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Rectenna for Radio Frequency Energy Harvesting: A Review

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Abstract: The emergence of wireless charging technology is also a topic of debate among consumers, fabricators, researchers, and academics. This paper focuses on the literature review of several works on the previous enhancement technique that effect the performance of antenna design with rectifying circuit (rectenna) for energy transfer system technology. Several techniques are applied on this microstrip antenna design work to enhance the antenna performance such as slot, parasitic element, fractal, antenna arrays and others. The parameters that are considered in this work are return loss, resonant frequency with bandwidth, gain and the antenna dimension.

Keywords: Patch antenna, rectenna, radio frequency, energy harvesting

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1. INTRODUCTION

The internet of things (IoT) has recently emerged as one of the most promising wireless technologies. It offers to link gadgets (machines, sensors, and other items) to the internet so that they may be included in current wireless communications networks [1]. Harvesting ambient radio-frequency (RF) energy using rectifying antennas (rectenna) is a possible solution for dealing with the aforementioned issue. Rectennas are used to receive RF signals from their surroundings and transform them into useful signals. Rectennas are significant because they can gather otherwise lost RF energy and transform it into useable DC form [2].

Wi-Fi technology and wireless mobile cellular technology are currently being widely used in urban, suburban, and rural regions alike and are becoming increasingly popular [3]. Their coverage areas are constantly maintained, ensuring that RF wave that is broadcast is always available. It has only been employed as a wireless transmission medium in the communications system up to this point in time. The existence of RF has not been widely exploited until recently. The RF waves, on the other hand, have the potential to be used as an energy generator.

Energy harvesting has developed as a potential solution for operating various low-power electronic devices in recent years [4]. Energy harvesting using radio frequency (RF) is a new technique that will power the next generator of wireless sensor networks (WSNs) without the use of batteries. RF energy harvesting is a crucial green technology that may be utilized to incapacitate a problem area through the employment of progressive wireless broadcasting and communications systems that provide the convenience of free energy.

Energy harvesting, also known as energy scavenging, is a technique in which natural energy is captured and stored in tiny wireless devices. Most wireless applications, remote sensing, Radio Frequency Identification (RFID), and body implants can use the gathered energy [5]. Energy harvesting is the collection of ambient energy from various renewable sources, such as solar [6], wind, and thermal (heat) [7], to power commercial wireless devices. Mechanical energy, vibration [8], movement, sound (acoustic) [9], light [10], electromagnetic energy, natural energy, human body energy, and others are examples of energy harvesting sources.

Radio Frequency Energy Harvesting (RF EH) is a viable solution for delivering power in electronic circuits of wireless sensor networks that demand tiny quantities of energy. The RF energy harvesting technique offers a bright future for low-power products including electronic devices and wireless sensor networks [11].

Environmental circumstances that are less secure and energy demanding have created widespread pollution, necessitating the adoption of alternative energy sources such as natural energy harvesting.

One of the benefits of energy harvesting is increasing the efficiency of devices or systems [12]. Second, to allow for the deployment of new technologies, such as wireless sensor networks, and third, to decreased manufacturing costs, such as computing costs, which can be reduced by harvesting waste heat and using it to power the computer. Extensive study has been done in recent years to develop various components of rectenna system in order to accomplish effective RF-to-DC signal conversion.

Furthermore, due to its limited useful life, the battery's replacement and disposal are inconvenient [13].

Unfortunately, deploying a large number of sensor nodes requires frequent battery replacement, which is both inconvenient and costly [14]. As a result, environmentally friendly technology is required to avoid the disposal of dangerous chemicals and metals included in batteries. The battery is the primary source of products, but its disposal causes significant harmful waste in the environment.

In this work, the examination of the literature will compare the many types of several enhancement techniques utilized in antenna and rectenna applications for RF Energy harvesting one again. It also displays the substrate material utilized for manufacturing, the resonance frequency, antenna gain, return loss obtained and others.

2. BASIC CONCEPTS OF RECTENNA

To transfer wireless power efficiently, a good antenna must be added to the system. The antenna picks up RF signals from the environment, and the rectifier circuit attracts the power from those signals and converts it to DC voltage [15]. An antenna is part of the fundamental RF harvester architecture [16]. Because of their advantages in terms of simplicity, lightweight, low production cost, and ability to quickly integrate into feed networks, microstrip patch antenna (MPAs) are gaining favor for usage in rectenna applications [17].

The receiving antenna is the most significant component in RF energy harvesting because it absorbs ambient RF signals in certain frequency band from a transmitting source through wireless channel and converts them to AC voltages. Typically, the antenna and rectifier circuits in an antenna are designed separately, with the antenna designed first using electromagnetic (EM) simulation and its parameters and then incorporated into a nonlinear circuit simulation tool used to design the rectifier. A rectenna system combines energy harvesting from the environment (receiving module) with energy processing and storage for later use (rectifying sub-module). As a result, the name rectenna comes from the combinations of the terms antenna and rectifier.

Rectennas use rectifier circuits to correct the AC current created in the antenna by microwaves. Harmonies of the fundamental frequency are generated by nonlinear components in rectifying circuits, such as diodes. The conversion efficiency of the receiver is critical for radio frequency energy transmission, not only for minimizing sending power but also for enabling energy transfer over long and variable distances. Figure 1 shows an effective antenna network and a circuit capable of converting RF signals to DC voltage are shown in this block diagram.

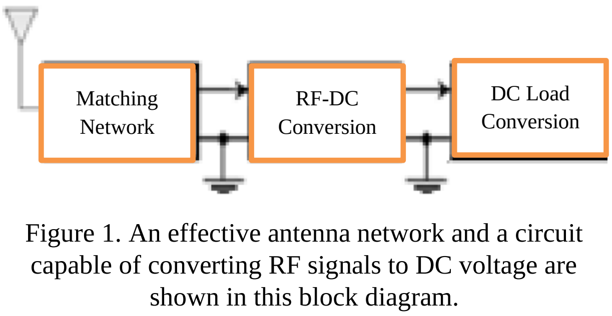


Figure 1. An effective antenna network and a circuit capable of converting RF signals to DC voltage are shown in this block diagram.

A harvesting antenna must meet particular characteristics such as high gain, omni-directional radiation, and compact construction in order to gather the most amount of RF energy from the environment. In energy harvesting, radio frequency waves are the primary source of ambient energy in both outdoor and interior settings.

The accuracy of the matching, the efficiency of the antenna, and the power efficiency of the voltage rectifier that transforms the received RF signals to DC voltage all contribute to the efficiency of and RF energy harvesting system.

3. RECTENNA USING SEVERAL TECHNIQUES

This energy transfer activity currently has a low amount of acquired RF source energy, which is affecting the device performance. Several techniques are used to enhance the performance of the rectenna. Several techniques are used to improve the antenna performance in this microstrip antenna design effort, including slot, parasitic element, fractal, antenna arrays, and others.

Jung in his research [17] presented a new RF energy harvesting antenna design that included a primary radiator and a parasitic radiator. This parasitic radiator had a two-turn loop construction that received most of the RF power emitted outside of the primary radiator's 3-dB beam width. Because DC power may be produced from dissipated RF energy, this parasitic radiator had no impact on the electrical performance of the primary radiator. Finally, the gain was 8.35 dBi, which was almost identical to the printed dipole's performance but without the parasitic radiator.

In other work, Maher [18] has proposed a broadband planar antenna with a semi-circular patch that serves as a radiator and four stubs in the bottom half for RF energy collecting. The antenna had a high gain and excellent radiation pattern, with a bandwidth of 2.1 to 7 GHz with resonance frequencies of 2.4, 3 GHz, 4.1 GHz and 5.8 GHz, which were suitable for RF energy harvesting.

Shen [19], in his work focused on the GSM-900, GSM-1800, and UMTS-2100 bands are used to define a dual-port triple-band L-probe microstrip patch rectenna design for ambient RF energy harvesting. By stacking two single-port patch antennas back-to-back, compact dual-port L-probe patch antennas is created. Each port can individually harvest RF signal from a half-space with gain higher than 7 dBi, and the antenna can collect RF energy from almost all directions when both ports are in a DC combining mode.

3.1 Slot

Slot is one of the techniques that potentially improve the antenna performance. The filling of slots on the conducting patch element might create meandering of the excited patch surface current channels, resulting in a lower resonant frequency and hence a smaller antenna. Slots can be used to increase bandwidth, miniaturize devices, and add multiband capabilities [20]. Besides that, the gain can be generated by loading on certain slot on the conducting patch element of an antenna, resulting in a smaller antenna with increased bandwidth. Table 1 and Figure 2 represent the previous work on antenna design for energy harvesting with effect of the slot technique.

Table 1. Summary of on antenna design for energy harvesting with effect of the slot technique.

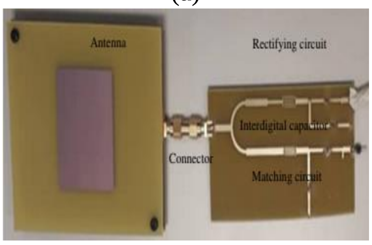
Author	Application	Technique	Resonant frequency	Remark
Amjad [21]	WLAN	rectangular slot	2.4 GHz, 5.8 GHz	gain 5.5 dBi and 6.3 dBi
Hassan [22]	Cellular network, WLAN	right-angle triangular aperture slot	1.8 GHz and 2.4 GHz	Gain 6.31 dBi and 7.82 dBi
Sharma [23]	WiMAX	integrated circular slot	2.65 GHz	bandwidth of 200MHz

Amjad [21] unveiled a dual-band WLAN microstrip patch antenna with a rectangular slot that can operate at 2.4 GHz and 5.8 GHz with efficiency of 45%. At 2.4 GHz, the results reveal a reflection coefficient of nearly -22 dB and a maximum gain of 5.5 dBi. At 5.8 GHz, the reflection coefficient is -48 dB, and the highest gain is 6.3 dBi.

In his research, Hassan [22] developed a dual band microstrip patch antenna with a right-angle triangular aperture slot for energy transfer. At dual frequencies of 1.8 GHz and 2.4 GHz, respectively, this proposed dual-band antenna has achieved the intended return loss of 44.707 dB and 32.163 dB. This proposed antenna design has a low cost of manufacture and high gain of 6.31 dBi and 7.82 dBi for dual band operating frequencies.

Sharma [23] describes a wideband microstrip patch antenna with an incorporated circular slot for RF energy harvesting at 2.65 GHz, which is the WiMAX frequency. Circular slots are incorporated into a square patch of the proposed antenna, which aids increasing the antenna's bandwidth.

(a)



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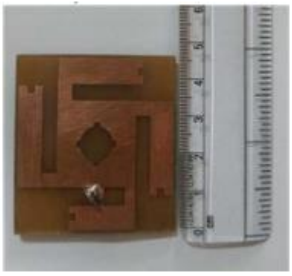


(c)

Figure 2. Antenna design for energy harvesting with effect of the slot technique.

3.2 Parasitic Element / Parasitic Array

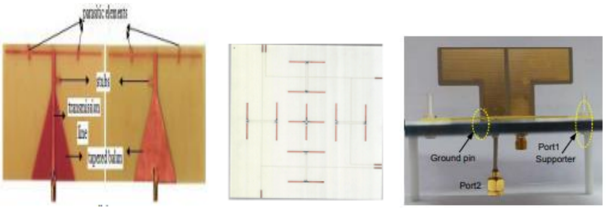
A parasitic element is one that feeds on the feeding of others. It does not have a feed of its own. As a result, with this form of array, we use elements that indirectly increase the radiation. These parasitic parts are not related to the feeding any way. By modifying the value of reactance installed on each parasitic element the function of the parasitic element can be modified [24]. Aside from that, the parasitic element can boost antenna gain and front-to-back (F/B) ratio. Previously, Albishti [25] in his paper write that a linear dipole with two parasitic elements by is designed and constructed for a 0.8 GHz and 2.4 GHz application with the capacity to eliminate the harmonic of higher order modes.

Table 2. Summary of antenna design for energy harvesting with effect of the parasitic element / parasitic array technique.

Author	Application	Technique	Resonant frequency	Remarks
Albishti [25]	Wireless Application	Parasitic Elements and a Stub	0.8 GHz and 2.4 GHz.	Unwanted Harmonic at 4.0 GHz
Lee [26]	WLAN	Steerable parasitic array	2.4 GHz	200 MHz bandwidth
Moon [27]	Wireless Transceivers	parasitic radiators	2.15 GHz	Harvest −2.0 dBm when input power is 9.25 dBm.

In the other statement, Lee [25] introduced a dual-control circuit for feeding and rectify loadings is suggested for planar beam steerable array antenna system. This antenna is 72 x 152 mm2 in size. His antenna successfully operates at 2.4 GHz with bandwidth of 200 MHz.

Besides that, Moon [26] introduces the primary and parasitic radiators, two elements of a unique energy harvesting antenna for various wireless transceivers. It has a gain of 8.50 dBi and operates at 2.15 GHz. This antenna is designed to collect RF energy from the primary radiator of a variety of wireless transmitters (or transceivers) used in the Korean WCDMA service utilizing a parasitic radiator.



(a) (b) (c)

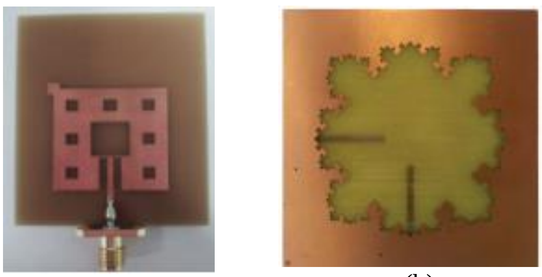
Figure. 3. Antenna design for energy harvesting with effect of the parasitic element / parasitic array technique.

3.3 Fractal Geometry

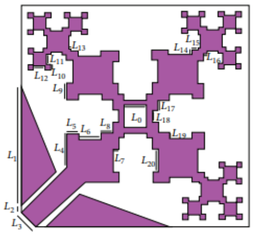
Fractal geometry has recently been offered as a means for miniaturizing traditional multiband antenna systems. Fractals are a type of geometrical shape that is made up of numerous iterations of a single basic shape. Sierpinski gaskets, Sierpinski carpets, Minkowski loops, and Koch Islands [28] are only a few examples of fractal patch antenna. Shrestha [29] presented a fractal-based compact dual band patch antenna for RF energy harvesting that operates at 2.45 and 5.8 GHz in his research and operates the return of 21.2 dB and 18.22 dB, respectively. The structure produced in his work is a basic fractal structure Sierpinski carpet etched onto a rectangular patch antenna with a rectangle geometry as the fractal literation generator.

Table 3. Summary of on antenna design for energy harvesting with effect of the Fractal geometry technique.

Author	Application	Technique	Resonant frequency	Remarks
Shrestha [29]	WLAN	Sierpinski carpets	2.45 and 5.8 GHz	return losses of 21.2 dB and 18.22 dB
Mahfoudi [30]	rectenna application	fractal slotted ground plane	Between 1.5 and 2.65 GHz	y bandwidth of 1.15 GHz
Manafi [31]	WLAN	Minkowski fractal	2.4 GHz and 5.8 GHz	received power at 25 cm = 0.4, 0.04 mW



(a) (b)



(c)

Fig. 4. Antenna design for energy harvesting with effect of the fractal geometry technique.

Mahfoudi [30] in his paper had been described a 70 % efficient wideband fractal slotted ground plane antenna with dual-linear polarization that can operate between 1.5 and 2.65 GHz. The simple concept of his design effect to be shrunk and readily extended into an array that can receive higher power to improve performance. This fractal slot geometry provided is an iterative model of a traditional square patch.

For wireless energy harvesting by deep brain stimulation (DBS) devices, Manafi [31] introduced a compact planar modified Minkowski fractal antenna operating at 2.4 GHz and 5.8 GHz. The suggested antenna has a gain of 3.2 dBi at 2.4 GHz and 4.7 dBi at 5.8 GHz, and its averaged SAR in human body tissue is considerably within legally permissible limit in both frequency bands.

3. CONCLUSION

The findings of this study suggest that RF applications including several techniques used such slot, parasitic element and fractal geometry may be successfully used as energy harvesting devices in a variety of designs, including antennas and rectenna (antenna with rectifier).

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REFERENCES

[1] A. Trikolikar and S. Lahudkar, "A Review on Design of Compact Rectenna for RF Energy Harvesting," 2020 International Conference on Electronics and Sustainable Communication Systems (ICESC), pp. 651-654, 2020.

[2] S. S. Alja'afreh, C. Song, Y. Huang, L. Xing and Q. Xu, "A Dual-Port, Dual-Polarized and Wideband Slot Rectenna for Ambient RF Energy Harvesting," 2020 14th European Conference on Antennas and Propagation (EuCAP), Copenhagen, Denmark, pp. 1-5, 2020.

[3] H. Elahi, K. Munir, M. Eugeni, S. Atek, P. Gaudenzi, "Energy Harvesting towards Self-Powered IoT Devices," Energies, vol. 13, pp. 1-31, 2020.

[4] J. Davidson, C. Mo, Recent Advances in Energy Harvesting Technologies for Structural Health Monitoring Applications, "Tuning analysis for the high-Q class-E power amplifier," Smart Materials Research, vol. 2014, pp. 1-14, 2014.
[5] H. H. Ibrahim, M. S. J. Singh, S. S. Al-Bawri, & M. T Islam, Synthesis, Characterization and Development of Energy Harvesting Techniques Incorporated with Antennas: A Review Study. Sensors, 20 (10), 2772, 2020.
[6] H. Sharma, A. Haque and Z. A. Jaffery, "An Efficient Solar Energy Harvesting System for Wireless Sensor Nodes," 2018 2nd IEEE International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES), pp. 461-464, 2018.
[7] N. Kumari and M. Rokotondrabe, "Thermal network modelling of hybrid piezo-pyro transducer for application in energy harvesting," 2019 IEEE 5th International Conference for Convergence in Technology (I2CT), pp. 1-4, 2019.
[8] L. Chunlong, H. Hui, L. Yun, L. Hongjing, Y. Kuan and L. Kewen, "Research on Transmission Line Vibration Condition Monitoring System and Energy Management Scheme Based on Micro Energy Harvesting," 2021 4th International Conference on Energy, Electrical and Power Engineering (CEEPE), pp. 255-259, 2021.
[9] L. H. Fang, R. b. A. Rahim, M. I. F. Romli, M. Z. Zakariya, J. B. A. M. Jobran and N. B. Kimpol, "Piezoelectric Array Configuration Technique into Enhance Power Catchment for Sound Energy Harvester System," 2020 International Conference on Sustainable Energy Engineering and Application (ICSEEA), pp. 1-9, 2020.
[10] M. S. Costa, L. T. Manera and H. S. Moreira, "Study of the light energy harvesting capacity in indoor environments," 2019 4th International Symposium on Instrumentation Systems, Circuits and Transducers (INSCIT), pp. 1-4, 2019.
[11] Y. Luo, L. Pu, G. Wang, Y. Zhao, "RF Energy Harvesting Wireless Communications: RF Environment, Device Hardware and Practical Issues," Sensors, vol. 19, no. 13, pp. 3010, 2019.
[12] C. Covaci, A. Gontean, "Piezoelectric Energy Harvesting Solutions: A Review," Piezoelectric Energy Harvesting Solutions: A Review. Sensors, vol. 20, no. 12, 3512, 2020.
[13] F. Mazunga, & A. Nechibvute, "Ultra-low power techniques in energy harvesting wireless sensor networks: Recent advances and issues," Scientific African, vol. 11, e00720, 2021.
[14] F. Engmann, F. A. Katsriku, J.-D. Abdulai, K. S. Adu-Manu, & F. K. Banaseka, "Prolonging the Lifetime of Wireless Sensor Networks: A Review of Current Techniques," Wireless Communications and Mobile Computing 2018, 1–23, 2018.
[15] L. G. Tran, H. K. Cha, W. T. Park, "RF power harvesting: a review on designing methodologies and applications," Micro and Nano Systems Letters, vol. 5, pp. 1-16, 2017.
[16] M. Mrnka, P. Vasina, M. Kufa, V. Hebelka, and Z. Raida, "The RF Energy Harvesting Antennas Operating in Commercially Deployed Frequency Bands: A Comparative Study," International Journal of Antennas and Propagation, pp. 1-11, 2016.
[17] S. Shrestha, S. R Lee, & D.-Y. Choi, "A New Fractal-Based Miniaturized Dual Band Patch Antenna for RF Energy Harvesting," International Journal of Antennas and Propagation, vol. 2014, pp. 1–9, 2014.
[18] Y.-B Jung, "Energy Harvesting Antenna for Various Communication Transceivers," 2014 IEEE MTT-S International Microwave Workshop Series on RF and Wireless Technologies for Biomedical and Healthcare Applications (IMWS-Bio2014), pp. 1-3, 2014.
[19] R. Maher E. Tammam, A. I. Galal, H. F. Hamed, "Design of a Broadband Planar Antenna for RF Energy Harvesting," 2016 International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT), pp. 1808 – 1810, 2016.
[20] S. Shen, C. Chiu and R. D. Murch, "A Dual-Port Triple-Band L-Probe Microstrip Patch Rectenna for Ambient RF Energy Harvesting," IEEE Antennas and Wireless Propagation Letters, vol. 16, pp. 3071-3074, 2017.
[21] R. Parikh and B. Singh, "Effects of Slots On Resonant Frequencies of a Microstrip Patch Antenna," 2018 Fourth International Conference on Computing Communication Control and Automation (ICCUBEA), pp. 1-5, 2018.
[22] O. Amjad, S. W. Munir, Ş. T. İmeci, and A.Ö. Ercan, "Design and Implementation of Dual Band Microstrip Patch Antenna for WLAN Energy Harvesting System," ACES Journal, Vol. 33, No. 7, 2018.
[23] N. Hassan, Z. Zakaria, W. Y. Sam, I. N. M. Hanapiah, A. N. Mohamad, A. F. Roslan, B. H. Ahmad, M. K. Ismail, M. Z. A. Abd Aziz, "Design of dual band microstrip patch antenna with right-angle triangular aperture slot for energy transfer application," RF and Microwave Computer Aided Engineering, vol 29, issue 1, pp. 1-11, 2019.
[24] H. Sharma, L. Shrivastava, "A Wideband Microstrip Patch Antenna with Integrated Circular Slot for RF Energy Harvesting," International Journal of Innovative Technology and Exploring Engineering (IJITEE), Vol. 8 Issue 11, pp. 778-781, 2019.
[25] M. Muramatsu, H. Nishiyama, H. Koizumi, "Effects of parasitic circuit elements in RF energy harvesting circuit." 2012 IEEE Third International Conference on Sustainable Energy Technologies (ICSET), pp. 18-22, 2012.
[26] A. B. Albishti, S A Hamzah, S M Shah, K N Ramli, N Abdullah, M S Zainal, L Audah, A Ubin, F C Seman, A K Anuar, S Z Sapuan, R Atan, M Esa and N N N Abd Malik, "Harmonic Suppression Dual-band Dipole Antenna with Parasitic Elements and a Stub," TELKOMNIKA, Vol.16, No.5, pp. 1918-1922, 2018.
[27] S.-J. Lee, W.-S. Yoon and S.-M. Han, "Planar Beam Steerable Parasitic Array Antenna System Design Based on the Yagi-Uda Design Method," International Journal of Antennas and Propagation, Vol. 2019, pp. 9, 2019.
[28] J. I. Moon, Y. B. Jung, "Novel Energy Harvesting Antenna Design Using a Parasitic Radiator,"

Progress in Electromagnetics Research, vol. 142, pp. 545-557, 2013.
[29] S. B. Kumar, P. K. Singhal, "RF energy harvesting using Sierpinski's gasket fractal antenna with EBG geometry," Journal of Information and Optimization Sciences, vol. 41, issue 1, 2020.
[30] S. Shrestha, S.-K. Noh, and D.-Y. Choi, "Comparative Study of Antenna Designs for RF Energy Harvesting," International Journal of Antennas and Propagation, vol. 2013, pp. 1-10, 2013.
[31] H. Mahfoudi, M. Tellache, & H. Takhedmit, "A wideband fractal rectana for energy harvesting applications." 2016 10th European Conference on Antennas and Propagation (EuCAP), pp. 1-4, 2016.
[32] S. Manafi, H. Deng, "Design of a Small Modified Minkowski Fractal Antenna for Passive Deep Brain Stimulation Implants," International Journal of Antennas and Propagation, vol. 2014, pp. 1-9, 2014.