Australian Journal of Basic and Applied Sciences, 8(4) Special 2014, Pages: 278-285

AENSI Journals

Australian Journal of Basic and Applied Sciences

ISSN:1991-8178

Journal home page: www.ajbasweb.com

Patch Antenna Design with Defected Microstrip Structure (DMS) of Quadruple C-Slot at WiMAX Application

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ARTICLE INFO

Article history:
Received 20 November 2013
Received in revised form 24 January 2014
Accepted 29 January 2014
Available online 5 April 2014

Keywords:
Microstrip patch antenna, defected structure, quadruples C-slots, reflection loss, WiMAX

ABSTRACT

In this paper, a rectangular microstrip patch antenna is perfectly matched to be designed for wireless communication with combinations of defected microstrip (DMS) structure of quadruple C-slots. The aim of this paper is to design a defected microstrip structure of quadruple C-slot antenna that meets the requirements of WiMAX applications in which having a resonant frequency at 2.659 GHz and return loss better than – 27.00 dB. Firstly, the design had been presented using CST Microwave Studio software. All the results regarding simulation and measurement for the proposed antenna are presented and discussed in this paper.

To Cite This Article: M.M. Ariffin, H. Nornikman, W.Y. Sam, A.M.M. Fareq, A.A.M.Z. Abidin, Z. Zahrialdha, O.M. Azlishah., Patch Antenna Design with Defected Microstrip Structure (DMS) of Quadruple C-Slot at WiMAX Application. ***Aust. J. Basic & Appl. Sci.**, 8(4): 278-285, 2014*

INTRODUCTION

Nowadays, the slotted microstrip antennas shaped with numerous shape structures have been widely used for various applications in antenna designs. Low profile, light weight, and easy to fabricate has led to wide usage compared to other conventional microwave antennas are the advantages of the microstrip patch antenna. FR-4 (Aziz, M. Z. A.A. *et al.*, 2012), RT Duroid (Ibrahim, R. A. R, *et al.*, 2010), Low Temperature Co-fired Ceramic or LTCC (Tang, C. W. *et al*,. 2005) and Taconix (Conway, G. A. *et al.*, 2009) is the example substrate that's used in designing the microstrip patch antenna.

The patch antenna operation frequency is influenced by the length, *L* as its length should equal to one half of a wavelength within the dielectric medium. The slot dimension can be tuned in order to obtain the frequency of the resonant mode that introduced by the slot.

There are many techniques that can be improving the performance of the patch antenna. The example techniques are slotted, parasitic patch; short-circuit pin, and metamaterial structure. Because of high demand in multiple application, the researcher had been introduced the technique to cater this problem. The antenna needed by the user must also easy to use, mobility and small in size. There are many techniques has been approached to design the multiband antenna that can operate in many frequencies range. The example technique is a Minkowski shaped patch (Lee, E. C. *et al*, 2011) inverted F-shaped patch (Yu, Y.-C., *et al*, 2009), slotted on the ground plane, slot on patch antenna, the geometry fractal structure (Saidatul, N. A. *et al*, 2009), defected ground structure or DGS (Antoniades, M. A. *et al.*, 2008), change design of patch shape, hook-like shape (Naser-Moghadasi, M., *et al.*, 2012) and also shorting pin technique.

In the current research, DGS or defected ground structure had been used in many research designs, especially in microstrip patch antenna and also in microwave filter. DGS can be achieved by etching the ground side pattern at the back of the substrate. In filter design, the DGS can produce the outstanding performance result in terms of sharpness and narrow selectivity at the targeted cutoff frequency (Parui, *et al.*, 2007). The common shaped of the DGS is the dumb-bell shaped DGS, such as in these papers: (Ahmad, *et al,* 2013, Zakaria,*et al.* 2012). The V-slot shaped DGS in microstrip antenna design have the capability of improving the cross-polarization and broadened the antenna bandwidth, stated in (Esa, M., *et al.*, 2010).

Compared with defected microstrip patch or DMS, the etching technique is done in the microstrip patch or the front side of the substrate. In (Moitra, S. *et al*, 2011), the novel DMS had been introduced to create the notch

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at the resonant frequency if the WLAN band without changing the others parameters of the ultra-wideband polygonal shaped antenna.

The slot technique for produce dual band frequency can be existed by placing a single or multiple slots on the patch part (in front) or on the ground plane (bottom) or both. There are many works that apply this method, for the examples are spiral (Wiriyacosol, P.,*et al*, 2006), H-shaped (Dzulkipli, N. I. *et al*, 2011), L-shaped (Rakluea, P. *et al*, 2005), circular (Kalteh, A. A., *et al.*, 2010), slotted PIFA (Soh, P. J. *et al*, 2012), CPW-fed (Fallahpour, M., *et al.*, 2012) and slot loop (Anantrasirichai, N., *et al.* 2005). There also research split ring resonator based on slot structure in order to improve the antenna performance such as quadruple P-spiral, meander line, and edge couple shaped.

In this paper, four units of the defected microstrip structure (DMS) of C-shaped of slots has to be embedded to rectangular patch, focusing to target the WiMAX signal for antenna application.

2. Antenna Design:

In this work, the value of resonance frequency has been selected for the patch is around 2.6 GHz in the WiMAX frequency range. For the substrate material used for this antenna is FR-4, with the thickness used is h = 1.6 mm and dielectric constant is εr = 4.3. The material of the ground FR-4 is from the copper with the thickness is 0.035 mm.

The input impedance is the important part in creating the antenna, the size of the feed for the waveguide port is adjusted to make sure the value of the impedance of this antenna is 50 Ω. The effect of changes the impedance value of this antenna structure is also due to the size of the slot.

Equation (1) to Equation (4) shows the calculated values the parameter of the antenna. The result as tabulated is for the calculation using the related formulas. However, for the simulation result the parameters have to be tuned to get an accurate and better for antenna response. The process to get the simulation result is by generated using the CST software. Therefore, the final result of the simulation process is in the optimum dimensions of quadruple C-slot microstrip patch antenna shown in Table 1 below. Equation (1) represents the patch width, Equation (2) represents the effective dielectric constant, Equation (3) represents the actual length of patch antenna while Equation (4) represent the length extension.

$$W = \frac{c}{2fr\sqrt{\frac{2}{\varepsilon r + 1}}} \quad (1)$$

$$\varepsilon_r = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{-\frac{1}{2}} \quad (2)$$

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \quad (3)$$

$$\Delta L = 0.413h\left[\frac{(\varepsilon_{reff} + 0.3)\left(\frac{w}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{w}{h} + 0.8\right)}\right] \quad (4)$$

Fig. 1 shows the schematic diagram of the defected microstrip structure of the quadruple C - slot. This quadruple C-slot structure is the combination of the wider C-slot and also smaller size of C-slot at the left and the right side. It shows that the optimal dimension value of the spit ring resonator is *D* = 11.83 mm, *Dc* = 1.0 mm, and *Wc* = 1.0, *Lw* = 1.0. Lastly, this structure will locate in the microstrip patch design.

Fig. 2 shows the proposed rectangular microstrip patch with the defects microstrip structureof quadruple C-slot that design in the CST Microwave Studio. The proposed antenna is designed on a FR-4 substrate (dielectric constant, ε_r = 4.3) with a substrate thickness of 1.6 mm.Two coppers are layered 0.035 mm thickness at the top and the bottom (ground) of the substrate. The input impedance is the important part in creating the antenna, the size of the feed for the waveguide port is adjusted to make sure the value of the impedance of this antenna is 50 Ω. The effect of changes the impedance value of this antenna structure is also due to the size of the slot.

Result:

The parameters that are considered in this paper are resonant frequency, return loss in dB, bandwidth, and also the gain of the rectangular microstrip patch antenna with the defected microstrip structureof the quadruple

C - slot. Fig. 3 shows the return loss of the rectangular microstrip patch antenna with the defected microstrip structure of the quadruple C - slot.

Refer to the graph, it is observed that the antenna will perform at its best be on a frequency of 2.659 GHz. The S11 parameter for this resonance frequency has dropped to - 27.15 dB. It shows that in the region before 2.659 GHz, the return loss is very poor and it only started to come down at a frequency of 2.659 GHz. This is the main fact that the resonance frequency of 2.659 GHz is selected.

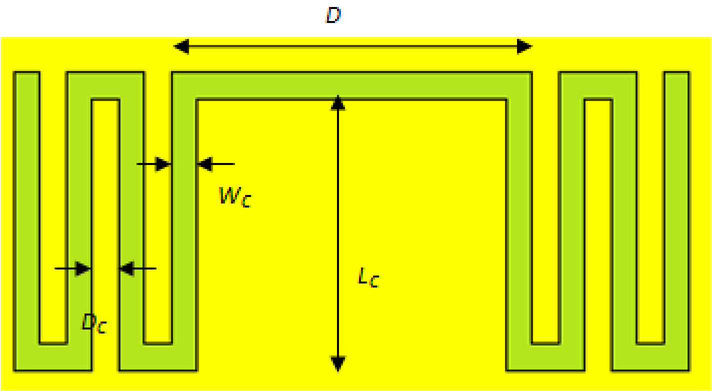

Fig. 1: Schematic diagram of defected microstrip structure of quadruple C-slot at FR-4 substrate.

Table 1: Actual and optimization dimension of defected microstrip structure of quadruple C-slot at FR-4 substrate.

Parameters	Actual dimension from calculation (mm)	Optimization dimension (mm)
Patch length, *L*	28.47	30.47
Patch width, *W*	36.72	36.72
Substrate length, *Lg*	61.0	77.0
Substrate width, *Wg*	37.47	45.72
Feeder length, *Lf*	31.24	31.24
Feeder width, *Wf*	2.83	2.83
Length of insert feed, *Yo*	11.27	3.27
Length of the slots, *Lc*	21.0	11.34
Width of the slots, *Wc*	1.0	1.0
Large of slot thickness, *Lw*	1.0	1.0
Slots width, *D*	11.77	11.83
Distance between the double slot, D_C	1.0	1.0
Length of the slot and patch (front), *A*	6.0	6.0
Length of the slot and patch (back), *B*	1.3	1.3
Distance between slot and patch, *D*	1.5	2.5
Width of slot in patch, *V*	2.97	2.0

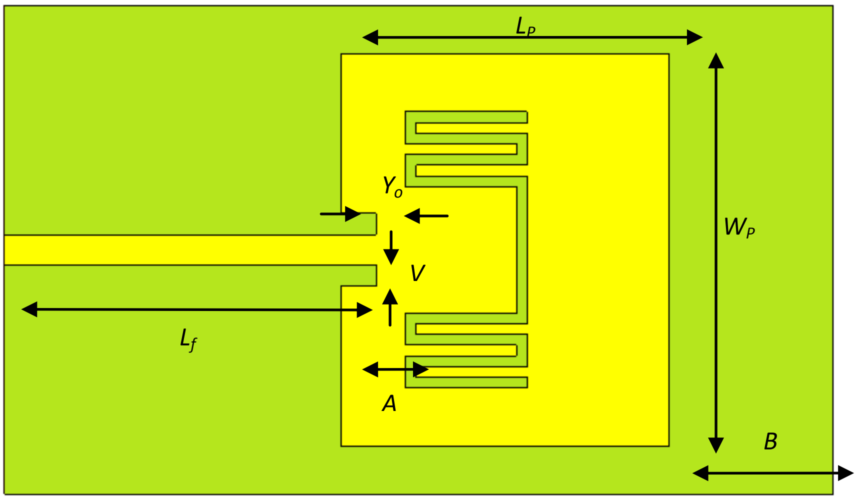

Fig. 2: Schematic diagram of the rectangular microstrip patch antenna with defected microstrip structure of quadruple C-slot (front view).

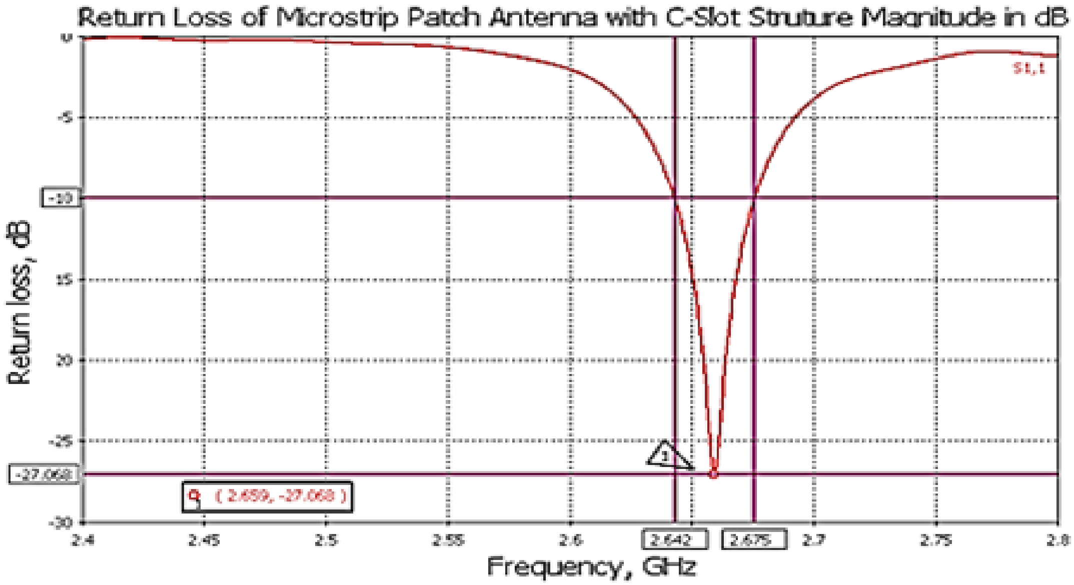

Fig. 3: Return loss of rectangular microstrip patch antenna with defected microstrip structure of (frequency range between 1.0 GHz to 5.0 GHz).

Fig. 4 (a) shows the location of the antenna on the simulation while Fig. 4 (b) shows the 3D radiation pattern of the rectangular microstrip patch antenna with the defected microstrip structure of the quadruple C - slot.This antenna that instead of directional antenna type, it falls to omnidirectional antenna type. It means that the antenna will receive or radiate in particular direction better than the other direction. The antenna radiate to the upper part of the patch antenna. The maximum gain of this antenna is 6.329 dB at the redzone spot on the figure.

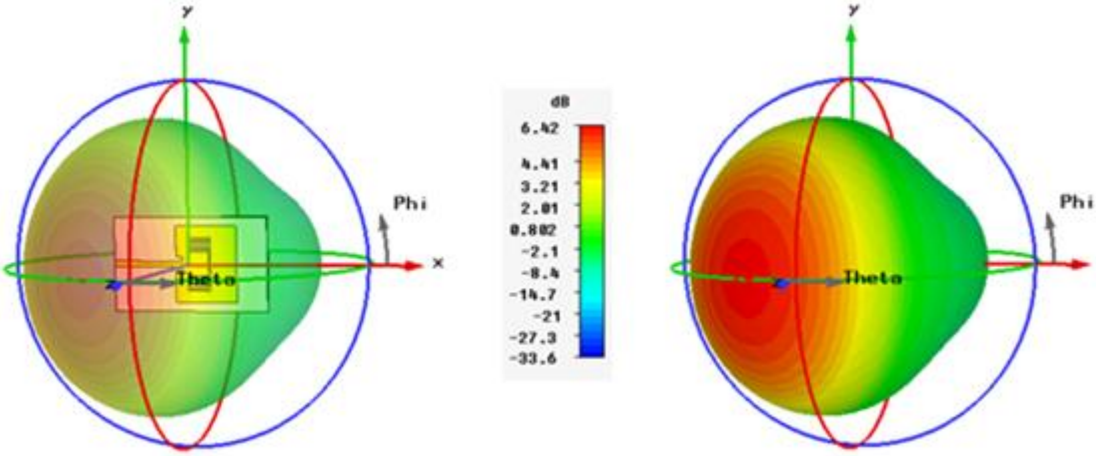

Fig. 4: 3D radiation pattern of the rectangular microstrip patch antenna with defected microstrip structure of quadruple C-slot, (a) antenna location, (b) radiation pattern (without antenna).

Fig. 5 shows the polar radiation pattern of the rectangular microstrip antenna with the defected microstrip structure of the quadruple C - slot. This antenna also has the directional radiation pattern. Other than that, the strongest point of the directive is at 0 degrees. The antenna will perform at its best when there is a straight line between the transmitter and receiver. The antenna will not perform at its best if the signal comes from at the back of the antenna. In order to perform better the antenna should be placed in front of it. The directivity from the simulation is at 6.819 dB.

The polar plot shows that the high gain can be achieved if the antenna is in a straight line between each other. At 0° is the direction where the gain is at its maximum. Furthermore, on 0° the gain is at 6.309 dB. This means that the antenna will receive a higher signal at the direction of 0 degrees. If the transmitter antenna has transmit at 5 dB and has suffered loss along the way and the loss can be assumed as 2 dB loss. The expected amplitude of the signal at the receiving side of the antenna is should be 3 dB. The 6.309 dB gain can improve the received signal by that value. In another word, the signal amplitude that will get is 9.309 dB.

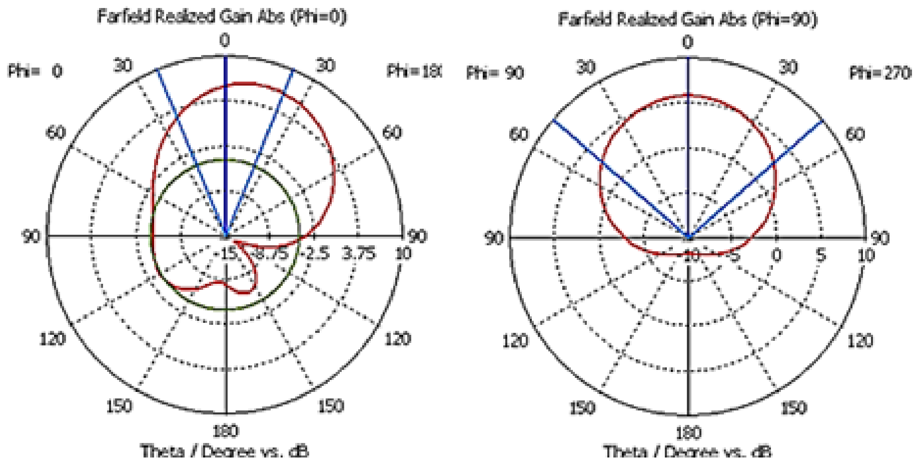

Fig. 5: 2D radiation pattern of the rectangular microstrip patch antenna with defected microstrip structure of quadruple C-slot at resonant frequency, (a) 0^0,(b) 90^0

Fig. 6 shows the computed distribution surface current of the rectangular patch antenna at the resonant frequency of the 2.659 GHz. It shows that the maximum surface current are exist in the phase = 900 and also at phase = 2700. The most effected location is on the defected microstrip structure of quadruple-C slot part compared with the small amount of surface current at the other part of patch antenna and at the feedline.

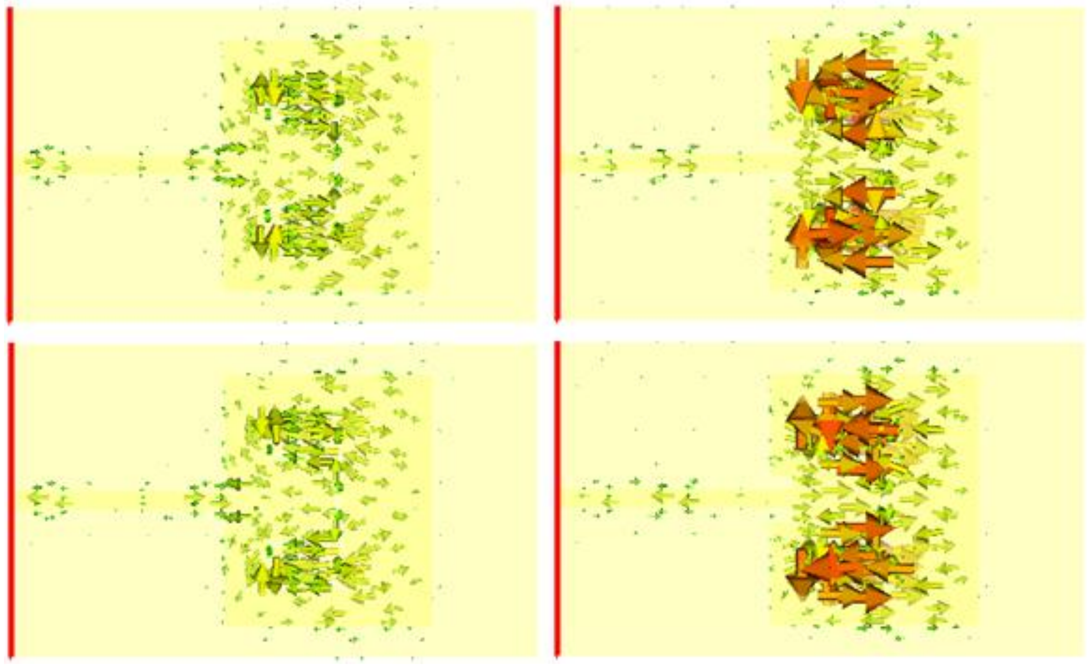

Fig. 6: Computed distribution surface current of the rectangular microstrip patch antenna with defected microstrip structure of quadruple C-slot at resonant frequency, (a) 0^0,(b) 90^0, (c) 180^0, (d) 270^0

The antenna also has been measured to get the exact return loss that the antenna will achieve. The return loss of the antenna is shown on Fig. 7. Based on the graph it is clearly shown that the lowest return loss is at a frequency of 2.69 GHz. This can also be said the best antenna performance will be at this particular frequency. The main reason of this statement is due to this is the frequency where the lowest return loss is recorded. The value of return loss at this particular point is -20.618 dB.

Fig. 8 shows the measured result of the rectangular microstrip patch antenna with quadruple C-slot structure. As we compare between the simulation result and the measurement result, we can observe that the transition of the frequency has occurred. The frequency has occurred from the original frequency of 2.66 GHz to 2.69 GHz. This 30 Hz difference is likely due to the fact the end result of fabricated antenna is not the way it's supposed to be. On the whole, the resonance frequency is still in the accepted region in the WiMAX lower frequency range which is ranging from 2.5 GHz to 2.69 GHz.

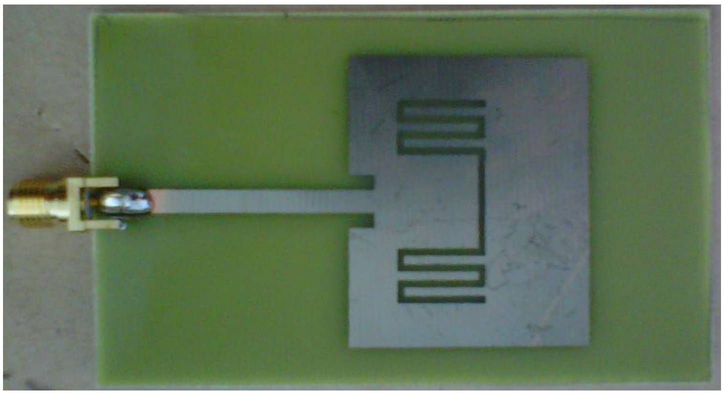

Fig. 7: Fabrication version of the microstrip patch antenna with defected microstrip structure of quadruple C-Slot usingthe SMA connector at the end of the feedline.

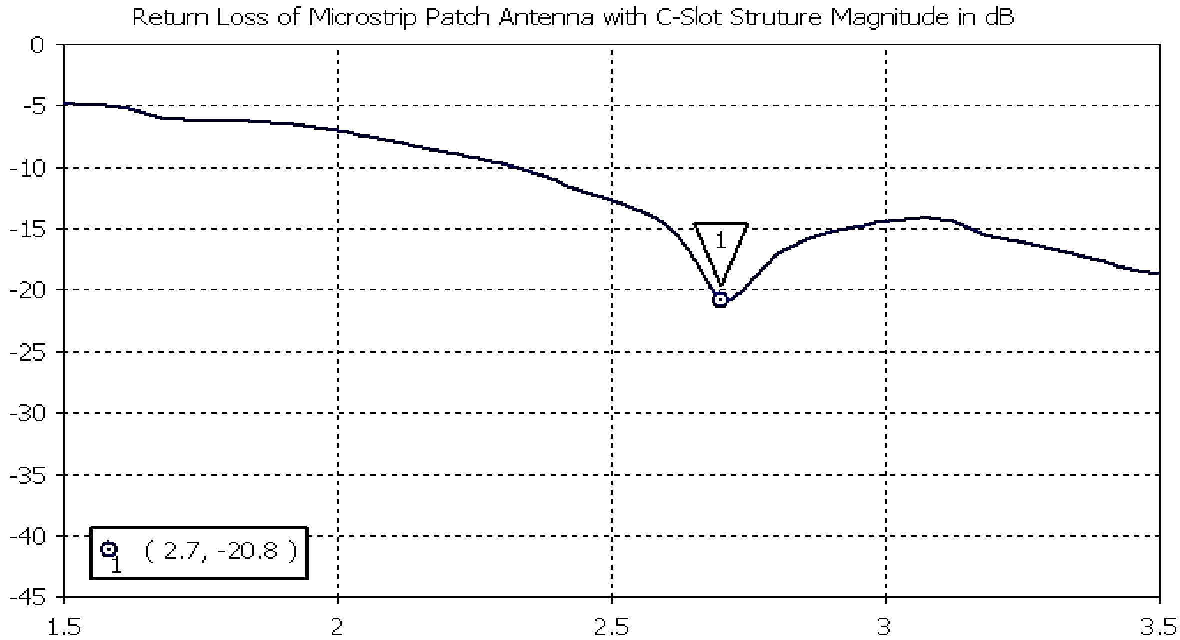

Fig. 8: Measured return loss of the rectangular microstrip patch antenna with defected microstrip structure of the quadruple C – slot.

This proposed patch microstrip antenna capabilityto integrate with other telecommunication devices such as amplifier (Othman, A. R., *et al.,* 2007.), switch (Shairi, N. A., *et al.* 2011), filters (Zahari, M. K., *et. a.l,* 2012, Ahmad, B. H.,*et all,* 2013, Shairi, N. A., *et al,* 2013), oscillator (Yoo, S.-S.,*et al,* 2011) and mixer to form a complete RF front-end transceiver system. This proposed antenna can improve its gain and return loss by combiningother techniques such as stacked patch, coplanar waveguide-fed and added the metamaterial structure on the patch side of the antenna.

Conclusion:

The conclusion of this paper is the performance of an antenna can be seen through the simulation and measurement result. The simulation results are obtained by using CST Microwave Simulator and superior result in performances can be clearly perceived. The proposed antenna which is quadruple C-Slot microstrip patch antenna is radiated in the upper limit of the WiMAX frequency range of 2.5 to 2.69 GHz. The return loss is slightly observed of - 20.619dB at the resonant frequency of 2.692 GHz and can be applied in WiMAX application. The antenna parameters can be obtained from the changes of parameter values and the result shows is close to the initial value. Last but not least, the main objectives in this paper have been achieved which is the proposed antenna can be operated at WiMAX applications which is frequencies ranging from 2.5 GHz to 2.69 GHz and return loss less than -10 dB.

ACKNOWLEDGEMENT

Mohamad Ariffin Mutalib would like to thank Universiti Teknikal Malaysia Melaka (UTeM) and the MyBrain15 program from Malaysian Ministry of Education for sponsoring this study. The authors would also like to thank UTeM for sponsoring this work under the PJP grant.The authors would like to thank Universiti Teknikal Malaysia Melaka (UTeM) and Universiti Malaysia Perlis (UniMAP) for their support in obtaining the information and material in the development of our work and we also want to thank the anonymous referees whose comments led to an improved presentation of our work.

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