International Journal of Electronics Engineering Research.
ISSN 0975-6450 Volume 16, Number 1 (2024) pp. 1-18

https://dx.doi.org/10.37622/IJEER/6.1.2024.001-018

Some Aspects on Design, Simulation, Fabrication, and Analysis of a Multi Frequency Micro-Strip Antenna

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Abstract

In this work we discussed in details about the fabrication of a rectangular micro-strip antenna with an inclined slit of 100µm width for multi band operation. A simple rectangular micro-strip antenna is first designed for its operation in the S-band at 2.43 GHz. Then, we introduced a 100µm inclined slit on the antenna connecting the two radiating edges which results in multi band operation. Simulations are performed to study the effect due to the slit at different locations of the antenna with different angle of inclination. Prominent result of multi band operation in L and S-bands are observed with the slit introduced on it. Considering the simulation results, antenna prototypes with the best configuration are fabricated which show best results for multi band operations. Various parameters of the fabricated antenna are measured experimentally and are compared with the simulation results. The proposed method is simple and it can be fabricated easily to achieve best results.

Keywords:- ***Inclined, slit, FR-4 substrate, dual-band***

INTRODUCTION

To meet the diversified requirement in advanced communication systems, it is essential to assemble several antennas in one device, which obviously escalate the cost and size of the system. Sometimes, due incompatibility of electromagnetic (EM) wave among different antennas, the overall system performances may be degraded. To overcome these drawbacks, the multiband antennas are becoming highly preferable. In many applications, dual band characteristics are essential instead of single band. Now-a-days, in wireless communication systems, such as: (a) WLAN, (b) WiMAX, (c) mobile phone, and (d) satellite communication have been popularly applied in public internet hotspots, home, and business areas. For these applications, to develop new systems, multi band antennas are required. Microstrip antennas (MSA) are becoming popular in microwave communication, as it meets the emerging challenges in respect of size, performances and cost [1-3]. Despite the advantages of such antenna such as: (i) light weight, (ii) low profile, and (iii) ease of fabrication, a major drawback of it is the narrow bandwidth [4]. However, this drawback can be overcome by making the antenna to resonate at multiple frequencies. Multi bands MSA is highly effective because, different band allocated can be achieved by using a single one. Multiple resonances within the same physical geometry are mainly achieved by changing the electrical length for the current distribution on the MSA. The performance of it is mainly depends on the substrate and its geometrical configurations [4]. The authors, in their earlier works, have discussed the results of their preliminary works for achieving multi band operation by cutting inclined slit on a MSA and presented elsewhere [5, 6, 7]. Reported works includes use of shorting post [8, 9], placing of stubs over the patch or feed line [10, 11], using meander line along with the MSA [12,13], planar inverted, as well as various truncated structure on the radiating patch [14-19] etc. for achieving multi band operation. A common method for achieving a multiband is to cut slots and slits of different shapes on the patch [20-28], the main challenges as reported by other researcher are to determine the proper position of the shorting posts, stubs, slots etc. and measurements of the width and length of the slots, which leads to an overall complicated process to design the antenna.In the proposed work, we have designed and developed a multi band MSA for wireless communication system to operate at 1.8 GHz and 2.4 GHz by cutting a slit with an inclination angle over the MSA rather than other classical approach. A MSA is designed and simulated for its operation at 2.43 GHz. This is followed by introduction of a slit of width 100μm placed with an inclination angle on it connecting the two edges. Results are observed through simulations for different slit positions and inclination angles to have an insight for impact of the slit on the overall performance. This is followed by fabrication of antenna prototypes. The main objective of our proposed work is to design a MSA for multi band operation by using a simple method instead of the complicated methods reported by the other research group.

Fig.1 shows the block diagram of the approach for the proposed work.

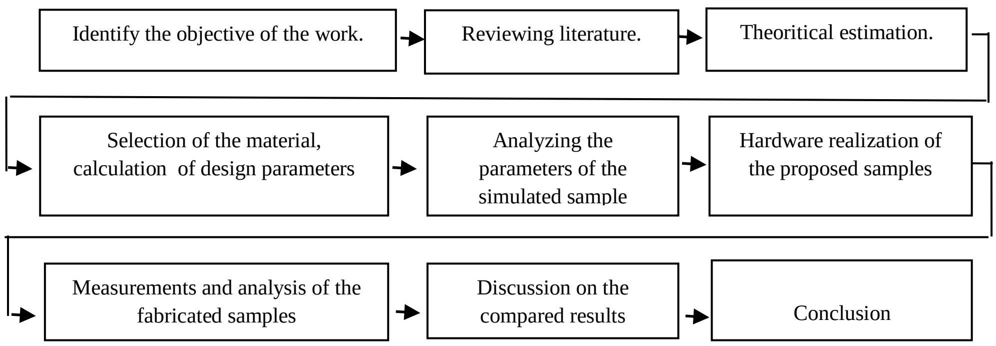

Figure.1: Block diagram of the approach

LITERATURE REVIEW

Works on shorting post for obtaining miltiple band has been reported by P. Bora and S. Bhattacharyya in 2015. Two shorting posts were incorporated at the two tips of the arms of a V-shaped MSA to operate with resonant frequencies at 5.41 GHz and 8.4 GHz [6]. T. Fujimoto and K. Tanaka in 2006 reported a stacked square-shaped MSA and achieve a dual-band operation at 2.4 GHz and 5.2 GHz [7].

A. Desmukh, et al. reported a dual band MSA in 2012 by using an open circuit stub on edge of the MSA. The stub of quarter wavelength is chosen, that offers capacitive and inductive impedance around the resonant frequencies of the MSA [8]. Use of stub for achieving multiband has also been reported by A. A. Chaudhari and R. K. Gupta in 2018 [9]. More than 20 dB isolation has been obtained by employing a stub in ground plane and by placing a stub in the feed line, The antenna was designed to operate at 2.1-2.7 GHz, 3.3-3.7 GHz and 4.9-5.35 GHz frequency bands.

Multi band MSA design by using a meander line had been reported in 2014 by X. Liu, Y. Li and W. Yu for its use in WLAN applications (2.4-2.484GHz and 5.15-5.825GHz). They reported a tapered rectangular MSA connected to 50Ω micro-strip feed-line that produced upper frequency band. The meander line which is incorporated with the ground plane (partial) produced lower frequency band [12]. Another work on printed meander-line MSA with a modified shaped ground plane and a back-coupled MSA was reported by A. Khaleghi in 2007 which is operated at 2.45 GHz and 5.25 GHz [13].

Planar inverted F-antenna (PIFA) with a parasitic element for multi band operation had been reported by F. N. M. Redzwan, et al. in 2014 for its use in LTE and WiMAX mobile communication [14]. A. V. Gevorkyan in 2017 designed and developed an E-shaped patch for achieving a multi band operation with its frequency of operation at 1.88 GHz and 2.55 GHz [15]. Work on a corrugated Y-shaped patch antenna for a multi band operation was proposed and reported by K.K. Naik, et al. in 2018 [16]. The antenna shows a resonance at 4.19 GHz, 8.79 GHz and 13 GHz, which can be used for radio communication, satellite communication and aeronautical radio navigation application. B. R. S. Reddy and D. Vakula reported a multi band antenna with truncated patch and fractal defected ground structure in 2015 for wireless application. The reported dual frequencies are at 1.575GHz and 1.227 GHz [17].

R. Palla and K. Naikketavath in 2020 reported on multi band antenna where the multi band operation was achieved by introducing different slits on a single band antenna. The antenna shows a multiple resonance at C-band (6.51 GHz), X-band (8.25 GHz, 9.96 GHz, 10.52 GHz) and Ku band (14.99 GHz). Also, defected ground method has been used to increase the bandwidth [18]. Antenna having slit and defected ground structure (DGS) has been also reported by S. Bondili, H. Prasad and V. S. Prasad in 2020, where the antenna shows a multi band operation with its operating frequencies at 3.271GHz, 4.92GHz, 6.35 GHz and 11.04GHz [19].

S. K. Dubey, et al. reported a U-slot loaded MSA for multi band operation in 2014. The MSA shows a resonance at 1.385 GHz and 2.385 GHz [20]. A dual band MSA with U shaped slot has been also reported by J. Ghalibafan, A. R. Attari and F. H. Kashani in 2010. The dual band is achieved by feeding the U-shaped slot via a broad band L-probe where the antenna shows the operation at frequencies of 2.31GHz and 3.78GHz [21]. Y. Liu, Z. Niu and X. Wang designed and reported a multi band antenna with H-shaped slot in 2009 for 5 GHz and 2.4 GHz wireless communication [22].

Combination of slits and slots on a MSA has been reported by R. Palla and D. Gopi in the year 2021, where the combinations allowed the MSA to operate in multi band at 1.81 GHz, 4.64 GHz, 5.39 GHz and 12.98 GHz for its use in aircraft surveillance, satellite radio and certain radar applications [23]. Work on multiband MSA has been reported by H. Hussain, H. Mohammed and J. Ali in 2020. The multi band operation was achieved by using a slot annular ring structure in the ground plane. It helps the antenna to resonate at 1.53-2.11 GHz, 2.9-3.34 GHz, 4.2-4.75 GHz and 4.94-5.39 GHz [24]. F. I. Khalifa, et al. reported a U-shaped slot MSA effectively operated at 2.4GHz and 4.6GHz for WLAN applications. The radiating patch has U-shaped slot, so it provides two current paths which lead to the two resonant frequencie [25]. Ajay Singh, et al. designed a V-slot antenna to generate resonant frequencies of 3.2GHz, 5.5GHz, 8.2GHz and 9.2GHz [26]. In 2021, Mahatma A. G and P.M. Hadalgi has reported a MSA by using loading rectangular slot in the form of C-shaped on the MSA, which was resonating at three different frequencies of 1.40GHz, 5.23GHz and 5.88GHz [27]. A rotated E-shaped MSA rotated by 270^0 is proposed by Apleen Kaur, J. Kaur and Naveen Kumar [28] in the year 2019.

Xi Wang, et al. had reported an MSA comprising of modified asymmetric bi-conical and six printed dipoles with concentric placement in a microstrip patch in 2013.The designed antenna was predicted for use in 2G/3G/LTE applications [29].

J. Dong, X. Yu and L. Deng reported a multi band antenna which comprises of two groups of mirrors, symmetrical internal and external curved structures that gives low frequency and high frequency excitation respectively. The designed antenna consists of a protruded stub with two rectangular slots on its back. It exhibits a dual band operation range in 0.74-1.00 GHz and 1.57-2.80 GHz frequencies [30].

Work on a multi band MSA having three arms radiating elements with different length has been reported by K. S. Lubis, et al. in 2016. The multiband operation was achieved due to the three different arm’s length of the MSA that resonates at three different frequencies (915 MHz, 2440 MHz and 5250 MHz) [31]. Premavani, C. Kalpana and S. N. Mulgi had reported a monopole MSA coupled with inverted U-slot ring in 2021for quad-band operation. The reported MSA operates in the frequency range of 1.5 GHz to 10 GHz [32]. In 2017, P. Amala, et al. reported a monopole isosceles triangular patch (MITP) antenna which shows a dual band operation with its frequency of operation at 15.1 GHz and 16.4 GHz [33].

A U-shaped feed probe and a double slots radiating MSA was reported by G. Yang, J. Li, R.Xu, J. Yang and Y. Qi. By adjusting the size of the slots, a multi band operation had been achieved [32]. Ground plane has been shifted to an optimum position and a strip has been attached to the ground plane to generate resonant frequencies of

2.78GHz and 5.54GHz [35].

A corner cut inset-fed dual band slot MSA generating frequencies of 1.76GHz and 2.4GHz was reported by R. G. Jangampally, V. K. Rao. Nalam and M. P. Avala [36]. By inserting two rectangular slots in the MSA and three slots in the ground plane, the antenna resonates at 3.5GHz and 5.8GHz [37].

A multi band MSA with DGS for various wireless applications was reported by D. K. Patidar and S. Chouhan in 2021 [38]. Two-layer stacked patch for GPS and WiFi applications was reported by Wai Mar Oo et al. in 2022 [39]. Md. T. Mushtaq et al. had reported a patch antenna having semi circular slot in the patch and defected ground structure to generate dual frequencies at 3.4GHz and 5.5GHz [40].

By designing multi band MSA, we can reduce the cost and overall size of the communication system. From the literature survey, it is observed that the earlier reported works for achieving multi band operation have complex structure and are difficult to fabricate. So, we proposed a simple technique to fabricate a rectangular MSA to generate multi band frequency which may be useful for communication systems.

METHODOLOGY

Initially, the dimension of the rectangular MSA(RMSA) is calculated for a single resonant frequency and then simulation is carried out in HFSS (Version. 13) platform. In an attempt to obtain a multi-band operation a slit is introduced on the RMSA. Best performed RMSA is achieved by optimizing the position (p) and the inclination angle (θ) of the slit.

The following steps are followed to design the proposed RMSA:

(a) The frequency range for which the RMSA is to be designed is selected.

(b) Suitable material to design the RMSA based on profile, size etc. is selected.

(c) The dimension of the RMSA is calculated for the required specifications.

(d) Simulation of the RMSA by using EM simulation software tool (HFSS) for analysis of the design.

(e) The parameters of the RMSA are varied in order to find the best performance.

(f) An inclined slit is cut on the RMSA and simulation is carried out for different slit position and angle.

(g) Finally, the hardware of the RMSA is fabricated and measurements are carried out.

(h) Performance validation and comparison of the simulation and experimental results are then done.

Figure.2 shows the flow diagram of the proposed design of the RMSA.

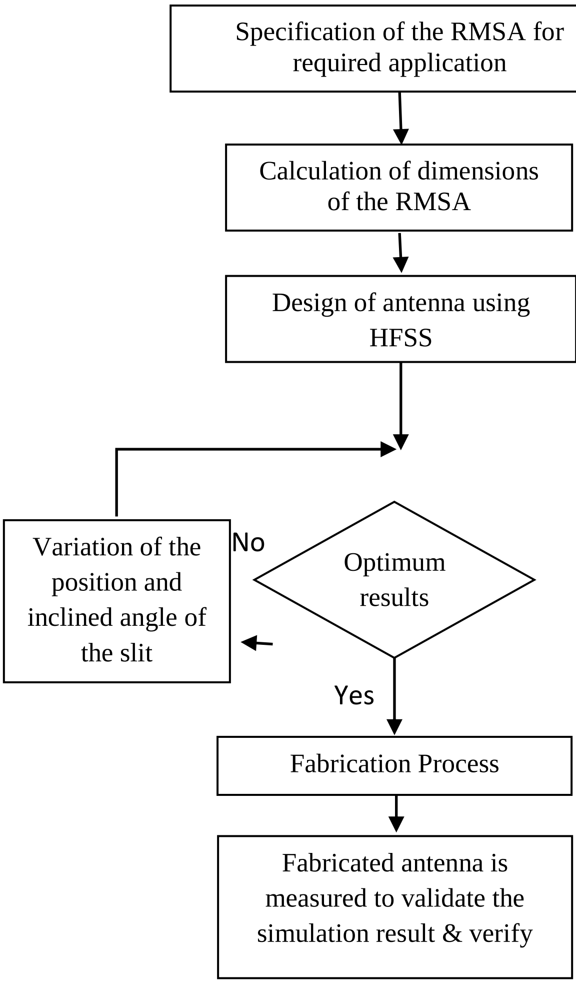

Figure.2: Flow diagram of proposed design

3.1 Design Consideration

The RMSA is designed to have an operation in the dominant TM_{10} mode resonating at 2.43 GHz whose resonant frequency can be expressed as [6]:

$$f_r = \frac{1}{2\sqrt{\mu_o \varepsilon_o}} \sqrt{\left(\frac{m}{l}\right)^2 + \left(\frac{n}{w}\right)^2} \qquad (1)$$

where $\boldsymbol{\mu_o}$ = permeability of the medium, $\boldsymbol{\varepsilon_o}$ = permittivity of the medium, $\boldsymbol{l}$ = length of RMSA, $\boldsymbol{w}$ = width of RMSA, and $\boldsymbol{m}$, $\boldsymbol{n}$ = 0, 1, 2, 3… In multi frequency resonant RMSA the cutting slit or inserting slots provides two current paths L_1 and L_2 which leads to two resonant frequencies f_1 and f_2 [19]. Now, the approximated values of f_1 and f_2 in accordance with L_1 and L_2 can be expressed as:

$$f_1 = \frac{v_0}{2L_1\sqrt{\varepsilon_r}} \qquad (2)$$

$$f_2 = \frac{v_0}{2L_2\sqrt{\varepsilon_r}} \qquad (3)$$

Where L_1 and L_2 are the average lengths of the current paths of first and second resonance frequencies, and v_0 is the speed of light in free space. FR-4 substrate is used to design the RMSA and micro-strip line feeding technique has been used to excite it. Thereafter, a slit with an inclination is introduced on the RMSA at different positions ***p*** and with different inclined angles ***θ***. Fig.3 (a & b) shows the schematic diagram of the RMSA proposed to fabricate. The parameters use to design the RMSA are given in Table 1. The ***p*** is varied in steps of 1mm along the width of the patch, from one of the non radiating edges as given in Fig.3 (b). Furthermore, for each value of ***p*** the angle ***θ*** is varied within a range 35˚ to 70˚ in steps of 5˚ assuring that the slit is being inclined over the patch. Fig. 4 (a & b) shows the fabricated prototypes of the RMSA.

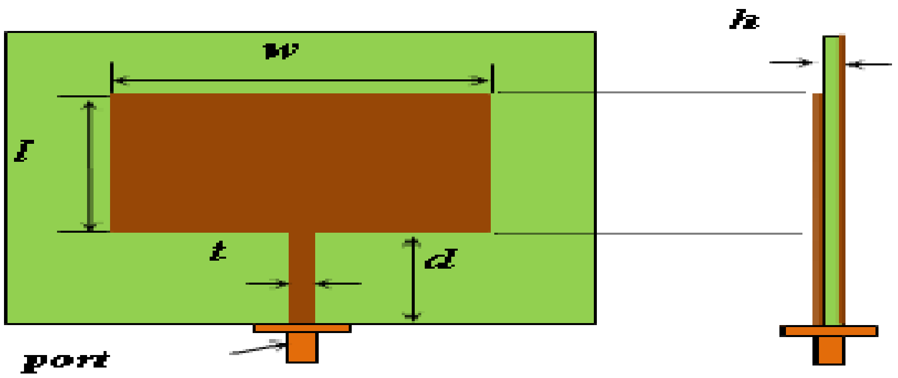

Figure.3 (a): Schematic diagram of the antenna

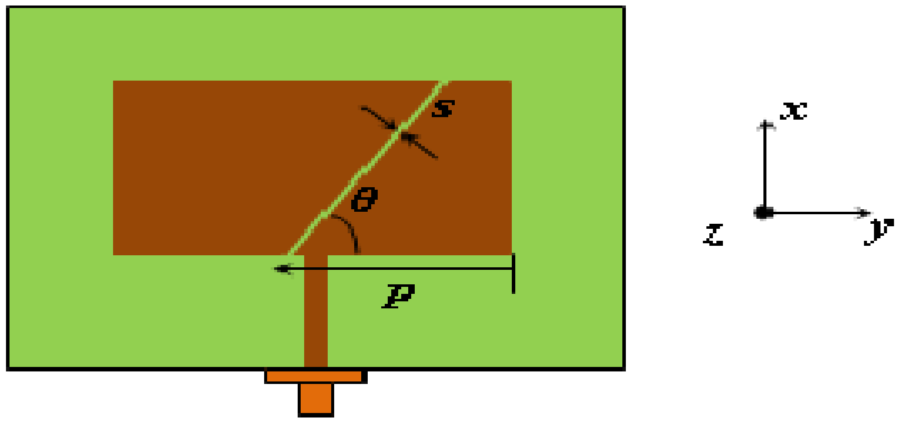

Figure.3(b): Schematic diagram of the antenna with inclined slit.

Table 1: Design Parameters of the RMSA

Parameters	**Values/ Dimensions**	**Material**
f_r	2.4 GHz	---
Ground	W_g=60mm, L_g=60mm	Copper
Substrate	W_s=60mm, L_g=60mm, h_s=1.5mm	FR-4
Patch	w=47mm, *l*=28.2mm	Copper
Feed line	W_f (t)=1.8mm,L_f (d)=15mm	Copper
Slit	s=100µm	---
p	1, ….,47mm	---
θ	35˚,..,70˚	---

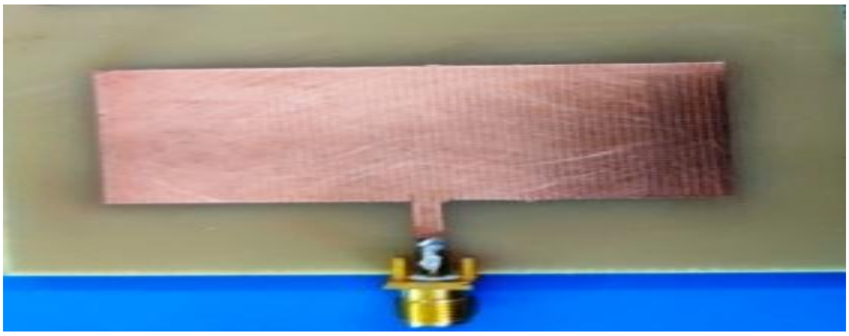

Figure.4(a): Fabricated RMSA prototypes without inclined slit

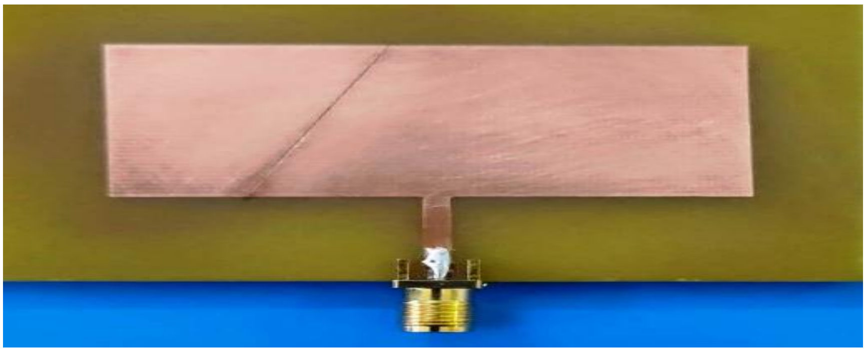

Figure. 4(b): Fabricated RMSA with inclined slit

1. Experimental Results

The prototypes are fabricated based on the best antenna configuration obtained from the simulation results. The matching performances and the radiation pattern measurements are carried out for the fabricated antennas with different slit position and angles.

4.1 Return loss measurement

The return loss measurement of the fabricated RMSA is recorded by using Vector Network Analyzer (Rhode and Schwartz ZNB 20). Fig.5 (a & b) show the simulation and experimental results of return loss for the RMSA with different values of ***p*** and ***θ***. From the observed return loss plots it is found that the simple RMSA shows a single resonant frequency in the S-band (2.4 GHz). As the slit is introduced the RMSA ensure a multi band behavior. As observed from the measured return loss, a prominent multi band behavior is observed for the RMSA with the slit placed at ***p*** = 39, 38, and 37mm for inclined angle of ***θ*** = 60˚, 65^0, and 70^0 respectively with its frequencies of resonance in the required L and S band. Table 2 shows the experimental and simulated results of return loss at their corresponding resonant frequencies. The observed deviations in the simulated and experimental results are due to tolerance during the fabrication of the RMSA, while cutting the slit or in the soldering process of the connector.

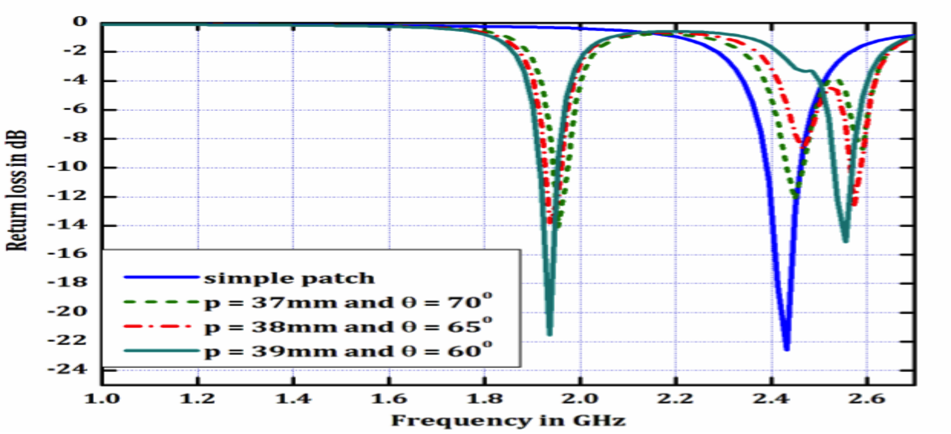

Figure.5(a): Simulated return loss plots of the patch antenna for different ***p*** and ***θ***

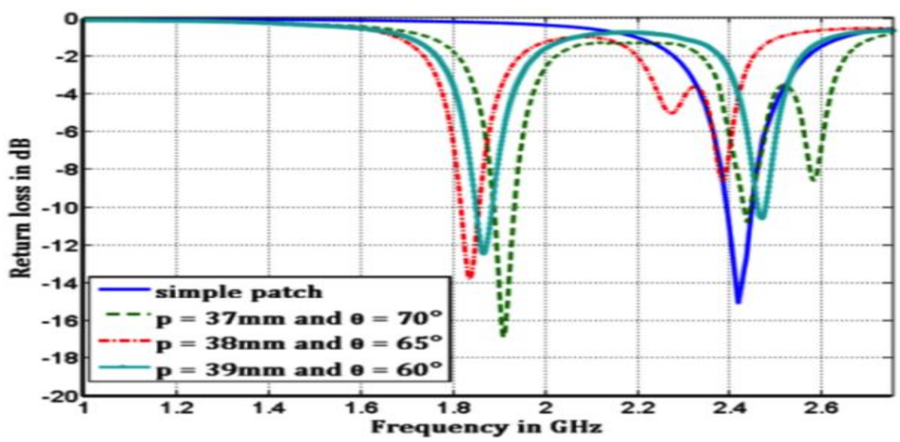

Figure. 5(b): Measured return loss plots of the patch antenna for different ***p*** and ***θ.***

1.1. Voltage Standing Wave Ratio

The value of voltage standing wave ratio (VSWR) should be from 1 to 2. The VSWR for different configuration of the RMSA at different frequencies of resonance are given in Table 2. The relation between VSWR and return loss (S_{11}) can be established as equation (2) as in [4]:

$$VSWR = \frac{1+10^{\frac{-S_{11}}{20}}}{1-10^{\frac{-S_{11}}{20}}} \qquad (2)$$

Table 2: Simulated and experimental return loss and VSWR at their corresponding resonant frequencies

Antenna configuration			Lower resonant frequency(f_1) (GHz)	Return loss (f_1) (dB)	VSWR (f_1)	Upper resonant frequency(f_2) (GHz)	Return loss (f_2) (dB)	VSWR (f_2)
Simple patch	Simulated		---	---	---	2.43	-22.60	1.16
	Measured		---	---	---	2.40	-14.71	1.44
Patch antenna with diagonal slit	***θ*** =70° ***p*** = 37mm	Sim.	1.95	-14.10	1.49	2.44	-12.20	1.65
		Meas.	1.91	-16.66	1.34	2.43	-10.58	1.83
	θ =65° ***p***= 38mm	Sim.	1.93	-13.82	1.51	2.57	-12.58	1.61
		. Meas.	1.83	-13.37	1.54	2.38	-8.31	2.22
	θ =60° ***p*** = 39mm	Sim.	1.93	-21.55	1.18	2.55	-15.13	1.42
		Meas.	1.86	-12.24	1.65	2.47	-10.21	1.89

1.2. Gain, Directivity and Efficiency

The gain of RMSA is defined as directivity times, a factor representing the radiation efficiency, which is defined as the ratio of the radiated power to the input power [29]. The values of gain, directivity and efficiency for the fabricated RMSAs as per result of the simulations are given in Table 3.

Table 3: Simulated results of gain, directivity and efficiency at their corresponding resonant frequencies

Antenna configuration	Resonant frequency (GHz)	Gain (dB)	Efficiency	Directivity (dB)
Solid	2.43	4.87	0.63	6.87
$\theta = 70^0$ p=37mm	1.95	2.21	0.41	6.10
	2.44	4.86	0.63	6.87
$\theta = 65^0$ p=38mm	1.93	2.11	0.40	6.01
	2.57	4.81	0.62	6.80
$\theta = 60^0$ p=39mm	1.93	2.13	0.41	6.07
	2.55	4.50	0.60	6.76

1.3. Radiation Pattern Measurement

Radiation patterns of proposed RMSA (with and without slit) are measured by using a PC automated turn table interfaced with the vector network analyzer, where a wideband horn antenna is placed at the transmitting side. The data are recorded for two principal planes at their resonant frequencies and are compared with the simulated radiation patterns. Experimental and simulation results of radiation patterns of the solid RMSA and RMSA having slits at ***p*** = 37mm and ***θ*** = 70˚ are shown in Fig. 6 (a & b), Fig.7 (a, b, c & d) respectively (——— experimental, ····· Simulated).

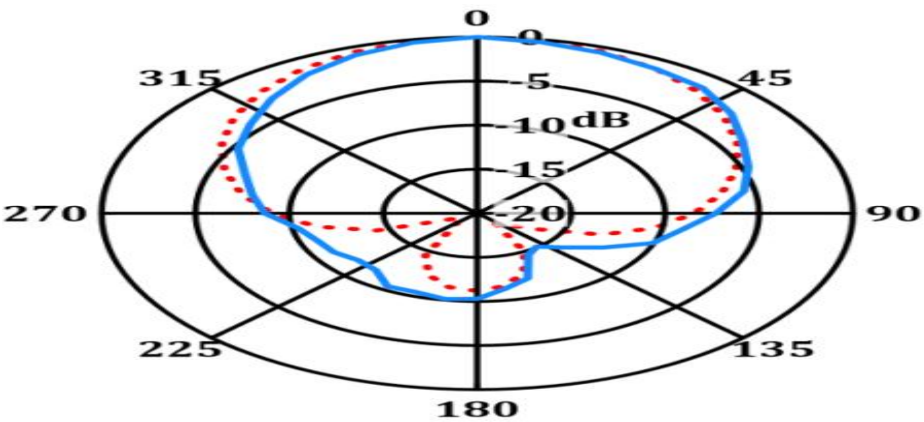

Figure.6 (a): x-z plane for simple patch at 2.43GHz

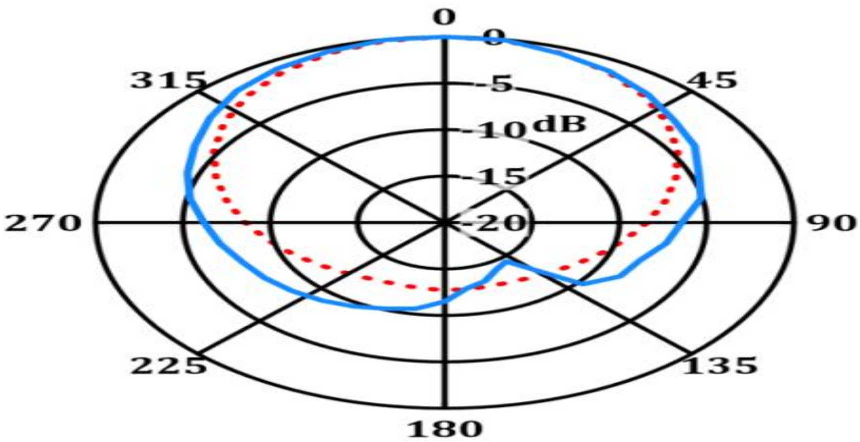

Figure.6 (b): y-z plane for simple patch at 2.43GHz

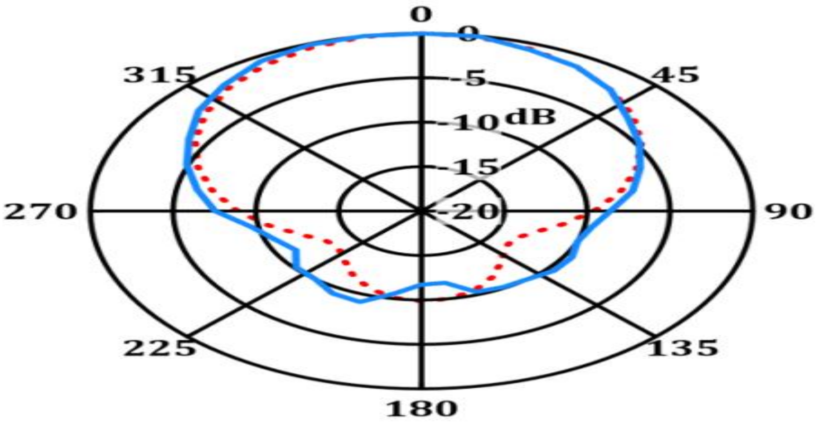

Figure.7 (a): x-z plane for ***p*** = 37mm and ***θ*** = 70˚ at 1.91GHz

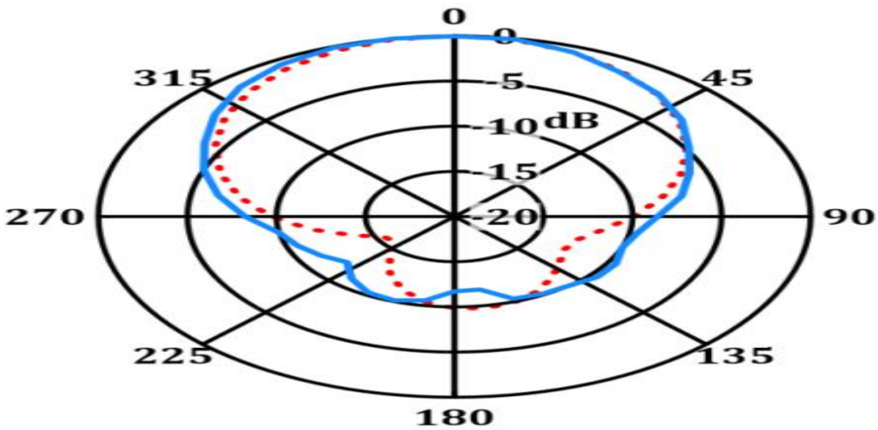

Figure.7 (b): y-z plane for ***p*** = 37 mm and ***θ***= 70˚ at 1.91GHz

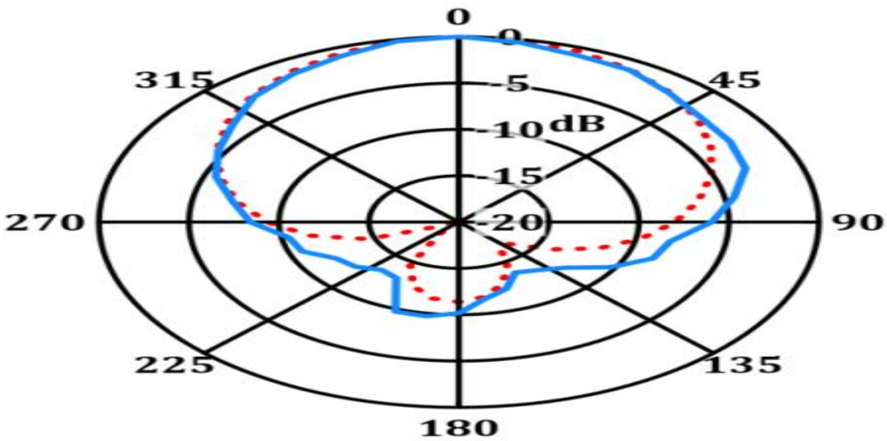

Figure.7(c): x-z plane for ***p*** = 37mm and ***θ*** = 70˚ at 2.43GHz

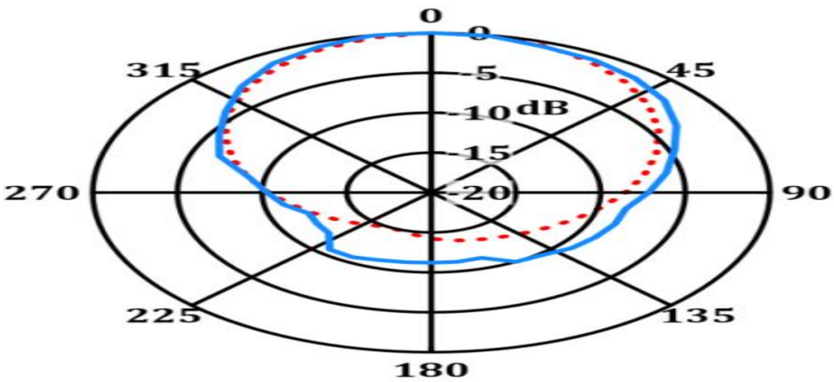

Figure 7(d) y-z plane for ***p*** = 37mm and ***θ*** = 70˚ at 2.43GHz

The simulated current distributions over the RMSA at their frequencies of resonance are shown in Fig. 8(a, b, & c) for the solid RMSA and the RMSA having slits at ***p*** = 37mm and ***θ***= 70˚.The simulated plot clearly shows the variations in current on surface of solid RMSA and the RMSA due to introduction of the inclined slit. For the higher resonant frequency near 2.44GHz the plots are along length of the RMSA, whereas, it is oriented along the width, which causes increase in the average length of the current path, that allow the RMSA to resonate at the lower frequency near 1.95GHz. Thus, both the experimental and simulated results with and without the inclined slit shows a broadside pattern for both the principal planes in the upper resonant frequency, whereas a slight tilt in the pattern from the broadside direction has been observed at the lower resonant frequency. The observed tilt in the pattern is due to the uneven current distribution along the RMSA width because of the inclined slit.

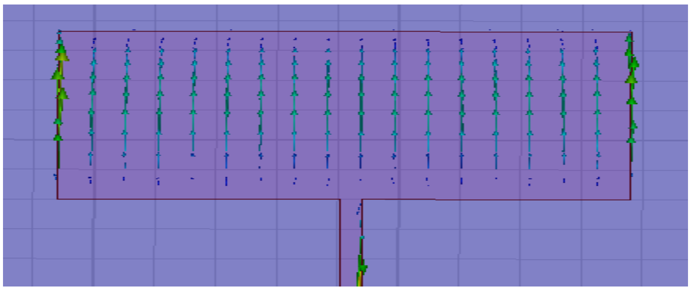

Figure.8(a) Surface current distribution over the simple patch at 2.43GHz

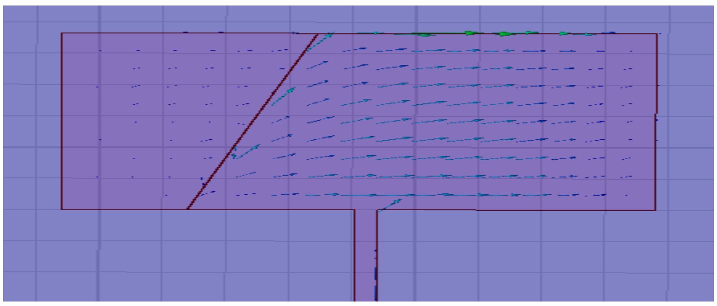

Figure.8(b) Surface current distribution over the patch for ***p*** = 37mm and ***θ*** =70˚ at 1.95GHz

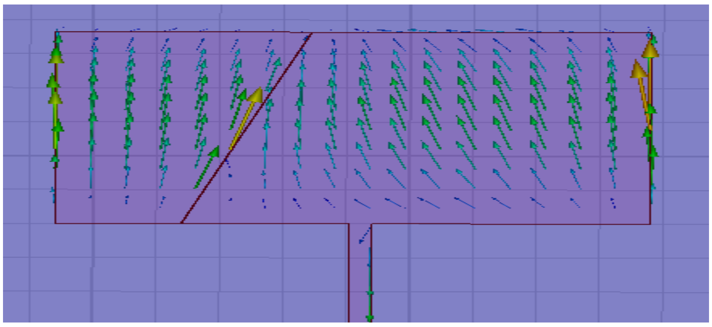

Figure.8(c) Surface current distribution over the patch for ***p*** = 37mm and ***θ*** =70˚ at 2.44GHz

The slit width is maintained at 100-µm. However, if we increase the slit width, the simulation result shows a shift in the frequencies of resonance to the higher region of the RF spectrum and resonates in S band only. The simulated results with the variation of the slit width for the RMSA having slit position ***p*** = 37mm at ***θ*** = 70˚ are shown in Table 4.

Table 4: Variation of slit width for the patch with slit position ***p*** = 37mm at ***θ*** = 70˚

Slit width	**100 µm**	**120µm**	**140 µm**	**180 µm**
Lower resonant frequency (f_1)	1.95 GHz	2.02 GHz	2.03 GHz	2.05 GHz
Return loss (f_1)	-14.10 dB	-14.70 dB	-18.65 dB	-20.54 dB
Upper resonant frequency (f_2)	2.44 GHz	2.45 GHz	2.45 GHz	2.47 GHz
Return loss (f_2)	-12.20 dB	-11.20 dB	-9.24 dB	-7.25 dB

DISCUSSION

From the simulation and experimental results it is observed that, the introduction of the inclined slit generate multiple frequency when placed at a given position. Amongst all the combination of slit positions and inclined angles over the RMSA, these presented configurations allow the RMSA to resonant at two required frequency of operation at L (1.8GHz) and S (2.4GHz) band. The configuration of the RMSA with slit position ***p*** = 37mm and ***θ*** = 70˚ shows a better matching performance for the multi band operation. The measured return losses are -16.66dB and -10.58dB at 1.91GHz and 2.43GHz respectively. From results of distribution of surface current as in Fig.8 (a), it is found that the distributed current direction is along length of RMSA, which generates upper resonant frequency. From the Fig. 8 (b), it is observed that the current distribution is oriented along width of the RMSA, which causes the increase in average length of the current path. As a result it generates lower resonant frequency.

It is also observed from experimental results that performance of the fabricated RMSA is poorer than the simulated one. This is due to some deformation in the introduction of the slit to the RMSA, or may be due to the excess etching of the sides of it. An optimum care is required to be taken during the time of fabrication of the RMSA for better performance.

CONCLUSIONS

The proposed simple technique may open the probability of achieving tuning operation of RMSA in two resonant frequencies. A detail comparison of results of the proposed RMSA with the results of some of the earlier reported works [35, 37] is given in the Table 5.

From Table 5 we can conclude that the primary advantage of the proposed RMSA to achieve multi band operation is in its simple design with lesser size as compared to earlier reported work with better performance.

Table 5 Comparison of reported and present work

Reported		
Antenna configuration	**Antenna size**	**Resonant frequency**
Corner cut inset-fed patch [35]	31×61.5 mm^2	1.76GHz 2.40GHz
Patch with DGS [37]	38×50 mm^2	1.81GHz 2.78GHz
Proposed RMSA		
Inclined slit ($\boldsymbol{p}$ = 37mmand $\boldsymbol{\theta}$ = 70˚)	28.2×47 mm^2	1.95GHz 2.44GHz
Inclined slit ($\boldsymbol{p}$ = 38mm and $\boldsymbol{\theta}$ =65˚)	28.2×47 mm^2	1.93GHz 2.57GHz
Inclined slit ($\boldsymbol{p}$ = 39mm and $\boldsymbol{\theta}$ =60˚)	28.2×47 mm^2	1.93GHz 2.55GHz

The results of the fabricated RMSA are in well agreement with the results of simulation. Further, due to the broadside radiation pattern and matching performances, the propose RMSA will be suitable for use in certain target applications such as: global positioning systems, aircraft surveillance, wireless communication (Bluetooth) etc. that mainly deals in L and S band operation.

Acknowledgment

Authors are thankful to the Head of the Dept. of Electronics and Communication Technology, Gauhati University, Assam, India for providing valuable suggestions and laboratory infrastructure during the work.

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