Jurnal Teknologi

Full paper

Wideband Aperture-Coupled Dielectric Resonator Antenna at 5.8 GHz

Mohd Haizal Jamaluddin*, Guan Chai Eu, Sharul Kamal Abdul Rahim, Nur Izyani Dzulkipli

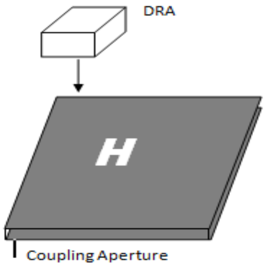
Wireless Communication Center, Fakulti Kejuruteraan Elektrik, Universti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

*Corresponding author: haizal@fke.utm.my

Article history

Received :2 October 2012
Received in revised form :
2 January 2014
Accepted :15 June 2014

Graphical abstract



Abstract

In this paper, a wideband aperture coupled dielectric resonator antenna (DRA) is presented using a rectangular dielectric resonator to increase operational bandwidth. By choosing a suitable combination of the DRA shape and slot, the resonance frequency from the aperture and DRA can be merged to achieve wideband frequency response without comprising antenna radiation efficiency and polarization. Effects of varying parameter in DRA size, slot dimension and feedline length on return-loss bandwidth are analysed. The proposed technique yields 43% bandwidth in simulation and 21% bandwidth in measurement.

Keywords: Dielectric resonator antenna (DRA); aperture-coupled; dielectric waveguide model; Microstrip Patch Antenna(MPA); bandwidth

Abstrak

Di dalam jurnal ini, antenna jalur lebar gandingan-pembukaan resonator dielektrik dipersembahkan menggunakan resonator dielektrik segiempat tepat. Dengan memilih kombinasi diantara bentuk resonator dielektrik dan slot, frekunsi resonan daripada pembukaan dan resonator dielektrik akan bergabung untuk mencapai frekuensi jalur lebar tanpa mengganggu kecekapan radiasi antenna dan polar antena. Kesan daripada mengubah-ubah parameter resonator dielektrik seperti saiz, dimensi slot dan panjang talian suapan terhadap jalur lebar kehilangan balikan dianalisis. Teknik yang dicadangkan berjaya memperolehi jalur lebar sehingga 43% untuk simulasi dan 21% untuk pengukuran.

Kata kunci: Resonator dielektrik antena; gandingan-pembukaan; model perambatan dielektrik; antena jalur tampal; jalur lebar

■1.0 INTRODUCTION

Microstrip patch antenna (MPA) has been used in mobile and wireless communication system over the last two decades. Lightweight, low cost construction and versatile design has boost MPA popularity in mobile communications application [1]. Recent advancement in mobile communications demands antenna to be in smaller size and high in achieved bandwidth. The presence of conductor loss and surface wave [2] in MPA limits its bandwidth performance at millimeter wave frequency. Another type of antenna known as Dielectric Resonator Antenna (DRA) has been demonstrated to be practical element for antenna application at high frequency. DRA is a low loss dielectric and cost effective antenna capable of achieving wide frequency response while maintaining low cross polarization [3]. There are a lot of techniques in broadening antenna bandwidth in DRA such as to notch DRA to lower inherent Q-factor of the resonator [4a], Multi-segment DRA [5-6], Cavity-Backed DRA [7a] and Aperture-coupled DRA [8-10]

Aperture-Coupled DRA combines a slot and DRA resonance to broaden bandwidth response up to 25 % [8]. The slot and DRA both radiate like a short magnetic dipole to preserve the radiation pattern and maintain low cross polarization, thus, in the same time capable of giving a large impedance bandwidth.

Normally, a single line slot is used with DRA in order to have a large impedance bandwidth as described in [8-10]. Several alphabetical slots have long been used in MPA to enhance the impedance bandwidth. The existence of 'C', 'U' and 'H' shaped slots have been proven able to increase impedance bandwidth for MPA [11-13].

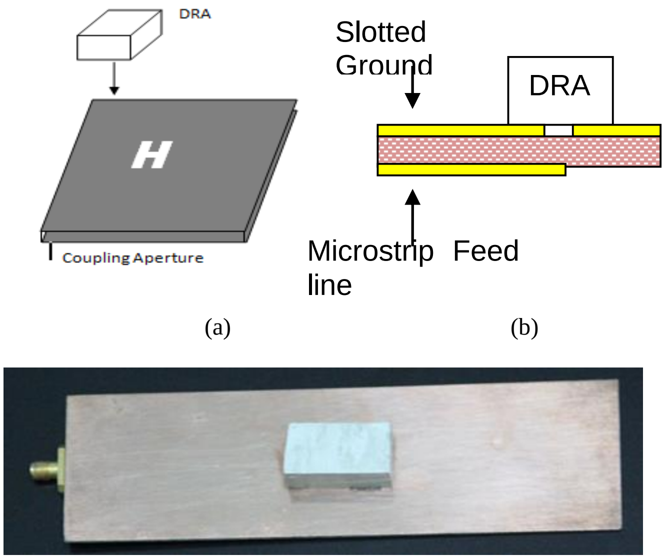
Due to this, here, in this paper, a new H-shaped slot aperture-coupled DRA is proposed. The antenna will be operated at 5.8 GHz with large bandwidth impedance

The paper is organized into few sections according to the design workflow. In Section II, antenna structure, geometry and coupling mechanism are briefly explained. Section III, parametric study and electromagnetic (EM) simulations were performed in Computer Simulation Technology (CST) design environment. Effects of varying each parameter on return loss and bandwidth were observed and each of them was optimized to achieve high bandwidth. The simulation and measurement results are compared in Section IV. Finally, some analysis and discussion are made at the end of section IV.

■2.0 STRUCTURE OF APERTURE-COUPLED DRA

Aperture coupled is an indirect feeding mechanism that excites DRA via coupling of the energy of the feed line through the opening in the ground plane [10]. Figure 1 depicts the DRA on top of the slotted ground plane and feed line on another side of the FR-4 substrate. The photo of fabricated DRA is also shown in Figure 1c. Copper-based ground plane and feed line of thickness 35 um are etched on the FR-4 substrate (dielectric constant, εr approx. 4.6).

DRA is mounted on the top of the feeding mechanism. The study of the antenna is concentrated on the rectangular DRA (RDRA) because of its ease of analysis and enhancement on bandwidth is possible by adjusting the aspect ratio of the DRAs. In RDRA, weight-height ratio, weight-length and length-height ratio can be tweaked to find maximum achievable bandwidth. In other shape like cylinder, only one dimension (radius-height) can be adjusted to get optimum bandwidth response. Henceforth, RDRA has 3 degrees of freedom compared to 1 degree in cylinder DRA can be utilized for performance tuning. Previous study rectangular DRA achieved more bandwidth compared to cylinder DR had been reported [14].



(a) (b)

(c)

Figure 1 Aperture coupled DRA (a) construction view (b) side view (c) prototype of aperture coupled DRA

■3.0 ANTENNA PARAMETRIC STUDIES

This section covered simulations results when parameters in slot dimension, DRA size and feed line vary. Finite difference time domain approach in CST design environment was used to simulate parameters to obtain optimum parameter value to meet the design objective.

3.1 Antenna Dimension

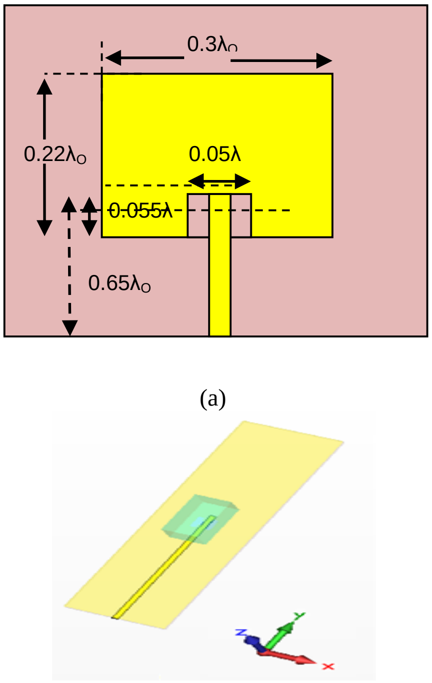
DRA is fixed at dielectric constant of 10 in this design to improve the antenna bandwidth response as dielectric constant is proportional to the Q-factor. Equation (1) & (2) show the relationship between the dielectric constant Q-factor and bandwidth response.

$$\text{Quality factor, } Q = \varepsilon_r^{\,3/2} \qquad (1)$$

$$\text{Bandwidth, BW} = \frac{VSWR-1}{Q(\sqrt{(VWSR-1)})} \qquad (2)$$

$$Q = 2\,w_0\,\varepsilon_r^{P}\left(\frac{Volume}{Surface}\right)^2 \qquad (3)$$

where εr is dielectric constant of resonator and VSWR is the maximum acceptable voltage standing wave ratio. Another method to lower the Q-factor is through suitable selection of volume source over surface ratio as formulated in (15). Investigation in this section is mainly on DRA width, height and length. DRA size approximation is based on dielectric waveguide model [3]. Figure 2 illustrates simulated MPA (15.6 mm x 11.62 mm) and DRA (18 mm (width) x 30 mm (length) x 14.5 mm (width) in microstrip-fed stripline. Simulation in Figure 3 shows DRA performs better in achieving wider bandwidth compared to MPA when same feeding mechanism is used.



(a)

(b)

Figure 2 Antenna using same feeding technique. (a)MPA (b) DRA

In Figure 4 DRA width is varies from 16 to 19 mm while length and height is fixed at 30 mm and 14.5 mm. In Figure 5 and Figure 6, DRA length and height are varied respectively. Increase in DRA width and length will shift the resonator frequency to lower frequency and increases coupling magnitude but achieved bandwidth become narrower. Figure 6 demonstrates good bandwidth is achieved only when adequate order of TEM mode is excited by varying DRA height.

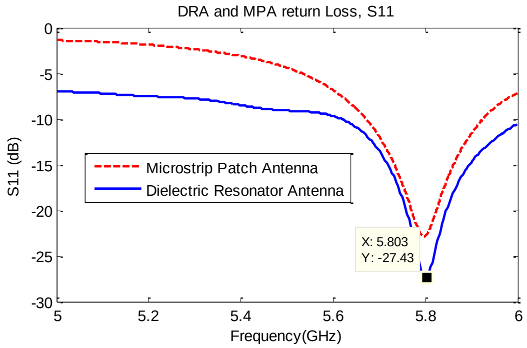


Figure 3 MPA vs. DRA in the same feeding technique

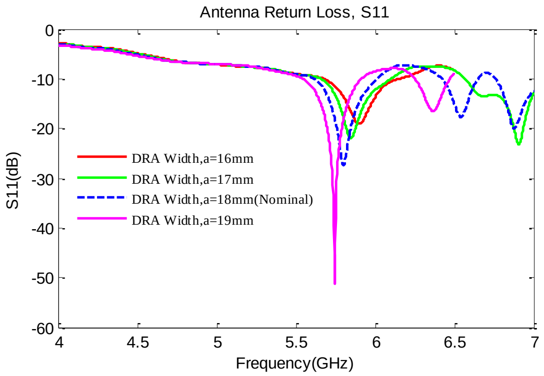


Figure 4 Return loss when DRA width varies

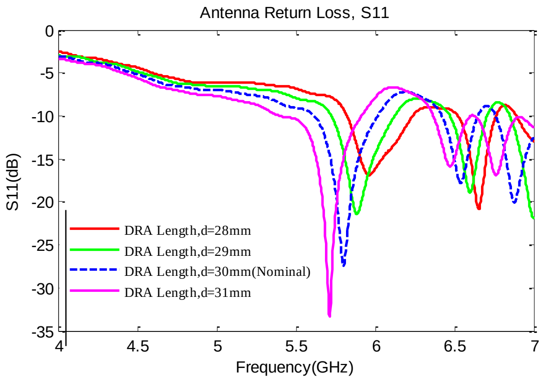


Figure 5 Return loss when DRA lenght varies

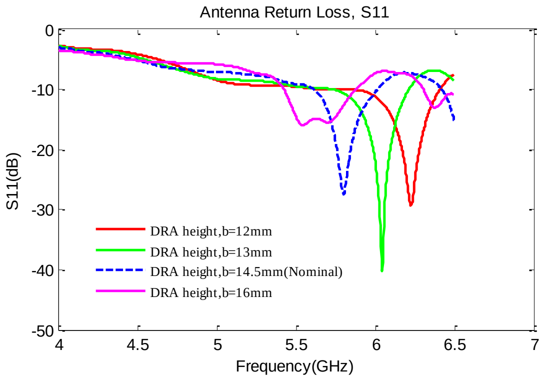


Figure 6 Return loss when DRA height varies

3.2 Aperture Dimension

In an aperture in the ground plane with DRA mounted on top, slot can be considered as an equivalent magnetic current with flow direction in parallel to the slot length. The orientation of the slot will excite the TEδ11 mode [4] of the DRA in the region of strong magnetic fields. In aperture coupling, slot size and dimension affects the amount of coupling into the feeding mechanism. In this project, "H" shape slot was studied in details on its capability to enhance return loss bandwidth as shown in Figure 7. Slot dimension as illustrated in Figure 7 was analyzed to obtain optimum slot size to excite maximum magnetic fields from DRA.

In this design, dimension "b" and "c" are considered as critical dimension because tolerance of 1 mm can cause the bandwidth percentage reduced to less than half of its original bandwidth as shown in Figure 8 and Figure 9 when b or c is not set on its nominal value. (b= 10 mm and c = 8 mm)

Maximum coupling is obtained when the slot size is fixed to values tabulated in Table 1. However, the resonance frequency is shifted to 5.2 GHz when slot is combined with DRA. The height of the DRA is experimentally adjusted to 12 mm to push the frequency upward by 600 MHz to 5.8 GHz based on simulation in previous study done on antenna dimension.

3.3 Microstrip Feedline

Feed line in aperture coupled DRA acts as an open stub to adjust antenna input impedance to 50 Ω. The ratio of feedline width over substrate height will decide the impedance of the antenna. In this study, FR-4 thickness of 1.6 mm with copper thickness 35 um is used as a substrate as FR-4 can be obtained easily and the cost is inexpensive. Therefore, feedline width has to be adjusted to 3.1 mm to match to the FR-4 thickness for optimum characteristic impedance to operate in designated center frequency as shown in Figure 10. Antenna position offset from the center of the slot degrades the bandwidth performance of the antenna as depicted in the Figure 11. Thus, feed line is placed in perpendicular to the centre of the slot in this project.

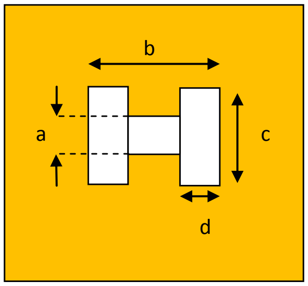


Figure 7 "H" shape slot dimension

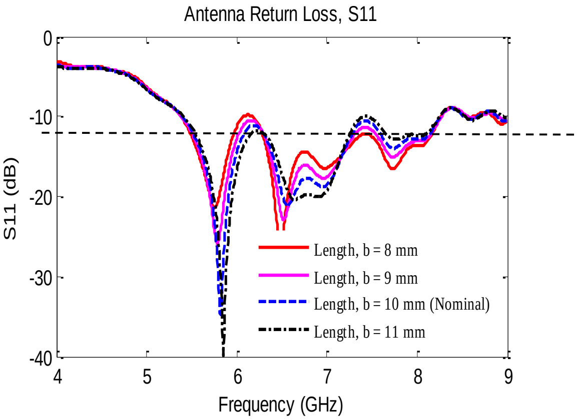


Figure 8 Parameter b varies from 8 mm to 11 mm

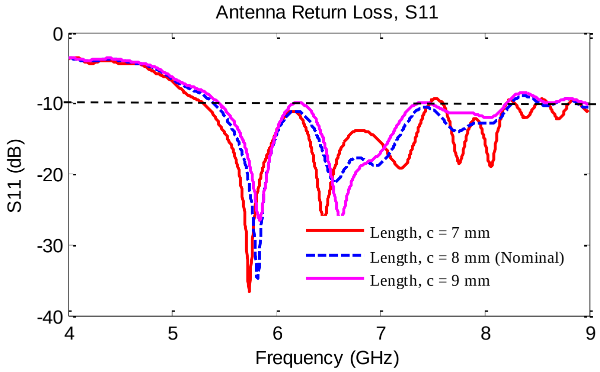
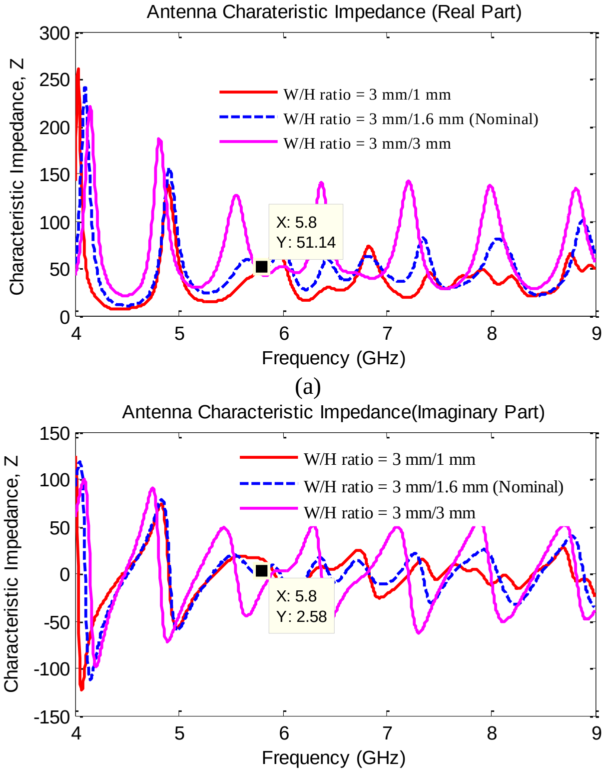


Figure 9 Parameter c varies from 7 mm to 9 mm

Table 1 Slot dimension for maximum coupling

Parameter	Length in millimeters (mm)
a	3
b	10
c	8
d	3



(a)

(b)

Figure 10 Antenna characteristic impedance (a) real component (b) imaginary component

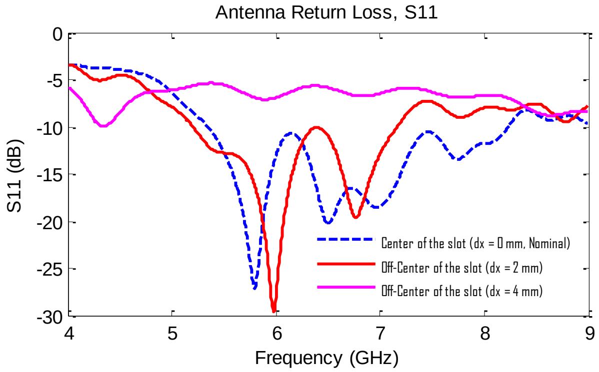


Figure 11 Feedline offcenter from the slot

3.4 The Effect of Ground Plane

The size of the ground plane variation from the analysis in Figure 12 shows E-plane co-polarization of bigger size ground plane is slightly better than the smaller ground plane. Throughout this simulation, size of the ground plane minor effect on the radiation pattern is observed. Thus, final size of the ground plane in this project is fixed to 156 mm x 50 mm.

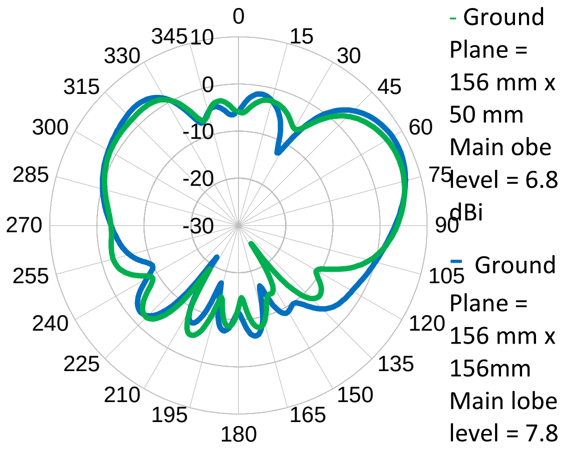


Figure 12 E-plane co-polarization for difference ground plane size

■4.0 EXPERIMENTAL RESULTS

A prototype antenna similar (Figure 1c) to the parameters obtained in previous section was fabricated. Actual prototype achieved 21 % bandwidth compared to 42.7% from simulation as illustrated in Figure 13. Achieved bandwidth disagreement between simulation and measurement is mainly due to the effect of DRA position off-center during mounting, effect of glue thickness in between DRA and feeding mechanism, and the actual dimension of rectangular DRA is not matched to simulation size due to imperfect cutting technique applied to dielectric resonator. The disagreement between simulation and measurement was simulated and plotted in Figure 14.

DRA off-center from the center of the slot during mounting is simulated and Figure 12 denotes the frequency of the simulation is shifted upward from 5.82 GHz to 5.92 after DRA is placed at dx = -3mm and dy = +1 mm from the center off the slot. After combining with the glue thickness, magnitude of magnetic fields excited by feed line is drastically reduced. In simulation, glue dielectric constant is assumed to be 4.6 and thickness is 0.12 mm. In actual measurement, there may be air bubble trapped in between the DRA and substrate that could increase the inherent Q-factor. As a result, designated frequency at 5.82 GHz is shifted to 6 GHz. The inherent Q-factor in actual measurement also increased, thus limit the return loss bandwidth. The return loss dipped at 5.7 GHz is believed to be coming from the slot resonance. Although achieved bandwidth in measurement (21%) is lower than simulation (42.7%), measurement result has demonstrated that high bandwidth could be realized by properly merging the resonance frequency from the dielectric resonator and the slot.

In parametric study, DRA and slot resonance frequency are assumed to be designed independently of each other. However, in reality even some minor loading such as DRA misalignment, from origin, glue effect and imperfect rectangular DRA edge affects matching to coupling at both resonances. Predicted parameters are included into the CST design model and the result in Figure 14 shows the simulation curve is quite similar to measurement.

Figure 15 shows the comparison between simulated and measurement radiation pattern of the antenna. An omni-directional antenna are achieved for both E- and H-plane with the proposed antenna.

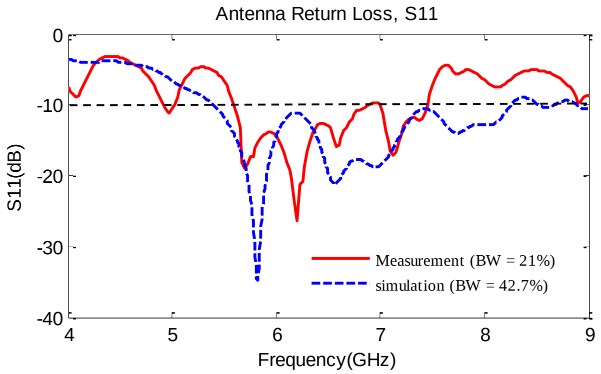


Figure 13 Simulation vs. measurement return loss bandwidth

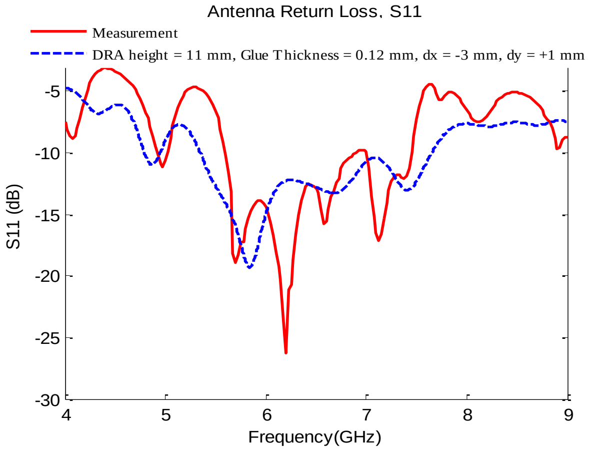
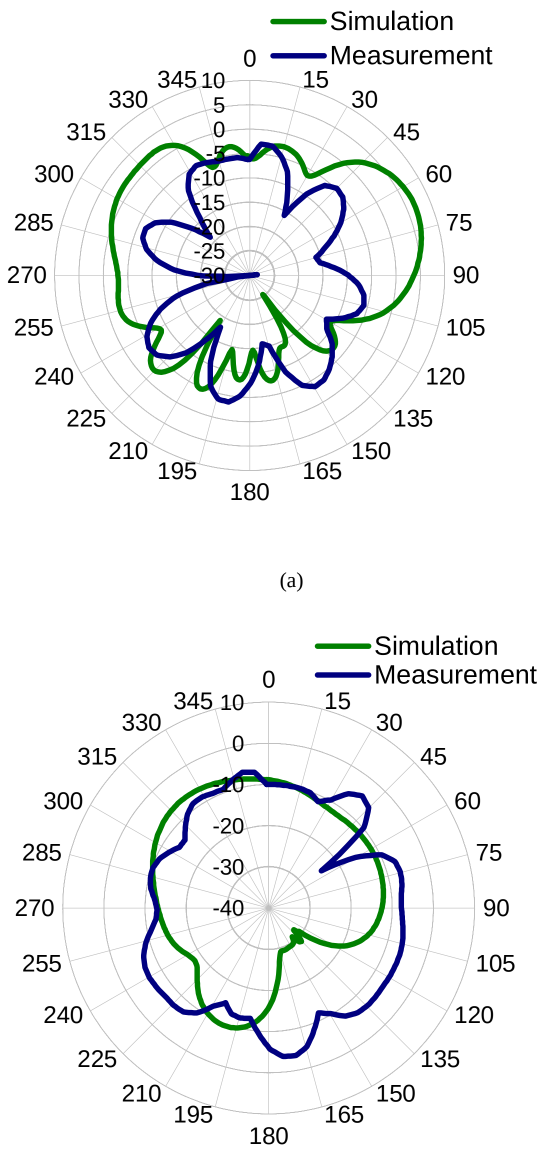


Figure 14 Predicted model vs. measurement return loss bandwidth



(a)

(b)

Figure 15 Radiation pattern comparison (a). E-plane (Co-polarization) and (b) H-plane (co=polar)

■5.0 CONCLUSION

In this paper, a wideband antenna operates at 5.8 GHz frequency band is demonstrated by merging the resonances from the slot and the dielectric resonator. Dielectric resonator and slot parameters optimization implemented in measurement has demonstrated wide bandwidth can be achieved via proposed technique without compromising the radiation patterns and polarization over the entire bandwidth.

Acknowledgement.

The authors would like to thank UTM GUP TIER 2 for the funding to enable this work to be completed. Also special thanks to WCC, UTM members for their support, helps and ideas.

References

[1] C.-H. Lai. 2008. Broadband Aperture-coupled Microstrip Antennas with Low Cross Polarization and Back Radiation. *Progress in Electromagnetics Research Letters*. 5: 187–19.

[2] Niamien, C., Collardey, S., Sharaiha, A. and Mahdjoubi, K. 2010. Surface Wave Loss and Material Loss in Printed Antennas Over Magneto-dielectric Materials. Antenna Technology and Applied Electromagnetics & the American Electromagnetics Conference (ANTEM-AMEREM). 1–4.

[3] K. M. Luk and K. W. Leong. 2003. *Dielectric Resonator Antennas*. Hertfordshire, England: Research Studies Press Ltd.

[4] A. Petosa, A. Ittipiboon, Y. M. M Antar, D. Roscoe, and M. Cuhaci. 1998. Recent Advances in Dielectric Resonator Antenna Technology. *IEEE Antennas Propagation Magazine.* 40: 35–48.

[5] Petosa, A.,Simons, N. , Siushansian, R., Ittipiboon, A. and Cuhaci, M. 2000. Design and Analysis of Multisegment Dielectric Resonator Antennas. *IEEE Transactions on Antennas & Propagation.* 48(5): 738–742.

[6] P. Rezaei, M. Hakkak, and K. Forooraghi. 2006. Design of Wideband Dielectric Resonator Antenna with a Two-segment slot. *Progress In Electromagnetics Research, PIER*. 111–124

[7] Kut Yuen Chow and Kwok Wa Leung. 2000. Theory and Experiment of The Cavity-backed Slot-excited Dielectric Resonator Antenna. *IEEE Trans. On Electromagnetic Compatibility*. 42(3): 290–296.

[8] Amelia Buerkle, Kamal Sarabandi and Hossein Mosallaei. 2005. Compact Slot and Dielectric Resonator Antenna with Dual Resonance, Broadband Characteristics. *IEEE Transactions on Antennas and Propagation*. 53(3): 1020–1024.

[9] Lee Ee and Ong, M. L. C. 2009. Aperture coupled, differentially fed DRAs. Asia Pacific Microwave Conference. 2781–2784.

[10] D. Cormos, A. Laisne, R. Gillard E Le Bolzer and C. Nicolas. 2003. Compact Dielectric Resonator Antenna for WLAN Applications. Electronics Letters. 39(7).

[11] S. K. Padhi. 2003. A Dual Polarized Aperture Coupled Circular Patch Antenna Using a C-Shaped Coupling Slot. IEEE Transactions on Antenna Propagation and Propagation. 51(12): 3295–3298.

[12] Sargolzaei, N., Javan, D. S., Sadat, S. 2007. Cross Slot Antenna with U-Shaped Tuning Stub for Ultra Wideband Applications. Wireless Communication Systems, 2007. ISWCS 2007. 4th International Symposium on 2007. 318–321.

[13] Shyh-Yeong Ke. 2002. Broadband Proximity-coupled Microstrip Antennas with an H-Shaped Slot in the Ground Plane. IEEE Antennas and Propagation Society International Symposium. 2: 530–533.

[14] E. A. C. Marcatili. 1969. Dielectric Rectangular Waveguide and Directional Coupler for Integrated Optics. *Bell Systems Technical Journal*. 2071–2103.

[15] Ittipiboon, A. *et al.* 1993. Aperture Fed Rectangular and Triangular Dielectric Resonators for Use as Magnetic Dipole Antennas. *IEEE Electronics Letters*. 29(23): 2001–2002.