Effects of Introducing Slots in Rectenna

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Abstract
Wireless power is turning out to be a promising technology in near future. This would not only be an alternative to batteries and wired supply, but also protect our environment from the harmful effects of batteries. In this paper analysis of introducing slots in the rectenna is studied. An experimental RF energy harvesting system to transmit wireless powers using microwaves is designed and then effects of slot loading on the resonance frequency, reflection coefficient, bandwidth, and gain are analysed. The design is achieved by creating two rectangular slots of same physical patch dimensions. The proposed circuit is a combination of RMPA , followed by a 3rd order stepped impedance low pass filter, matching network and rectifier using a Schottky diode for microwave(RF) to DC conversion. The performance of the rectenna is simulated by electromagnetic simulator Computer Simulation Technology (CST) Microwave Studio. Rectenna offers 198 mV of output DC voltage at distance of about 15 cm from router.

Keywords: *Rectangular Microstrip Patch Antenna (RMPA), Low Pass Filter (LPF), Rectenna, Computer simulation Technology (CST-MW), Industrial Scientific Medical (ISM), Slot Loading.*

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INTRODUCTION

Wireless applications introduce surplus Electro-Magnetic (EM) energy into the environment-energy which can be scavenged and reused. A rectifying antenna, also popularly known as rectenna, is one such means for harvesting that energy. To demonstrate the potential of such a design, an efficient rectenna was developed for operating at low powers in Industrial-Scientific-Medical (ISM) band at a single frequency of 2.45 GHz. Over 100 years ago, the concept of wireless power transmission began with the patented ideas and demonstrations by Tesla[1]. Rectenna is needed to utilize this wireless energy in an efficient manner. The incident RF power is transformed into dc power by the rectifying circuit. The network for proper impedance matching is composed of capacitive and inductive elements. This matching network makes sure that maximum power is transferred from antenna to rectifying circuit. Figure 1 gives the block diagram of a basic rectenna.

Noteworthy efforts have been dedicated to the improvement of the bandwidth, return loss or the reflection coefficient and reduction of size[2-12].The easiest among them is by modifying the radiating patch i.e slot loading or by modifying the ground plane i.e. Defect Ground Structure. In all papers they both have been designed for optimum results.

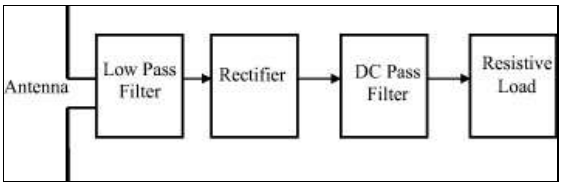

Fig. 1: *Basic Rectenna Block Diagram.*

METHODOLOGY

Antenna, Filter Design and Fabrication

Figure 2 shows the basic rectangular patch antenna. The reflection coefficient, radiation pattern, gain, directivity and VSWR are found by simulating the antenna on CST and measured by spectrum analyser. The front view of the proposed rectenna is shown in Figure 4. It consists of a rectangular microstrip patch antenna operating at resonant frequency of 2.45 GHz with 50Ω microstrip line feed. The printing of rectenna is on a FR4-epoxy substrate with relative dielectric constant $\varepsilon r=4.3$ and thickness h=1.6 mm[13-18]. Initially we design the RMPA at desired frequency of 2.45 GHz in the fabrication and designing process of rectenna

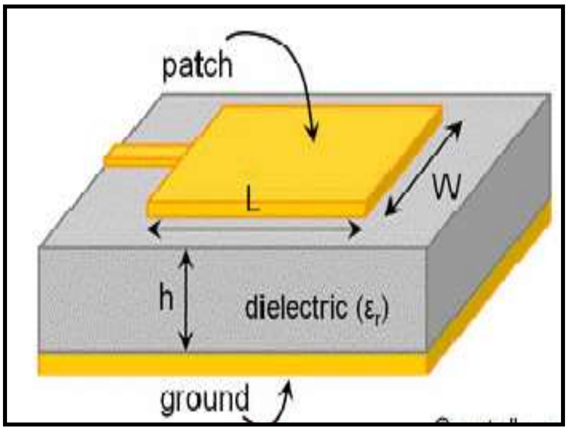

***Fig. 2**: Rectangular Micro-Strip Patch Antenna.*

***Table 1**: Parameters and Design Specifications of Antenna.*

S No.	Antenna Parameters	Values
1	Resonating Frequency	2.45 GHz
2	Dielectric Constant (relative)	4.3
3	Substrate thickness	1.6 mm
4	Loss Tangent	0.02

***Table 2**: Calculated Dimensions of Patch Antenna.*

S No.	Antenna Parameters	Values in mm
1	Patch width	36.855
2	Patch height	29.2

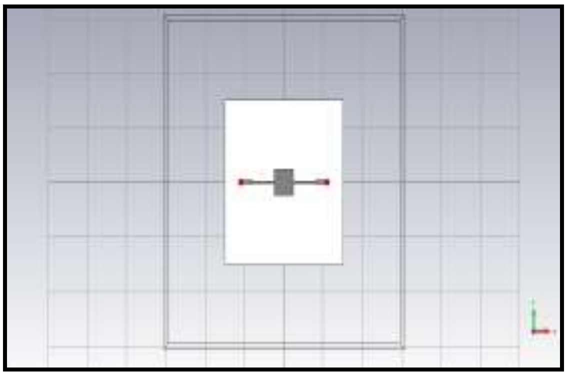

***Fig. 4**: Geometry of Low Pass Filter in CS.T*

***Table 3**: Filter Design Parameters at 2.45 GHz.*

S No.	Parameter	Inductor section	Capacitor section
1.	Characteristic Impedance	Z_{OL}= 93 Ω	Z_{oc}= 24 Ω
2.	Effective Dielectric Constant	ε_{ref} $f_{L= 2.94}$	ε_{ref} $f_{C = 3.53}$
3.	Width of Microstrip Line	W_L=0.88 mm	W_C=8.94 mm
4.	Length of Microstrip Line	I_L=8.438 mm	I_C=7.245 mm

Rectifier Designing

A rectifier is a device that converts bidirectional alternating current (AC) to unidirectional direct current (DC).The process is known as rectification. A simple half wave rectifier is considered in this paper.

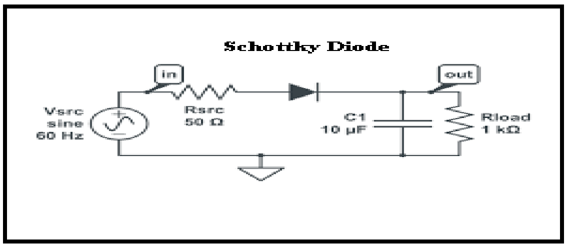

***Fig. 5**: Rectifier Circuit.*

Slot Loading

Micro-strip slot antennas were invented in 1938 by Alan Blumlein. Slot antennas or slot radiators are antennas used in the frequency range of 300 MHz to 25 GHz. They are mostly used in navigation radar.

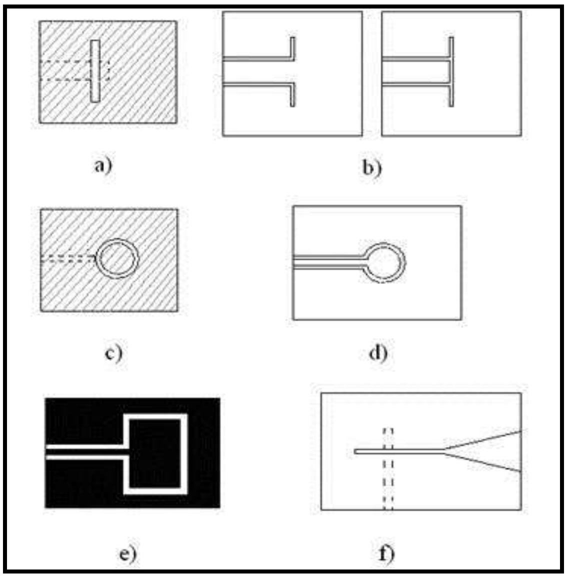

Fig.6: *Types of Slot in Antenna*

(A) Rectangular Slot with Micro-strip Feed.
(B) Rectangular Slot with Coplanar Feed.
(C) Angular Slot with Micro-strip Feed.
(D) Angular Slot with Coplanar Feed.
(E) Rectangular Ring Slot.
(F) Tapered Slot.

These slots provide the merits of low profile, low cost, size reduction, easier integration and compatibility with other circuits and conformability to a shaped surface. Nowadays, numerous slot antenna designs for 2.4/5 GHz dual band WLAN operations have been reported in the literatures[19-21]. Slot antennas are an about λ/2 elongated slot, cut in a conductive plate (Consider an infinite conducting sheet), and excited in the centre. Microstrip slot antenna is very simple in structure .It consists of microstrip feed that couples electromagnetic waves through the slot above and slot radiates them.

Equal slots of dimension 16 mm x 1 mm are cut.

Figure 6 below shows the conclusive design of rectenna in CST software which is now ready for final simulation. Figure 7 shows the design with slots cut on antenna thereby making it a multiband rectenna.

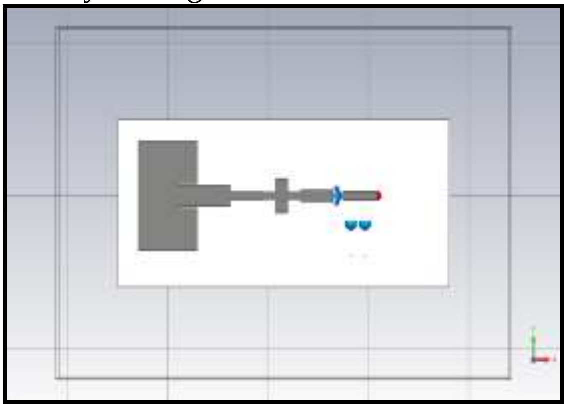

Fig. 6: *CST View of Rectenna.*

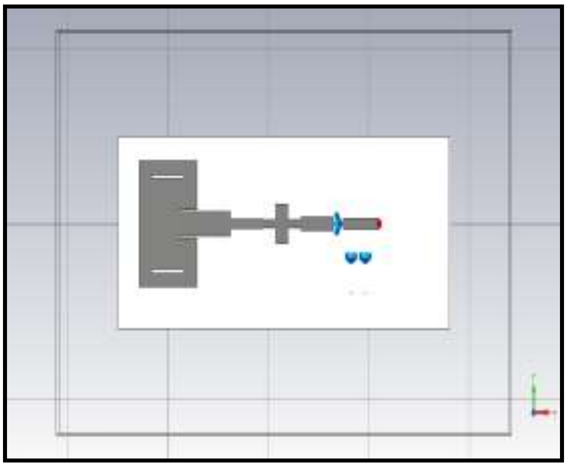

***Fig. 7**:* *CST View of Slotted Rectenna.*

RESULTS

Fig.8 and Fig.9 shows the simulated result of unslotted rectenna and slotted rectenna on CST simulation software respectively. It shows -32.485 dB at 2.45 GHz without slot while -27.43 dB at 2.45 GHz, -39 dB at 3.25 GHz with slotted rectenna which is quite improved result for rectenna with slots.

Figure10 shows comparison of reflection coefficient for rectenna with and without slot loading. Bandwidth changes from 710 MHz to 827 MHz. The result clearly shows that the return losses further decreases when slots are added to the design.Fig.11 shows the radiation pattern of the slot loaded rectenna. The radiation efficiency is found to be -0.101, thus rectenna has 97.7 % radiation efficiency.

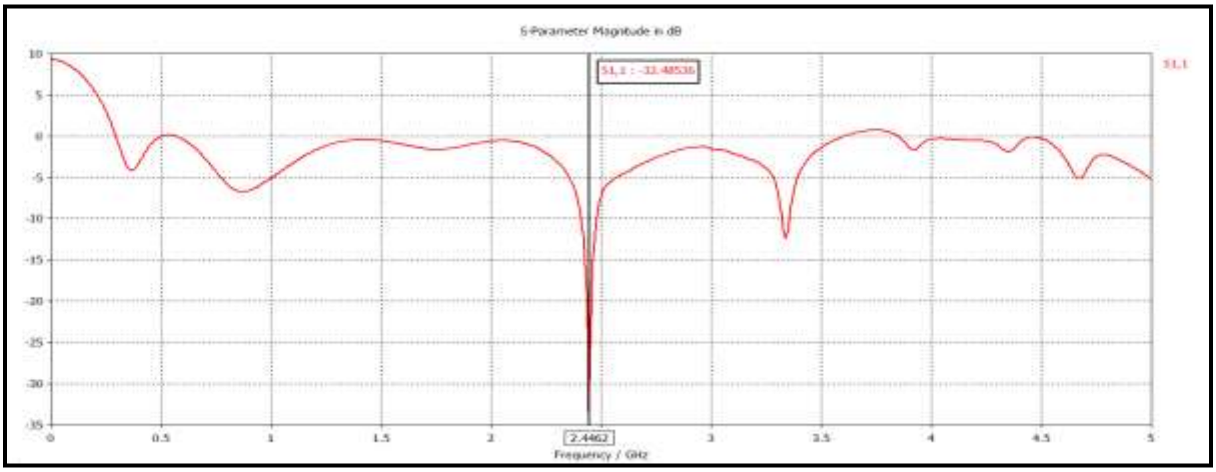

Fig. 8: *Simulated S11 of the Rectenna.*

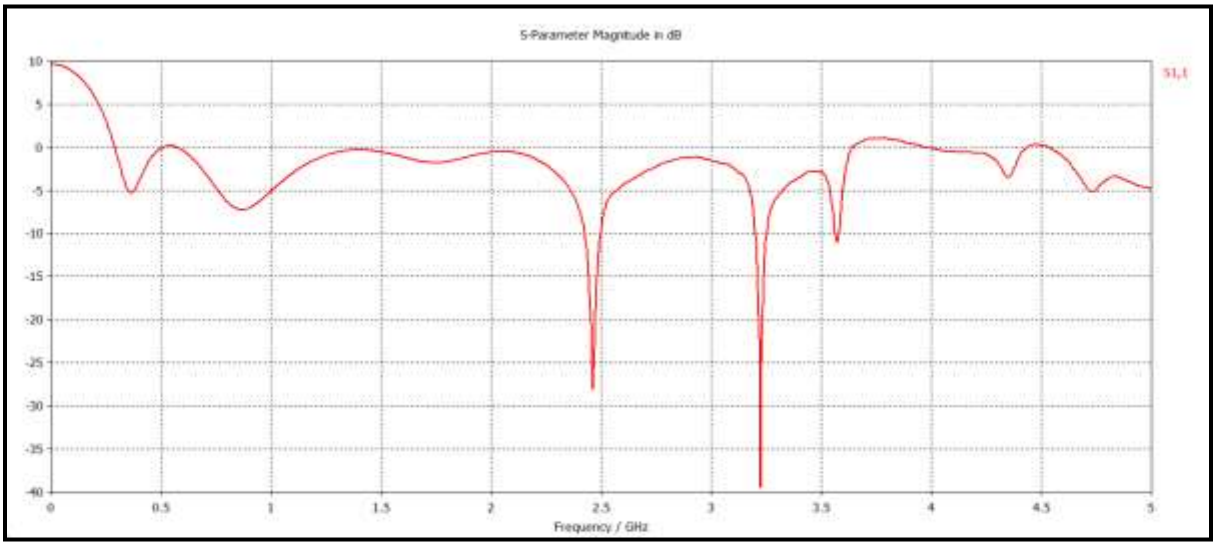

Fig. 9*: Simulated S11 of the Slotted Rectenna.*

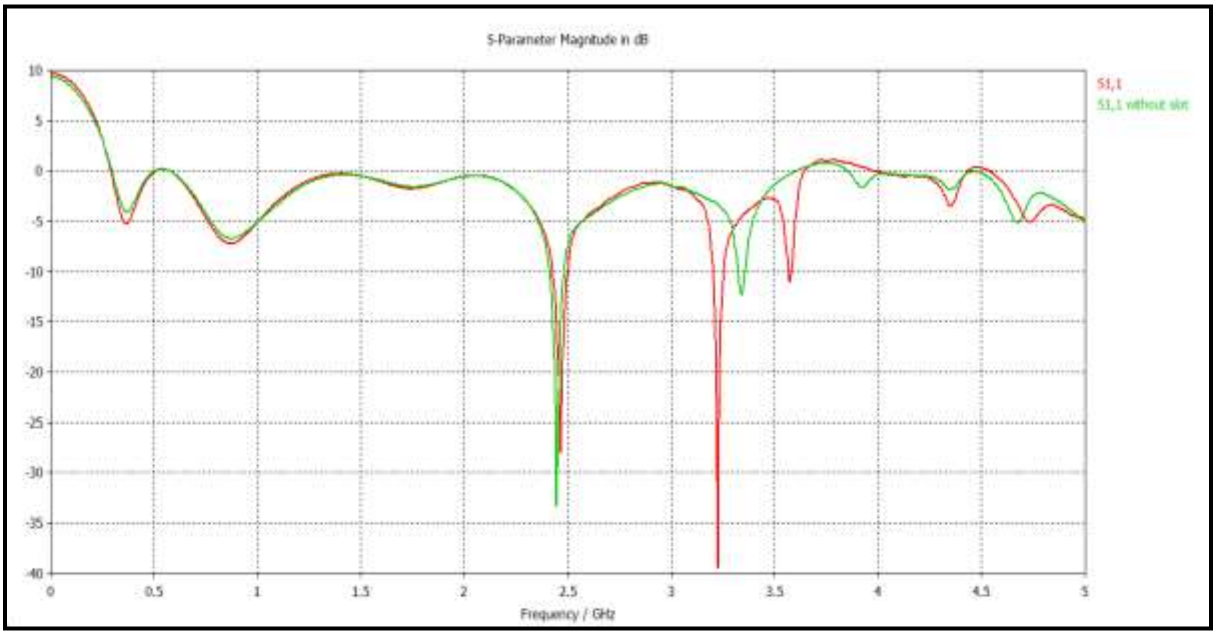

***Fig. 10:** Comparison of Reflection Coefficient for Rectenna with and without Slot Loading.*

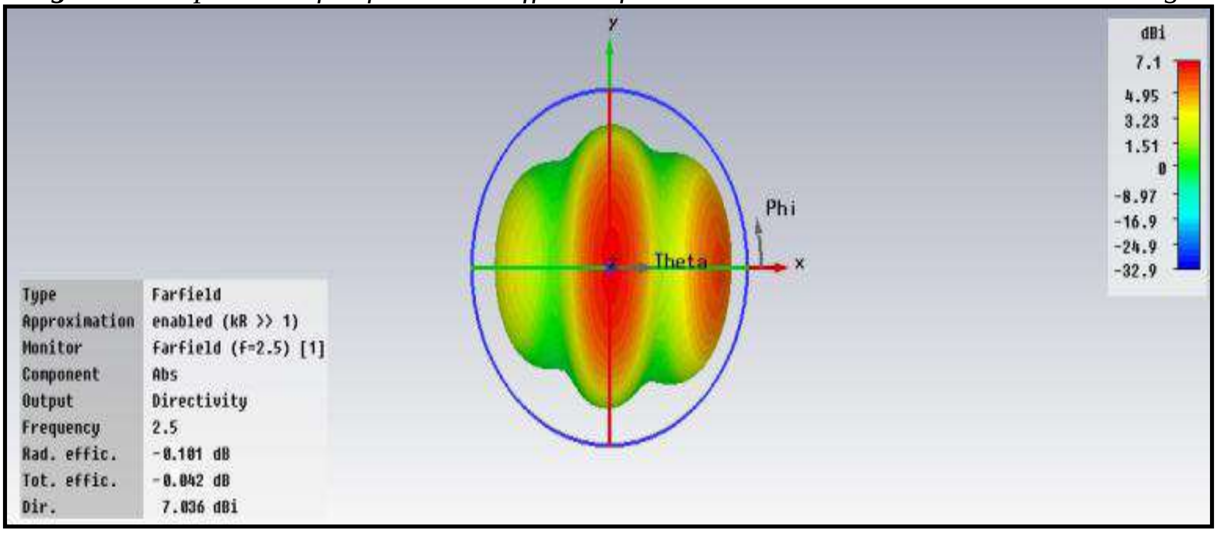

***Fig. 11**: Radiation Pattern of the Rectenna with Slot Loading.*

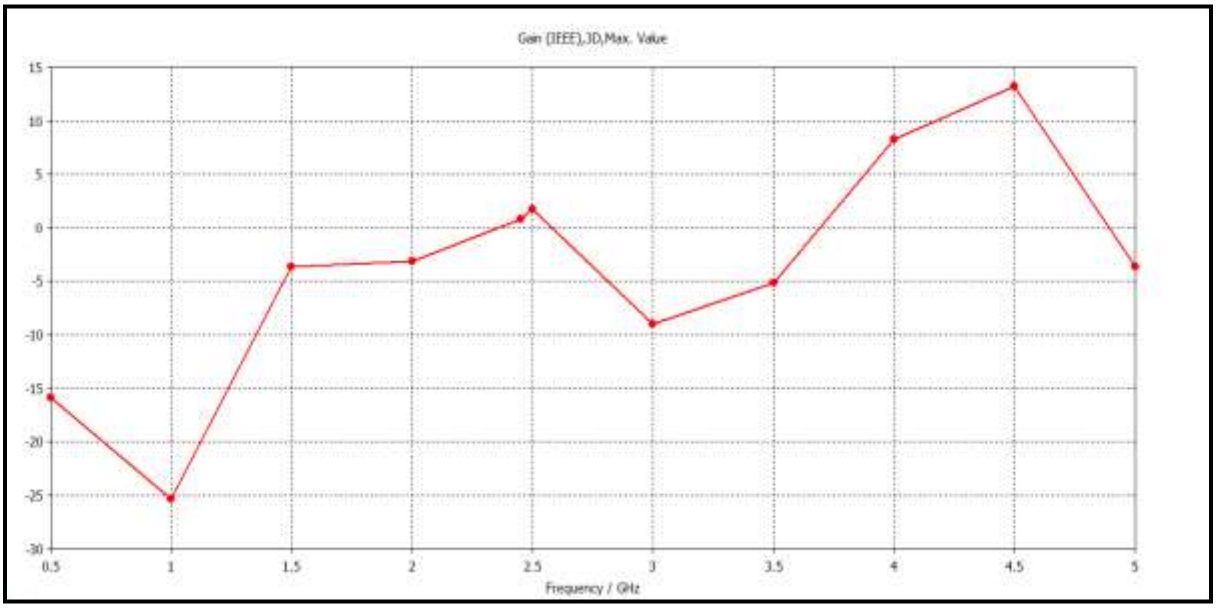

***Fig. 12**: Gain Plot of the Slot Loaded Rectenna.*

Figure 12 shows the gain plot for the slot loaded rectenna. Max gain of 14 dB is seen at a frequency of 4.5 GHz. Figure13 shows the working of the rectenna successfully. Instead of a resistor at the load, an LED (Light Emitting Diode) is connected and the glowing of the LED indicated the working of the rectenna. The rectenna is placed in front of the Wi-Fi router which radiates electromagnetic waves at 2.45 GHz. The designed rectenna offers 198 mV of output DC voltage at a distance of 15 cm from the Wi-Fi router.

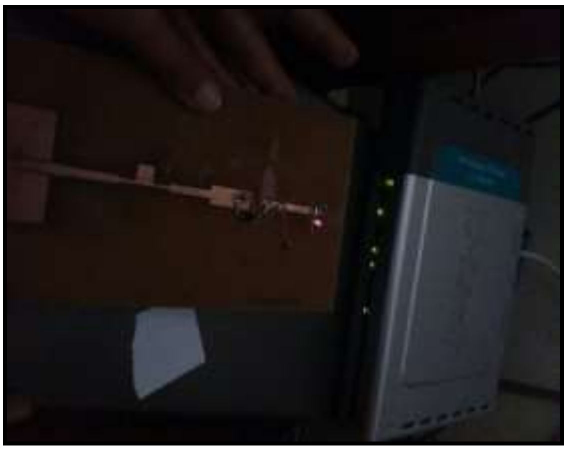

***Fig. 13**: Fabricated Rectenna with LED as a Load.*

CONCLUSIONS

In this paper, a rectenna is fabricated using a RMPA, low pass filter, matching network and single stage rectifier circuit. Here a compact, planar rectenna is designed for wireless power reception in ISM (Industrial, Scientific, Medical) frequency band of operations.

The system consists of 3 major blocks. (i) Antenna which is used for receiving the signal is operated in the far field region.(ii) Impedance matching circuit which is used for matching the antenna with the rectifier. (iii) A half wave rectifier is used to convert the AC to the DC which has an efficiency of 65 %. These blocks are individually and integrally verified using simulations and measurements successfully.

There are some improvements which can be done in the future work. (i) The rectifier can be replaced by the full wave rectifier for higher efficiency. (ii) The impedance matching here is generally done for the first harmonics and the other harmonics are filtered out. Instead of filtering them, they can also be matched for good impedance matching. (iii) A rectenna array can be used to increase the DC signal received at the output.

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