Progress In Electromagnetics Research M, Vol. 64, 211–217, 2018

Unidirectional UWB Magneto-Electric Antenna for Medical Telemetry

Johnbosco I. E. Anosike[1], Li-Ying Feng[1, *], Hong-Xing Zheng[2], Ying Liu[1], and Yue-Xin Liu[1]

Abstract—An implantable magneto-electric antenna (IMEA) aiming for operation at ultra-wideband (UWB: 3.1–10.6 GHz) frequency spectrum is presented for biotelemetry usages for the first time. The IMEA is composed of a horizontal planar bowtie radiator, from which its middle part excites the antenna, and a vertically inclined rectangular radiator. The two radiators are complementary and correspond to electric and magnetic dipoles, respectively. The radiators are built over a square dielectric material ($\varepsilon_r = 6$, $\sigma = 0.0005$) with a cavity for embedding suitable accompanying circuitry system. The IMEA with its biocompatible insulator (PEEK: $\varepsilon_r = 3.2$, $\tan\delta = 0.01$) measures 1456 mm^3 in volume. HFSS software was used to carry out numerical optimization of the IMEA with a simple multilayered model of body tissue (Skin, Fat and Muscle) as the host environment. The simulated result of the proposed IMEA shows over 90% impedance bandwidth ($S_{11} < -10$ dB) and records a remarkable high gain of 2 dBi within 70% bandwidth. The radiation efficiency is around 50%, and a unidirectional radiation pattern with little back lobe is observed.

1. INTRODUCTION

Innovative implantable healthcare technologies have been the backbone and future of medicine in recent times. Some of these implantable devices such as artificial cardiac pacemaker, remote intelligent drug delivery systems (RIDDS), among others, are capable of remotely transmitting high rate of data in real time for efficient management of patients' health status by physicians [1, 2]. Such implantable devices could take advantage of remote monitoring, control, and delivery, therefore improve the patient's comfort and care. Small size, low profile, broadband, and high efficient implantable antennas are desired in these systems.

Designing efficient antenna requires cautious considerations especially when targeting at operation inside a biological body whose lossy nature could threaten antenna electromagnetic performance. In various papers, good biocompatibility and SAR requirement have been achieved for implantable antennas. However, in the quest to manage the overall size of implantable devices, antenna performance factors such as radiation efficiency, gain, bandwidth and general propagation ability are often structurally traded for miniature antenna. In other instances, unidirectional antennas have been substituted where their omnidirectional one is proven ineffective in directing energy for targeted, fast and efficient transmission function, and for significant reduction in exposure of body tissues to unnecessary electromagnetic radiation [1, 3–5]. However, the investigated cases are few, regrettably operate at low frequency spectrum and record low gains (−32.15 dB at 404.5 MHz MedRadio band [2], −14 dBi at ISM Bands [6]).

Received 9 November 2017, Accepted 12 February 2018, Scheduled 21 February 2018
* Corresponding author: Li-Ying Feng (fengliying_tute@126.com).
[1] School of Electronic Engineering, Tianjin University of Technology and Education, Hexi, Tianjin 300222, China. [2] School of Electronic and Information Engineering, Hebei University of Technology, Tianjin 300401, China.

Luk et al. successively investigated complementary antennas that offer amazing physical and electrical characteristics such as low profile structural designs, low back radiation, wide bandwidth coverage and considerate gain and beamwidth stability for free space application. The complementary antenna is made up of a planar dipole and a shorted patch that is vertically-oriented. The two constituents of the antenna represent an electric and a magnetic dipole, respectively, and when these two are excited simultaneously and appropriately in amplitude and phase, a unidirectional pattern is realized with identical E and H planes [7–9].

Based on this principle, in attempt to resolve the heavy compromises between size and performance that trails implantable medical device (IMD) antennas, a new magneto-electric antenna is proposed for medical implants in this paper for the first time. It has unique unidirectional characteristics that offer slightly stable high gain values across the UWB frequency range. The idea of an outer-wall structured implantable antenna [1] was borrowed, hence a hollow structural modification for housing components of the implantable device was introduced. UWB frequency spectrum proposed by IEEE802.15-TG6 for Wireless Body Area Network applications was employed to minimize structural size and power consumption, and to improve data size and transmission rate for the medical telemetry systems [3, 10–12]. The proposed antenna can offer a satisfactory throughput for implantable antenna with a radiation efficiency about 50% and high gain about 2 dBi which can satisfy the requirements of the UWB medical telemetry application.

Throughout the design and parametric considerations of this work, ANSYS HFSS has been used. The simulation results obtained are based on a simple multilayered body tissue model that is engineered to ease design and speed up simulation time [13].

2. ANTENNA GEOMETRICAL CONFIGURATION/STRATEGIES

The proposed implantable magneto-electric antenna (IMEA) geometry is illustrated below as 2D and a disintegrated 3D in Fig. 1 and Fig. 2, respectively. It is made up of a planar electric dipole (ED) and a perpendicularly adjoined magnetic dipole (MD) excited by a lump port at the center of the radiating pair of the ED. The constituent of the ED follows an isosceles trapezoidal shape while the MD follows a rectangular patch outline. All shapes are optimized to achieve targeted design size and performance.

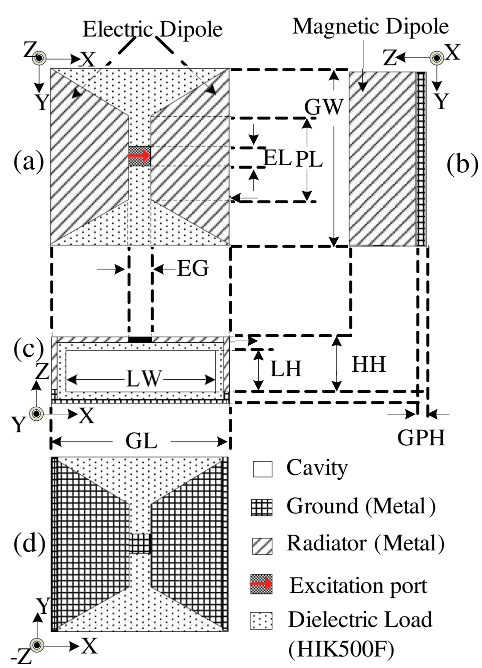

Figure 1. 2D structural design of the proposed IMEA. (a) Top view. (b) Side View. (c) Front view. (d) Bottom view.

The IMEA radiators are stationed on a 90° bent edge of a defected ground plane shown as 'GPH' in Figs. 1(b) and (c). It was discovered that the bent edge gave the ground plane a primary extension support for gain enhancement. This defection and edge feature became necessary for minimizing the huge effect of reflection and losses on the gain caused by the attenuation of biological materials at higher frequencies. Compared with the large ground plane used in the conventional antennas [18, 19], the proposed defected ground plane with bend edge (see Fig. 2) can reduce the antenna size greatly.

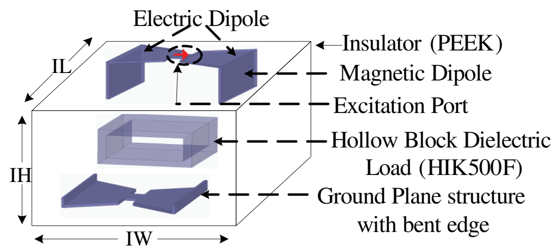

Figure 2. Disintegrated 3D structural design of the proposed IMEA.

In Fig. 2, both the ED and MD of the IMEA are stationed accordingly on top of a hollow 1 mm thick 'HIK500F' dielectric material ($\varepsilon_r = 6$, $\sigma = 0.0005$). The 'HIK500F' is a stable candidate material that accommodates changes in temperature and frequency, and offers low moisture absorption irrespective of the biological medium [14]. The resultant final antenna dimensions are shown in Table 1, after simulation study was carried out to determine and adjust the effects of all parameters on the overall antenna performance.

A square hollow cutting through the 'HIK500F' dielectric block load from two ends was introduced as seen in Fig. 2, exploiting the achieved volumetric size for a possible circuit or IMD battery storage function while still maintaining an improved radiation efficiency [1].

Table 1. Dimensions of the proposed IMEA.

Parameter	GL	GW	GPH	PL	HH	EL
Optimized Value (mm)	11	12	0.5	6.5	5.5	1
Parameter	EG	LW	LH	IL	IH	IW
Optimized Value (mm)	1.5	9	4	14	8	13

In Fig. 2, it can also be observed that a 1 mm thick polyetheretherketone (PEEK with $\varepsilon_r = 3.2$, $\tan\delta = 0.01$) biocompatible material is used to insulate the whole structure from its intending host to eliminate major biocompatibility issue like short-circuiting that may lead to implant rejection. 'PEEK' at a very thin thickness value insulates and significantly lowers power loss as well [13].

3. BIOLOGICAL MODEL

The characterization of antennas in human body remains a challenging task even with the employment of electromagnetic simulation tools. In-body wireless communication devices usually experience high attenuation resulting from the lossy nature of their host surrounding. Though the electric property of a biological body may vary from one body part to another, it is still preferable to design antennas in a characterized model mimicking the real host for its operation [3]. Using the simulation software a simple multilayer body model which depicts a common bio implant host environment shown in Fig. 3 was adopted for study of the proposed IMEA.

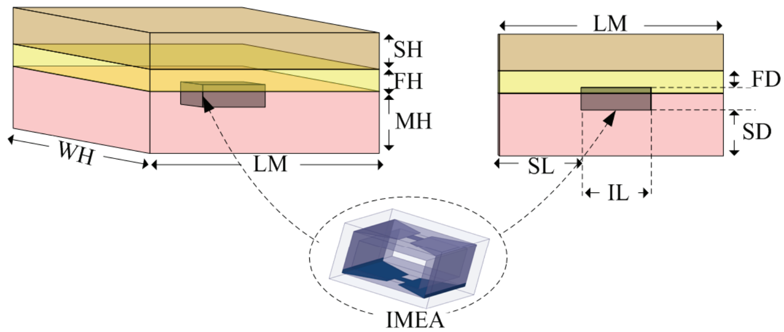

Figure 3. Model of multi-layered biological tissue employed with the proposed IMEA introduced therein: $LM = WH = 24\,\text{mm}$, $SH = 4\,\text{mm}$, $FH = 3\,\text{mm}$, $MH = 10\,\text{mm}$, $SL = 5\,\text{mm}$, $IL = 14\,\text{mm}$, $FD = 1\,\text{mm}$, $SD = 4\,\text{mm}$.

The model consists of a top skin layer, a middle layer of fat, and a bottom layer of muscle tissue. Each of the dielectric values of the frequency of interest was obtained using the reproduced work of Gabriel et al. on dielectric properties of biological tissues [15]. See Table 2 below for details.

Table 2. Dielectric properties of employed tissues at 5.8 GHz.

Tissue	Relative Permittivity (ε_r)	Loss tangent (σ)
Skin	38.624	0.34841
Fat	4.9549	0.18335
Muscle	48.485	0.31715

The IMEA was embedded within the established model in the muscle layer and a little into the subcutaneous fatty layer as shown in Fig. 3. Antennas in such a dynamic electric environment are drastically affected by electric wave properties. The combination of the model body and 'HIK500F' gives the antenna a dielectric loading effect that lowers propagation velocity of the wave and effective wavelength which directly permits creation of electrically smaller antenna.

4. SIMULATION RESULT

HFSS finite element method simulator was used to simulate the proposed IMEA. The return loss (S_{11}) of the antenna in the bio model used is shown in Fig. 4 where it can be seen that the return loss of the proposed antenna is below $-10\,\text{dB}$, starting from 3.5 GHz to beyond 10.6 GHz. It covers an appreciable 100% out of the 110% impedance bandwidth of an entire UWB (3.1–10.6 GHz) for WBAN. As expected from implantable antenna under ideal laboratory experimental situation, this result in bandwidth could differ slightly because tissue conductivity is known to decrease with permittivity between high and low water content tissues [16].

It should be mentioned that the simulated results are based on the dielectric properties of employed tissues at 5.8 GHz (see Table 2). The effects of the parametric changes on the output of the antenna were also monitored. We have redone the simulation based on the dielectric properties of employed tissues at 6.8 GHz and 8.8 GHz. It is found that for both 6.8 GHz and 8.8 GHz cases, the proposed antenna can also cover from 3.5 GHz to beyond 10.6 GHz. Fig. 4 also shows that for the overlapping gain bandwidth from 3.5 GHz to around 7.3 GHz, the proposed IMEA depicts a 70% approximated 2 dBi gain.

Magneto-electric antennas in free space applications are relatively notable for substantial and stable gain [8]. The observed fluctuation and attenuation in gain towards the high frequencies hypothetically are due to absorption effects of the biological material surrounding the IMEA. Notwithstanding the overall throughput in gain within the entire frequency range holds a comparatively higher gain ability than most unidirectional implantable antennas mentioned in this work.

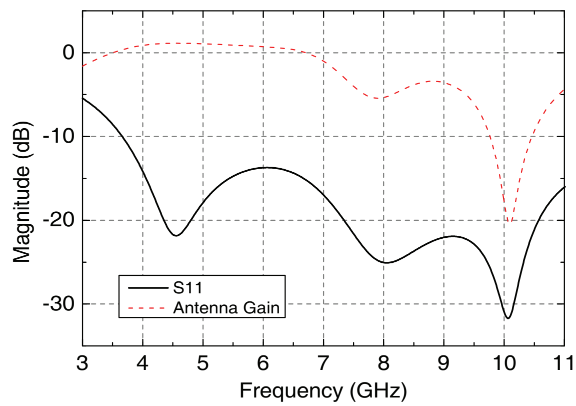

Figure 4. Simulated return loss (S_{11}) and gain plot of proposed IMEA.

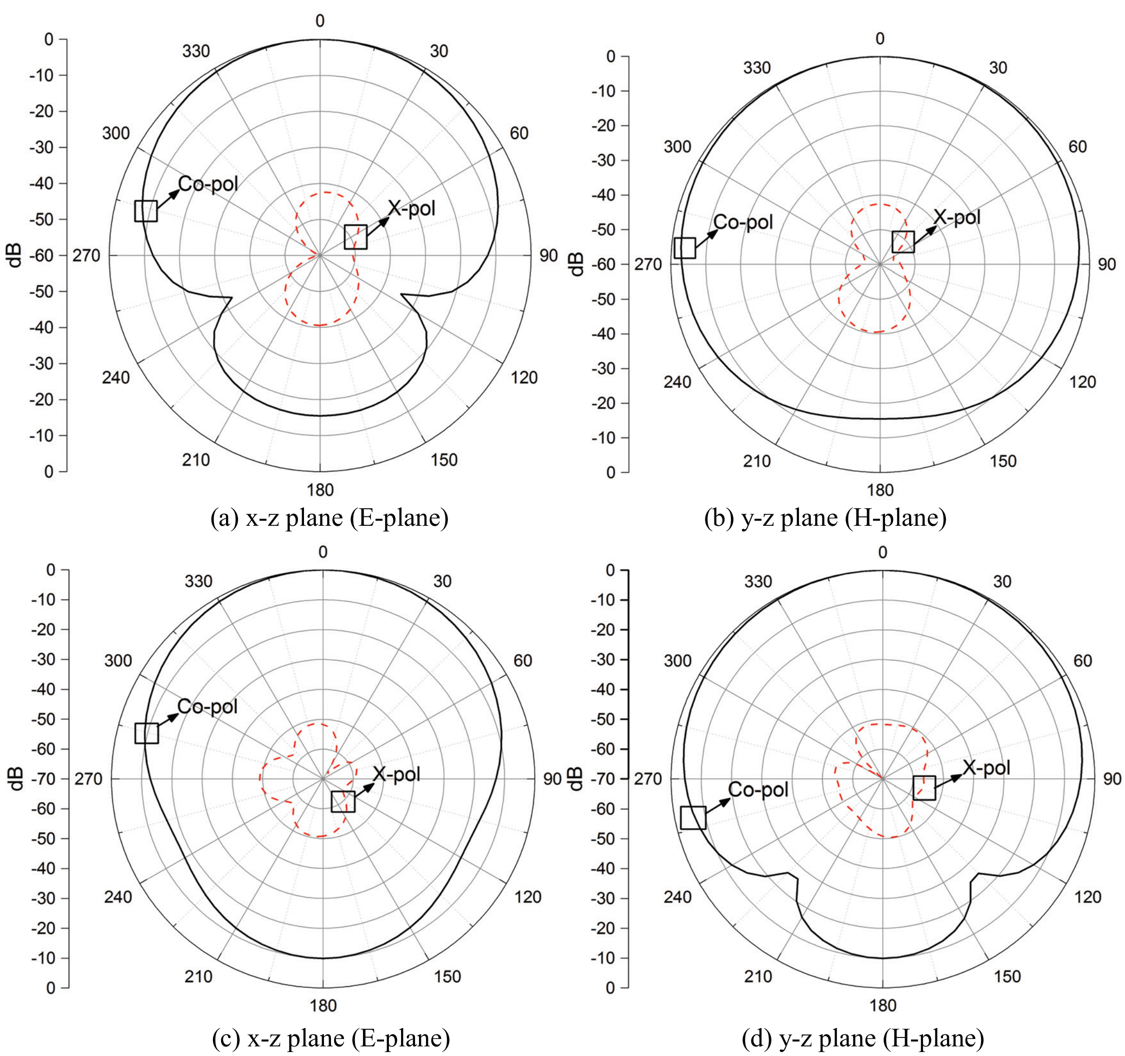

Figure 5. Radiation pattern of the proposed IMEA; (a) 4.8 GHz in x-z plane, (b) 4.8 GHz in y-z plane, (c) 5.8 GHz in x-z plane, (d) 5.8 GHz in y-z plane.

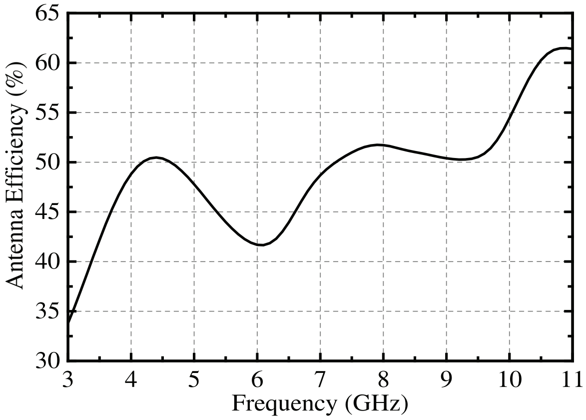

Figure 6. Simulated efficiency of the proposed IMEA across the radiation band.

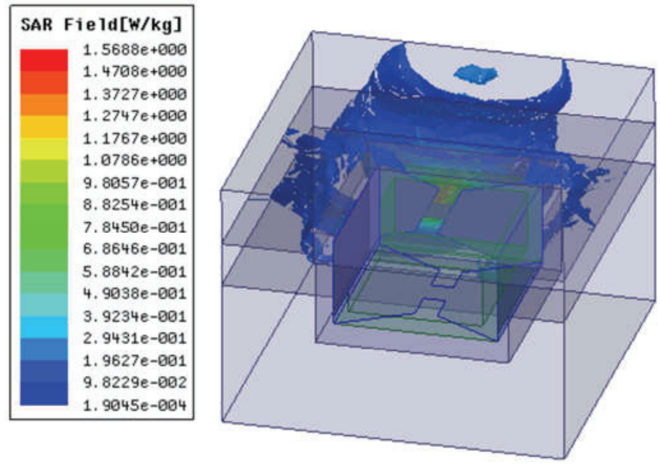

Figure 7. SAR distribution result for proposed IMEA.

The IMEA radiation behavior was recorded at 4.8 GHz and 5.8 GHz, and the respective E-plane cut and H-plane cut radiation pattern plots are shown in Fig. 5 below. A well-defined broadside radiation pattern can be observed in the simulated frequencies to demonstrate its unidirectional characteristics. For both simulated cases, co-polarized fields in the bore sight direction of the radiation are far stronger than the cross-polarized partners with at least 40 dB.

The antenna efficiency is shown in Fig. 6 where the IMEA has efficiency of around 50%. The deduced behavior of the antenna across the acceptable UWB range despite its lossy surrounding presents it as a robust antenna for implants.

The Specific Absorption Rate (SAR) Field simulation result at 5.8 GHz shown in Fig. 7 indicates that for 1 gram of model tissue used with 1 mW input power at the excitation point, the SAR measures 1.569 W/Kg. Absorbing excess electromagnetic power could harm body tissue, hence the need to consider the quantity that is tolerable by the body model [4]. The value obtained satisfies the US maximum 1.6 W/Kg regulated SAR value [17]. Nonetheless, in practice it is not enough to determine the total level of harmfulness of antenna's electromagnetic power to a body by SAR without involving other parameters like the duration of time at which the tissue is exposed to the EM fields etc.

5. CONCLUSION

A unidirectional magneto-electric antenna for medical implant purpose has been designed and modeled for UWB IMDs. It radiates at 50% efficiency with maximum antenna gain of 2 dB. Its return loss ($S_{11} < -10\,\mathrm{dB}$) covers a bandwidth between 3.5 GHz to beyond 10.6 GHz. A cavity space within the antenna volume is engineered for the use in embedding accompanying miniature components for IMDs, thus tackling antenna performance inadequacies caused by heavy miniaturization of antenna size in IMDs. The proposed IMEA with its insulator occupies a final volume of 1456 mm^3, falling within acceptable volumetric range for implantable antennas [4]. This work expands research into the usability of 3D shaped robust antennas for medical implantable purposes. The results obtained are relatively realistic through use of virtual body tissue emulating model for the antenna parameter tuning. The design ideology employed is significant in defining the appropriate electrical features and performance ability of the antenna for real in-body applications.

ACKNOWLEDGMENT

This work was supported by Tianjin Research Program of Application Foundation and Advanced Technology, China and the National Natural Science Foundation of China under Grant 14JCQNJC0110, and 61371043, respectively.

REFERENCES

1. Sumin, Y., K. Kihyun, and N. Sangwook, "Outer-wall loop antenna for ultrawideband capsule endoscope system," *Antennas Wirel. Propag. Lett. IEEE*, Vol. 9, 1135–1138, 2010.
2. Challa, N. R. and S. Raghavan, "Design of multiband implantable loop antenna for in body applications," *2015 Conference on Power, Control, Communication and Computational Technologies for Sustainable Growth (PCCCTSG) Kurnool*, 239–242, Andhra Pradesh, India, 2015.
3. Yazdandoost, K. Y., "UWB antenna for body implanted applications," *2012 42nd European Microwave Conference*, 932–935, Amsterdam, 2012.
4. Abadia, J., F. Merli, J. F. Zurcher, J. R. Mosig, and A. K. Skrivervik, "3D-spiral small antenna design and realization for biomedical telemetry in the MICS band," *Radioengineering*, Vol. 18, No. 4, 359–367, Dec. 2009.
5. Gordillo, A. C. and I. Balasingham, "On directive antennas application to implant — on-body UWB communications," *The 19th Annual Wireless and Optical Communications Conference (WOCC)*, 1–5, Shanghai, 2010.
6. Kumar, S. A. and T. Shanmuganantham, "Implantable CPW fed X-shaped monopole antenna for ISM band," *2013 National Conference on Communications (NCC)*, 2–5, New Delhi, India, 2013.
7. Luk, K. and H. Wong, "A new wideband unidirectional antenna element," *Int. J. Microw. Opt. Technol.*, Vol. 1, No. 1, 35–44, 2006.
8. Ding, C. and K. Luk, "Low-profile magneto-electric dipole antenna," *IEEE Antennas Wirel. Propag. Lett.*, Vol. 15, 1642–1644, Jan. 2016.
9. Ge, L. and K. M. Luk, "A magneto-electric dipole for unidirectional UWB communications," Vol. 61, No. 11, 5762–5765, Jul. 2013.
10. IEEE Computer Society, *IEEE Standard for Local and metropolitan area networks — Part 15.6: Wireless Body Area Networks*, 1–271, 2012.
11. Chávez-Santiago, R., C. García-Pardo, A. Fornes-Leal, A. Vallés-Lluch, I. Balasingham, and N. Cardona, "Ultra wideband propagation for future in-body sensor networks," *2014 IEEE 25th Annual International Symposium on Personal, Indoor, and Mobile Radio Communication (PIMRC)*, 2160–2163, 2014.
12. Zengin, F., E. Akkaya, B. Türetken, and S. E. San, "Design and realization of ultra wide-band implant antenna for biotelemetry systems," *30th URSI General Assembly and Scientific Symposium*, 5–8, URSIGASS, Istanbul, 2011.
13. Kiourti, A. and K. S. Nikita, "A review of implantable patch antennas for biomedical telemetry: Challenges and solutions," *IEEE Antennas and Propagation Magazine*, Vol. 54, No. 3, 210–228, Jun. 2012.
14. Laird, "Eccostock®HIK500F — High temperature, low loss, adjusted dielectric constant stock," [Online], Available: www.lairdtech.com.
15. Italian National Research Council — Institute for Applied Physics, "Dielectric properties of body tissues in the frequency range 10 Hz–100 GHz," *Inrc*, 2012, [Online], Available: http://niremf.ifac.cnr.it/tissprop/.
16. Magill, M. K., G. A. Conway, and W. G. Scanlon, "Robust implantable antenna for in-body communications," *Proceedings of the 2015 Loughborough Antennas Propagation Conference (LAPC)*, 1–4, 2015.
17. Bakogianni, S. and S. Koulouridis, "Design of a novel miniature implantable rectenna for in-body medical devices power support," *2016 10th European Conference on Antennas and Propagation (EuCAP)*, 1–5, Davos, 2016.
18. Morabito, A. F., A. R. Lagana, and T. Isernia, "Isophoric array antennas with a low number of control points: a 'size tapered' solution," *Progress In Electromagnetics Research Letters*, Vol. 36, 121–131, 2013.
19. Morabito, A. F., A. R. Laganà, G. Sorbello, and T. Isernia, "Mask-constrained power synthesis of maximally sparse linear arrays through a compressive-sensing-driven strategy," *Journal of Electromagnetic Waves and Applications*, Vol. 29, No. 10, 1384–1396, 2015.