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Low-Power RF Energy Harvesting Antennas

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Abstract: A nascent technology termed RF energy harvesting have the potential to transform the powering of systems and devices. It enables the conversion of ambient electromagnetic radiation into electrical energy suitable for powering wireless sensor networks, IoT devices, and mobile devices. This technology has several advantages, including the capability to function in distant or inaccessible areas and the elimination of battery requirements. Recently, much research has been conducted to enhance the efficiency and range of RF energy harvesting systems. Optimizing captured energy while reducing losses from impedance mismatches and other variables is a primary challenge in this domain. Impedance matching, antenna design, and rectification circuits are among the techniques researchers have devised to tackle this problem. Impedance matching is a crucial element of RF energy harvesting systems since it guarantees the optimal transmission of power from the source to the load. The approach achieves maximum power transmission by aligning the antenna's impedance with that of the rectifier circuit. The antenna's alternating current signal is transformed into direct current power suitable for powering electronic equipment using rectification circuits. Various topologies, including voltage doubler, half-wave, and full-wave rectifiers, may be used in the construction of these circuits. The application requirements and the frequency of the incoming RF signal dictate the selection of the rectifier circuit. RF energy harvesting has several potential uses, including powering distant sensor networks, smart homes, medical devices, and wearable technology, among others. It facilitates the installation of devices and systems in distant or inaccessible areas and offers a sustainable and cost-efficient alternative to conventional battery-operated systems. In conclusion, RF energy harvesting is an intriguing technology that is swiftly advancing and with the potential to transform the powering of systems and devices. Despite significant advancements in this domain, more research is essential to enhance the efficiency of energy harvesting, expand the scope of applications, and address the outstanding technical challenges.

Keywords: *Harvesting, Optimizing, Despite, transformed.*

INTRODUCTION

The conversion of energy from the electromagnetic (EM) field into the electrical domain, specifically into voltages and currents, is referred to as radio frequency energy harvesting (RFEH). RFEH is particularly attractive for body area networks since it enables the wireless powering of low-power sensors and equipment across many application situations. Designers and researchers encounter a formidable challenge in harnessing energy from RF sources due to the intersection of electromagnetic fields and electronic circuits. Consequently, the development of a high-performance RF energy harvester requires expertise from both domains.

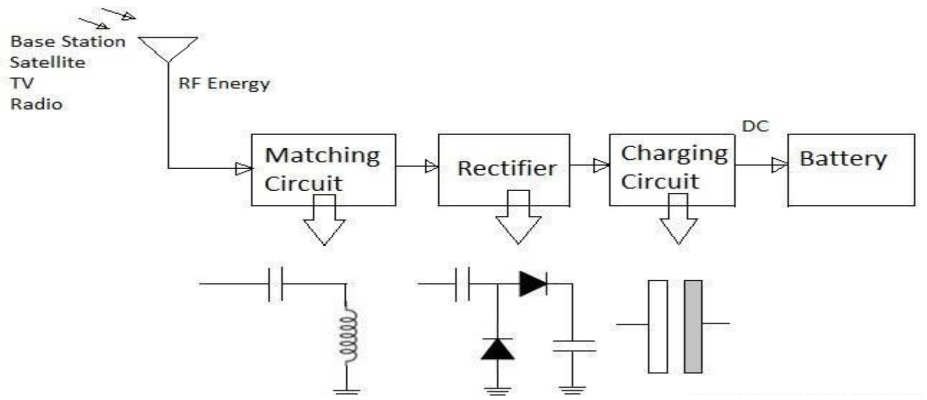

Figure 1: Typical block diagram of RF energy harvesting circuit

This section will introduce many approaches of Radio Frequency Energy. Cutting-edge approaches

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for harvesting. Their benefits and constraints are delineated. The application and historical context are also elucidated. The operation of the RF harvester has been summarized. Microwaves, infrared radiation (IR), visible light, ultraviolet radiation, X-rays, and gamma rays are categorized as frequencies that exceed those of the RF spectrum. In the realm of information and communications technology, "radio frequency" denotes the frequency band used for the transmission and broadcasting of wireless telecommunications signals. Radio frequency is used across several domains. The distinct segments of the frequency spectrum are allocated to diverse technological sectors. This is referred to as the radio spectrum. The VHF (very high frequency) band, including frequencies from 30 to 300 MHz, is used for FM radio, television broadcasts, amateur radio, and related activities. The ultra-high frequency (UHF) band is used by several electronic communication equipment. Mobile phones, Bluetooth, wireless LAN, television, and terrestrial radio all operate inside this domain.

Radiofrequency is generated by oscillating current a certain number of times and then emitting it into space as electromagnetic radio waves from a conductor termed an antenna. By "empty space," we refer to space filled with air instead of solid things, excluding outer space. Conductors transmit and receive RF signals due to the skin effect, whereby RF current adheres to the surface of conductors rather of entering and traversing them like it does with other non-conductive objects. This effect is the fundamental basis of radio technology.

What is Radio Frequency Energy Harvesting?

The conversion of energy from the electromagnetic (EM) field into the electrical domain, specifically into voltages and currents, is referred to as radio frequency energy harvesting (RFEH). RF energy harvesting is the conversion of ambient electromagnetic energy into usable electrical power. Any kind of radio wave, including emissions from television/FM stations, Wi-Fi routers, cellular towers, or radar, may constitute ambient energy. RFEH is particularly attractive for body area networks since it enables the wireless powering of low-power sensors and equipment across many application situations.

Harvesting energy from RF sources is a formidable challenge for designers and researchers, since they operate at the intersection of electromagnetic fields and electrical circuitry. Consequently, expertise from both fields is essential for the design of a high-performance RF energy harvester. The innovative technique of Radio Frequency Energy Harvesting (RFEH) has garnered significant attention in recent years, especially within the IoT industry. RF energy is especially advantageous for wearables, ultra-low-power electronics, Internet of Things edge devices, microcontrollers, and wireless sensor networks, surpassing other energy collecting methods. This fundamental insight elucidates why RF energy harvesting is garnering significant interest as a sustainable power alternative. Radio waves are ubiquitous nowadays, and evasion is impossible. Moreover, RF harvesting is well aligned with the specific needs of IoT devices, which are often tiny, macro-sized, or even nano-sized, and designed to function in very harsh, remote conditions. Sensors are often integrated into health monitors or other industrial applications, rendering them unreachable for battery change or maintenance. Consequently, RF energy harvesting serves as a nearly ideal power source for IoT devices. The inherent nature of RF energy as almost free energy is another reason for its superior performance compared to battery-based power options. Despite the affordability or durability of batteries, their use incurs an excessively high lifespan expense. Maintaining, recharging, or replacing batteries across an entire IoT SSGMCE business in Shegaon, which comprises hundreds or even thousands of sensors, is not economically viable. Conversely, applications for RF energy harvesting aim to be economical and self-sufficient. Over an extended period and consistently over the application's lifetime, they often need little to no maintenance.

The frequency spans from 9 kHz to 300 GHz. This extensive frequency range encompasses several distinct bands or bandwidths. The energy produced is modest at low RF frequencies, and it increases as the frequency rises.

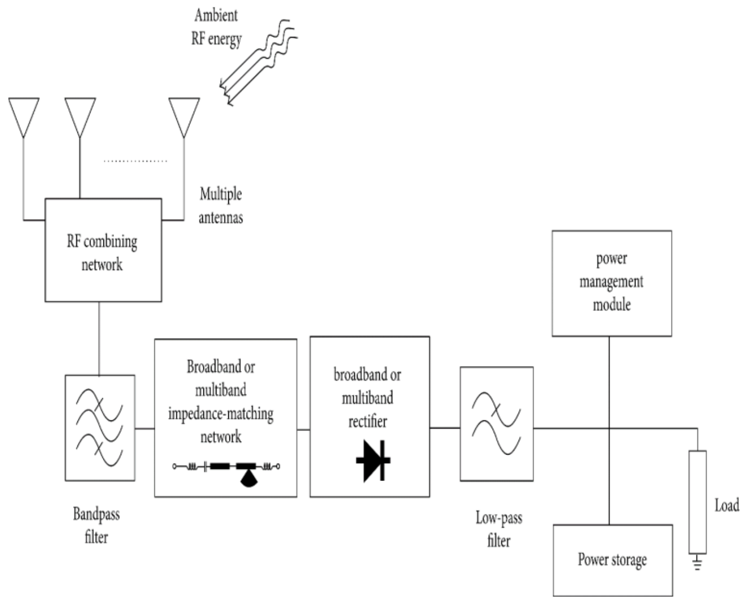

Figure 1. Block Diagram of RF Energy Harvester

Working of RF Energy Harvester

The procedure is really straightforward. The receiving antenna captures the RF energy, which is then processed via many steps to generate power. Let us examine this method succinctly:
The RF signals are sent by the source, which may be any electronic device or circuit, and received by the application circuit, equipped with its own energy conversion circuit, inducing a potential difference along the antenna's length and facilitating the movement of charge carriers through it. The charge carriers go to the RF to DC conversion circuit, where they are momentarily held in the capacitor and converted into DC current.
The energy is then amplified or transformed to the load's requisite potential value via the Power Conditioning circuit. Satellite stations, radio stations, and wireless internet represent but a fraction of the many sources that emit RF signals. The signal would be detected by any application equipped with an integrated RF energy harvesting circuit, which would then transform it into electrical energy.
Upon reception of the signal by the receiving antenna, a potential difference is induced throughout the antenna's length, resulting in further movement of the charge carriers inside the antenna. This marks the beginning of the conversion process. From the antenna, these charge carriers proceed to the wire-connected impedance matching circuit. The impedance matching network (IMN) guarantees that both the antenna (RF source) and the Rectifier/Voltage Multiplier (Load) get the maximum power transfer. The impedance of an RF circuit is as essential for effective power transmission between the source and the load as the resistance in a DC circuit.
The sinusoidal waveform of the RF signal received by the antenna indicates that it is an alternating current (AC) signal requiring conversion to direct current (DC). The rectifier or voltage multiplier circuit rectifies and amplifies the signal according to the application's specifications after traversing the IMN. The rectifier circuit is neither a half-wave, full-wave, nor bridge rectifier; instead, it functions as a voltage multiplier or specialized rectifier that enhances the rectified signal based on the application's requirements.

Advantages of RFEH

The following are the advantages of RFEH:

- It captures the electromagnetic waves used for power generation and storage, which are readily available thanks to wireless technologies like cellular towers and WiFi kiosks.
- When power requirements are extremely high, this alternative method can be used to recharge batteries.
- With a good amount of RF to DC conversion efficiency (less than 75 percent), it is the most effective source of energy generation.

- Since this method does not result in waste, it is one of the viable options for producing green energy.
- Because it uses less mains power to charge batteries and other consumer electronics, it saves money on electric bills.
- When traveling, RF to DC power converters can be used as a backup power source.
- RF energy harvesters, in contrast to solar power, can function even in conditions of darkness.

Disadvantages of RFEH

Following are the disadvantages of RFEH

- The RF-based harvesting method uses wireless sources that are affected by weather, obstacles, and other changes in the atmosphere.
- The RF harvesting chip's RF to DC converter input receives very little power and also changes over time.
- Diodes, capacitors, batteries, and other electronic components are utilized in an RF harvester. Therefore, its effectiveness is largely dependent on how well these parts work.
- The RF energy harvesting receiver's design is complicated for a wide frequency range.
- The RF harvester system cannot function without RF sources.

Limitations of RFEH

The capacity for power transmission via radio waves constrains RF energy collecting. The distance between the transmitter and receiver constrains the efficacy of RF energy harvesting. The receiver obtains less power as the distance increases. Wireless energy harvesting is constrained by its reliance on external sources that are vulnerable to meteorological variations, physical impediments, and the availability of radio wave sources. The obtained power from the sources sometimes varies over time and is insufficiently low. The efficacy of the devices' components, including capacitors, diodes, and backup storage batteries, diminishes system efficiency with time. A receiver designed for operation inside a single frequency band is constrained to the spectrum of that band, complicating the design of receivers over an extensive frequency range.

Advocates of remote harvesting for IoT devices claim that this approach may energize a distant sensor in an urban environment. Nonetheless, it is evident that a somewhat lengthy antenna and an exact alignment with a television station or other power source are necessary. Moreover, all associated IoT devices must be realigned in the case of a power supply alteration. This undermines the primary objective of power harvesting for the Internet of Things, which is to eliminate the need for physical access to the powered device.

Remote power harvesting for wearable devices is unfeasible only owing to the antenna specifications. Justifying deployment is challenging when one considers that the incidence of solar energy far exceeds the permissible levels of RF in densely populated regions of any industrialized country. Furthermore, there exists a restriction on the permissible RF power levels in public spaces, making any alteration of the situation improbable. Given the scrutiny surrounding RF exposure owing to possible health hazards, it is probable that the permissible levels may be lowered.

Observation

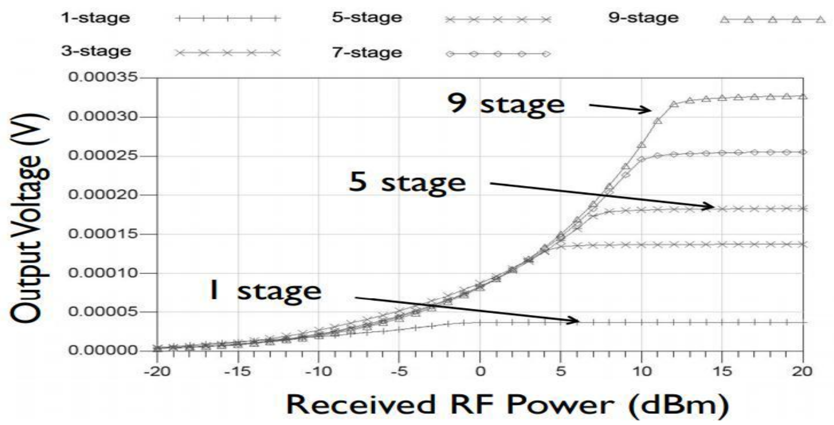

Figure 2: Effect of number of stages

CONCLUSION

The project centered on the design and production of antennas for RF energy harvesting at a frequency of 915 MHz, as well as the development of rectifiers and matching circuits using ADS (Advanced Design System) software.

The antennas were constructed using ADS to resonate at the target frequency of 915 MHz, hence assuring efficient energy collection. The design procedure included evaluating parameters such as antenna dimensions, impedance alignment, and radiation pattern to enhance energy harvesting efficiency.

Rectifiers and matching circuits were devised and constructed utilizing ADS to transform the harvested RF energy into useable electrical power. These components are essential for optimizing power transmission and reducing losses throughout the energy collecting process.

The project sought to capture RF energy at a frequency of 915 MHz by designing, simulating, fabricating, and testing antennas, rectifiers, and matching circuits. This technology effectively captures and converts RF energy into useable electrical power, enabling applications such as powering low-power devices, wireless sensors, and IoT devices, thereby promoting energy efficiency and sustainability.

REFERENCES

[1] G. Andia Vera, A. Georgiadis, A. Collado, and S. Via. Design of a 2.45 ghz rectenna for electromagnetic (EM) energy scavenging. In Proceedings of the IEEE Radio and Wireless Symposium, pages 61–64, January 2010.

[2] Surface mount mixer and detector Schottky diodes. Alpha Industries. Data Sheet.

[3] MA4E1317, MA4E1318, MA4E1319-1, MA4E1319-2, MA4E2160 GaAs flip chip Schottky barrier diodes. M/A-COM Products. Data Sheet.

[4] Comparative Study of Antenna Designs for RF Energy Harvesting, Sika Shrestha,1 Sun-Kuk Noh,2 and Dong-You Choi

[5] Microstrip Patch Antenna Design in Circular Topology for Ultra High-Frequency 900MHz Radio Spectrum: Size Reduction Technique and Defected Ground Structure Effects, Saidatul HamidahAbd Hamid, Goh Chin Hock, Tiong Sieh Kiong, (©2019 IEEE)

[6] Microstrip Patch Antenna For 2.4GHz Using Slotted Ground Plane, Karthikeya Anusury, Haneesh Survi, Paritosh Peshwe, (10th ICCCNT - 2019 July 6-8, 2019, IIT - Kanpur, India)

[7] Sandhya Chandravanshi, S.S Sarma, and M.J. Akhtar, “Design of triple and differential rectenna for RF energy harvesting”, IEEE Transactions on Antennas and Propagation, vol. 66, no.6, pp. 2716-2726, June 2018.

[8] Z. Tang, J. Liu, and Ying zeng Yin, “Enhanced cross-polarization discrimination of wideband differentially fed dual-polarized antenna via a shorting loop”, IEEE Antennas and Wireless Propagation Letters, vol.17, no.8, pp. 1454-1458, August 2018.

[9] E. A. Kadir, A. P. Hu, M. Biglari-Abhari and K. C. Aw, "Indoor WiFi energy harvester with multiple antenna for low-power wireless applications," 2013 IEEE 23rd International Symposium on Industrial Electronics (ISIE), Istanbul, 2013, pp. 526-530.

[10] H. Jabbar, Y. S. Song and T. T. Jeong, "RF energy harvesting system and circuits for charging of mobile devices," in IEEE Transactions on Consumer Electronics, vol. 56, no. 1, pp. 237- 253, February 2010.

[11] Devi, K. K. A., N. M. Din, and C. K. Chakrabarthy, "Optimization of the voltage doubler stages in an RF-DC convertor module for energy harvesting," Circuits and Systems, Vol. 3, No. 3, Jul. 2012

[12] E. Khansalee, Y. Zhao, E. Leelarasmee and K. Nuanyai, "A dual-band rectifier for RF energy harvesting systems," 2013 11th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON), Nakhon Ratchasima, 2013, pp. 1-3.

[13] J. P. Curty, N. Joehl, F. Krummenacher, C. Dehollain and M. J. Declercq, "A model for μpower rectifier analysis and design," in IEEE Transactions on Circuits and Systems I: Regular Papers, vol. 52, no. 12, pp. 2771-2779, Dec. 2005.