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 $T_{21}$ mode [10].

## IV. Conclusion

A U-slot microstrip antenna operating at a higher order $T_{21}$ 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 $\pm35^\circ$ at the center frequency, and both beams' squint mode is less than $4^\circ$ within the antenna bandwidth. Realized gain of the forward beam is 7.92 dB at the center frequency, whereas it is 5.94 dB for the backward beam. The difference between both beams' maxima is less than 2 dB across the entire bandwidth. The proposed design is a desirable candidate for stationary terminals of various indoor wireless communication networks.

## References


Based on the parametric study, Table I lists the structural parameters and measured CP performances of constructed prototypes. Fig. 7 shows their measured results of return loss and axial ratio (AR). In those constructed prototypes, Antenna 1 is a slot antenna fed by a straight CPW feeding line as shown in Fig. 1(a). Antennas 2–4 are a slot antenna fed by a wide tuning stub as shown in Fig. 1(b). The photographs of Antenna 1 and Antenna 4 are shown in Fig. 8. In Table I and Fig. 7, the measured results show that Antenna 1 protruded by an open slot has the CP operation and an AR bandwidth is about 23.1%. For improving the impedance and 3-dB AR bandwidths, a wide tuning stub at the top of CPW feeding line is used for Antennas 2–4. When suitable dimensions of $W_1$, $L_1$, and $W_2$ are chosen as shown in Table I, the VSWR < 2 impedance bandwidth of Antenna 4 can reach 111% which is larger than that of Antenna 1 (without a wide tuning stub). Also, the 3-dB AR bandwidth of Antenna 4 can reach 27% which is as larger as compared with that of Antenna 1. As $W_2$ is decreased from 4.5 to 3.5 mm, both 3-dB AR and impedance bandwidths become smaller. As $W_2$ is larger than 4.5 mm, the CP performance becomes worse. For brevity, its results are not shown in Table I. Fig. 9 shows the measured and simulated results (return loss and CP axial ratio) of Antenna 4 that have a reasonable agreement and the best value of AR can reach about 0.5 dB. In order to perceive that the CP operation can be generated, Fig. 10 shows the magnetic current distribution of Antenna 4 varying with time.
at 3700 MHz. At $\omega t = 0^\circ$, the predominant magnetic current is above the wide tuning stub and is oriented in a direction $\phi = 0^\circ$ relative to the $+x$ axis. At a later time instant with a 90° phase lagging ($\omega t = 90^\circ$), the principal magnetic current is along the open slot, whose direction is 90° relative to the $+x$ axis. At $\omega t = 180°$ ($270°$), the magnetic current distribution is just opposite to that at $\omega t = 0°$ ($90°$). The magnetic current distribution varying as a function of time in such a fashion can depict the behavior of predominantly right- and left-hand CP radiations in the $z > 0$ and $z < 0$ half spaces, respectively.

Fig. 11 shows the measured and simulated far-field radiation patterns of Antenna 4 in the $xz$ and $yz$ planes at the center frequency of 3700 MHz. The far-field radiation patterns have lower AR values around the broadside directions (i.e., $\pm z$ directions). They are mainly RHCP for $z > 0$ and LHCP for $z < 0$. From Fig. 11, it is seen that measured and simulated results are with reasonable agreement. In 3-dB AR bandwidth (3.2–4.2 GHz), the measured and simulated results of peak antenna gain of around 5 dBi are close for each other. The open slot can provide the perturbation into the wide slot for applications to 2–6 GHz WiMAX and the 3-dB AR bandwidth of 27% for applications to 3.3–3.8 GHz WiMAX. Under the use of inexpensive FR4 microwave substrate, the proposed antenna has the measured antenna gain of around 5 dBi.

### IV. Conclusion

The novel broadband CPW-fed CP slot antenna has been demonstrated. The open slot can provide the perturbation into the wide slot antenna for the CP operation. Moreover, the use of wide tuning stub can improve the impedance and 3-dB AR bandwidths. Based on the parameter study, many prototypes have been successfully implemented. In addition to the simple unipolar configuration, experimental results show that the proposed antenna has the impedance bandwidth of 111% for applications to 2–6 GHz WiMAX and the 3-dB AR bandwidth of 27% for applications to 3.3–3.8 GHz WiMAX. Under the use of inexpensive FR4 microwave substrate, the proposed antenna has the measured antenna gain of around 5 dBi.

### References


### A Topology-Based Miniaturization of Circularly Polarized Patch Antennas

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**Abstract**—A novel approach for the miniaturization of circularly polarized patch antennas is presented. This enables a size reduction of as high as 75%, compared to a conventional corner-truncated circularly polarized patch antenna. The proposed design procedure consists of a number of intermediate steps, each of which produces antenna miniaturization as well as the desired polarization and impedance matching properties. This is very challenging in miniaturizing circularly polarized probe-fed patch antennas. It is shown that two resonant frequencies can be tuned independently to produce a dual band antenna with two orthogonal polarizations. Finally, two circularly polarized miniaturized patch antennas with different miniaturization factors are fabricated, and their input impedances, radiation patterns and axial ratios are discussed.

**Index Terms**—Anisotropic media, circularly polarized antennas, microstrip antennas.

### I. Introduction

Many modern satellite and terrestrial point-to-point communications systems use circularly polarized (CP) waves in order to maximize the polarization efficiency and thus improve the polarization link budget [3]. Although a CP antenna with a low profile, small size and light weight is highly desirable in many applications such as compact satellite or mobile platforms [4], most miniaturization techniques are developed for linearly polarized antennas [5]–[7]. This is mainly due to the fact that antennas with extremely small lateral dimensions are incapable of internally generating the required conditions for CP operations.

Many compact CP patch antennas have been proposed and investigated [8]–[10]. These efforts have relied mainly on intuitive techniques such as inserting several slots or slits in suitable locations on the patch itself. In such antenna designs, the splitting of two near-degenerate orthogonal modes with equal amplitudes and a 90° phase difference is achieved by slightly adjusting the embedded slots, such as a cross-slot in a patch or slots at the boundary of the patch. These inserted slots

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