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Dielectric Resonator Rectenna System using Full Wave Rectification Configuration

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Abstract**:** ***With the wireless communication advances in the recent years, the level of RF energy present in the environment rises day by day. Only fractional part of RF energy presented is used, on contra, the remaining RF energy is the wastage in the form of waves that become challenging issue to harvest. Here, one of the RF harvesting systems known as Rectenna is implemented. Star shaped Dielectric Resonator Antenna (DRA) is used as receiver to collect RF energy at ISM frequency band (2.45 GHz) from atmosphere. The received RF energy is fed to Full wave rectifier circuit. The parametric study shows the 24.733 dBm power is harvested for 30 dBm input power is fed. The maximum 81.67 % RF to DC conversion efficiency is achieved.***

Keywords **:** ***Dielectric Resonator Antenna, Full wave Rectifier, impedance matching, Star DRA.***

I. INTRODUCTION

In these recent times, the energy harvesting from electromagnetic and exploiting system has been enhanced as the interesting research area matter around the world to reduce the wastefulness of unused rf power within the atmosphere as the presence of microwave frequencies in atmosphere very dangerous to living things' health directly or indirectly. Thus, the receiving the signal having a desired resonant frequencies & converting it into dc signal is one of the challenging research area in RF energy harvesting system. [1] Moreover, Some of the electronic components, semiconductor devices, transducers or sensors receives power, converts into another form of power, but they are expensive, unsuitable to replace battery and sometimes inconvenient. There are very less options to deliver wireless power. As a result, the transformation of wireless power requirement has been enlarged for RF wireless power supplier in the area of communication systems. Hence, the RF Energy harvesting systems are attractive among other RF wireless power suppliers as they are substitutes of DC sources in wireless communication devices operated on low power supply. The methods for acquiring, converting and storing the RF energy are very important for an RF energy harvester as an unused RF energy presented in environment is utilized and RF pollution of environment can be avoided.[2] Hence, It is called as green for the environment. Also, human health become safe from RF radiations.[2]

Rectenna is one of the most important section of the RF energy harvesting system. Mainly, The Rectenna system is combination of a receiving antenna and rectification module.

An antenna which is heart of rectenna first receives RF signals in desired frequency range and fed to the rectification circuit through the ensured coupling. The proper coupling is necessary for getting impedance matching to achieve maximum power transfer to load [3,4].

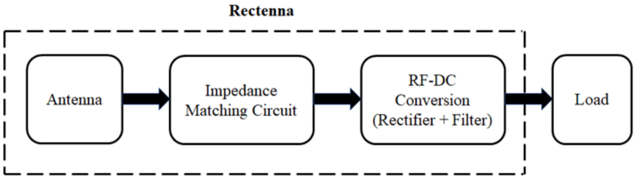

Fig.1: The functional block diagram of Rectenna system

The output of Rectifier is not pure DC signal. To block AC harmonics produced due to nonlinear characteristic of the diodes and smooth out the DC signal, a Capacitor filter is connected at the output of rectifier circuit. Unwanted power distortion and noise signal can be also avoided with this circuit. The amount of harvested energy depends upon the rectenna system efficiency (i.e. RF-DC efficiency/ ηRF-DC), distance between rectenna antenna and RF source, propagation path medium, antenna efficiency, antenna gain, directivity and strength of RF power existing in a medium. The overall AC-DC conversion efficiency can be calculated by

$$\eta_{RF-DC} = \frac{output\ DC\ power\ at\ load\,(P_{DC})}{input\ AC\ power\ received\ by\ antenna\,(P_{AC})}$$

And hence,

$$\eta_{RF-DC} = \left(\frac{(V_{DC,out})^2}{R_{load}}\right) * \frac{1}{P_D * A_{eff}} \qquad (1)$$

Since last two to three decades, A Dielectric resonator antenna is more attractive because of its major advantages like high radiation efficiency. hence it is used as a receiver antenna [5] .

II. RECTENNA DESIGN

To design the rectenna, an Antenna with high radiation efficiency is considered. First, the Star shaped DRA is implemented by applying self-similarity property of fractal geometry on Triangular DRA at 2.45GHz resonant frequency and 5.93 dBi of overall gain is achieved[6].

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Consequentially, the rf signal received by the antenna is given to the input of the Full Wave Rectifier circuit through proper impedance matching circuit. If Rectifier circuit is not properly matched to the antenna, the part of rf power received by antenna cannot absorbed by a rectifier and reflected back to the environment and the rectified power is automatically reduced. Hence the design of the proper impedance matching circuit is crucial in the rectenna system as the impedance will change as a function of both input power and frequency due to the nonlinearity of the rectifying for optimum performance. Impedance mismatching is also responsible for degradation of conversion efficiencies. The matching circuit is a combination of shunt and series capacitors and inductors.

There should proper impedance matching between the Star DRA and Full Wave Rectifying circuit. This is achieved by exporting the impedance parameter (S11 parameter) vs frequency plot data form HFSS into ADS 2017. Fig .2 shows the final optimized impedance matching circuit. The components are inductors and capacitors only.

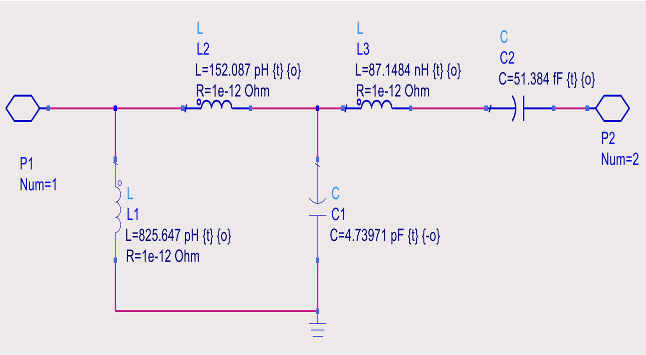

Fig.2: Impedance matching circuit for between star DRA and Full wave rectification circuit

These components of impedance matching circuit are not realizable physically, we have to convert them into equivalent Transmission line components. When designing microstrip line components, it is necessary to create lumped component elements for shunt and series capacitors and inductors. This causes ease of fabrication. So the microstrip components are converted and the converted components are shown in fig.3 for the full wave rectifying configuration based rectenna system

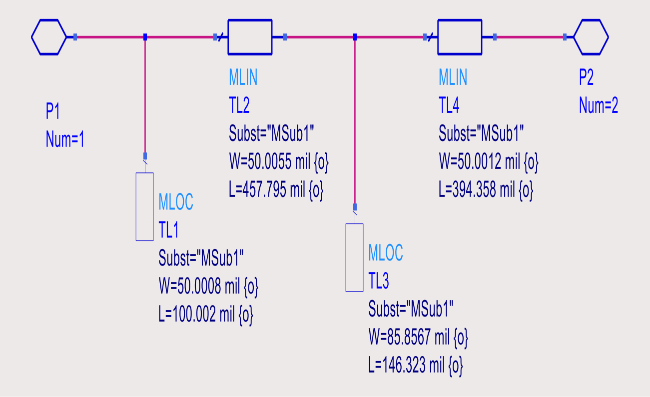

Fig.3: The equivalent microstrip component circuit for impedance matching.

Fig.4 shows the whole system, including the Rectenna system including impedance matching circuit, rectifier circuit, capacitor filter, and load on one simulation platform in ADS software. Fig. 4 shows full wave rectifier circuit wave Rectifier circuit. D1, D2, D3 and D4 connections shows the bridge rectifier configuration. Capacitor C1 is used as filter to suppress AC components from Rectified DC signal. D5 and D6 configuration is used as a zero-impedance equivalent circuit to void short circuit of D4 diode when it conducts.

III. PARAMETRIC STUDY OF RECTENNA

The parametric studies are carried out after implementing Rectenna system in ADS-2017. The results are evaluated at 220 Ω load by taking 25 dBm power as an input.

As a result , the DC current of 21.37 mA is achieved with respect to 48 mA peak AC current which is output current of antenna as plotted in fig.5.

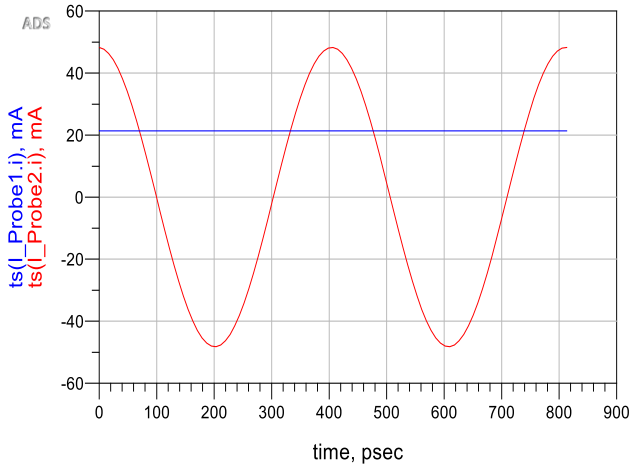

Fig.5: The plots of output DC current of the load and AC input current

Fig. 6 shows output power and input power level with 220Ω load. 23.444dBm of output DC power is measured with 24.733 dBm peak AC input power.

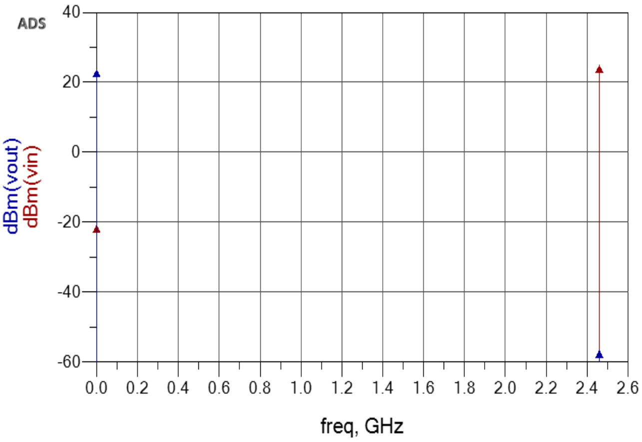

Fig.6: Output DC power and input AC power at 2.4 GHz frequency with 220 ohm in ADS

Furthermore, the output load voltage of 4.7 V is measured with respect to 5.5 V peak input voltage at the load of 220 ohm as shown in Fig.7.

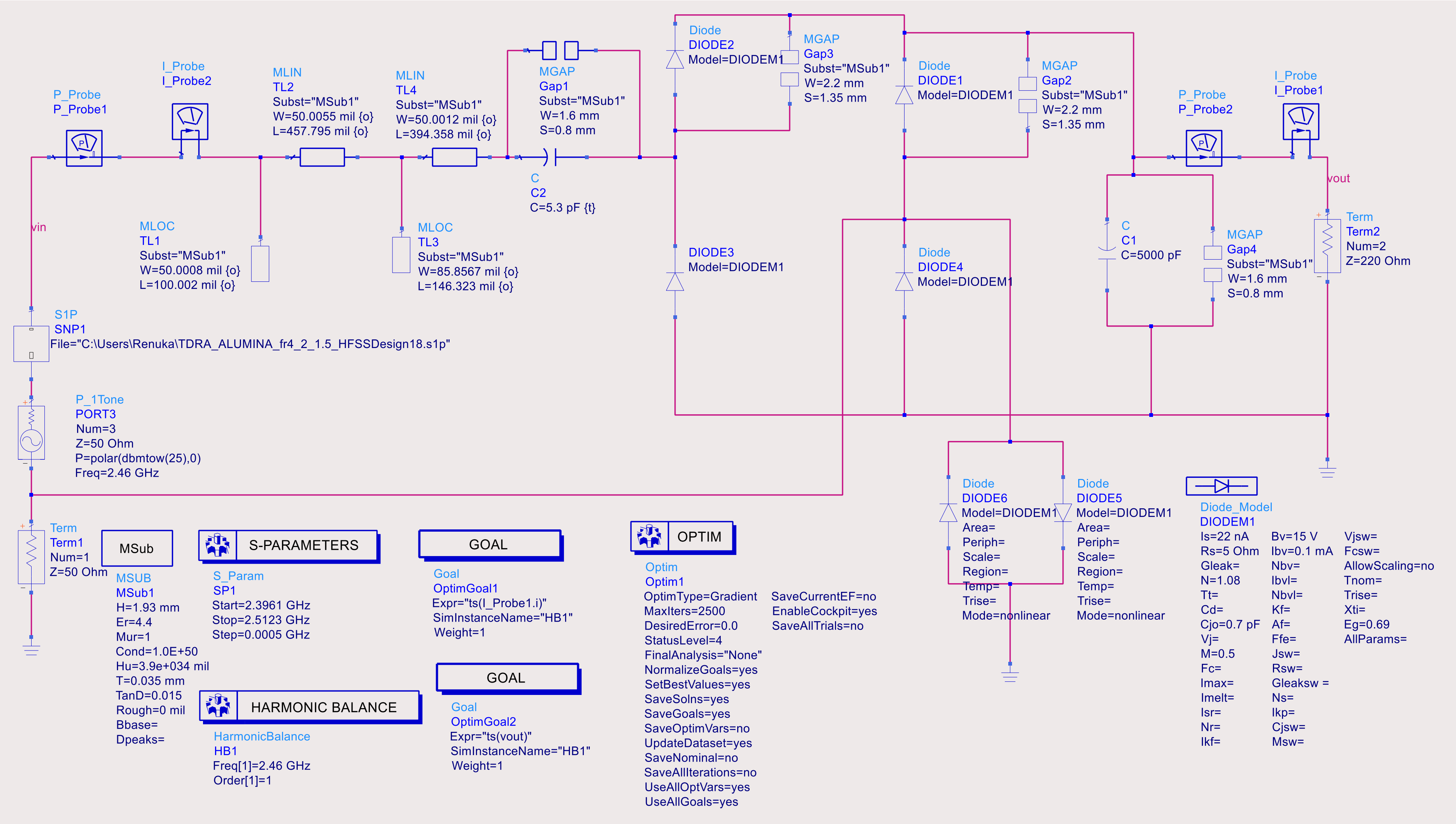

Fig.4: The layout of Rectenna system based on Full Wave Rectification configuration

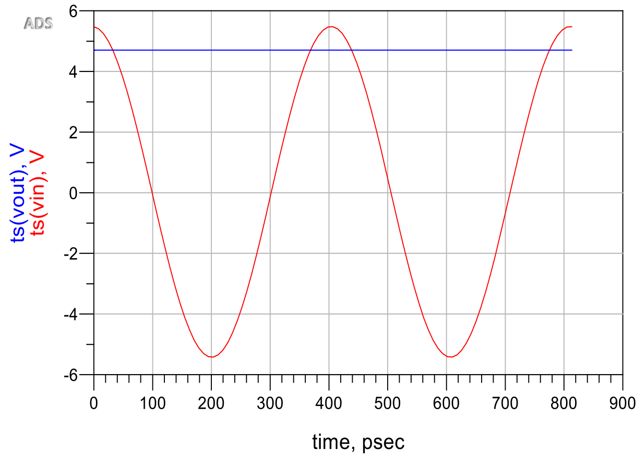

Fig.7: The waveforms of output DC voltage and input AC voltage of the system at 220ohm load resistance.

Additionally, the rf to dc conversion efficiency of the system is measured at different load resistances by feeding 25 dBm AC power and tabulated in table-I. the plot of efficiency vs load resistance shown in fig.6 states that the efficiency increases as increasing load upto 470 ohm and maximum efficiency of 81.67% is achieved. Further increasing load, efficiency starts to decline. So, 470 ohm is maximum load which can be connected.

Table-I: The measurement of Efficiency and output voltage at different loads.

RL	50	100	220	300	360	470	510
Eff. (%)	49.02	64.17	75.76	79.85	80.95	81.67	80.67
Vout (V)	1.58	2.77	4.70	5.55	6.05	6.59	6.99

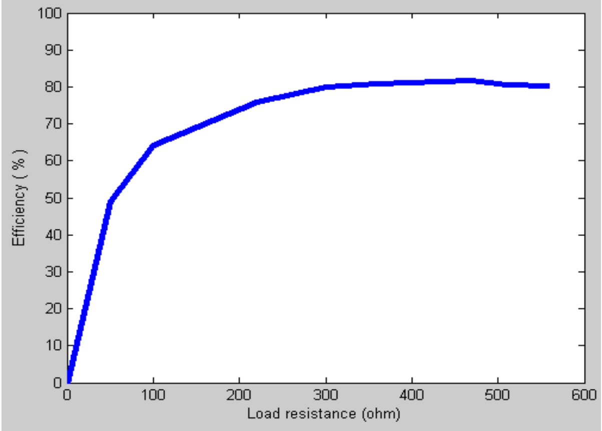

Fig.8: The variations in efficiency with respect to different loads by taking input power of 25 dBm.

Now, consider wavelength(λ)=c/f=12.24 cm, antenna received gain(G_R)= 5.93dBi and the effective area(Aeff)= 47.45 cm^2 at resonant frequency of 2.45 GHz. As a result, The RF- to- DC conversion efficiencies and output dc voltages are measured with respect to various input power levels at 220ohm load resistance and plotted as shown in fig.8 and fig.9 respectively. P_D is the received power density (mw/cm^2) of Star shaped DRA. It shows that the rf to dc conversion efficiency of the rectifying circuit increases as increasing in input power densities of the antenna up to 32.5 dBm input power and 16.0591 mw/cm2 antenna received power density. When 32.5 dBm input power is applied, 83.22 % highest conversion efficiency is achieved with 11.81 volts output voltage having 16.0591 mw/cm2 antenna power density by taking 220ohm load.

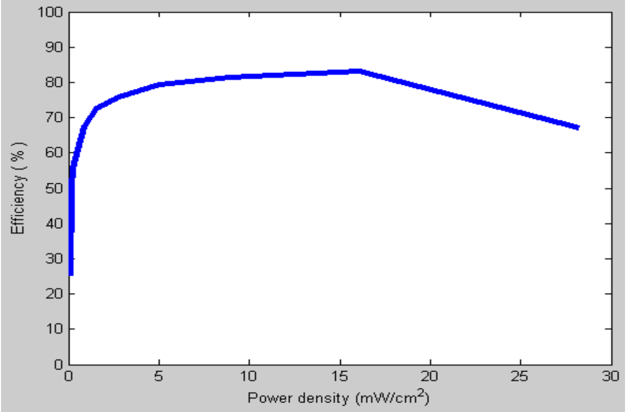

Fig.8: RF to DC conversion efficiency with variation in input power densities at 220 ohm load

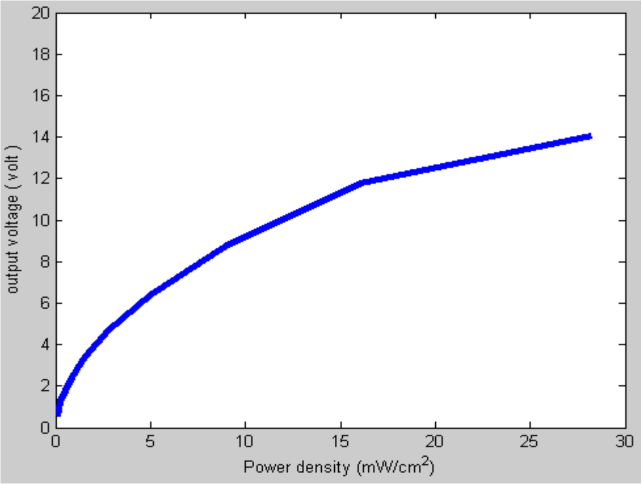

Fig.9: The variations in output voltage with respect to different input power densities at 220 ohm load

IV. CONCLUSION

All in all, the rectenna system with full wave rectifier configuration is implemented and parametric studies are carried out. From measurement it is concluded that The results show that the RF to DC conversion efficiency of the rectenna improves as increasing in input power densities of antenna up to 32.5 dBm input power and 16.0591 mw/cm2 antenna received power density. When 32.5 dBm input power is applied, 83.22 % highest conversion efficiency is achieved with 11.81 volts output voltage having 16.0591 mw/cm2 antenna power density by taking 220ohm load. Additionally, 21.37 mA and 4.7 Volts are observed at the output of 220 ohm load. Also 23.444 dBm of DC power is harvested at the 220 ohm load.

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