

Rf Energy Harvesting: Advances and Challenges in Antenna Design

Shashikant V. Golande¹, Dr. Arun Kumar Yadav², Chaitrali B. Yadav³,
Abhijit R. Bendre⁴

¹Department of Electrical Engineering, Mahakaushal University, Jabalpur, MP

²Department of Electrical Engineering, Mahakaushal University, Jabalpur, MP

³Department of Electrical Engineering, TSSM' SBSCOER, Narhe, Pune

⁴Department of Electrical Engineering, NGI, FOE, Pune

ABSTRACT

Wireless sensor networks (WSNs) have drawn a lot of attention lately because of their numerous applications in a variety of disciplines, including industrial automation, healthcare, environmental monitoring, and smart cities. However, sensor nodes' limited energy resources significantly impair WSNs' long-term performance and sustainability. RF energy harvesting has shown to be a workable solution to this issue by allowing sensor nodes to scavenge energy from nearby RF sources. Regarding RF energy harvesting techniques in WSNs, this paper provides a comprehensive review of the designs, concepts, and performance evaluation of a number of RF energy harvesting systems. Modern RF energy harvesting circuits, antenna designs, and power management techniques are discussed.

Keywords: Wireless sensor networks (WSNs), RF energy harvesting, RF sources, and antenna designs.

I. INTRODUCTION

Wireless Sensor Network shaver revolutionized our capacity to observe an interact with the physical world WSNs. These networks are made up of a large number of small, low-cost, and low-power sensor nodes strategically positioned to wirelessly collect and send data.

The energy constraint issue in WSNs has been addressed by a variety of energy gathering techniques. Sensor nodes can obtain energy from ambient sources such as solar, thermal, vibration, and radio frequency thanks to these techniques.

Due to the widespread usage of radio frequency (RF) waves in the environment, including in broadcast radio and television, Wi-Fi, and cellular networks, RF energy harvesting has received particular attention among these techniques. This improves the sensor nodes' lifespan and reduces the need for battery replacement or recharging, increasing WSNs' cost and sustainability efficiency.

This study provides a comprehensive analysis of RF energy harvesting techniques in WSNs. The principles of RF energy harvesting go into great detail into the sources of RF energy, the characteristics of propagation, and the harvesting methods.

II. LITERATUREREVIEW

The link between the two was established in 1819 when Hans Christian Oersted discovered that electric currents generate magnetic fields. This discovery opened up new possibilities for modern technologies and electromagnetism. Oersted's study had a significant impact on two important theoretical advancements: Ampere's Law and Faraday's Law.

With the publication of Maxwell's Equations in 1864, James Clerk Maxwell developed these concepts and greatly advanced our understanding of the interactions between electric and magnetic fields. His research from 1873 highlighted the connections between these forces, opening the door for later developments in technology such as wireless power transfer (WPT). In 1888, Heinrich Hertz provided the first empirical proof of electromagnetic waves by using advanced technology to transmit electricity over short distances. In the study of electromagnetic waves, this marked a significant turning point. Nikola Tesla was inspired by Hertz and developed alternating current (AC) technologies that revolutionized the distribution of power. Tesla's efforts, especially his solutions for coil overheating,

laid the groundwork for modern WPT technology. His famous 1899 Tesla coil experiment demonstrated the viability of wireless energy transfer.

Tesla's latter experiments, conducted between 1899 and 1901, aimed to wirelessly transmit electrical energy over long distances. However, these efforts were constrained by the state of the technology at the time. A major breakthrough in WPT was made in 1964 when W.C. Brown successfully powered a helicopter using microwaves. Later in 1975, the JPL Goldstone Facility.

III. HARVESTING RADIOFREQUENCY ENERGY IN BROADBAND AND MULTIBAND

There are several different frequency bands accessible for ambient radio frequency energy, including Wi-Fi, 3G/4G, GSM, and TV broadcast channels. In order to optimize the amount of energy, multiband and broadband radio frequency harvesting techniques seek to simultaneously collect energy from many frequency bands.

Relays and several antennas tuned to different frequency bands are used in multiband RF energy harvesting systems. Using a power combiner; the rectifier outputs are combined to generate a single DC output. Two bands make up the RF energy gathering apparatus shown in Figure 3.1.

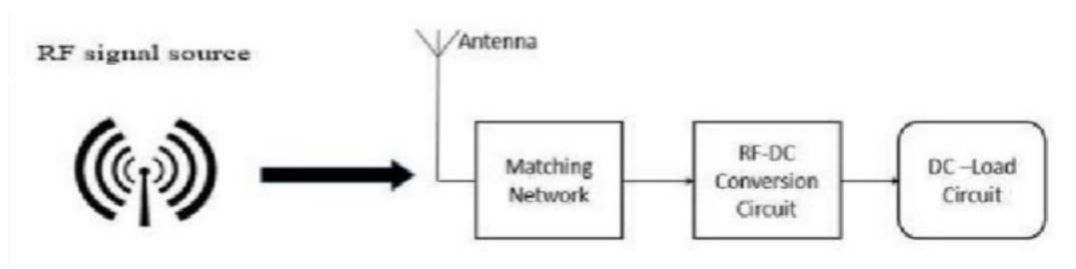


Fig.3.1. Block diagram of a broadband RF energy harvesting system

IV. METHODOLOGY

Optimizing rectenna arrays to capture radio frequency energy from various sources is the main goal of this study. The following elements make up the suggested array design:

1. Antenna elements: Broadband antennas that can pick up radio frequency energy from a variety of frequency bands.
2. Rectification circuits: Low input power level-optimized, high-efficiency rectifiers.
3. Impedance matching networks: Adaptive networks that guarantee the best possible power transfer between rectifiers and antenna elements.
4. DC combining network: An effective circuit for merging several rectenna elements' outputs.

The following antenna design optimization strategies are used to optimize RF energy acquisition from various sources:

1. Multi-band antenna design: Using several resonant structures to span several relevant frequency bands.
2. Wideband antenna design: To capture energy across a large frequency range, broadband antenna elements are used.
3. Diversity in polarization: Using antennas with various polarizations to harvest energy from sources with varied orientations.

To maximize energy harvesting performance, array geometry must be optimized. We look into the following areas:

1. Element spacing: Maximizing energy capture and minimizing mutual coupling by optimizing the distance between antenna elements.
2. Array configuration: Determining the best arrangement for many source scenarios by investigating several array layouts, such as linear, planar, and 3D configurations.
3. Element orientation: Examining how each element's orientation affects the performance of the array as a whole.

We concentrate on the following rectification circuit design elements in order to increase the rectenna array's conversion efficiency:

1. Schottky diode selection: Assessing various Schottky diodes to determine which one is best for low-power radio frequency energy harvesting.
2. Configuration of a voltage doubler: Putting voltage doublers circuits into practice and refining them to boost output voltage and increase efficiency.

3. Adaptive threshold voltage compensation: Creating circuits that dynamically modify the threshold voltage of the rectifier in response to input power levels.

Maximizing power transfer requires effective impedance matching between rectification circuits and antenna elements. We look into the following strategies:

1. Networks that match broadband: Creating matching networks that can sustain high impedance matching over a broad frequency range.
2. Matching networks that adapt: Putting in place reconfigurable matching networks that can adapt to different frequencies and input power levels.
3. Matching in several stages: Investigating the application of multi-stage matching networks to enhance overall system performance.

The following simulation and optimization techniques are used to assess and improve the rectenna array design:

1. HFSS (High-Frequency Structure Simulator): An electromagnetic simulation program for modeling antennas and arrays.
2. Advanced Design System (ADS): A circuit simulation program for designing rectification circuits and impedance matching networks.
3. Optimization algorithms: Particle swarm and genetic algorithms for circuit parameter and array geometry optimization.

The following configuration is used for experimental measurements in order to verify the simulation results and evaluate the optimized rectenna array's performance:

1. RF signal generators: A way to simulate various RF energy sources using multiple sources.
2. Spectrum analyzer: Used to determine the strength of incident radio frequency signals.
3. Power meter: Used to measure the rectenna array's DC output power.
4. Anechoic chamber: For controlled measurements and to reduce interference from the surrounding environment.

CONCLUSION

The several methods for collecting radio frequency (RF) energy for wireless sensor networks (WSNs) were thoroughly examined in this article. This section explored the fundamentals of radio frequency (RF) energy harvesting, including the sources of RF energy, propagation characteristics, and harvesting techniques. We also discussed radio frequency (RF) energy harvesting device topologies and design difficulties, with a particular emphasis on the circuits, antenna designs, and power management algorithms of these systems. We wrapped up by discussing the difficulties facing this discipline and potential avenues for further research. These include creating network algorithms and protocols, cutting down on interference, boosting productivity, and harnessing hybrid energy. The development of novel structures, techniques, and algorithms for radio frequency energy harvesting should be the main goal of future research.

REFERENCES

- [1] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, "Wireless sensor networks: A survey," *Computer Networks*, vol. 38, no. 4, pp. 393–422, 2002.
- [2] S. Sudevalayam and P. Kulkarni, "Energy harvesting sensor nodes: Survey and implications," *IEEE Communications Surveys & Tutorials*, vol. 13, no. 3, pp. 443–461, 2011.
- [3] S. Ulukus, A. Yener, E. Erkip, O. Simeone, M. Zorzi, P. Grover, and K. Huang, "Energy harvesting wireless communications: A review of recent advances," *IEEE Journal on Selected Areas in Communications*, vol. 33, no. 3, pp. 360–381, 2015.
- [4] X. Lu, P. Wang, D. Niyato, D. I. Kim, and Z. Han, "Wireless networks with RF energy harvesting: A contemporary survey," *IEEE Communications Surveys & Tutorials*, vol. 17, no. 2, pp. 757–789, 2015.
- [5] S. Bi, C. K. Ho, and R. Zhang, "Wireless powered communication: Opportunities and challenges," *IEEE Communications Magazine*, vol. 53, no. 4, pp. 117–125, 2015.
- [6] H. J. Visser and R. J. M. Vullers, "RF energy harvesting and transport for wireless sensor network applications: Principles and requirements," *Proceedings of the IEEE*, vol. 101, no. 6, pp. 1410–1423, 2013.
- [7] S. Kim, R. Vyas, J. Bito, K. Niotaki, A. Collado, A. Georgiadis, and M. M. Tentzeris, "Ambient RF energy-harvesting technologies for self-sustainable standalone wireless sensor platforms," *Proceedings of the IEEE*, vol. 102, no. 11, pp. 1649–1666, 2014.
- [8] T. S. Rappaport, *Wireless Communications: Principles and Practice*, 2nd ed. Upper Saddle River, NJ: Prentice Hall, 2002.
- [9] C. R. Valenta and G. D. Durgin, "Harvesting wireless power: Survey of energy-harvester conversion efficiency in far-field wireless power transfer systems," *IEEE Microwave Magazine*, vol. 15, no. 4, pp. 108–120, 2014.

- [10] X. Lu, P. Wang, D. Niyato, D. I. Kim, and Z. Han, "Wireless charging technologies: Fundamentals, standards, and network applications," *IEEE Communications Surveys & Tutorials*, vol. 18, no. 2, pp. 1413–1452, 2016.
- [11] J. A. Hagerty, F. B. Helmbrecht, W. H. McCalpin, R. Zane, and Z. B. Popovic, "Recycling ambient microwave energy with broad-band rectenna arrays," *IEEE Transactions on Microwave Theory and Techniques*, vol. 52, no. 3, pp. 1014–1024, 2004.
- [12] Y.-H. Suh and K. Chang, "A high-efficiency dual-frequency rectenna for 2.45 and 5.8 GHz wireless power transmission," *IEEE Transactions on Microwave Theory and Techniques*, vol. 50, no. 7, pp. 1784–1789, 2002.
- [13] U. Olgun, C.-C. Chen, and J. L. Volakis, "Investigation of rectenna array configurations for enhanced RF power harvesting," *IEEE Antennas and Wireless Propagation Letters*, vol. 10, pp. 262–265, 2011.
- [14] E. Khansalee, Y. Zhao, E. Leelarasmee, and K. Nuanyai, "A dual-band rectifier for RF energy harvesting systems," in *Proc. IEEE TENCON*, 2014, pp. 1–4.
- [15] H. Sun, Y.-X. Guo, M. He, and Z. Zhong, "A dual-band rectenna using broadband Yagi antenna array for ambient RF power harvesting," *IEEE Antennas and Wireless Propagation Letters*, vol. 12, pp. 918–921, 2013.
- [16] J. Zbitou, M. Latrach, and S. Toutain, "Hybrid rectenna and monolithic integrated zero-bias microwave rectifier," *IEEE Transactions on Microwave Theory and Techniques*, vol. 54, no. 1, pp. 147–152, 2006.
- [17] J. A. Hagerty and Z. B. Popovic, "An experimental and theoretical characterization of a broadband arbitrarily-polarized rectenna array," in *Proc. IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 3, 2001, pp. 1855–1858.
- [18] H. Nishimoto, Y. Kawahara, and T. Asami, "Prototype implementation of ambient RF energy harvesting wireless sensor networks," in *Proc. IEEE Sensors*, 2010, pp. 1282–1287.
- [19] S. Bandyopadhyay and A. P. Chandrakasan, "Platform architecture for solar, thermal, and vibration energy combining with MPPT and single inductor," *IEEE Journal of Solid-State Circuit*