Reduction in Return Loss of a Novel Reconfigurable Antenna at 3.4 GHz by FR4 Substrate Using Double PIN Diodes

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Abstract
Aim: The main objective of the project is to reduce the return loss of a reconfigurable antenna at 3.4 GHz by using FR4 substrate with Double PIN diodes. Materials and Methods: Two diode configurations of single PIN diode and Four diodes configuration of double PIN diodes are used with a sample size of 6. Results: From HFSS simulation software Return Loss(-30.2dB) and VSWR (1.10) of Reconfigurable Monopole antenna is improved by FR4 substrate using Double PIN diodes. Attained significance ratio(P=0.05) in statistical analysis. Conclusion: Double PIN diode of a reconfigurable Monopole antenna performs well (Return Loss is reduced by -7dB) when compared with a single PIN diode of a reconfigurable Monopole antenna.

Key-words: Monopole Antenna, PIN Diode, WLAN, WIFI, Return Loss, VSWR, FR4 Substrate, Novel Reconfigurable Monopole Antenna, Antenna Design.

1. Introduction

The research is about reducing the return loss of reconfigurable monopole antennas using a double PIN diode(Shah et al. 2019). The importance of this project is the need for low return loss antennas for satellite communication(Kumar, Kishan Kumar, and Prasanth 2015). The reconfigurable antennas are used in current portable devices WLAN and WIFI applications (Dwivedy, Behera, and Mishra 2015), (Zarin et al. 2019).
Antenna plays a major role in many portable devices for the purpose of point to point communication with increased VSWR and reduced Return loss (Unru, Ashcherbagin, and Arashtaev 2019). Because of its advantages such as a simple design, small dimensions, and ease of manufacturing, the monopole antenna is favoured in reconfigurable antenna design (Palsokar and Lahudkar 2017). Many techniques are available to reduce the return Loss by adding the PIN diodes (Reddy et al. 2015). The proposed reconfigurable Monopole antennas with better return loss can be used for various applications (Shah et al. 2019). The use of different shapes such as E-shape monopole, B-shape monopole, and other techniques are used to design multi-band antennas for wireless communication applications (Thao et al. 2015).

Previously our team has a rich experience in working on various research projects across multiple disciplines (Sathish and Karthick 2020; Varghese, Ramesh, and Veeraiyan 2019; S. R. Samuel, Acharya, and Rao 2020; Venu, Raju, and Subramani 2019; M. S. Samuel et al. 2019; Venu, Subramani, and Raju 2019; Mehta et al. 2019; Sharma et al. 2019; Malli Sureshbabu et al. 2019; Krishnaswamy et al. 2020; Muthukrishnan et al. 2020; Gheena and Ezhilarasan 2019; Vignesh et al. 2019; Ke et al. 2019; Vijayakumar Jain et al. 2019; Jose, Ajitha, and Subbaiyan 2020). Now the growing trend in this area motivated us to pursue this project.

The unanswered problem is the reduction in Return Loss of Reconfigurable Monopole antenna for high frequencies. The purpose of this project is to reduce the return loss of reconfigurable monopole antennas using PIN diodes with FR4 substrate at 3.4 GHz frequency for different diode configurations.

2. Materials and Methods

This study was conducted at Antenna and Wave propagation lab in Saveetha School of engineering. The study was based on Return Loss reduction of Reconfigurable Monopole antenna using Double PIN diodes comparing with a Reconfigurable antenna using Single PIN diode, Sample size was calculated by using previous study Results (Shoukat et al. 2016) using clincalc.com by keeping alpha error-threshold by 0.05, 95% confidence interval, Power 80%. In this study we compare the Parameters like Return Loss, VSWR by taking 6 samples, one sample group by using previous literature (Shoukat et al. 2016).

The first group contains 2 samples of Single PIN diodes, while the second group contains 4 samples of double PIN diodes,
Design of Reconfigurable Monopole Antenna Using Double PIN diode

The antenna was designed (Fig.1) on FR4 dielectric substrate with a thickness of 1.6mm and a dielectric constant of 4.4 and simulated in HFSS Software. The dimensions of the microstrip antenna are calculated using following formulae mentioned in equations (1-7):

Fig. 1 - Design of Reconfigurable Monopole antenna(21.8mm,50mm) with dielectric constant $\varepsilon_r=4.4$ using Double PIN diodes in HFSS

Width of the patch is calculated as follows:

$$Patch\ width = \frac{c}{2f\sqrt{(\varepsilon_r+1)/2}}$$ (1)

Effective Dielectric Constant ($\varepsilon_e$) of antenna is calculated as:

$$\varepsilon_e = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_{r-1}}{2} [1 + \frac{12h}{Patch\ width}]^{\frac{1}{2}}$$ (2)

Effective length of patch is calculated as:

Eff. Length $Le = \frac{c}{2f\sqrt{\varepsilon_e}}$ (3)

Length of extension $\Delta L$ is the additional length due to the fringing fields and it is calculated as:

$$\Delta L = \frac{0.412h(\varepsilon_e+0.3)(\frac{Patch\ width}{h}+0.264)}{(\varepsilon_e-0.258)(\frac{Patch\ width}{h}+0.8)}$$ (4)

Actual length of patch is calculated using:

$$Patch\ length = Le - 2\Delta L$$ (5)

Proposed antenna Width and Length of patch calculated from the above equations are:

Patch Width ($W1 = 2.5mm, W2 = 4mm, W3 = 8.5mm, W4 = 2mm$) = 21.8mm (6)
Patch Length \( (L_1 = 12.8\, mm, L_2 = 10.1\, mm, L_3 = 8.5\, mm, L_4 = 18.6\, mm) = 50\, mm \) \( (7) \)

The antenna is simulated by using the above design equations in HFSS Software.

**Design of Reconfigurable Monopole Antenna Using Single PIN Diode**

Single PIN diode is inserted at one of the slots in a patch of a Reconfigurable Monopole antenna design (Fig.2) where we need to change the resistance values(0.1uohms,1000Gohms) for ON and OFF conditions of a PIN diode switch.

Fig. 2 - Design of Reconfigurable Monopole antenna(21.8mm,50mm) with dielectric constant \( \varepsilon_r=4.4 \) using Single PIN diode in HFSS.

The 8th Generation Intel core processor(up to 8MB cache) was used in the testing setup configuration to design the antenna in the HFSS software. The antenna is designed at a frequency of (3.4GHz) and is used as the testing input. The antenna can be constructed by defining the variables\( (L,W,H,F) \) and assigning the boundaries and lumped ports of the antenna using HFSS software. The frequency sweep is applied to the configuration to validate and to obtain the results.

**Data Collected by Making the ON and OFF Conditions of PIN Diodes**

**Statistical analysis:** SPSS version 21 was used for statistical comparison of parameters like Return Loss and VSWR. The independent sample test and group statistics are calculated using SPSS software. The width of the substrate, height of the substrate and the length of the antenna are independent variables, while return loss and VSWR are dependent variables.
3. Results

Table 1 - Return Loss(dB) and VSWR Values obtained for Proposed Reconfigurable Monopole Antennas using Double PIN Diodes(Diode ON and OFF Conditions) with FR4 Substrate

| D1 | D2 | Return Loss | VSWR |
|----|----|-------------|------|
| ON | ON | -30.2       | 1.10 |
| ON | OFF| -17.18      | 1.4  |
| OFF| ON | -17.18      | 1.4  |
| OFF| OFF| -18.05      | 1.32 |

Table 2: Return Loss(dB) and VSWR values obtained for reconfigurable monopole antennas using single PIN diodes (Diode ON and OFF conditions with FR4 Substrate.

| D1 | Return Loss(dB) | VSWR |
|----|-----------------|------|
| ON | -23.8           | 1.09 |
| OFF| -16.7           | 1.02 |

Table 3 - Return Loss(dB) and VSWR Values obtained for Proposed Reconfigurable Monopole Antennas using Double PIN Diodes(Diode ON and OFF Conditions) with FR4 Substrate

| D1 | D2 | Return Loss | VSWR |
|----|----|-------------|------|
| ON | ON | -30.2       | 1.10 |
| ON | OFF| -17.18      | 1.4  |
| OFF| ON | -17.18      | 1.4  |
| OFF| OFF| -18.05      | 1.32 |

Table 4 - Independent Sample T-test Result Reveals that (P=0.05) which shows Statistically significant when Compared for Return Loss between single PIN Diode and Double PIN Diode

| Groups                        | Levene’s Test for Equality of Variances | t-test for Equality of Means | 95% Confidence Interval of the Difference |
|-------------------------------|-----------------------------------------|-----------------------------|-----------------------------------------|
|                               | P | Sig. | t | df | Sig. (2-tailed) | Mean Difference | Std. Error Difference | Lower | Upper |
| Return Loss                   | .088 | .052663 | -2.38 | 4 | 0.75 | -12.63000 | 5.28825 | -27.31254 | 2.05254 |
| Equal variances assumed       | .088 | .052663 | -2.38 | 4 | 0.75 | -12.63000 | 5.28825 | -27.31254 | 2.05254 |
| Equal variances not assumed   | .088 | .052663 | -2.38 | 4 | 0.75 | -12.63000 | 5.28825 | -27.31254 | 2.05254 |

Table 5 - Group statistics results reveal Mean value of Return Loss and standard deviation for Double PIN Diodes

| Group                        | N  | Mean | Standard deviation | Standard Error mean |
|------------------------------|----|------|--------------------|---------------------|
| Return loss Single PIN diode | 2  | -31.7500 | 7.0036             | 4.95000             |
| Double PIN diodes            | 4  | -19.1200 | 5.77768            | 2.88848             |
The Results of Reconfigurable monopole antenna by using Double PIN diodes are obtained. The minimum Return Loss and VSWR obtained is represented in Fig.3 & Fig.4. It shows the variations of Return Loss and VSWR for ON and OFF conditions. The amount of loss of power is minimum when the diode is ON and the power loss is maximum when the diode is OFF. VSWR is minimum when the diode is ON and Maximum when the diode is OFF.

Fig. 3 - Single PIN Diode (a) Return loss Vs Frequency, when Diode is ON. (b) VSWR Vs Frequency, when DIODE is ON. (c) Return loss Vs Frequency, when DIODE is OFF. (d) VSWR Vs Frequency, when DIODE is OFF.

From Fig. 3(a), It was observed that the Return Loss Vs Frequency at 3.4GHz is plotted and the minimum return loss for Reconfigurable monopole antenna using Single PIN diode is -23.8dB, when the Diode is ON.

From Fig. 3(b), The VSWR against Frequency graph is plotted using Single PIN diode and the minimum VSWR at 3.4 GHz is 1.09, When the Diode is ON.

From Fig. 3(c), Return Loss Vs Frequency graph is plotted using Single PIN diode and the minimum Return Loss at 3.4 GHz is -16.7dB, When the Diode is OFF.
From Fig. 3(d), The VSWR against Frequency graph is plotted using Single PIN diode and the minimum VSWR at 3.4 GHz is 1.02, When the Diode is OFF.

Fig. 4 - Double PIN diodes (a) Return loss Vs Frequency, when the DIODES (D1 = D2 =ON). (b) VSWR Vs Frequency, when the DIODES (D1 = D2 =ON). (c) Return loss Vs Frequency, when the DIODES (D1 = ON, D2 =OFF). (d) VSWR Vs Frequency, when the DIODES (D1 = ON, D2 =OFF). (e) Return loss Vs Frequency, when the DIODES (D1 = OFF, D2 =ON). (f) VSWR Vs Frequency, when the DIODES (D1 = ON, D2 =OFF). (g) Return loss Vs Frequency, when the DIODES (D1 = D2 =OFF). (h) VSWR Vs Frequency, when the DIODES (D1 = D2 =OFF).
From Fig.4(a), it was observed that the Return Loss Vs Frequency graph is plotted using a Double PIN diode and the minimum Return Loss at 3.4GHz is -30.2dB, when both the Diodes are ON.

From Fig.4(b), The VSWR against Frequency graph is plotted using Double PIN diodes and the minimum VSWR at 3.4 GHz is 1.10, When both the Diodes are ON.

From Fig.[4(c),4(e)], it was observed that the Return Loss Vs Frequency graph is plotted using a Double PIN diode and the minimum Return Loss at 3.4GHz is -17.8dB, when the Diodes are D1=ON, D2=OFF (or) D1=OFF, D2=ON.

From Fig.[4(d),4(f)], The VSWR against Frequency graph is plotted using Double PIN diodes and the minimum VSWR at 3.4 GHz is 1.4, When the Diodes are D1=ON, D2=OFF (or) D1=OFF, D2=ON.

From Fig.4(g), it was observed that the Return Loss Vs Frequency graph is plotted using a Double PIN diode and the minimum Return Loss at 3.4GHz is -18.5dB, when both the Diodes are OFF.

From Fig.4(f), The VSWR against Frequency graph is plotted using Double PIN diodes and the minimum VSWR at 3.4 GHz is 1.32, When both the Diodes are OFF.

4. Discussions

Based on the above results, the performance of the Reconfigurable monopole antenna appears to be better for Double PIN Diodes than Single PIN diode and it is statistically significant (P=0.05).
For Double PIN diode monopole antenna, the obtained Return loss at 3.4GHz is -30.2dB and the VSWR 1.10 when both the Diodes are ON, and the Return Loss is -17.8dB, VSWR is 1.4 for the diodes D1 in ON and D2 in OFF Condition. When both the diodes are in OFF condition the Return Loss -18.05dB, VSWR is 1.32. These values of Return Loss and VSWR appears to be better compared to the Reconfigurable monopole antenna for polarization diversity (Sung 2018) in which Return Loss=-19.2dB is lesser value due to the usage of jean substrate and polarisation Reconfigurable structure. VSWR is better for the proposed reconfigurable monopole antenna compared to Hybrid Reconfigurable antenna (“Design and Analysis of a Reconfigurable Antenna for Dual Band ISM Medical and Wi-Fi Applications” 2019) due to the usage of frequency reconfigurable property of the antenna. The ReturnLoss is better compared to the Optimization of A Beam Reconfigurable Antenna using PIN Diodes (Luis, De Luis, and de Flaviis 2009) in which Return Loss=-16.4dB is lesser value due to beam reconfigurable property of an antenna. The Return Loss is better when compared with a reconfigurable slot ring antenna using PIN diodes (Shirazi, Li, and Gong 2015) with a Return Loss -27.8dBis lesser due to lesser frequency with slot ring. There is no opposing citation and the design done based on the above procedure appears to be good.

Our institution is passionate about high quality evidence based research and has excelled in various fields ((Vijayashree Priyadharsini 2019; Ezhilarasan, Apoorva, and Ashok Vardhan 2019; Ramesh et al. 2018; Mathew et al. 2020; Sridharan et al. 2019; Pc, Marimuthu, and Devadoss 2018; Ramadurai et al. 2019). We hope this study adds to this rich legacy.

The double PIN diode configuration to reduce the return loss of a reconfigurable monopole antenna is used to support only dual band operation.

Usage of reconfigurable monopole Antenna with reduction in Return Loss for quad band and penta band applications.

5. Conclusion

Reconfigurable Monopole antennas using Double PIN diodes appear to be better (Return Loss is reduced by -7dB) when compared with a single PIN diode. It operates in a dual band mode (WLAN, WIFI) when all the switches are in ON condition, and Single band when it is in OFF condition.

Declarations

Conflict of interests: No conflict of interest in this manuscript.
Authors Contributions

Author NS was involved in data collection, data analysis, manuscript writing. Author SWR was involved in conceptualization, data royalization and critical review of manuscript.

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