Progress In Electromagnetics Research C, Vol. 30, 131–145, 2012

A RECONFIGURABLE ULTRAWIDEBAND (UWB) COMPACT TREE-DESIGN ANTENNA SYSTEM

M. Jusoh[1, *], M. F. Jamlos[1], M. R. Kamarudin[2], M. F. Malek[3], M. A. Romli[1], Z. A. Ahmad[1], M. H. Mat[3], and M. S. Zulkifli[3]

[1]School of Computer and Communication Engineering, Universiti Malaysia Perlis (UniMAP), Kangar, Perlis 01000, Malaysia

[2]Wireless Communication Centre (WCC), Faculty of Electrical Engineering, Universiti Teknologi Malaysia, UTM Skudai, Johor 81310, Malaysia

[3]School of Electrical System Engineering, Universiti Malaysia Perlis (UniMAP), Kangar, Perlis 01000, Malaysia

Abstract—A novel compact tree-design antenna (NCTA) with the ability of reconfigurable ultra-wideband (UWB) of 3.1 GHz to 10.6 GHz to five multi-narrowband applications is proposed. This antenna has a novel radiating element design that consists of seven small circles (7-filter) surrounding a central circle. Moreover, the NCTA incorporates the 7-filter that functioned as filter into the antenna design. The compact 38 mm × 38 mm antenna integrates three PIN diode switches, which are connected to a single National Instrument Data Acquisition (NI-DAQ) Board. The DAQ itself is controlled (ON/OFF state) by a virtual instrument known as "Lab VIEW Interface Software". The activation of specific PIN diode switches in the configuration that is controlled by the DAQ then, in turn, determines the frequency agility. The presented antenna is capable of performing up to five multibands. The operating frequencies are as follows; band 1 (2.72–11.8 GHz), band 2 (2.4–4 GHz, 5.3–11.6 GHz), band 3 (2.7–6.5 GHz, 7.1–11.6 GHz), band 4 (2.7–4.4 GHz, 5.2–6.5 GHz, 7.1–11.7 GHz) and band 5 (2.6–3.5 GHz, 4.8–7.0 GHz, 7.4 GHz–11.5 GHz). Furthermore, the antenna has a gain of up to 6 dBi which is considered better than that of conventional antenna. The proposed antenna produces a proficient divisive radiation pattern at 4 and 6 GHz. The experimental

Received April 10 2012, Accepted 7 June 2012, Scheduled 12 June 2012

* Corresponding author: Mohd Faizal Jamlos (faizaljamlos@unimap.edu.my).

results exhibit the success of the antenna performance. It is competent as future candidate for cognitive radio and military applications.

1. INTRODUCTION

Reconfigurable antenna, switchable antenna and multi-mode antenna are referred to the interpretation of similar antennas with a multi-frequency band by different radiation patterns, polarizations and directivity controlled by electrical switches. Recently, attention toward reconfigurable antenna has increased significantly among researchers due to its various benefits. Reconfigurable antenna is suitable for commercial and military communication, where it can support multiple functions through one antenna. Furthermore, the antenna size and cost can be minimized in contrast to the conventional antenna.

Theoretically studied, the dynamically reconfigurable antenna can be realized by using RF switches, such as PIN diodes, MEMs and GaAs FETs. These devices can be used for frequency tuning by turning the switches 'ON' and 'OFF' [1–8], or useful as impedancematching devices [9, 10]. This paper describes and analyzes the performance of a novel design of a compact switchable antenna that incorporates RF switches. Through a specified combination of PIN diodes at an ideal location, five agility frequency bands are eventually performed: band 1 (2.72–11.8 GHz), band 2 (2.4–4 GHz, 5.3–11.6 GHz), band 3 (2.7–6.5 GHz, 7.1–11.6 GHz), band 4 (2.7–4.4 GHz, 5.2–6.5 GHz, 7.1–11.7 GHz) and band 5 (2.6–3.5 GHz, 4.8–7.0 GHz, 7.4–11.5 GHz).

This is achieved by implementing three switches that connect to a single National Instruments Data Acquisition Board (NI-DAQ). The NI-DAQ capability to perform a fast switching response of 10 μs cycle time has attracted great attention from the authors. The NI-DAQ itself has eight output ports (8-O/P) of A0–A; however, only three ports (3-O/P) are occupied since only three RF (3-RF) switches are available. The first RF switches are connected to the D0, the second RF switches to the D1, and the third to the D2 of NI-DAQ. The LabVIEW Interface Software is introduced to control the NI-DAQ and to ensure communication reliability between the antenna and NI-DAQ. LabVIEW is a program development application, much like various commercial C or BASIC development systems, or National Instruments LabWindows; however, what makes LabVIEW special is its use of a *graphical* programming language, G, to create programs in block diagram form instead of using text-based language to create lines of code [11].

To the authors' knowledge, there are no such antennas with the ability to electronically switch up to five frequency operating bands [3, 4, 9]. In paper [3], a square patch loaded with a hexagonal slot with extended slot arms has achieved a reconfigurable dual frequency microstrip antenna using varactor diodes. Paper [4] discussed a planar monopole antenna capable to achieve two frequency operating bands only, UWB (3 to 10 GHz) and narrowband (3 to 5 GHz) using additional switches. A two-layer microstrip antenna fed by a coplanar waveguide attained a reconfigurable dual frequency band, 8.73 to 10.95 GHz and 7.68 to 9.73 GHz [9].

Moreover, another advantage of the proposed antenna lies in its design and size. The antenna has a novel radiating element design that consists of seven small circles (7-filter) surrounding a single central circle. The 7-filter acted as an antenna filter with tolerable certain frequencies radiated. The filter embedded into the presented antenna design can be considered novel compared to the conventional antenna, which required an external circuit to carry out the filter task [12, 13]. Dimension-wise, the presented antenna of 38 mm $\times$ 38 mm is miniature compared to the conventional microstrip antenna that has similar features [1]. Furthermore, the antenna has experimental gain up to 6 dBi and executes a radiation pattern with a divisive geometrical representation at $f_1 = 4$ GHz and $f_2 = 6$ GHz. The antenna gain is better than that of the conventional antenna as discussed in [14–16]. Meanwhile, this antenna development has obtained a new modern mobile and wireless communication device, which is compact, handy with a switchable frequency [7].

The simulated and measured results of the proposed antenna are presented in detail. All simulations and experiments are carried out by CST Studio Suite and Agilent Technologies E83628 PNA Network Analyzer respectively. This paper is organized as follows: Section 2 discusses the antenna materials and method, including the structure of the antenna, NI-DAQ board and the measurement setup. Section 3 discusses a PIN diode switch configuration for the experimental antenna's return loss, gain and radiation pattern. Finally the paper concludes in Section 4.

2. MATERIALS AND METHODS

2.1. Structure of Reconfigurable NCTA

The reconfigurable novel compact tree design antenna is printed on both sides of the substrate. As depicted in Figure 1(a), the antenna has a novel radiating element design that consists of seven small circles (7-filter) surrounding the middle antenna pole. The 7 filters allow selected resonating frequencies to operate. The partial ground plane placed on the back of the substrate plays an important role towards

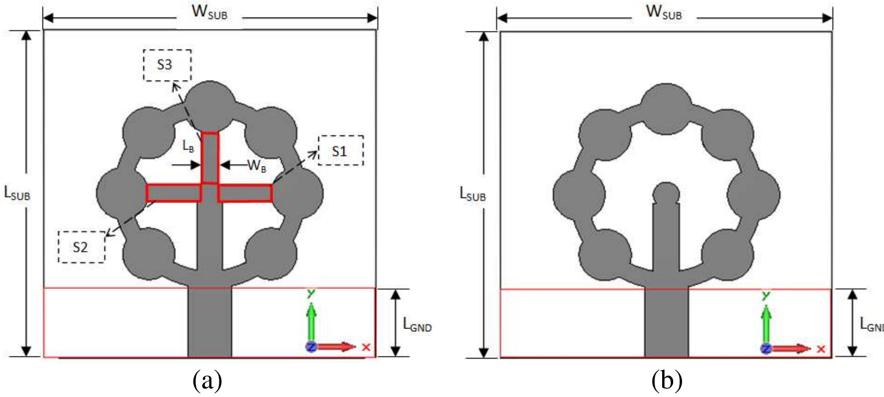


Figure 1. Simulated geometry of the antenna, (a) ON state, (b) OFF state.

the realization of the UWB antenna. This unique antenna is fed by a 50-Ω microstrip line feed.

The unique design of the antenna proposed basically comes from a single circle structure, as in [17–19]. The surface current result shows that more current is distributed near the edge of the circle. As a result, the research has reduced the inner circle diameter and introduced a ring with 1-mm size that surrounded the circle. This eventually allows the ring to cater to the entire required current distribution; however, the antenna's S_{11} performance still failed to achieve a UWB application. Therefore, seven small circles (7-circle) have been implemented on the ring, and three bridges that link the 7 circles to the ring are drawn as in Figure 1. Besides, the diameter of the 7 circles functions as a tuning circuit of the antenna's matching network.

The integration of RF switches to switch the predefined reconfigurable bandwidth by controlling the switches' state (ON and OFF) to the desired application as indicated in Table 1 is investigate. This concept can be proven in simulation by representing the RF switches with a copper strip line. The presented reconfigurable antenna consists of three RF (3-RF) switches outlined by red rectangles. As shown in Figure 1, they are labeled as S1, S2 and S3. The presence of the switches symbolizes the ON state condition as shown in Figure 1(a), which means that more current will flow to the antenna via 2, 4 and 6 of the 7 filters, which will make the UWB antenna application accessible. When the switch is in the OFF state, a gap exists between the inner circles and the 7-filter, and no current can flow through the gap as shown in Figure 1(b). Hence, the tri-band antenna application is

Table 1. Effect of parameters on the variation of 7-filter diameter.

7-filter Diameter	5 mm	6 mm	7 mm	8 mm
Lower Freq.	2.77 GHz	2.81 GHz	2.79 GHz	2.85
Upper Freq.	12.51 GHz	11.86 GHz	11.23 GHz	10.40
Bandwidth Ratio	4.51 : 1	4.22 : 1	4.02 : 1	3.64 : 1
Min. Impedance Matching	−38 dB	−54.8 dB	−26.5 dB	−22 dB

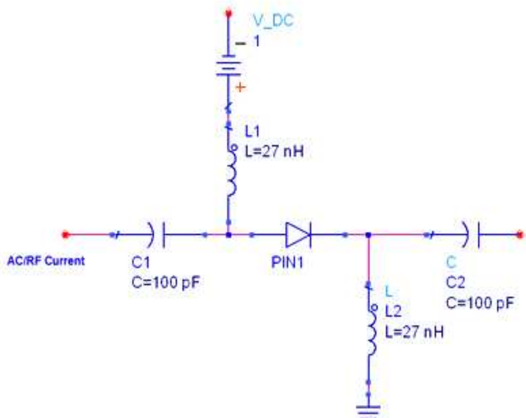


Figure 2. Schematic equivalent of RF switches circuit design.

attainable.

Figure 2 shows the schematic of the RF switching circuit inserted between the middle antenna circle and selected 7-filters (2, 4 and 6). The switching circuit was developed from the SMC (surface mount component) which consists of one PIN diode, two DC (direct current) block capacitors, two RF choke inductors, and a DC supply as shown in Figure 4(a). The RF switch can function when the PIN diode is in ON mode. This can be realized when there is a DC current flowing through it. Therefore, NI-DAQ is implemented as a switching device, which supplies a DC current according to the PIN diode configuration as in Table 2. The inductors function as a short circuit to the DC current instead of choking the alternating current (AC) that passes from capacitors from flowing to the DC supply and ground, while capacitors will block the DC current and allow RF and AC signals to flow simultaneously.

Table 2. PIN diode switch configuration of experimental and simulated antenna.

Type of Switch	Number of PIN diode switch	PIN diode status				
Reconfigurable RF switches (R-RFS)	S_1	ON	OFF	OFF	ON	OFF
	S_2	ON	ON	OFF	ON	OFF
	S_3	ON	OFF	ON	OFF	OFF
Simulated Operating Band		2.72 –11.8	2.4 – 4.0 5.3 – 11.6	2.7 – 65 7.1 - 11.6	2.7 – 4.4 5.2 – 6.5 7.1 – 11.7	2.6 – 3.5 4.8 – 7.0 7.4 – 11.5
Experimental Operating Band		3.3 – 10.8	3.15 –7.15	3.1 – 625 6.95 –8.4	2.0 – 2.2 3.0 – 5.75 6.75 –8.1	2.95 –3.65 5.0 – 7. 35

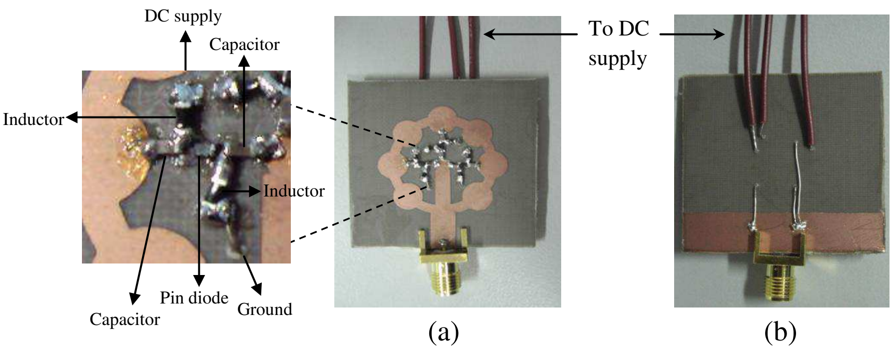


Figure 3. The Geometry of the fabricated antenna, (a) RF switches, (b) ground plane surface.

The presented antenna is developed using a Taconic TLY-5 substrate with relative permittivity of 2.2, substrate thickness of 1.5748 mm, copper thickness of 35 µm and tangent loss of 0.0009. The antenna is etched on the both sides of $L_{\mathrm{SUB}} \times W_{\mathrm{SUB}}$, 38 mm × 38 mm positive Taconic board. Each 7-filter has a diameter of 6 mm and partial ground dimension of 38 mm × 9 mm. Figures 3(a) and (b) show the fabricated RF switches and the ground plane surface of the proposed antenna, respectively. The three brown wires are connected to the DC supply, while the other three copper wires are soldered to the proposed antenna ground.

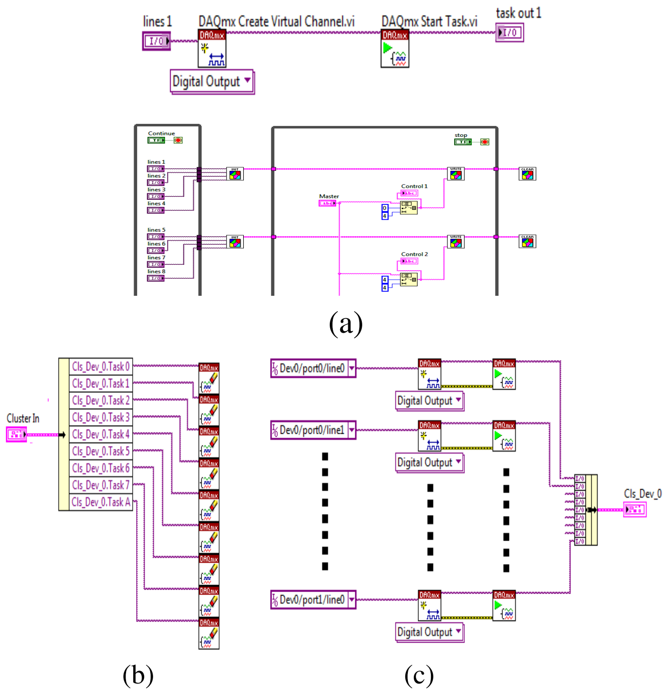


Figure 4. Virtual channel creation, (a) start task programming operation, (b) task clearing function, (c) assignment of virtual channel to single NI-DAQ output port.

2.2. National Instruments Data Acquisition Board (NI-DAQ)

The proposed antenna system is developed from three major components: a single antenna, a single NI-DAQ (switching device), and LabVIEW Interface Software programmed from a personal computer (PC) as shown in Figure 4. The antenna consists of a 3-RF switch, which is connected to the NI-DAQ's output ports D0–D2. Therefore, the activation of the 3-RF switch depends on the NI-DAQ's ports' status (ON/OFF), while the ports' status is controlled by the LabVIEW Interface Software. The LabVIEW software plays a significant role in ensuring high communication reliability between the antenna and NI-DAQ.

LabVIEW is a program development application, much like various commercial C or BASIC development systems, or National Instruments LabWindows. However, LabVIEW differs from those applications in one important aspect. Other programming systems use *text-based* languages that create lines of code, while LabVIEW uses a *graphical* programming language, *G*, to create programs in block diagram form [11]. In this research, the LabVIEW software functions as a virtual controller instrument to the actual output ports. The interface software will create virtual output ports like genuine NI-DAQ ports. The NI-DAQ is linked to the LabVIEW software via Universal Serial Bus (USB) ports. This board is manufactured with 12 digital input/output lines categorized as either Port 0 or Port 1. Port 0 contains 8 digital input/output lines (D0–D7), while Port 1 consists of 4 digital input/output lines (D0–D3). The interface software that runs in the PC will provide 0 or 1 output which indirectly supplies 0 volts or +5 volts, respectively.

Figure 4 visualizes the complete block diagram of LabVIEW's process function throughout the research. The functions can be divided into three phases: 1) initializing, 2) processing and 3) clearing. the first phase is to create the virtual control, the second to assign the required function (0 or 1) to the virtual control, and the third to start the NI-DAQ. The total number of output ports required in this antenna system is 3. Therefore, only one NI-DAQ is necessary (3 out of 12 ports), as shown in Figure 4. Figure 5 shows the schematic diagram of the integration of antenna into NI-DAQ.

2.3. Measurement Setup

The entire measurement process has been carried out in the research cluster of Universiti Malaysia Perlis (UniMAP) with the help of Agilent Technologies E83628 PNA Network Analyzer and 2D Anechoic

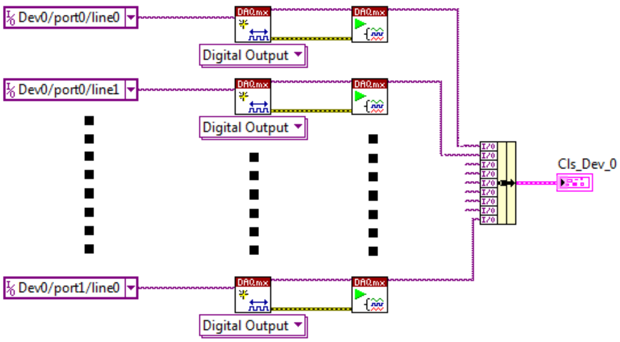


Figure 5. Schematic diagram of integration antenna into NI-DAQ.

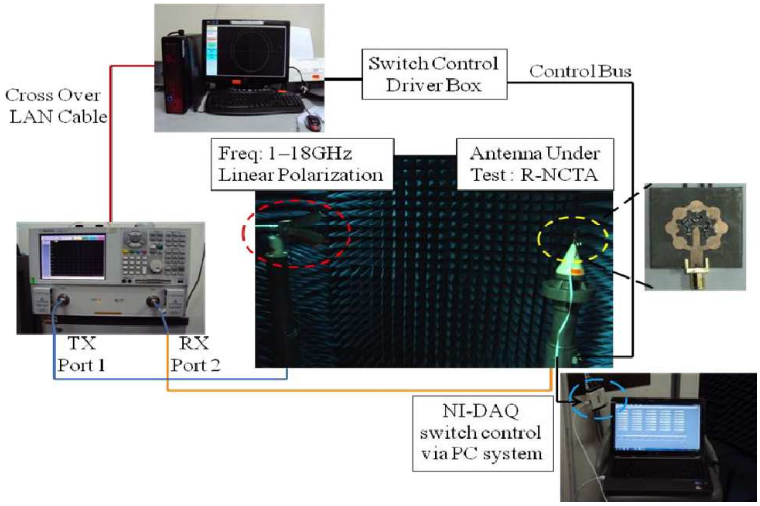


Figure 6. Agilent 2D PNA antenna test system block diagram.

Chamber. Figure 6 visualizes the antenna test system configuration. The horn antenna (highlighted by red dash ellipse) acts as a transmitter, while the antenna being tested highlighted by yellow dash ellipse) functioned as a receiver. The switchable configuration is controlled by the NI-DAQ device (highlighted by the blue dash circle) which integrates with the PC system.

3. RESULTS AND DISCUSSION

The presence of the 7-filter assists the author in realizing a five multiband operating frequencies. Therefore, research analysis has been focused on the significance of the 7-filter diameters. Table 1 demonstrates that the variation of the 7-filter diameters (5, 6, 7 and 8 mm) results in an influence on impedance matching, bandwidth ratio, and high and low frequencies. The 7-filter has the ability to control the upper frequency of the antenna significantly and the lower frequency slightly, which is clearly illustrated in Figure 7. The increase of 7-filter diameter from 5 to 8 mm filters approximately 2.2 GHz bandwidth as well as reduces the bandwidth ratio from 4.51 : 1 to 3.64 : 1. This shows the presented antenna with the filter embedded through the design itself.

Despite the 7-filter capability, further work should be focused on the integration of reconfigurable RF switches (R-RFS) and the antenna in order to obtain antenna with the frequency operating agility. This antenna is competent at working at five multi-bands with a certain configuration of RF switches as visualized in Table 2. In Figure 8(a), the antenna operates in UWB frequency band with three main frequencies resonance — 3.3 GHz, 6.1 GHz and 9.1 GHz. This is made successful by ensuring that all of the R-RFS are turned ON. As a result, the experimental antenna is capable of catering to frequencies between 3.3 and 10.8 GHz. In the case where S1 and S3 switches are turned OFF, the antenna could operate at a single frequency band as visualized in Figure 8(b). The dominant resonant frequency seems to be measured at 3.5 GHz. As S1 and S2 are OFF, the experimental antenna achieved operation between the bands of 3.1 to 6.25 GHz and 6.95 to 84 GHz as shown in Figure 8(c). Figure 8(d) shows that the measured antenna operates at three different frequency bands centered at 2.1, 3.1 and 7.2 GHz when S1 and S2 of antenna are ON. The experimental antenna also operates proficiently between the bands of 2.95 to 3.65 GHz and 5.0 to 7.35 GHz when all the R-RFS are turned OFF, as illustrated in Figure 8(e).

Figure 9 shows the simulated gain of antenna's five bands through predefined R-RFS. The antenna gain demonstrates a great increase from initial frequency points to 7 GHz. The maximum and minimum

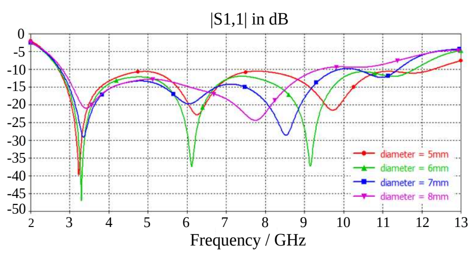
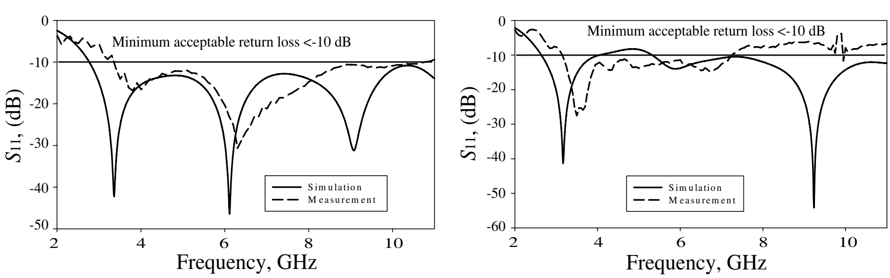


Figure 7. Simulated effect of reflection coefficient on the variation of 7-filter diameter.



(a) (b)

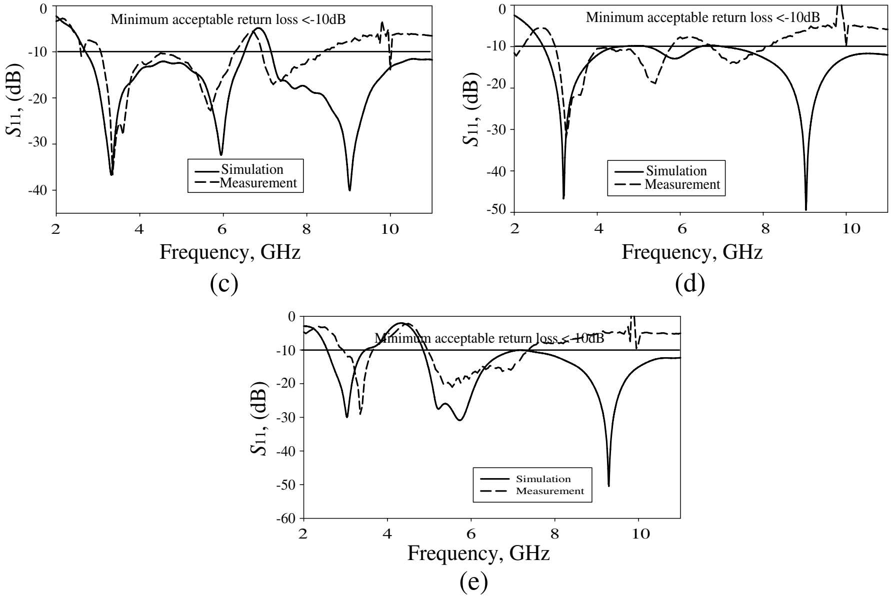


Figure 8. Experimental and simulated reconfigurable switches by turning the R-RFS ON/OFF, (a) all R-RFS (S1, S2 and S3) are ON, (b) S1 and S3 are OFF, (c) S1 and S2 are OFF, (d) S3 is OFF, and (e) all R-RFS are OFF. Those switches not mentioned are considered to be ON.

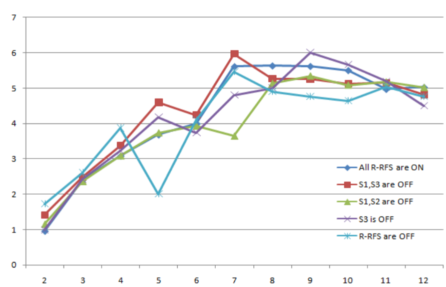
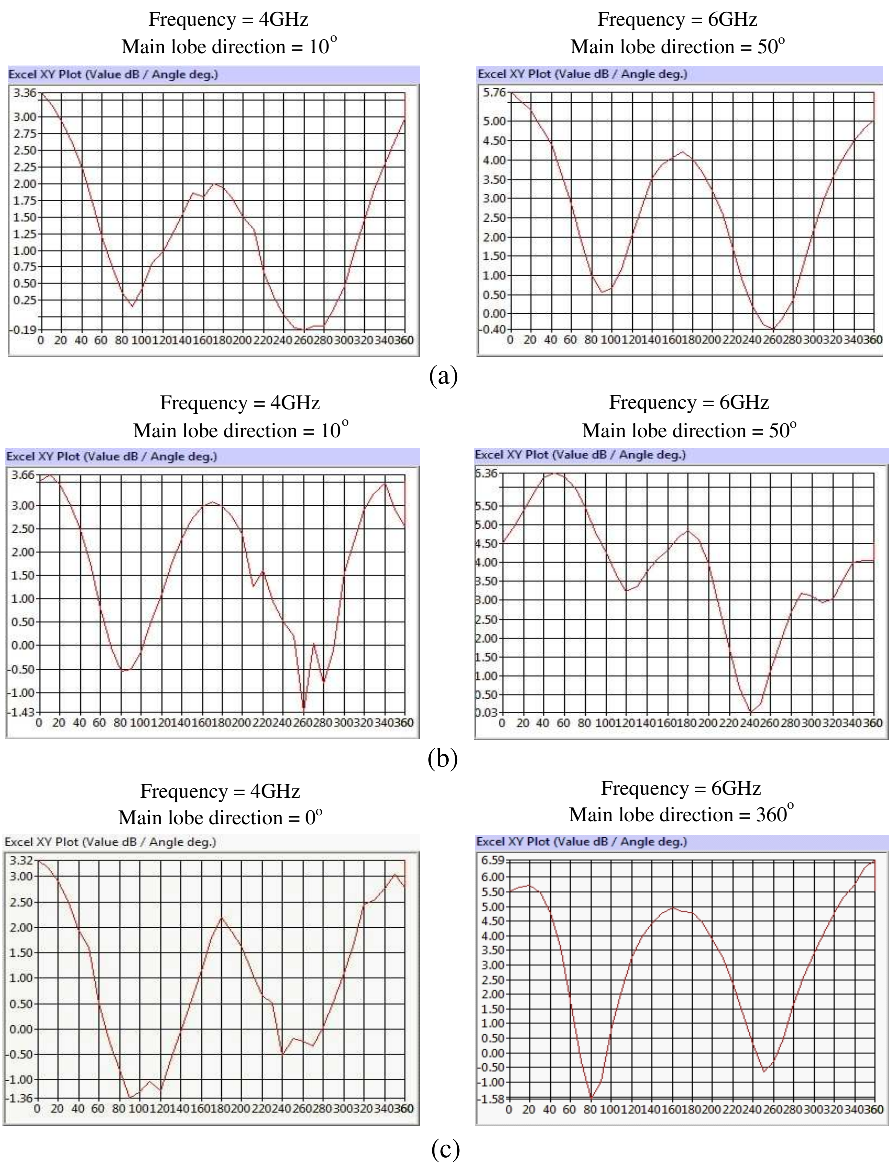
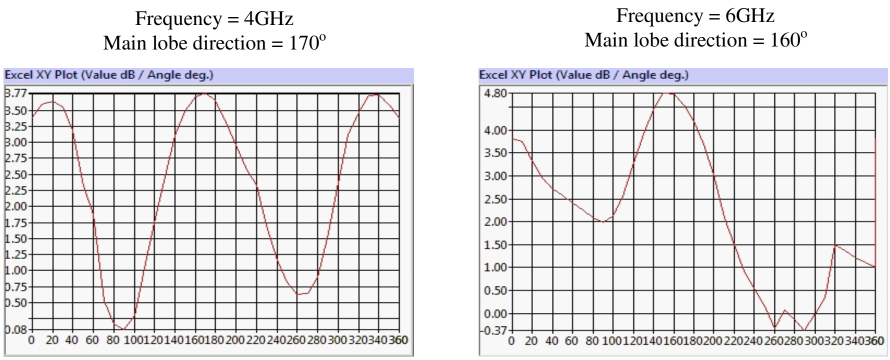


Figure 9. Simulated gain for five multi-bands.

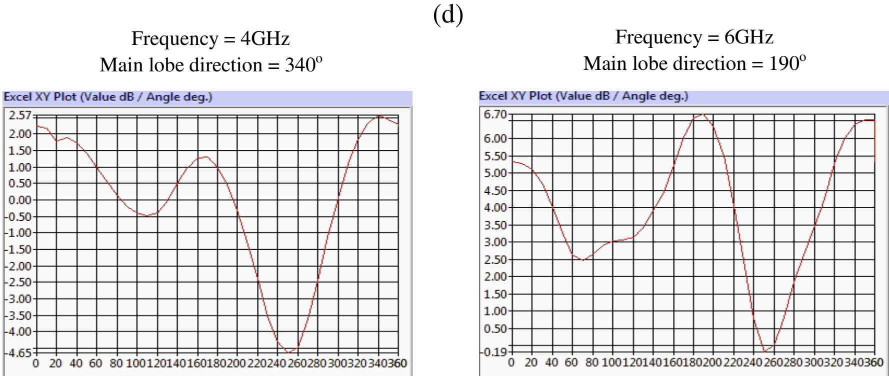
measured gains of the antenna indicate 5.8 dB at 7 GHz and 2 dBi at 3 GHz, respectively. Additionally, it has a superior impedance bandwidth ratio of 7 : 1 throughout the UWB frequency operation.

Measured radiation patterns on the E-plane (xy-plane) of the antenna for each R-RFS configuration at 4 and 6 GHz are presented in Figure 10, which shows a non-stable radiation pattern with a divisive geometrical representation. The peak main beam has a different direction for each of the specified frequencies of 4 and 6 GHz.





(d)



(e)

Figure 10. The measured E-plane (co-polar) radiation pattern on specified frequencies ($f_1 = 4\,\text{GHz}$ and $f_2 = 6\,\text{GHz}$) by turning the R-RFS, (a) all R-RFS (S1, S2 and S3) are ON, (b) S1 and S3 are OFF, (c) S1 and S2 are OFF, (d) S3 is OFF, and (e) all R-RFS are OFF. Those switches not mentioned are considered to be ON.

4. CONCLUSION

This paper successfully develops a novel compact tree-design antenna with reconfigurable frequency operation capability. The uniqueness of antenna comes from the novel radiating element design which consists of one middle circle surrounded by seven small circles (7-filter). Moreover, the compact antenna switching mechanism employs three PIN diode switches. The activation of certain PIN diode switch configurations determines the frequency band operation. The simulated and experimental performances of five multibands applications are presented in detail. Additionally, the proposed antenna produces a proficient divisive radiation pattern at 4 and 6 GHz with a gain up to 6 dBi. The measured results show satisfactory performance with tolerable impedance matching ($S_{11} < -10\,\text{dB}$).

REFERENCES

1. Hamid, M. R., P. Gardner, P. S. Hall, and F. Ghanem, "Switchable wideband-narrowband tapered slot antenna," *Loughborough Antennas & Propagation Conference*, 241–244, Loughborough, UK, November 16–17, 2009.
2. Chen, Q., M. Kurahashi, and K. Sawaya, "Dual-mode patch antenna switched by PIN diode," *IEEE Topical Conference on Wireless Communication Technology*, 148–149, 2003.
3. Shynu, S. V., G. Augustin, C. K. Aanandan, P. Mohanan, and K. Vasudevan, "Design of compact reconfigurable dual frequencies microstrip antennas using varactor diodes," *Progress In Electromagnetic Research*, Vol. 60, 197–205, 2006.
4. Ghanem, F., J. R. Kelly, and P. S. Hall, "Switched UWB to narrowband planar monopole antenna," *European Conference on Antennas and Propagation*, Barcelona, April 12–16, 2010.
5. Ali, T. M., T. A. Rahman, M. R. Kamarudin, and M. N. Md Tan, "Reconfigurable linear array antenna with beam shaping at 5.8 GHz," *Asia Pacific Microwave Conference, APMC*, 2008.
6. Kiriazi, J., H. Ghali, H. Ragaie, and H. Haddara, "Reconfigurable dual-band dipole antenna on silicon using series MEMS switches," *IEEE Antennas and Propagation Society International Symposium*, Vol. 1, 403–406, 2003.
7. Ali, M. T., M. N. Md Tan, A. R. B. Tharek, M. R. B. Kamarudin, M. F. Jamlos, and R. Sauleau, "A novel reconfigurable planar antenna array (RPAA) with beam steering control," *Progress In Electromagnetics Research B*, Vol. 20, 125–146, 2010.
8. Shynu, S. V., G. Augustin, C. K. Aanandan, P. Mohanan, and K. Vasudevan, "Design of compact reconfigurable dual frequency microstrip antennas using varactor diodes," *Progress In Electromagnetics Research*, Vol. 60, 197–205, 2006.
9. Saed, M. A., "Reconfigurable broadband microstrip antenna fed by a coplanar waveguide,"*Progress In Electromagnetics Research*, Vol. 55, 227–239, 2005.
10. Kamarudin, M. R. B., P. S. Hall, F. Colombel, and M. Himdi, "Electronically switched beam disk-loaded monopole array antenna," *Progress In Electromagnetics Research*, Vol. 101, 339–347, 2010.
11. http://www.ni.com/labview/.
12. Panda, J. R., P. Kakumanu, and R. S. Kshetrimayum, "A wide-band monopole antenna in combination with a UWB microwave band-pass filter for application in UWB communication system,"

Annual IEEE India Conference (Indicon), 2010.

13. Yoon, J., D. Kim, and C. Park, "Implementation of UWB antenna with bandpass filter using microstrip-to-CPW transition matching," *Asia Pacific Microwave Conference, APMC*, 2009.
14. Sadat, S., M. Fardis, F. G. Gharakhili, and G. R. Dadashzadeh, "A compact microstrip square-ring slot antenna for UWB applications," *Progress In Electromagnetics Research*, Vol. 67, 173–179, 2007.
15. Lee, J. N. and J. K. Park, "Compact UWB chip antenna design using the coupling concept," *Progress In Electromagnetics Research*, Vol. 90, 341–351, 2009.
16. Sadat, S., M. Houshmand, and M. Roshandel, "Design of a microstrip square-ring slot filled by an H-shape slot for UWB applications," *Progress In Electromagnetics Research*, Vol. 70, 191–198, 2007.
17. Mokhtaari, M. and J. Bornemann, "Directional ultra-wideband antennas for planar technologies," *Proceedings of the 38th European Microwave Conference*, 2008.
18. Jusoh, M., M. F. Jamlos, M. R. B. Kamarudin, and M. F. B. A. Malek, "A MIMO antenna design challenges for UWB application," *Progress In Electromagnetic and Research B*, Vol. 36, 357–371, 2012.
19. Jusoh, M., M. F. Jamlos, M. R. Kamarudin, F. Malek, M. H. Minhat, and M. A. Jamlos, "A novel compact tree-design antenna (NCTA) with high gain enhancement for UWB application," *Journal of Electromagnetic Wave and Application*, Vol. 25, Nos. 17–18, 2472–2486, 2011.