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Research paper

The Effect of U-Slot Designs on The Performances of Microstrip Patch Antenna

Norlina Mohd Zain [1]*, Muhammad Zairil Muhammad Nor[1], Mohd Tarmizi Ali[2], Nur Darina Ahmad[3], Mashitah Mohd Hussain[1], Amar Faiz Zainal Abidin[4]

[1]*Fakulti Kejuruteraan Elektrik, UiTM Cawangan Johor Kampus Pasir Gudang, Masai, Johor, Malaysia*
[2]*Fakulti Kejuruteraan Elektrik, Universiti Teknologi MARA, Shah Alam, Selangor, Malaysia*
[3]*Fakulti Kejuruteraan Elektrik, UiTM Cawangan Pulau Pinang Kampus Permatang Pauh, Pulau Pinang, Malaysia*
[4] *Faculty of Engineering Technology, Universiti Teknikal Malaysia Melaka, Durian Tunggal, Melaka, Malaysia*
**Corresponding author E-mail: norlina119@johor.uitm.edu.my*

Abstract

Slotted techniques are widely used in to enhance the performances of microstrip patch antenna. This includes enhancing their return loss, VSWR, bandwidth, directivity and other more. In this paper, the effect of different U-slot on microstrip patch antenna performances focusing on return loss, VSWR, bandwidth, directivity, radiation pattern and gain are highlighted. Cutting a U-shaped slot on the middle of patch is used to bandwidth of antenna can be enhanced. The SMA or coaxial probe is used as a feeding to this structure. A parametric study has been carried out to investigate the effect of different SMA position on symmetric U-slot, the arm length of the U-slot, and the distance between feed point and arm U-slot. The optimized antenna shows operating frequency band ranges from 2.1 – 2.8 GHz. The microstrip patch antenna with U-slot was designed and simulated using CST Microwave Environment software. It can be concluded that the U-slotted microstrip patch antenna yields high bandwidth ranges from 2% - 3%.

Keywords: *U-slot, SMA coaxial probe, return loss, VSWR, radiation pattern.*

1. Introduction

In recent years, the demands in enhancing the capability of classical microstrip antenna bring out many studies and research in achieving their objective of research. The limitation of basic patch antenna is their narrow properties in bandwidth that precludes classical microstrip patch antenna has a very narrow frequency bandwidth that precludes its use in typical communication systems. However, if the frequency bandwidth could be widened, a broadband microstrip antenna would prove very useful in commercial application such as Wireless Local Area Networks (WLAN) and Bluetooth.

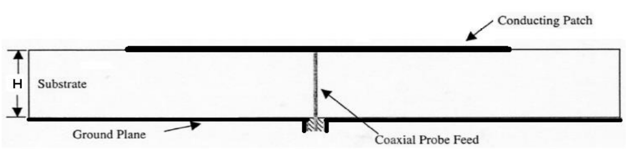
In [1], author presented an experimental study of a new kind of broadband antenna with probe feed microstrip antenna with U-slot, in the case of designing the antenna for low frequencies the ratio of probe diameter to wave length will be reduced. Therefore, the probe radius has significant effect on the performance of the antenna. The U-slotted along with the finite ground plane are used to achieve an excellent impedance matching to increase the bandwidth [2]. Being such advantageous, a U-slotted on the microstrip patch antenna is considered for our design. The U-slot introduces a capacitive component to counteract the large input inductance when thick substrate is used [3].

In this paper, author detailing the design guidelines for U-slot antennas operating at different resonance frequencies. The basic structure of Microstrip patch antenna was taken under design consideration. Microstrip patch antenna uses a radiating patch of perfectly conducting material separated from the copper ground plane using dielectric substrate material. Coaxial probe feed method, being easy and flexible as it can be placed at any desired location to match impedance was considered for our design.

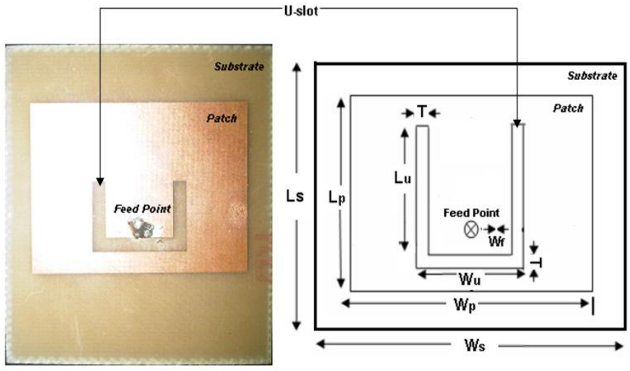
A parametric studies of the relation between the arm length of the U-slot, the distance between feed point and arm U-slot, and the position of feed point has been carried out. The antenna performances has been simulate using CST Microwave Environment software and all the simulated result are being compared with measurement data.

2. Antenna Design and Configuration

The configuration of the proposed antenna is shown in Fig. 1. Proposed antenna complement with a single square patch, which is characterized by (L_p,W_p) and a coaxial probe was used as feeding structure. Coaxial probe is one of the most popular feeding approaches due to ease in impedance matching. The antenna is fed using 50 Ω microstrip line, through a quarter wavelength for impedance matching.



(a)



(b)

Fig. 1: Geometry of antenna with U-slot (a)side view (b)top view.

Table 1: Dimensions of The Initial U-slot Antenna Used in Parametric Studies

Ls (mm)	*Ws* (mm)	*Lp* (mm)	*Wp* (mm)	*Lu* (mm)	*Wu* (mm)	*T* (mm)	*Wf* (mm)
45	40	32	24	8	14	2	5

The substrate material selected for proposed design is FR4 with dielectric constant of (ε_r = 4.7) and thickness of dielectric (substrate) is 1.6 mm. The initial geometric parameters are provided in Table 1. The dimensions and position of the U-slot, *Lu* was varied from 6 mm to 14 mm in 1 mm step. While for feeding point, *Wf* was varied from 3 mm to 6 mm also in 1 mm step. Next, the feed point position was varied in the middle of the patch at the positions A, B and C as shown in Fig. 2. All the parameter studies have been discussed in result and discussion part.

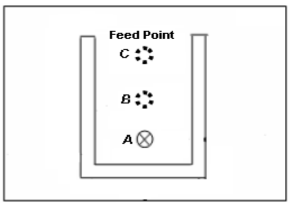


Fig. 2: A sample feed point position was varied at position A, B and C.

3. Results and Discussion

The simulation and measurement results of proposed antenna are discussed in this part. Equation (1) shows the percentage for the bandwidth of microstrip patch antenna without and with U-slot.

$$BW\% = \frac{F_H - F_L}{F_C} \times 100 \quad (1)$$

Fig. 3 and Table 2 shows the comparisons of the simulated return loss, S_{11} and bandwidth of microstrip patch antennas for without and with U-slot at 2.4 GHz. The bandwidth of without U-slot is about 0.56% and with U-slot is about 2.90%. It can be observed that the implementation of U-slot operating of frequency can enhanced the bandwidth of microstrip antenna.

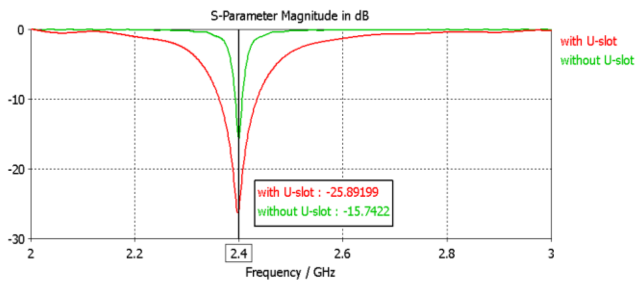


Fig. 3: Return loss of antenna for without and with U-slot.

Table 2: Comparison Between Without and With U-slot

	S_{11}(dB)	BW (%)
Without U-Slot	-15.7422	0.56
With U-Slot	-25.89199	2.90

3.1. The Feed Point at The Position A(0,-2.5) with Changing *Wf* and *Lu*

Table 3 shows the simulated data on analysis of U-slot antenna with different parameters value for the feed point at the position A(0,-2.5). Based on the changes of width of the feed (*Wf*) from 3 mm to 6 mm and arms length U-slot (*Lu*) from 8 mm to 11 mm, it can lead to the decrement of the resonant frequencies (*fres*) ranges from 2.512 GHz to 2.022 GHz. This shows that the different feeding point can change the value of resonant frequency of the proposed antenna.

Table 3: Analysis on Different Parameters Value for The Feed Point at The Position A

Wf (mm)	*Lu* (mm)	*fres* (GHz)	S_{11} (dB)	VSWR (V)	BW%	Gain (dB)
3	8	2.512	-4.3472	4.0792	-	-
	9	2.484	-11.071	1.7761	1.29	2.01
	10	**2.462**	**-36.393**	**1.1003**	**2.53**	**3.307**
	11	2.45	-12.973	1.5793	1.15	2.375
4	8	2.421	-10.271	1.884	0.7	2.439
	9	**2.383**	**-27.063**	**1.0872**	**2.53**	**2.871**
	10	2.351	-10.098	1.9098	0.85	2.61
	11	2.324	-6.267	2.891	-	-
5	**8**	**2.314**	**-26.439**	**1.0981**	**2.46**	**2.582**
	9	2.262	-11.989	1.672	2.03	3.219
	10	2.2081	-6.642	2.7418	-	-
	11	2.1	-4.675	3.8051	-	-
6	**8**	**2.206**	**-20.986**	**1.197**	**2.36**	**3.29**
	9	2.147	-10.32	1.8768	0.84	3.208
	10	2.085	-6.352	2.8556	-	-
	11	2.022	-4.492	3.9533	-	-

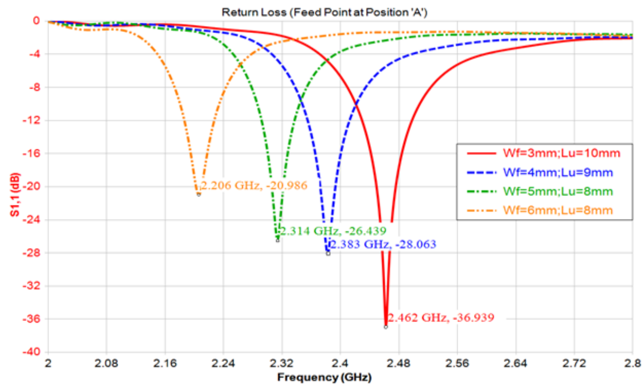


Fig. 4: Variation of return loss with frequency at different value of *Wf* for the feed point at the position A.

Fig. 4 depicted the comparison between the best selected result of antenna designs with the variation of *Wf* value and *Lu* value. The *Wf* value range from 3 to 6 mm while the *Lu* value range from 8 to 10 mm. The combination of different value of Wf and Lu lead to different performances of return loss, VSWR, and bandwidth. It can be observed that the antennas have very good return loss at 2.462 GHz, 2.383 GHz, 2.314 GHz and 2.462 GHz. Lastly, the best antenna parameter is at *Wf* equal to 3 mm with *Lu* equal to 10 mm where this antenna can has a higher S_{11} is about -36.939 dB and the impedance bandwidth of antenna is about 2.46% centered about 2.462 GHz.

3.2. The Feed Point at The Position B(0,2.5) with Changing *Wf* and *Lu*

From Table 4, it shows the simulated data on analysis of different parameters value for the feed point at the position B(0,2.5). This is based on the changes of *Wf* from 3 mm to 6 mm and *Lu* from 6 mm to 12 mm with 2 mm step from center position. It can be seen that the increment of *Wf* and *Lu* leads to the decrement in the resonant frequencies (*fres*) ranges from 2.512 GHz to 2.16 GHz. It can also be observed that the resonant frequency shift to lower frequency range with changes of feeding point positions.

Table 4: Analysis on Different Parameters Value for The Feed Point at The Position B

Wf (mm)	*Lu* (mm)	*fres* (GHz)	S_{11} (dB)	VSWR (V)	BW%	Gain (dB)
3	6	2.521	-4.452	3.966	-	-
	8	2.524	-6.32	2.869	-	-
	10	**2.526**	**-28.769**	**1.07**	**3.76**	**1.716**
	12	2.59	-12.523	1.619	2.46	1.568
4	6	2.472	-4.774	3.730	-	-
	8	2.436	-13.779	1.515	2.30	2.359
	10	**2.425**	**-11.712**	**1.709**	**2.60**	**2.397**
	12	2.396	-9.358	2.033	-	-
5	6	2.372	-9.225	2.057	-	-
	8	**2.328**	**-35.38**	**1.085**	**2.90**	**3.430**
	10	2.3	-7.594	2.432	-	-
	12	2.281	-9.501	2.007	-	-
6	6	2.268	-15.474	1.405	2.07	3.060
	8	**2.218**	**-17**	**1.328**	**2.52**	**3.126**
	10	2.184	-7.0405	2.601	-	-
	12	2.16	-10.391	1.866	1.47	2.760

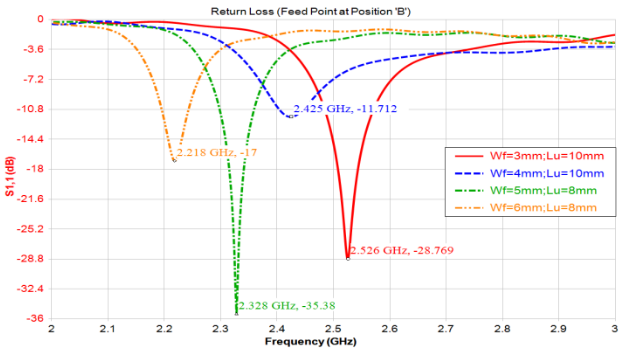


Fig. 5: Variation of return loss with frequency at different value of *Wf* for the feed point at the position B.

Fig. 5 shows the variation of S_{11} values between the best result selected from different distances *Wf* of 3 mm, 4 mm, 5 mm and 6 mm respectively for the feed point at the position B. The arms length (*Lu*) are also different. *Lu* are 10 mm with (*Wf*=3 mm), 10 mm with (*Wf*=4 mm), 8 mm with (*Wf*=5 mm) and 8 mm with (*Wf*=6 mm). From Fig. 5, it can be observed that the antennas have very good return loss at 2.526 GHz, 2.425 GHz, 2.328 GHz and 2.218 GHz. Lastly, the best antenna is about *Wf* equal to 5 mm with *Lu* equal to 8 mm caused this antenna has higher S_{11} is about -35.38 dB and the bandwidth of antenna is about 2.90% centered about 2.328 GHz.

3.3. The Feed Point at The Position C(0,7.5) with Changing *Wf* and *Lu*

Table 5 shows the simulated of analysis on U-slot antenna on different parameters value for the feed point at the position C(0,7.5), based on the changing of *Wf* from 3 mm to 6 mm and *Lu* from 11 mm to 14 mm. An increase in *Wf* and *Lu* were leading to decrease in the resonant frequencies (*fres*) from 2.828 GHz to 2.476 GHz. It can also be observed that the resonant frequency shift to lower frequency with increasing value of *Wf* and *Lu*.

Table 5: Analysis on Different Parameters Value for The Feed Point at The Position C

Wf (mm)	*Lu* (mm)	*fres* (GHz)	S_{11} (dB)	VSWR (V)	BW %	Gain (dB)
3	11	2.828	-6.814	2.679	-	-
	12	2.688	-10.699	1.824	1.34	3.011
	13	**2.568**	**-21.712**	**1.179**	**2.69**	**3.317**
	14	2.46	-14.197	1.485	1.79	3.213
4	11	2.798	-10.253	1.887	0.86	2.985
	12	2.668	-18.419	1.273	2.71	3.270
	13	**2.556**	**-18.945**	**1.255**	**2.35**	**3.264**
	14	2.454	-8.236	2.265	-	-
5	11	2.792	-16.003	1.377	2.77	3.344
	12	**2.668**	**-27.382**	**1.089**	**2.7**	**3.431**
	13	2.562	-11.206	1.759	1.13	3.452
	14	2.465	-5.509	3.258	-	-
6	**11**	**2.798**	**-27.728**	**1.086**	**2.75**	**3.232**
	12	2.676	-15.804	1.387	2.21	3.242
	13	2.573	-8.269	2.257	-	-
	14	2.476	-4.185	4.231	-	-

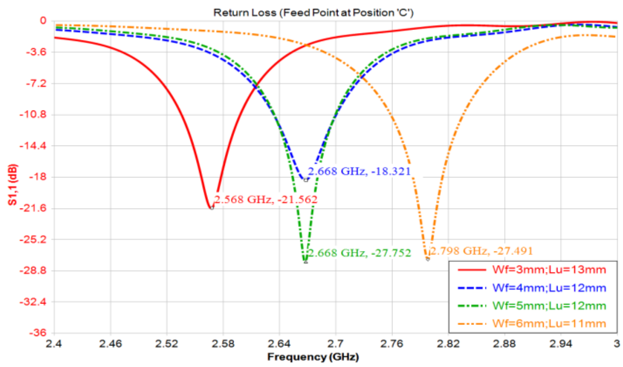


Fig. 6: Variation of return loss with frequency at different value of *Wf* for the feed point at the position C.

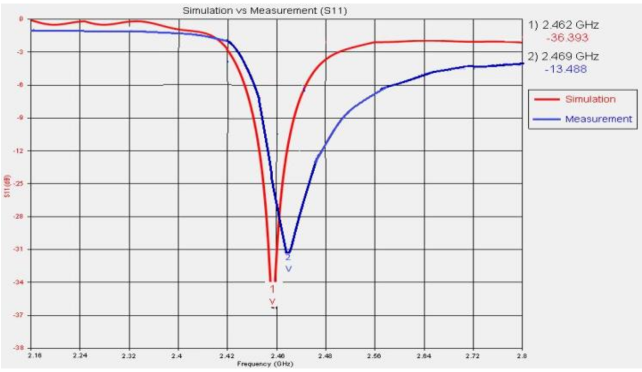
Fig. 6 shows the comparison of S_{11} between the best result selected from different distances *Wf* of 3 mm, 4 mm, 5 mm and 6 mm respectively for the feed point at the position C. The arms length (*Lu*) are also different. *Lu* are 13 mm with (W_f=3 mm), 12 mm with (W_f=4 mm), 12 mm with (W_f=5 mm) and 11 mm with (W_f=6 mm). From Fig. 6, it can be observed that the antennas have very good return loss at 2.568 GHz, 2.668 GHz and 2.798 GHz. Lastly, the best antenna is about *Wf* equal to 5 mm with *Lu* equal to 12 mm caused this antenna has higher S_{11} is about -27.752 dB and the impedance bandwidth of antenna is about 2.70% centered about 2.668 GHz.

3.4. The Simulation and Measurement Results

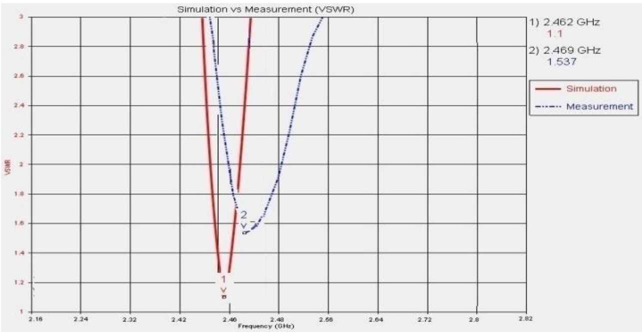
The U-slot antenna for the feed point at the position A with parameter 1 (*Wf* =3 mm; *Lu*=10 mm) and the feed point at the position B with parameter 2 (*Wf*=5 mm; *Lu*=8 mm) have been fabricated and measured to compare with the performance of the simulation result. The antenna is characterized using vector network analyser. The simulated and measured S_{11} and VSWR are compared in figures below.

3.4.1. Simulation vs Measurement of U-slot antenna for the feed point at the position A with parameter 1 (*Wf*=3 mm; *Lu*=10 mm)

In Fig. 7, the simulated values of the S_{11} and VSWR of the final design of U-slotted microstrip patch antenna are compared with the measured data. The measured S_{11} value and VSWR of the antenna with parameter 1 condition is -13.488 dB and 1.537 V respectively.



(a)



(b)

Fig. 7: The simulation and measurement (a)$S_{11}$and (b)VSWR of U-slot antenna for the feed point at the position A with parameter 1 (*Wf* =3 mm; *Lu* =10 mm)

The measured impedance bandwidth of antenna is about 3.68% centered about 2.469 GHz. The measured return loss and VSWR shifts to higher frequency. The deviation is mainly caused by fabrication inaccuracy, may be caused by losses on the patch.

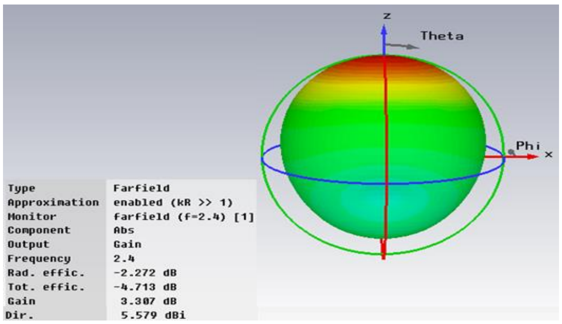


Fig. 8: The Farfield of the U-slot antenna for the feed point at the position A with parameter 1 (*Wf*=3 mm; *Lu*=10 mm)

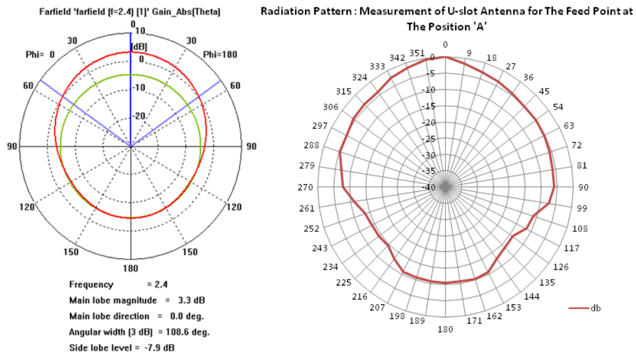
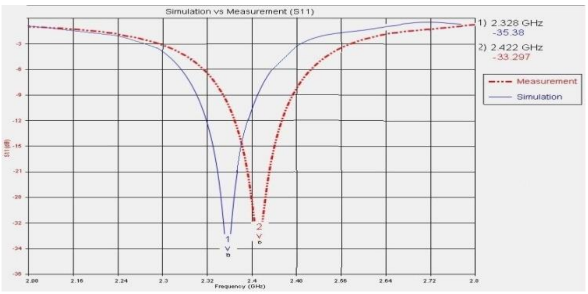


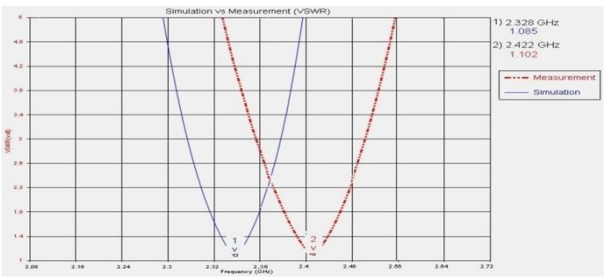
Fig. 9: Radiation pattern of the U-slot antenna for feed point at the position A with parameter 1 (*Wf* =3 mm; *Lu* =10 mm) (a) simulation (b) measurement.

The simulated and measured radiation patterns of U-slot antenna for the feed point at the position A with parameter 1 (*Wf*=3 mm; *Lu*=10 mm) are shown in Fig. 8 and 9, respectively. From Fig. 8, the gain of antenna is about 3.307 dB and directivity of antenna is about 5.579 dBi. From Fig. 9, the 3 dB beam widths of the antenna is about 108.6˚. The main lobe magnitude and side lobe level are about 3.3 dB and -7.9 dB. The difference between simulation and measurement result occurred since radiation pattern process was not measured inside anechoic chamber.

3.4.2. Simulation vs Measurement of U-slot antenna for the feed point at the position B with parameter 2 (*Wf*=5 mm; *Lu*=8 mm)



(a)



(b)

Fig. 10: The simulation and measurement (a)S_{11} and (b)VSWR of U-slot antenna for the feed point at the position B with parameter 2 (*Wf* =5 mm; *Lu*=8 mm)

Fig. 10(a) shows the graph for return loss, S_{11}, between simulation and measurement values of U-slot antenna for the feed point at the position B with parameter 2 (*Wf*=5 mm; *Lu*=8 mm). The solid line represents simulation result while the dashed line represent measurement results. From simulation result, the obtained S_{11} value was −35.38 dB at resonance frequency 2.308 GHz, meanwhile, from measurement the result is −33.297 dB with resonance frequency shifted to the right at frequency 2.422 GHz. The difference between simulation and measurement might be due to the fact that human error such as measurement process. The other factors that contributed the differences are environmental effect and equipment error.

Fig. 10(b) shows the voltage standing wave ratio (VSWR) between simulation and measurement result. The dashed line represent measurement with the result 1.102 at frequency 2.422 GHz while solid line represent simulation result with the result of 1.085 at frequency of 2.308 GHz. A perfectly matched antenna would have a VSWR of 1:1. The measured impedance bandwidth of antenna is about 2.7% centered about 2.422 GHz. Reasonable good agreement between the simulation and measurement can be observed, although the measured return loss and VSWR shifts slightly to higher frequency.

The simulated and measured radiation patterns of U-slot antenna for the feed point at the position B with (*Wf* =5 mm; *Lu*=8 mm) are shown in Fig. 11 and 12, respectively.

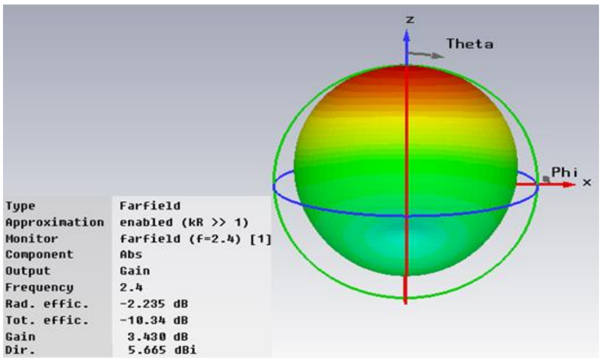


Fig. 11: The Farfield of the U-slot antenna for the feed point at the position B with parameter 2 (*Wf*=5 mm; *Lu*=8 mm)

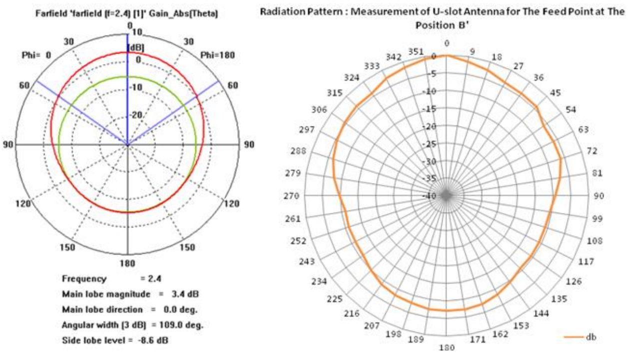


Fig. 12: Radiation pattern of the U-slot antenna for feed point at the position B with parameter 2 (*Wf* =5 mm; *Lu* =8 mm) (a) simulation (b) measurement.

From Fig. 11, the gain of antenna is about 3.430 dB and directivity of antenna is about 5.665 dBi. From Fig. 12, the 3 dB beam widths of the antenna is about 109.0˚. The main lobe magnitude and side lobe level are about 3.4 dB and -8.6 dB. The difference between simulation and measurement result occurred since radiation pattern process was not measured inside anechoic chamber.

4. Conclusion

In conclusion, the bandwidth of proposed antenna is 2.90% compared to without U-slot design where it only gives about 0.56% bandwidth. It can be said that the U-slot inserted into the patch can be used as enhancement technique for bandwidth of antenna. The effect of change in feeding point at position A and B gives variation of resonant frequency where it shifted the resonant at lower frequency side while increasing the value of *Wf* and *Lu*. While for effect of changes on feeding point at position C gives effect on shifted resonance frequency to higher frequency side. Clearly, the arm length of U-slot, the distance between feed point and the arm U-slot, and the position of feed point remain important factors in achieving band frequency operation and further parametric studies on these variable, as well as U-slot positions are required.

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