A compact reconfigurable slotted microstrip patch antenna using pin diode for wireless applications

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Abstract. A compacted (44 x 44 x 3.2 mm$^3$) frequency reconfigurable microstrip antenna that uses electrical switching with PIN diodes is proposed for WiMAX (3500 MHz- 3910 MHz) and high frequency LTE (3500 MHz and 2600 MHz) band. The rectangular microstrip patch was at first designed to operate at the frequency of 3500 MHz as a central frequency and then reconfigured using two electrical PIN diodes placed symmetrically on slot etched at the end of the patch surface to cover further desired frequency applications. For state 1 ($S_1 = ON, S_2 = ON$), the designed antenna operates solely 3500 MHz suitable for both domestic LTE and WiMAX. For state 2 ($S_1 = OFF, S_2 = OFF$), the antenna covers further 2600 MHz for LTE and (3850 MHz – 3910 MHz) for WiMAX. The proposed antenna is designed and simulated using HFSS licensed software. Simulation results show the max gain produced by the antenna is 7.4 dBi with a radiation efficiency of 98% and a maximum bandwidth of 180 MHz.

1. Introduction

There is an evolutionary tendency in Wireless Communication Systems (WCS) that requires the use of antennas capable of accessing services in several frequency bands, sometimes with the utilization of a single antenna [1]. The antennas capable of that are known as Reconfigurable antennas [2].

Reconfigurable antennas have managed to grab the attention of researchers as a way to overcome the drawbacks and deficiencies of traditional antennas by providing the capability to operate multiple frequencies for multiple services on single antenna terminal, thus paving the way to become an alluring feature in the present day WCS [3]. To reconfigure generally signifies arranging parts of something to attain objectives [4].

To achieve Re-configurability, RF MEMS, diodes, attenuators, or tunable materials [5] are often used. By orienting the state of these switches embedded in the antenna, the frequency band can selectively be achieved [6]. For instance, when the switch is in the off state, the antenna operates one frequency band, and when it is in ON state the antenna operates another frequency band [7]. MEMS tunershave been used for wireless applications due to their promising merits of adequate isolation and linearity [8]. However, one of the drawbacks is that they need high DC propulsion voltages not to mention slow switching [9]. To overcome such drawbacks, RF PIN diodes due to their promising advantage of fast switching, easy realization, high current handling capability, and low cost have recently been used to reconfigure the antenna frequency for wireless applications [10].

Therefore, in this research paper, a switchable- frequency microstrip patch with switchable slot antenna is presented. The proposed antenna comprises a radiating patch and a slot in the patch plane. The patch is designed to produce a radiation that is shapely omni-directional, while the slot embedded with RF
2. Design and Configuration

This section presents the geometry structure of the proposed reconfigurable slotted antenna. Figure 1 illustrates the structural geometry of the designed reconfigurable microstrip patch antenna. The antenna is designed on Roger RT/Duroid 5880 substrate with dielectric constant ($\varepsilon_r$) 2.2, loss tangent of 0.0009, and a thickness of $h = 3.2\text{mm}$. With the help of the mentioned parameters, Length, Width, feedline, slot, and matching system parameters were calculated. Thus, the patch size is of $24.34\times30.88\text{mm}^2$ at the frequency of $3.5\text{GHz}$. Inset feedline was used due to its susceptibility to bandwidth improvement. The length of the inset transmission line is $l_f = 21\text{mm}$ and width of with it dimensions of $W_f = 2.99\text{mm}$ and inset gap $G$ of $g = 1.482\text{mm}$. To obtain the desired results of the design, the dimensions have been further optimized using the trial and error method. To achieve the compact factor, the antenna was miniaturized using small slots on the antenna sides. Furthermore, the reconfigurability of the antenna was achieved by cutting slot at the back of the radiating patch with the dimensions of $24.34\times30.88\text{mm}^2$.

Subsequently, Two BAP65-02,115 pin diode models were placed at corners of the slot as Figure 2 shows. In ON state, both the switches were fed forward biased resistor $R_s = 1\text{ohm}$ and parasitic inductance of $L_{pr} = 0.6\text{nH}$. In OFF state, the switches were fed inverted biased resistor $R_p = 20\text{kohm}$ and a reversed biased parasitic capacitance $C_t = 0.5\text{pF}$. Capacitor of $1\mu\text{f}$ was also used as DC blocker. In OFF state, the switch acts as an isolator and blocks current passing through the switch. However, in ON state, the patch radiates and is properly grounded and resonates at $3.5\text{GHz}$. Through this operation, the antenna reconfigures its frequency from one band to another without any change to the dimensions. All expected switch states can be seen in table 2.

After much optimization, the overall size of the proposed compact reconfigurable microstrip patch antenna is $44.09\times44.09\times3.2\text{mm}^3$. switch provides switchable frequency functionality. The designed antenna is designed to have the capability to reconfigure between eight different bands ranging from 2.6 to 3.91 GHz using two RF PIN diode switches positioned in the slot, thus covering various wireless applications. The size of the antenna is comparatively small with dimensions of $(44 \times 44 \text{mm}^2)$. The antenna is simulated using HFSS licensed version and the details of the design are described in below sections. The simulated results are demonstrated, and the performance of the antenna based on certain criteria is investigated.
Figure 1. Geometry of the designed antenna (a) side view and (b) front view.

Table 1. Calculated dimension of the proposed antenna

| Parameter                  | Symbol | Values       |
|----------------------------|--------|--------------|
| Resonant Frequency         | $f_r$  | 3.5GHz       |
| Length of patch            | $L_p$  | 24.34mm      |
| Width of patch             | $W_p$  | 30.88mm      |
| Thickness of a substrate   | $h$    | 3.2mm        |
| Relative dielectric constant | $\varepsilon_r$ | 2.2         |
| Resistance at the edge     | $R_{bi}$ | 156.25Ω     |
| Inset feed length          | $L_f$  | 19mm         |
| Feed width                 | $W_d$  | 2mm          |
| Inset gap                  | $G$    | 1mm          |
| Ground length              | $L_g = L_s$ | 44.09mm  |
| Ground width               | $W_g - W_s$ | 44.09mm  |
| Width of the slot          | $W_{slot}$ | 24mm       |
| Thickness of the slot      | $H_{slot}$ | 1.2mm     |
| Resistance in Forward biased | $R_w$  | NA          |
| Parasitic Inductance       | $L_{pi}$ | NA         |
| Resistance in reverse biased | $R_p$  | NA          |
| Capacitance in Reverse biased | $C_{r}$  | NA          |
| DC block capacitor         | $C_d$  | NA          |
The proposed antenna is simulated using a licensed version of ANSYS’s High Frequency Electromagnetic field simulation (HFSS). The obtained results are tabulated and discussed in the below sections.

3. Result and Discussion

The proposed reconfigurable antenna is designed and simulated. Figure 1 illustrated the designed antenna. Respectively, the return loss results are provided in Fig. 3 while fig. 4 shows the VSWR for all modes in the antenna. As the two figures show, the return loss for the all achieved frequencies are below -10dB. it can be noted that the highest return loss is recorded as -26.6dB at the frequency of 3.91GHz and the lowest of -7.5dB at the frequency of 2.60GHz. The effects of the parasitic of the structural geometry of the antenna changes in OFF state. While in ON state, the antenna resonated exactly at 3.5GHz. The proposed antenna has the capability to switch at eight different bands. The achieved bands and their corresponding bandwidth are tabulated in table. 3.

VSWR of all achieved bands were recorded lower than 2 except at 2.6GHz. This shows the proposed antenna is having a good match and that much of the power is radiated.

The obtained gain against frequency is presented at fig. 5. The maximum achieved gain is 7.29dB when the antenna is at OFF-OFF state. The lowest realized gain was recorded as 7.04dB when the antenna is operating at ON-ON state. Correspondingly, a maximum directivity of 7.43dB was achieved which is slightly higher than the gain due to directivity not taking into account the efficiency of the radiation.

The radiation pattern of the antenna was also plotted and presented in fig. 6 with clear representation of Electric field and magnetic field. From the figure, Omni-directional pattern was obtained at all states with state F1 has the optimal one. Hence, giving the proposed the characteristic of linear and circular polarization. Since the antenna was aimed to be used in smart phones, Omni-directional pattern came out as the most desired pattern. The Achieved overall efficiency of the simulated antenna is 98%.
Table 3. Simulation Result of the designed antenna

| Switch Modes | Operating Frequencies | Return Loss | Bandwidth | VSWR |
|--------------|-----------------------|-------------|-----------|------|
| ON-ON mode   | 3.5 GHz               | -21dB       | 140MHz    | 1.2  |
| ON-OFF mode  | 3.10 GHz 3.90 GHz     | -25.26dB    | 116MHz    | 1.4 1.13 |
| OFF-ON mode  | 2.95 GHz 3.85 GHz     | -25dB       | 132MHz    | 1.11 1.5 |
| OFF-OFF mode | 2.6 GHz 3.85-3.91 GHz | -26.6dB     | 186.5MHz  | 1.18 1.13 |
4. Conclusion

A compacted frequency-switchable slotted microstrip patch antenna has been explained in this paper. The designed antenna has the capability to reconfigure up to eight different bands ranging from 2.60 to 3.91GHz, thus suitable for quite number of wireless applications including LTE and WiMAX. Maximum gain and directivity of 7.30dB and 7.43dB and maximum bandwidth 186 MHz. An Omni-directional radiation pattern was achieved in all states. This further strengthened the use of the antenna in smartphones.

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