A Crooked U-Slot Dual-Band Antenna With Radial Stub Feeding

Hyo Rim Bae, Soon One So, Choon Sik Cho, *Member, IEEE*, Jae W. Lee, *Member, IEEE*, and Jaeheung Kim, *Member, IEEE*

***Abstract*—We propose a dual-band antenna using a crooked U-slot with radial stub feeding. This antenna has a simpler topology than other antennas designed for realizing dual-band characteristics. In addition, the proposed antenna adjusts to desired frequencies easily. The crooked U-slot made on the bottom layer provides the advantage of making impedance matching possible over a wide band at the low frequency, while the radial stub is used for feeding and also for providing additional resonance at the high frequency. The operating frequencies of the proposed antenna are chosen as 2.4 and 5.2 GHz, obtained by optimizing the physical dimensions of the crooked U-slot and radial stub. Measured results of return loss show -26.2 and -12.2 dB at 2.4 and 5.2 GHz, respectively. Measured gain is 0.47 and -1.97 dBi at 2.4 and 5.2 GHz, respectively.**

***Index Terms*—Crooked U-slot, dual-band antenna, radial stub feeding.**

I. INTRODUCTION

MODERN wireless communication systems demand more and more frequency bands due to ever-increasing wireless service requirements. As these systems also seek smaller dimensions for the real estate, antennas need to decrease their dimensions and add more operating frequency bands while maintaining their performance. Specifically, the demand for dual-band antenna design is increasing continuously. Microstrip patch antennas using a circular ring topology [1], slot antennas using a rectangular topology [2], and inverted-F antennas [3] are the most popular topologies used for achieving dual-band operation. In this work, a feeding structure is built by employing a radial stub feed line incorporating a crooked U-slot defected ground structure (DGS). Various types of U-slot antennas have been researched in the hopes of gaining wideband performance [4]–[7]. The bandwidths of U-slot antennas reach about 20%. U-slot configurations have also been employed for dual- and multiband performance [4]–[6]. Generally speaking, multiple U-slots should be used to obtain multiband operation. However, in this letter we adopt a single U-slot for a dual-band antenna with a crooked configuration on the bottom layer. The crooked U-slot, which reduces the size of the antenna, is realized by increasing the number of its crooked turns. The desired low operating frequency determines the physical dimensions of the U-slot. While the feeding radial stub generates an additional resonance at high frequency, the proposed crooked U-slot ensures resonance at low frequency.

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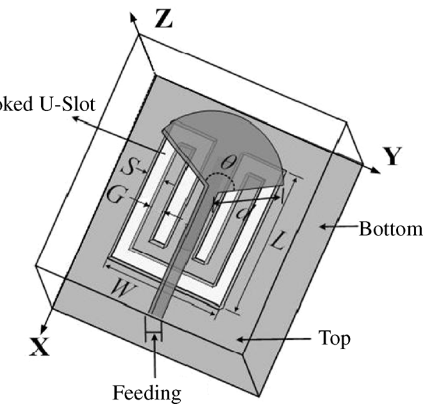

Fig. 1. Configuration of the proposed antenna.

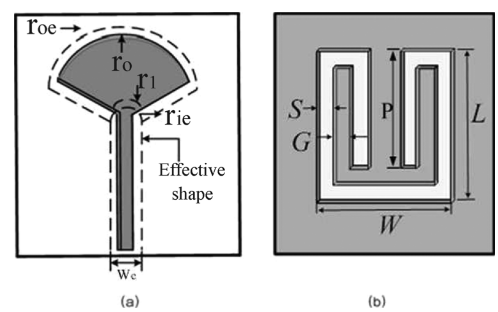

Fig. 2. The top and bottom layers of the proposed antenna. (a) Top side (b) Bottom side.

Ever since the radial stub theory was proposed, this topology has been used as a feeding structure for presenting a wide impedance band [8], [9]. In this letter, we adopt this radial stub on the top layer to feed the antenna and additionally provide an improved resonance at the high frequency. In addition, this makes the impedance matching of the U-slot simpler.

II. DESIGN PHILOSOPHY

Fig. 1 shows the configuration of the proposed antenna, which consists of a radial stub on the top layer and a crooked U-slot on the bottom layer. The entire size of the antenna is 30 mm $\times$ 40 mm. Fig. 2 represents the top and bottom layers of the proposed antenna in more detail, where $\mathrm{width} = 30$ mm,

TABLE I
CALCULATED Q-FACTORS AND SIMULATED RESONANT FREQUENCY

	Resonant Frequency (GHz)	3dB Bandwidth (GHz)	Q-factor
Basic U-slot (Fig. 8)	1.6	0.4	4
Proposed crooked U-slot (Fig. 4)	2	0.11	18.18

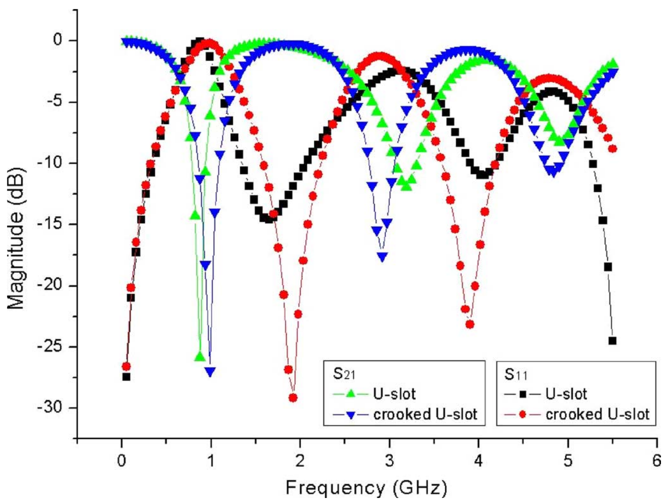

Fig. 3. S-parameters of the DGSs.

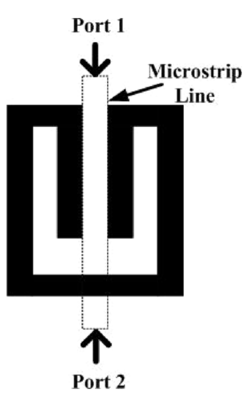

Fig. 4. Simulation circuit of crooked U-slot DGS.

length = 40 mm, height = 0.787 mm, L = 22.7 mm, S = 1.1 mm, W = 27.9 mm, and G = 10.9 mm are used. The value for the feed line is $\theta = 110^{\circ}$, w_e = 2.45 mm, r_o = 16.31 mm, and d = 8.5 mm.

The U-slot behaves like a bandstop DGS structure at the first resonance frequency, which is 986 MHz. However, due to its distributive nature, the U-slot has a passband at the second harmonic frequency, as indicated in the simulated S parameters in Fig. 3. Based on the 3-dB fractional bandwidths of the S_{11} responses in Fig. 3, the Q-factor of the crooked and uncrooked U-slots can be determined. Traditional DGS works like a band-pass filter in this letter. Therefore, we used a crooked U-slot like a band-pass filter. We can also see in Fig. 3 that the crooked U-slot has a harmonic constituent. We use this characteristic and compare S_{11} with S_{21} to obtain the resonance frequency as our target frequency. Hence, the crooked U-slot works like a band-pass filter in this letter. Fig. 4 is the simulation circuit used for extracting the crooked U-slot's S-parameter with a microstrip line. Simulated resonant frequency and calculated Q-factors are given in Table I.

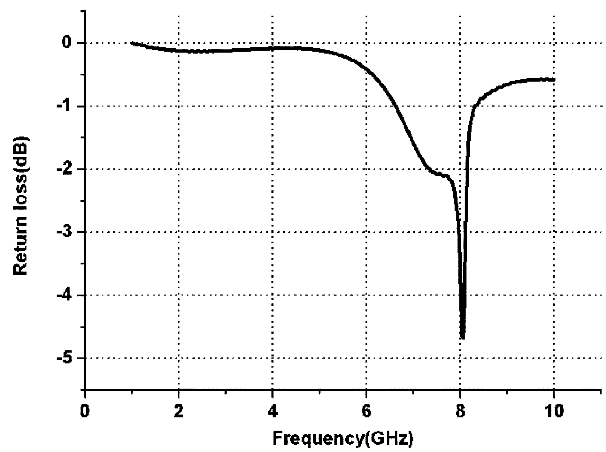

Fig. 5. Simulated result of the return loss for the radial stub without crooked U-slot.

Henceforth, the radial stub is analyzed to be used for feeding and providing an additional resonance. In general, characteristic of the radial stub is represented by the effective dimension proposed by magnetic wall model [5], and effective angle and arc of a circle generated by effective dimension play important roles in deciding the high-frequency characteristic.

Effective dimensions provided in the magnetic wall model are expressed as follows: [10], [11]

$$r_{ie} = \frac{w_e}{2\sin\left(\frac{\theta}{2}\right)} \tag{1}$$

$$r_{oe} = r_o\sqrt{1 + \frac{2d}{\pi r_0}\left[\ln\frac{\pi r_0}{2d} + 1.7726\right]} + \frac{w_e - w}{2\sin\left(\frac{\theta}{2}\right)} \tag{2}$$

where θ is the angle of the radial stub, w is width of the feed line, and w_e is effective width of the feed line. Characteristic of the radial stub is obtained by its angle (θ) and radius (d) because its effective angle and arc are calculated by the effective dimension as illustrated in (1) and (2). Fig. 5 shows that the radial stub without crooked U-slot operates solely at 8 GHz with a low Q-value, and this resonant frequency is lowered with the U-slot. The radial stub can achieve a wide impedance bandwidth match and stable radiation patterns over the frequency range [12].

The crooked U-slot is, to a high degree, related to 2.4 GHz. The length P for the U-slot can be varied as shown in Fig. 6. Fig. 7 shows simulated results of the return loss by varying length P. When total slot length is 42.7 mm (P = 0.75L), the U-slot operates at 2.4 GHz because the half-wavelength is 42.11 mm at 2.4 GHz.

The crooked U-slot can have various numbers of turns as shown in Fig. 8. Fig. 9 shows the simulated result of return loss

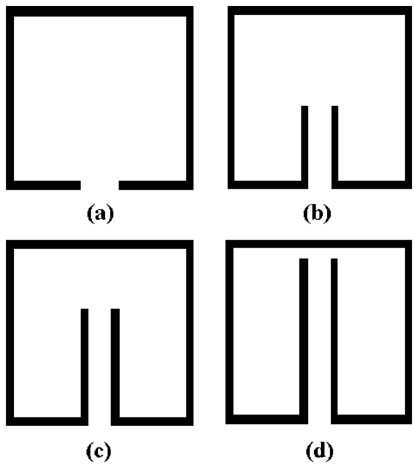

Fig. 6. U-slot with the radial stub by varying P length. (a)$\mathrm{P}=0$. (b)$\mathrm{P}=\mathrm{L}/4$. (c)$\mathrm{P}=\mathrm{L}/2$. (d)$\mathrm{P}=3\mathrm{L}/4$.

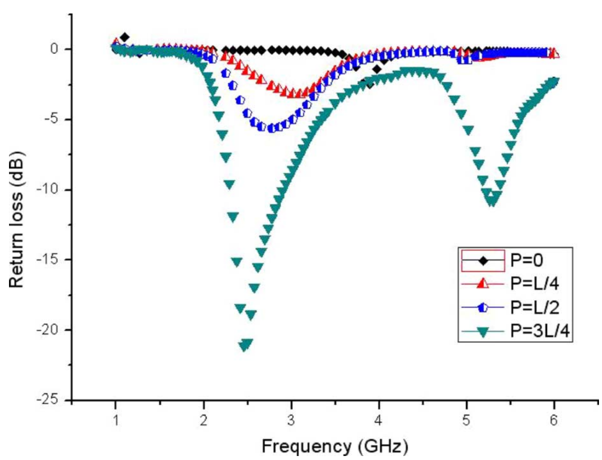

Fig. 7. Simulated result of the return loss for the U-slot with the radial stub by varying P length.

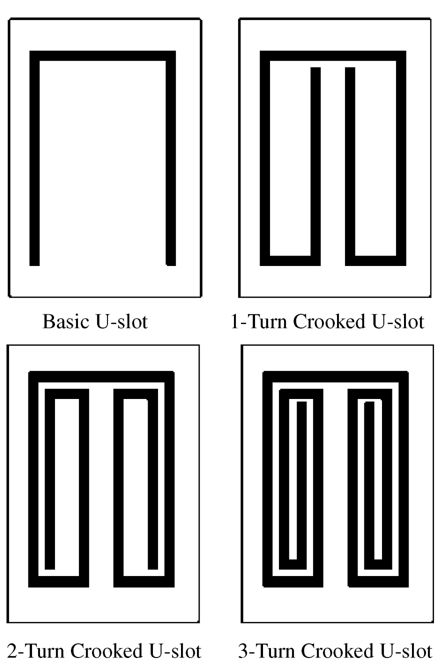

Fig. 8. Number of turns for the crooked U-slot with the radial stub.

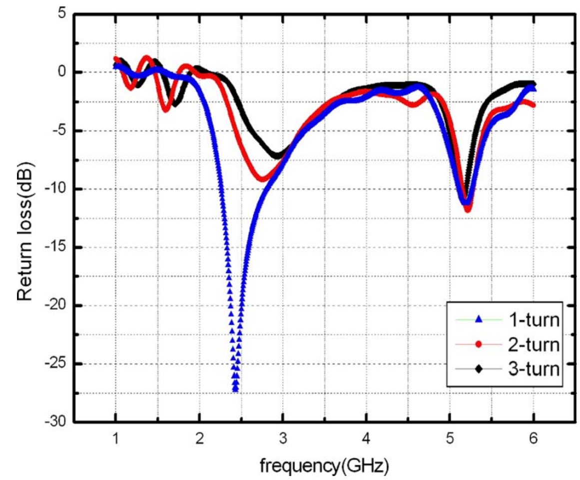

Fig. 9. Simulated result of the return loss by varying number of turns of the crooked U-slot with the radial stub.

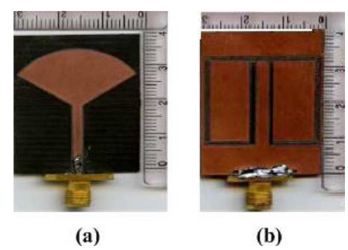

Fig. 10. The top and bottom layers of the proposed antenna. (a) Top side. (b) Bottom side.

by varying the number of turns in the crooked U-slot. Since the proposed crooked U-slot DGS is adapted, the proposed antenna can operate for dual bands at 2.4 and 5.2 GHz. The Q-value of the crooked U-slot antenna with radial stub is lower than that predicted because of cross coupling between the crooked U-slot DGS and the radial stub. Also, the proposed antenna with the crooked U-slot is changed to operate for dual bands at 2.4 and 5.2 GHz. The characteristics of the crooked U-slot deteriorate by increasing the total length (or varying the number of turns) because as the total length of the spiral slot increases, the impedance matching becomes worse. Finally, the optimization was performed providing one-turn structure for the proposed U-slot.

The proposed crooked U-slot printed on Rogers RT 5880 laminate has 17 μm thickness(t), and relative permittivity constant (ϵ_r) of 2.2. Also, loss tangent ($\tan\delta$) is 0.0009 and height(h) is 0.787 mm for the proposed antenna.

III. Measurement Result

The proposed dual-band crooked U-slot antenna was designed and simulated using CST microwave studio 5.1 at 2.4 and 5.2 GHz. Fig. 10 shows a photogragh of fabrication for the proposed dual-band antenna. Fig. 11 shows the simulated and measured return losses for the proposed crooked U-slot antenna. Although variations exist due to the DGS fabrication process, it is found that the proposed dual-band antenna achieves the desired performance at the target frequency bands. That is, return loss is accurately matched at the resonant frequency

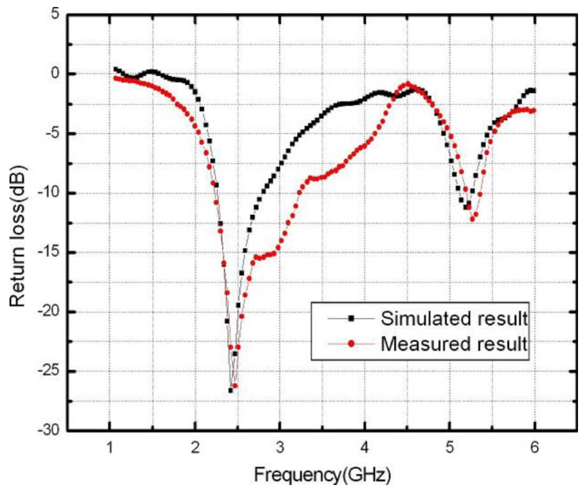

Fig. 11. Measured return loss of the proposed antenna.

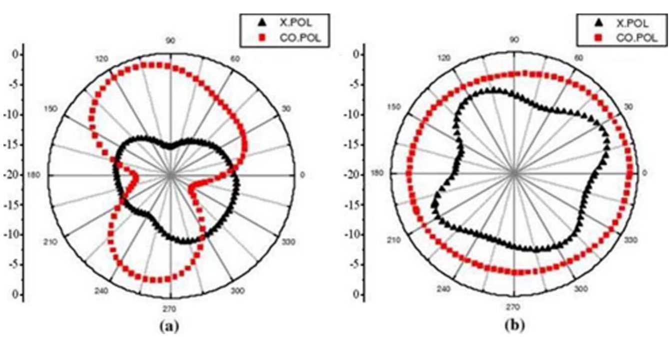

Fig. 12. Measured radiation patterns at 2.4 GHz. (a) X–Y. (b) Y–Z.

(2.4, 5.2 GHz). The return losses of the proposed antenna at 2.4 and 5.2 GHz were obtained as -26.2 and -12.2 dB. The impedance bandwidth ($S_{11} < -10$ dB) is achieved as 22.5% (2.26~2.80 GHz) at 2.4-GHz band on simulation, whereas measured bandwidth is obtained as 35% (2.25~3.19 GHz). Impedance bandwidth at 5.2 GHz ($S_{11} < -10$ dB) on simulation is 4% (5.09~5.31 GHz), and measured impedance bandwidth is 4% (5.22~5.45 GHz). The impedance bandwidth for the high frequency is quite narrow compared to that for the low frequency. This result is in good agreement with the simulated result. Fig. 12 shows the measured radiation pattern for the proposed antenna at 2.4 GHz, and Fig. 13 shows that for the proposed antenna at 5.2 GHz. The measured gains for the antenna are 0.47 dBi and -1.97 dBi, at 2.4 and 5.2 GHz, respectively.

IV. Conclusion

A dual-band crooked U-slot stub antenna using radial stub feeding was proposed. The radial stub and deformed U-slot used for realizing dual-band operation were optimized for

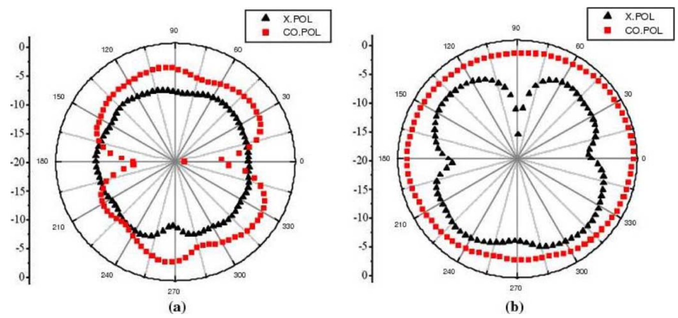

Fig. 13. Measured radiation patterns at 5.2 GHz. (a) X–Y. (b) Y–Z.

providing dual-band performance and making wide impedance matching possible. Operating frequencies are chosen at 2.4 and 5.2 GHz on simulation, and measurement results are in good agreement with the simulation result. Measurement results of return loss for the proposed antenna is -26.2 and -12.2 dB at 2.4 and 5.2 GHz, respectively. In addition, the measured radiated gain for the proposed antenna is 0.47 and -1.97 dBi at 2.4 and 5.2 GHz, respectively. The radiation patterns of the proposed antenna exhibit the same characteristics as the conventional dipole antennas show.

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