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Dielectric Resonator Rectenna for RF Energy Harvesting System

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Abstract: ***Recently, the various methods for RF energy harvesting and reutilizing has become the challenging matter around the world to minimize the wastage of RF energy in the form of electromagnetic waves within the atmosphere. An associate approach of collecting a particular range of frequencies & conversion into dc current- Rectenna is proposed here. Star shaped Dielectric Resonator Antenna is implemented as antenna for receiving RF energy at 2.44 GHz resonant frequency. It is observed that* Star shaped *DRA exhibits a radiated power of 0.8825 W with respect to 1W incident power and maximum gain of 5.9672 dBi. The RF power received by Antenna is given to a Rectifier circuit via proper impedance matching circuit. The rectified pulsating DC power is given to capacitor filter to suppress harmonics .***

Keywords* : *Dielectric Resonator Antenna, Rectifier, Schottky diode and TDRA.

I. INTRODUCTION

The low energy harvesting technologies includes sources like pressure differentials, temperature differentials, light, vibration and convert into low power energy signals. These techniques need specific requirement depending on used sensors and also one more disadvantage is lifetime of sensor. Now a days, RF energy is most available in atmosphere everywhere due to wide uses of wireless communication devices. One of the options for the RF energy rummaging from RF emission is Antenna. Received RF energy from antenna is converted into DC power to utilize. It is an approach of Rectenna that is the challenge to design for gratifying energy and exploiting into DC source for of low power operated systems. [1] The challenge for RF energy harvesters is to synchronize unpredictable levels of the available power with conversion circuit.

The Microwave RF energy harvesting system has an important module known as Rectenna that converts microwave power into DC power. It contains of an Antenna which is heart of rectenna, Rectifying diodes which operates without an internal power source and filters.

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The main challenge to design rectenna is that the maximum received RF power from antenna should be converted into DC power.

The Microwave RF energy harvesting system has an important module known as Rectenna that converts microwave power into DC power. It contains of an Antenna which is heart of rectenna, Rectifying diodes which operates without an internal power source and filters. The main challenge to design rectenna is that the maximum received RF power from antenna should be converted into DC power.

A Rectenna is fundamentally combination of receiver antenna and rectifier which transform RF or Microwave energy into useful DC energy. Dielectric Resonator antenna (DRA) is used here as an antenna for receiving rf signal because of their advantages.

Since last two decade, The area of research on DRA is going on well as they have some attractive advantages compare to microstrip patch antenna like compact size, light weight, low metallic losses, high radiation efficiency, wide bandwidth, and low cost. DRAs are available in different shapes [2]-[3]. Triangular DRA (TDRA) have some advantages like simple comprehensive design, smaller area than any other DRA for given resonant frequency and variable aspect ratios. In addition to this, there is no conducting material excluding feed line, so negligible metallic (conducting) losses exist [4]-[7].

In this paper, TDRA at 2.45 GHz resonant frequency is implemented in Ansoft HFSS.13 software. Furthermore, Star shaped DRA is obtained using self-similarity fractal topology and optimizing dimensions of the antenna. Besides this, the received rf signal from antenna is fed to Rectifier circuit via proper impedance matching circuit and it is implemented and simulated in ADS 2017.

II. ANTENNA DESIGN

In an equilateral triangular DRA on the ground plane, the resonance frequency of the TMlmn mode is approximately given as:

$$f_{r(mn)} = \frac{C}{2\sqrt{\varepsilon_r}}\left[\left(\frac{4}{3a}\right)^2 (m^2 + mn + n^2) + \left(\frac{p}{2h}\right)^2\right]^{\frac{1}{2}} \quad (1)$$

Where $C = 1/\sqrt{\mu_0 \varepsilon_0}$ is the speed of light in free space, ε_r is the relative permittivity of the medium, μ_r is the relative permeability which is equal to 1 for non-magnetic medium, the side length of the triangle geometry is *a*, and the height of the resonator is *h*.

The *l*, *m* and *n* are the resonance frequency indices, but l index depends on m and n values. Hence the modes are defined by m and n only.

The indices l, m and n should be satisfied by the criteria l+m+n = 0, but not all of them can be zero at the same time. ρ = 1 for the fundamental TM10-1 mode.

To design Triangular DRA (TDRA), equilateral Triangular shape is considered here because the center point of the symmetrical triangle is located at the same distance from each corner of the triangle which gives simplicity, symmetricity and flexibility. Alumina ceramic dielectric material having 99.5 % of purity and 9.8 of relative permittivity is chosen as Dielectric resonator for DRA as explained in [8]. Furthermore, The Koch snowflake approach of the fractal antenna is one of the self-similarity properties for increasing the outer perimeter of the triangle shape ultimately to increase the effective area of the resonator surface as explained in the [9]. Star shaped DR is achieved by applying this fractal geometry on Triangular DR. Fig.1 shows the geometry of star DRA excited by same coplanar microstrip feeding that is supported by a 53 X 63 mm2 substrate (FR402) with a dielectric constant (εr)=4.25 and thickness of 1.51 mm which is same as substrate of TDRA. Fig.2 shows the fabricated star shaped DRA.

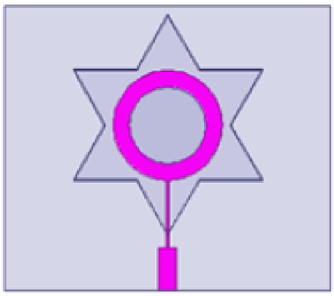

Fig.1: The structure of Star shaped DRA (Top view)

Fig.2: The Fabricated Star shaped DRA

III. PARAMETRIC STUDY OF ANTENNA

The parametric results were carried out by using Ansoft HFSS.13 software. Fig.3 shows the reflection coefficient (S11) vs frequency plot for star shaped DRA. The results show that the reflection coefficient (S11) for TDRA is -35.924 dB at 2.4319 GHz resonant frequency. The reflection coefficient is less than -10 dB over the range from 2.3961 to 2.512 GHz frequency same as to that of TDRA. The Star DRA has a 0.8825 W received power with 1 W incident power and 88.25 % radiation efficiency and Fig.4 shows the 3D pattern of the overall gain of Star DRA.

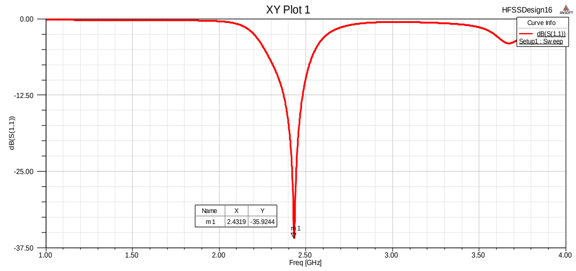

Fig.3: The reflection coefficient (S11) vs frequency plot for Star shaped DRA

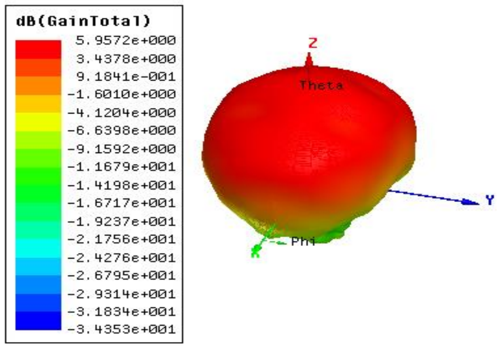

Fig.4: The overall Gain of Star DRA

The E plane field is measured by taking ϕ= 0˚and H plane field is measured by taking ϕ= 90˚. Both Co and cross polarised E-plane and H-plane field patterns are plotted when ϕ=0 (x-z plane) and ϕ=90 (y-z plane) are taken at 2.44 GHz as plotted in Fig. 5. Also, cross polarized fields are very weak in the broadside direction which is less than -20 dB. The co-polarized which is desired polarised component and the cross polarized which is undesired polarised component for both E- and H- planes are presented here. The ratio of Co polarised and cross polarized fields in the broadside direction (ϕ= 0˚) is nearly 33 dB which is enough high. This cross polarized power levels are at 33 decibels down compared to the desired Co polarised power level.

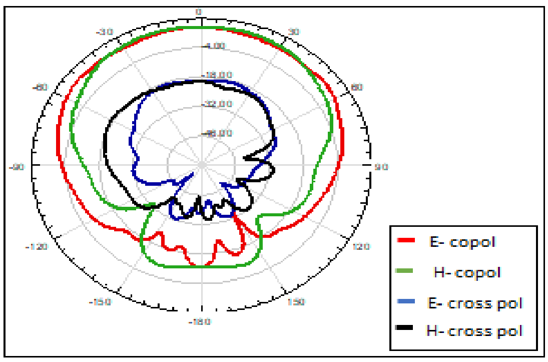

Fig.5: Co- polarized and Cross polarized E and H plane field patterns at 2.44 GHz.

IV. RECTENNA DESIGN

The rectenna system consists of an antenna as receiver and AC-DC converter circuit. A receiving antenna receives the electromagnetic waves within predefined specific frequency spectral range,

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followed by appropriate impedance matching circuit to ensure proper coupling between the antenna and rectifying circuit to achieve maximum power transfer.

Since our system basically consists of an antenna, a rectifier circuit (nonlinear element) and filter, a proper impedance matching circuit between the proposed antenna and rectifier is required to ensure maximum power transfer and optimum performance. To generate proper impedance matching circuit ADS 2017 impedance matching utility is used where optimization of impedance matching components can be done according to our goals with maximum power delivered to the load.

The return loss vs frequency plot data of TDRA in the form of s1p file exported from HFSS software is imported in ADS-2017 software and the impedance matching circuit is designed between s1p (S11 parameter) data file and Schottky diode based Half wave voltage doubler rectifier circuit. After designing, tuning and optimizing, the designed impedance matching circuit with proper matching is exposed in Fig.6.

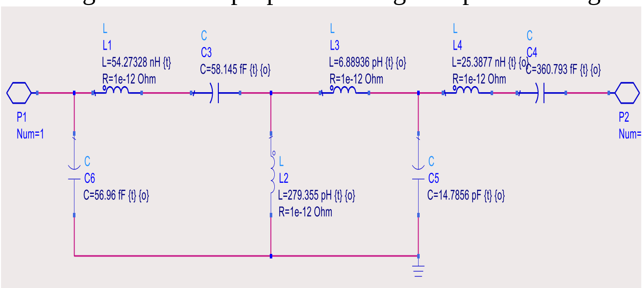

Fig.6: Impedance matching circuit for Half wave voltage doubler rectifier circuit

The implemented final impedance matching circuit of Rectenna system using a half wave rectifier and voltage doubler circuit after converting the inductor and capacitor components into microstrip components is drawn in Fig.7.

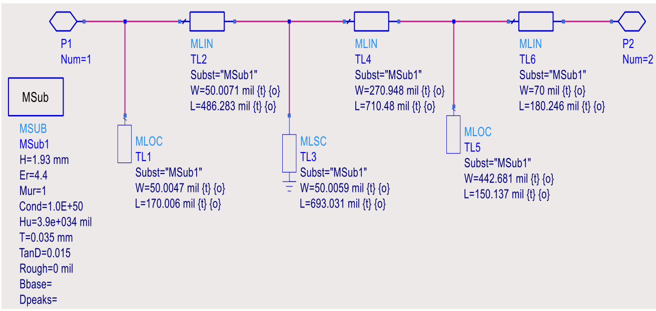

Fig.7: Impedance matching circuit for Half wave voltage doubler rectifier configuration

Fig.8 shows the whole system, including the Rectenna system including impedance matching circuit, rectifier circuit, capacitor filter, voltage doubler circuit and load on one simulation platform in ADS software.

V. SIMULATED RESULTS OF RECTENNA

After implementing Rectenna system in ADS-2017, different parameters and quantities are measured and analyzed at 220 Ω load by giving 25 dBm input power.

Fig.9 shows S11 parameter vs frequency plot in ads. This plot is approximately same as measured in HFSS software shown in Fig.3 from 2.3961 GHz to 2.5123 GHz. Hence this plot shows that there is a perfect impedance matching between the antenna and rectifier circuit.

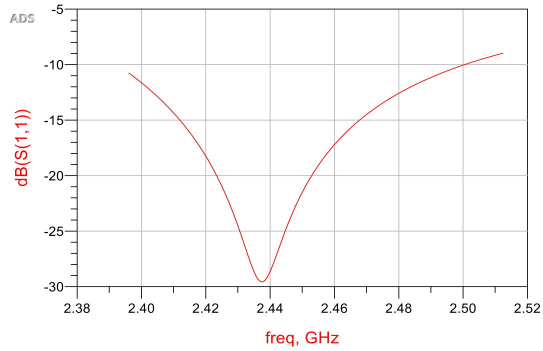

Fig.9: S11 vs frequency plot in ADS

Currents at the input and output ports are shown in Fig.10. Here, the output DC current is 31.86 mA with 35 mA peak AC current.

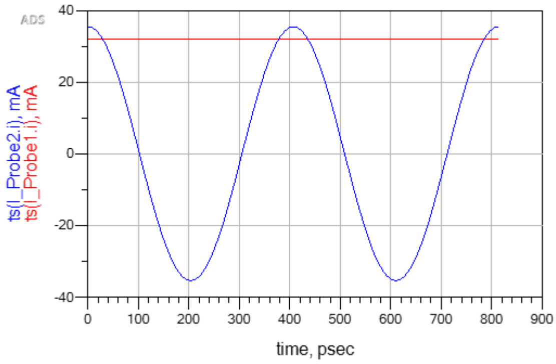

Fig.10: Output DC current and Input AC current plot with 220ohm load in ADS

Fig.11 shows output voltage and input voltage level with 220ohm load. 3.398 V output DC voltage is measured with 6V peak AC input voltage.

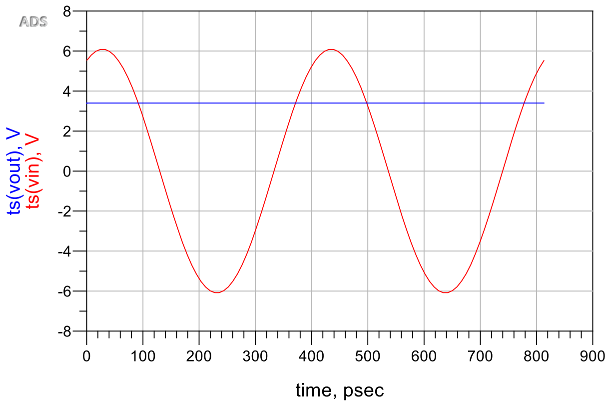

Fig.**11: Output DC voltage and Input AC voltage with 220ohm load in ADS**

Furthermore, the conversion rf-dc efficiency of the rectifying circuit as a function of load resistance is calculated for 25 dBm input power as shown in Table-1 and is plotted as shown in Fig.12. It shows that the efficiency is 68.75% at load 360 ohm, so 360 ohm is optimum load resistance.

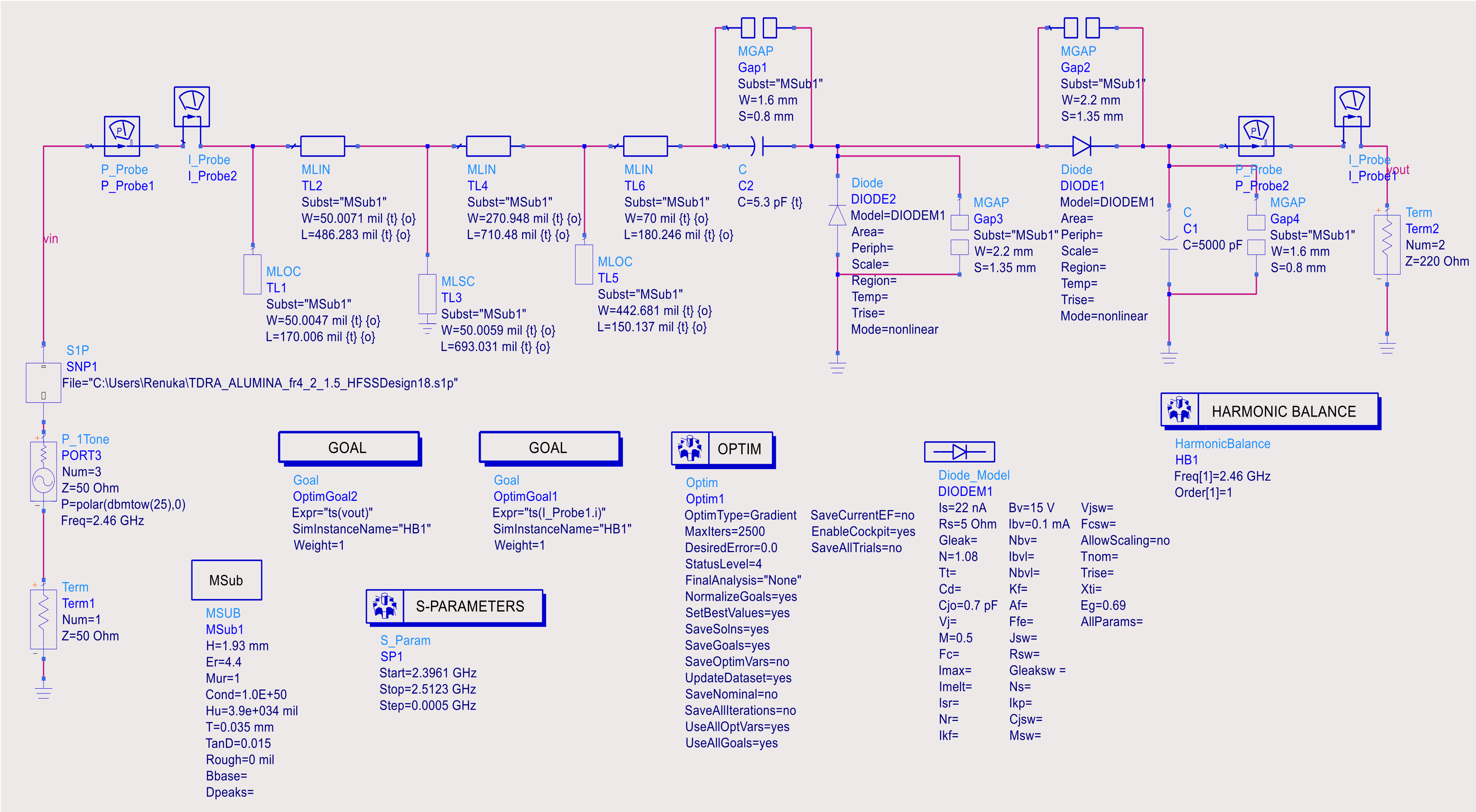

Fig.8: The Schematic diagram of Rectenna system with Half Wave Rectifier configuration

Table-I: Efficiency and output voltage with respect to Variable load resistances.

RL	50	100	220	300	360	470	510	560
Eff. (%)	48	60	67	68.1	68.7	67.5	67.8	66
Vout (V)	1.5	2.3	3.3	3.7	3.9	4.2	4.3	4.5

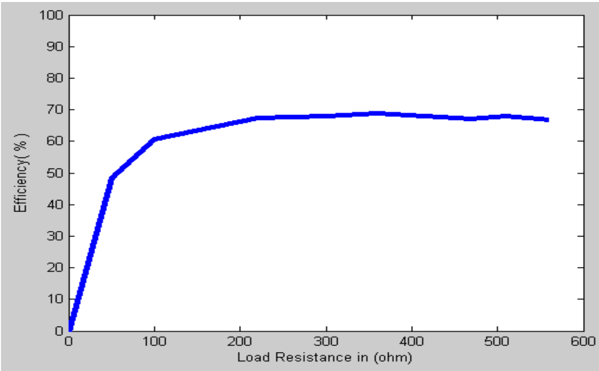

Fig.12: Efficiency vs load resistance at 25 dBm input power

Now, RF- to- DC Conversion Efficiency and output DC voltage as a function of output power with various input power levels at 2.44 GHz frequency by considering 220ohm load resistance. Aeff is 47.45 cm^2 by considering λ=c/f=12.24 cm at 2.44 GHz frequency, GR= 6dB=3.98 (Antenna gain)and P_D = received power density (w/m^2) of star DRA. The input power is varied from 10 dBm to 40 dBm to measure output power and then plotted conversion efficiency vs antenna power densities as shown in Fig.13.

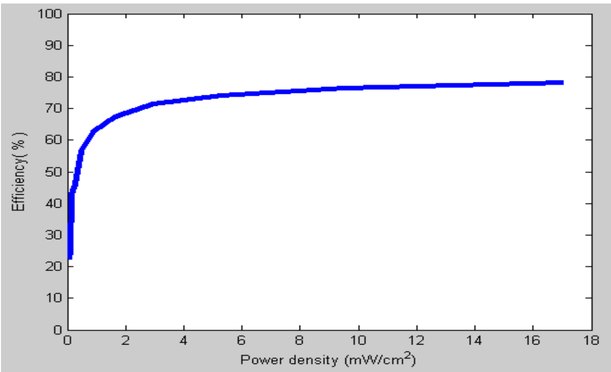

Fig.13: RF to DC conversion efficiency with variation in power densities at 220 ohm load

VI. CONCLUSION

Accordingly, the Dielectric Resonator Antenna with high antenna efficiency, design rectennas for RF wireless energy harvesting are implemented and parametric studies are carried out. It is observed that the overall gain is 5.9672 dB, and the impedance bandwidth is 4.7% (2.36- 2.5 GHz) with 2.43 GHz resonant frequency. The overall gain of 5.9672 dB is high enough to use the antenna in wireless applications at 2.44 GHz resonant frequency. The received signal from antenna is fed to Rectifier through impedance matching circuit and then fed to Half wave (HW) rectifier with voltage doubler circuit including filter. The simulated results show that 31.86 mA output DC current, 3.398 V output DC voltage and 20.625 dBm DC power are achieved at 220ohm load for 25 dBm AC power. It is determined that Rf -DC efficiency rises with increasing power densities of antenna up till 17.043 mw/cm2 power density. The highest efficiency achieved by this proposed rectenna is 78.25% at 17.043 mw/cm2 power density for 35 dBm input power. Also, the efficiency increases with increasing load resistance at 25 dBm input power up to 360-ohm load.

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