Wide Band Dual-Beam U-Slot Microstrip Antenna

Ahmed Khidre, Kai-Fong Lee, Atef Z. Elsherbeni, and Fan Yang

***Abstract*—A wide band dual-beam microstrip antenna is proposed in this communication. Two radiation beams off broadside are obtained by operating the patch antenna at the higher order TM_{02} mode instead of the fundamental TM_{01} mode, which radiates a broadside beam. Broadening the antenna bandwidth is achieved by using the U-slot technique. Unlike previous work on the conventional U-slot microstrip antenna, the effect of the U-slot inclusion on the performance of a patch antenna operating at the TM_{02} mode is studied across the entire achieved bandwidth. The antenna analysis is carried out with the aid of full wave simulation, and an antenna prototype is fabricated and measured for validation. Good agreement between the simulated and measured results is observed. The antenna operating frequency range is 5.18–5.8 GHz with VSWR less than 2, which corresponds to 11.8% impedance bandwidth. It exhibits two radiation beams, directed at 35° and -33° with 7.92 dBi and 5.94 dBi realized gain, respectively at 5.5 GHz.**

***Index Terms*—Dual-beam, U-slot microstrip patch antenna, wide band.**

I. Introduction

Indoor wireless links have intrinsic characteristics that affect the system performance, such as the multipath effect that causes signal fading, and interference effect from adjacent cells that degrades the bit error rate. From the physical layer perspective, one solution to combat these impairments is the use of directional antennas rather than the traditional omnidirectional ones [1]. They have the ability to confine the power in certain directions instead of scattering the power everywhere. As a result of less power loss toward unwanted directions, the multipath and interference effects are reduced. Directional antennas can be single or dual/multi-beam. Dual/multi-beam antennas are antennas that have more than one directive beam from a single aperture. These antennas are useful for indoor wireless systems which require coverage of multiple areas [2], as they reduce the required number of antennas and are found to improve the link quality [3], resulting in easier network deployment.

Microstrip antennas have been widely used in many modern communication systems, because of its robustness, planar profile, and low cost. Most of these antennas operate at their fundamental TM_{01} mode, which gives a broadside beam [4]. Microstrip antenna operating at the higher order TM_{02} mode has dual symmetric radiation beams, with each beam directed at $\pm 45^\circ$ respectively [5]–[7]. It is well known that the major drawback of a microstrip antenna is its narrow bandwidth ($\sim$3%). One of the popular techniques for broadening the patch antenna bandwidth is to incorporate a U-slot on its surface as proposed in [8] and [9]. However, the U-slot technique was studied only at the fundamental TM_{01} mode of the patch [10]. To the best of authors' knowledge, there is no published report on the study of the U-slot patch antenna excited at the higher order TM_{02} mode.

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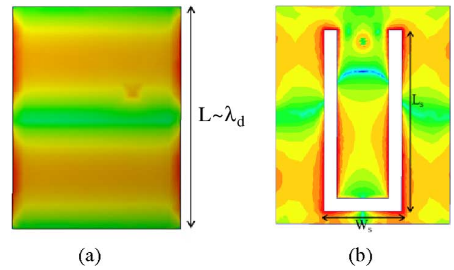

Fig. 1. Current distributions: (a) a plain rectangular patch; (b) U-slot microstrip patch antenna at the higher order TM_{02} mode.

In this communication, a U-slot microstrip antenna operating at the TM_{02} mode to attain dual radiation beams with wideband performance (>10%) is proposed. The U-slot inclusion on the patch's surface introduces asymmetry, which affects the radiation characteristics, such as pattern symmetry, pattern stability, x-pol level, and the direction of the beams. An investigation on how these parameters are affected is presented. The realized gain and efficiency for each beam, and the difference between their maxima levels are also presented. The proposed design is validated with experimental measurement of a fabricated prototype.

II. Antenna Operation Principle and Design

A. Operation Principle

To design a rectangular patch antenna operating at the TM_{02} mode that gives dual radiation beams, the patch length L should be λ_d, instead of $\lambda_d/2$ for the fundamental mode, where λ_d is the wavelength in the dielectric substrate. According to the cavity model of the patch antenna [4], the current on the patch's surface, has two maxima at TM_{02} mode as shown in Fig. 1(a). Therefore, for a U-slot to work effectively, it should intercept both current maxima. Fig. 1(b) shows the current distribution on the surface of a U-slot patch antenna. It is obvious that the presence of two maxima on the patch indicates a λ_d resonator at the TM_{02} mode. Meanwhile the three current nulls are observed and the slot length is around $3\lambda_\mathrm{d}/2$. It should be mentioned that optimization and parametric study are needed for the U-slot parameters to acquire a wide bandwidth.

B. Antenna Geometry

The proposed antenna geometry is shown in Fig. 2, where a coaxial-fed rectangular patch is printed over a Rogers RT\Duroid substrate of thickness $h = 3.175$ mm and permittivity $\varepsilon_r = 2.2$. A U-slot is cut on the patch's surface, which is mounted over the substrate of size $L_g \times W_g = 67 \times 74$ mm. The other side of the substrate is coated with metal, which is the ground plane of the antenna. The dimensions of the antenna that give a broad impedance bandwidth are listed in Table I, which are obtained via iterative process.

C. Parametric Study

The parameters that have critical influence on the antenna performance are chosen for parametric study. These parameters are: L, W, Ls, and b. Parameters L and Ls are responsible for the patch and U-slot electric lengths, whereas W changes the patch impedance [11]. Lastly, b tells how the U-slot intercepts the current maxima on the patch's surface. To study their effects on the antenna performance, parametric study is carried out on the parameters mentioned above, using the full wave simulator Ansoft HFSS [12]. Simulation results of the reflection coefficient at different values of these parameters are shown in Figs. 3 and 4. From Fig. 3, it is observed that L and Ls control the lower and

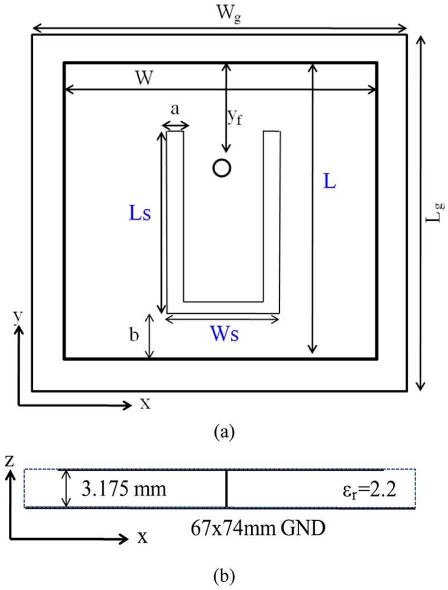

Fig. 2. Geometry of the proposed U-slot microstrip antenna: (a) top view; (b) side view.

TABLE I
DIMENSIONS OF PROPOSED U-SLOT MICROSTRIP ANTENNA

Parameter	L	W	Ls	Ws	a	b	y_f
Units (mm)	34	27	28.25	12	2	2	5.5

higher resonant frequencies of the antenna, respectively, as expected. With the proper selection of L and Ls, an overlap between both resonances occurred leading to a wide impedance bandwidth. On the other hand, a small variation of the antenna width W does not show significant effect on the bandwidth as it is obvious from Fig. 4(a). It should be pointed out that wider variation of W is not suggested, because it might excite the horizontal higher order TM_{20} mode. Finally, from Fig. 4(b), the parameter b that represents the position of the U-slot on the rectangular patch, controls the separation between the two resonances which consequently affects the achieved impedance bandwidth.

III. EXPERIMENTAL RESULTS AND DISCUSSION

The prototype of the proposed antenna in Fig. 2 was fabricated and investigated experimentally. A photo of the proposed antenna prototype is shown in Fig. 5. The antenna overall size is $1.8\ \lambda_\mathrm{d} \times 2.0\ \lambda_\mathrm{d} \times 0.086\ \lambda_\mathrm{d}$ ($67 \times 74 \times 3.175$ mm), where λ_d is the dielectric wavelength at 5.5 GHz. The Simulated and measured results of the proposed antenna and a plain rectangular patch of same dimensions $L \times W$ are shown in Fig. 6. From the figure, the U-slot effect for broadening the antenna bandwidth is obvious. The impedance bandwidth realized by simulation and measured results are listed in Table II. According to the measured results, the U-slot technique increases the impedance bandwidth for more than two times. The difference between the simulated and measured results is due to the defects in the prototype during fabrication.

A contour plot for the projected 3D radiation pattern of the proposed antenna is generated with full wave simulation at 5.5 GHz and is shown in Fig. 6, where two distinct directive beams are clearly seen. The maximum radiation lies in the yz plane, whereas a null exists in the xz plane.

To study the effect of the U-slot inclusion, as well as the variation of the pattern along the frequencies of the entire bandwidth, the radiation patterns at 5.3, 5.5, and 5.8 GHz in the yz plane is presented in Fig. 7.

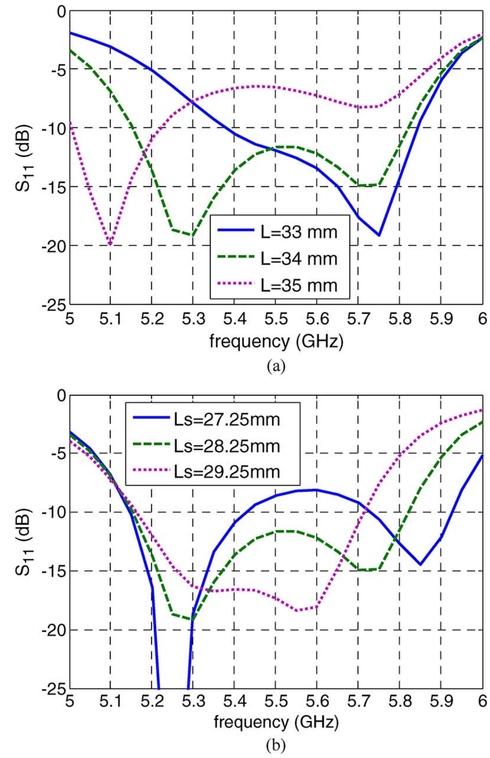

Fig. 3. Simulated S_{11} of the proposed antenna: (a) variation of patch length L, while all other parameters in Table I are fixed; (b) variation of Ls, while all other parameters in Table I are fixed.

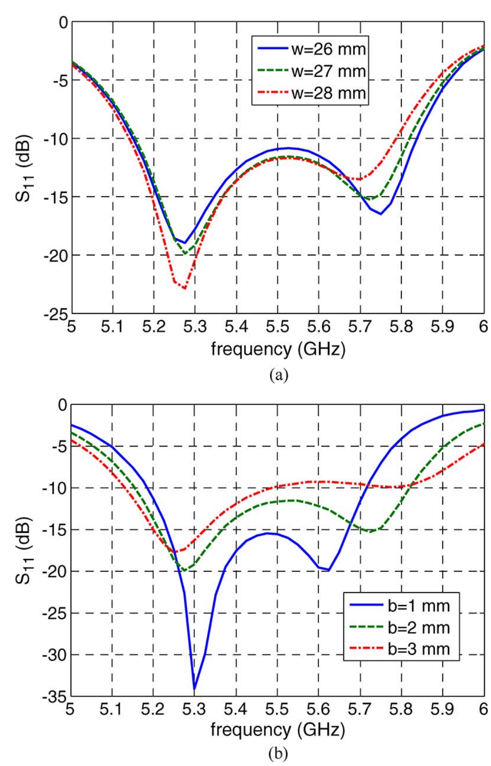

Fig. 4. Simulated S_{11} of the proposed antenna: (a) variation of patch width W, while all other parameters in Table I are fixed; (b) variation of the slot position b, while all other parameters in Table I are fixed.

Good agreement between the simulated and measured results for the co-pol patterns is observed. The beams are not of equal levels and their directions are not in $\pm 45^\circ$ as in the case of a plain rectangular patch.

Fig. 5. Proposed U-slot microstrip antenna prototype, antenna overall size is $1.8\ \lambda_d \times 2\ \lambda_d \times 0.086\ \lambda_d\ (67 \times 74 \times 3.175\ \mathrm{mm})$, where λ_d is the dielectric wavelength at 5.5 GHz.

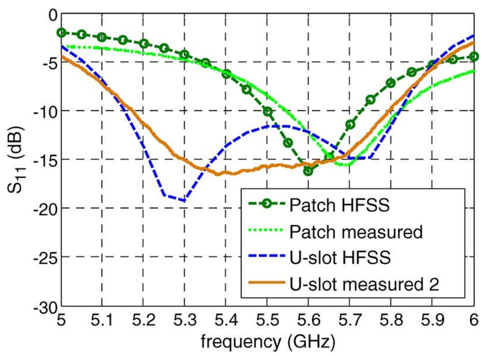

Fig. 6. Simulated vs. measured results for S_{11} of both U-slot and plain rectangular patch antenna.

TABLE II
IMPEDANCE BANDWIDTH OF THE PROPOSED U-SLOT MICROSTRIP ANTENNA

Bandwidth	HFSS	Measured
Without U-slot	4% (5.5-5.72GHz)	5.0% (5.54-5.822GHz)
With U-slot	12% (5.17-5.81 GHz)	11.3% (5.18-5.8 GHz)

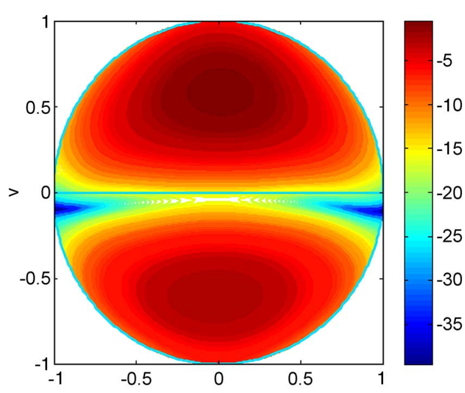

Fig. 7. A contour plot for the projected 3D radiation pattern of the proposed antenna on the xy plane at 5.5 GHz, generated by full wave simulation.

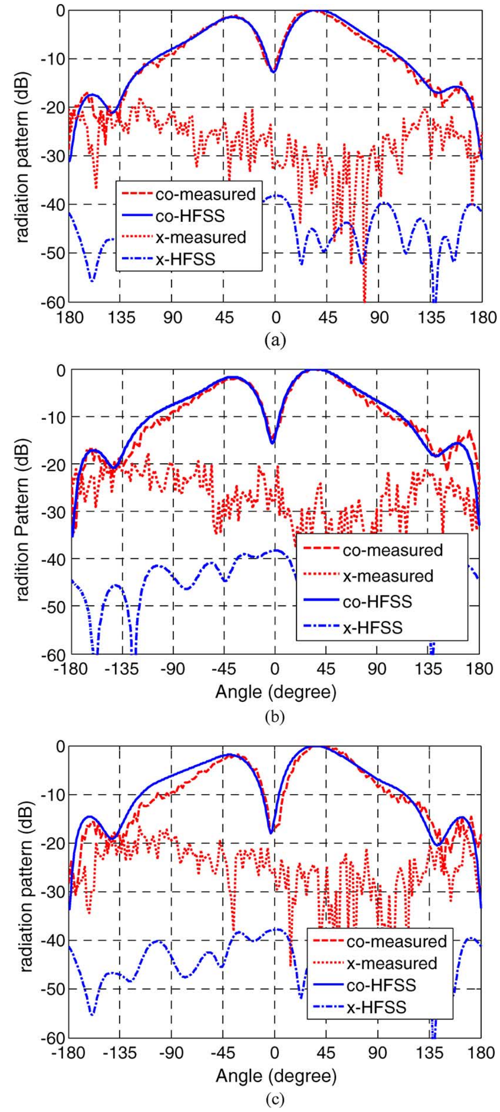

Fig. 8. Simulated vs. measured results for the co-polarization and cross polarization of the proposed antenna in yz plane: (a) at 5.3 GHz; (b) at 5.5 GHz; (c) at 5.8 GHz.

This is attributed to the asymmetry introduced by the U-slot. Regarding the x-pol patterns a discrepancy between the simulated and measured results is observed. This discrepancy is mainly because the signal level of the x-pol component is about -40 dB lower than the co-pol level as shown in Fig. 7. It is lower than the effective dynamic range of our anechoic chamber. Therefore, inside the anechoic chamber the measured signal suffers from the chamber's limitation and its level is higher than the simulated results. Another reason is the presence of the RF cables and connectors that feed the antenna in a close proximity during the pattern measurements. The induced currents on these components radiate and alter the radiation patterns of the antenna. Because the x-pol component is much weaker than the co-pol component (40 dB lower), the distortion of the x-pol patterns is more significant. In the plane cuts $(0^\circ \leq \phi < 90)$, the x-pol level is higher, and the realized gain is lower than in the yz plane. For example, at $\phi = 45^\circ$, the maximum attained x-pol level along the entire bandwidth is -8 dB, whereas the gain is reduced by 2.4 dB.

The directions as well as the realized gain of the beams are evaluated from the patterns in the yz plane, since it is the plane of maximum radiation. They are tabulated in Table III, where the measured directions of the forward and backward beams are 36° and -34° at 5.5 GHz, respectively. Both beams' squint is within 4° across the antenna bandwidth. Also, at 5.5 GHz, the measured realized gain of the forward beam is about 7.92 dBi, whereas for the backward beam it is 5.94 dBi. The maximum difference between the beams' maxima is $\sim$2 dB across

TABLE III
THE SIMULATED (HFSS) VS. MEASURED (M) RESULTS FOR THE DIRECTIONS AND REALIZED GAIN OF THE FORWARD AND BACKWARD BEAMS OF THE PROPOSED ANTENNA IN THE yz PLANE AT 5.3, 5.5, AND 5.8 GHz

Frequency (GHz)	Forward Beam				Backward beam			
	Direction (θ_m°)		Gain (dBi)		Direction (θ_m°)		Gain (dBi)	
	HFSS	M	HFSS	M	HFSS	M	HFSS	M
5.3	37°	38°	8.11	8.57	-37°	-36°	6.63	5.3
5.5	36°	34°	7.82	7.92	-37°	-34°	6.1	5.94
5.8	36°	36°	7.67	7.23	-39°	-32°	5.82	5.44

the antenna bandwidth. The maximum difference between the beams' maxima is a crucial criterion in multi-beam antenna design. The efficiency obtained from both beams is calculated and found to be greater than 95%. The realized gain and estimated efficiency for each beam are similar to the single broadside beam of the conventional U-slot antenna operating at the TM_{01} mode [10].

IV. CONCLUSION

A U-slot microstrip antenna operating at a higher order TM_{02} mode has been proposed and investigated. The antenna has 11.3% bandwidth (5.17–5.81 GHz) and exhibit dual radiation beams. The beams are directed around $\pm 35^{\circ}$ at the center frequency, and both beams' squint is less than 4° within the antenna bandwidth. Realized gain of the forward beam is 7.92 dBi at the center frequency, whereas it is 5.94 dBi for the backward beam. The difference between both beams' maxima is less than 2 dBi across the entire bandwidth. The proposed design is a desirable candidate for stationary terminals of various indoor wireless communication networks.

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Broadband CPW-Fed Circularly-Polarized Slot Antenna With an Open Slot

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***Abstract*—A novel broadband CPW-fed circularly-polarized slot antenna with an open slot is presented. The broadband circular polarization can be achieved simply by opening the radiation slot at the lower left of slot. From the experimental results, the 3-dB axial-ratio bandwidth can reach as large as 1000 MHz (27% relative to the center frequency of 3700 MHz) which can cover the 3.3–3.8 GHz WiMAX band. In addition, the proposed design has the VSWR $\leq$ 2 impedance bandwidth of 5330 MHz (111% relative to the center frequency of 4795 MHz) which can cover the 2–6 GHz WiMAX band. The proposed antenna also has a peak antenna gain of about 5.3 dBic and gain variations can be less than 1 dBic for frequencies within the CP bandwidth.**

***Index Terms*—Circular polarization, coplanar waveguides (CPW), slot antennas.**

I. INTRODUCTION

The CPW-fed wide slot antennas have received much attention and have been increasingly used because the advantages of wide bandwidth, low profile, uniplanar geometry and easy integration with monolithic microwave integrated circuits. On the other hand, in order for deploying a transmitter and a receiver without causing a polarization mismatch between them and overcoming the multipath fading problem, circular polarization is becoming popular in wireless communications to enhance the system performance. The operation principle of CP antennas is to excite two orthogonal modes with equal amplitude but in phase quadrature. It can be achieved by introducing some symmetric or asymmetric perturbations into a wide slot antenna. These perturbations can be implemented through from their feeding lines [1]–[4] or slot configurations [5]–[9]. In order to achieve a wide axial ratio (AR) bandwidth further for the CP wide-slot antenna, a number of designs [1], [2], [4], [6], [9]–[12], have been proposed. By implanting a pair of grounded strips [2], [6], [9], [10] or three inverted-L-shaped grounded strips [11], the AR bandwidth can be improved. For a sequential rotation array configuration fed by an asymmetrical [1] or a symmetrical [12] CPW-fed line, the technique by arranging the antenna elements can significantly increase the AR bandwidth. Also, by using a slot composed of multiple circular sectors [4], the CP bandwidth of a wide-slot antenna can be improved. However, antenna configurations of these designs are so complex that they lead to a high complexity of antenna design and fabrication.

In this communication, a structurally new and simpler CP slot antenna has been proposed. With an open slot introducing an asymmetric perturbation at the lower left of slot, the proposed antenna fed by a wide tuning stub can provide wide circular-polarized and impedance bandwidths. In this design, the 3-dB AR bandwidth can reach as large as 1000 MHz (3.2–4.2 GHz) which is about 27% (relative to the center frequency of 3700 MHz) to cover the 3.3–3.8 GHz WiMAX band. The

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