Narrowband to Narrowband Frequency Tunable Slotted Dipole Antenna

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Abstract. In this paper, the slotted dipole antenna structure is proposed to have four narrowband frequencies with ability to be reconfigured. Narrowband reconfiguration can be achieved by controlling the length of slotted dipole by using switches. The narrowband frequency is to be at 1.8 GHz (GSM), 2.4 GHz (WLAN), 2.6 GHz (4G), and 3.5 GHz (5G) respectively. The longest dipole length produced 1.8 GHz, the second-longest dipole length produced 2.4 GHz, the third-longest dipole length produced 2.6 GHz, while the smallest dipole length produced 3.5 GHz. To maintain the stability of the RF current in the system, sixteen capacitors were used. As well eight inductors were used to isolate the RF current and power supply. The PIN diode was used as a switch to allow the induced current to stop and pass into the slot which means that it can be used to select the desired frequency. Depending on switching configuration, the operating frequency is tuned. Good matching is achieved for all configurations. The simulated result of gain for the four operating is higher than 2 dB while the omnidirectional radiation pattern has been obtained thus makes the proposed antenna suitable for wireless application.

Keywords: Frequency tunable antenna, slot antenna, dipole antenna, PIN diode

1. Introduction

In this age of globalization, the development of the communication system is changing rapidly over the years. Therefore, the reconfigurable antenna has been introduced as this type of antenna can cover various operating frequencies in a single terminal [1]. The reconfigurable antenna functions to accommodate different telecommunications networks over a broad frequency range. For a growth development in mobile communication, there is a need for a new approach in terms of antenna design, reconfiguration antenna, and switching mechanism. This is because modern mobile communications system often include multiple radio transceivers operating at different frequencies [2] is need a lot of innovation. The other types of reconfigurable antenna are radiation pattern, bandwidth, and polarization which is reported in [3]. Therefore, a frequency reconfigurable antenna is chosen for this project as it can cover a variety of different frequencies and beam widths based on a single radiating element [2]. Frequency reconfigurable antenna provides a single, lightweight antenna which gives diversity in having the characteristic of wideband, narrowband, and even multiple bands [4], [5].

The switching mechanism can be achieved by using a pin diode or a microelectromechanical radio frequency (RF-MEMS) system, whereas the variable reactive loading mechanism can be worked using the varactor or capacitance [6], [7]. Research on this type of antenna has been documented using dual-band antenna at 1.5GHz, tri-band antenna at 3.5 GHz, and broadband antenna at 2.47 GHz. [8] is proposed to operate at one frequency at one time.

Some of the papers also proposed a multiband design to support various applications [9], [10]. Therefore, there will be several designs to support the applications. Because a single antenna single band will make the work harder as needed to design new structures each time thus will increase the size of the structure. Also, there is a high-frequency mode that interferes with the operation of the system and may, therefore, require a filter circuit at the output. Thus, the slotted dipole antenna designed is suitable because it is a single band antenna that can support various applications. Moreover, this type of antenna can solve the problem of co-site interference [6].

Narrowband antenna can also be implemented by combining a dipole antenna and slot antenna to be able to generate the desired frequency bands. The design of narrow band frequency reconfigurable antenna has been widely investigated. Reference [11] proposed to use the Koch dipole antenna to control the effective radiating length. However, the number of switches used is 50 thus increases the size of the antenna and measurement period.

Thus, in this project the frequency reconfigurable antenna was configured either by switching in and out some parts of the antenna or by adjusting the effective length of the antenna, respectively to switch and tune the operating bands by using the switching method of the PIN diode. This PIN diode is chosen for this project due to fast switching frequency, low cost, more reliable, and high power handling capability other than other switching methods [5], [7], [12], [13].

2. Antenna design and reconfigurations.

In this section, the design of the proposed antenna is described in detail. The antenna is designed on an FR-4 substrate with a relative permittivity (ε_r) of 4.3 and a thickness (*h*) of 1.6 mm. The size of the substrate is 90 mm × 60 mm. The switch used is a BAR50-02V PIN diode. The S2P of the BAR50-02V diode from the manufacturer's and incorporated on the simulation to represent the presence and absence of the diode.

Figure 1 describes the antenna structure and the biasing network and mechanism for the control of switches of the antenna. On the ground layer, the antenna consists of dipole slot, with length is extended vertically for compactness, based on a design proposed in [2]. These two arm slots are connected to the coplanar waveguide transmission line, with a larger rectangular box in the middle which acts as a balun to achieve a stable and better impedance.

The dipole arms at the corresponding resonant frequency are approximately half-a-wavelength long. The longest dipole arm is 35 mm long which is about half a wavelength at 1.8 GHz. The second-longest dipole arms are 25.5 mm in length while the third and fourth longest dipole arms are 23.8 mm and 14.4 mm in length. To achieve the best results, a computer simulation tool was used to optimize the values of all the geometrical parameters. The CST software is used to simulate the designed antenna.

The implementation of the ideal diode for reconfiguration proof of concept has been designed for the initial design of the antenna at each operating frequency. Then, the actual three pairs of pin diode switches are then inserted into the antenna. The function of the six-pin diode is to switch to the OFF state and ON state to obtain the four modes reconfigurable configuration. The antenna structure is modified by integrating a biasing circuit into the structure for activating and deactivating the diodes. Each capacitor acts as a DC block while each of the inductors acts as an RF choke. To have a smooth flow of RF current between the radiating ground and allow the biased DC to pass through, six biasing lines are mounted at the ground region with sixteen RF capacitances with a value of 100 pF.

Meanwhile, eight RF inductors with a value of 27 nH are positioned in between the biased wire and the ground plane of the dipole antenna to isolate the RF current to flow to the DC bias axis. A series of 0.3 mm slits are inserted into the ground plane. These slits act as a way to isolate the bias voltages applied from each other to the different switches. The pin-diode are denoted D2, D3, D4, D5, D6 and D7. These pairs of diodes are located along with dipole arms. Table 1 shown the configuration of the switch for the frequency reconfigurable operation of the slotted dipole antenna.

The geometric parameters of the antenna being proposed is as follows (all units are in mm): *Ws* = 90, *Ls*= 60, *h*= 1.6, *Ht* = 0.035, *g*= 0.5, *k*= 19, *m*= 13, *n*= 5, *L1*= 1, *L2*= 25.5, and *L3*= 9.5).

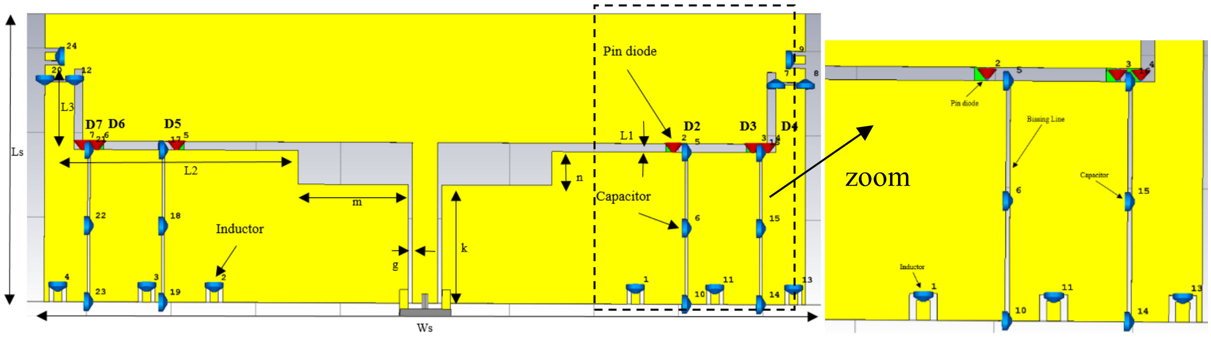


Figure 1: Geometry of the proposed antenna (a) front view (b) back view

Table 1 . Narrowband to Narrowband switch configuration

Frequency	State of switch					
	D2	***D3***	***D4***	***D5***	***D6***	***D7***
1.8 GHz	0	0	0	0	0	0
2.4 GHz	0	0	1	0	0	1
2.6 GHz	0	1	0	0	1	0
3.5 GHz	1	0	0	1	0	0

*1 = ON
*0 = OFF

3. Result and discussion

Figure 2 illustrated the simulated reflection coefficient result where the implementation of pin diode had been done for the designed reconfigurable antenna. The black line represented the longest dipole arms where the all states are in OFF states. It radiates at 1.8 GHz. Next, is the red line that represented the second longest dipole arm where the D4 and D7 are in ON states and the other are in OFF states. It radiates at 2.4 GHz. The blue line represented the second shortest dipole arms where the D3 and D6 are in ON states and the others are in OFF states, it radiates at 2.6 GHz. At last, the pink line represented the shortest dipole arms where the D2 and D5 are in ON states and the others are in OFF states. Thus, it radiates at 3.5 GHz. It is observed that a good impedance matching was achieved for all switch configuration as all value of the reflection coefficient is above -10 dB.

Figure 3 shown the simulated current distribution associated with the reconfigurable antenna. This figure illustrated the current distributions at four different frequencies. From the figure can be seen that the currents path traveling along the dipole arms. Figure 3(a) indicates that the current distributed mainly along the longest arm at a low frequency which is at 1.8 GHz. At the middle range frequency, the current highly flows until the edge of dipole arms that indicated the frequency of 2.4 GHz as shown in Figure 3(b). Next, the current flow for the second middle frequency which is 2.6 GHz shown the most highly current flow on slotted dipole antenna as shown in Figure 3(c) whilst for the current distribution of high frequency is likely to flow along with the dipole antenna as shown in Figure 3(d).

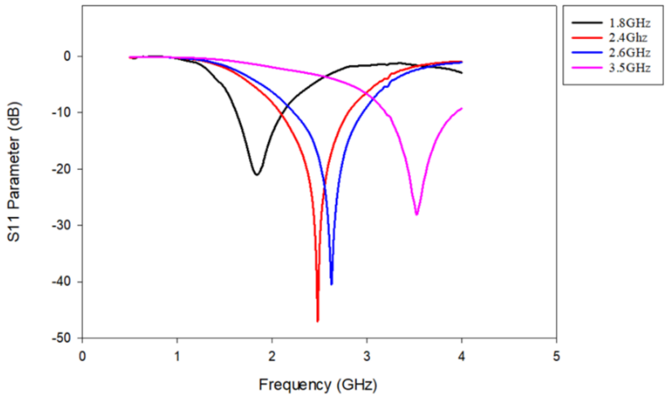


Figure 2: Simulation Result of S11 at 1.8 GHz, 2.4 GHz, 2.6 GHz, and 3.5 GHz

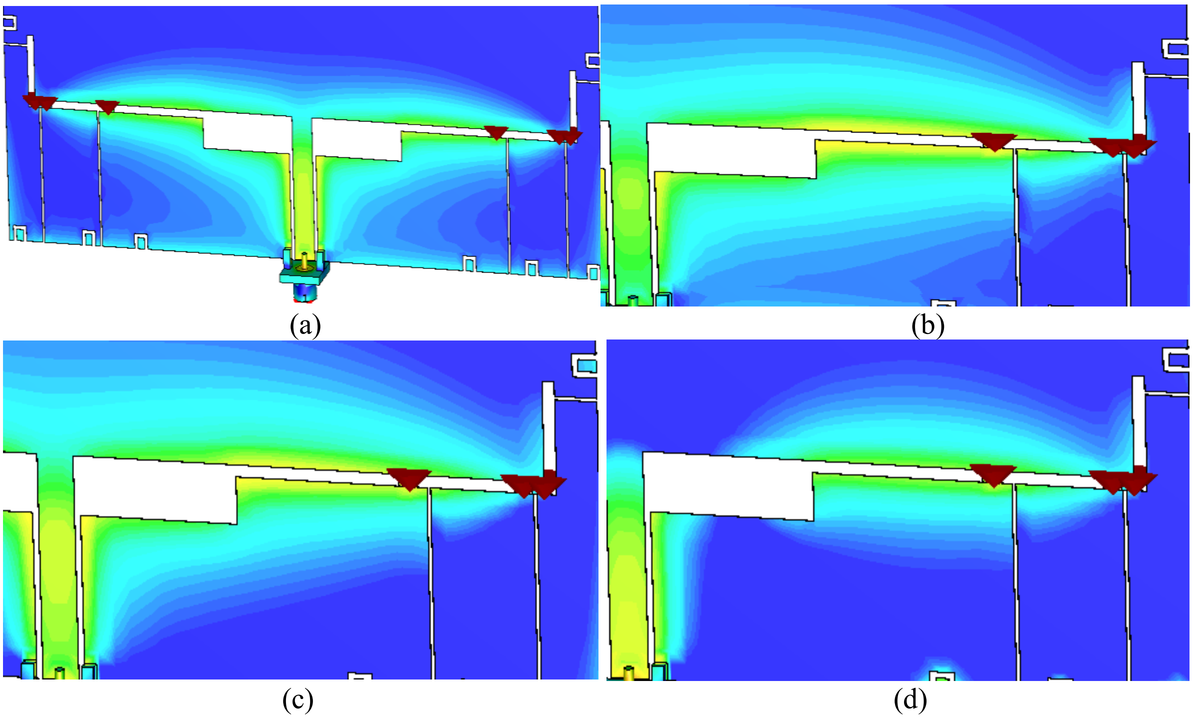
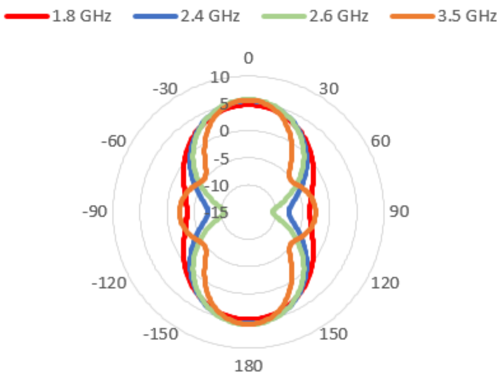


Figure 3: Simulated current distribution for reconfigurable antenna (a) overall view at 1.8 GHz (b) 2.4 GHz (c) 2.6 GHz (d) 3.5 GHz



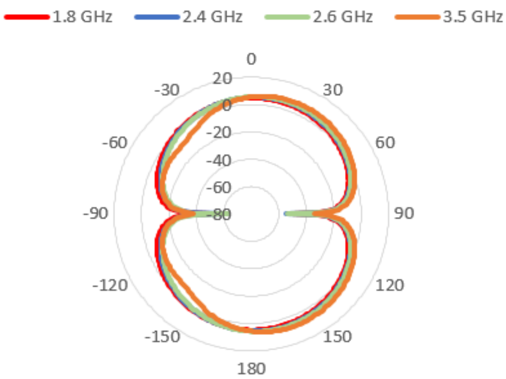


Figure 4: Simulated radiation pattern of Y-Z plane **Figure 5**: Simulated radiation pattern of X-Z plane

The radiation pattern of the Y-Z plane and X-Z plane are presented in Figure 4 and Figure 5. The trends were at 1.8 GHz, 2.4 GHz, 2.6 GHz, and 3.5 GHz. It is expected the radiation pattern of the dipole where in the Y-Z plane which is E-plane shown the typical shape of eight shape whereas the radiation pattern in the X-Z plane which is H-plane shown almost the doughnut-shaped for the four narrowband frequency. These simulated results were justified for the omnidirectional radiation characteristic of a dipole antenna. The better omnidirectional antenna, the more suitable to transmit signals in complex scenes [14]. Thus, it is observed that the length of dipole arms radiated. Apart from that, these findings shown that, in terms of their form, radiation patterns correspond to different states with the same frequency are very similar. Thus, a good simulation of the radiation pattern has been achieved.

The simulated total efficiency and gain at all narrowband frequencies are shown in Table 2. At 2.6 GHz, the simulated gain is 5.783 dB higher compared to other narrowband frequencies. It is observed that the gain of the four operating frequencies is above 2 dB which justified the specification of the proposed antenna. For first configuration, the total efficiency has the highest efficiency which is 91.4% compared to other operating frequencies. The efficiency is different for the frequency bands due to the position of PIN diode placing in the antenna as well as mismatch caused by copper stripes. Overall, the three operating frequency which is at 1.8 GHz, 2.4 GHz and 2.6 GHz has achieved a quite high efficiency which shows the proposed antenna is suitable for wireless application.

The result of efficiency is differed from one configuration to another. This is expected as the matching (S_{11} value) is different. Referring back to result presented in Figure 2, a good matching with reflection coefficient value of -40 dB is achieved for 2.4 GHz and 2.6 GHz. This reflects the good radiation efficiency of these configurations and consequently produced good gain value. The result is vice versa for configuration 1.8 GHz and 3.5 GHz. The comparison of the proposed antenna and other reported work is given in Table 3. This shows that this project achieved some good performance than the existing work in terms of less complexity with good performance.

Table 2 . Simulated efficiency and gain for frequency reconfigurations

Frequency (GHz)	**Total efficiency (dB)**	**Total efficiency (%)**	**Gain (dB)**
1.8	-2.451	55.7	2.2
2.4	-0.4488	90.2	5.3
2.6	-0.3914	91.4	5.8
3.5	-4.564	40.0	3.2

Table 3 . Comparison of the proposed antenna and other reported work

Ref	**Antenna Structure**	**Frequency switching**	**Type of switches**	**Number of switches**
[1]	Slot dipole antenna	Mode 1: 2.00 GHz– 2.40 GHz Mode 2: 2.68 GHz – 3.50 GHz Mode 3: 3.53 GHz – 5.27 GHz	Varactor diode	6
[2]	Slot dipole antenna	Mode 1: 2.4 GHz Mode 2: 3.5 GHz Mode 3: 5.2 GHz	PIN diode	6
[11]	Fractal dipole antenna	Mode 1; 691 MHz – 1880 MHz Mode 2: 725 MHz – 2350 MHz & 3010 MHz	Ideal switches (Metal patch)	28
[15]	Slot dipole antenna	1.5 GHz – 4.5 GHz	Varactor diode	4
Proposed in this article	Slotted dipole antenna	Mode 1: 1.8 GHz Mode 2: 2.4 GHz Mode 3: 2.6 GHz Mode 4: 3.5 GHz	PIN diode	6

4. Conclusion

Narrowband to narrowband frequency reconfigurable antenna has been designed and simulated. The operation of narrowband to narrowband frequency reconfigurable antenna contains slotted dipole antenna that integrates the pair of dipole arms in the ground plane. The design begins with the use of copper strip as a switch for proof of the concept. Modification were made to the design to enable the use of actual switches which are PIN diode and switching network. As the number of pin diodes is fewer, the complexity of the biasing network and cost is reduced. Based on the simulation result, the slotted dipole antenna is operated at 1.8 GHz, 2.4 GHz, 2.6 GHz, and 3.5 GHz. From the analysis can be seen that the radiation pattern is in omnidirectional pattern with good value of gain. Overall, the usefulness of providing different operating frequencies makes the proposed antenna ideal for use in electronic devices that will operate in several frequencies.

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Acknowledgments

Authors thanks Universiti Malaysia Perlis, Universiti Teknologi Malaysia, Universiti Teknikal Malaysia Melaka, Universiti Tun Hussein Onn Malaysia and Research Management and Innovation Centre for the support of the research work under collaborative research grant 9023-00003.