

A 6.0 GHz SMALL PRINTED MONOPOLE ANTENNA FOR WIRELESS IMPLANTABLE BODY AREA NETWORK APPLICATIONS

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Abstract—Wireless implantable body area network (WiBAN) is useful for monitoring vital human parameters in medical diagnosis such as breast cancer, heart attack and high blood pressure. The main objective of this paper is to design a small printed monopole antenna for WiBAN applications at 6.0 GHz. The small implantable antenna was tested in a lossy environment by being submerged into canola oil that mimics the dielectric properties of human breast fat tissue. The antenna performances were measured by using vector network analyzer (VNA) in order to evaluate the return loss and operating bandwidth of the antenna. The other parameters such as efficiency, radiation pattern and gain are evaluated by simulation of CST Studio 2012 software. When compared, there is good agreement between the simulation and measurement results. The simulated antenna gain and efficiency are 5.8 dBi and 97%, respectively, when submerged into canola oil. The antenna radiation pattern is directional, and it has 6 lobes implying its coverage in more directions which is of good benefit due to body movement. The antenna's polarization was tested by placing a wideband antenna at several degrees around the proposed

Received 28 May 2013, Accepted 6 July 2013, Scheduled 9 July 2013

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antenna. The value of S_{21} was also analyzed to investigate the path gain of the selected links.

1. INTRODUCTION

Recently, the functions and possibilities of implanted device systems have attracted increased research attention for future telecommunications [1–5]. The development of research in wireless body centric sensing systems occurs as the system is improving the quality of people life. Implanted devices are largely investigated specially for health monitoring systems, biotelemetry, hyperthermia, breast cancer detection, etc. Wireless sensors through in-body are used to monitor the patient's vital signs and can provide real time feedback. Also, they can be a part of diagnostic procedure, maintenance of chronic condition, supervised recovery from a surgical procedure and to monitor effects of drug therapy [6]. This device also can be used in such applications as home/office security, finding missing pets/kids and in military sector.

Dissimilar to the antenna at free space environment, designing an implantable antenna can be very challenging. Since the antenna is implanted into a lossy environment (for example, human body), the antenna efficiency is reduced, and the antenna also encounters very strong multipath losses. There are difficulties in using human body acting as medium for signal propagation due to the dissimilar tissue and organ. Attenuation occurs due to weakly conducting tissue and reflection at each of the boundaries of dissimilar tissue. The implantable antenna is required to have a small size for ease of implantation in human body. The power consumption should also be very low in order to ensure user safety and to make sure that the antenna can last long time to avoid battery replacement, which requires a surgery.

WiBAN offers a lot of advantages for personal communication and medical application. In order to operate as such systems, the antenna must be in small size and provide better performances than antenna operating in free space environments [6–11]. Based on the previously reported research works, printed monopole antenna has become a major field of interest due to its compact size, omni-directional radiation patterns, large bandwidth (BW) and high radiation efficiency [12–20]. The printed monopole antenna has therefore been chosen for WiBAN application, due to the aforementioned characteristics. According to an earlier reported works, a compact ring printed monopole antenna is presented [21]. The antenna performances are investigated in canola oil and beef as those

materials can represent human breast fat and human muscle. The results for both simulation and measurement are satisfactory for each others. As the antenna operates well in lossy environment, an enhancement is made to improve the antenna structure (reducing the size of antenna) and performances (gain and efficiency).

The design of an implantable small printed monopole (ISPM) antenna for WiBAN application at 6.0 GHz is presented in this paper. In order to increase the proposed antenna's efficiency, the gain, return loss, radiation pattern, operating BW and reducing the driving power have all been optimized. The CST Microwave Studio Suite software has been used for all the simulations. The antenna was submerged into canola oil which represents the human breast fat tissue in order to measure its performances. Note that the canola oil should be characterized as a medium for signal propagation in order to achieve a reliable wireless communication. Therefore, wideband wearable antenna was placed in a free space environment, while the small antenna was immersed in canola oil. The wave propagation between the two antennas was evaluated in terms of antenna polarization.

2. ANTENNA CONFIGURATION

An ISPM antenna was specifically designed at 6.0 GHz when it is immersed into canola oil. The antenna consists of a single metallic

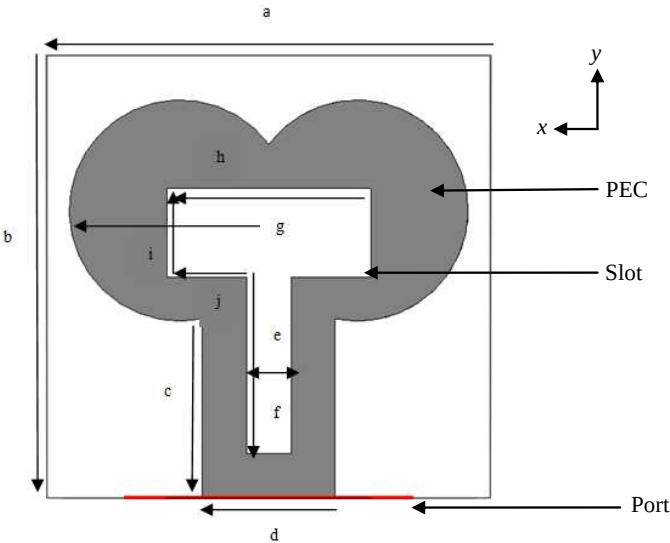


Figure 1. Simulated geometry of the proposed antenna.

(copper) layer with 0.036 mm thickness and it is printed on one side surface of the FR4 substrate. The FR4 dielectric constant is $\epsilon_r = 4.7$, with 0.019 loss tangent and 1.6 mm thickness. The proposed antenna design's optimum configuration and its prototype are shown in Figure 1 and Figure 2 respectively. The antenna's dimensions are 10 mm $\times$ 10 mm $\times$ 1.6 mm. The antenna's radiating elements is composed of half bone shaped design with T slot and feed line. The radiator is centre fed by a microstrip line with 4.1 mm length and width of 4.1 mm and 3 mm, respectively. It should be noted that no ground plane is added in the proposed design, since the body (or any lossy material) will act as a reflector to the antenna [23]. The optimized dimensions for the antenna are: $a = 10.0$ mm, $b = 10.0$ mm, $c = 5.0$ mm, $d = 3.0$ mm, $e = 1.0$ mm, $f = 4.0$ mm, $g = 2.5$ mm, $h = 4.6$ mm, $i = 2.0$ mm and $j = 1.8$ mm.

3. EXPERIMENTAL SETUP

There are two approaches for antenna design: (i) designing the antenna in free space, and then refining it for tissue implantation and (ii) directly designing the antenna within the lossy environment. In this paper, the antenna is designed in a free space environment and further implanted inside the human breast fat tissue model. Detuning resonance frequency was observed and attributed to the effect of the surrounding tissue. Since a small antenna is used for implantable application, the antenna must be biocompatible to avoid any harm to the user. Two ways of preserving the antenna's biocompatibility are: (i) by covering a structure of the antenna with a superstrate



Figure 2. The prototype of the proposed antenna.



Figure 3. Antenna testing in free space environment.

dielectric and (ii) by coating the antenna with a thin insulating layer. Figure 3 shows the small antenna, coated with a thin layer of plastic, in free space environment. The antenna was connected to a coaxial SMA connector when submerged into canola oil during measurement, in order to obtain accurate results.

As mentioned earlier, canola oil is chosen to mimic the human breast fat tissues due to their similar dielectric properties. According to the literature review, the tissue data are from 1 to 14 GHz, and its permittivity and conductivity vary from approximately 2.55 to 2.35 and 0.01 to 0.04 S/m, respectively [22]. Table 1 shows the dielectric properties of canola oil at frequency of 1.0 to 10 GHz. The antenna is positioned at 5 mm from the top of canola oil. Figure 4 shows the model

Table 1. The measurement of dielectric properties for canola oil.

Frequency (GHz)	The real part of permittivity, ϵ'	The imaginary part of permittivity, ϵ''
1	2.8782	0.1738
2	2.9196	0.1736
3	2.873	0.153
4	2.8724	0.0956
5	2.7735	0.1505
6	2.8662	0.1796
7	2.7846	0.1903
8	2.7222	0.1894
9	2.7186	0.1649
10	2.7147	0.1575

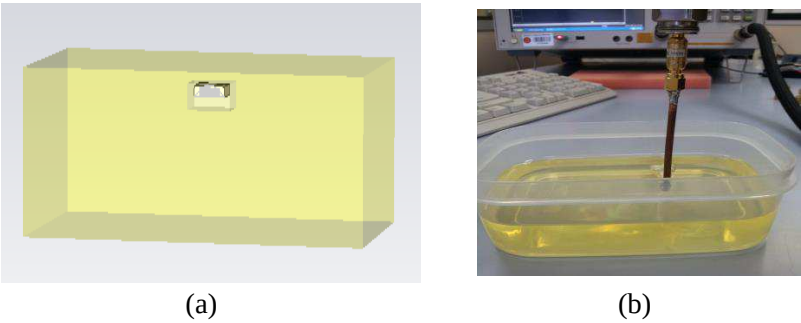


Figure 4. Antenna testing in canola oil. (a) Simulation. (b) Measurement.

used for antenna simulation and measurement. For measurement, the plastic bowl with dimensions of $100\text{ mm} \times 100\text{ mm} \times 25\text{ mm}$ was used as container for canola oil.

4. RESULTS AND DISCUSSIONS

The simulated and measured return losses of the small implantable antenna in free space environment are shown in Figure 5. The simulation and measurement results are excited at 7.0 GHz with a -10 dB impedance BW of 1620 MHz (6.5–8.1 GHz). The simulated gain of the small antenna is 2.1 dBi at 7.0 GHz, and the efficiency of the antenna is 78%, which indicates that the small implantable antenna can perfectly operate at 7.0 GHz in free space environment.

The simulation and measurement results of the small antenna in a lossy environment are illustrated in Figure 6. Both simulation and measurement results are tuned at 6.0 GHz with a -10 dB impedance BW of 3200 MHz (4.3–7.5 GHz). Compared to the free space environment, the antenna's resonant frequency is reduced when submerged into canola oil, due to the effect of surrounding environment. As the antenna is placed in lossy environment, attenuation occurs due to reflection at each of the boundaries of dissimilar layers (air and canola oil). The simulated gain of the small antenna is 5.8 dBi at 6.0 GHz while the efficiency of the antenna is 97%. It is shown that the antenna performs better in a lossy medium. The radiation pattern of the small implantable antenna is shown in Figure 7, with 6 lobes of maximum directivity which implies that the antenna is capable of covering the signal from various locations.

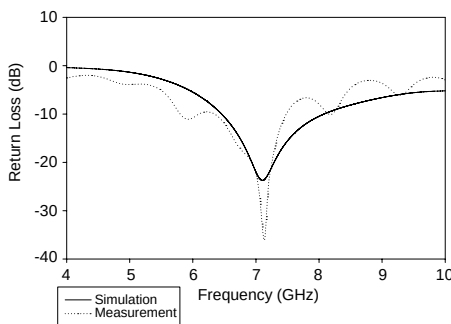


Figure 5. Comparison of simulated and measured return losses for the ISPM antenna in free space environment.

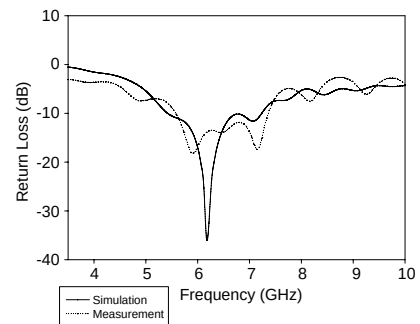


Figure 6. Comparison of simulated and measured return losses for the ISPM antenna when submerged in canola oil.

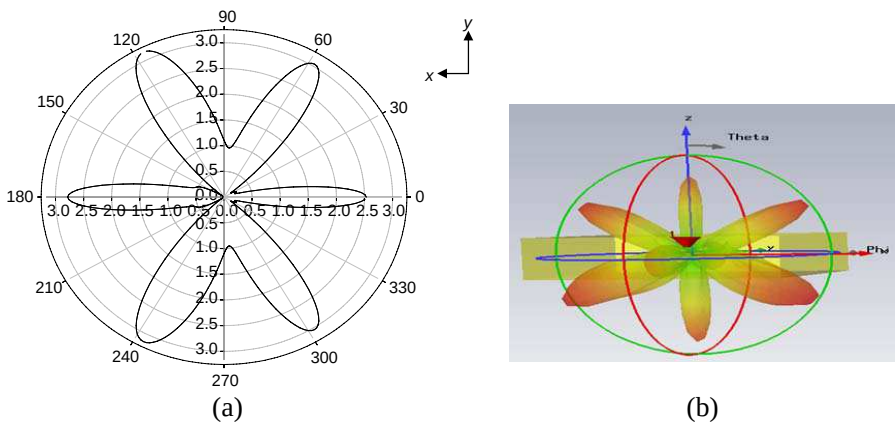


Figure 7. The simulated far field radiation pattern at 6.0 GHz. (a) Polar plot. (b) 3-dimension plot.

5. ANALYSIS OF IMPLANTABLE ANTENNA AT DIFFERENT POLARIZATION

In this section, the polarization of implantable antenna is analyzed at different locations herein named as polarizations 1, 2, 3 and up to 8 as shown in Figure 8. A wideband wearable antenna is used in order to validate the investigation. The main purpose of this experiment is to

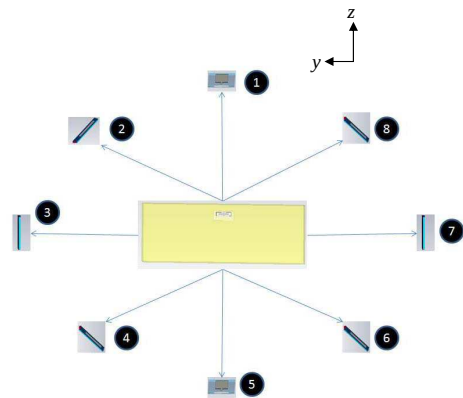


Figure 8. Wideband wearable antenna's locations.

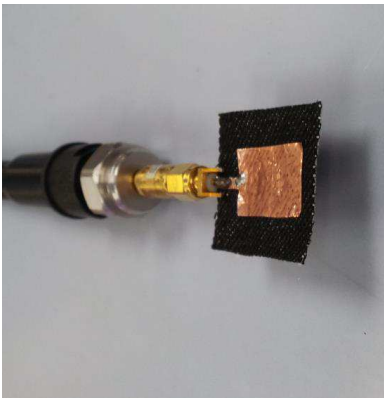


Figure 9. Wideband wearable antenna.

prove that the small implantable antenna is able to receive signal from various locations according to the radiation pattern shown in Figure 7. As shown in Figure 9, the wideband wearable antenna has dimensions of 30 mm × 30 mm × 0.07 mm. The antenna radiating element consists of copper with a rectangular shape and center fed by SMA connector. The wearable antenna is able to operate at frequency 3.0–7.2 GHz. The wearable antenna was used because it can curve easily, which makes it suitable to be attached to any part of the body. It should be mentioned here that the body has several structures and shapes. Therefore, it is quite possible to evaluate the wireless propagation between the antenna submerged in canola oil and the wearable antenna attached to the body. The experimental setup is illustrated in Figure 10. The small

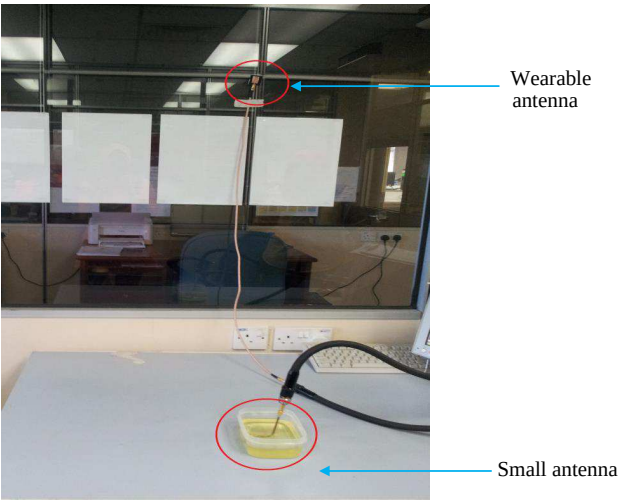


Figure 10. Measurement setup.

Table 2. The measured path gain, S_{21} (dB) for the four rotations.

Polarization	In face	Out face	Left	Right
1	−31.60	−32.02	−34.05	−38.94
2	−43.86	−42.2	−55.07	−52.79
3	−44.12	−42.43	−41.55	−52.75
4	−63.74	−47.94	−42.23	−50.21
5	−68.51	−50.87	−60.7	−60.28
6	−63.74	−47.94	−42.23	−50.21
7	−44.12	−42.43	−41.55	−52.75
8	−49.10	−54.12	−46.12	−70.59

antenna is fixed in canola oil while the wearable antenna moves along the locations as shown in Figure 8. Table 2 shows the value of path gain, S_{21} (dB) between the small implantable antenna and wearable antenna for four rotation.

For measurement setup, the small implantable antenna was submerged into canola oil and connected to the vector network analyzer. The location of small antenna is fixed in one position as shown in Figure 10. The distance between the small antenna and wearable antenna is approximately 100 cm. The location of the wearable antenna is changed as shown in Figure 8. For each location, the wearable antenna rotates to four positions: the radiating element of wearable antenna (i) faces the small antenna (In face), (ii) faces opposite direction to the small antenna (Out face), (iii) rotates to the left of the small antenna and (i) rotate to right of the small antenna. Figure 11 shows the antenna rotations. The wearable antenna was also connected to the vector network analyzer as a port 2 in order to get the value of S_{21} . The wireless propagation between both antennas is evaluated in terms of path gain, S_{21} (dB).

As shown in Table 2, location 1 demonstrates the best polarization

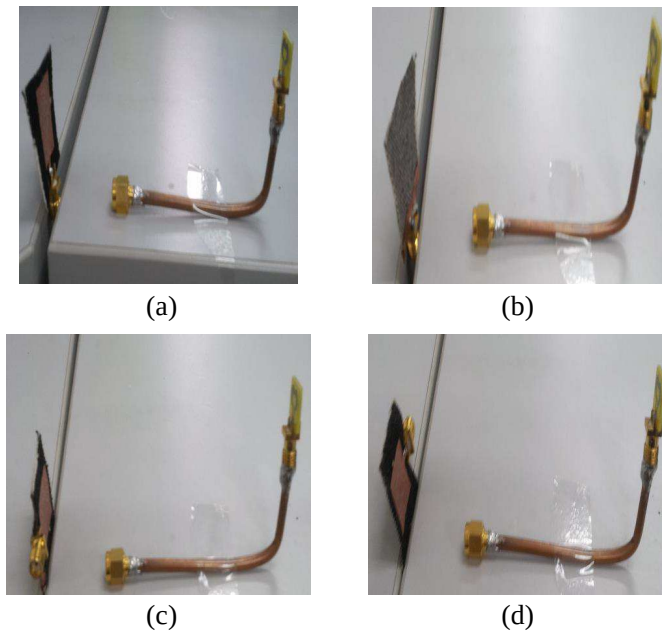


Figure 11. The antenna rotations. (a) In face. (b) Out face. (c) Right. (d) Left.

since both antennas were polarized in similar direction, and besides, the two antennas face each other directly. This could help the wearable antenna to be well-connected with the small antenna in canola oil and thereby yielding more stable polarization. However, the other locations still offer stable polarization as the value of path gain is still below the threshold value of noise level (-100 dBm). Therefore, the small implantable antenna is suitable and reliable for wireless communication application, as it provides good performance in terms of wave propagation.

6. CONCLUSIONS

A small printed monopole antenna has been presented and implemented for WiBAN application. The proposed antenna was successfully designed to operate at 6.0 GHz. The overall dimensions of the proposed antenna were $10\text{ mm} \times 10\text{ mm} \times 1.6\text{ mm}$, and an equivalent BW of 1.8 GHz has been achieved. Measurement was done by submerging the ISPM antenna in canola oil which represents simplified human breast fat model, and acceptable performances were recorded. Both simulation and measurement results agree reasonably well. The small physical size and good quality performances have made the proposed antenna a suitable candidate for application in wireless implantable communication system. The antenna is also appropriate where there is occurrence of several movements. Wideband wearable antenna was chosen as it can be easily attached to the body since the body has a various structures. The antenna performance evaluation was investigated in terms of polarization.

ACKNOWLEDGMENT

The authors wish to acknowledge the Government of Malaysia, Ministry of Higher Education (MOHE) and UTM (vot 00G36, 01H00, 04H36) and Ministry of Science, Technology and Innovation (MOSTI) (vot 4S056) for funding this work; and the members of Wireless Communication Centre (WCC), Faculty of Electrical Engineering, Universiti Teknologi Malaysia are specially acknowledged for their helps and kindness.

REFERENCES

1. Hall, P. S. and Y. Hao, Eds., *Antennas and Propagation for Body Centric Wireless Communications*, Artech House, Boston; London, 2006.

2. Soontornpipit, P., C. M. Furse, and Y. C. Chung, "Design of implantable microstrip antenna for communication with medical implants," *IEEE Trans. Microwave Theory Tech.*, Vol. 52, 1944–1951, Aug. 2004.
3. Kim, J. and Y. R. Samii, "Implanted antenna inside a human body: Simulation, designs and characterizations," *IEEE Trans. Microwave Theory Tech.*, Vol. 52, 1934–1943, Aug. 2004.
4. Xia, W., K. Saito, M. Takahashi, and K. Ito, "Performances of an implanted cavity slot antenna embedded in the human arm," *IEEE Trans. on Antennas and Propag.*, Vol. 57, 894–899, Apr. 2009.
5. Hall, P. S., Z. H. Hu, and Y. I. Nechayev, "Characterisation of narrowband communication channels on the human body at 2.45 GHz," *IET Microw. Antennas Propag.*, Vol. 4, 722–732, 2010.
6. Panescu, D., "Wireless communication systems for implantable medical devices," *IEEE Engineering in Medicine and Biology Magazine*, Vol. 27, No. 2, 96–101, Apr. 2008.
7. Vidal, N., S. Curto, J. M. Lopez-Villegas, J. Sieiro, and F. M. Ramos, "Detuning study of implantable antennas inside the human body," *Progress In Electromagnetics Research*, Vol. 124, 265–283, 2012.
8. Germio, J., J. Parron, and J. Soler, "Human body effects on implantable antennas for ISM bands applications: Model comparison and propagation losses study," *Progress In Electromagnetics Research*, Vol. 110, 437–452, 2010.
9. Kamarudin, M. R., Y. I. Nechayev, and P. S. Hall, "Performance of antennas in the on-body environment," *Antenna and Propagation Society International Symposium*, Vol. 3A, 475–478, 2005.
10. Ito, K., I. Ida, and M.-S. Wu, "Body effect on characteristics of small loop antenna in pager systems," *Antenna and Propagation Society International Symposium*, Vol. 2, 1081–1084, 1992.
11. Noroozi, Z. and F. Hojjat-Kashani, "Three-dimensional FDTD analysis of the dual-band implantable antenna for continuous glucose monitoring," *Progress In Electromagnetics Research Letters*, Vol. 28, 9–21, 2012.
12. Gao, Y., B. L. Ooi, et al., "Band-notched ultra-wideband ring-monopole antenna," *Microwave and Optical Technology Letters*, Vol. 48, No. 1, 125–126, 2006.
13. Liu, J., K. P. Esselle., S. G. Hay, and S. S. Zhong, "Study of an extremely wideband monopole antenna with triple band notch characteristics," *Progress In Electromagnetics Research*, Vol. 123,

- 143–158, 2012.
14. Chen, B., Y. C. Jiao, Y. C. Ren, L. Zhang, and F. S. Zhang, “Design of open slot antenna for bandwidth enhancement with a rectangular stub,” *Progress In Electromagnetics Research Letters*, Vol. 25, 109–115, 2011.
 15. Sadat, S., M. Fardis, G. Geran, and G. Dadashzadeh, “A compact microstrip square ring slot antenna for UWB applications,” *Progress In Electromagnetics Research Letters*, Vol. 67, 173–179, 2007.
 16. Xie, Y., L. Li, C. Zhu, and C.-H. Liang, “A novel dual-band patch antenna with complementary split ring resonators embedded in the ground plane,” *Progress In Electromagnetics Research Letters*, Vol. 25, 117–126, 2011.
 17. Lee, W. S., K. S. Oh, and J. W. Yu, “A wideband planar monopole antenna array with circular polarized and band notched characteristics,” *Progress In Electromagnetics Research*, Vol. 128, 381–398, 2012.
 18. Zhang, S.-M., F.-S. Zhang, W.-M. Li, W.-Z. Li, and H.-Y. Wu, “A multi-band monopole antenna with two different slots for WLAN and wimax applications,” *Progress In Electromagnetics Research Letters*, Vol. 28, 173–181, 2012.
 19. Li, B., Z.-H. Yan, and C. Wang, “Dual rectangular ring with open-ended CPW-FED monopole antenna for WiMAX/WLAN applications,” *Progress In Electromagnetics Research Letters*, Vol. 25, 101–107, 2011.
 20. Teng, X. Y., X. M. Zhang, Z. X. Yang, Y. Wang, Y. Li, Q. F. Dai, and Z. Zhang, “A compact CPW-FED omni-directional monopole antenna for WLAN and RFID applications,” *Progress In Electromagnetics Research Letters*, Vol. 32, 91–99, 2012.
 21. Ramli, N. H., M. R. Kamarudin, N. A. Samsuri, and E. A. Ahyat, “Investigation on a compact ring printed monopole antenna for wireless implantable body area network (WiBAN) applications,” *Microwave and Optical Technology Letters*, Vol. 55, No. 5, 1053–1058, 2013.
 22. Sill, J. M., “Second generation experimental system for tissue sensing adaptive radar,” Master’s Thesis, Department of Electrical and Computer Engineering, Schulich School of Engineering, University of Calgary, Calgary, AB, Canada, 2005.
 23. Ito, K., I. Ida, and M.-S. Wu, “Body effect on characteristics of small loop antenna in pager systems,” *Antennas and Propagation Society International Symposium*, Vol. 2, 1081–1084, 1992.