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Rectangular Shaped Microstrip Patch Antenna with Multiple Slits and Slots

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***Abstract*—This paper presents a complex microstrip patch antenna design for Ku-band satellite communication applications. FR4 and RogerRT6002 have alternatively been used as substrates having dielectric constant of 4.4 and 2.94 respectively. The patch ground and feedlines are made of copper. The proposed antenna is unique in shape with rectangular slots. The performance of the antenna has been analyzed in terms of far field gain. The most significant results were obtained using FR4 substrate, which gave a gain of 7.88 dB, at 11.32 GHz and a reflection coefficient of -10.48 dB. The final microstrip patch antenna design was simulated, built and tested. Simulated and measured S11 frequencies perfectly match at 11.32 GHz with simulated and measured magnitudes of -10.48 dB and -29.64 dB respectively.**

Keywords — microstrip patch antenna, frequency, far field gain.

I. Introduction

Communication systems are becoming compact in size and hence compact antennas with improved performance are required for these communication systems [1]. In this paper we proposed a novel design of a rectangular microstrip patch antenna with rectangular slots whose operating frequencies comply with the Ku-band. The Ku-band typically falls between downlink frequencies of 10.7GHz to 12.75GHz and uplink frequencies of 13.75GHz to 14.5GHz. Ku-band is one of the most preferred choices in VSAT systems which can be adopted for satellite television broadcast and satellite television [2].

The rectangular slots are cut in the metal which is mounted on the substrate. We use here the FR4 epoxy as the substrate material with a height of 1.6 mm, relative permittivity of 4.4 [3]. Among the four most popular feed techniques, microstrip-line feed is easy to fabricate, simple to match by controlling the inset position and rather simple to model [4], thus this antenna was fed using this method. The rectangular and circular patches are the basic and most commonly used microstrip antennas. These patches are used for the simplest and the most demanding applications. Rectangular geometries are separable in nature and their analysis is also simple [5].

The ordinary microstrip patch antenna can be modeled as a simple LC resonant circuit. Currents flow from the feeding point to the top and bottom edges. When two slots are incorporated into the patch, the resonant feature changes. In the middle part of the patch, the current flows like normal patch. It represents the initial LC circuit and resonates at the initial frequency. However, at the edge part of the patch, the current has to flow around the slots and the length of the current path is increased. This effect can be modeled as an additional series inductance. So the equivalent circuit of the edge part resonates at a lower frequency. Therefore, the antenna changes from a single LC resonant circuit to a dual resonant circuit. These two resonant circuits couple together forming a wide bandwidth [6]. In our antenna this method was used to increase the far field gain by creating an E-shape side for the antenna and increasing the number of legs to four thus increasing the length of the current path to increase the gain. The several factors affecting the bandwidth of the microstrip antenna such as the thickness of the substrate, the dielectric constant of the substrate and the shape of the patch are also studied in this paper [7]. The antenna parameters such as resonant frequency, return loss and radiation pattern are simulated and discussed in this paper.

II. Design Steps and Simulation Results

The antenna is designed and simulated with the help of Sonnet Software. The substrate FR4 was chosen with width 1.6mm due to its cheap price and availability for fabrication. The bottom and top part of the antenna were kept symmetrical for ease of design and optimal results. The antenna is edge fed using the line feed method. At the beginning, the antenna width was smaller, had only two side legs and did not have any slots but required far field gain was not achieved. Thus we started by increasing the width. By studying current flow and density simulation of the antenna, multiple steps were taken to increase antenna gain. First, we cut the sides of the antenna creating the spaces at the top and the bottom which increased the gain by creating a dual resonant circuit. Then, five rectangular slots were cut in the antenna as the two middle slots were one. Later on separating that slot into two proved more beneficial thus resulting in a total of six rectangular slots of different sizes. The sizes of the slots were chosen after multiple alterations in the most optimized way that would keep a sufficient surface of metal for current flow and to increase current density thus increasing the gain. Then, using the same dual resonant circuit method, the number of side legs was increased to four as that highly increased the gain. However, the widths of the two outer legs and the two middle legs are not equal. The sizes were also chosen to increase far field gain as much as possible. The length of the two middle legs were shorter than the other two, but matching the length of all the side legs proved more beneficial as the current would flow in all four legs in a more equally distributed way. Finally, a channel connecting the top and

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bottom side of the antenna by circling around the right side legs was created which increased far field gain by 0.8 dB. The current, however, was not flowing in a part of it so that part was omitted in the final design which did not affect the gain at all. Figure 1 shows the final design and its dimensions. Table I shows all the final design dimensions. Figure 2 shows the current flow and density in the antenna at the frequency 11.32 GHz. The current density mostly increases near the small slots and parallel slits. Final results, S11 -10.48 dB at frequency 11.32 GHz and radiation pattern (7.88 dB) are shown in Figure 3 and Figure 4. Note that the cross polarization level is -10 dB.

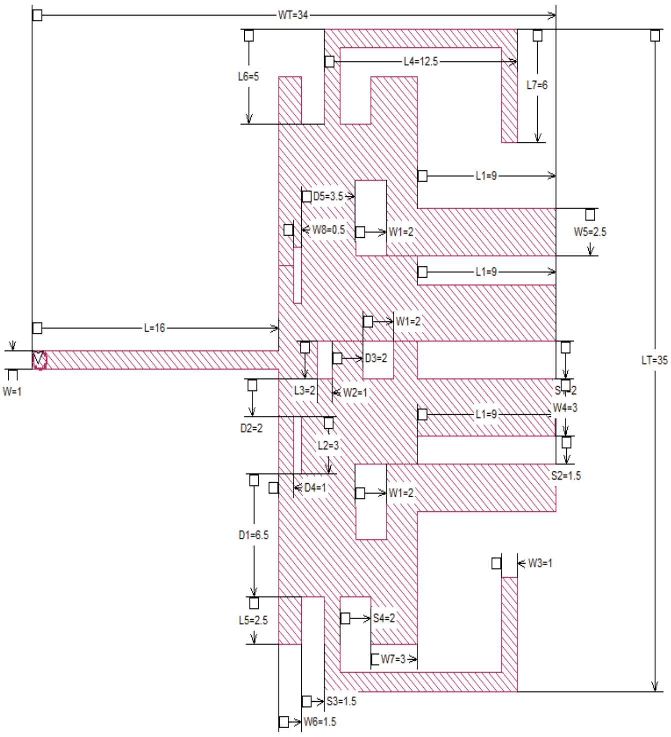

Fig. 1. Top view of the Final Antenna

TABLE I. DIMENSIONS OF FINAL DESIGN

Variable	Value (mm)	Variable	Value (mm)
LT	35	WT	34
L	16	W	1
L1	9	W1	2
L2	9	W2	1
L3	2	W3	1
L4	12.5	W4	3
L5	3	W5	2.5
L6	5	W6	1.5
L7	6	W7	3
S1	2	W8	0.5
S2	1.5	D1	6
S3	1.5	D2	2
S4	2	D3	2
D4	1	D5	3.5

After finalizing the design, the most optimized design with the highest far field gain was sought, so the antenna was simulated after the sizes of the antenna and slots were changed multiple times. Then, the same changes were simulated after the dielectric substrate was changed to RogerRT6002. Three antennas were simulated using both substrates FR4 and RogerRT6002 for dielectric material. The thickness of the FR4 substrate was 1.6 mm, and the RogerRT6002 substrate was 0.762 mm. The air thickness in both was 60 mm. Table II and Table III indicate the changes in the design and the results for S11 (dB), resonance frequency (GHz) and gain (dB) with using FR4 and RogerRT6002 for comparison.

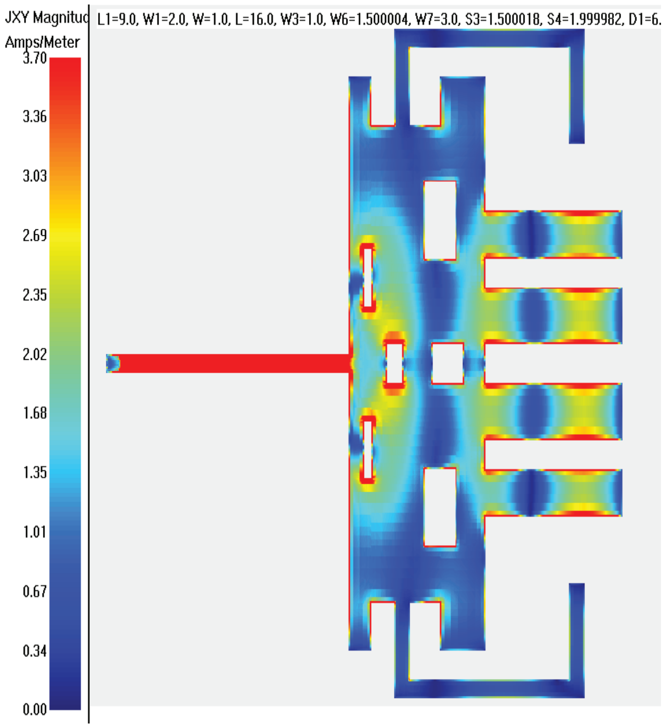

Fig. 2. Simulated Current flow and density at 11.32 GHz

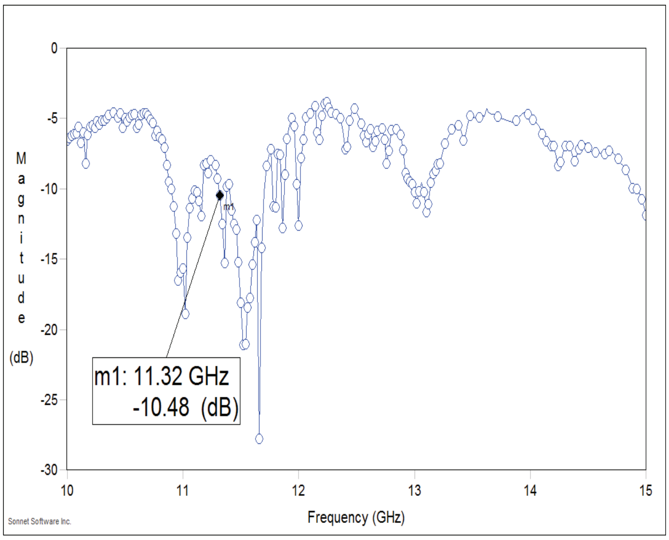

Fig. 3. Simulated Resonance frequency, S11

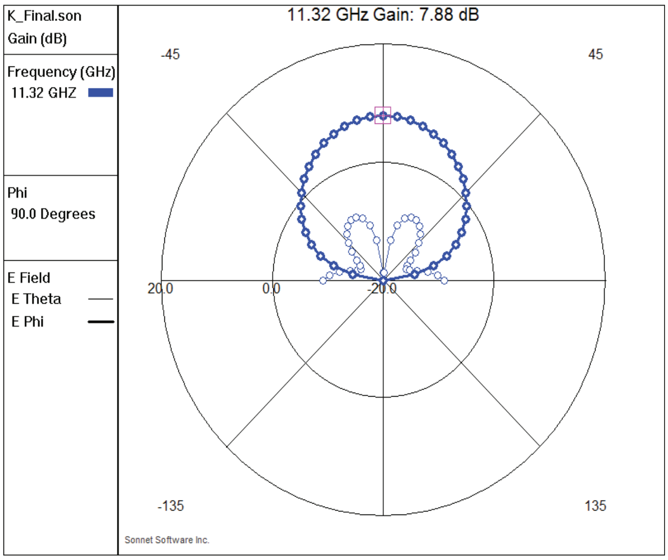

Fig. 4. Simulated Far field Gain

TABLE II. RESULTS FOR SUBSTRATE FR4

Antenna	L1 (mm)	W1 (mm)	Reflection Coefficient S11(dB)	Resonance Frequency (GHz)	Gain (dB)
1	9	1	-11.73	11.32	7.56
2	10	1	-11.96	11.0	6.1
3(Final)	9	2	-10.48	11.32	7.88

TABLE III. RESULTS FOR SUBSTRATE ROGER RT6002

Antenna	L1 (mm)	W1 (mm)	Reflection Coefficient S11(dB)	Resonance Frequency (GHz)	Gain (dB)
1	9	1	-7.17	14.2	11.18
2	10	1	-3.38	13.2	10.5
3	9	2	-5.62	14.5	10.10

Finally, after selecting Antenna 3 with FR4 substrate which met the design specs, the antenna was simulated using different air and dielectric material thicknesses to achieve the required reflection coefficient S11 (dB), resonance frequency (GHz), and gain (dB) values represented in Table IV. First, air thickness was set to 10 mm and then increased by 10 mm for each simulation until reaching 60 mm. Then, using air thickness 60 mm, the substrate material was changed and simulated. Finally, the achieved design specs were 7.88 dB gain with reflection coefficient -10.48 dB for the resonance frequency 11.32 GHz using air thickness 60 mm and FR4 substrate thickness 1.6 mm. Figure 5 shows a 3D view of the antenna with all three layers, from top to bottom, air, metal and dielectric material.

At the end, the final antenna design using FR4 substrate was fabricated, and the input pin was soldered to the antenna in the edge feeding position. The antenna was finally tested for resonance frequency and S11 values. Figure 6 shows the fabricated antenna. Figure 7 shows the antenna test for resonance frequency and S11. Point M1 represents resonance frequency 11.32 GHz, perfectly matching the simulation, with an S11 magnitude of -29.64 dB which exceeds the simulation results.

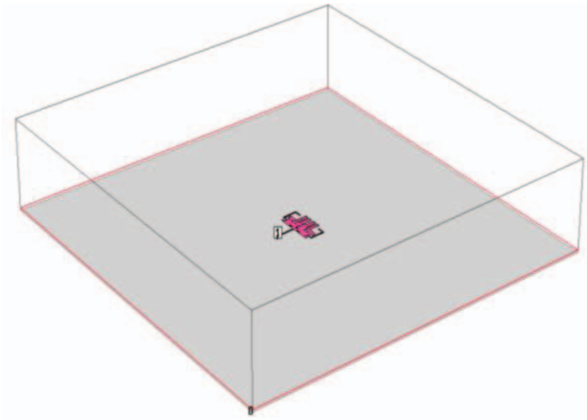

Fig. 5. 3D view of Final Antenna

TABLE IV. CHANGING OF S11, FREQUENCY AND GAIN VALUES DEPENDING ON AIR THICKNESS AND DIELECTRIC THICKNESS

Air Thickness (mm)	Dielectric Thickness (mm)	Reflection Coefficient S11(dB)	Resonance Frequency (GHz)	Gain (dB)
10	1.6	-15.65	11.32	7.22
20	1.6	-9.76	11.32	6.92
30	1.6	-10.09	11.32	7.57
40	1.6	-10.51	11.32	7.85
50	1.6	-10.58	11.32	7.33
60	1.5	-12.96	11.5	7.20
60	1.6	-10.48	11.32	7.88
60	1.7	-9.28	11.32	7.14

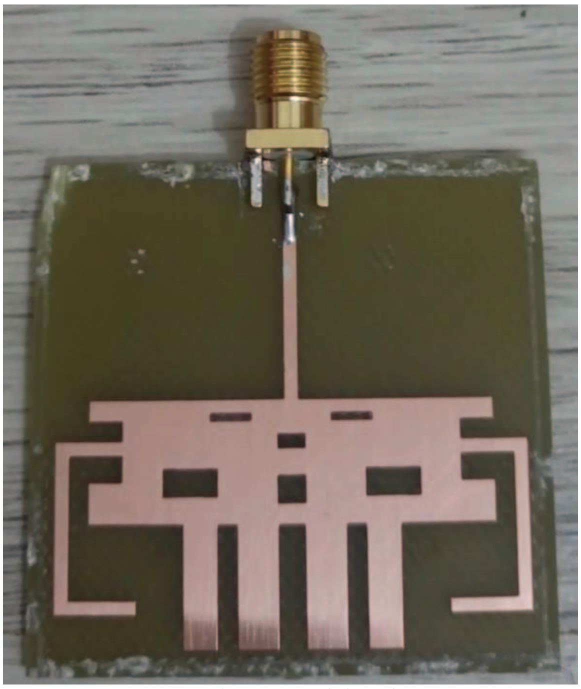

Fig. 6. Fabricated antenna

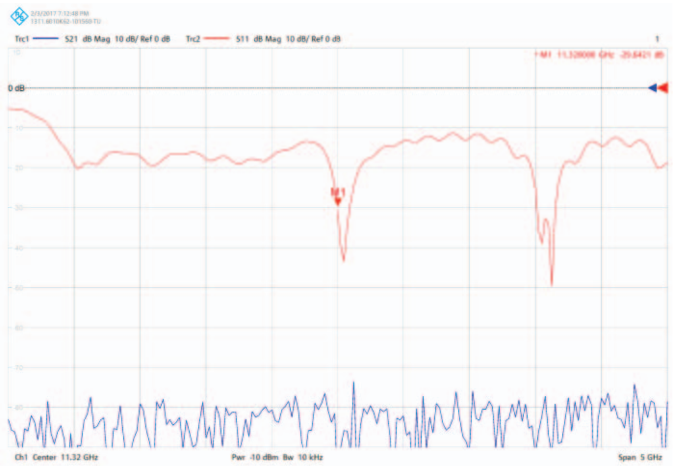

Fig. 7. Tested Resonance frequency, S11

III. CONCLUSION

The simulated antennas gave the desired results and sufficient gain for relevant frequencies. For the FR4 substrate, the antenna variations gave a good resultant gain at frequencies 11.32, and 11.0 GHz. For the RogerRT6002 substrate, a desired antenna gain of 10.10 and 11.18 dB was achieved, but the results were obtained with a low reflection coefficient therefore they are not considered significant for this research. The final antenna simulation using the FR4 substrate resonates at frequency 11.32 GHz with S11 of -10.48 dB achieving far field gain of 7.88 dB. However, the final antenna was built and tested resulting in a perfectly matching to the simulation S11 frequency 11.32 GHz with a magnitude of -29.64 dB. Furthermore, radiation pattern measurements are in progress.

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