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Research Article

Effect of Slot Rotation on Rectangular Slot based Microstrip Patch Antenna

Priyanka†*, Ajay Kumar† and Rajat Arora‡

†Department of Electronics & Communication, Beant College of Engineering & Technology, Gurdaspur, Punjab-143521, India
‡Department of Electronics & Technology, Guru Nanak Dev University, Regional Campus Gurdaspur, Punjab-143521, India

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Abstract

In this paper, a rectangular slot based microstrip patch antenna is designed and their analysis is done to evaluate their effect due to rotation of slot for wireless communication applications. The proposed antenna is suitable for numerous applications such as bluetooth, wi-fi, WLAN, and other mobile communication systems depending on the angle of rotation. The results showed sufficient isolation among different resonant frequencies with improvement in gain and directivity. The results obtained had showed better improvement in the return loss and radiation pattern in comparison to the other existing slot antennas.

Keywords: *Microstrip patch antenna, rectangular slot, s-parameter, mobile communication, radiation pattern.*

1. Introduction

The most suitable antennas for most of the wireless communication applications including aerospace and mobile applications are microstrip patch antennas due to for their low weight, conformability, higher bandwidth and ease of installation (A. E. Daniel *et al*, 1995). However, due to continuous trend of miniaturization of communication devices, novel designs with wide bandwidth for multiple applications have become a challenging issue. This is due fundamental limitations of small antennas that is governed by the quality factor (Q) (K. F. Lee *et al*, 2011). Microstrip patch antennas posses certain major drawbacks like narrow-bandwidth, low gain, high return loss etc; despite several advantages (S. Arya et.al, 2012). Numerous advances in the design of compact microstrip antennas have been presented over the last years. Different shape modifications such as bending, folding or meandering can also provide an easy miniaturization technique. Several researches have been reported to overcome the drawbacks of such antennas (Y. P. Zhang *et al*, 2006). A single microstrip element is capable of achieving desired characteristics but some essential characteristics like high gain, beam scanning, or steering capability can only be achieved when the discrete radiators are arranged in the form of an array (K. Buell *et al*, 2006) (D. M. Pozar, 2006). Elements in a straight line located finite distance apart are called linear array. Elements in an antenna can be arranged to form linear or planar to achieve higher directivity with additional gain (R. Chair *et al*, 2005). Array antennas can perform many functions such as scanning the beam of an antenna system, increasing the directivity and bandwidth and performing various other functions which would be otherwise difficult to get from single element. But sometimes, these wide band solutions are drawback because the antenna receives other non-desired frequencies and some kind of a filtering network is needed to cancel such frequency range (J. Anguera *et al*, 2003) (A. Boag *et al*, 1995) (K. F. Lee *et al*, 2008). The alternate solution is the multi-frequency antenna that focuses only on the frequencies of interest.

This paper presents the design and analysis of an integrated antenna with a rectangular slot under the patch. A proximity feed is applied after analyzing the appropriate coordinates so that the designed antenna can behave well for different frequency applications. The effect of rotation of slot at various angles (0^0, 30^0, 45^0, 60^0, 75^0, 100^0, 130^0 and 145^0) has been taken to calculate the various parameters like s-parameters, VSWR, radiation pattern and gain of the following slot antennas. The results confirmed the formation of the proposed design with good gain and bandwidth for multi-frequency applications.

2. Mathematical Analysis

The dimensions of the antenna depend on the operating frequency range at which the micro-antenna is assumed to be operated (R. Arora *et al*, 2013) (S. Arya *et al*, 2012) (R. Arora *et al*, 2014) (K. O. Odeyemi *et al*, 2011) (F. Yang *et al*, 2001). The length and width

*Corresponding author: **Priyanka**

of the antenna can be calculated theoretically as equation (i) and equation (ii) respectively.

$$\Delta L = 0.412h \frac{(E_{reff} + 0.3)(\frac{w}{h} + 0.264)}{(E_{reff} - 0.258)(\frac{w}{h} + 0.8)} \quad (i)$$

where, E_{reff} is the effective dielectric constant, h is the height of dielectric substrate, and w is the width of the patch.

$$w = \frac{c}{2f_0\sqrt{\frac{(\varepsilon_r + 1)}{2}}} \quad (ii)$$

where, c is the velocity of light in free space, f_0 is the resonant frequency and ϵ_r is the dielectric constant of the substrate.

For sensible designs, some finite ground plane is essential beneath the substrate. For such practical design of microstrip patch antenna, it is necessitate that the ground plane should be greater than the patch dimensions by approximately six times the substrate thickness. Thus, the dimensions of the ground plane may be given as

$$L_g = 6h + l \quad (iii)$$

$$W_g = 6h + w \quad (iv)$$

The input parameters of the microstrip patch antenna are estimated using these above equations before finalizing the design for 3D modelling.

3. Antenna Design

The model is designed using FEM supported high frequency structure simulator (HFSS) software. 3D modelling is done on the Roger's RT/duroid 5880 (tm) substrate. Figure 1 shows the schematic layout of the designed slot based microstrip patch antenna. It consists of a small rectangular slot (empty rectangular space) cut on the substrate. The location of the proximity feed point is set using theoretical analysis. A rectangular patch is installed above the slot. The substrate and a patch are separated with each other by a dielectric material (air). Though both are independent of each other, however, the output depends on the distance, position and the orientation of a slot.

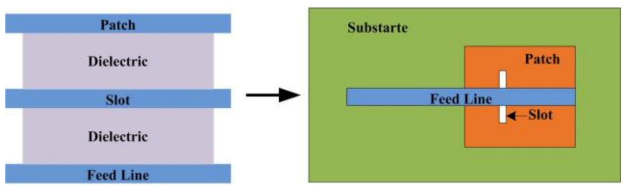

Fig.1 Layout of simulated slot patch antenna

The dimensions and the type of material used for designing the proposed micro-antenna are shown in Table 1. The antenna is enclosed in the rectangular (75 mm x 75 mm) shaped domain with thickness 1 mm. The domain contains air or vacuum inside it. The basis to enclose the micro-antenna in domain surrounded by a perfectly matched layer (PML) is to absorb the radiation from the antenna with minimum reflection so that it contains minimum return loss. Table 2 shows the material properties selected for different parameters that are equally responsible for the successful design of an antenna. The material chosen for the ground and the patch are same. The frequency range selected for the proposed design is in-between 1.0 GHz to 10.0 GHz that lies in the L, S, C and X-band of the frequency spectrum.

Table 1 Materials and Dimensions

Name	Height	Length	Width	Material
Substrate	3.0 mm	50 mm	50 mm	Rogers RT/duriod 5880 (tm)
Ground	-12.0 mm	50 mm	50 mm	Perfect electric conductor
Patch	0.5 mm	20 mm	15 mm	Perfect electric conductor
Feed Line	0.1 mm	40 mm	5mm	Perfect electric conductor

Table 2 Material Properties

Parameters	Rogers RT 5880	Air in rectangular domain
Permittivity (ϵr)	2.2	1.0
Permeability (µr)	1.0	1.o
Density (kg/m3)	-	1.16

A slot is cut in such a way that it provides soft and smooth edges. The feed line is selected in such a way that the designed microstrip patch antenna may work successfully for the number of frequency regions.

4. Results and Discussions

The results verify the alteration in frequency bands and bandwidth with respect to change in position of the feed point. For this design simulation, the processing speed of the computational machine is 3.4 GHz with 4 GB RAM. The virtual memory used while simulation is 2.1 GHz.

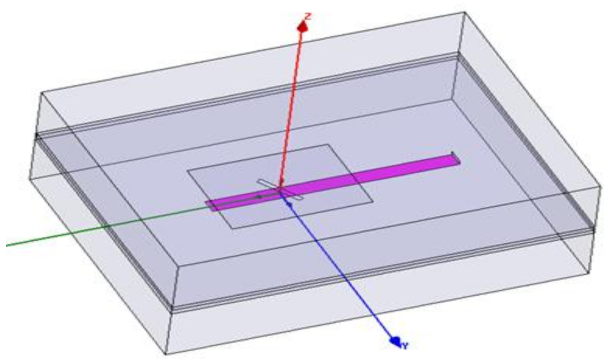

Fig.2 Schematic of the antenna design

Precise sized meshing is not selected to avoid the computational load. Frequency domain setting is selected for simulating the model. The characteristic impedance (Z_0) of the simulated design comes out to be 30Ω (approx). Theoretically, the value of Z_0 is 50 Ω that shows small existence of standing waves while propagation of RF signals. Figure 2 shows the schematic of the antenna design.

The effect of rotation of slot at various angles (0^0, 30^0, 45^0, 60^0, 75^0, 100^0, 130^0 and 145^0) has been taken to calculate the various parameters like s-parameters, VSWR, and radiation pattern that are shown from fig. (a) to fig. (h) in sequential manner. Figure 3 shows the plot between return losses versus frequency with slot rotation at above said angles.

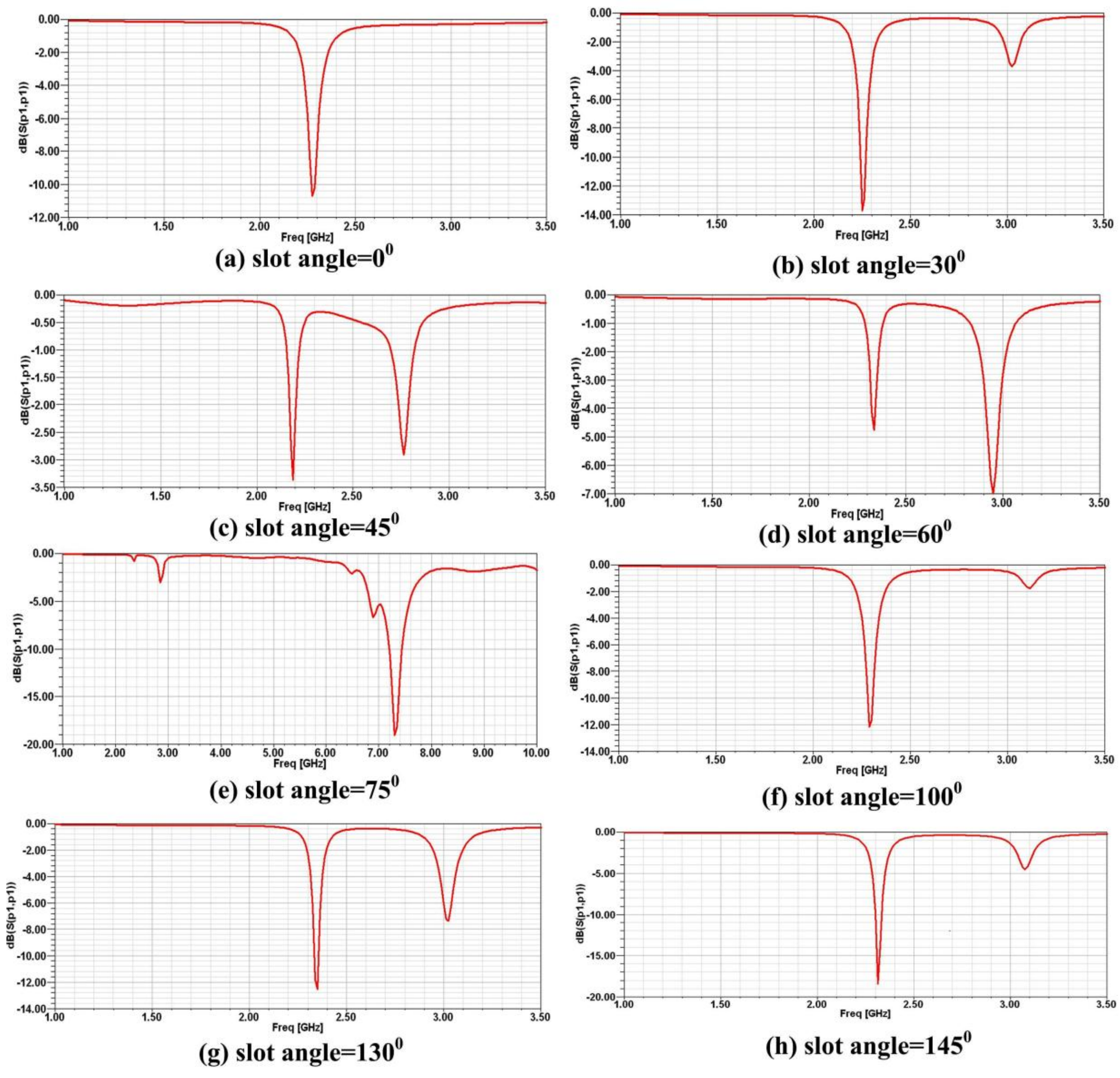

Fig.3 Plot of an antenna showing return loss vs frequency

The graph clearly shows different resonant frequencies at different rotation angles. Resonant frequencies are considered for the dips that lie beyond -10 dB. The high value of return loss means that the reflection wave return back to the source is very small and the amount of radiation power is very high. Thus, from this graph, it is verified that by rotating the slot, the proposed antenna can operate in different frequency regions. Table 3 shows the angle of slot with respect to feed line and their obtained resonant frequencies with bandwidth.

Table 3 Slot Rotation and Resonant Frequency

Angle of Rotation for slot	Resonant frequencies (GHz)	Bandwidth (GHz)
0^0	2.27	0.02
30^0	2.5	0.02
45^0	Not resonating due to high return losses	
60^0	Not resonating due to high return losses	
75^0	7.15	0.12
100^0	2.29	0.02
130^0	2.35	0.01
145^0	2.31	0.04

The value of the resonant frequencies for these different frequency regions is confirmed by the far field radiation plots as is shown in figure 4. Similarly, figure 5 shows the VSWR values for different slot angles.

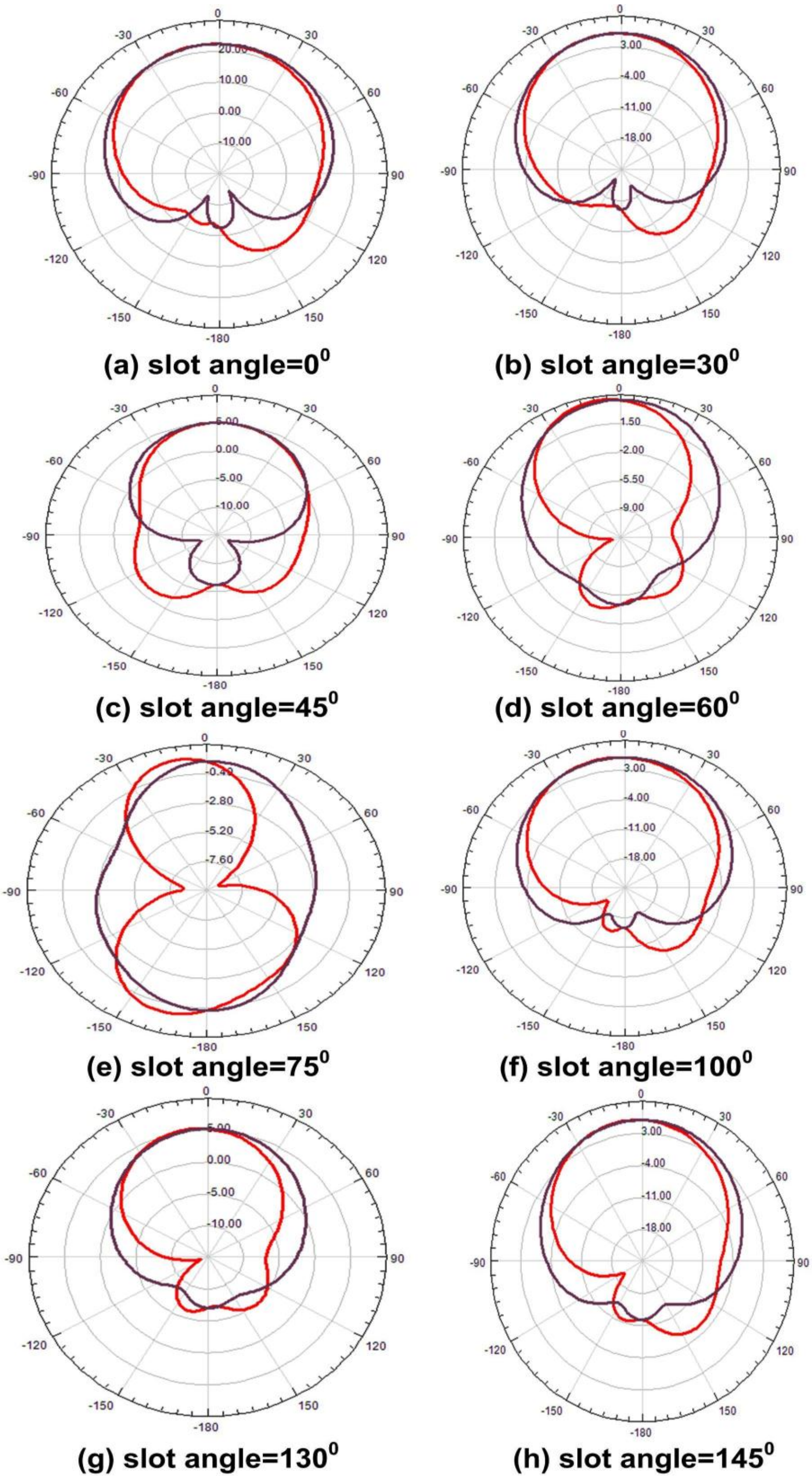

Fig.4 Radiation patterns for different slot angles

From these results, we estimate that the as-designed microstrip patch antenna may work successfully for different frequency applications. The radiation pattern is also changing with respect to rotational angle of a slot. However, the gain of all the antennas is almost constant. The bandwidth of the operating frequency shows that the designed antenna may work well for the mobile communication.

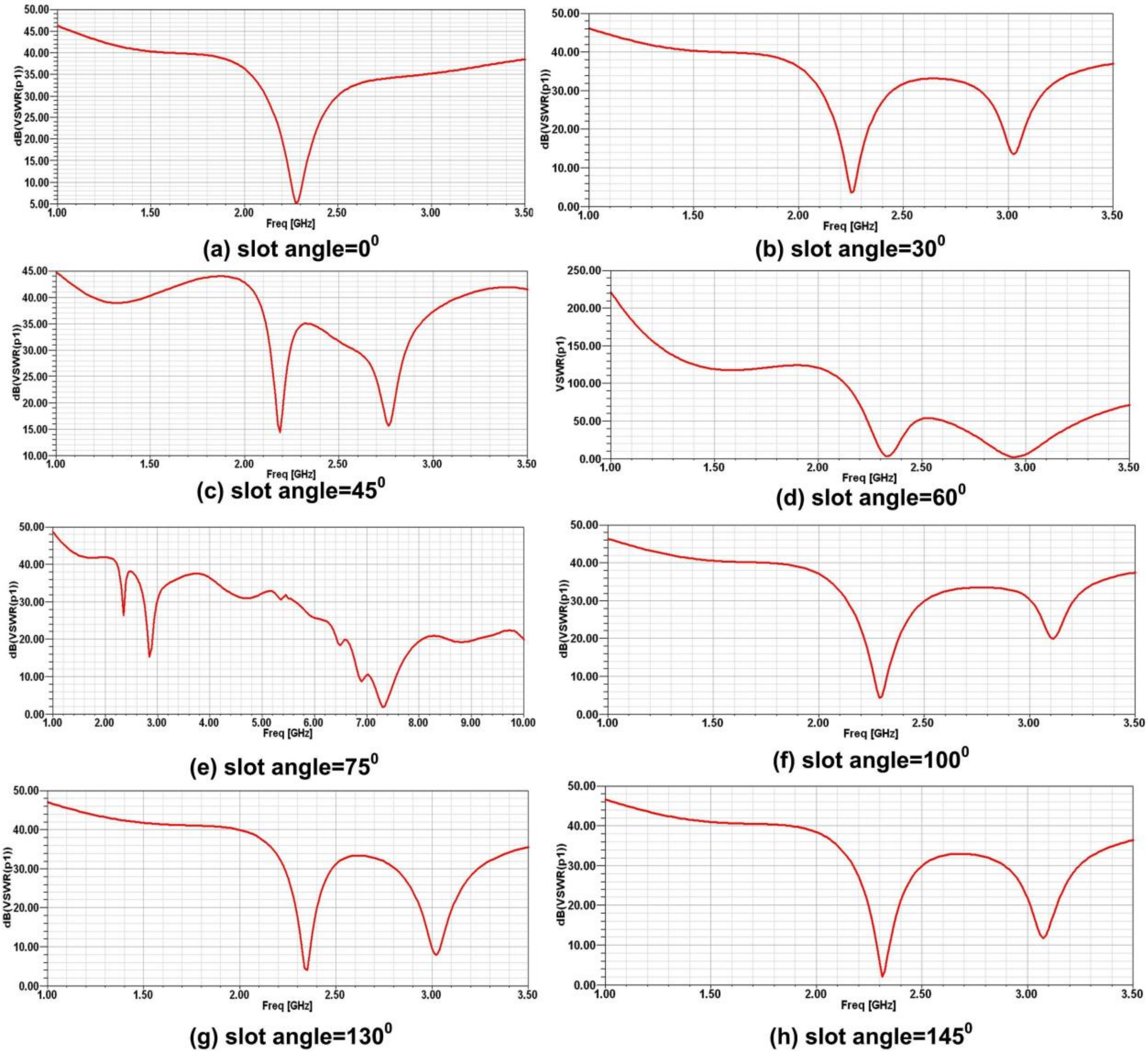

Fig.5 Graph showing VSWR values at different rotational angles of slot

Conclusions

In this work, a rectangular slot patch antenna is simulated to evaluate the effect of rotating a slot with respect to feed line. A simple proximity feed line is involved to analyse the results. A simple and easy method is used to design the rectangular patch and a slot is cut to devise the proposed structure. The results verified the formation of the proposed design for different wireless applications. Best results were obtained at slot angle=75^0. At this angle, losses (return loss & tangent loss) are very low and VSWR<2.The estimated bandwidth at this angle is well enough to be operated successfully for mobile communication applications.

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