Progress In Electromagnetics Research, Vol. 144, 319–328, 2014

Frequency Reconfigurable Microstrip Patch-Slot Antenna with Directional Radiation Pattern

Huda A. Majid, Mohamad K. A. Rahim*, Mohamad R. Hamid, and Muhammad F. Ismail

Abstract—In this paper, frequency reconfigurable slot-patch antenna with reflector at the back of an antenna is presented. The proposed antenna consists of a microstrip patch antenna and a microstrip slot antenna where the slot antenna is positioned at the ground plane underneath the patch. Three switches are placed in the slot. The antenna is capable to reconfigure up to six different frequency bands from 1.7 GHz to 3.5 GHz. The microstrip patch antenna produces three different frequency bands with directional radiation pattern while the microstrip slot antenna produces another three frequency bands with bidirectional radiation pattern. Due to the reflector placed at the back of the antenna, the radiation pattern is directional at all frequency bands. Simulated and measured results are used to demonstrate the performance of the antenna. The simulated and measured reflection coefficients and radiation patterns are presented and compared.

1. INTRODUCTION

Reconfigurable antenna is an antenna that capable to reconfigure its characteristics such as frequency, pattern, bandwidth, and polarization to adapt to the environment. The reconfiguration is not limited to a single characteristic but can be a combination of different characteristics depending on the application. Recently, frequency reconfiguration has attracted significant attention due to the introduction of future wireless communication concept such as cognitive radio which employs wideband sensing and reconfigurable narrowband communication [1]. Moreover, frequency reconfigurable antennas have the potential to reduce the size of front end system and allow pre-filtering at the receiver. Thus, it can support many wireless applications in one single terminal system.

As describe in [2], the idea of reconfigurable antenna appeared in early 1930s. In 1979, a pattern reconfigurable antenna was designed for satellite communication [3]. The proposed antenna is capable to reconfigure six different beam angles. A pattern reconfigurable antenna with multi-beam reconfiguration for satellite communication has also been reported in [4]. In 1999, a reconfigurable leaky patch antenna using PIN diode was presented in [5]. From 1999 until the present day, microstrip antenna has been used as a platform to design reconfigurable antenna [6–12].

Generally, the resonance of antennas, such as dipole antennas, monopole antennas, loop antennas, slot antennas and microstrip antennas, is determined by the effective length of the radiator. The effective length of an antenna plays an important role in determining the operating frequency. In this case, frequency reconfiguration can be achieved by controlling the effective length of an antenna. There are a few methods of controlling mechanisms that can be used to achieve frequency reconfiguration. The effective length of an antenna can be changed by adding or removing part of the length by using electronic switches. Nowadays, electronic switches, such as PIN diodes, FETs and RF MEMS, are commonly used

Received 29 October 2013, Accepted 13 December 2013, Scheduled 3 February 2014
* Corresponding author: Mohamad Kamal Abd Rahim (mkamal@fke.utm.my).
The authors are with the Communication Engineering Department, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, Skudai, Johor 81310, Malaysia.

for frequency switching. Although RF MEMS has many advantages, PIN diode is favourable to many researchers as it has acceptable performance, low cost and ease of fabrication. For instance, in [13], PIN diodes are placed on the fractal dipole antenna to produce tunable frequency bands. A similar approach for slot antenna is also reported in [14]. The usage of RF MEMS to achieve frequency tuning has been reported in [15, 16]. Another way to change the resonant frequency is by using variable reactive loading (typically capacitance) such as varactor diodes. It allows smooth frequency changes with the changes of capacitance value. The disadvantage of using varactor diodes is the limited frequency range switching. An H-shaped antenna with frequency selectivity using varactor diode has been presented in [17]. Similar approach has also been reported in [18]. Structural or mechanical changes can also be used to deliver larger frequency shifts. The main challenge of using this method lies in the physical design which is the size of the antenna and the actuation mechanism including its maintenance. These types of antennas have been reported in [19].

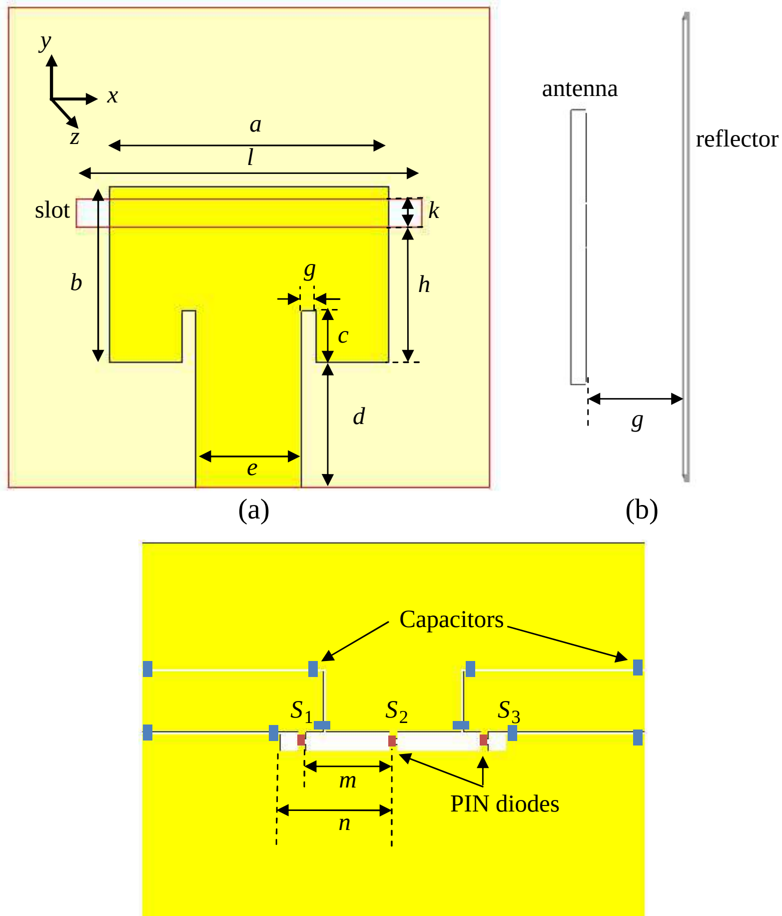
Microstrip slot antenna has the potential to be a better candidate for frequency reconfiguration because it offers wide frequency range tuning and the conveniences of tuning the resonant frequency with switches of varactors across the slot. A combination of PIN diode and varactor diode is used in [20] where a reconfigurable slot antenna is capable to reconfigure up to nine frequency bands. The antenna is capable to switch between two modes which are the standard and half-slot mode. The standard mode operates when the PIN diode is switched on and varactor diode tuned to give five different frequency bands from 0.8 GHz to 1.48 GHz. The half-slot mode operates when the PIN diode is switched off and the varactor diode tuned to give four different frequency bands from 0.42 GHz to 0.96 GHz. Similar approach has been reported in [21] where a microstrip slot antenna is capable to reconfigure four different frequency bands in the range of 0.54 GHz to 0.95 GHz. Four PIN diodes are used to tune the length of the slot thus provides four different frequency reconfigurations. PIN diodes are used in [22] where the antenna is capable to switch between 2.4 GHz and 2.9 GHz. By using two PIN diodes, the designed antenna is capable to operate in two modes. The first mode is the right-side radiated mode (RR mode), and the second mode is the left-side radiated mode (LR mode). The antenna has limited frequency reconfiguration where the RR mode operates at 2.4 GHz while the LR mode operates at 2.9 GHz.

In this paper, the detailed design and analysis of frequency reconfigurable slot-patch antenna with reflector is presented. The proposed antenna is a combination of a microstrip patch and slot antenna. The slot is positioned at the ground plane underneath the patch. Three switches are used to reconfigure six different frequency bands. The microstrip patch antenna produces three reconfigurable frequency bands while the slot produces another three frequency bands at the lower frequency region. In order to produce directional radiation pattern at all frequency bands, a reflector is installed at the back of the frequency reconfigurable slot-patch antenna [23]. The simulated and measured results of those antennas are presented and compared.

2. ANTENNA DESIGN AND OPERATION

The proposed antenna is described in this section. The design starts with a microstrip patch antenna where Figure 1(a) demonstrates the geometry of the design with a slot inserted at the ground plane. Taconic RF35 with a permittivity of 3.5 and substrate thickness of 3.04 is used for the antenna design. The dimension of the antenna is tabulated in Table 1. The patch of the antenna is designed to operate at 4.13 GHz. Inset feed is used to match the impedance between the patch and the transmission line. Proper impedance matching produces the best return loss at the wanted frequency. A slot is then introduced in the ground plane where it is positioned underneath the patch. In order to obtain the best return loss at the resonant frequency, the positions of the slot (h) and inset feed (c) are optimized.

The resonant frequency of the antenna is 4.13 GHz while with the introduction of the slot in the ground plane, the resonant frequency is shifted to the lower frequency region at 2.24 GHz. The length of the slot is approximately $0.5\lambda_g$ at 2.24 GHz. In this case, λ_g is to be considered, as the patch is almost covering the slot where the substrate acts as a cavity to the slot. The reflection coefficient for both antennas are below -10 dB. The radiation pattern of the antenna is shown in Figure 2 while Figure 3 shows the radiation pattern of the antenna with slot in the ground plane. As predicted, the radiation pattern for the microstrip patch antenna is directional in pattern. Meanwhile, the introduction of slot at the ground plane produces a bidirectional radiation pattern. From the explanation above, with the



(c)

Figure 1. Geometry of the proposed antenna, (a) front view, (b) side view, and (c) back view of the proposed antenna.

Table 1. Dimension of the designed antenna.

Parameters	Dimension (mm)
a	29
b	18.3
c	6.4
d	13
e	9
g	1.5
h	14.05
k	3
l	36
m	14
n	18

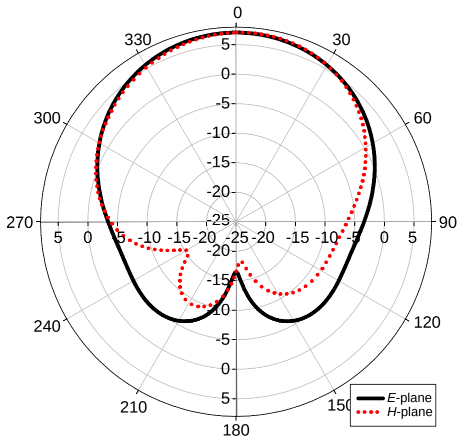


Figure 2. Simulated radiation pattern of the microstrip patch antenna.

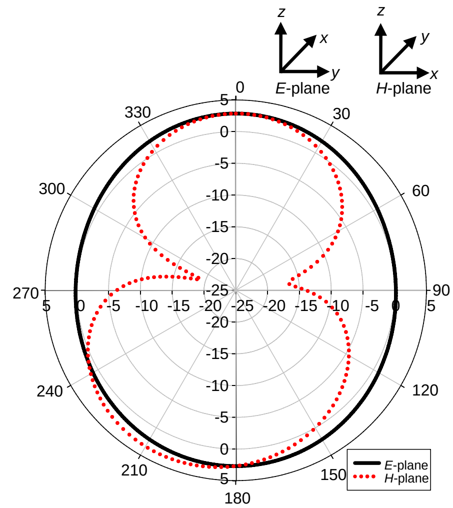


Figure 3. Simulated radiation pattern of the microstrip patch antenna with slot inserted in the ground plane.

insertion of the slot in the ground plane of the microstrip patch antenna, the slot acts as the radiator while the patch acts as the feeding network. With this idea, by positioning switches in the slot, frequency reconfiguration can be achieved.

Subsequently, three PIN diodes are positioned in the slot in order to obtain frequency reconfiguration. Due to the different radiation patterns obtained at the higher and lower frequency bands, a reflector is placed behind the antenna to produce directional radiation pattern at all frequency bands. PIN diode S-parameter representative is used in the simulation.

The proposed antenna is designed to operate at six reconfigurable frequency bands with directional radiation pattern. An aluminium plate is used as the reflector in order to provide directional radiation pattern. Figure 4 shows the structure of the proposed antenna. The size of the antenna is 80 mm × 60 mm, and the size of the reflector is 122 mm × 102 mm. The patch antenna resonates at 4.13 GHz. Meanwhile, the slot length is 36 mm which is approximately $0.5\lambda_g$ of 2.24 GHz. The patch size is $a = 29$ mm × $b = 18.3$ mm. The inset feed has a width of $c = 1.5$ mm and height of $d = 6.4$ mm. Meanwhile, the length of feed line is $e = 13$ mm where the width is 9 mm. The gap between the antenna and the reflector is $g = 33$ mm. The lengths of k and l are 13.95 mm and 18 mm, respectively. The gap between the reflector and the antenna is optimized where the gap is quarter free-space wavelength, $0.25\lambda_o$ of F_2 as the antenna is resonating at the middle frequency of the slot mode. Table 2 tabulates the switch configurations and resonant frequency of the proposed antenna. From observation, the simulated

Table 2. Switch configuration and resonant frequency of the proposed antenna.

Frequency	S_1	S_2	S_3	Simulated proposed antenna (GHz)	Measured proposed antenna (GHz)
F_1	0	0	0	2.19	1.82
F_2	0	0	1	2.35	2.05
F_3	1	0	1	2.55	2.32
F_4	0	1	0	3.1	3.02
F_5	0	1	1	3.25	3.2
F_6	1	1	1	3.5	3.5

* 1 = ON, * 0 = OFF.

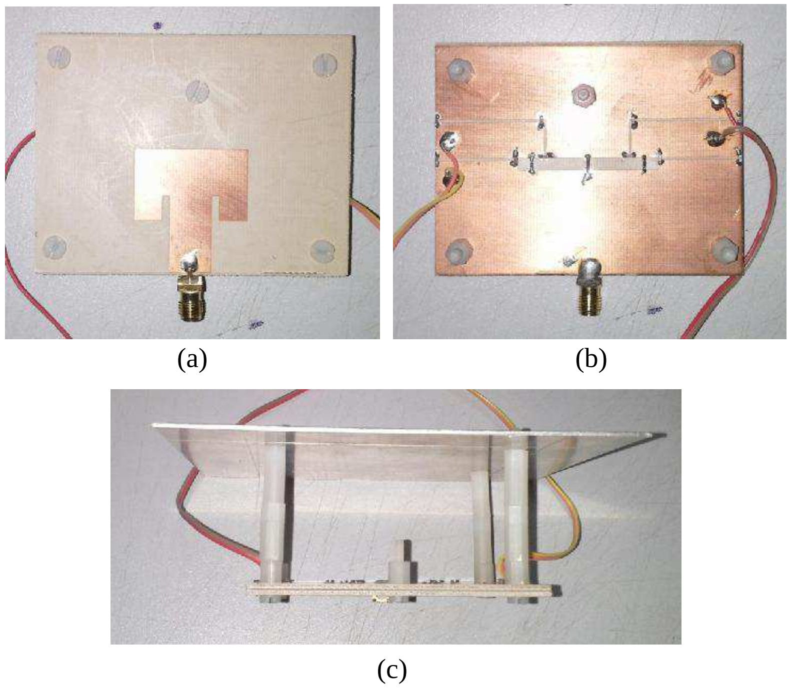


Figure 4. Fabricated antenna where (a) front view, (b) back view (without reflector), and (c) side view of the antenna.

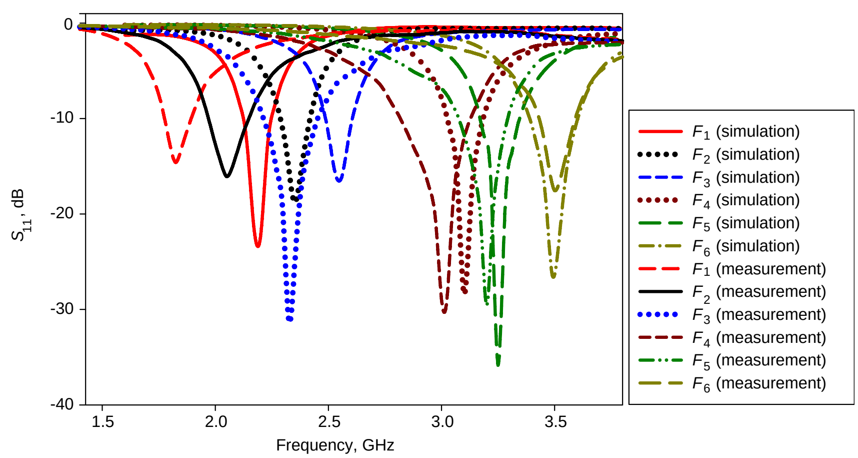
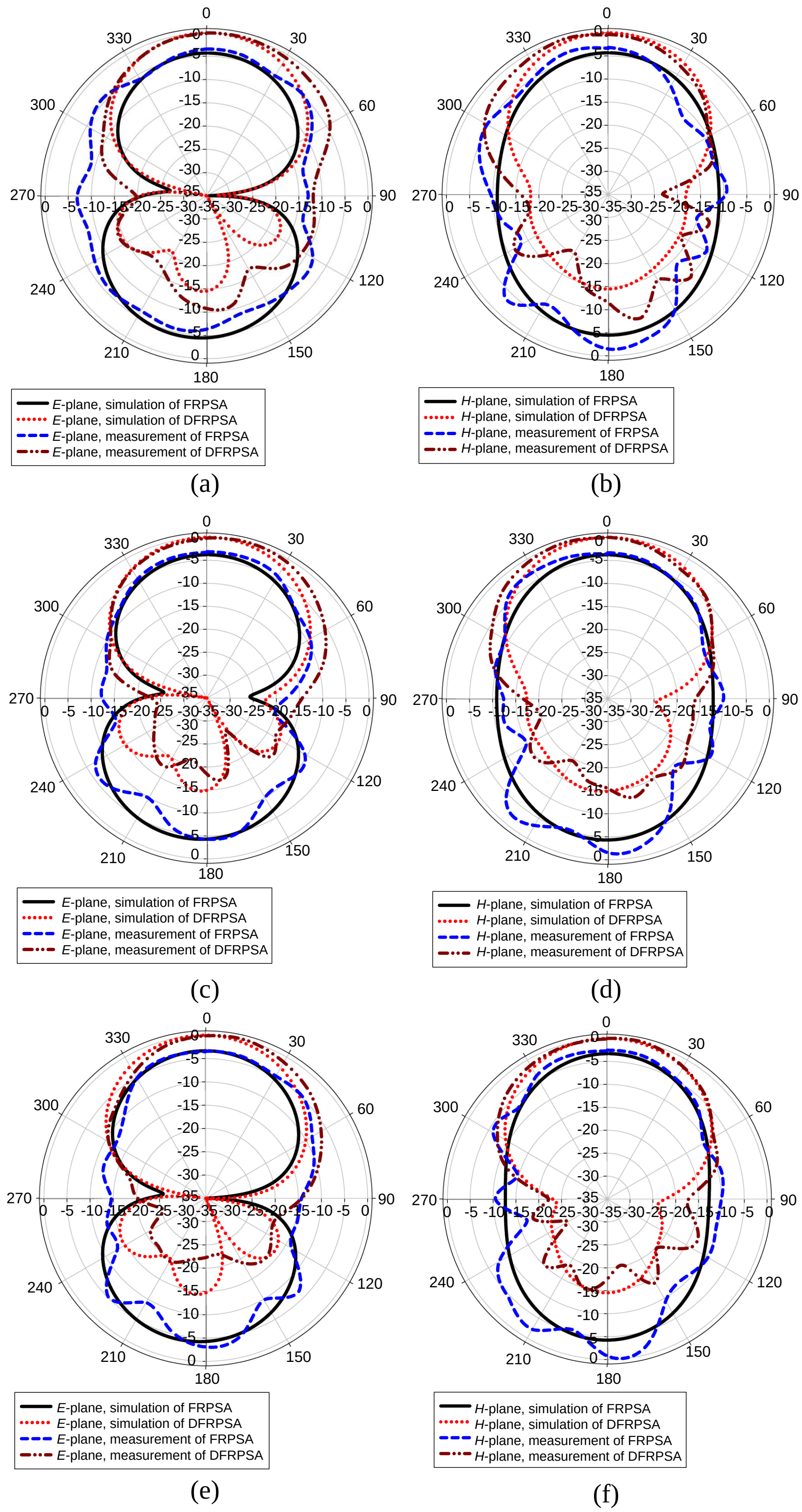


Figure 5. Simulated and measured reflection coefficient in dB of the proposed antenna.

and measured resonant frequencies of F_4 to F_6 have similar values because the patch acts as the radiator where it is not affected by the switches. Meanwhile, F_1 to F_3 are produced by the slot radiator. The existence of the PIN diode in the slot gives different values for resonant frequencies of F_1 to F_3. The different values of resonant frequency between the simulated and measured results is due to the parasitic effect of the PIN diode, where in the simulation, the overall dimension and material of the PIN diode is not included.

3. RESULTS AND DISCUSSIONS

The fabricated antenna is illustrated in Figure 4. The simulated and measured reflection coefficients in dB of the antenna are illustrated in Figure 5. As observed, the fabricated antennas are capable to reconfigure to six different narrow bands. The measured and simulated results are tabulated in Table 2 where good correlation between the measured and simulated results is obtained. A small shift on the resonant frequency is due to the fabrication tolerances.



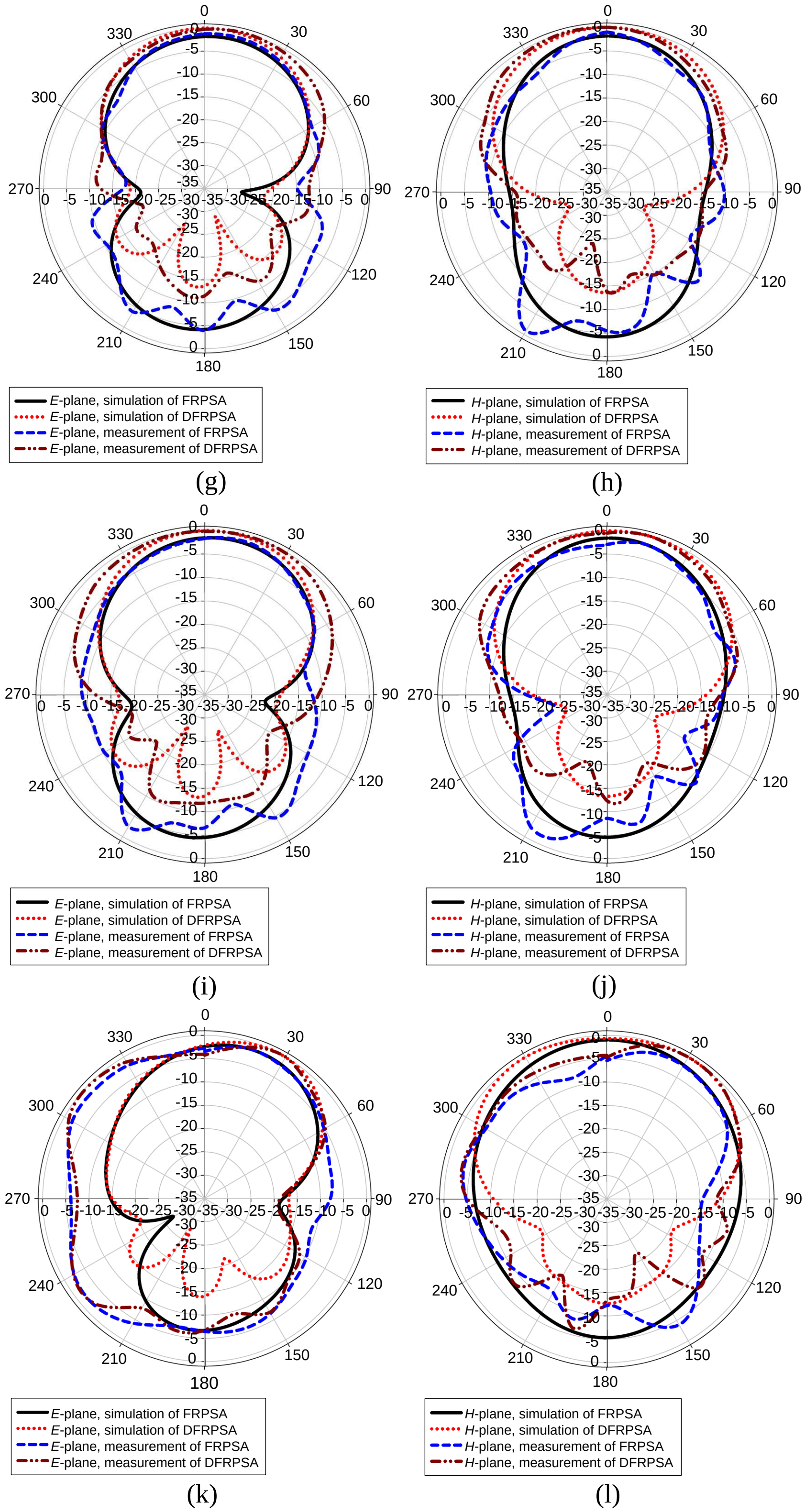


Figure 6. Simulated and measured radiation patterns comparison of the antenna with and without reflector where (a) E-plane of F_1, (b) H-plane of F_1, (c) E-plane of F_2, (d) H-plane of F_2, (e) E-plane of F_3, (f) H-plane of F_3, (g) E-plane of F_4, (h) H-plane of F_4, (i) E-plane of F_5, (j) H-plane of F_5, (k) E-plane of F_6, (l) H-plane of F_6.

The measured and simulated radiation patterns are illustrated in Figure 6. Good correlation between the measured and simulated radiation patterns is achieved. The radiation patterns of the antenna with reflector (DFRPSA) and the antenna without reflector (FRPSA) are directional and omnidirectional, respectively. The measured gain and the front to back ratio of the DFRPSA and the FRPSA are tabulated on Table 3. The measured gain shows that the antenna with reflector has a higher gain than the antenna without reflector, while the front to back ratio shows that the antenna with reflector has a higher value than the antenna without reflector at all frequency bands. As can be seen, an increment of gain up to 3 dB is achieved after the introduction of the reflector, while the front to back lobe ratio is increased up to 18 dB.

Table 3. Measured gain and front to back ratio of the proposed antenna with and without reflector.

Frequency	Measured gain FRPSA (dBi)	Measured gain DFRPSA (dBi)	Measured front to back ratio FRPSA (dB)	Measured front to back ratio DFRPSA (dB)
F_1	4.2	7.35	1.16	18.33
F_2	2.73	6.18	1.67	11.22
F_3	2.35	5.28	0.33	22.16
F_4	1.81	3.76	4.89	11.63
F_5	0.95	2.67	3.96	13.72
F_6	0.10	2.1	3.69	8.99

Table 4 shows the comparison of the simulated and measured gains and front to back ratios of the proposed antenna. The lower value of measured gain and front to back lobe ratio is due to the parasitic effect of the PIN diode where the overall dimension and material of the PIN diode are not included in the simulation. The material losses of the PIN diode might decrease the efficiency thus reduce the value of gain and front to back ratio of the measured results.

Table 4. Simulated and measured gain and front to back ratio of the proposed antenna.

Freq.	Simulated gain (dBi)	Measured gain (dBi)	Simulated front to back ratio (dB)	Measured front to back ratio (dB)
F_1	8.67	7.35	14.47	18.33
F_2	8.5	6.18	14.83	11.22
F_3	8.51	5.28	14.56	17.16
F_4	7.92	3.76	13.56	11.63
F_5	7.62	3.67	13.3	13.72
F_6	5.40	3.1	11.89	8.99

4. CONCLUSIONS

A frequency reconfigurable patch-slot antenna with directional radiation pattern has been designed and measured. It has been demonstrated that the frequency reconfigurability can be achieved by inserting switches in the slot of the antenna. Six frequency bands can be reconfigured. Due to the reflector installed at the back of the antenna, the proposed antenna gives a directional radiation patterns at all frequency bands.

ACKNOWLEDGMENT

The authors thank the Ministry of Higher Education (MOHE) for supporting the research work, Research Management Centre (RMC), School of Postgraduate (SPS) and Radio Communication Engineering Department (RACeD) Universiti Teknologi Malaysia (UTM) for the support of the research under Grant Nos. QJ13000.7123.02H02, 4L811 and 4L008.

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