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Design Challenges of Rectenna for Energy Harvesting from Microwave Pollution

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Abstract: We are always exposed to a significant amount of microwave energy emitted by the wireless fidelity (Wi-Fi), television broadcasting, and different wireless communication systems which has many adverse effects. However, by harvesting the microwave energy from the surrounding, the microwave pollution can be reduced as well as the microwave energy can be effectively utilized. Rectenna is an electronic device which is used to harvest the microwave pollution. In this paper, the design procedure of a rectenna system is described and the key design challenges are highlighted for wireless energy harvesting. The key design parameters include harmonic suppression, the design of low-power rectifier circuits and the effect of load conditions on the rectenna conversion efficiency. The effect of load conditions against rectenna performances is extracted using Advanced Design System (ADS). Effect of different rectifier circuits including Half Wave Configuration and voltage-doubler are in the context of wireless energy harvesting systems. The article gives a comprehensive exposure to the rectenna design, the possibilities of wireless energy harvesting and likewise useful for researchers working in the field of wireless power transfer systems.

Key words: High gain antenna, low-power rectifier, rectenna, wireless energy harvesting, wireless power transfer.

Introduction

At this time, a huge amount of ambient RF energy including multiband is continuously available in the surrounding which is unutilized. Although, the amplitude of available RF energy is very small and also the amount of energy varies depending on the distance between different sources of energy as mobile, radio, and television base-stations. Thus, it is extremely difficult to harvest a significant amount of ambient wireless energy. The key components of the proposed solutions are a rectifier and an antenna circuit thus, named as "Rectenna". However, numerous solutions are proposed in the literature extracting dc power from different frequency bands (Matsunaga et al., 2015; Song et al., 2015; Sun and Geyi, 2016; Mitani et al., 2017; Sun et al., 2017). Matsunaga et al. have presented a 5.8 GHz large rectenna array for wireless energy harvesting (Matsunaga et al., 2015) achieving an RF-DC conversion efficiency of above 40%. In Song et al. (2015), a broadband rectenna is reported for 2.45 GHz band based on high gain antenna and achieves a conversion efficiency of 55% for an input power of –10 dBm.

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However, the reported rectenna is able to detect a minimum input power of –35 dBm with a conversion efficiency of 10%. Hucheng et al. present a polarization-independent rectenna for 2.45 GHz band which achieves improved conversion efficiency of 78% (Sun and Geyi, 2016). Mitani et al. (2017), analyzed a voltage doubler circuit and it was shown that a voltage doubler circuit improves the RF-DC conversion efficiency compared to a Half Wave Rectifier (HWR). Sun et al. (2017) utilized a wide half-power-beamwidth (HPBW) antenna array to extract more ambient wireless energy. In Siniscalchi et al. (2017) a Schottky diode is used and in Toshiyuki et al. (2017) a novel Schottky diode is designed for high-efficiency rectenna design. Oishi et al. (2016) used a mott barrier (metal-semiconductor junction) diode for rectenna design and improved conversion efficiency was shown over Schottky diodes.

Numerous solutions are proposed in the literature including high gain, dual-polarized, and broadband antennas, efficient rectifiers, and different diodes to improve the efficiency of a rectenna for wireless energy harvesting. In this paper, we present a comprehensive study of the effect of different components including filter, a rectifier circuit, and load conditions on the output of a rectenna. A simple rectenna is designed for 2.45 GHz band; the detailed analysis is presented. The simulation of the designed Advanced Design Systems (ADS) software and the design challenges are discussed.

Design Challenges

A rectenna system comprises an antenna, filters, rectifier and load, as shown in Figure 1. An antenna is a primary component of a rectenna system. It has a great impact on the amount of total harvested power. The amount of total received power is directly proportional to the total received power. The amount of total received power (P_r) is completely dependent on the antenna performances, expressed using FRISS:

$$P_r = \frac{G_T P_T G_R \lambda^2}{(4\pi R)^2} \tag{1}$$

where G_T and G_R are the gain of transmitting and receiving antennas respectively, P_T is the transmitted power (ambient wireless power), λ is the operating wavelength, and R is the distance between transmitting and receiving antennas. However, the antenna does not affect the conversion efficiency of the rectifier.

Since the location of transmitting antennas (radio base stations or Wi-Fi routers) are fixed, the amount of received power strongly depends on the location of the rectenna and the gain of the receiving antenna. Thus, it is very essential to consider the location where rectenna has to be placed before starting the design. Moreover, the frequency band should be identified with the highest amount of ambient power to harvest the maximum amount of energy, as shown in Figure 1. It is evident in Figure 2 that at NIT Silchar, India, a maximum amount of ambient wireless power is available for LTE 2100 MHz band. Hence, if a rectenna is designed for LTE 2100 MHz band, a maximum amount of wireless energy can be harvested for this location.

A microstrip antenna is preferred due to its low profile, and multi-polarization characteristics for a rectenna design. However, the microstrip antenna suffers from poor gain, and impure polarization because of the excitation of strong surface waves. Numerous techniques as an antenna array and director-based designs are proposed in the literature to improve the antenna gain but those methods pare down the angular coverage of the antenna which is undesired for rectenna systems (Sun et al., 2017). A multilayered substrate-based gain enhancement technique (Kumar et al., 2017, 2018) is the desired method which improves the antenna gain, and radiation efficiency as well as maintains angular coverage of the antenna.

A wireless energy harvesting system deals in few μW or mW. So, it is important to take care of losses due to various aspects like impedance matching, diode losses, and losses due to materials used for fabrication of a rectenna. Generally, an RF component as an antenna and filters are designed for a 50 Ω ports which have moderate power handling capacity and noise immunity. Even though we need to take care of impedance matching at each stage of a rectenna

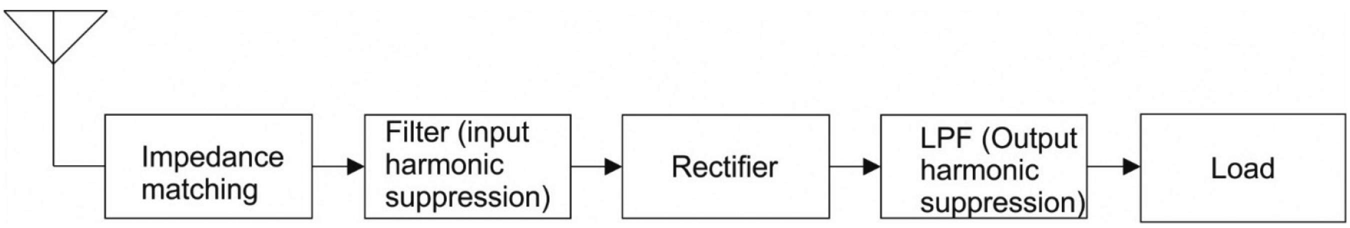

Figure 1: Basic block diagram of a rectenna system.

otherwise a significant amount of loss may occur leading to extremely poor rectenna performances. It is well-known that a single microstrip operates at higher order modes named harmonics. These harmonics degrade the performance of the rectifier circuit leading to poor rectification efficiency.

Hence, a bandpass filter is connected preceding to the rectifier. The configuration of a rectifier circuit and diode decide the performance of a rectifier. The ambient available power is present in the form of low amplitude high-frequency RF energy; hence, normal rectifier diodes cannot be used to design a rectenna. A Schottky or a mott barrier (metal-semiconductor junction) diode is a suitable choice for a low power rectifier designs. Even a Full Wave Rectifier (FWR) has the highest efficiency, it cannot be used due to the loss in the diodes. So, an HWR with voltage doubler configuration is the most suitable choice for a low power rectifier design.

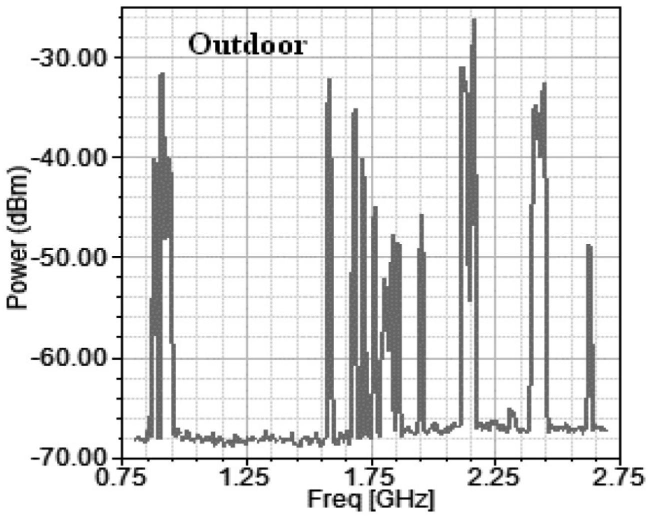

Figure 2: Measured spectrum using a circularly polarized antenna at NIT Silchar, India in an outdoor surrounding.

Thereafter, an LPF is required to generate the pure DC. It is observed in the literature that the load has a significant impact on conversion efficiency. An optimized load gives the best conversion efficiency of a particular design. However, it is impractical to use an optimized load so a prior estimation of the load should be known to design a stable wireless energy harvesting systems.

Rectenna Design

In this section, an HWR based rectifier is designed for 2.4 GHz band using ADS software for wireless energy harvesting system. The schematic of a rectifier and matching parameter is shown in Figure 3 and Figure 4, respectively. The rectifier is designed for an FR4 substrate of dielectric constant 4.4 and thickness of 1.57 mm. A matched 50 Ω RF source is used to feed the rectifier. A microstrip bandpass filter is designed at 2.4 GHz which is connected to the Hitachi 1ss168 Schottky diode (D1). An additional diode (D2) is connected to protect the main diode which bypasses the negative half cycle.

Thereafter a matched microstrip liner and a 22 μF capacitor are connected to purify the pulsating DC coming out from the diode D1. A power probe is connected to measure the output for different input power and load conditions. The output power of the rectifier for different input power is shown in Figure 5.

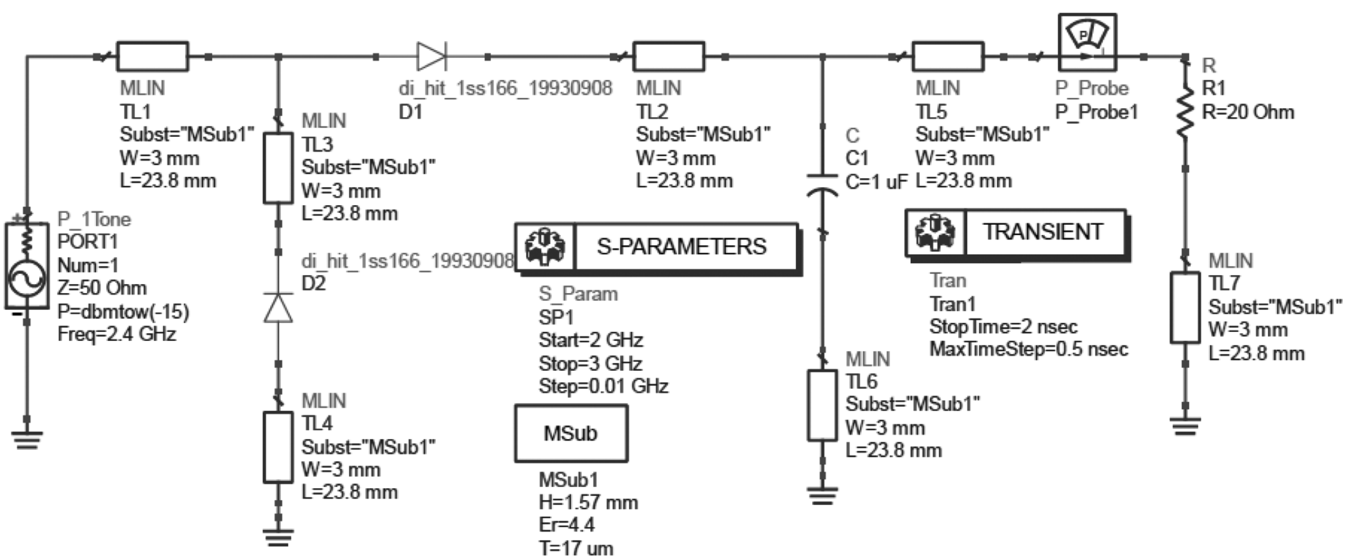

Figure 3: Schematic of the rectenna designed in ADS.

It is evident that, as the input power level is increasing, the output power is increasing. The output power of the rectifier versus load is depicted in Figure 6. The input power level is set to 10 dBm and the load is varied to analyze the performance of the rectifier.

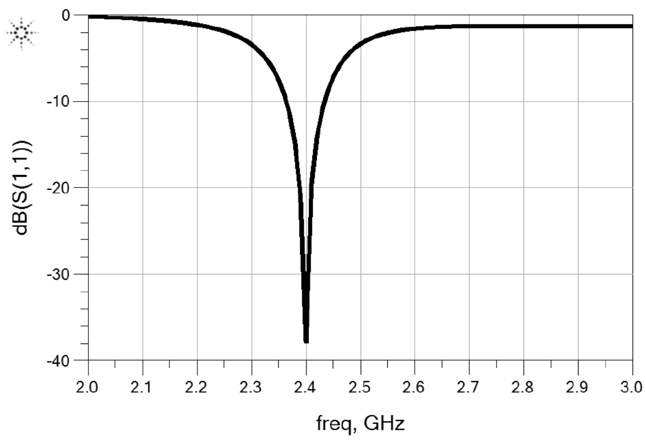

Figure 4: S_{11} parameter of the rectenna.

Initially, the load is set to 10 Ω and further changed to 50 Ω, 500 Ω, and 1 KΩ. It is evident that the rectifier performs well for a load of 50 Ω with a peak output power of above 38 mW. Whereas, for 10 Ω, 500 Ω, and 1000 Ω, the rectifier has poor performance. Thus, an optimized load is required to extract the maximum amount of wireless energy.

Conclusion

The design challenges of a wireless energy harvesting system are discussed and the optimal conditions to extract the maximum amount of ambient wireless energy are suggested. The role and effect of each element of a rectenna system are highlighted and the design challenges of each element are included. The performance of a Schottky diode based HWR is demonstrated and it is shown that there is a significant effect of loading conditions on the performance of the overall systems.

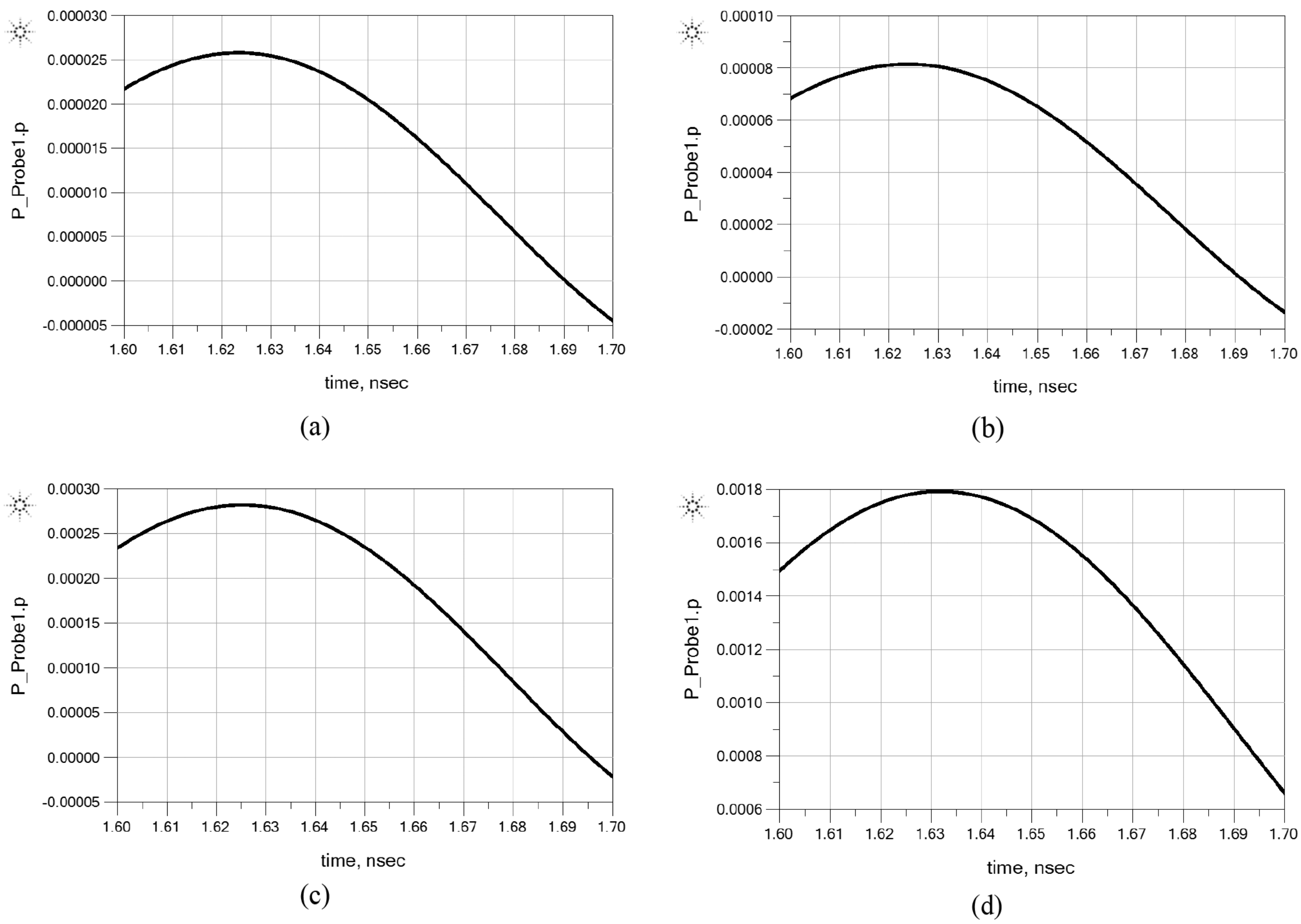

Figure 5: Output power of rectifier for different input power level: (a) –15 dBm, (b) –10 dBm, (c) –5 dBm and (d) 0 dBm.

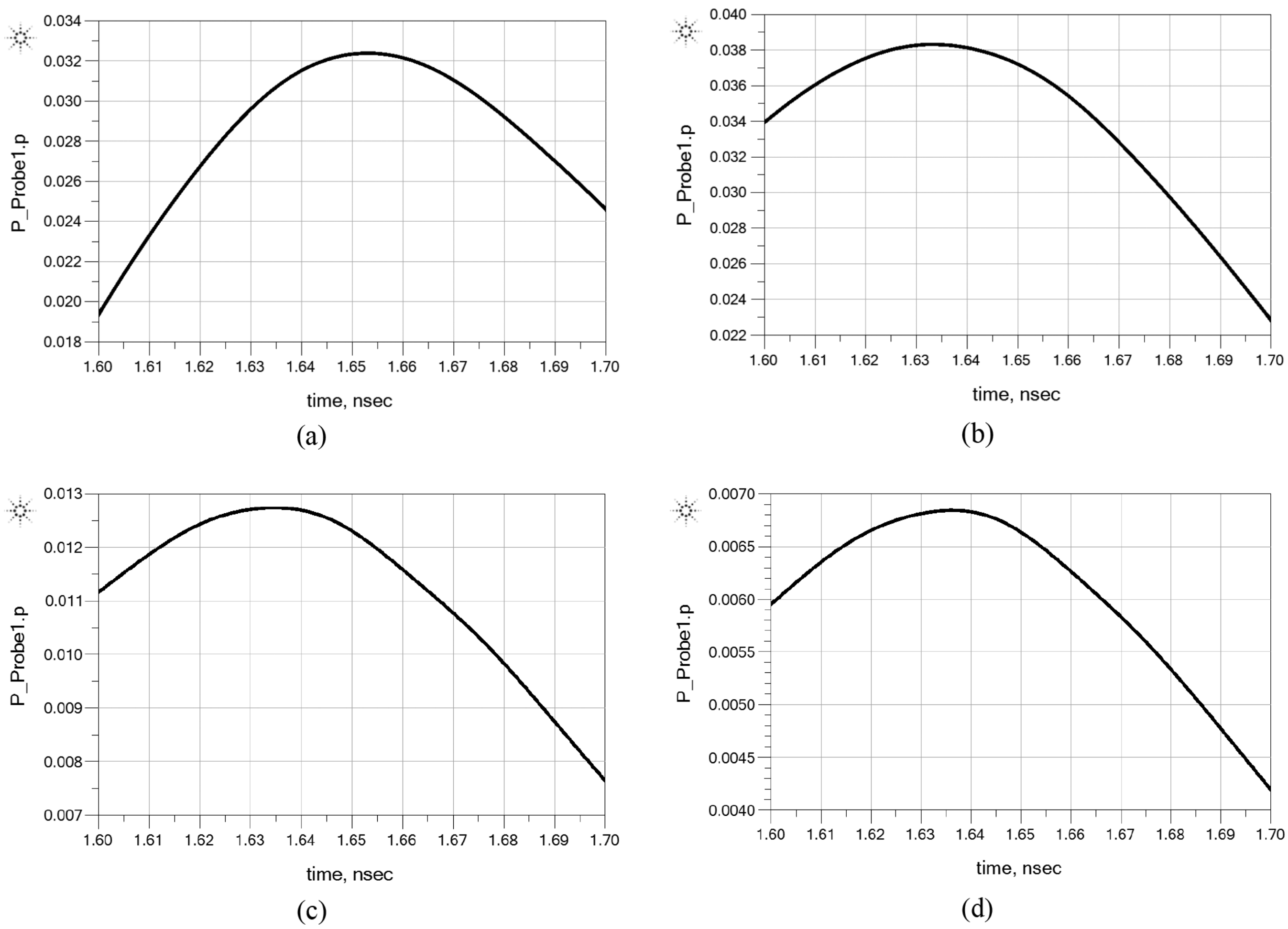

Figure 6: Output of the rectifier for different load conditions: (a) 10 Ω, (b) 50 Ω, (c) 500 Ω and (d) 1 KΩ.

References

Kapilevich, B., Shashkin, V., Litvak, B., Yemini, G., Etinger, A., Hardon, D. and Y. Pinhasi (2016). W-Band Rectenna Coupled with Low-Barrier Mott Diode. *IEEE Micro. Wireless Compo. Lett.*, **26:** 637-639.

Kumar, J., Basu, B., Taludar, F.A. and A. Nandi (2017). Graphene-based multimode inspired frequency reconfigurable user terminal antenna for satellite communication. *IET Comm.*, **12:** 67-74.

Kumar, J., Basu, B., Taludar, F.A. and A. Nandi (2017). X-band Antenna Printed on Multilayered Substrate. *IET Micro. Antenna Propag.*, **11:** 1504-1509.

Matsunaga, T., Nishiyama, E. and I. Toyoda (2015). 5.8-GHz Stacked Differential Rectenna Suitable for Large-Scale Rectenna Arrays with DC Connection. *IEEE Trans. Antennas Propag.*, **63:** 5944-5949.

Mitani, T., Kawashima, S. and T. Nishimura (2017). Analysis of Voltage Doubler Behavior of 2.45-GHz Voltage Doubler-Type Rectenna. *IEEE Trans. Antennas Propag.*, **65:** 1051-1057.

Oishi, T., Kawano, N., Masuya, S. and M. Kasu (2017). Diamond Schottky Barrier Diodes with NO_2 Exposed Surface and RF-DC Conversion Toward High Power Rectenna. *IEEE Electron Device Lett.*, **38:** 87-90.

Siniscalchi, M., Pieruccioni, A., Vanzini, F., Reyes, L. and L. Barboni (2017). Schottky Diode Assessment for Implementing a Rectenna for Radio-Triggered Wireless Sensor Networks. *IEEE Micro. Wireless Comp. Lett.*, **27:** 763-765.

Song, C., Huang, Y., Zhou, J., Zhang, J., Yuan, S. and P. Carter (2015). A High-Efficiency Broadband Rectenna for Ambient Wireless Energy Harvesting. IEEE Trans. Antennas Propag., **63:** 3486-3494.

Sun, H. and W. Geyi (2016). A New Rectenna with All-Polarization-Receiving Capability for Wireless Power Transmission. *IEEE Antenna Wireless Propag. Lett.*, **15:** 814-817.

Sun, H. and W. Geyi (2017). A New Rectenna Using Beamwidth-Enhanced Antenna Array for RF Power Harvesting Applications. *IEEE Antenna Wireless Propag. Lett.*, **16:** 1451-1454.