to its low profile, easy fabrication and robust applications in satellite communications, aircraft, space crafts, etc. In wireless communication, there has been an increase in the number of protocols required to be incorporated in a single device. It can be achieved using single-band antennas for each required application or using a multiband antenna which has the same size and structure as of a single band. Multiband antennas are suitable for devices having to cater for a few protocols. Besides, multiband antennas need expensive filters for suppressing unwanted signals, thereby increasing the cost.

Reconfiguration, an alternative technique, allocates the same space as single and multiband antennas [1]. Instantaneous bands can be reconfigured and can thus effectively cover several bands or radiation patterns with more desirable side-lobe distribution. It has inherent filtering behaviour as it is matched only for the desired band and can thus eliminate the cost of expensive filters required for multiband antennas [1], [2].

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\[ L = \frac{c}{2f_0\sqrt{\varepsilon_{\text{eff}}}} = 0.824 \ h \left( \frac{W}{\varepsilon_{\text{eff}} + 0.3} \right) \left( \frac{W}{\varepsilon_{\text{eff}} - 0.258} \right) \]  

\[ W = \frac{c}{2f_0 \sqrt{\varepsilon_{\text{eff}}}} = \frac{\varepsilon_r + 1}{2} \left[ \frac{1}{\varepsilon_r - 1} \right] \]  

\[ Z_c = R_{\text{in}} \cos^2 \left( \frac{\pi}{L} \right) \]  

Where, \( \varepsilon_r = 4.4, \ h = 1.6 \text{ mm}, \ Z_c \) is characteristic impedance.

Designed antenna can be depicted in Fig 1(a & b). The ground plane is a defected ground structure (DGS) with two concentric square slots of 2mm width. Two PIN diodes have been mounted as the RF- switches in the slots of the ground plane for frequency reconfiguration.

Table I: Antenna Parameters for Inset Patch Antenna

| Parameter         | Values (mm) |
|-------------------|-------------|
| Patch length (l)  | 34.4        |
| Patch width (w)   | 45.64       |
| Inset length (yo) | 25.38       |
| Substrate length (L) | 50         |
| Substrate length (W) | 58         |

Table II: Switching of the PIN diode changes the current distribution in the defected ground plane, resulting in changes in the resonant frequency. The obtained \( S_{11} \) values for all the four possible switching combinations have been combined and presented in Fig 3. The resonant frequency of the patch is attained at 1.7350 GHz from the OFF state of both the diodes. The frequency shifts to 1.7450 GHz on the switching ON state of the diode (D1) on the upper slot. Similarly, the frequency changes to 1.81 GHz on reversing the ON-OFF states of the diodes from the previous state. The resonant frequency further changes to 1.635 GHz on turning ON both the diodes. The shift in frequencies is attributed to the change in current length, brought in by the change in defect ground length on changing states of the diodes. The return loss values obtained for all the above four cases is well below the -10 dB mark and reflected in

Fig 1: Designed Antenna (a) Inset Patch

Fig 2: RLC equivalent circuit for RF PIN Diode (a) Forward bias, (b) Reverse Bias.

Fig 1: Designed Antenna (b) Defected Ground Plane with integrated switches.

Infineon BAR 63-02V has been carefully chosen due to its suitable isolation value. The equivalent circuit of this PIN diode is represented by an inductor \( L \) for both states of the switch. In ON state \( L \) is in series with a resistance \( R_s \) and in OFF state capacitor \( C_T \) is parallel with resistance \( R_p \) as depicted in Fig 2. The datasheet provided by the manufacturer gives these values as \( L=0.6 \text{nH}, R_s =1.2 \ \Omega, C_T = 0.3 \text{ pF}, R_p =15 \text{ K}\Omega \) [15].

### III. ANALYSIS OF SIMULATED RESULTS

The PIN diodes have been modelled as an equivalent lumped RLC circuit. Table II shows four different configurations of the two switches. Switching of the PIN diode changes the current distribution in the defected ground plane, resulting in changes in the resonant frequency. The obtained \( S_{11} \) values for all the four possible switching combinations have been combined and presented in Fig 3. The resonant frequency of the patch is attained at 1.7350 GHz from the OFF state of both the diodes. The frequency shifts to 1.7450 GHz on the switching ON state of the diode (D1) on the upper slot. Similarly, the frequency changes to 1.81 GHz on reversing the ON-OFF states of the diodes from the previous state. The resonant frequency further changes to 1.635 GHz on turning ON both the diodes. The shift in frequencies is attributed to the change in current length, brought in by the change in defect ground length on changing states of the diodes. The return loss values obtained for all the above four cases is well below the -10 dB mark and reflected in
Table II. The simulated impedance bandwidth is observed approximately 20 MHz for all the switching states of configuration.

| Freq. | State D1, D2 | Freq. Shift (GHz) | S11(dB) |
|-------|-------------|-------------------|---------|
| F1    | OFF, OFF    | 1.7350            | -16.2160|
| F2    | OFF, ON     | 1.7450            | -21.0722|
| F3    | ON, OFF     | 1.81              | -18.662 |
| F4    | ON, ON      | 1.635             | -27.324 |

The radiation patterns, for all the four different combinations of diode states, in the 2-D plane are shown in Fig 4. As can be observed the pattern is directional in the elevation E-plane for all four cases. The H-plane pattern is close to omnidirectional for all four cases.

Fig 3: S11 for different configuration of PIN diodes as per the table II
Fig 4: (a), (b), (c) and (d): E-Plane and H-plane for frequencies F1, F2, F3 and F4

From the 3-D polar plots shown in Fig 5, it is observed that there has been no change in the shape of radiation pattern even if the resonant frequency has changed from 1.6 to 1.8 GHz meeting the criterion for a frequency reconfigurable antenna. Gain obtained for the frequencies F1, F2, F3 and F4 is 0 and 1dB.
The current distribution of the antenna is changed by switching diodes ON and OFF which alters the current over the surface of the antenna resulting into changes in resonating frequency. The Fig 6 (a, b, c & d) and Table III shows the surface current density for frequencies 1.735, 1.745, 1.81, 1.635 GHz respectively for the different states of the PIN diodes. As can be seen in Fig 6 (d) when both the PIN diodes are ON current flows through both the square slots and the current length is maximum. Corresponding resonating frequency 1.64GHz is the least.

Fig 6: (a), (b), (c) and (d): Current distribution for frequencies F1, F2, F3 and F4
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### Table III: Surface current Densities

| State    | Freq (GHz) | Jsurf (A/m) |
|----------|------------|-------------|
| BOTH OFF | 1.7350     | 6.41        |
| OFF, ON  | 1.7450     | 7.96        |
| ON, OFF  | 1.81       | 7.94        |

Smith chart shown in Fig 7 depicts the impedance for the two reconfigured frequencies F1 and F4. The normalised impedance for the frequencies F1 and F4 is $1.1696 + j0.0241$ and $1.5464 + j0.0929$. The Impedance of the antenna was found close to be $50\Omega$.

![Smith Chart](image)

**Fig 7: Smith Chart for the frequencies F1 and F4**

### IV. MEASURED RESULTS

The simulated design was extended to fabrication. The top and bottom view of the fabricated antenna along with the biasing lines for the diodes have been shown in Fig 8(a & b). The fabricated antenna was subjected to performance tests in the lab environment. Agilent Network Analyzer N9923A, SN: MY 52412490 was used to carry out the measurements as shown in Fig 9. The RF PIN diodes were switched ON and OFF using external DC supply. The measured frequencies observed for the different states are 1.75, 1.775, 1.815 and 1.61 GHz. The comparison of simulated and measured frequencies F1, F2, F3 and F4 for the different combination of switches as per Table IV.

The simulated and measured reflection coefficients plots are shown below in Fig 10 (a, b, c and d).
Fig 8: Fabricated Prototype of Inset Patch Antenna: (b) Ground Plane with incorporated diodes

Figure 9: Experimental Setup of Inset Patch Antenna

Figure 10: Experimental Results of Inset Patch Antenna: (a) Both switches in OFF state, F1 Frequency
Figure 10: (b) Switch 1 in OFF and Switch 2 in ON state F2 Frequency

Figure 10: (c) Switch 1 in ON state and Switch 2 in OFF state, F3 Frequency
Figure 10: (d) Both switches in ON state, F4 Frequency

Table IV: Comparison between Simulated and Measured Results for Inset Patch Antenna

| Freq | State | Simulated Freq Shift (GHz) | Simulated S11 (dB) | Measured Freq (GHz) | Measured S11 (dB) |
|------|-------|---------------------------|--------------------|--------------------|------------------|
| F1   | OFF, OFF | 1.7350 | -16.2160 | 1.750 | -13.21 |
| F2   | OFF, ON  | 1.7450 | -21.0722 | 1.7750 | -15.88 |
| F3   | ON, OFF  | 1.81 | -18.662 | 1.815 | -19.87 |
| F4   | ON, ON  | 1.635 | -27.324 | 1.610 | -27.11 |

The measured results have been observed to be close to the simulated results. The measured S11 lies below -10 dB and the VSWR values from (4) are between 1 and 2 for all four states. The simulated and measured impedances for the resonant frequencies have been found close to 50 ohms. The simulated and measured S11 results are compared in Table IV.

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V. CONCLUSION

A novel frequency reconfigurable antenna is proposed by inserting RF switches in the DGS slots for L band applications. The minor difference in the simulation and measured results is attributable to slight variations in the design parameters of the fabricated antenna beside the interference due to biasing lines.

VSWR = \frac{1+\Gamma}{1-\Gamma} \quad (4)

Lr = -20\log_{10}\Gamma \quad (5)

where, Lr is Return Loss and \Gamma is reflection coefficient.
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The designed antenna is a prototype that can be improvised for better performance using substrates of lower dielectric constants which will yield larger bandwidth and high radiations and better efficiency. Also, use of dc blocking capacitors may lead to better results. The antenna is low profile and can be easily mounted on Satellites, Aircraft or Military applications.

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