# Triple Band Rectifier Design for RF Energy Harvesting in Wireless Sensor Networks

**K. Karthika, C. Kavitha, K. Kavitha, T. Jaspar Vinitha Sundari**

***Abstract:*** ***The atmospheric energy harvesting is a vital innovation to the achievement of wireless sensor systems. In day to day life, different form of energy resources is present better communication. Among those energy sources, Radio Frequency (RF) energy is one of the best sources with broad coverage of signals from various wireless communication systems. Collecting a wide recurrence band RF signals are valuable to support the aggregate level of energy. In this paper, the design of triple bands rectifier to rectify the harvested RF energy from cellular system frequency bands and Wi-Fi sources available in atmospheric environment is presented. Advanced Design System (ADS) simulator was utilized to design a 4-stage voltage multiplier RF energy harvesting circuit. This voltage multiplier makes use of Agilent diode HSMS-2850 for rectification purpose. The exploratory outcome demonstrates that the proposed design can gather more power than the power obtained from a single band.***

***Keywords:*** ***Ambient energy, sensor networks, voltage multiplier, rectifier, radio frequency***

## I. INTRODUCTION

A wireless sensor networks (WSN) is used to monitor the ambient conditions like pressure, temperature, humidity, etc. This type of network consists of spatially dispersed sensor nodes for sensing the environmental conditions. This has no centralized controller. The main part of wireless sensor networks is nothing but sensor nodes. Sensor nodes are also called as Mote. Sensor nodes are responsible for gathering information from the particular area and transfer it to the neighbor nodes. The significant factor for the devices is usually the life time of battery and its substitution. Concerning the Radio Frequency(RF) energy-harvesting method can crucially increase the battery life time and further the requirement for a battery can also be avoided With the development in the field of ultra-low power MCU's, wire-free transmitters and receivers and well-organized energy harvesting techniques [1], the autonomous wireless sensor network has become more and more established.

In recent days, this type of energy transfers and harvesting systems has turned out to be an alternative method to control the future generation wireless networks.

Latest advancement in Radio Frequency energy-harvesting technology had increased the feasibility of self-sustainable modules. The variety of dependable electromagnetic resources was widely broadcasted to supply energy from RF power sources [2]. But the design of proper and suitable RF energy harvesting systems to provide sufficient power is a challenging one, as the RF power density was too small. In recent years, many research works are going in energy harvesting with radio frequency for obtaining sustainable and reliable energy schemes. Generally, the RF energy sources are broadly classified into two groups: intentional sources and ambient sources.

In the current scenario, there are abundant quantity of RF power sources are available for transmitting the electromagnetic (EM) waves to the atmosphere such as wireless local area network (WLAN) routers, cellular network base stations, and TV and radio broadcasting towers [1]. Numerous other unidentified RF energy sources are also used in government sectors like military, police, amateur radios and so on. The usage of Radio Frequency power systems is increasing vastly and many research fields uses such systems in areas like portable medical devices, RFID tags, low power wireless sensors and so on. The necessity of using these energy harvesting and power transmissions have been growing for many applications.

The motivation behind utilizing hubs in a few applications, for example structural health monitoring, human health monitoring, security reconnaissance in military and combat zones, mechanical analysis in industries or to gauge the temperature, the pressure of a typical area-continuous power supply is very imperative. As the changeability of natural sources such as light, wind, rain, fog, vibration and other unpredictable weather factors, the radio frequency became the most available and popular source for harvesting energy using WSN. RF signals are abundant and constantly accessible in any ambient conditions, and further turn out to be basically free power resources.

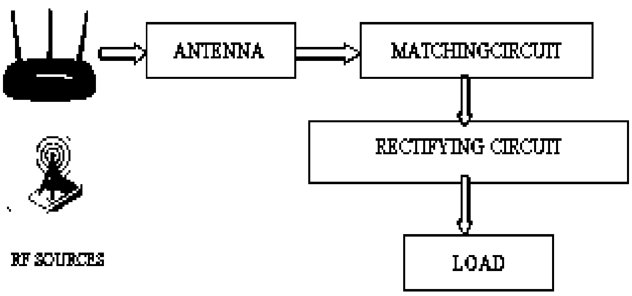


**Fig.1 Block Diagram of RF Energy Harvesting System**

The Fig.1 shows the general block diagram of Radio Frequency energy harvesting system. There are varieties of

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sources for energy harvesting. The solar panels photovoltaic are used for harvesting the solar energy. These solar panels with desired capacity help to harvest sufficient energy from the natural sunlight for applications such as from indoor lighting. When the sunlight radiation is higher, and the obstacles (such as tall buildings, shadows of tree) between the sun and the panel is low, the solar panel tends to harvest large amount of energy in the day time and reduces steadily as the sunlight decrease in evening.

The most common form of ambient energy sources is used to generate hydroelectric power, solar energy, wind energy and thermal energy from volcanic activities. The size of the wireless sensor is as comparable with the energy harvesting devices and that becomes the new challenge for harvesting energy. Sometimes due to the locations of the sensor, energy harvesting system may not yield better performance. Different parameters like characteristics of the energy sources, other requirement for their applications, nodes and protocol's power management function are all important. This requires proper tradeoff when designing energy harvesting circuits.

With the help of multiple ISM band micro-stripantennas, the new model for RF energy harvesting has been presented [3]. An antenna along with rectifier called Rectenna has also been used for energy harvesting [4]. In the modern world, the mobile technology and Wi-Fi technology has an abundant growth since these are the sources for RF energy harvesting [5].RF energy harvesting technology is not new, yet it capable to harvest a minute quantity of energy. The unused energy can be properly utilized to enhance the period of operation in WSNs and also reduce the replacement cost of battery. For low frequency operation (KHz - few MHz), rectifier circuit was designed using both p-n diodes and transistors. At microwave frequencies (f > 1 GHz), to achieve desired results, Schottky diodes are used with shorter transit times. Two diodes and two capacitors are used in voltage doubler circuit. A voltage multiplier circuits can be achieved for higher order modes by cascading sections of diodes and capacitors additionally.

Far field and near field systems are the two different categories of wireless Power Transfer and energy harvesting. Near field region is suitable for energy harvesting in the short coverage distance. It also exploits electric/magnetic induction or resonance for achieving greater efficiency [6]. In the far-field system, the RF-DC conversion was carried out by charge pumps and rectifiers to accumulate the emitted electromagnetic waves in the remotely dense region. The beam forming technique collects a huge quantity of power in the far-field region [7]. Several of the solutions headed for addressing the challenges in wireless power transfer and energy harvesting solutions are presented in much more detail. Multi-band and broadband rectifiers were used to maximize the amount of harvested power, the load variation effects were minimized [8].

## II. PROPOSED METHODOLOGY

In an idle state, a node is in the state of always being ready to receive so that it is consuming a great amount of power and that leads to a major problem. Generally battery has a very short span of lifetime. In some cases, based on the location of the sensor, replacement of battery may be practically unattainable. In the modern world, the mobile technology and Wi-Fi technology has an abundant growth. Since these are the sources for RF energy harvesting, this motivates to do the project which aims at designing a single rectifier circuit that can able to operate at three different bands (two GSM bands and single ISM band).

Good performance can be ensured by matching rectifier to the antenna at all the desired frequency bands. This requires triple-band matching network for perfect matching. The circuit complexity will be increased by the use of lumped components and conventional transmission lines.This leads to the design of multiband matching network for the rectifier.The work presented in this paperhas reduced circuit complexity and provides tuning at every matching frequency. Thus makes the circuit to operate at three desired bands.The design procedure includes harmonic balance optimization. Here efficiency and optimization objective can be maximized by assigning the output load resistor, rectifier circuit capacitor(s) and the matching networks as optimization variables. Especially, a L-matching section that contains series inductor and a shunt capacitor was used.

Impedance matching is the process to increase the power transfer from source to destination (load) and reduces the reflections from the destination (load).The matching network for the given circuit can be designed using impedance matching tool in ADS.By this waysimulating the proposed circuit and extracting its scattering parameters will allow the software to givedifferent solutions that differs among each other, on the different components that are essential to match the proposed circuit. Perfect matching can be achieved when the relationships between source impedance and the load is$Z_S=Z_L^*$where * indicates the complex conjugate.

Due to fast switching speed, schottky barrier diode is preferable for RF rectifier design. Its maximum breakdown voltage gets decreased by increasing the frequency. This will bring out a low system power capacity and low output DC voltage. There may come some losses due to diodes. To reduce diode losses

- The diode should have large saturation current.
- Low junction capacitance which results in low threshold voltage.
- Small series resistance and small junction resistance

For this, the best solution will be provided by Avago HSMS family Diodes. Here "HSMS 2850" is used. The use of this diode will minimize the losses due to diodes. The diode's specifications are as follows:

- Junction Capacitance =0.18 pF
- Saturation Current =3 e-6 A
- Series Resistance = 25 Ω

Four stage rectifier design is selected to have high sensitivity and matching at the required triple bands. The fig.2 shows the schematic of the triple band rectifier design where L1= 2.99 nH, L2= 39.01 nH, L3= 0.99 nH, L4= 0.99 nH, C=2.201 µF, C1=0.201 pF.


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The proposed design has a LC voltage boosting network at input side and three lumped inductors L2, L3, and L4 at different stages of the rectifier. These inductors are used toprovide the matching at the three desired frequency bands.

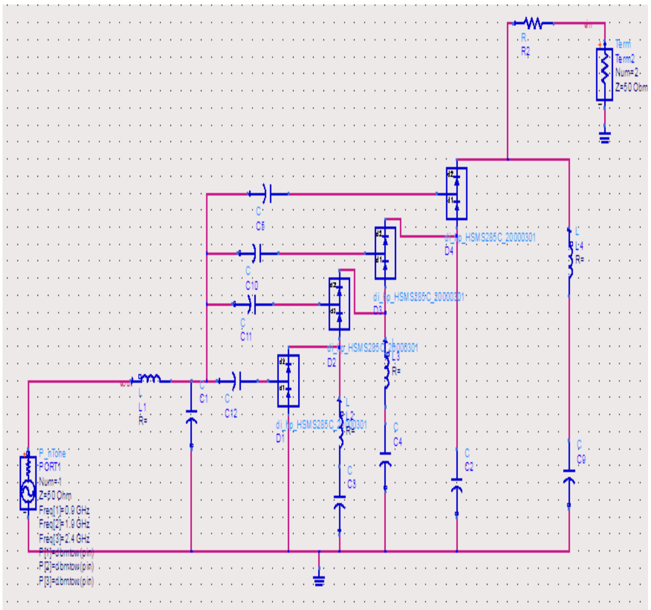

**Fig.2 Triple Bands Rectifier Circuit**

An inductor L2 is connected to stage 1 of the rectifier in series with the loading capacitor. Likewise, L3 is connected to stage 2 in series with the loading capacitor and L4 is included to stage 4. The inductors L2, L3 and L4 controls the matching at three desired frequencies. By shorting L4, the proposed circuit has a matching at 0.9 GHz and 1.9 GHz bands. By shorting L3, matching occurs at 0.9 GHz and 2.4GHz where the matching at 1.9 GHz is absent. Likewise, matching at 0.9 GHz is absentwhen L2 is shorted. From this it is clear that the inductor L2controls the matching at0.9 GHz, L3helps to provide matching for 1.9 GHz and L4takes the control of matching at 2.4GHz. Based on the proper selection of values for these inductors,it is possible to achieve perfect impedance matching at all the three desired frequency bands

## III. RESULTS AND DISCUSSION

The proposed simulation work was carried out in ADS (2009) software.Harmonic balance simulation is usedsince it is the best choice for most microwave circuits.

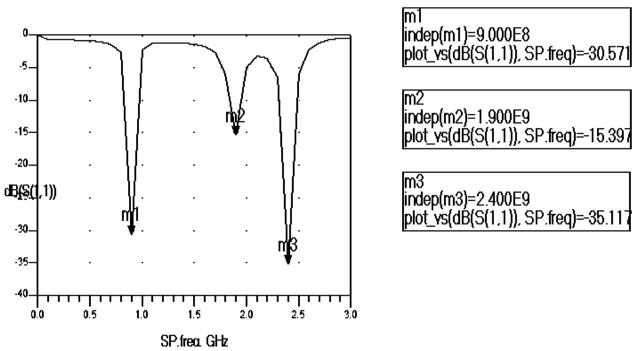


**Fig.3Simulated S11 of Triple Bands Rectifier**

The given triple band rectifier circuit resonates well at the desired triple bands and it is shown in fig.3. It also implies that at the desired frequencies the return loss is very less. The return losses are about -30.571 dB at 0.9 GHz,-15.397 dB at 1.9 GHz and -35.117 dB at 2.4 GHz respectively.

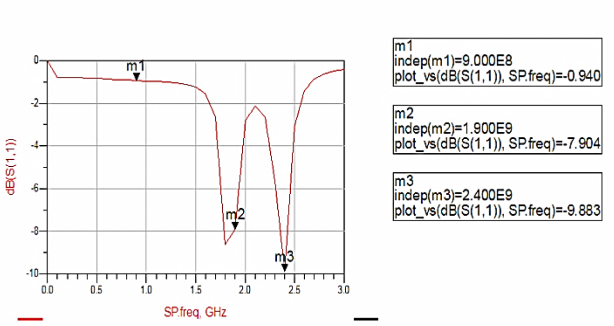


**Fig.4 Simulated S11 of Triple Bands Rectifier when L2 is shorted**

Fig.4 implies that the given triple bands rectifier circuit resonates well at two bands only. The above result was obtained by shorting the inductor L2. The return losses are about -0.940 dB, -7.904 dB and -9.883 dB at 0.9 GHz, 1.9 GHz and 2.4 GHz respectively. This implies, at 0.9 GHz most of the transmitted signals get reflected because the inductor L2that is responsible for matching at 0.9 GHz gets shorted.

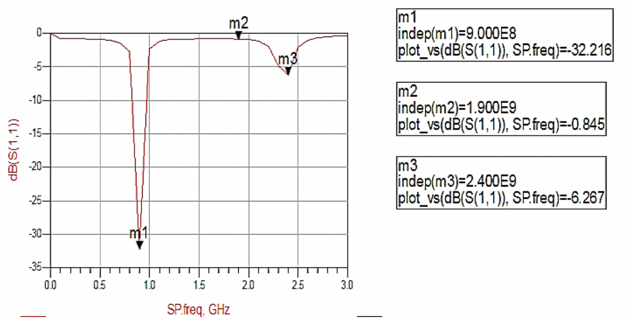


**Fig.5 Simulated S11 of Triple Bands Rectifier when L3 is shorted**

The simulated results for shorting the inductor L3 is shown in Fig.5.The above plot shows that the given triple bands rectifier circuit resonates well at two bands. The obtained return losses are about -32.216 dB at 0.9 GHz, -0.845 dB at 1.9 GHz and -6.267 dB at 2.4 GHz. This shows that at 1.9 GHz most of the transmitted signals get reflected. This happens when the inductor L3 which is responsible for matching at 1.9 GHz gets shorted.


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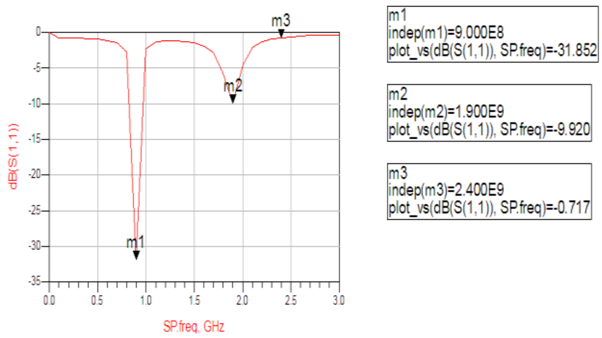


**Fig.6 Simulated S11 of Triple Bands Rectifier when L4 is shorted**

Simulated result of S11 of triple bands rectifier when L4 is shorted is shown in fig.6. It implies that the given triple bands rectifier circuit resonates well at two bands only. The return losses are about -31.852 dB, -9.920 dB and -0.717 dB at 0.9 GHz, 1.9 GHz and 2.4 GHz respectively. This implies that at 2.4 GHz most of the transmitted signals get reflected. This happens when L4 which is responsible for matching at 2.4 GHz gets shorted.

## IV. CONCLUSION

Due to modernization, electromagnetic energy is present everywhere in the environment.By harvesting these energy, it is possible to provide solution to the battery replacement problem in wireless sensor network's applications. Here a single rectifier circuit is proposed to harvest RF energy from ambience. This single circuit can able to receive and rectifies powers from three different bands such as 0.9 GHz, 1.9 GHz and 2.4GHz. A four-stage rectifier is used. The inductors are used to control the matching frequencies.By shorting different inductors, impedance matching at different frequencies can be achieved. The simulationresults show that this single circuit has good matching to the three desired bands.

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