

A Circularly Polarized Table-Like Air Patch Antenna With Four Grounded Metal Legs

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Abstract—A novel circularly polarized table-like air patch (CP-TAP) antenna is proposed in this letter. With four inherently built-in grounded legs at four corners of the patch, the new antenna can be easily self-supported on the ground plane without any dielectric supporting structure. Two feeding structures of the CP-TAP antenna are proposed. A single-probe-fed prototype operating at 2.45 GHz demonstrates a bandwidth of 7% for return loss of 10 dB and a bandwidth of 1.6% for 3-dB axial ratio. With a new n -shaped proximity coupling probe configuration, the impedance bandwidth of the proposed CP-TAP antenna can be as wide as 25%. In all cases, the peak gain of the proposed CP-TAP antenna is more than 1 dB higher than that of a conventional air patch antenna with comparable feeding structures. It can be expected that with the attractive features of low profile, high gain, and self-supporting, the new antenna configuration can find many practical applications.

Index Terms—Circularly polarized (CP) antennas, microstrip antennas, patch antennas.

I. INTRODUCTION

LOW-PROFILE antennas are always a popular choice for the communication systems where conformability, light weight, and ease of manufacturing are required. Various low-profile antennas have been invented in past few decades. It is indisputable that the most widely used conformal low-profile antenna would be microstrip patch antennas. Among various microstrip patch antennas, circularly polarized (CP) microstrip antennas have gained tremendous attention for many niche applications, including GPS receivers, passive radio frequency identification (RFID) readers, as well as phased array radars [1], [2].

In a microstrip CP antenna, two orthogonal resonant modes whose initial phase is offset by 90° need to be excited with equal magnitude. For example square-shaped CP patch antennas support two orthogonal TM_{01} modes. Many pioneer works on CP microstrip patch antennas are available in the literature [3]–[7]. In many practical applications, air-filled CP patch antennas [7] are frequently used due to their low manufacturing cost, free of surface waves, low dielectric loss, as well as higher gain and low probability of having passive intermodulation when power is high. In using an air-filled CP patch antenna, dielectric posts or other dielectric structures are needed to support the top metal

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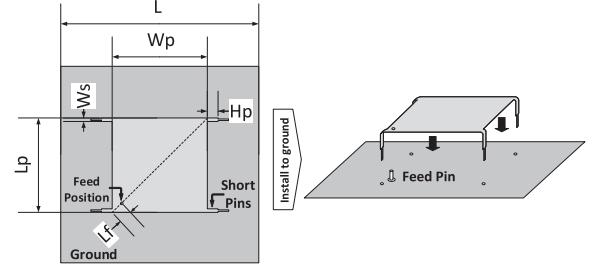


Fig. 1. Configuration and installation of the single-probe-fed CP-TAP antenna.

patch. A lot of practical technologies [8]–[10] have been developed to enhance the impedance bandwidth (IPBW) of patch antennas, including the L-probe feeding configuration [10]. To the authors' best knowledge, there is no CP air patch antenna that builds in a natural and stable self-supporting structure without compromising antenna radiation performances.

In this letter, a novel CP table-like air patch (CP-TAP) antenna is proposed. The top rectangular metal patch of the antenna is steadily propped up by four inherently built-in grounded metal legs at the four corners of the patch to form a semi-open resonator. The four grounded legs together with the top patch are integrated parts of the antenna to support two orthogonal TM_{11} modes. Two feeding options to the CP-TAP antennas are discussed in this letter, including a single-probe feeding method and a dual- n -probe feeding option. Without any dielectrics involved, the direct benefits of this all-metal self-supporting CP antenna structure include low installation cost, high power-handling capability, and long operational life as compared to conventional air patch antenna with dielectric supporters.

II. ANTENNA CONFIGURATION AND WORKING MODES

The detailed configuration of a single-probe-fed CP-TAP antenna with four grounded legs is sketched in Fig. 1. Suppose the length and width of the top rectangular patch are L_p and W_p , respectively. The typical values of L_p and W_p are slightly larger than $0.5\lambda_0$, which is half-wavelength at the center frequency. Four metal shorting legs at four corners of the patch are with height of H_p and thin width of W_s . The four “legs” not only support the dual TM_{11} modes, but also provide a reliable mechanical support to the “table” in the air. A finite ground plane with size of $L \times L$ is assumed, but the actual size of L is not critical in a practical design. For a single-probe-fed CP-TAP antenna, a coaxial probe is located along a diagonal line of the patch and L_f distance away from a leg. In order to couple the energy from one mode to another in a single-probe-fed CP-TAP antenna, L_p needs to be slightly larger than W_p . By adopting dual- n -shaped

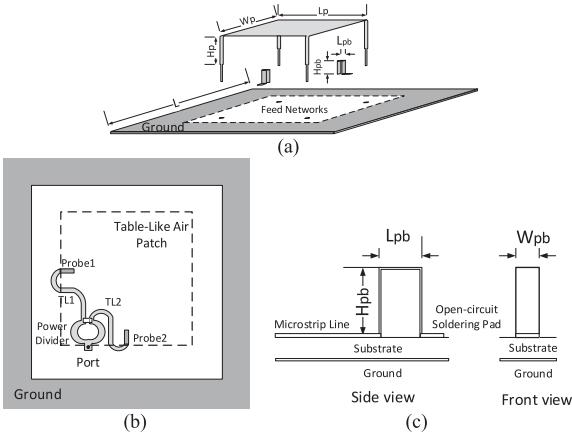


Fig. 2. (a) Configuration of dual- n -probe-fed CP-TAP antenna. (b) Feeding network of the antenna. (c) Configuration of the n -probe.

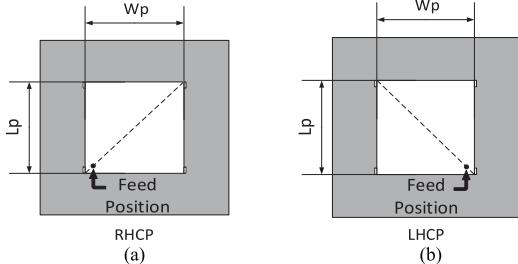


Fig. 3. (a) Single-probe-fed RHCP TAP antenna. (b) Single-probe-fed LHCP TAP antenna.

coupling probes, the impedance-matching bandwidth and axial-ratio (AR) bandwidth can be significantly enhanced. Compared to the coaxial probe-fed CP-TAP antennas, the typical height H_p for a dual- n -shaped probe-fed antenna is relatively larger and can be as large as 0.12 wavelength at the center frequency. The configuration of a CP-TAP antenna with dual- n -shaped probes is shown in Fig. 2(a), with its feeding network shown in Fig. 2(b). Fig. 2(c) depicts the detailed configurations of the n -probe.

Fig. 3(a) and (b) shows the feeding arrangements for the single-probe-fed right-hand CP (RHCP) and left-hand CP (LHCP) TAP antennas, respectively. It can be seen that an LHCP antenna is a mirror counterpart of an RHCP antenna with L_p slightly larger than W_p . As illustrated in Fig. 2(b), the feeding network of the dual- n -probe-fed CP-TAP antenna can consist of a Wilkinson power divider and two transmission lines. The Wilkinson power divider is used to split the input power equally, and the two transmission lines provide a 90° phase difference between the two feeding probes.

Unlike a conventional rectangular CP patch antenna, the new CP-TAP antenna supports two orthogonal TM₁₁ modes instead of TM₀₁ modes. To provide a better understanding of the working modes, the electric field distributions of the two orthogonal modes underneath the metal patch of a CP-TAP antenna are visualized with commercial 3-D EM software HFSS by setting the phase of the excitation signal with 0° and 90° , separately, which are illustrated in Fig. 4(a) and (b). It can be seen that in a CP-TAP antenna, the electric field on the radiating edges presents a sinusoidal distribution due to the existence of the four shorting legs, which differs from a uniform distribution in a conventional CP air patch antenna.

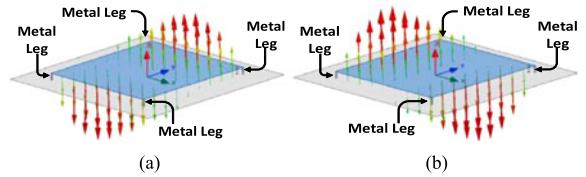


Fig. 4. Electric field distribution underneath the patch of CP-TAP antenna (a) with excitation phase of 0° and (b) with excitation phase of 90° .

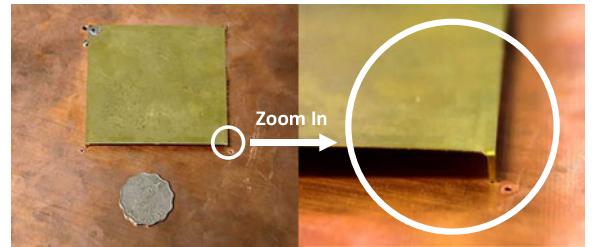


Fig. 5. Photographs of a prototype single-probe-fed right-hand CP-TAP antenna.

TABLE I
PHYSICAL DIMENSIONS OF THE SINGLE-PROBE-FED CP-TAP ANTENNA

	L	L_p	W_p	W_s	L_f	H_p
mm	200	73.5	67	1	4.5	4
λ_0	1.633	0.6	0.547	0.008	0.037	0.033

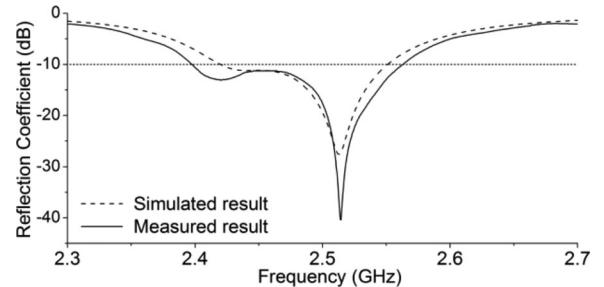


Fig. 6. Simulated and measured reflection coefficient of the prototype single-probe-fed CP-TAP antenna working at 2.45 GHz.

III. DESIGN EXAMPLES

A. Single-Probe-Fed CP-TAP Antenna

A prototype of a single-probe-fed CP-TAP antenna working at 2.45 GHz is designed and prototyped using copper sheet as shown in Fig. 5. Three-dimensional EM software HFSS is used for the EM design. The physical dimensions of the fabricated prototype antenna are listed in Table I. The EM simulated and measured reflection coefficients of the antenna are superimposed in Fig. 6, showing very good agreement. The bandwidth of -10 -dB reflection coefficient spans from 2.38 to 2.55 GHz, showing 6.9% impedance-matching bandwidth. The measurement was done using Agilent E5071B Network Analyzer. Fig. 7 shows the simulated and the measured peak gain (PG) and AR of the single-probe-fed CP-TAP antenna versus frequency. All the radiation properties are measured using the SATIMO SG-128 spherical scanner system in the Radiofrequency Radiation

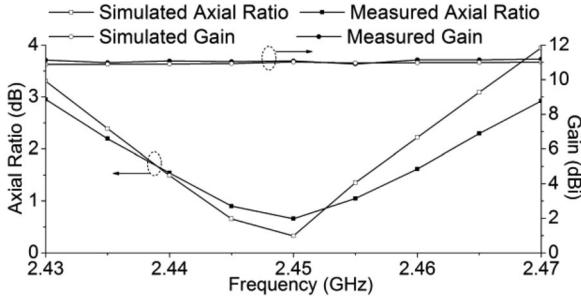


Fig. 7. Simulated and measured PG and axial ratio versus frequency of the prototype single-probe-fed CP-TAP antenna.

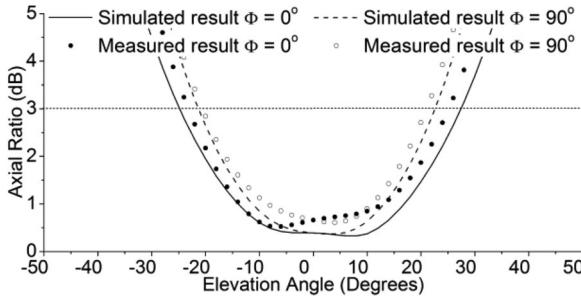


Fig. 8. Axial ratio versus elevation angles of the single-probe-fed CP-TAP prototype antenna measured at 2.45 GHz.

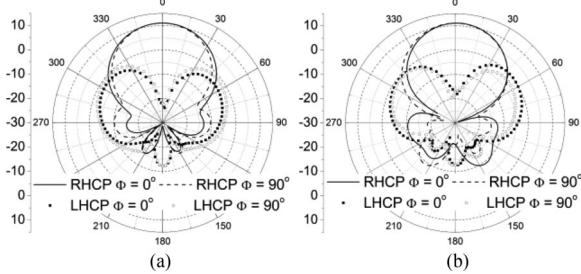


Fig. 9. Radiation patterns of the single-probe-fed RHCP TAP antenna prototype at 2.45 GHz. (a) Simulated results for RHCP and LHCP patterns. (b) Measured results for RHCP and LHCP patterns.

Research Laboratory of the Chinese University of Hong Kong, which is an ISO17025 accredited laboratory. It is seen from the figures that the simulated PG over the operational frequency band is about 11.3 dBi, while the measured gain is about 11.1 dBi.

The AR bandwidth (ARBW) below 3 dB is found to be 2.43–2.47 GHz, of which the fractional bandwidth is about 1.63%. The results for the simulated and the measured AR versus elevation angles in two major cutting planes measured at 2.45 GHz are superimposed in Fig. 8. It is seen that the measured AR beamwidths (ARMWs) below 3 dB in the cutting planes of $\phi = 0^\circ$ and $\phi = 90^\circ$ are about 45° and 42°, respectively, which is identical to the simulated results. The measured and the EM simulated radiation patterns of the single-probe-fed CP-TAP antenna are plotted in Fig. 9. As shown, the PG appears at $\theta = 0^\circ$ both in the $\phi = 0^\circ$ and $\phi = 90^\circ$ cutting planes. The measured 3-dB beamwidths of the gain are about 48° and 47° in the $\phi = 0^\circ$ and $\phi = 90^\circ$ cutting planes, respectively. The measured front-back ratio (F-BR) mainly depends on the size of the ground

TABLE II
PHYSICAL DIMENSIONS OF THE DUAL- n -PROBE-FED CP-TAP ANTENNA

	L	L_p	W_p	H_p
mm	200	63	62	15
λ_o	1.633	0.52	0.51	0.124
	W_s	L_{pb}	H_{pb}	W_{pb}
mm	1	6.5	12	2
λ_o	0.008	0.053	0.098	0.017

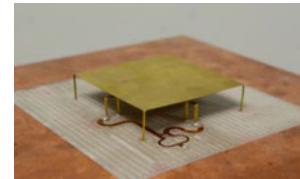


Fig. 10. Photograph of a dual- n -probe-fed CP-TAP prototype antenna.

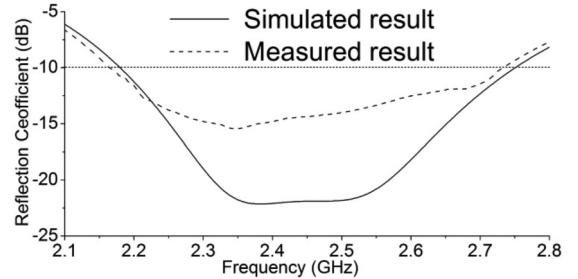


Fig. 11. Simulated and measured reflection coefficients of the prototype dual- n -probe-fed CP-TAP antenna without feeding networks.

plane and is larger than 22 dB for this prototype antenna. Fig. 9 also shows that this prototype antenna is an RHCP antenna, as the field component for the LHCP wave is lower by about 30 dB at the zenith of the radiation pattern. In the $\phi = 0^\circ$ cutting plane, the measured half-power beamwidth (HPBW) of the RHCP pattern is about 48°, while in the $\phi = 90^\circ$ cutting plane, the HPBW is about 47°. The description above demonstrates that the proposed single-probe-fed CP-TAP antenna has a good radiation performance for CP applications.

B. Dual- n -Probe-Fed CP-TAP Antenna

A prototype of a wideband CP-TAP antenna using dual- n -probe feeding is designed and fabricated. The dimensions of the prototype antenna are listed in Table II. The photograph of the prototype antenna is shown in Fig. 10. The simulated reflection coefficient of the prototype antenna looking at an n -probe without a feeding network is shown in Fig. 11, demonstrating impedance-matching frequency band from 2.15 to 2.75 GHz or fractional bandwidth of about 25%.

The simulated and measured ARs and PGs are compared in Fig. 12. The PG measured at 2.4 GHz is about 8.3 dBi. As displayed in Fig. 12, the 3-dB AR frequency band ranges from 2.1 to 2.7 GHz, or more than 24% fractional bandwidth, showing a good CP behavior over a wide frequency band. The simulated radiation patterns are shown in Fig. 13(a), while the measured ones are shown in Fig. 13(b). Over the frequency band from 2.1

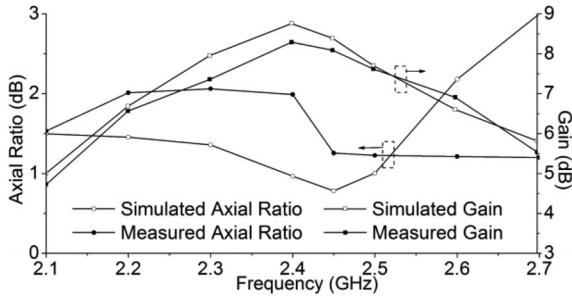


Fig. 12. Simulated and measured PGs and ARs versus frequency of the dual- n -probe-fed CP-TAP prototype antenna.

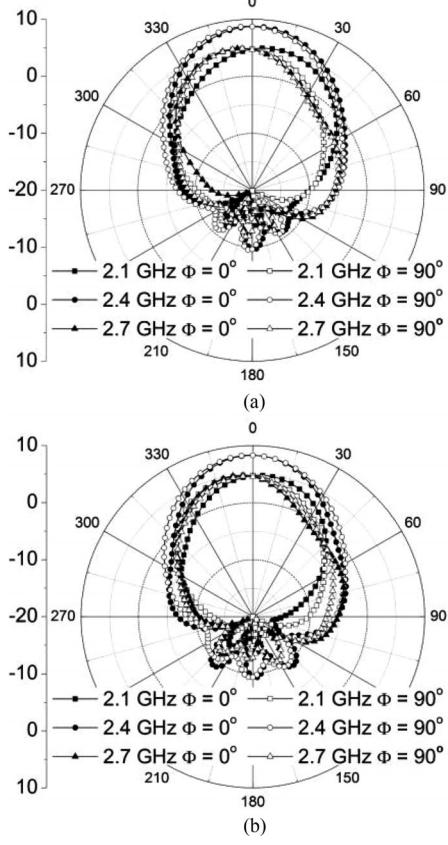


Fig. 13. Radiation patterns of the dual- n -probe-fed CP-TAP antenna at different frequencies. (a) Simulated results. (b) Measured results.

to 2.7 GHz, the radiation pattern varies slightly, providing nearly constant radiation performance with HPBW of about 50°.

A theoretic performance comparison on IPBW, ARBW, PG, HPBW, 3-dB ARMW, and F-BR between a conventional single-probe-fed CP air patch antenna, an dual-L-probe-fed air patch antenna, a single-probe-fed CP-TAP antenna, and a dual- n -probe-fed CP-TAP antenna is presented in Table III. All the narrowband antennas for comparison are set in the same height of 4 mm, and the height of all the wideband CP antennas is set to 15 mm. All the results are simulated at 2.45 GHz by HFSS. A few interesting conclusions can be drawn.

- 1) The impedance and 3-dB ARBs of the proposed CP-TAP and conventional air patch antennas in single-probe feeding cases are comparable.
- 2) The impedance and 3-dB ARBs of a dual- n -probe CP-TAP and a dual-L-probe-fed conventional CP air patch antennas are comparable.

TABLE III
THEORETIC PERFORMANCE COMPARISON BETWEEN CONVENTIONAL CP PATCH ANTENNAS AND CP-TAP ANTENNAS

Antenna Type (patch size in $\lambda_0 \times \lambda_0$)	IPBW (%)	ARBW (%)	PG (dBi)	HPBW (Degree)	ARMW (Degree)	F-BR (dB)
Single-probe-fed air patch (0.45×0.45)	6.5%	1.42%	9.8	58°	78°	22
Dual-L-probe-fed air patch (0.4×0.4)	26%	25%	7	68°	81°	18
Single-probe-fed TAP (0.6×0.55)	7%	1.63%	11.3	47°	50°	22
Dual- n -probe-fed TAP (0.51×0.52)	25%	> 25%	8.3	50°	42°	18

- 3) The PG for CP-TAP antennas is more than 1 dB higher than that of corresponding conventional ones in all cases due to its relative larger patch area.
- 4) As the consequence of the higher gain, the 3-dB and ARMWs for CP-TAP antennas are relatively narrower as compared to conventional air patch antennas. Such CP antennas with narrower beamwidths can be used in some niche applications, such as an RFID reader at a checkpoint.

IV. CONCLUSION

A novel CP-TAP antenna is proposed and experimentally verified. Four grounded metal legs are inherent parts of the antenna to support a pair of TM₁₁ modes. A unique advantage of such antenna configuration is its self-supporting capability providing a firm mechanical structure of the air patch and saving a great deal of efforts in manufacturing and antenna installation. Additionally, compared to conventional CP air patch antennas, the proposed CP-TAP antenna provides a higher gain by more than 1 dB. Prototypes of CP-TAP antennas with two feeding configurations are built and measured. Both theoretical and experimental matching and radiation performances have shown good potentials of the new CP antenna configuration for the applications where a large number of high-gain, low-cost, and easy-to-install planar CP antenna elements are needed.

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