On the Circular Polarization Operation of Annular-Ring Microstrip Antennas

Hua-Ming Chen, *Member, IEEE*, and Kin-Lu Wong, *Senior Member, IEEE*

***Abstract*—Circular polarization (CP) operation of an annular-ring microstrip antenna with a pair of inserted slits at its fundamental TM_{11} mode is proposed and experimentally investigated. Two examples of the proposed antenna fed using a microstrip line at the inner and outer patch boundaries are studied. Results show that the proposed antenna can have good CP performance and, moreover, the required antenna size at a fixed CP operation can be much less than that of a conventional circularly polarized circular microstrip antenna operated at the TM_{11} mode. Details of the proposed antenna for CP operation are described and experimental results of the CP performance are presented and discussed.**

***Index Terms*—Circular polarization, printed antennas.**

I. INTRODUCTION

CONVENTIONAL designs of single-feed microstrip antennas for circular polarization (CP) are usually achieved by truncating patch corners of a square patch, using nearly square or nearly circular patches, cutting a diagonal slot in the square or circular patches, protruding or inserting a pair of symmetric perturbation elements at the boundary of a circular patch [1], [2]. Recently, CP operation of single-feed triangular microstrip antennas using a nearly equilateral triangular patch [3], an equilateral triangular patch with an inserted slit [4] or a tip-truncated equilateral triangular patch [5] has also been reported and, due to their physically smaller patch size as compared to the square or circular microstrip antennas, such circularly polarized triangular microstrip antennas are suitable for applications in systems where limited realty space is available. For example, the personal communications equipment. This also suggests that the triangular microstrip antenna can be treated as a compact design of regular-size square or circular microstrip antennas. Also, it is noted that the related CP designs of microstrip antennas are mainly on square, circular, and triangular microstrip patches. Relatively very few CP designs using an annular-ring microstrip patch are available in the open literature. The related design that has been reported uses an annular-ring patch with an extended ear operated at the higher order modes of TM_{12} and TM_{32} [6].

In this paper, we demonstrate a new CP design method of using an annular-ring microstrip antenna operated at its fundamental TM_{11} mode. The CP operation is obtained by inserting a pair of slits inserted at the opposite sides of the inner boundary of the annular-ring patch. It is expected that by choosing a proper slit length, the fundamental resonant TM_{11} mode of the annular-ring patch can be split into two near-degenerate orthogonal modes with equal amplitudes and 90° phase difference, which results in a CP radiation. Also, it is noted that, for operating at the TM_{11} mode, the annular-ring microstrip antenna studied here can be treated as a circular microstrip antenna with a circular slot embedded in the patch center. In this case, it is expected that the excited patch surface current path of the TM_{11} mode will be longer for the proposed antenna here than for the regular-size circular microstrip antenna; that is, the CP operation of the proposed antenna can be at a lower frequency than the circular microstrip antenna. This suggests that the proposed antenna studied here can be considered as a compact design of a circular microstrip antenna.

However, in practical designs, it is found that the proposed antenna at the TM_{11} mode is difficult to be excited using a single probe feed with 50-Ω input impedance, especially for the case with a large inner radius. This can be inferred from the fact that at the TM_{11} mode excitation, a circular patch with a center slot of increasing radius will make its minimum input impedance inside the patch quickly increases, which usually makes it impossible to locate a 50-Ω input-impedance feed position inside the patch. To overcome this problem, the feed method of using a microstrip line is studied here. Two cases of placing the microstrip feed line at the inner and outer patch boundaries are demonstrated. Such feed arrangements are also suitable for integration with the possible associated microwave circuitry. Details of the proposed antenna design and obtained CP performance are presented and discussed.

II. ANTENNA CONFIGURATIONS

Two typical antenna designs shown in Figs. 1 and 2 are studied. The annular-ring patch with outer radius b and inner radius a is printed on a substrate of thickness h and dielectric constant ε_r. A pair of narrow slits of length ℓ_s and width w_s is inserted at the annular-ring's inner boundary in the x direction. In such an arrangement, the fundamental TM_{11} mode can be split into two near-degenerate resonant modes and the resonant mode in the x direction can have a slightly larger resonant frequency than the resonant mode in the y direction. Also, with the increasing of the inner radius, the two orthogonal modes will both have larger excited patch surface current paths, which makes the resulting CP operation to be occurred at a lower frequency. This corresponds to the requirement of a less antenna size when the proposed antenna is in place of the regular-size circular microstrip antenna.

Manuscript received June 5, 1998; revised February 8, 1999.

H.-M. Chen is with the Department of Physics, National Kaohsiung Institute of Technology, Kaohsiung, Taiwan, 807 R.O.C.

K.-L. Wong is with the Department of Electrical Engineering, National Sun Yat-Sen University, Kaohsiung, Taiwan, 804 R.O.C.

Publisher Item Identifier S 0018-926X(99)07974-0.

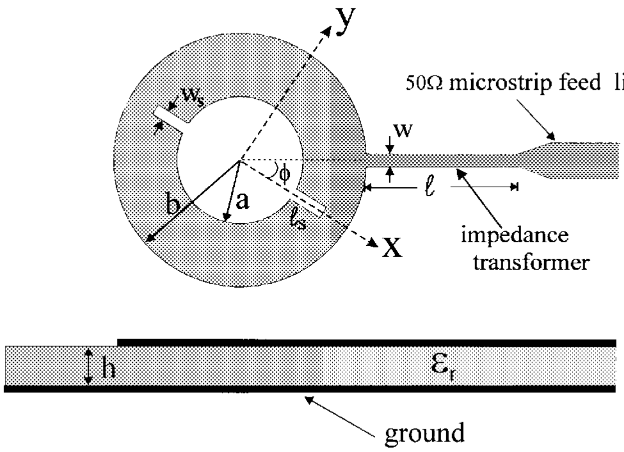

Fig. 1. Geometry of a circularly polarized annular-ring microstrip antenna with a pair of inserted slits (antenna 1). The microstrip feed line is at the outer boundary of the patch.

For both feed arrangements in Figs. 1 and 2, a right-hand CP operation can be obtained when the microstrip feed line is placed in the $\phi = 45^\circ$ plane. On the other hand, when the microstrip line is placed in the $\phi = 135^\circ$ plane, a left-hand CP operation can be achieved. It is also noted that, the section of transmission line of length ℓ and width w between the 50-Ω microstrip feed line and the outer/inner patch boundary for impedance transformation is determined here by

$$50 = Z_T[(Z_A + jZ_L \tan \beta\ell)/(Z_T + jZ_A \tan \beta\ell)] \quad (\Omega) \quad (1)$$

where Z_A is the impedance at the outer or inner patch boundary; Z_T and β are, respectively, the characteristic impedance and wavenumber of the transmission-line section. By directly solving (1), we can select a proper transmission-line section to transform Z_A, usually a complex impedance, to 50 Ω. The determination of the impedance transformer based on (1), instead of using a quarter-wavelength impedance transformer, can make the present design with a much better impedance matching. Furthermore, it should be noted that in the design shown by Fig. 2 with an inner-boundary-fed case, the impedance transformer is connected through a via hole to a 50-Ω probe feed. This design is especially suited for the compact active microstrip antenna in which the associated active circuitry can be integrated inside the annular-ring patch and placed in between the impedance transformer and the via hole.

III. Experimental Results and Discussion

A. Proposed Antenna with Outer-Boundary-Fed Microstrip Feed Line

Consider the geometry shown in Fig. 1 (denoted as antenna 1 below), the typical design with right-hand CP operation is studied. The annular-ring patch is selected to have an outer radius 20 mm and an inner radius 10 mm and the copper-clad substrate of thickness 1.6 mm and relative permittivity 4.4 is used. It is first found that by adjusting the inserted slit length to be 2.34 mm (the slit width fixed to be 1 mm), the CP operation can be obtained and, for good impedance matching, the impedance transformer is selected to have a width 0.8 mm

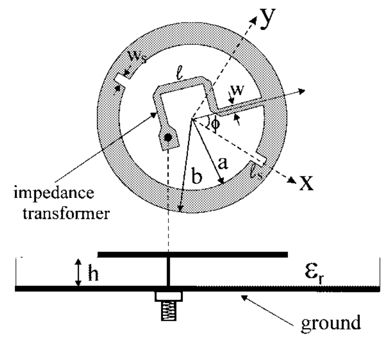

Fig. 2. Geometry of a circularly polarized annular-ring microstrip antenna with a pair of inserted slits (antenna 2). The microstrip feed line is at the inner boundary of the patch.

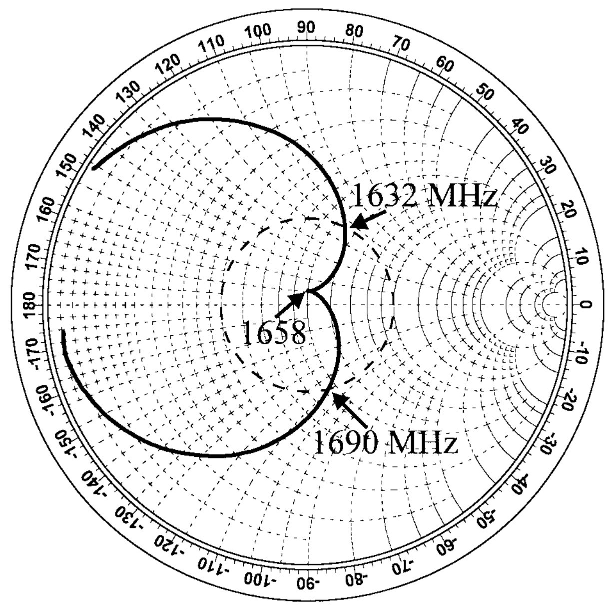

Fig. 3. Measured input impedance of antenna 1 shown in Fig. 1; $h = 1.6$ mm, $\varepsilon_r = 4.4$, $a = 10$ mm, $b = 20$ mm, $\ell_s = 2.34$ mm, $w_s = 1.0$ mm, $\phi = 45^\circ$, $\ell = 32$ mm, $w = 0.8$ mm.

and length 32 mm. Fig. 3 shows the measured input impedance on a Smith chart. It is clearly seen that two near-degenerate resonant modes are excited with good impedance matching. The measured axial ratio versus frequency in the broadside direction is presented in Fig. 4. The center frequency, defined as the frequency with a minimum axial ratio, is at 1658 MHz and the CP bandwidth, determined from 3-dB axial ratio, is about 14 MHz or 0.84%. For comparison, the results are also listed in Table I in which a reference antenna, having the same size as the proposed antenna (antenna 1) studied here, is constructed using the design method of a regular-size circular microstrip antenna with a tuning stub [7]. We can see that the center frequency (1658 MHz) of antenna 1 is only about 0.83 times that (2008 MHz) of the reference antenna. This indicates that the CP design of antenna 1 can have a 32% antenna size reduction as compared to the reference antenna at a fixed CP operation. And, the CP bandwidth and maximum received power of antenna 1 are also observed to be lower than those of the reference antenna, which is largely due to the antenna size reduction of antenna 1.

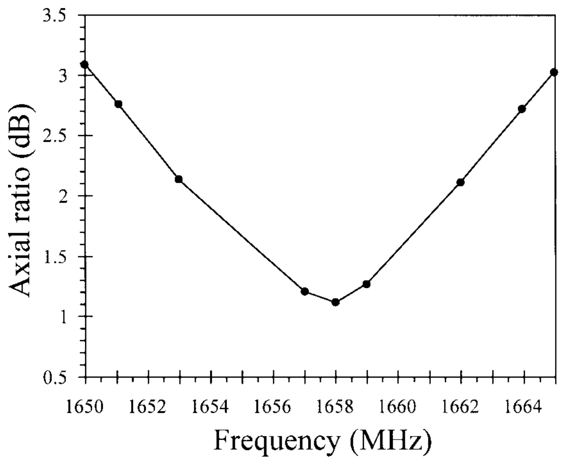

Fig. 4. Measured axial ratio in the broadside direction of antenna 1 given in Fig. 3.

TABLE I
COMPARISON BETWEEN THE PROPOSED ANTENNAS (ANTENNA 1 WITH PARAMETERS GIVEN IN FIG. 2 AND ANTENNA 2 WITH PARAMETERS GIVEN IN FIG. 6) AND THE REFERENCE ANTENNA. THE REFERENCE ANTENNA HAS THE SAME ANTENNA SIZE ($b = 20$ mm WITH $h = 1.6$ mm, $\varepsilon_r = 4.4$) AS ANTENNAS 1 AND 2 AND IS CONSTRUCTED USING THE DESIGN METHOD OF A REGULAR-SIZE CIRCULAR MICROSTRIP ANTENNA WITH A TUNING STUB [7]

	Center frequency	Bandwidth (VSWR < 2)	CP bandwidth (3dB axial ratio)	Maximum received power
Antenna 1	1658 MHz	58 MHz (3.5%)	14 MHz (0.84%)	-49.0 dBm
Antenna 2	1526 MHz	49 MHz (3.2%)	12 MHz (0.8%)	-49.2 dBm
Reference	2008 MHz	98 MHz (4.9%)	24 MHz (1.2%)	-48.8 dBm

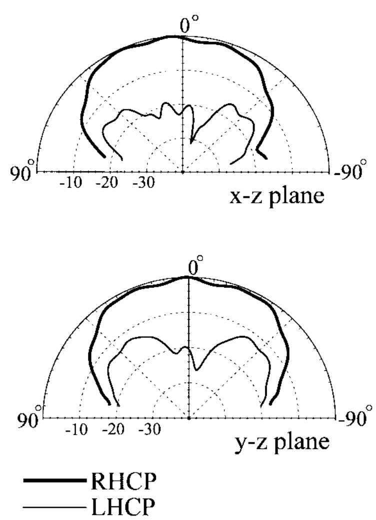

Fig. 5. Measured radiation patterns of antenna 1 given in Fig. 3 in two orthogonal planes at $f = 1658$ MHz.

The radiation patterns in two orthogonal planes are also measured. Fig. 5 plots the radiation patterns of antenna 1 at 1658 MHz, and good right-hand CP operation is observed.

B. Proposed Antenna with Inner-Boundary-Fed Microstrip Feed Line

In the proposed CP design shown by Fig. 2 (denoted as antenna 2 in the following), the outer radius of the circular

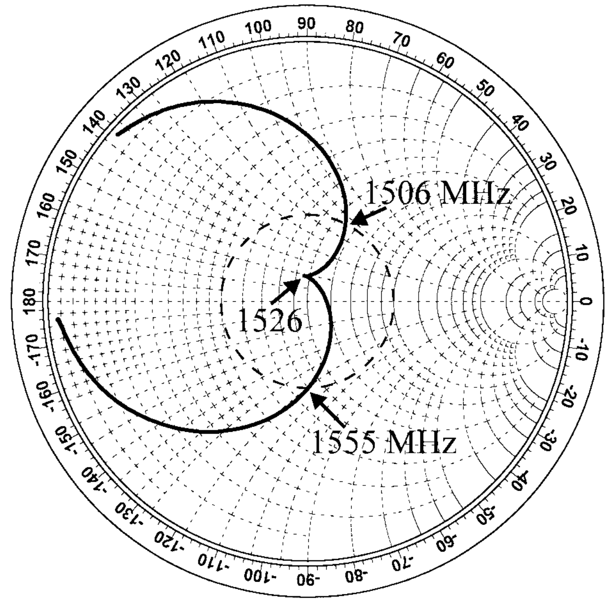

Fig. 6. Measured input impedance of antenna 2 shown in Fig. 2; $h = 1.6$ mm, $\varepsilon_r = 4.4$, $a = 13$ mm, $b = 20$ mm, $\ell_s = 2.0$ mm, $w_s = 1.0$ mm, $\phi = 45°$, $\ell = 31$ mm, $w = 0.68$ mm.

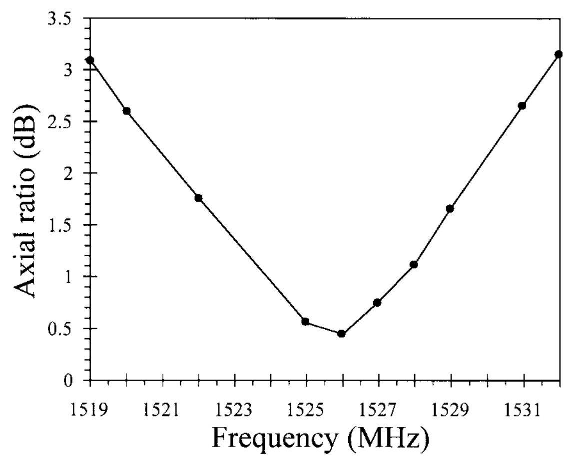

Fig. 7. Measured axial ratio in the broadside direction of antenna 2 given in Fig. 6.

patch and the substrate parameters are the same as antenna 1 shown in Section III, but the inner radius is chosen to be 13 mm, larger than that of antenna 1. The impedance transformer has a length 31 mm and a width 0.68 mm, and the insert slit is of length 2.0 mm and width 1.0 mm. And, the right-hand CP operation is also demonstrated; that is, the transmission-line section for impedance transformer is placed in the $\phi = 45°$ plane. The measured input impedance of antenna 2 is shown in Fig. 6, and the measured axial ratio in the broadside direction is presented in Fig. 7. From the results obtained, it is seen that the center operating frequency is significantly lowered from 2008 MHz (the reference antenna) to be 1526 MHz, which indicates a 24% reduction in the center frequency and corresponds to a 42% antenna size reduction as compared to the design of a regular-size circular patch antenna. The corresponding results are also listed in Table I. The obtained CP bandwidth is found to be 12 MHz or about 0.8%, about

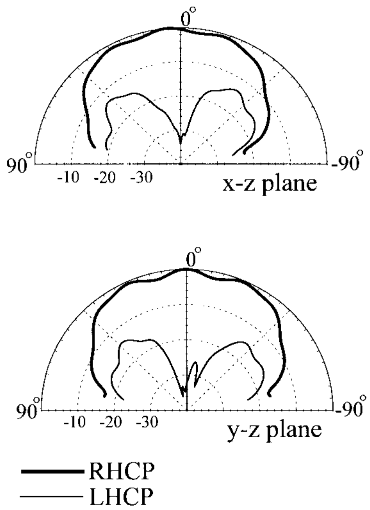

Fig. 8. Measured radiation patterns of antenna 2 given in Fig. 6 in two orthogonal planes at $f = 1526$ MHz.

the same as that of antenna 1 in Section III, which is also smaller than that of the reference antenna due to the antenna size reduction. Finally, the measured radiation patterns in two orthogonal planes of antenna 2 at the center frequency are also plotted in Fig. 8. Again, good right-hand CP radiation is observed.

IV. Conclusions

Novel CP operation of microstrip-line-fed annular-ring microstrip antennas operated at the TM_{11} mode has been successfully implemented. The CP operation is mainly achieved by inserting a pair of slits at the inner boundary of the annular-ring patch. And, the proposed design with an antenna size reduction to about 32–42%, as compared to a regular-size circular microstrip antenna at a fixed CP operation, has been demonstrated. Due to its compact antenna size, the proposed antenna is suitable for applications in systems where compact CP operation is the major concern, especially for the design of an active compact CP microstrip antenna.

References

[1] P. C. Sharma and K. C. Gupta, "Analysis and optimized design of single feed circularly polarized microstrip antennas," *IEEE Trans. Antennas Propagat.*, vol. AP-31, pp. 949–955, Nov. 1983.

[2] J. R. James and P. S. Halls, Eds., *Handbook of Microstrip Antennas.* London, U.K.: Peter Peregrinus, 1989, ch. 1.

[3] Y. Suzuki, N. Miyano, and T. Chiba, "Circularly polarized radiation from singly fed equilateral-triangular microstrip antenna," *Inst. Elect. Eng.*, vol. 134, pt. H, pp. 194–198, Apr. 1987.

[4] J. H. Lu, C. L. Tang, and K. L. Wong, "Circular polarization design of a single-feed equilateral-triangular microstrip antenna," *Electron. Lett.,* vol. 34, pp. 319–321, 1998.

[5] C. L. Tang, J. H. Lu, and K. L. Wong, "Circularly polarized equilateral-triangular microstrip antenna with truncated tip," *Electron. Lett.*, vol. 34, pp. 1277–1278, 1998.

[6] A. Bhattacharyya and L. Shafai, "A wider band microstrip antenna for circular polarization," *IEEE Trans. Antennas Propagat.*, vol. 36, pp. 157–163, Feb. 1988.

[7] K. L. Wong and Y. F. Lin, "Circularly polarized microstrip antenna with tuning stub," *Electron. Lett.,* vol. 34, pp. 831–832, 1998.

Hua-Ming Chen (M'98) was born in Tainan, Taiwan, on August 4, 1960. He received the B.S. degree in physics from National Tsing Hua University, Hsinchu, Taiwan, the M.S. degree from the Institute of Electro-Optics from National Chiao Tung University, Hsinchu, Taiwan, and the Ph.D. degree in electrical engineering from National Sun Yat-Sen University, Kaohsiung, Taiwan, in 1983, 1987, and 1996, respectively.

Since 1988, he has been with the Department of Physics, National Kaohsiung Institute of Technology, Kaohsiung, Taiwan, where he became an Associate Professor in 1996. His current research interests include numerical electromagnetics, antenna analysis, and microstrip circuit design.

Kin-Lu Wong (M'91–SM'97) received the B.S. degree in electrical engineering from the National Taiwan University, Taipei, Taiwan, in 1981, and the M.S. and Ph.D. degrees in electrical engineering from Texas Tech University, Lubbock, TX, in 1984 and 1986, respectively.

From 1986 to 1987, he was a Visiting Scientist with Max-Planck-Institute for Plasma Physics, Munich, Germany. Since 1987 he has been with the Department of Electrical Engineering at National Sun Yat-Sen University, Kaohsiung, Taiwan, where he became a Professor in 1991. He also served as Chairman of the Electrical Engineering Department at the same university from 1994 to 1997. During the year of 1998–1999, he was a Visiting Scholar with the ElectroScience Laboratory, The Ohio State University, Columbus. He has published over 165 refereed journal papers and numerous conference articles. He is the author of *Design of Nonplanar Microstrip Antennas and Transmission Lines*.

Dr. Wong is a member of the National Committee of the Republic of China for URSI, Microwave Society of the Republic of China, and Chinese Institute of Electrical Engineers. He received the Outstanding Research Award from the National Science Council of the Republic of China in 1993, the Young Scientist Award from URSI in 1993, the Outstanding Research Award from the National Sun Yat-Sen University in 1994, and the Excellent Young Electrical Engineer Award from Chinese Institute of Electrical Engineers in 1998. He is listed in *Who's Who of the Republic of China* and *Who's Who in the World.*