DESIGN OF RECTENNA FOR BATTERY LESS SENSOR USING RF POWER HARVESTING

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***Abstract:** In this paper, we propose a compact and highly efficient Rectenna design (rectifying antenna), operating on ISM band with the center frequency of 2.4 GHz. A RF to DC conversion through Schottky diode (HSMS2860) is used to generate the dc voltage to operate a battery-less IoT Sensor for RF power harvesting using the designed Rectenna. We have achieved more than 80% efficiency through Advanced Design System (ADS-2016) simulation software at different power densities. Further a rectenna circuit is designed using RF to DC Schottky detector diode and a microstrip patch antenna. The rectenna circuit design is simulated through ADS 2016 simulation software. The Battery less sensor requires 2V- 2.5V dc voltage to perform an optimum performance. As per simulation and theoretical/practical modeling we have achieved more than 80% efficiency at single Schottky diode and its operating from 915 MHz to 5.8 GHz. Rectenna operates at lower power densities start from 0.4uW/cm. The proposed rectenna design is a possible candidate to be used as sensors/devices at frequency of 2.4GHz with current technologies e.g. ZigBee, Wi-Fi, BLE and future probable application could be long range radio sensor using the latest new generation LoRa technology its line of sight range between 10km-20km.*

***Keywords-** Rectenna, Antenna, RF power Harvesting, RF to DC, Remote Battery less Sensor, IoT's.*

I. INTRODUCTION

In recent years no of innovations and developments are growing very fast in the field of communication and RF technology. I am introducing here the Battery less rectenna design which could be a probable solution for new generations sensors and RF nodes with without battery component. We know the design and concept antenna but when the Antenna interface with a rectifying circuit and converts RF field to DC useful voltage called the Rectenna. It's a different type of antenna used to convert electromagnetic energy signal into a dc voltage. In RF power harvesting first, we capture the RF power signal and convert to an ambient electromagnetic wave. Rectenna is a very important element in such a system or it's a rectifying antenna consisting of receiving antenna and rectifier circuit. It converts the RF to dc voltage and terminated by a resistive R load. The rectifier circuit consists of Schottky diode and required matching components. The diode generated the higher order harmonics noise which rejected by impedance matching between diode and antenna. The DC voltage received at the output of the rectenna and the filter restrict the high frequency noise components. In this paper explained the design and concept of an efficient Rectenna which is operating at 2.4 GHz frequency band. A prototype of a Battery less sensor node application, operating from ultra-low power densities, also developed and is discussed in this paper. The efficiency optimization is the most important aim while designing of rectenna circuit. Its critically dependent on antenna operating frequency, RF captured power, and the output circuit load.
The rectenna efficiency mostly affected due to diode losses and matching circuit between antenna and rectenna circuit.

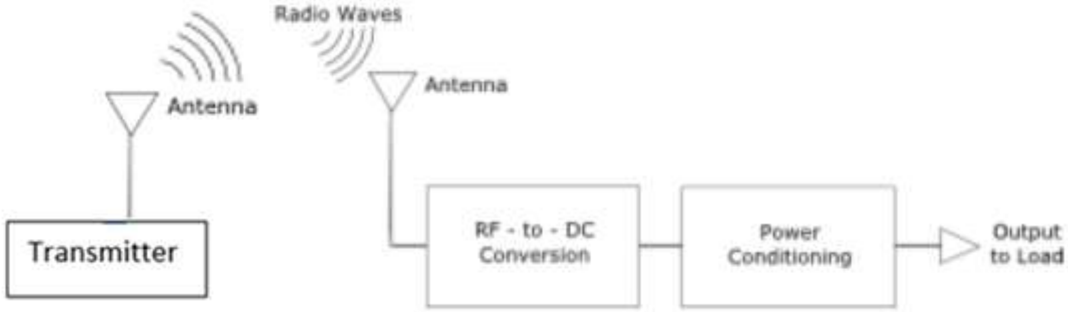

Fig. 1: Concept of Battery less Sensor RF Power Harvesting

The antenna collected the wireless energy and its interface with rectifying diode through filter and matching circuit. The new generation wireless communication development system and very less power consumption technologies have been introduced e.g Battery operated sensors, devices and nodes in energy efficient applications as per required geographic locations and its demands the low power consumption so that lower power requirement is the main criteria before reaching the full operational use.

In Smart applications have been used very low power devices and here very attractive solution can be developed using the RF harvesting without battery application. These applications are being used in smart city, lower power consumption devices, IoT's devices, GPRS, 3G,4G solutions. It's very attractive and competitive in urban and semi-urban environment as like other sources sunlight, vibrations, thermal.

II. ELECTROMAGNETIC FIELD STUDY

As the demand for wireless sensor technology-based applications are increases, the need for external power supply drastically increases as well. Besides the problems of recharging and replacing, size and weight, batteries are an exhaustible source with an adverse environmental effect. For these reasons, it is highly desirable to find an alternative solution to overcome these power limitations [1].

The environment represents a relatively good source of available energy compared with the energy stored in batteries or supercapacitors. In this context, energy harvesting, also known as power harvesting and energy scavenging, is an alternative process for primary batteries, where energy is obtained from the ambient environment. An energy harvester typically captures, accumulates, stores, and manages ambient energy to convert it into useful electrical energy for battery less sensor application. The use of energy searching minimizes the maintenance and cost of operation; therefore, batteries can be eventually removed in WSNs as well as in portable electronic devices [1].

Many potential ways to harvest energy from environment are available, including solar and wind powers, radio frequency energy and ocean waves, and thermal energy and mechanical vibrations. Hence, many papers have been published on energy harvesting as a feasible alternative to batteries. Therefore, the battery-less sensor uses the power harvested to provide measurements of air's temperature and velocity. A completely different approach is proposed. The ambient electromagnetic field in the urban and semi urban environments become ever more important and raises a growing interest last years. In fact, base stations for mobile telephony and several other RF transmitters' springs up everywhere around the word. Moreover, several RF spectral surveys were conducted to estimate the ambient electromagnetic field levels. Here we have taken reference it has been presented and discussed some measurements performed by the ANFR, the National French Agency for Frequencies management [1]. The major RF contributors in the UHF band (0.3 - 3 GHz), are the digital television (DTV), the GSM 900 and 1800, the UMTS and the Wi-Fi Bands. The measured electric field strength, from a selection of 20 points close to base stations (~10 to ~100 meters) in Paris and surroundings, at each of the following frequency bands: DTV (470 to 790 MHz), GSM-900 (921 to 960 MHz), GSM-1800 (1805 to 1880 MHz), UMTS (2110 to 2170 MHz) and Wi-Fi (2400 to 2480 MHz) [1]. Results show that the electric field strength is around about 1 V/m. We consider a 2.15 dBi gain dipole antenna and an incident plane wave of E = 1V/m (ρ = 0.265 µW/cm²). Results show that when the frequency increases, the effective aperture (Aeff) and the captured RF power (PRF) decrease [1].

It's an important to note that the power density available depends on the radio frequency source and the distance. Values of this power are presented in below reference table for different RF energy sources [2]

Table 1 - Available Power density

Source	Distance	Power Density
50km Am radio station	5/10km	159/40[uW/m2]
100 GSM base station	100/1000 m	800/8[uW/m2]
0,5 mobile phones	1/10 m	40/0.4[mW/m2]
1W Wi-Fi router	1/10 m	80/0.84[mW/m2]

III.SIMULATION/EXPERIMENT APPROACH

We have produced variable power density using signal generator and an amplifier. Measurements is performed by varying the distance R from the antenna transmitter to the rectenna circuit or the output power. Through load resistance measured the output voltage and its connected to the voltmeter.

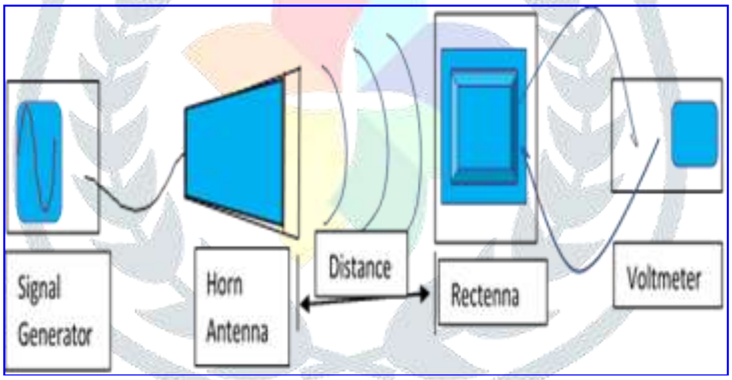

Fig. 2: Test the Rectenna performance

IV. RECTENNA DESIGN

Essential elements of the rectenna

The antenna of rectenna can be any type such as a dipole, Yagi-Uda antenna, microstrip antenna, monopole, coplanar patch, spiral antenna, or even parabolic antenna. We have selected a microstrip patch antenna operating at 2.4GHz, W=47mm, L = 39mm, FR4=1.6mm material is used,

Dielectric constant Er =4.3

Rectifying circuit is used as rectenna

Single Schottky HSMS2860 rectifier diode used for RF to Dc conversion purpose. The circuit, especially the diode, mainly determines the RF to DC conversion efficiency.

***Advantages for rectenna*:**

The life time of the rectenna is almost unlimited and it does not need replacement. It is "green" for the environment (There is no deposition to pollute the environment) used in Energy harvesting applications.

Rectenna design concept:

The rectenna circuit design consists of three elements: Antenna, matching network (transmission line), and rectifying circuit (diode) as shown in Fig. 3, 4 & 5-

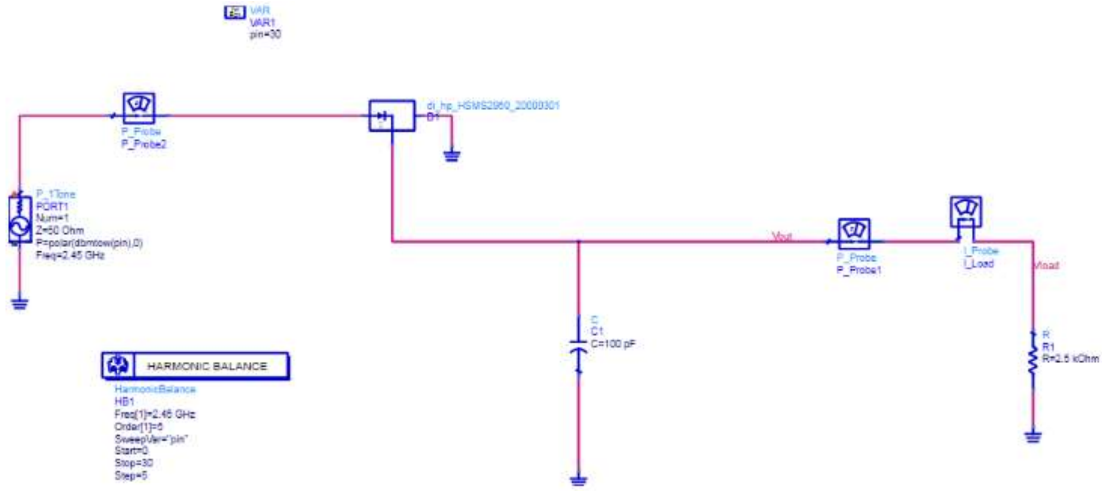

Fig. 3: Rectifying circuit, transmission line and Antenna

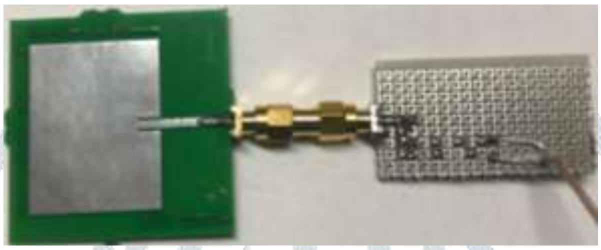

Fig. 4: Proposed Rectenna design.

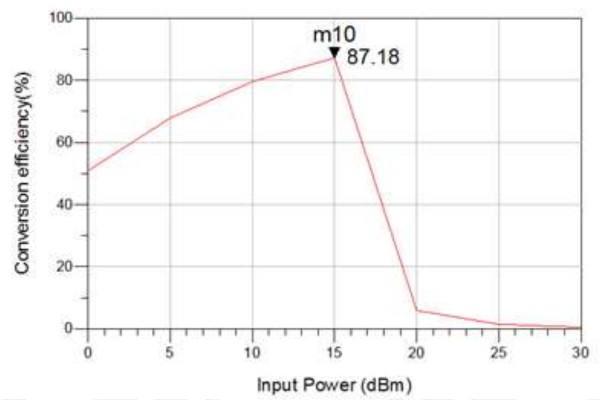

Fig. 5: Rectenna Efficiency (Using ADS 2016).

The selection of antenna has a great effect on the size and the order of the system's complexity. Patch antenna with a probe feed often causes a multilayer architecture. The rectifying circuit and patch antenna share a common ground and are located on the different layers. This architecture reduces the coupling between antenna and rectifying circuit to some extent. Patch antenna fed with a microstrip line often causes single layer architecture. The patch and rectifying circuit is in the same plane. The larger size is often needed compared with the multilayer patch antenna architecture. Coupling between the antenna and rectifying circuit also should be considered in the design. The planar dipole, loop, and bow-tie antenna often reach single plane architecture. The filter, matching network, and rectifying circuit usually are realized by the coplanar strip line. This architecture often leads to a very low system cost. Using the harmonic rejection antenna in the rectenna for saving a filter part has been reported. In this way, the insertion loss introduced by the filter can be eliminated and higher system efficiency can be expected.

Bandwidth: To maximize the output power at given location for that the rectenna collected energy from systems operating at different frequencies.

Impedance matching: To optimize the rectenna for maximum power transfer, the antenna impedance must be matched to the impedance of rectifier diode. For example, A Schottky diodes were used for rectification, and a source-pull simulation was used to obtain the diode input impedance. For a variable input power, the resulting DC voltage is quantified for each source. The results shown on the Smith Chart indicate that the optimum source impedance should be presented to each diode moving counter-clockwise with an increase in frequency and closer to the center of the Smith Chart with an increase in input power. The region of optimal source impedance is used to optimize the antenna design which needs to match the diode impedance.

Efficiency: The efficiency of the rectenna system is basically equivalent to its transfer function. RF-DC conversion efficiency of the rectenna with a diode depends on the microwave power input intensity and the optimum connected load. When the power is small, or the load is not matched, the efficiency becomes quite low. The efficiency is also determined by the characteristic of the diode which has its own junction voltage and breakdown voltage, if the input voltage to the diode is lower than the junction voltage or is higher than the breakdown voltage the diode does not show a rectifying characteristic. As a result, the RF-DC conversion efficiency drops with a lower or higher input than the optimum. It is worth noticing that all the recorded high conversion efficiencies were generated from high power incident level due to the reason we mentioned above. For low power incident level, a measured conversion efficiency also low achieved at a power incident of 250 µW/cm2, of course, in principle a high efficiency should be achievable.

Table2 - Battery less Rectenna Design parameters

Sr. No	Design Parameters Name	Parameters
1.	RF Transmission Power	PTX=100 mW
2.	Input received power	Pin = Pd x Aeff
3.	Specified distance (R) reference to Fig. 2.	R=140 m
4.	Power Density (uW/cm2)	Pd = PtGt/4πR2
5.	Aeff (Effective area/ aperture)	Aeff = λ2 x Gr /4π
6.	Rectenna efficiency	η = Pout / Pin
7.	Transmitting Antenna gain	Gt = 2.15dBi
8.	Receiving Antenna gain	Gr = 2.15dBi
9.	Speed of Light	C = 3x10^8
10.	λ0 - speed of light / frequency m/sec	λ0 = C/f (m/sec)

1. The **efficiency of the rectenna** system is basically equivalent to its transfer function. The general definition of any efficiency (η) used hereafter is the ratio of the output power Pout over the input power Pin,
   η = (Pout / Pin) x 100 → (1)
2. The conversion efficiency (η) of the whole x` is the DC power at the receiver end over the AC input power captured by the system (antenna). This efficiency is strongly dependent on the power density (Pd) distributed across the receiver aperture. The maximum incident power density can be expressed as Pd=Pt x Gt/4πR2 → (2) Pd = 0.87uW/cm2
3. Where Pt is transmitted power, Gt and Gr are the gains of the transmitter and receiver antennas, and R is the distance
4. The effective area Aeff for antenna is given as Aeff = λ2 x Gr /4π → (3) Aeff= 96.92cm2
5. Therefore, use equations (2) and (3) to obtain the power received by antenna
6. As Pin = Pd x Aeff → (4) Pin= 84.6uW
7. Because the rectenna output is DC power, thus the output power we can obtain from the output voltage generated on the load resistance by Pout = V2 out. DC/Rload →(5) Pout=75uW
8. Therefore, from equation (1), (4) and (5) the conversion efficiency can be obtained by
9. η = ((V2out.DC/Rload)/Pd x Aeff)*100 →(6) η = >87%
10. We should have pointed here the definition is slightly different from the one used in the photovoltaic community and it will give higher efficiency due to the use of the effective aperture rather than the physical antenna aperture

- **Simulation Results:** Microstrip Patch Antenna, VSWR, Return loss, Radiation patterns:

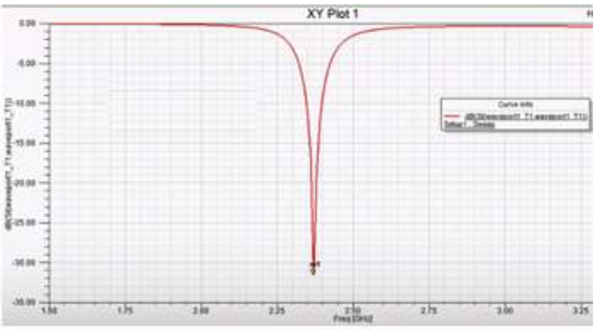

Fig. 6: Return loss (S1,1), S Parameter

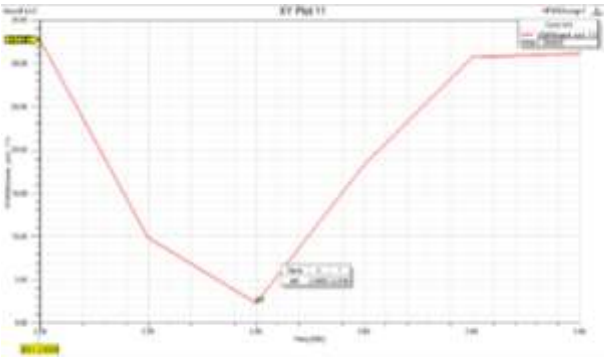

Fig.7: VSWR

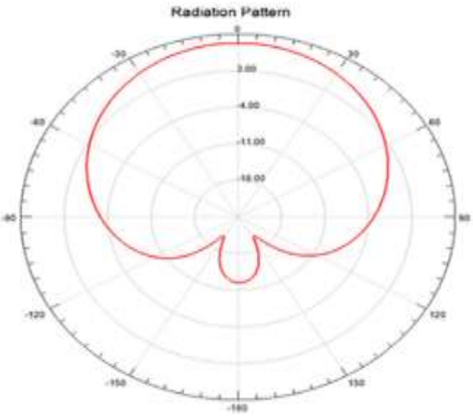

Fig. 8: Radiation Pattern

V.CONCLUSION

We have designed a rectenna for battery less sensor for RF power harvesting remote applications. It was investigated that this antenna operates in the ISM band and return loss obtained at frequency 2.4GHz is -31dB. A Rectifier circuit is also designed using HSMS2860 Schottky RF to DC conversion diode. At voltage level of 2.15V, efficiency more than 80% is achieved. The proposed rectenna could be used as sensors/devices at frequency of 2.4GHz, e.g. ZigBee, Wi-Fi, BLE etc.

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