Progress In Electromagnetics Research Letters, Vol. 51, 7–14, 2015

Dual-Helix Monopole Antenna with Circular Polarization Operation for Minimally Invasive Surgery System

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Abstract—A novel dual-helix monopole antenna with circular polarization (CP) operation is proposed. By utilizing a pair of asymmetrical strip-sleeves shorted at the ground plane, the proposed CP design at 2.45 GHz ISM band can easily be achieved and provides the impedance bandwidth (RL $\geqq$ 10 dB) about 240 MHz and the 6 dB axial-ratio (AR) bandwidth about 126 MHz. The measured peak gain and radiation efficiency are about 9.1 dBic and 81% across the operating bands, respectively.

1. INTRODUCTION

During the last few years there have been rapid developments in wireless communication technology. The range of medical devices and systems being used on and into the human body are increasing rapidly, and the related devices are of special interest in new sensing and wireless monitoring systems for healthcare. Antenna is a key component of a wireless medical communications system (WMCS) that transmits/receives the required information. The detection range and accuracy directly depend on the performance of transmit/receive antennas. Numerous antennas for medical communication systems have been developed, including printed symmetrical dipole antenna with metal loading for the 2.45 GHz implanted device [1], a symmetrical spiraling conductors with the square-ring ground plane [2], two short-circuited coupled split ring resonators (SRRs) [3], a helical folded dipole antenna [4], a shorted meander patch antenna [5], a meander monopole antenna with a shorting stub [6], an implanted cavity slot antenna [7], a miniature 2.45 GHz microstrip antenna based on the short pin technique [8], an implanted H-shaped cavity slot antenna [9], and a small spiral structure [10]. However, the above mentioned antennas are only focused on the linear polarized operation. Meanwhile, the loss caused by the multi-path effects between the transmitter and the receiver can be reduced by using the circularly polarized (CP) antennas. The various antennas with CP proposed in the literature so far include a compact microstrip antenna fed by an orthogonal 3 dB directional coupler with 90° phase difference [11], a combination monopole/quadrifilar helix antenna [12], a miniature folded printed quadrifilar helical antenna (FPQHA) [13], and a dual-band CP monopole antenna with shorted strip sleeves [14]. However, the above CP antennas are designed with the common limitation of large size (e.g., [11, 14]) and/or complex structure (e.g., [12, 13]). Moreover, highly compact antennas are increasingly required for the practical minimally invasive devices Therefore, in this article, a novel dual-helix monopole antenna with circular polarization operation is proposed for ISM wireless communication. By introducing a pair of asymmetrical strip-sleeves shorted at the ground plane, the proposed CP design can provide the impedance bandwidth (RL $\geqq$ 10 dB) about 240 MHz and the 6 dB AR bandwidth about 126 MHz for 2.45 GHz ISM applications, respectively. Good CP radiation has also been observed. Details of the proposed CP monopole antenna design are described in this study, and the related results for the obtained performance operated across the 2.45 GHz band are presented and discussed.

Received 9 October 2014, Accepted 13 November 2014, Scheduled 26 December 2014
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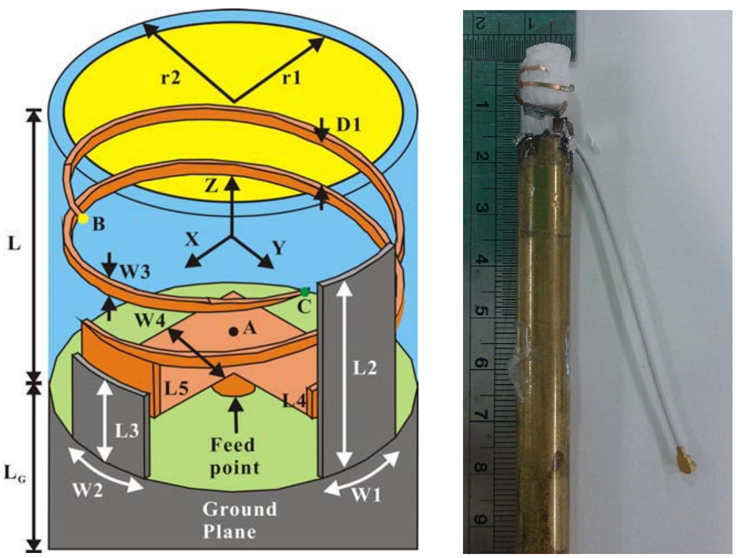
2. ANTENNA DESIGN

Figure 1 illustrates the geometrical configuration of the proposed CP monopole antenna for 2.45 GHz ISM application. A $50\,\Omega$ feed coaxial line is arranged below the orthogonal microstrip lines to excite the radiating helical elements with the overall volume of $\pi \times 5 \times 5\,\mathrm{mm}^3$. The proposed CP antenna consists of a pair of helical monopole strips (Section AB and AC) with the 0.25 operating wavelength of the fundamental mode at 2450 MHz. For compact operation, the proposed orthogonal monopole strips are arranged to be a dual-helix antenna for smaller antenna size. Then, dual strip-sleeves with the dimensions of $L3 \times W2$ and $L2 \times W1\,\mathrm{mm}^2$ in the x- and y-axis, respectively, are introduced to disturb the surface current in the x- and y-axes on the ground plane to generate phase delay of 90 degrees for CP operation. The proposed dual strip-sleeves are shorted at the fixed position, which is simpler than that of the planar CP design [14] shorted at particular position. This indicates that CP operation can be easily obtained by only adjusting dual strips' lengths and widths. Moreover, based on the above guidelines, the antenna is optimized by using a commercially available software package Ansoft HFSS [15]. Then, return loss is measured with an Agilent N5230A vector network analyzer. Fig. 1 displays the design parameter values obtained by the above strategy. In addition, the results are simultaneously optimized by applying the following setting in Ansoft HFSS: $L = 10\,\mathrm{mm}$, $L1 = 28.3\,\mathrm{mm}$, $L2 = 7\,\mathrm{mm}$, $L3 = 3\,\mathrm{mm}$, $L4 = 1\,\mathrm{mm}$, $L5 = 2\,\mathrm{mm}$, $L_G = 600\,\mathrm{mm}$, $W1 = 3\,\mathrm{mm}$, $W2 = 3\,\mathrm{mm}$, $W3 = 0.4\,\mathrm{mm}$, $W4 = 3\,\mathrm{mm}$, $r1 = 5\,\mathrm{mm}$, $r2 = 5.4\,\mathrm{mm}$, $D1 = 2\,\mathrm{mm}$.



(a) (b)

Figure 1. Geometry and photograph of the proposed CP monopole antenna with a pair of asymmetrical strip-sleeves for 2.45 GHz ISM application. (a) Geometry. (b) Photograph.

3. RESULTS AND DISCUSSIONS

Figure 2 summarizes the simulated and measured results of return loss, input impedance and axial ratio for the proposed CP monopole antenna. First, from the experimental results shown in Fig. 2(a), a measured 2 : 1 VSWR (10-dB return loss) bandwidth of 240 MHz (2290–2530 MHz) can be observed. Meanwhile, this CP monopole antenna also provides a 6-dB axial ratio (AR) bandwidth ranging from 2388 to 2514 MHz, which can comply with the bandwidth requirements of the desired 2.45 GHz ISM band. The related results are listed in Table 1 as comparison where f_L and f_H, respectively, represent the lower and higher cutoff frequencies (RL = 10 dB or AR = 6 dB).

Since the manufacturing tolerances of compact monopole antenna is limited and the feeding SMA connector placed close to the proposed antenna, the measured resonant frequencies and input impedance

Table 1. Simulated and measured return loss and axial ratio against frequency for the proposed CP monopole antenna.

The proposed CP Antenna		Simulated	Measured
Return Loss	$f_L \sim f_H$ (MHz)	$2355 \sim 2490$	$2290 \sim 2530$
	BW (MHz/%)	135/5.6	240/9.96
6 dB Axial Ratio	$f_L \sim f_H$ (MHz)	$2392 \sim 2500$	$2388 \sim 2514$
	BW (MHz/%)	108/4.4	126/5.14

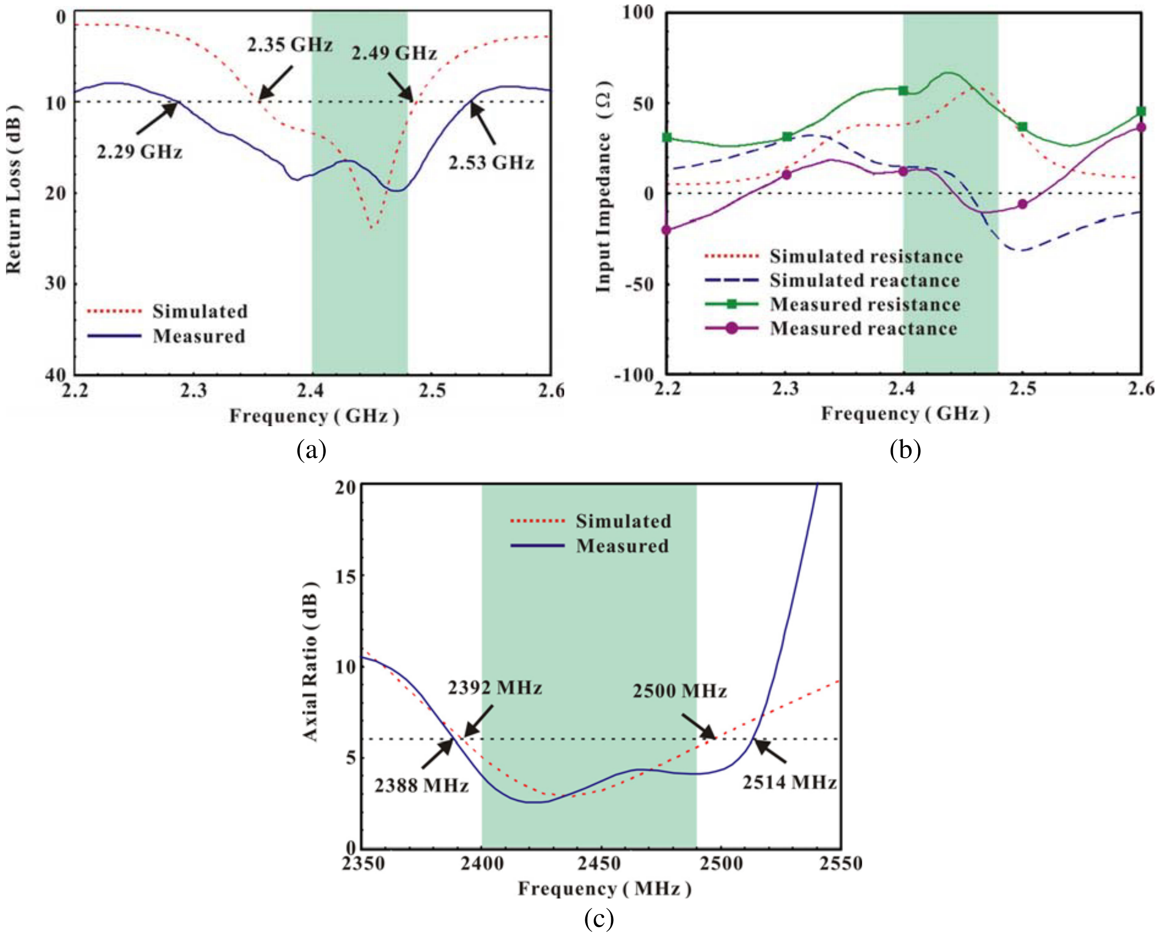


Figure 2. Simulated and measured results against frequency for the proposed compact CP monopole antenna. (a) Return loss. (b) Input impedance. (c) Axial ratio.

for the proposed antenna slightly differ from the simulated results obtained at some parameter settings. Then, to more thoroughly understand the excitation of the operating ISM band, Fig. 3 illustrates the simulated surface current distributions on the helical monopole and dual shorted strip-sleeves on the ground plane at typical frequencies. According to the surface current distributions, the fundamental mode at 2370 MHz band with a 0.25 wavelength surface current distribution is excited along the longer helical monopole strip ($A \rightarrow B$) with a maximum strength at point A and a decrease to be generally null at the end of the spiral strip (point B). Also, a resonant mode at 2470 MHz band is excited with maximum strength along the shorter helical monopole strip ($A \rightarrow C$). Next, dual shorted strip-sleeves with various lengths in the x- and y-axes are introduced to disturb the surface current in the x- and y-axes on the ground plane, respectively, to generate phase delay of 90 degrees to obtain CP operation.

For achieving better impedance matching and the desired axial ratio (AR), we need to slightly modify corresponding parameters in cooperating with the antennas modification to excite CP radiation. Return loss and AR performance are mainly affected by the shorted strip-sleeves to ensure a phase lag or leading for this proposed CP antenna. Fig. 4 shows the simulated results of return loss and axial ratio against frequency for the proposed CP antenna with various antenna structures for comparison. The

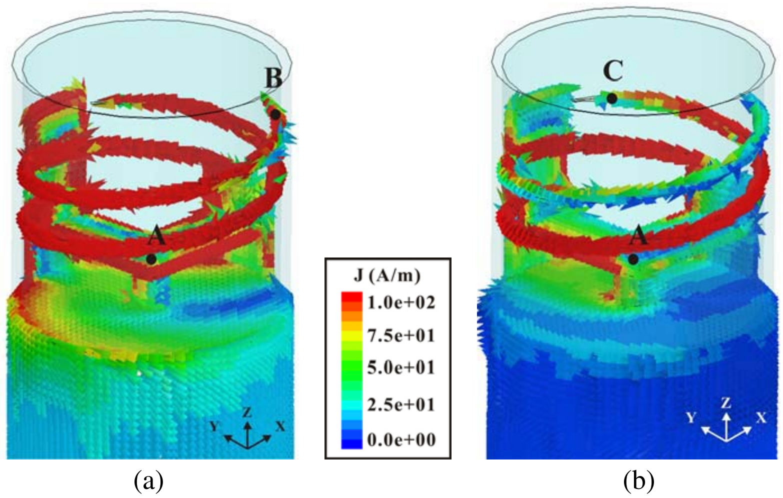


Figure 3. Simulated surface current distribution for the proposed compact CP monopole antenna. (a) 2370 MHz. (b) 2470 MHz.

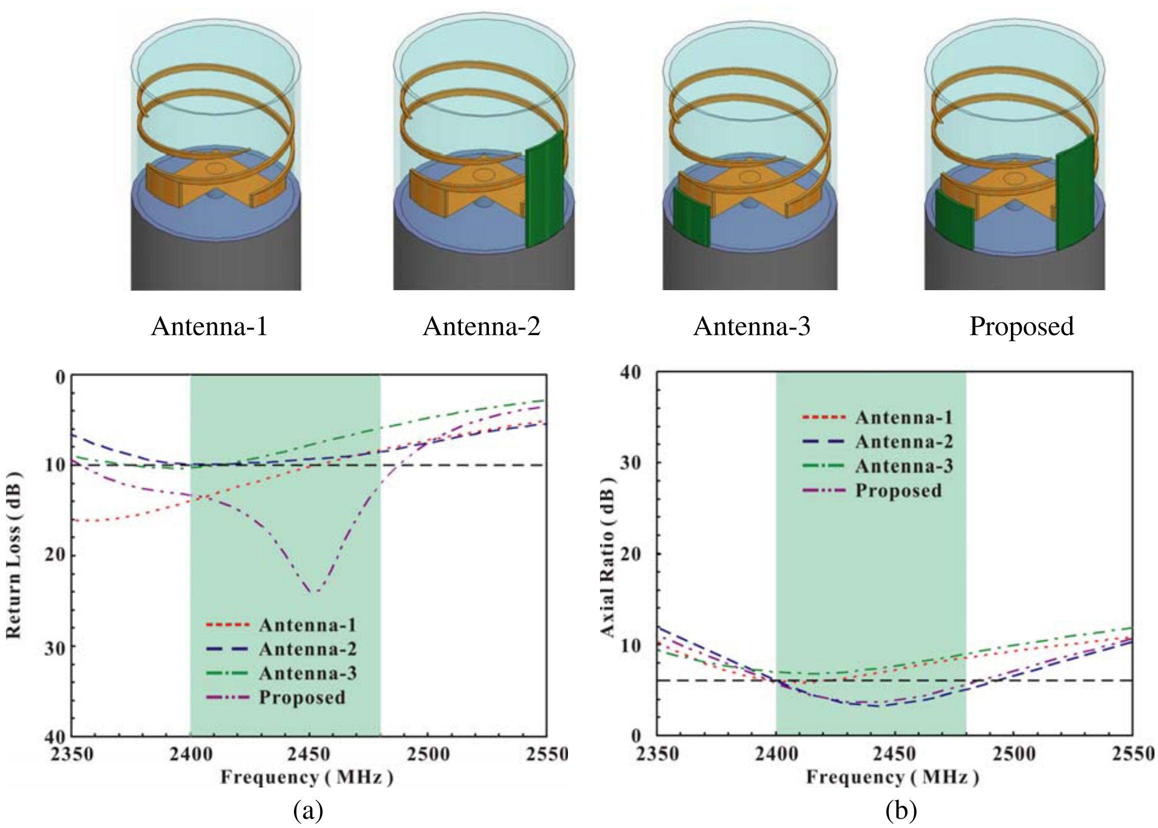


Figure 4. Simulated results of return loss and axial ratio against frequency for the proposed compact CP monopole antenna with various structures. (a) Return loss. (b) Axial ratio.

green area represents the needed operating bandwidth for the operating band ($2400 \sim 2484$ MHz) in the figure. From the related return loss in Fig. 4(a), it is obviously observed that good impedance matching at 2.45 GHz band is obtained for the proposed CP antenna; however, the performance for the other ones is significantly affected by the asymmetric shorted strip-sleeves. Moreover, from the related axial ratio results in Fig. 4(b), we find that the introduced shorted strip-sleeves make the CP performance better across 2.45 GHz band.

Furthermore, Fig. 5 shows the simulated return losses (RL) and axial ratios (AR) against frequency for the proposed CP antenna with dual shorted strip-sleeves of various widths ($W1$ and $W2$). It can also be found that when the widths of $W1$ and $W2$ increase from 1 mm to 3 mm, good impedance matching can be obtained; however, that for the case with the width of 4 mm becomes worse. Moreover, from the simulated results in Fig. 5(b), the axial ratio is slightly varied to be insensitive for all cases. Then, Fig. 6 plots the simulated RL and AR against frequency for the proposed CP antenna with the y-axial shorted strip-sleeve of various lengths ($L2$). As $L2$ increases from 6 mm to 9 mm, the operating frequency is significantly reduced such that optimal matching occurs at an $L2$ of 7 mm. In Fig. 6(b), the axial ratio is still insensitive for all cases, making the proposed antenna excite a CP wave across its operating band of $2400 \sim 2484$ MHz. Effects of varying the length $L3$ of the shorted strip-sleeve along

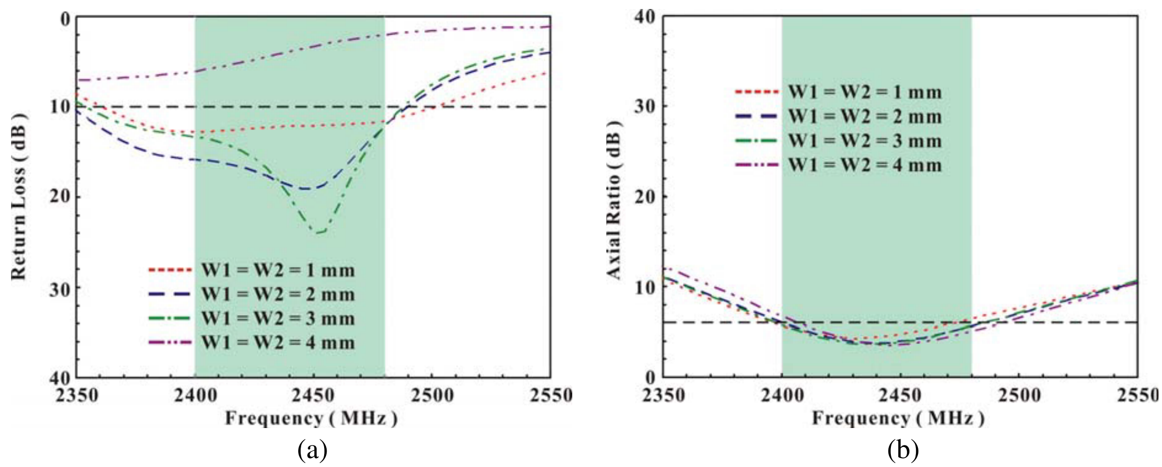


Figure 5. Simulated results of return loss and axial ratio against frequency for the proposed compact CP monopole antenna with various widths ($W1$ and $W2$) of dual shorted strip-sleeves. (a) Return loss. (b) Axial ratio.

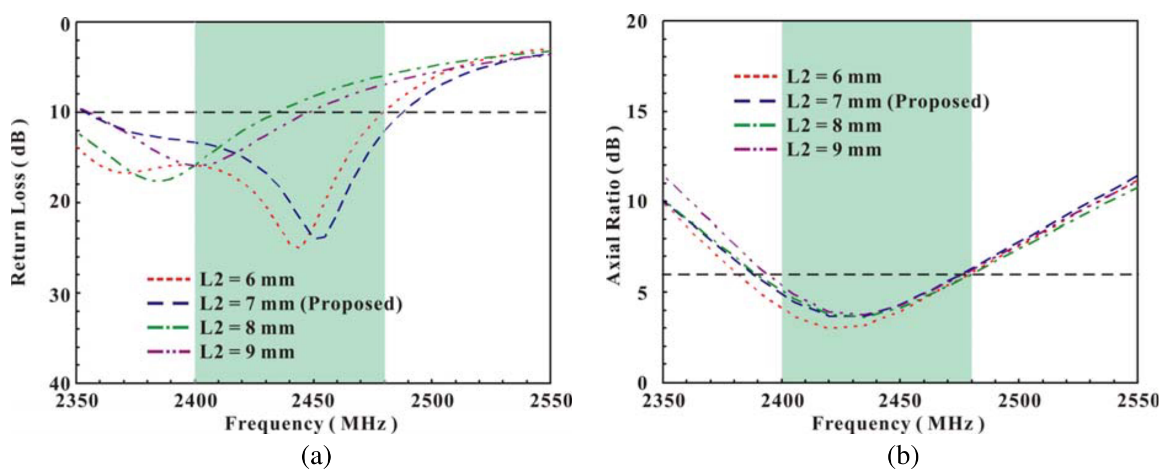


Figure 6. Simulated results of return loss and axial ratio against frequency for the proposed compact CP monopole antenna with various lengths of $L2$. (a) Return loss. (b) Axial ratio.

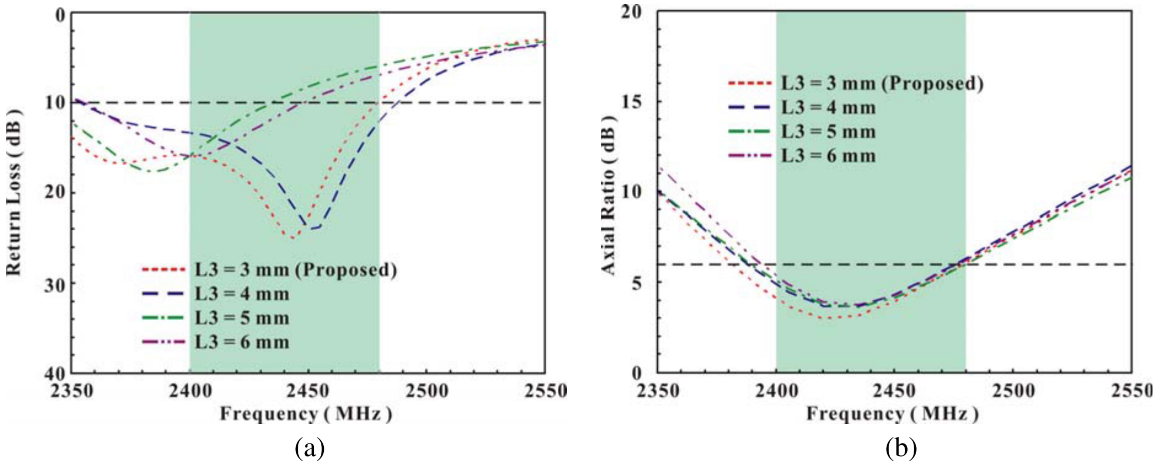


Figure 7. Simulated results of return loss and axial ratio against frequency for the proposed compact CP monopole antenna with various lengths of $L3$. (a) Return loss. (b) Axial ratio.

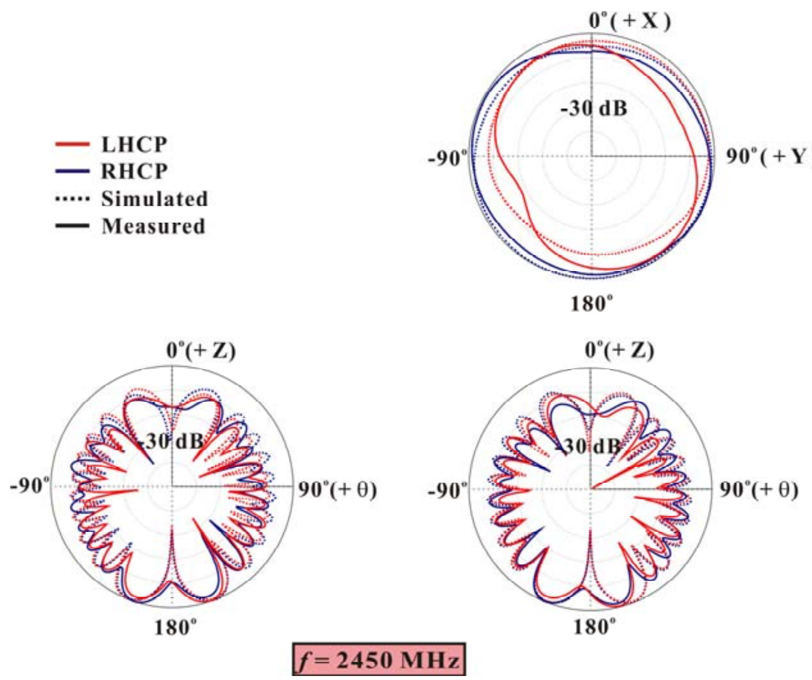


Figure 8. Measured and simulated 2D radiation patterns for the proposed compact CP monopole antenna.

the x-axis are also studied. The simulated RL results for the length $L3$ varied from 3 to 6 mm is shown in Fig. 7(a) and similar to those shown in Fig. 6(a). Meanwhile, in Fig. 7(a), the axial ratio varies slightly, indicating that the dependence of the AR value on the length of the strip-sleeve is reduced.

By following the generally applied methodology for the measurement of antenna gain, directivity and efficiency from IEEE Standard Test Procedures for Antennas: ANSI/IEEE-STD149-1979 [16], an Agilent N5230A vector network analyzer linking with a computer workstation running 3D NSI 800F far-field measurement software is introduced to study the far-field performance of the proposed CP antenna inside an anechoic chamber. A broadband double-ridged horn antenna (DRHA) with the operating frequency of 1–18 GHz is introduced as the transmitted antenna. Note that by spinning this linearly-polarized DRHA, the axial ratio value is measured and determined by the amount of variation while the source is continuously rotating on the plane [17]. The measured and simulated 2-D radiation patterns

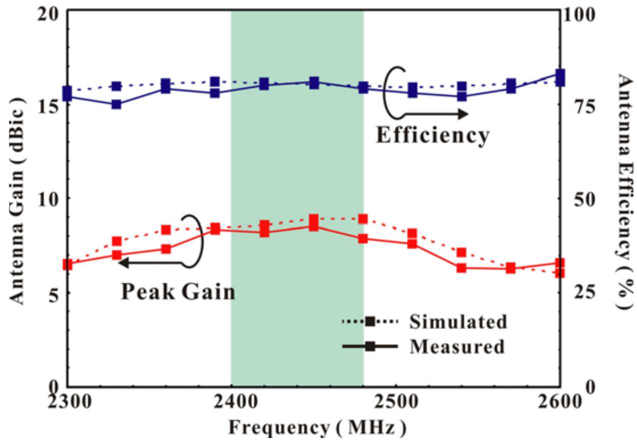


Figure 9. Measured and simulated peak gains and radiation efficiencies across the operating frequencies for the proposed compact CP antenna.

at ISM 2.45 GHz band are shown in Fig. 8. Results show that the helical monopole antenna radiates right-hand circular polariztion (RHCP) wave with a cross polarization level (XPL) of 1 dB on a wide azimuth range. Meanwhile, good symmetry of dipole-like radiation has been observed in the XZ and YZ planes with more dips due to the ground cylinder of 60 mm (about 5 operating wavelengths at 2.45 GHz band) Fig. 9 presents the measured antenna gain and efficiency for the proposed compact CP antenna. For frequencies over the 2.45 GHz band, probably due to the ground length of 600 mm much larger than the size of the proposed dual-helix monopole antennas, the antenna gain is approximately $8.5 \sim 9.1$ dBic. The antenna efficiency is around $78 \sim 81\%$ across the 2.45 GHz operating band.

4. CONCLUSIONS

A novel compact circularly polarized helical monopole antenna is proposed for the application of 2.45 GHz ISM system. By appropriately introducing a pair of strip-sleeves shorted at the ground plane, the proposed CP design can provides the impedance bandwidth (RL $\geqq$ 10 dB) about 240 MHz and the 6 dB axial-ratio (AR) bandwidth about 126 MHz for 2.45 GHz band ISM applications. The measured peak gain and radiation efficiency are about 9.1 dBic and 81% across the operating band, respectively.

ACKNOWLEDGMENT

This paper was supported by the Metal Industries Research and Development Centre, Taiwan.

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