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Circularly polarized high-power antenna with higher-order mode excitation

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Research Paper

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Abstract

A circularly polarized high-power antenna with higher-order mode excitation (TM_{01}) is presented in this paper. The proposed structure consists of metal plates placed on the conical horn antenna's aperture for achieving TM_{01} to circular polarized TE_{11} mode conversion at the output. The structure is simulated on CST Microwave Studio. The designed antenna exhibits high gain and a directive radiation pattern. The axial ratio of the proposed structure is below 3 dB. The simulated and measured reflection coefficient for TM_{01} mode excitation is below −10 dB over a frequency range of 2.95–3.13 GHz. The structure is purely metallic, and the calculated high-power microwave (HPM) capability is up to the MW level. The proposed antenna is helpful for portable HPM systems.

Introduction

In modern microwave systems, a high-power microwave (HPM) antenna is necessary to efficiently transmit high-power signals from the HPM source to the target. In HPM systems, HPM sources are used to generate high-power pulses for a very short duration [1]. These high-power pulse signals are transmitted or radiated through a mode converter and horn antenna [2]. Many other types of antennas have also been designed, e.g. the helical antenna [3], TEM horn antenna [4], impulse radiating antenna [5] to radiate microwave signals. But all these antennas support polarization operation linearly. These antennas (linearly polarized) cannot efficiently deliver the power if they are not appropriately aligned with the target. A circularly polarized (CP) antenna must be designed to radiate HPM signals to avoid this issue. Several methods have been proposed to convert linearly polarized waves to CP waves, e.g. waveguide mode converter [6, 7], metasurfaces [8–10], various types of slots [11, 12], meander line [13, 14], and grating structures [15–17]. The conventional polarizer (CP type) generally accepts TE_{11} mode as input [18], and they are not convenient with higher-order input mode. HPM systems produce output as TM_{01} mode [19]. Many mode converters have been presented to provide CP TE_{11} mode [20–22], but all reported converters are not compact enough. Besides this, only a few CP antenna designs are reported for HPM systems. Therefore, there is scope for the improvement of compactness of the polarizer excited with higher-order mode.

Many microwave lens forms are reported, such as Fresnel lenses, for instance, and dielectric lenses, but the advantages of metal plate lens are light in weight, low cost, and easy to build and compact as compared to other ones.

So in this contribution, we designed an antenna, which performs mode conversion (TM_{01} to CP TE_{11} mode) as well as transmission of the signal. This article aims at developing a CP high-power antenna with higher-order mode excitation. The designed antenna exhibits high gain and radiation efficiency with excellent power handling capability. Four sections are discussed in this paper. In "Design principle and structure" section, the high-power antenna's design principle and geometrical details are explained. In "Results and discussion" section, the simulated and measured results of the antenna are presented. Conclusions are summarized in the last section.

Design principle and structure

The high-power antenna is used for several applications like airborne, portable HPM operation, material's electric characterization, and so on. The main design parameters of the HPM antenna are high-power capability, gain, radiation pattern, and reflection coefficient (S_{11}). The designed structure should be low profile, efficient, and easy to fabricate. Therefore to achieve all these characteristics, we developed an antenna based on a mode conversion process.

The proposed structure consists of metal plates placed on the horn antenna's aperture to produce CP TE_{11} mode at the output. Here, the conical horn antenna is used as a radiator, which exhibits high gain and radiation efficiency, and it also supports circular polarization.

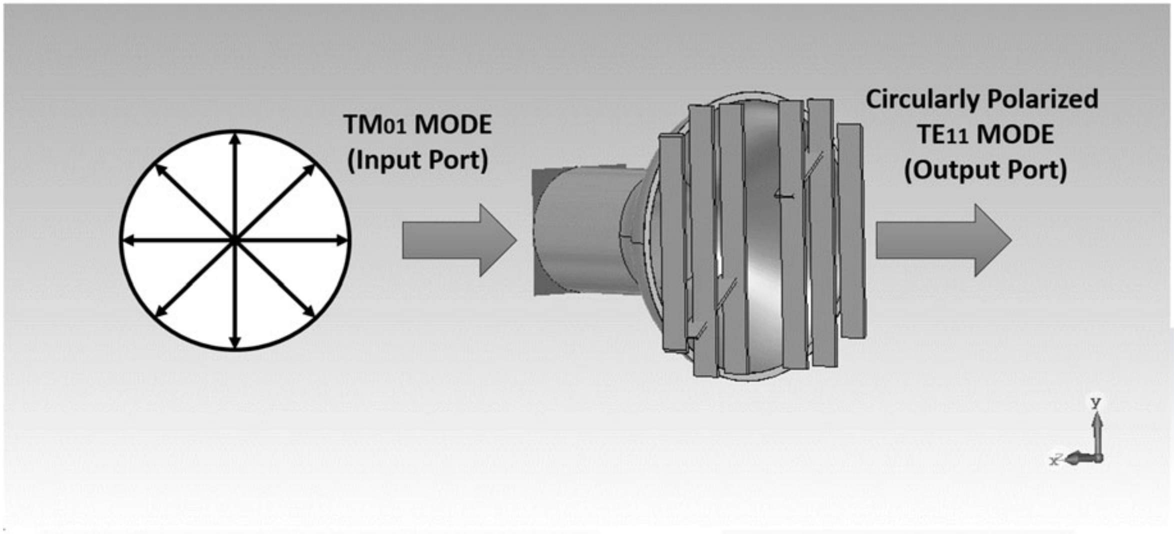

Fig. 1. Generation of circularly polarized output from higher mode excitation.

In this paper, the input power is in the form of the TM_{01} mode of the conical horn antenna, as shown in Fig. 1. In a circular waveguide, TM_{01} mode is the first higher-order mode. This mode field pattern consists of radially diverging *E*-field lines. The direct radiation of TM_{01} mode through the antenna produces a divergent beam; this results in minimum power at the center. For efficient radiation, there must be maximum power at the center.

For avoiding this issue, a CP antenna must be designed to radiate HPM signals. Therefore, we designed a metal plate structure, which converts the TM_{01} mode into CP TE_{11} mode. Here, the metal plate structure consists of seven vertical plates. All plates have the same thickness, and the gap between the two plates is also the same. Initially, the dimensions of each metallic rectangular vertical plate are $20 \times 2\ \mathrm{cm}^2$. Spacing between two consecutive metal plates is 3 cm, as shown in Fig. 2(a). After that, the center metallic rectangular plate is placed at an angle of +45° from the *yz*-plane (with a small cut from the center) to produce left-handed circular polarization (LHCP) output. If placed at an angle of −45°, right-handed circular polarization output will be provided, as shown in Fig. 2(b).

Once the optimum dimension plate structure is appropriately designed, we can place it on the conical horn antenna's aperture to get the CP TE_{11} at the output. Figure 2 shows the layout of the proposed antenna.

The proposed structure composed of a set of parallel metal plates, and it can be divided into an *E*-plane or an *H*-field.

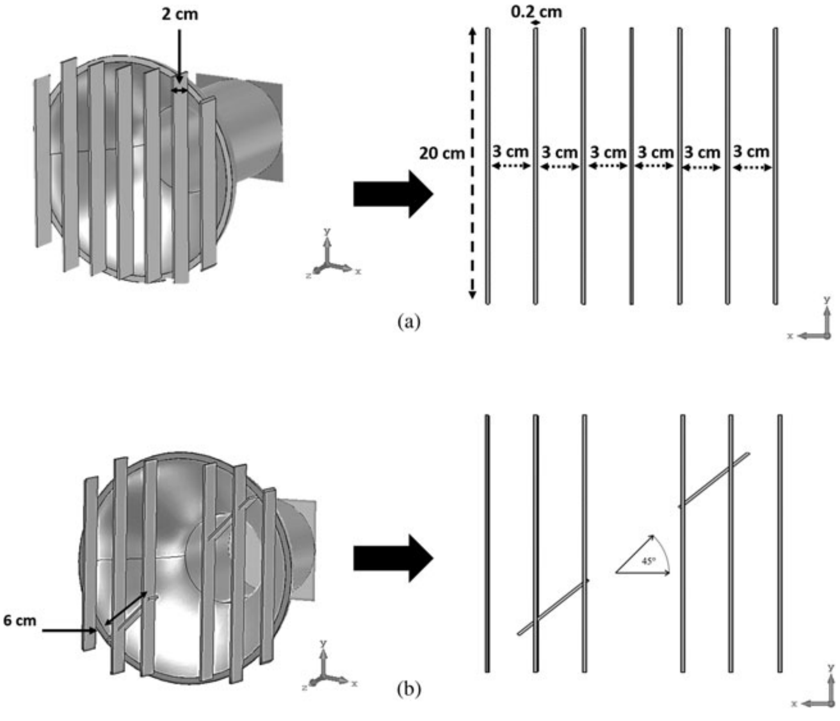

Fig. 2. The layout of the proposed structure.

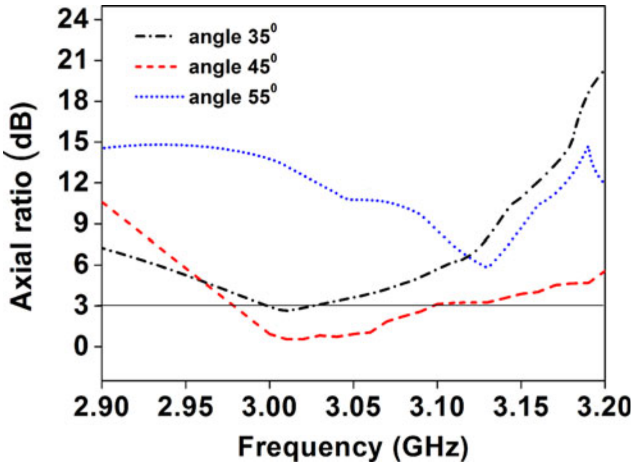

Fig. 3. Axial ratio versus frequency plot of the proposed high-power antenna.

Here, one plane (*E*-plane) works as an accelerating plane, and the other lens works as a delay plane. Here, it is noticed that when the electromagnetic (EM) wave travels in an *E*-plane, the phase velocity (V_g) is higher than the phase velocity (V_0) in the free space. Similarly, when the EM wave travels in the *H*-plane, the phase velocity (v_g) is less than the phase velocity (V_0) in the free space [23]. It ensures that we can obtain or achieve the desired phase distribution of the EM wave by adjusting the gap between the two metal plates and the two metal plate width. In this letter, for excitation of TM_{01} mode at the horn's input port, a TM_{01} mode feed is designed to make a conical monopole and an inverted cone, as shown in Fig. 5. The designed feed converts coaxial-TEM mode to TM_{01} mode. The designed TM_{01} mode feed is applied at the conical horn antenna's input port. The output TE_{11} mode can be divided into vertical polarization and horizontal polarization. Each orthogonally polarized components (horizontal or vertical) have equal amplitudes but out of phase (by 90°), which is essential for circular polarization.

Results and discussion

The proposed high-power antenna is designed and simulated using CST Microwave Studio. Here, the conical horn antenna is used as a polarizer as well as a radiator, which exhibits high gain and radiation efficiency. The proposed antenna is designed at 3 GHz frequency. A metallic plane sheet of thickness 0.2 cm is used to

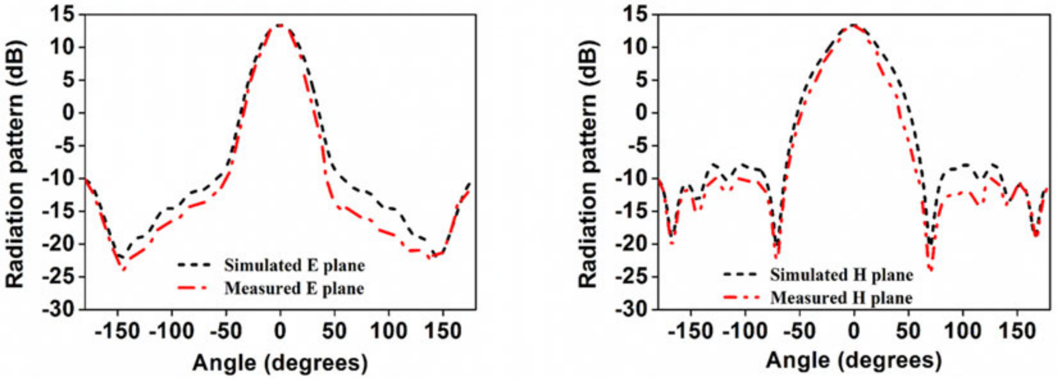

Fig. 4. Simulated and measured radiation patterns at 3 GHz with higher mode excitation (TM_{01}) at input port.

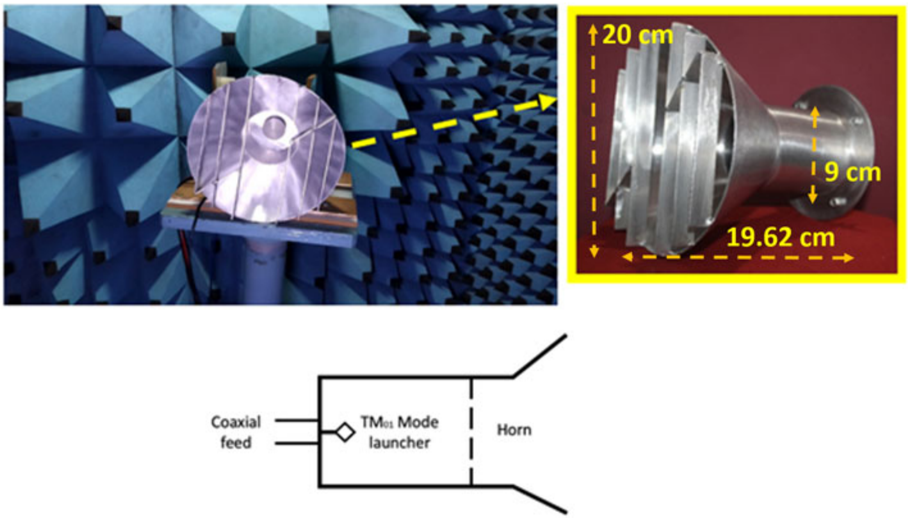

Fig. 5. High-power antenna testing and measurement setup in an anechoic chamber.

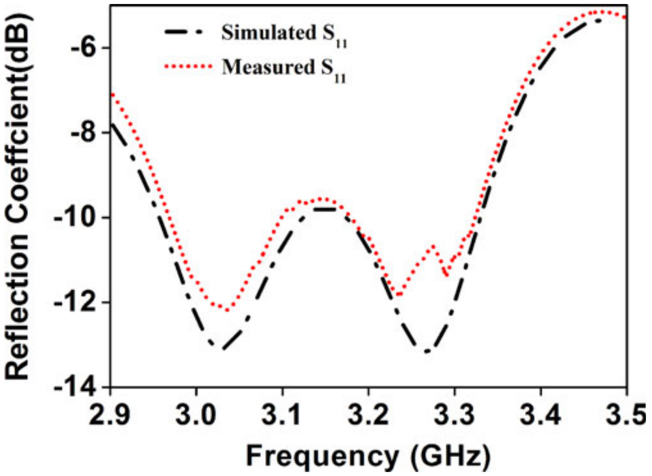

Fig. 6. Comparison of measured and simulated *S*-parameters.

design a proposed polarizer. The optimized parameter values for metal plate structure are length = 20 cm and width = 2 cm.

Figure 3 shows the center metal plate's effect at an angle of +45° (with a small cut from the center) to produce LHCP output. This figure shows how this center plate improves the performance of the proposed structure. Figure 3 shows that at an angle of 35°, the axial ratio is 3 dB (at the operating frequency). When we increase the angle by 10° (i.e. 45°), the axial ratio is below 3 dB (~1 dB). Further increasing the angle by 10° (i.e. 55°), the axial ratio increases to 14 dB (at the operating frequency). This figure ensures that at an angle of 45°, the axial ratio is below 3 dB over the frequency band 2.97–3.10 GHz.

The gain is an important design parameter for any high-power directive antenna. It also shows how strong a signal of an antenna can be radiated or received in a specific direction. Besides, a high-gain antenna will radiate maximal power in a particular direction. The proposed antenna has a high gain of up to 13.4 dB at 3 GHz frequency, as shown in Fig. 4.

The mode conversion (TM_{01} mode to circular polarized TE_{11} mode) can be verified from the measured radiation pattern. The simulated and measured radiation pattern at 3 GHz is plotted and shown in Fig. 4. The radiation pattern measurement is performed by exciting the TM_{01} mode at an antenna's input port in an anechoic chamber, as shown in Fig. 5. Due to mode conversion (TM_{01} to CP TE_{11}), the radiation pattern becomes maximum at the boresight with a metal plate structure. The reflection coefficient (S_{11}) is also measured using vector network analyzer and measured results compared with the simulated one. Figure 6 shows the simulated and measured *S*-parameter (S_{11}) for an antenna. Both curves are in good agreement.

The power-handling capability of the HPM antenna is also calculated by simulation. Generally, the breakdown would be different for different vacuum conditions. The metal electric field breakdown strength is about 1 MV/m [24]. This paper considers the maximum electric field limit as 3 MV/m for the breakdown. Here, the maximum *E*-field remains below 1584 V/m for a maximum of 0.5 W input power. Therefore, the proposed antenna can handle a high power of up to 1.8 MW. The electric field strength will be increased three times greater than that of air if we use SF_6 gas fixed outside the aperture to prevent air breakdown [25]. Since only metal plates are used in the structure, it shows a compact, very lightweight, and low-cost solution for CP HPM antenna design.

Table 1 shows a comparison between the proposed design and earlier published mode converter designs. Earlier presented converters have also been designed to radiate microwave signals, but all these structures support TEM to CP TE_{11} operation [20, 26, 27]. The design proposed in [28] supports TM_{01} to CP TE_{11} process, but high-power capability is not discussed in the paper. The proposed work aims to design a compact size CP high-power antenna, HPM antenna, that can convert the TM_{01} input signal to CP TE_{11} output. The designed antenna exhibits high gain, power capability and is very compact compared to other designs.

Conclusion

In conclusion, a CP high-power antenna with higher-order mode excitation is presented in this paper. The proposed antenna converts the TM_{01} input signal to the CP TE_{11} output. This structure also receives a directive radiation pattern. The measured radiation patterns are in agreement with the simulated results. The calculated electric field shows that the designed antenna can handle a high-power input signal. The designed antenna is compact and lightweight, and easy to fabricate. Therefore, it is suitable for airborne and portable HPM systems and space applications.

References

1. **Reddy S and Sambasivarao DR** (2017) Design of an UWB travelling wave antenna for high power transient applications. *IEEE International Conference on Antenna Innovations & Modern Technologies for Ground, Aircraft and Satellite Applications (iAIM)*, Bangalore, pp. 1–3.
2. **Schamiloglu E** (2004) High power microwave sources and applications. *IEEE MTT-S International Microwave Symposium Digest*, vol. **2**, pp. 1001–1004.

Table 1. Comparison between the proposed design and earlier published mode converter designs

Reference	Operating frequency (GHz)	Length (cm)	Gain (dB)	Axial ratio (dB)	Power handling capability	Mode conversion
Yuan *et al.* [26]	4	36	19.8	1.2	–	TEM to CP TE_{11}
Wang *et al.* [27]	1.8	12.5	–	2.5	–	TEM to CP TE_{11}
Sun *et al.* [20]	1.5	4.2	–	2.5	1.5 GW	TEM to CP TE_{11}
Yuan *et al.* [28]	4	35	–	0.7	–	TM_{01} to CP TE_{11}
This paper	3 GHz	19.62	13.4	1	1.8 MW	TM_{01} to CP TE_{11}

3. **Liang Y, Zhang J, Liu Q and Li X** (2018) High-power dual-branch helical antenna. *IEEE Antennas and Wireless Propagation Letters* **17**, 472–475.
4. **Wang S and Xie Y** (2017) Design and optimization of high-power UWB combined antenna based on klopfenstein impedance taper. *IEEE Transactions on Antennas and Propagation* **65**, 6960–6967.
5. **Xiao S, Altunc S, Kumar P, Baum CE and Schoenbach KH** (2010) A reflector antenna for focusing subnanosecond pulses in the near field. *IEEE Antennas and Wireless Propagation Letters* **9**, 12–15.
6. **Yuan CW and Zhong HH** (2006) A novel TM_{01}–TE_{11} Circularly Polarized (CP) mode converter. *IEEE Microwave and Wireless Component Letters* **16**, 455.
7. **Li JW, Deng GJ, Guo LT, Huang WH and Shao H** (2018) Polarization controllable TM_{01}–TE_{11} mode converter for high power microwaves. *AIP Advances* **8**, 055230.
8. **Li Z, Liu W, Cheng H, Chen S and Tian J** (2015) Realizing broadband and invertible linear-to-circular polarization converter with ultrathin single-layer metasurface. *Scientific Reports* **5**, 18106.
9. **Zhu H, Cheung S, Chung KL and Yuk T** (2013) Linear-to-circular polarization conversion using metasurface. *IEEE Transactions on Antennas and Propagation* **61**, 4615–4623.
10. **Baena J, del Risco J, Slobozhanyuk A, Glybovski S and Belov P** (2015) Self-complementary metasurfaces for linear-to-circular polarization conversion. *Physical Review B* **92**, 245413.
11. **Shi JH, Shi QC, Li YX, Nie GY, Guan CY and Cui TJ** (2015) Dual-polarity metamaterial circular polarizer based on giant extrinsic chirality. *Scientific Reports* **5**, 1–7.
12. **Wang J, Wu W and Shen Z** (2014) Improved polarization converter using symmetrical semi-ring slots. in APSURSI, Memphis, USA, pp. 2052–2053.
13. **Joyal MA and Laurin JJ** (2012) Analysis and design of thin circular polarizers based on meander lines. *IEEE Transactions on Antennas and Propagation* **60**, 3007–3011.
14. **Fei P, Shen Z, Wen X and Nian F** (2015) A single-layer circular polarizer based on hybrid meander line and loop configuration. *IEEE Transactions on Antennas and Propagation* **63**, 4609–4614.
15. **Mutlu M, Akosman AE and Ozbay E** (2012) Broadband circular polarizer based on high-contrast gratings. *Optics Letters* **37**, 2094–2096.
16. **Mutlu M, Akosman AE, Kurt G, Gokkavas M and Ozbay E** (2012) Experimental realization of a high-contrast grating based broadband quarter-wave plate. *Optics Letters* **20**, 27966–27973.
17. **Wang J, Shen Z, Wu W and Feng K** (2015) Wideband circular polarizer based on dielectric gratings with periodic parallel strips. *Optics Letters* **23**, 12533–12543.
18. **Kirilenko AA, Steshenko SO, Derkach VN and Ostryzhnyi YM** (2019) A tunable compact polarizer in a circular waveguide. *IEEE Transactions on Microwave Theory and Techniques* **67**, 592–596.
19. **Benford J, Swegle JA and Schamiloglu E** (2001) *High Power Microwaves*, 2nd Edn, New York: Taylor and Francis.
20. **Sun Y, He J, Yuan C and Zhang Q** (2018) Design and experimental demonstration of a circularly polarized mode converter for high-power microwave applications. *Review of Scientific Instruments* **89**, 084701.
21. **Peng S, Yuan C, Zhong H and Fan Y** (2013) Design and experiment of a cross-shaped mode converter for high-powermicrowave applications. *Review of Scientific Instruments* **84**, 124703.
22. **Chittora A and Yadav SV** (2020) A Compact Circular Waveguide Polarizer with Higher Order Mode Excitation. *2020 IEEE International Conference on Electronics, Computing and Communication Technologies (CONECCT). IEEE.*
23. **Jiao Y, Pan J, Jin Z and Xiong G** (2016) The Analysis of E-plane Metal Lens in Beam Forming. In *2016 2nd International Conference on Advances in Energy, Environment and Chemical Engineering (AEECE 2016)* (pp. 335–338). Atlantis Press.
24. **Xiao R, Chen C, Sun J, Zhang X and Zhang L** (2011) A high-power high-efficiency klystron like relativistic backward wave oscillator with a dual-cavity extractor. *Journal of Applied Physics* **98**, 101502.
25. **Chang C, Zhu XX, Liu GZ, Fang JY, Xiao RZ, Chen CH, Shao H, Li JW, Huang HJ, Zhang QY and Zhang ZQ** (2010) Design and experiments of the GW high-power microwave feed horn. *Progress In Electromagnetics Research* **101**, 157–171.
26. **Yuan CW, Zhong HH, Liu QX and Qian BL** (2006) Circularly polarised mode-converting antenna. *Electronics Letters* **42**, 136–137.
27. **Wang XY, Fan YW, Shu T, Yuan CW and Zhang Q** (2018) Tunable circularly-polarized turnstile-junction mode converter for high-power microwave applications. *Chinese Physics B* **27**, 068401.
28. **Yuan CW, Zhong HH, Liu QX and Qian BL** (2006) A novel TM 01–TE 11 circularly polarized (CP.) mode converter. *IEEE Microwave and Wireless Components Letters* **16**, 455–457.

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