Miniaturized Circularly Polarized Loop Antenna for Biomedical Applications

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Abstract—A novel circularly polarized antenna is proposed at 2.42-2.48 GHz Industrial, Scientific, and Medical band for implantable applications. By properly positioning the feed and slots, either right-hand circular polarization property or left-hand circular polarization property can be realized. Slow wave concept is utilized by loading patches to the radiated loop antenna to achieve miniaturization. Thus, a compact size of 13 mm × 13 mm × 1.27 mm is obtained. Compared to the unloaded loop antenna of the same size, the centre frequency shifts from 1.93 GHz to 882.5 MHz, which suggests a miniaturization of 54.4%. The simulated results show that a wide bandwidth of 18.2% can be realized with $|S_{11}|$ below -10dB and axial ratio below 3 dB. The simulated realized gain is -32 dBi at 2.45 GHz. The measurement is carried out in both skin-mimicking gel and pork, and a bandwidth of 27.8% and 29.4% can be achieved with $|S_{11}|$ below $-10$ dB, respectively. The measurement of $|S_{11}|$ reveals that circular polarization can be obtained for the proposed configuration.

Index Terms—Biomedical application, circular polarization, implantable antenna, loop antenna.

I. INTRODUCTION

With the growing concern of human health and the convenience of medical care, the idea of biomedical devices that can be implanted into human bodies has been brought up and widely studied [1]. It is no longer a fiction but a reality in many clinical applications including retinal prosthesis [2], [3], neural recording [4], glucose monitoring [5] and etc. However, to be truly beneficial, an implantable antenna is commonly needed to communicate with the equipment outside a human body wirelessly. Thus, monitoring patients remotely can be realized without direct physical contact and rigorous schedule can be avoided.

Many groups have focused on the study of implantable antennas. Some research works are based on the adoption of multi-layer configurations to reduce the antenna size [6]–[8]. Some works focus on the design of dual-band or triple-band antennas [5], [8]–[11]. Dual-band antennas can be applied to a system with dual-mode operation, where the Medical Implant Communications Service (MICS) band is intended for data communication and the Industrial, Scientific, and Medical (ISM) band is intended for start-up signal, thus saving the total power consumption [12]. Additionally, a 3D-spiral small antenna was proposed for biomedical telemetry [13] and a differentially fed antenna was proposed for better connection with differential output of the circuitry [14]. Furthermore, in consideration of the matching and compatibility issues of implanted antennas, the effect of insulating layers on the performance of implanted antennas was analyzed systematically [16]. Flexible and conformal antennas were also proposed for biotelemetry in practical implanted systems [17], [18].

A planar inverted-F antenna (PIFA) is the most commonly adopted antenna type for implantable systems [5]–[8], [10], [11], [19]. Slot antennas [20]–[22] and loop antennas [23], [24] were also proposed for some applications. For the operating frequency of implantable systems, the MICS band covering 402–405 MHz is the most popular for implantable antenna designs, but the antenna with proper size for implantation is usually electrically too small at this band and adequate radiation efficiency cannot be guaranteed. To realize the compactness of the antenna, other frequency bands like the 433.1–434.8 MHz, 902–928 MHz, and 2.42-2.48 GHz Industrial, Scientific, and Medical (ISM) bands are also suggested for implantable medical device biotelemetry in some countries [25]. But high frequency would cause high absorption of electromagnetic energy by a human body [26] and high free-space path loss in propagation as well. Studies have been conducted on choosing the optimal frequency [27], [28], and the 2.42-2.48GHz ISM band is adopted for a compromise between size and appropriate coupling in this paper.
Considering the coupling between an implanted antenna and an external antenna of the base station used to collect the patients’ information, on one hand, it is difficult to position the implanted system within an adequate area and maintain a perfect angle with respect to the external side during surgery. On the other hand, under certain circumstances, we should ensure the mobility of the patients with an implanted system. Therefore, for robust communications between the implant system and the exterior device, it is desirable to employ a circularly polarized (CP) antenna, as it is independent of the orientation of the transmitter and the receiver. Usually, the single-feed CP antenna is preferred for its compactness compared with dual-feed or multi-feed CP antennas. Different methods have been studied to achieve a single-feed CP antenna, such as introducing slight perturbation by truncating patch corners, adding tails and cutting cross slots [29], adopting aperture-coupled feeding configurations [30], [31] and cutting a gap to a loop antenna [32]. Besides, further compactness can be realized by employing high permittivity substrates [33] and adopting a slow wave structure such as adding shorting pins in close proximity to the feeding probe [34], and loading parasitic elements [36].

Compared to having a CP antenna on base station only, having CP on the implanted antenna gives a potential gain increase of 3 dB over the linearly polarized implantable antennas. Designing a CP antenna for implants is very challenging as the miniaturization for implantable applications is also needed to be satisfied. Good circular polarization should be realized within a limited size. A broadband implantable system has better tolerance to different human tissue environments and can provide high data rate exchange with external apparatus, which is essential for applications such as cochlear implant, neural signal recording and other high-resolution imaging purposes. Few groups have studied CP antenna for implantable applications. In [18], a conformal antenna was studied with polarization diversity for ingestible system, and a cross dipole with CP property is presented as a receiver antenna outside human body. However, the axial ratio (AR) of the conformal antenna needs further improvement. More recently, a capacitively loaded CP patch antenna was proposed for 2.45 GHz ISM band biomedical applications [35]. The antenna was well designed and discussed, but the bandwidth with AR below 3 dB was not broad enough, therefore its CP performance would be more affected by the variation of human tissues.

In this paper, a novel CP antenna is proposed for biomedical applications at ISM (2.42-2.48GHz) band. After optimization, a compact size of 13 mm × 13 mm × 1.27 mm and a wide bandwidth with AR below 3 dB are achieved. The manuscript is organized as follows: In Section II, we described the configuration of the proposed CP antenna, together with its simulation performance. In Section III, the working principles of miniaturization and CP property are analyzed. Section IV presents the communication link of the proposed antenna. And measurement results of the antenna both inside skin-mimicking gel and pork are given in Section V, followed by the conclusion in Section VI.

II. ANTENNA DESIGN AND DISCUSSION

Our goal is to design a CP antenna at ISM band covering from 2.42-2.48GHz for biomedical applications. The antenna is intended to be implanted into a human arm and close to the skin surface. Because skin and muscle have a larger dielectric constant than fat, they contribute more in reducing the size of the implant antenna. When comparing skin with muscle, it is quite obvious that an implantable antenna placed in the skin would be closer to the external receiver, minimizing the power loss caused by the tissue. Therefore, the skin model is preferred and its dimension is selected to imitate a 2/3 equivalent human arm. As shown in Fig. 1, a simple one-layer-skin model with dimension of 60 mm × 180 mm × 60 mm is built to imitate the human environment during simulation. The dielectric properties of the skin tissue are set frequency dependent according to [37].

![Skin-tissue](image1.png)

**Fig.1. Simulation environment of the antenna embedded in the skin tissue with depth of h.**

![Dielectric properties](image2.png)

**Fig. 2.** The dielectric properties of the skin tissue in simulation [37].
as shown in Fig. 2. We can see from the figure that the dielectric properties of skin at 915 MHz are found to be \(\varepsilon_r=41.35\) & \(\sigma=0.87\) S/m. The antenna is embedded in the skin tissue with a depth of \(h\) and its upper surface directed towards the skin surface. To achieve antenna compactness, Rogers 3010 (\(\varepsilon_r=10.2, \text{tan} \delta=0.0035\)) with thickness of 0.635 mm is used for both substrate and superstrate.

A. Configuration of the Circularly Polarized Implantable Antenna

The configuration of the proposed antenna is shown in Fig. 3, where the square loop is connected with four \(LC\) loadings. For convenience, the centre of the configuration is set as the original point, and the coordinate system is illustrated at Fig. 3 as well. As can be seen from the figure, four small patches are connected to the loop with four high impedance lines separately at different quadrants. Besides, two shorting pins with diameter of 0.9 mm are located at quadrant I and III, separately. It should be noted that all the loadings are symmetric around the original point. The proposed antenna is fed at quadrant IV. After optimization when \(h=3\) mm, a compact size of 13 mm \(\times\) 13 mm with a ground plane of 14 mm \(\times\) 14 mm can be achieved and the detailed parameters are listed in Table I.

The antenna is designed and optimized for right-hand circular polarization (RHCP), and it should be mentioned that if the positions of feed and shorts are simply mirrored along x axis, left-hand circular polarization (LHCP) can be achieved. Fig. 4 shows the simulated \(|S_{11}|\) together with the AR for both the RHCP and LHCP configurations, with respect to the 50-\(\Omega\) reference. With \(|S_{11}|\) below -10 dB and AR below 3 dB, a wide bandwidth of 18.2% can be achieved for the optimized RHCP configuration, covering from 802 MHz to 963 MHz (with a centre frequency of 882.5 MHz). While for the LHCP configuration, the performance stays almost the same. Broadband performance can be achieved for both configurations.

As can be seen from the \(|S_{11}|\) curve of the proposed antenna, there is a resonance at 828 MHz besides 2.45GHz. The current distributions at 828 MHz on the antenna and ground plane are shown in Fig. 5. As can be seen from the figure, the introduction of the two shorts mainly contributes to the appearance of the resonance at 828 MHz. Strong current appears on the ground plane at this resonance, therefore the changing of ground size would affect its impedance matching.

The implantable antenna is not an efficient radiator because of its compact size and tissue loss. And its radiation efficiency is lower than 1%, which is the common case for most implantable antennas [7], [19], [20], [38]. The simulated gain

![Fig. 3. Top and side views of the proposed antenna.](image)

**TABLE I**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(x)</td>
<td>3.35</td>
<td>(y)</td>
<td>5</td>
</tr>
<tr>
<td>(g)</td>
<td>0.5</td>
<td>(l)</td>
<td>13</td>
</tr>
<tr>
<td>(l_1)</td>
<td>11.6</td>
<td>(l_2)</td>
<td>1.8</td>
</tr>
<tr>
<td>(l_3)</td>
<td>7.4</td>
<td>(l_4)</td>
<td>3.05</td>
</tr>
<tr>
<td>(l_5)</td>
<td>1.5</td>
<td>(l_6)</td>
<td>5.15</td>
</tr>
<tr>
<td>(l_1)</td>
<td>5.15</td>
<td>(w)</td>
<td>0.7</td>
</tr>
<tr>
<td>(s_1)</td>
<td>0.5</td>
<td>(s_2)</td>
<td>0.5</td>
</tr>
</tbody>
</table>
pattern at 915 MHz is plotted in Fig. 6 for either configuration, respectively. The maximum realized gains at boresight are both $-32 \text{ dBi}$. It should be mentioned that the realized gains are simulated for the antenna located in $60 \text{ mm} \times 180 \text{ mm} \times 60 \text{ mm}$ one-layer-skin.

Fig. 5. The current distributions of the proposed antenna at 828 MHz.

model at a depth of 3 mm, and both the gain values and patterns would change with the phantom size.

B. Analysis of the Influence of Embedded Depth $h$ and the Variation of Tissue Properties

The antenna discussed previously is assumed to be embedded in the skin tissue with a depth of 3 mm. However, in practical situation, the implementation of the implantation cannot be that accurate. Thus, the changing of the embedded depth should be considered. Fig. 7 presents the simulated $|S_{11}|$ and AR with the varying of embedded depth $h$. With the increasing of $h$, the resonant frequency shifts down slightly and the required band is still covered. The AR is much more sensitive to $h$, and the CP performance can still be maintained until the embedded depth exceeds 10 mm.

Additionally, the properties of human tissue vary from person to person, therefore the antenna performance should be stable with the tissue variation. For the proposed CP antenna, when the dielectric properties of the human tissue vary from $\pm 10\%$ to $\pm 30\%$, the simulation results are given in Fig. 8 and from the figure we can see that the CP properties together with the $|S_{11}|$ performances are stable with the variation of human tissue properties in the desired band.

C. Analysis of the Influence of Biocompatible Insulating Layer

In practical scenarios, biocompatible insulating layer is necessary for an implant due to the high conductivity of human tissues. It could have an important impact on the EM characteristics of the proposed antenna, and with the employment of biocompatible insulation, short-circuit effect could be avoided [16], therefore the effect of biocompatible encapsulation is studied.

The substrate used for this antenna is Rogers 3010 with a dielectric permittivity of 10.2. To reduce the influence of bio-

![Fig. 6. Simulated gain patterns at 915 MHz (when $h = 3 \text{ mm}$). (a) RHCP configuration, (b) LHCP configuration.]

![Fig. 7. Simulated $|S_{11}|$ and AR with the varying of $h$ (unit:mm).]
compatible encapsulation, alumina \((\varepsilon_r=9.2-j0.0736, \tan\delta=0.008)\) is adopted in the simulation, because its permittivity is close to Rogers 3010. During simulation, alumina with thickness \(d\) is coated around the antenna and the simulated \(|S_{11}|\) together with the AR is shown in Fig. 9. As can be seen from the figure, with increasing of \(d\), the resonant frequency shifts up and the AR is affected as well. When reaches 0.1 mm, the required ISM band is still covered with good circular polarization property (AR < 3 dB). But when keeps increasing to 0.5 mm, neither the \(|S_{11}|\) nor the AR can meet the requirement, in which case, the antenna needs further optimization.

D. The Specific Absorption Rate (SAR) Evaluation

The IEEE C95.1-1999 standard [39] and the IEEE C95.12005 standard [40] set restrictions on the SAR level to evaluate the RF radiation safety. It seems that standard C95.1-1999 is more critical than C95.1-2005. Thus, the standard C95.1-1999 is applied in this paper, which means the SAR averaged over any 1 g of tissue should be less than 1.6 W/kg. To simulate the SAR value of the proposed antenna, two calibration planes are set in Ansoft HFSS at the centre of the antenna, with one along \(x\)-axis and the other along \(y\)-axis. The simulation results show that when the net-input power is initially set to be 1 W, the 1-g maximum averaged SAR values at 915 MHz is 599 W/kg. It implies that the antenna can be fed with a maximum power of 2.6 mW for the input signal to meet the SAR regulations.

III. OPERATING PRINCIPLE

To verify the working principle of the proposed antenna, taking the RHCP configuration for example, the miniaturization and CP property are analyzed.

A. Miniaturization of the Proposed Antenna

Fig. 10 shows three antenna configurations which are established with a fixed size of 13 mm \(\times\) 13 mm, namely case 1 to case 3 to understand the miniaturization mechanism of the proposed antenna. For easy comparison with the proposed antenna, they are embedded in the same simulation environment as the proposed one and all the three cases are excited by coaxial feed at the corner of quadrant IV.
As can be seen in Fig. 10(a), *case 1* is a simple square loop antenna loaded with two shorts at its corner symmetrically. The width of the loop is set to be \(w = 1.8\) mm. The \(|S_{11}|\) and AR are simulated for the loop with and without shorts. As depicted in the figure, for the loop without shorts, one-wavelength resonance with linear polarization is formed at 1.93 GHz. While two shorts are loaded, another close resonance appears with linear polarization.

For *case 2* in Fig. 10(b), the width of the loop stays unchanged, and four square patches are added and connected to the loop with four high impedance lines at different quadrants. Since an antenna can be modeled as a transmission line, we regard *case 2* as a host transmission line loaded with a high impedance line and a square patch as shown in Fig. 11(a). The corresponding equivalent circuit is shown in Fig. 11(b), where the T-network consisting of two inductors \(L_1\) and \(C_1\) stand for the inductance and capacitance of the host transmission line, \(L_2\) is the inductance of high impedance line and \(C_2\) is the total capacitance induced by the loading. It is obvious that the LC loading would bring in slow wave effect and cause miniaturization of the structure.

\[\text{Fig. 10. Three cases embedded in tissue with a depth of 3 mm, together with their simulated } |S_{11}| \text{ and directional patterns: (a) Case 1, (b) Case 2, (c) Case 3. Simulated } |S_{11}| \text{ varying with } a \text{ and } w \text{ for each case.}\]

\[\text{Fig. 11. Transmission line with LC loading: (a) structure; (b) equivalent circuit.}\]
The four LC loadings are of the same dimensions and the length of the patch is labeled as \( a \). As can be noticed, with the increasing of \( a \), the resonant frequencies shift to a lower band. Comparing case 2 to case 1, when the length of square patch \( a \) increases to 3.75 mm, the resonant frequency shifts from 1.93 GHz to 1.42 GHz, and 26\% of miniaturization can be achieved.

For further miniaturization, the width of the loop \( w \) decreases while the length of the patches \( a \) keeps increasing. Thus, case 3 is established as depicted in Fig. 10(c). To save enough space for the feed and shorts, the feed and shorts are moved to the square patches in corresponding quadrants with their positions \( x = y = 3 \). It can be seen from the simulated \( |S_{11}| \) that the required band can be covered by tuning of \( a \). Compared to case 1, the centre frequency could change from 1.93 GHz to 0.86 GHz (when \( a = 5.25 \text{ mm}, w = 0.3 \text{ mm} \)), and 55.4\% of miniaturization can be achieved.

The directional patterns of three cases are also displayed in Fig. 10. It can be noted that there is a trade-off between size reduction and overall antenna performance. With the improvement of miniaturization, the directivity at boresight and the radiation efficiency decrease from case 1 to case 3. But the final performance of the proposed antenna should meet the requirement of communication, which would be discussed later in this paper.

Based on the principle discussed above, miniaturization of the proposed antenna could be achieved by loading four patches and high impedance lines to form slow wave propagation. In this paper, to meet the ISM band requirement, a wide bandwidth covering from 2.42-2.48GHz is obtained after final optimization, which means a final miniaturization of 54.4\% is achieved compared to case 1.

### B. CP Property of the Proposed Antenna

As can been seen from Fig. 4, the AR performance of the proposed antenna is almost the same and around 2 dB in the required band, therefore we select 2.45GHz to perform the analysis. When the magnitudes of the two components are identical and the time-phase difference between them is odd multiples of \( \pi/2 \), circular polarization can be achieved. At this frequency, when the input power is set to be 1 W, the simulated magnitudes of \( E_x \) and \( E_y \) are 139.6 mV/m and 137.1 mV/m, and the simulated phases are 125.4 deg and 22.1 deg, respectively (when \( \text{phi}=0 \text{ deg} \), \( \text{theta}=0 \text{ deg} \)). Then the AR can be calculated as follows:

\[
\text{AR} = \frac{\text{major axis}}{\text{minor axis}} = \frac{\text{OA}}{\text{OB}}
\]

(1)

where,

\[
\begin{align*}
\text{OA} &= \left[ \frac{1}{2} \left( E_x^2 + E_y^2 + \left( E_x^4 + E_y^4 + 2E_x^2E_y^2\cos(2\Delta\phi) \right)^{1/2} \right) \right]^{1/2} \\
\text{OB} &= \left[ \frac{1}{2} \left( E_x^2 + E_y^2 - \left( E_x^4 + E_y^4 + 2E_x^2E_y^2\cos(2\Delta\phi) \right)^{1/2} \right) \right]^{1/2}
\end{align*}
\]

(2)

Thus, AR equals to 1.26, or 2.04 dB, and circular polarization is produced.

It should be mentioned that there are two factors that would affect the impedance matching and CP property of the antenna. One is the locations of the feed and shorts, which are constrained by the antenna configuration and can be presented by and . It turns out that the changing of \( (x, y) \) would mainly affect the AR performance of the proposed antenna. After final optimization, \( x \) and \( y \) are chosen to be 3.5 and 1.5, respectively. The other factor is the ground plane size. As depicted in Fig. 3, the ground plane is larger than the antenna loop and the length difference is represented by \( g \). When \( g \) equals to 0 mm, the ground has the same size with the loop antenna. Good AR can be achieved when the ground plane is larger than the antenna loop, but with the increasing of \( g \), the centre frequency of the AR deviates from that of the return loss. Thus, \( g \) is set to be 0.5 mm in this paper.

### IV. COMMUNICATION LINK

In the case of up-link communication (from the implant to the base station), an antenna in free space with a centre frequency of 2.45GHz lying at the \( x \)-y plane is viewed as the receiver antenna, and the implantable antenna is considered to be at the transmitter side. The distance between the transmitter and the receiver is labeled as \( d \). The communication link margin (LM) can be calculated as:

\[
\text{LM} = P_r - \text{PL} + G_r - \text{RNF} - \text{SNR}
\]

(4)

\[
\text{PL} = 20\log\left( \frac{4\pi d}{\lambda} \right) \text{dB}
\]

(5)

where \( P_r \) is the radiated power of the transmitter antenna, \( \text{PL} \) is the path loss and \( \text{RNF} \) is the receiver noise floor, \( G_r \) is the gain of the receiver antenna and \( \text{SNR} \) is the signal to noise ratio of the receiver.

In this paper, the values of \( \text{RNF} \) and \( \text{SNR} \) are from [14] and the various parameters of the link budget are listed in Table II. Note that the \( |S_{11}| \) at 2.45GHz is around -19 dB, thus the impedance mismatch loss can be neglected. Besides, since the maximum output power for the transmitter chip is -19dBm [15], it is considered to be the input power of the transmitter antenna \( P_r \), and the loss for propagating through the tissue is included in the Tx antenna gain -32dBi as in the EM
simulation. For the receiver antenna, supposing it is well matched to 50Ω with CP property, the impedance mismatch and polarization mismatch losses can be approximated as 0 dB. It should

### TABLE II

<table>
<thead>
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<th>Parameters of the Link Budget</th>
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<tr>
<td>Operating frequency</td>
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<td>Tx power $P_t$</td>
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<tr>
<td>Tx antenna gain $G_t$</td>
</tr>
<tr>
<td>Rx antenna polarization</td>
</tr>
<tr>
<td>Rx antenna gain $G_r$</td>
</tr>
<tr>
<td>Receiver noise floor RNF</td>
</tr>
<tr>
<td>SNR (BER=1E-5)</td>
</tr>
</tbody>
</table>

Fig. 12. Variation of link margin with respect to the distance $d$ between two CP antennas.

be noted that when the receiver antenna has linear polarization property, the polarization mismatch loss is about 3 dB.

According to (4), the LM varying with distance $d$ can be calculated as shown in Fig. 12. To realize wireless communication, the LM should be better than 0 dB. From the figure, we can see that when the distance between two antennas is within 2 m, up-link communication can be established in our case.

### V. ANTENNA MEASUREMENT

The fabricated antenna is depicted in Fig. 13 and a compact size of 214.6 mm$^3$ (13 mm × 13 mm × 1.27 mm) is achieved. Fig. 14 shows the measurement setup. To validate the antenna performance, the antenna measurement is performed under two scenarios. One is in a plastic container filled with pork, and the other is in a plastic container filled with skin-mimicking gel [5]. According to the simulation, the tissue size does not have much effect on the return loss of the implantable antenna. Thus, the dimensions of the pork and skin-mimicking gel during measurement are almost the same and chosen to be 72 mm × 135 mm × 30 mm. Fig. 15 displays the comparison of the measured and simulated $|S_{11}|$. As can be seen from the figure, two resonances are observed clearly in measurement results. The measured antenna bandwidths measured in pork and skin-mimicking gel are 29.4% (709–954 MHz) and 27.8% (737–975 MHz), respectively. The required band is covered for both cases. The discrepancy is probably brought in by the reasons as follows: (1) the fabrication discrepancy. (2) tissue sinking into the gap between substrate and superstrate during measurement. (3) the differences of dielectric properties between simulation and measurement. (4) the cable connected to the antenna during measurement.

It should be noted that, a coaxial cable was connected with the antenna in the measurement, and it would affect the performance of the proposed antenna [41]. The case of antenna with the coaxial cable is simulated and compared to the result.
given in this paper. Results show that the impedance matching is affected by the introducing of the cable, and the resonant frequency shifts down in a similar way to our measurement result. Besides, in realistic scenarios, implantable antennas for telemetry applications are always integrated with other electronics together in one board, are not suffering any feeding cable effects.

To demonstrate the CP property of the proposed antenna, a linear polarized dipole connected with a balun is placed outside the tissue gel to serve as a receiver. The dipole is placed 150 mm away from the implanted antenna as shown in Fig. 14.

The measurement of $|S_{21}|$ was carried out in four directions, including two pairs of orthogonal directions, 0 deg (Tx and Rx antennas are at the same polarization) and 90 deg (Tx and Rx antennas are at the orthogonal polarization), +45 deg and −45 deg, respectively and the measurement results are given in Fig. 16. From the comparison of $|S_{21}|$ in the desired band, we can see that the received power has a maximum difference only up to 5 dB, which suggests CP property of the proposed antenna.

VI. CONCLUSION

Designing a circularly polarized antenna is a new topic for implantable antennas, to which careful attention should be paid. Both the difficulty in combining the designing principle of circular polarization with miniaturization technique and the sensitivity of the circular polarization property with respect to the tissue variations present a challenging task for implantable antenna designers.

In this paper, a circularly polarized antenna has been proposed for biomedical applications at 2.45GHz ISM band. Either RHCP or LHCP property can be achieved and the RHCP configuration has been discussed. In order to reduce the size of the implanted antenna, four LC loadings are adopted to form slow wave effect. Through optimization, we finally achieved a compact size of 13 mm × 13 mm × 1.27 mm, which is 54.4% smaller compared to the unloaded loop antenna of the same size. The effect of embedded depth, the influence of encapsulation layer and SAR performance are evaluated. Additionally, the miniaturization technique is explained through introducing three antenna prototypes, the performances of these three antennas are compared extensively. Furthermore, the communication link analysis is performed to evaluate the implanted antenna’s reliability. Finally, the measurement is performed and the results show that the desired ISM band can be well covered and CP property is obtained.

REFERENCES


Lijie Xu was born in Jiangyin, Jiangsu, China, in 1987. She received the B.S. degree from the Department of Optoelectronic Technology, Nanjing University of Science and Technology (NUST), Nanjing, China in 2009, where she is currently working toward the Ph.D. degree.

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Dr. Guo was a recipient of the Young Investigator Award 2009, National University of Singapore. He received the 2013 “Raj Mittra” Travel Grant Senior Researcher Award and the Best Poster Award in 2014 International Conference on Wearable & Implantable Body Sensor Networks (BSN 2014), Zurich, Switzerland. He will be the General Chair for 2015 IEEE MTT-S International Microwave Workshop Series on Advanced Materials and Processes for RF and THz Applications (IMWS-AMP 2015) in Suzzhou.
China. Dr. Guo was the General Chair for IEEE MTT-S International Microwave Workshop Series 2013 on “RF and Wireless Technologies for biomedical and Healthcare Applications” (IMWS-Bio 2013) in Singapore. He served as a Technical Program Committee (TPC) Co-Chair for IEEE International Symposium on Radio Frequency Integration Technology (RFIT2009). He has been a TPC member and session chair for numerous conferences and workshops. He is serving as an Associate Editor for the IEEE Antennas and Wireless Propagation Letters and IET Microwaves, Antennas and Propagation.

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He has authored and coauthored over 90 journal and conference papers.