PERFORMANCE ANALYSIS OF A NOVEL DUAL-BAND PLANAR ANTENNA FOR MICROWAVE COMMUNICATIONS

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ABSTRACT

The dual-band operation of a microstrip patch antenna on a Duroid 5870 substrate for Ku- and K-bands is presented. The fabrication of the proposed antenna is performed with slots and a Duroid 5870 dielectric substrate and is excited by a 50 Ω microstrip transmission line. A Professional simulation platform is used here which is based on the MoM (Methods of Moments) in this work. The measured impedance bandwidth (2:1VSWR) achieved is 1.07 GHz (15.93 GHz–14.86 GHz) on the lower band and 0.94 GHz (20.67–19.73 GHz) on the upper band. A stable omnidirectional radiation pattern is observed in the operating frequency band. The proposed prototype antenna behavior is discussed in terms of the comparisons of the measured and simulated results.

I. INTRODUCTION

The implementation of the microstrip patch antenna is a milestone in wireless communication systems and is continuing to fulfill the changing demands of the new generation of antenna technology. Microstrip patch antennas are widely used in wireless communication systems because they are low profile, of light weight, of low cost, of conformal design, and easy to fabricate and integrate. Many researchers have heavy interest in designing Ku- and K-band antennas and still face a major challenge to implement these applications. The patch is the dominant figure of a microstrip antenna; the other components are the substrate and ground, which are the two sides of the patch [1]. Many dual-band antennas have been improved to face the rising demands of a modern portable wireless communication device that is capable of integrating more than one communication standard into a single system. For this reason, different types of antenna designs have been proposed [2–14].

A dual polarized microstrip patch antenna has been proposed for Ku-band applications with dimensions of 15*15mm, and such an antenna has achieved a 950 MHz bandwidth with a maximum gain of 7.6 dB, as noted in [15]. In [16], a multiband patch antenna was designed for Ku- and K-band applications with dimensions of 8*10mm, a bandwidth of 760 MHz, and a peak gain of 4.5 dB. In [17], a Ku-band patch antenna using notches and slit was proposed, whose dimensions are7.6*10mm, with a substrate thickness of 0.8 mm; Teflon is used as the dielectric substrate material, and the antenna obtained a maximum bandwidth of 600 MHz. In [18], a dual-band compact microstrip antenna was proposed for Ku-band applications using three pairs of thin slits from the sides of a rectangular patch, whose dimensions are 9.5*10mm, Rogers RT/Duroid 5880 is used as the dielectric substrate material, with a substrate thickness of 0.254 mm; the antenna obtained a maximum bandwidth of 90 MHz. In [19], a dual-frequency triangular slotted microstrip patch antenna was proposed for Ku-band applications, where the patch dimensions are 8.5mm*7.96mm*1.905mm; the substrate thickness is 1.905 mm (Rogers RT/Duroid 6010 is used as the dielectric substrate material), and the maximum bandwidth is 576 MHz. In all of the previous proposed antenna designs, narrow bandwidth was achieved for Ku-band applications.

A printed double-T monopole antenna was proposed in [20]. In [21], a compact dual-band microstrip antenna for Ku-band applications was proposed, whose dimensions are 9.50mm*10mm*0.254mm and which achieved a return loss of −23.83 dB at 12.54 GHz and −14.04 at 14.15 GHz, with a gain greater than 4 dBi. Comparatively, the proposed antenna has a limited return loss. A surface mount dual-loop antenna was proposed in [22]. A dual-band reduced-size PIFA was proposed in [23]. These antennas provided dual-band features to cover the 2.4/5.2 and 5.8 GHz WLAN bands. The limitations of these antennas were that they could not deliver a uniform omnidirectional radiation pattern. A low-cost microstrip-fed dual-frequency printed dipole antenna was proposed for wireless communications in [24]. This antenna's size is large and its bandwidth is limited. In [25], a printed dual-band dipole antenna with U-slot arms was proposed for the 2.4/5.2 GHz WLAN operation. The 370 MHz bandwidth of that antenna is insufficient to cover the desired band. In [26], a dual broadband design of a rectangular slot antenna was proposed for 2.4 and 5 GHz wireless communications. The antenna dimension is 75mm*75mm, the substrate permittivity is 4.70, and the thickness is 0.80 mm. In [27], a dual-band WLAN dipole antenna using an internal matching circuit was proposed. The antenna dimensions are 12mm*45mm and FR4 is used as the dielectric substrate material to cover the desired bands.

In this study, a 20mm*20mmmicrostrip patch antenna was designed on a 1.575 mm thick Duroid 5870 substrate for use in Ku- and K-band applications. A downlink frequency of 15.56 GHz and an uplink frequency of 20.41 GHz, with return losses of -32.56dB and -31.13dB, respectively, a peak gain of 3.90 dB, and 98.5% average efficiency were achieved. The detailed design and simulation results for the proposed antenna were demonstrated later.

II. ANTENNA DESIGN

The proposed antenna design with a microstrip transmission line is shown in Figure 1. The microstrip transmission line is one type of high-grade printed circuit fabric. This line comprises a track of copper or any other conductor with an insulating substrate. The other portion of the insulating substrate contains a backbone that is made of a similar conductor. The antenna is comprised of six conducting slots on the patch and two on the ground. A circular slot and five rectangular slots are on the patch, and two rectangular slots are on the ground of the proposed antenna. The design procedure begins with the radiating patch with the substrate, the ground plane, and a feed line. The antenna is printed on a 1.575 mm thick Duroid 5870 substrate material that exhibits a relative permittivity of 2.33, a relative permeability of 1, and a dielectric loss tangent of 0.0012. A circular and five rectangular slots are cut from the rectangular copper patch. Another two rectangular slots are also cut from the ground plane.

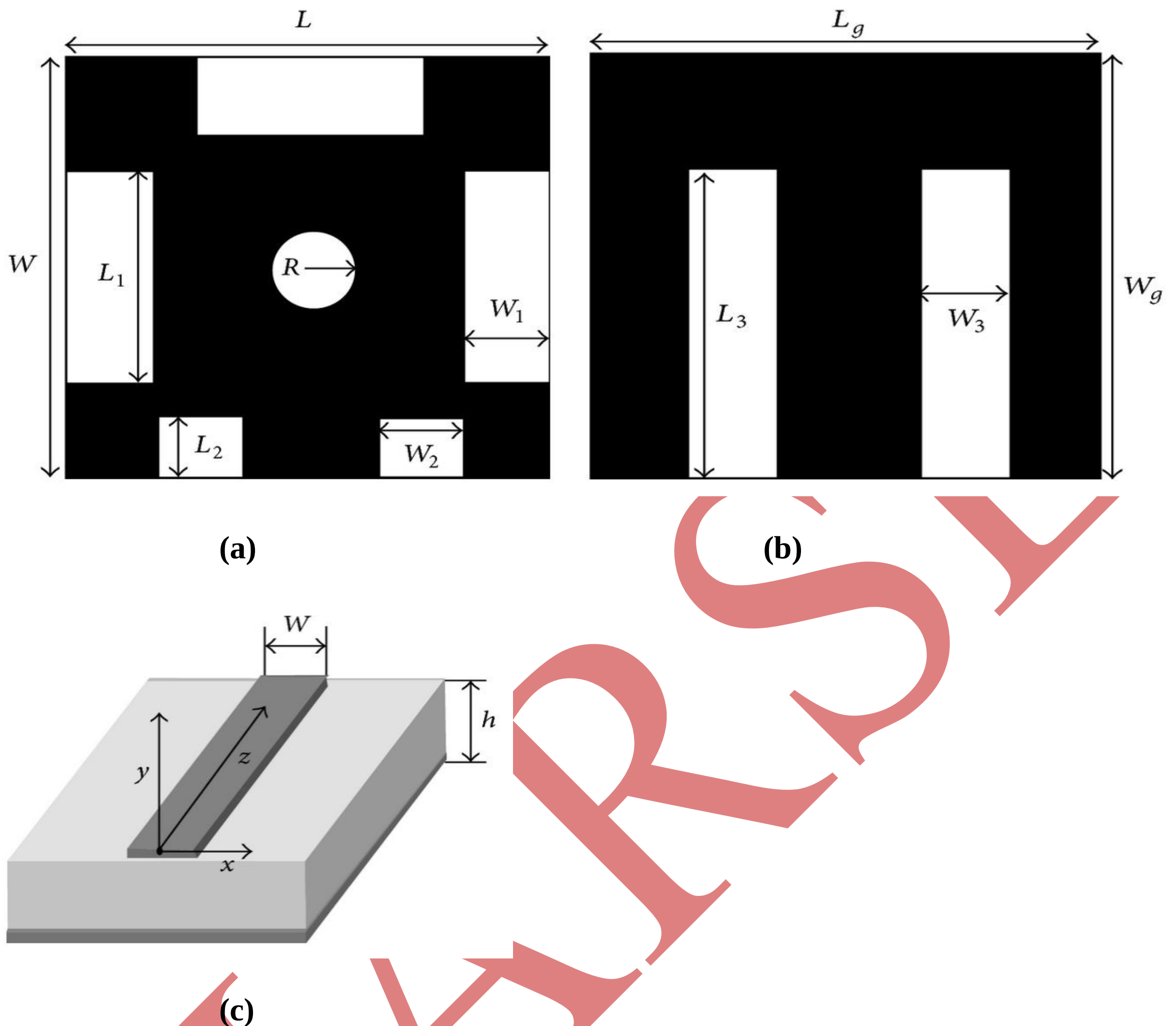

Figure 1: Proposed Antenna: (A) Top View, (B) Bottom View, And (C) Microstrip Transmission Line.

Thus, the proposed slotted circle patch antenna is finally achieved. Here, the microstrip line is used to feed the signal into the proposed antenna.

The subminiature version A (SMA) 50 Ω connector is used at the end of the antenna feeding line for the input RF signal. The proposed antenna prototype is shown in Figure 2. The antenna design and the dimensions were investigated by using the professional antenna simulation software, which is based on Methods of Moments (MoM) and the optimal dimensions were finally determined as follows: L=20mm, L_g=20mm, L_1=8 mm, L_2=3mm, L_3=16mm, R=2mm, W=20mm,W_g=20 mm, W_1=4mm, W_2=3mm, and W_3=3mm.

There are different types of materials for an antenna substrate; for example, Duroid 5870 is a high-frequency laminate and PTFE (polytetrafluoroethylene) composite amplified using glass microfibers. To increase the advantages of fiber reinforcement for circuit applications and circuit producers, these microfibers have been used aimlessly. The dielectric constant of the Duroid 5870 substrate material is lower than that of other products, and it is suitable for higher-frequency bands, where dispersion and losses must be decreased because of the low dielectric loss. Due to the lack of extensive water absorption features, Duroid 5870 substrate is typically used in heavy moisture environments. The Duroid 5870 is simply cut, machined, and sheared to shape, and it is impervious to all reagents and solvents usually used in engraving printed circuit boards or plating holes and edges. Duroid 5870 has the lowest electrical loss of any amplified PTFE substrate material, lower absorption due to the fact that moisture is isotropic, and constant electrical characteristics over frequency. Duroid 5870 has been used in circuitry for commercial airline telephones, stripline and microstrip circuits, military radar systems, millimeter-wave applications, point-to-point digital radio antennas, and missile guidance systems. For these reasons, the Duroid 5870 substrate material was chosen for the proposed antenna design to achieve operation in the desired bands. The dielectric properties of the various substrate materials are listed in Table 1.

Table-1 Dielectric properties of different substrate materials.

Material	Permittivity	Loss tangent
RT Duroid 6010	10.2	0.0023
FR4	4.66	0.020
AL_2O_3(Alumina)	9.8	0.0009
RT Duroid 5870	2.33	0.0023

The length, width, VSWR, and return loss of the patch antenna can be calculated from (1), presented in [28], where L and W are the length and width of the patch, c is the velocity of light, $\varepsilon_r$is the dielectric constant of the substrate, h is the thickness of the substrate, $f_o$is the target centre frequency,ε_e is the effective dielectric constant, and ρ is the radiation coefficient:

III RESULT AND DISCUSSION

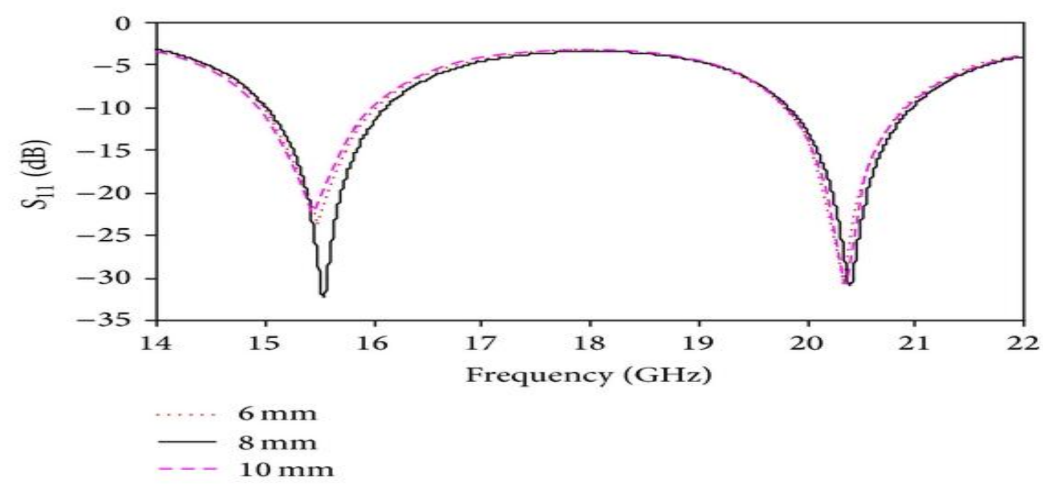

Fig. 2 Simulated return loss for different values of L_1

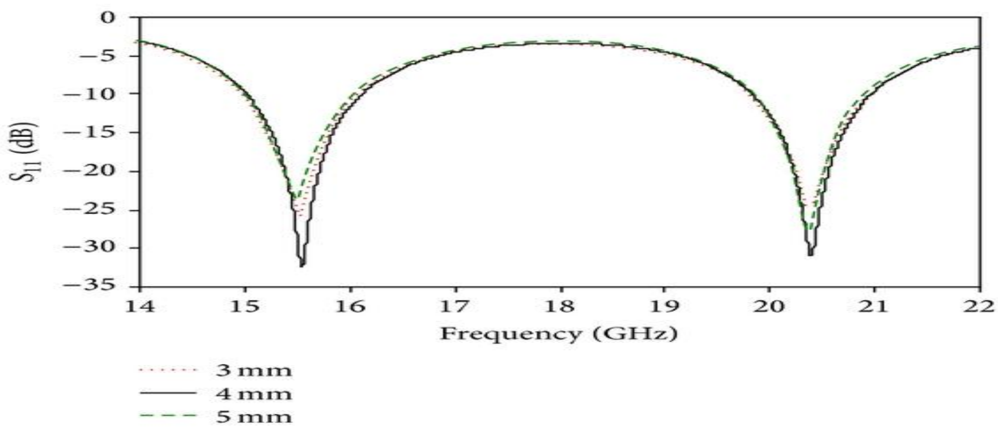

Fig.3 Simulated return loss for different values of W_1

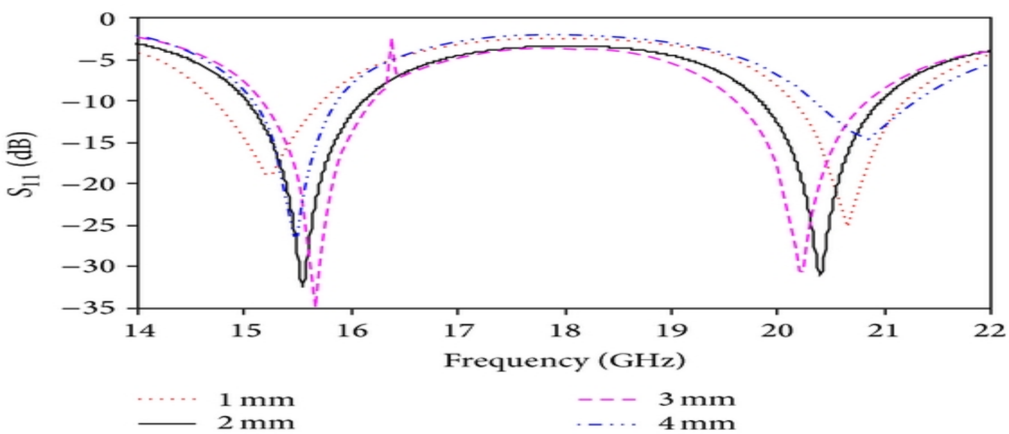

Fig.4 Simulated Return Loss for Different Values of R.

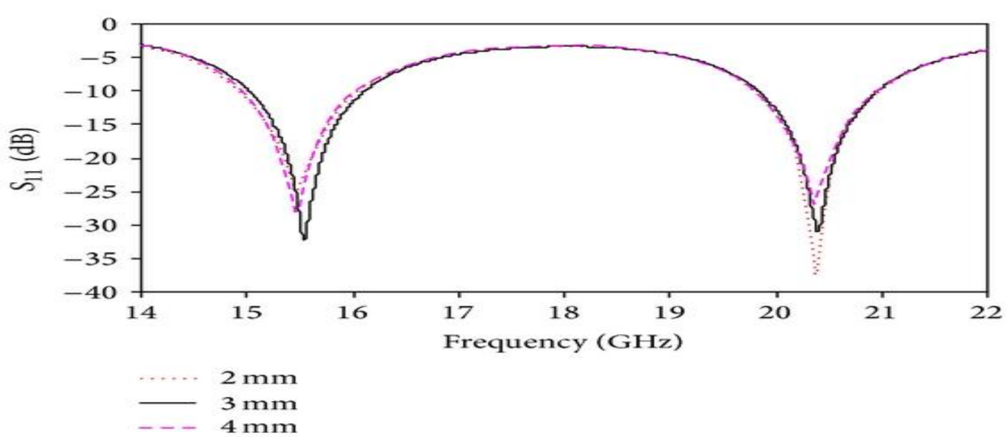

Fig.5 Simulated Return Loss for Different Values of W_2.

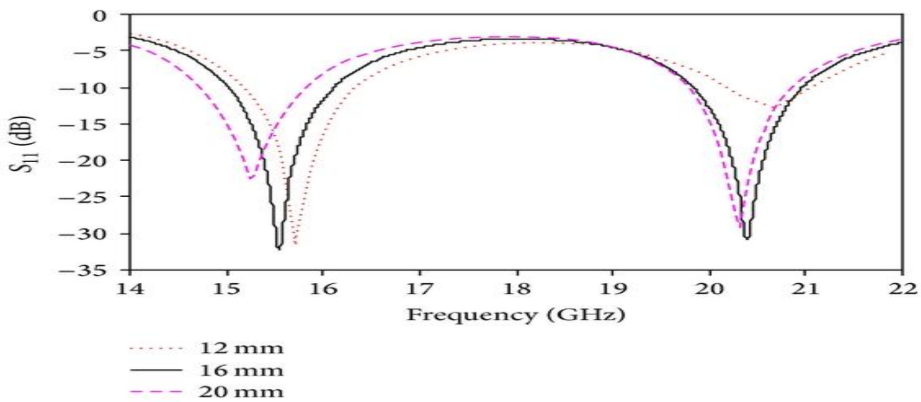

Fig.6 Simulated Return Loss for Different Values Of L3

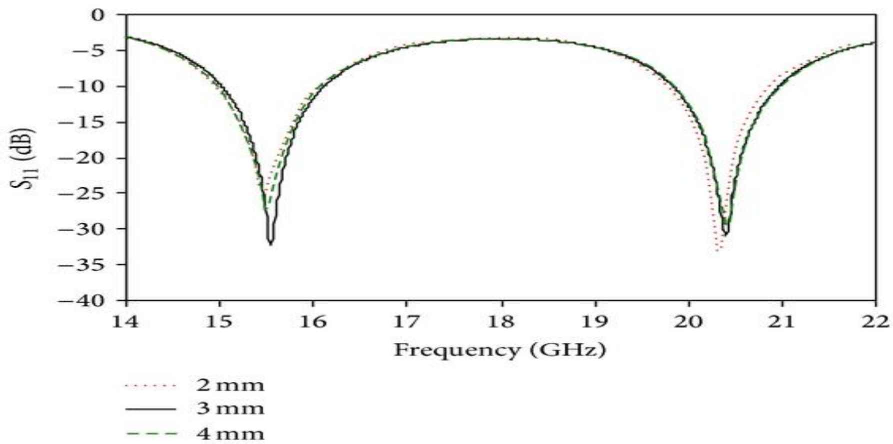

Fig.7 Simulated Return Loss for Different Values of W_3.

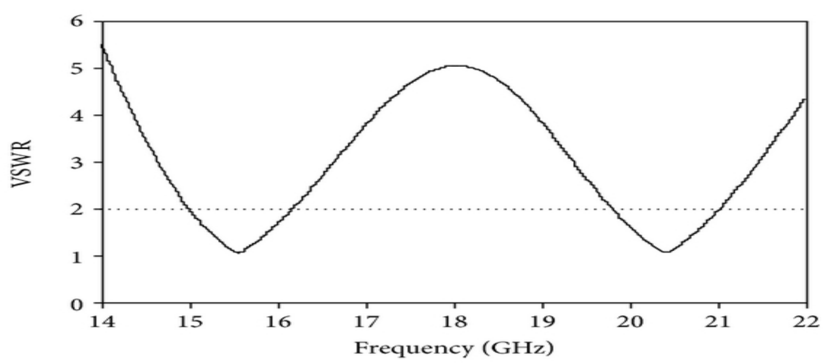

Fig.8 VSWR of The Proposed Antenna.

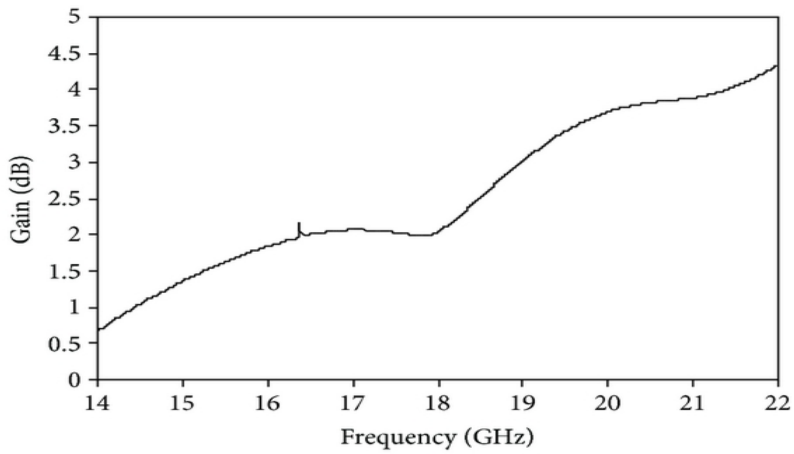

Fig.9 Gain of the Proposed Antenna.

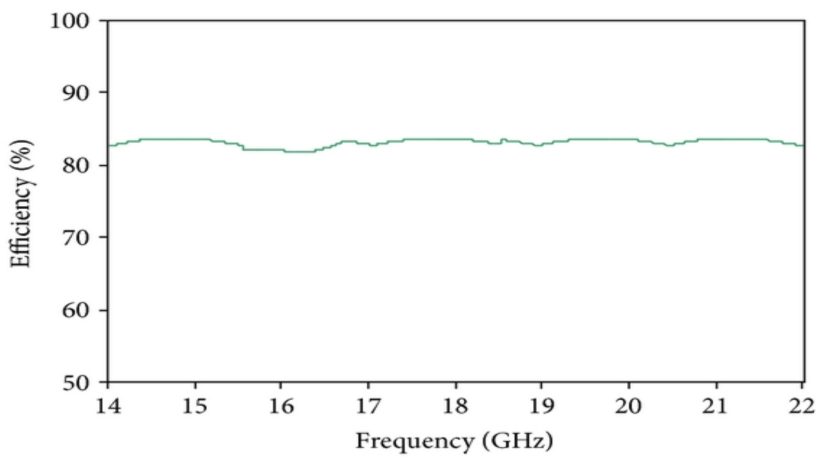

Fig.10 Radiation Efficiency of the Proposed Antenna.

The simulated VSWR of the proposed antenna is shown in Figure 9. The standard value of VSWR is less than 2 for the operational bands of the microstrip patch antenna. The value of VSWR achieved is less than 2 in the desired operating bands. The simulated gain of the proposed antenna is shown in Figure 10. The achieved gains are 1.87 dB on the lower band and 3.87 dB on the upper band. The radiation efficiency of the proposed antenna is displayed in Figure 11. The 82.80% efficiency was observed over the entire operating band of Ku-and K-band applications.

Figure 11 shows the current distribution of the proposed antenna for (a) 15.56 GHz and (b) 20.41 GHz. A large amount of current flows through the feeding line. The electric field was initiated at this point. The creation of the electric field near the slots is reasonable. As a result, the excitation is strong over all the parts of the antenna for both the lower band and the upper band.

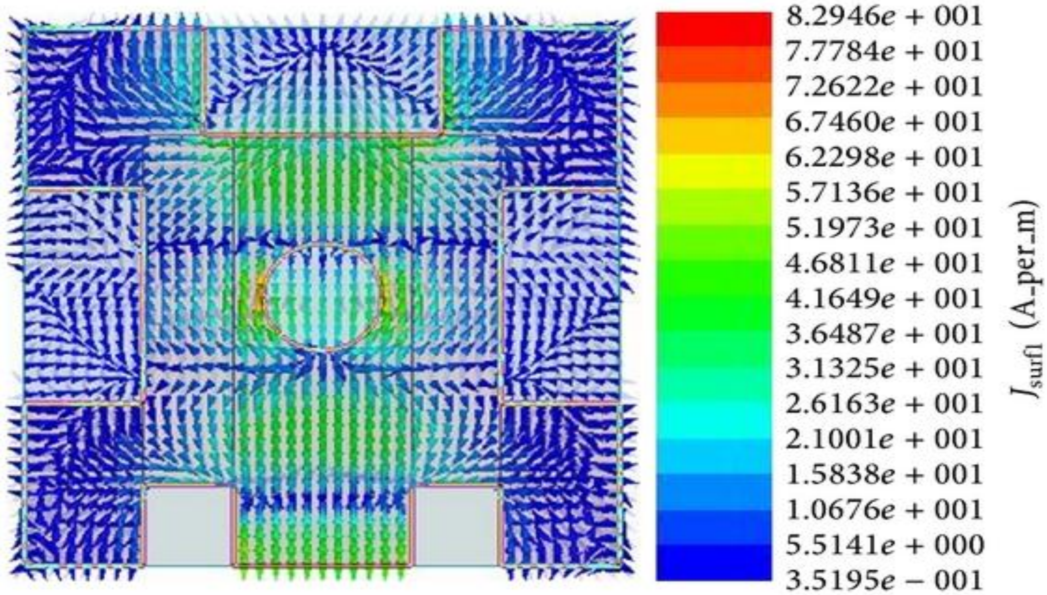

Fig. 11 Simulated Current Distribution.

IV. CONCLUSION & FUTURE SCOPE

The proposed design and characterization of a prototype of a microstrip antenna with dual-band operation on a substrate of Duroid 5870 material to cover Ku- and K-band applications were described. The 10 dB bandwidth of 1.07 GHz in the 1st resonance at 15.46 GHz and of 0.94 GHz in the 2nd resonance at 20.27 GHz were found, which satisfies the conditions of any Ku- and K-band application. Good agreement between the simulation and measured results was observed. Attractive radiation patterns, low cross-polarization, and efficiency with improved bandwidth and higher gain make the proposed antenna compatible for use in Ku- and K-band applications.

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