DESIGN AND ANALYSIS OF RECONFIGURABLE ANTENNA FOR WIDE BAND APPLICATIONS

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Abstract. The relevance of reconfiguration in a dynamic environment is to improve an antenna’s performance by allowing it to transition between multiple frequencies. In this paper, we designed a reconfigurable patch antenna and fed it by strip line feeding by placing 2 slots to obtain different resonant frequencies. The feature of reconfigurability is attained by using Pin Diodes. In our design, we take a 2 pin diode. The proposed Antenna can operate on different frequencies i.e. 2.88GHz, 5.5GHz, 10.8GHz and 11.1GHz with the efficiency of 90% and more at different conditions of the diodes. This analysis is done by using HFSS Software.

Keywords—Reconfigurable Antenna, Pin Diode, X-band, C-band, microstrip feed line.

1. Introduction
Rapid escalation in the area of wireless communication there is a demand for reconfigurable antennas for multimode operations to use in various applications. The word reconfigurability defines the ability of an antenna to adjust the characteristics of the antenna like resonant frequency, polarization and radiation pattern instead of single antenna. The dynamicity of the antenna is obtained by switching mechanism to design a reconfigurable antenna. Some of the switching techniques are varactor diodes, Pin Diodes and RF MEMS switches. Each and every switch has its own advantages. Though we have several switching techniques like RF mems, varactor diodes etc. We have chosen the pin diode as our switch because of it is high linearity, high-Speed response, low noise, low cost and more reliable [1]. On two sides of the substrate the bow-tie radiator is printed and micro strip line feeding is given. The Pin diode is used for switching mechanism and is embedded to it. It is proposed for to operate on 3 states but the design is complex [2]. In [3] Slot antenna is proposed which gives a bidirectional radiation pattern, operates in three resonant frequencies by using 2 pin diodes [4]. In A frequency reconfigurable pixel antenna was proposed [5] they used 6 RF pin diodes but they get only three resonant frequencies and less cross polarization. In [6] a compact micro strip patch antenna with slot is proposed they have used two pin diodes to operate at WiMAX frequencies [7]. A reconfigurable slot antenna is proposed for to operate in LTE, AMT-fixed service and WLAN applications [8]. In [11], this paper presents the overview of RF MEMS components and the reconfigurable antennas designed and produced in the Middle East Technical University using the in-house fabrication process. In [12], frequency reconfigurable antenna has been designed for three applications and characteristic was achieved by placing two diodes between the rectangular T-shaped patch and split
ring patch. In [13], band-notched ultra wide band antenna is discussed; it can switch between two nick bands and tune central frequency simultaneously. To switch the lower and upper frequency bands PIN diodes are used in the construction. When the diode state is fixed, the nick bands may transition between 4.2GHz and 5.8GHz, and when the state of the PIN diodes is ON & OFF, the tuning ranges are 4.2GHz to 4.8GHz and 5.8GHz to 6.5GHz, respectively. In [14], a compact reconfigurable slot patch antenna was proposed with the operating frequencies range of 2GHz to 6GHz for WLAN applications. In [15], proposed antenna consisting a square radiating patch with two switches and it can be operate either 2.2GHz or 2.45GHz based on the state of the PIN diodes.

2. Design Equations

To begin, basic parameters such as substrate height \((h)\), operating frequency \((f_r)\), and substrate material \((\varepsilon_r)\) must be identified.

Step1: Patch Calculations- The width of the patch affects the resonant frequency. It is defined as

\[
W = \frac{c}{2f_r \sqrt{\varepsilon_r + 1}} \tag{1}
\]

Where, \(c\) is speed of light: \(c = 3 \times 10^{11}\) mm

The length of the patch is depending on effective length and effective of \(\Delta L\)

\[
L = L_{eff} - 2\Delta L \tag{2}
\]

Where, \(L_{eff}\) is the effective length it affects the return losses and it defined as

\[
L_{eff} = \frac{c}{2f_r \sqrt{\varepsilon_{eff}}} \tag{3}
\]

\[
\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r + 1}{2} \left[ 1 + 12 \frac{h}{W} \right]^{-1/2} \tag{4}
\]

\[
\Delta L = 0.412h \left( \frac{(\varepsilon_{eff} + 0.3)(W/2 + 0.264)}{(\varepsilon_{eff} - 0.258)(W/2 + 0.8)} \right) \tag{5}
\]

Step2: Substrate Calculations

The length and width of the substrate are effects the resonant frequency and fringing effects

\[
L_g = L + 6h \tag{6}
\]

\[
W_g = W + 6h \tag{7}
\]

Where, \(h\) is the height of the substrate

\[
h = \frac{0.0606\lambda}{\sqrt{\varepsilon_r}} \tag{8}
\]

Step3: Feed Calculations

The proper selection of length and width of the feed reduce the losses in the antenna

\[
L_f = \frac{\lambda_g}{2} \tag{9}
\]

\[
W_f = \frac{L_f}{2} \tag{10}
\]

Where,

\[
\lambda_g = \frac{\lambda}{\sqrt{\varepsilon_{eff}}} \tag{11}
\]

Step4: Radiation Calculations

Position: \(-\frac{\lambda_g}{6}, -\frac{\lambda_g}{6}, -\frac{\lambda_g}{6}\)

Length: \(-\frac{\lambda_g}{6} + \frac{\lambda_g}{6} + L_g\)
3. Proposed Design
The patch is designed on the substrate with a thickness (h) of 1.6mm, relative permittivity (єr)=2.1 is the main consideration. The overall dimensions of patch width and length (W×L) of the proposed antenna is (24.09×19.73) mm. The substrate dimensions width (Wg), length(Lg) and height(h) are (Wg×Lg×h) of the antenna are (39.15×34.79×1.6) mm. The switching mechanism can be achieved by using P-I-N diodes. The proposed antenna has given the 3 slots and by using 2 switches we can operate the antenna in different frequencies. The proposed design is shown fig1.

![Figure 1. Proposed Antenna Model](image)

| S.no | Label | Dimension(mm) |
|------|-------|---------------|
| 1.   | Wg    | 39.15         |
| 2.   | Lg    | 34.79         |
| 3.   | W     | 24.09         |
| 4.   | L     | 19.73         |
| 5.   | Ls1   | 2             |
| 6.   | Ws1   | 6             |
| 7.   | Ws2   | 2             |
| 8.   | F2    | 2             |
| 9.   | F1    | 10.196        |

The diodes are used in this design are P-I-N diodes, these are used for proper biasing. When the PIN diode is ON it provides low impedance and when it is OFF it provides high impedance. Two diodes are used in the proposed model to switch from one resonant frequency to another frequency. The symbol and schematic diagram at ON and OFF conditions were shown figure 2 and figure 3.
4. Simulation Results

The antenna's electrical characteristics are shown by the parameter below. The Return loss (dB), Gain, Directivity, Efficiency, and VSWR are the main characteristics of an antenna. The VSWR figure shows how the antenna and feed line are mismatched. The efficiency of antenna characteristics shows their capabilities. The radiation pattern depicts how the antenna's energy is distributed. The other variable is the effectiveness of an antenna is determined by its directivity, which also shows the direction of the antenna's energy dispersion.

The core of an antenna design is the S11 parameters, often known as the return losses. The simulated result of Return loss (s11) i.e., Return loss plot for the diode all conditions is shown in fig.4. The curve below -10dB represents that antenna is radiating. The antenna is resonating at 5.5GHz when both switch condition is ON state and having a return loss is about -26.07dB. The antenna resonating at 2.8GHz when switch1 is off and switch 2 is on and having a return loss is about -17.31dB. The antenna is resonating at 11.02GHz when switch1 is on and switch 2 is off and having a return loss is about -15.8dB. The antenna resonating at 11.1GHz when both switches are in off state and having a return loss is about -12.75dB.
The term VSWR i.e., Voltage Standing Wave Ratio refers to how much power is radiated back. The above fig.5 shows the VSWR plots for diode all conditions. Theoretical condition states that the curve between 1 to 2 means there will be less reflections. When both the switches are in on state, the VSWR curve is at 1.43 at freq. 5.5GHz which indicates a red color. When switch 1 is off and switch 2 is on, the VSWR curve is at 1.32 at freq. 2.8GHz which indicates a green color. When switch 1 is on and switch 2 is off, the VSWR curve is at 1.31 at 11.01GHz which indicates a brown color. When both the switches are in off state, the VSWR curve is at 1.98 at 11.15GHz which indicates a sky blue color in above fig.5. The occurred VSWR plots for all diode conditions is between 1 to 2 which satisfies the theoretical statement.

The term gain of an antenna is the ability of the antenna to radiate more or less in any direction. The gain is the main parameter of an antenna for the measurement of antenna efficiency. In fig.6, the gain of an proposed antenna for all diode conditions is given. When both the switches are in on state, the
gain is 7dB. When switch1 off and switch2 is on, the gain is 5dB. When switch1 on and switch 2 off, the gain is 6.2dB. When both the switches are in off state, the gain is 5.54dB.

Figure 7. Directivity of Antenna for the diode all conditions

The term antenna directivity is defined as the ratio of radio intensity in a given direction from the antenna to the radiation intensity averaged over all directions[10]. The directivity is one of the main parameter of an antenna for the measurement of antenna efficiency. In fig.7. the directivity of an proposed antenna for all diode conditions is given. When both the switches are in on state, the directivity is 7.13dB. When switch1 off and switch2 on, the directivity is 5.48dB. When switch1 on and switch2 off, the directivity is 6.65dB. When both the switches are in off state, the directivity is 5.8dB. The term antenna efficiency is the ratio of gain to the directivity of an antenna. By taking the directivity and gain of an proposed antenna, we can calculate the efficiency of an antenna. Since the proposed antenna having 4 conditions, so there will antenna efficiency for all 4 conditions. The efficiency of an antenna when both switches are in on state is 96%. The efficiency of an antenna when switch1 off and switch2 on is 90%. The efficiency of an antenna when switch1 on and switch2 off is 92%. The efficiency of an antenna when both switches are in off state is 92%.

\[
\text{Antenna Efficiency} = \frac{\text{Gain}}{\text{Directivity}}
\]
Figure 8. Radiation Pattern of antenna for all diode conditions

Table 2. Switching Comparisons of a diode

| Switch conditions | Resonant frequency (fr) (GHz) | Gain (dB) | Directivity (dB) | Efficiency (%) | Return loss (S11) |
|-------------------|------------------------------|-----------|------------------|----------------|-------------------|
| S1-on S2-on       | 5.5GHz                       | 7         | 7.13             | 96             | -25.74           |
| S1-on S2-off      | 10.8GHz                      | 6.29      | 6.5              | 92             | -12.40           |
| S1-off S2-on      | 2.88GHz                      | 5         | 5.4              | 90             | -21.34           |
| S1-off S2-off     | 11.1GHz                      | 5.5       | 5.8              | 92             | -13.42           |

The above table 2 gives the summary and comparison of all the diode conditions i.e., both on, both off, on & off and off & on. When both switches are on produces the maximum gain compared to the remaining switching conditions.

TABLE 3. Comparison With Few References

| S.NO | Resonant Frequency (fr) (GHz) | Gain (dB) | Directivity (dB) | Efficiency (%) | Type of substrate ($\epsilon_r$) | No. of pin diodes | Feeding type   |
|------|------------------------------|-----------|------------------|----------------|--------------------------------|------------------|---------------|
| 1    | 3.5 (both on) 3.1,3.9 (on-off) 2.9,3.8 (off-on) 2.6,3.8,3.9 (both off) | 7.29 (both off) 7.04 (both on) | 7.43            | 90             | Roger RT/Duro id 5880 (2.2) | 2                | Inset feed line |
| 2    | 2.3,4.5 (All off) 2.6(on,off,off) 5.4(All on) | 2.3,2 (All off) 2.2 (on,off,off) 5.3 (All on) | 2.3,3.45 (All off) 2.25 (on,off, off) 5.43 (All on) | 70,72,80          | FR4                     | 3                | Stepped feed line |
Table 3 gives the comparison of the study that we have done on different papers. Our proposed design model has been compared with few References and is listed in table 3. By observing the listed comparisons, the proposed model gave better results and the efficiency is also approximately 95 %, the gain is approximately 7dB.

5. Conclusion
The antenna reconfiguration is attained by using pin diodes. In the proposed design, we used two switches by observing different switching conditions we attained multiple frequencies such as 5.5 GHz, 10.8GHz, 2.8GHz, and 11.1GHz with better gain, directivity & efficiency. The efficiency of the proposed model is 96%, 92%, 90% and 90% at different states of the switch. Table 2 shows the comparison of all the possible conditions of switches and table 3 gives the comparison with few references. The proposed antenna covers the S, C&X band application which covers the broadband services & satellite communication.

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