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Design & Analysis of RF Energy Harvesting System for Energizing Low Power Device

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Abstract

Finite electrical battery life is encouraging the companies and researchers to come up with new ideas and technologies to drive wireless mobile devices for an infinite or enhance period of time. Common resource constrained wireless devices when they run out of battery they should be recharged. For that purpose main supply & charger are needed to charge drained mobile phone batteries or any portable devices. Practically it is not possible to carry charger wherever we go and also to expect availability of power supply everywhere. To avoid such disadvantages some sort of solution should be given and that can be wireless charging of mobile phones.[4] If the mobile can receive RF power signals from the mobile towers, why can't we extract the power from the received signals? This can be done by the method or technology called RF energy harvesting. RF energy harvesting holds a promise able future for generating a small amount of electrical power to drive partial circuits in wirelessly communicating electronics devices. RF power harvesting is one of the diverse fields where still research continues. The energy of RF waves used by devices can be harvested and used to operate in more effective and efficient way.

Keywords: Rectangular patch antenna, 7 stage voltage multiplier, Schottky Diode

I. INTRODUCTION

Energy harvesting has been around for centuries in the form of windmills, watermills and passive solar power systems. In recent decades, technologies such as wind turbines, hydroelectric generators and solar panels have turned harvesting into a small but growing contributor to the world's energy needs. This technology offers two significant advantages over battery powered solutions, virtually inexhaustible sources and little or no adverse environmental effects. Recently, the availability of the free RF energy has increased due to advent of wireless communication and broadcasting systems [3]. Wireless power transmission technology via microwave was advanced from 1960's.

Until this time, the electrical power generated by RF energy harvesting techniques is small; depending on techniques it is enough to drive low power consumption devices. Therefore, it is possible to increase the battery life and to reduce the environmental pollution [1]. Radio waves are available in our daily lives in form of signals transmission from TV, radio, wireless LAN and mobile phone.

This work is being carried out by many researchers for the following reasons:

- The energy is freely available in space.
- Complementing the low power sources used for energizing the low power electronic devices, as an application to green technology.

A. Block Diagram of the System:

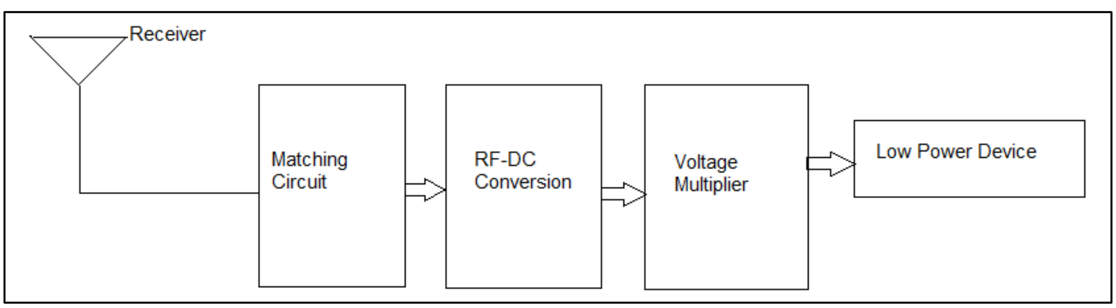

Fig. 1: Conceptual Block Diagram of the System

The energy harvesting device can be allocated into three parts: Antenna Design, RF-DC Conversion, Charging circuit.

II. Background

A. Microstrip Patch Antenna:

A Microstrip Patch Antenna (MPA) consists of a conducting patch of any planar or nonplanar geometry on one side of a dielectric substrate with a ground plane on other side. Due to its planar configuration and ease of integration with microstrip technology, the microstrip patch antenna has been heavily studied and is often used as elements for an array [3]. A large number of microstrip patch antennas have been studied to date. An exhaustive list of the geometries along with their prominent features is available. The rectangular and circular patches are the basic and most commonly used microstrip antennas. These patches are used for the simplest and the most demanding applications. Rectangular geometries are separable in nature and their analysis is also simple. The circular patch antenna has the advantage of their radiation pattern being symmetric. A rectangular microstrip patch antenna in its simplest form is shown in Figure 2 [3].

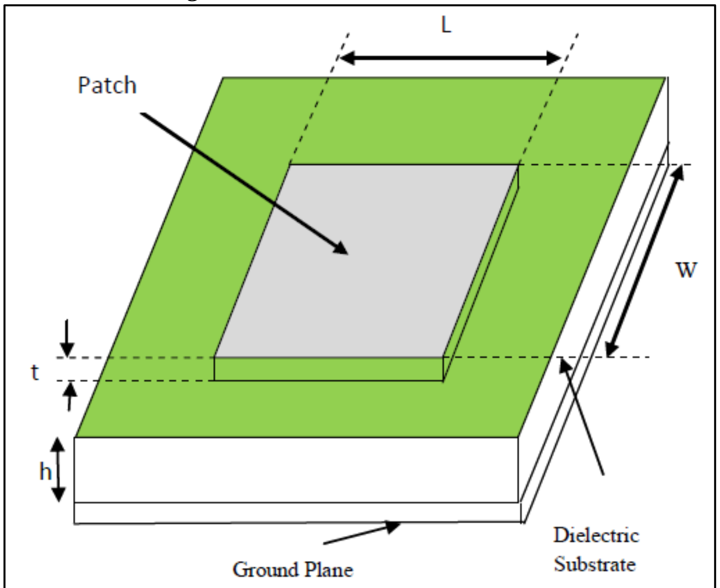

Fig. 2: Rectangular Microstrip Patch Antenna [3]

Where, w= Width of Substrate, L= Length of Substrate, t= Thickness of Patch, h= Height of Patch

The feeding technique used is Microstrip feeding. In the Microstrip feeding technique, the feed line is quarter wavelength long which is used for the impedance matching between the 50Ω line impedance and the Patch Antenna impedance. This is easy to fabricate. Impedance matching is simple by controlling insert feed position. The spurious radiation is low (nearly -20 dB) and have narrow bandwidth (1-5%).

B. Matching Network:

The crucial task of matching network is to reduce the transmission loss from an antenna to a rectifier circuit and increase the input voltage of a rectifier circuit. To this end, a matching network is usually made with reactive components such as coils and capacitors that are not dissipative. Maximum power transfer can be realized when the impedance at the antenna output and the impedance of the load are conjugates of each other. This procedure is known as impedance matching. Currently, there exist three main matching network circuits designed for RF energy harvesting, i.e. transformer, shunt inductor, LC network.[4]

We note that when the impedance of a load is the same as the characteristic impedance of the transmission line, there are no reflected waves and all the forward going power is dissipated in the load. Here, the technique used is quarter wave transformer. Note that the quarter wave transformer only matches the circuit at one frequency. Often time it has a small bandwidth of operation, i.e. it only works in the frequencies in a small neighborhood of the matching frequency. Sometimes cascades of two or more quarter wave transformers are used in order to broaden the bandwidth of operation of the transformer.

C. RF/DC Converter:

The demands on the RF/DC modules are quite high, as the RF - Amplifier and the cavity are sensitive to reflected power. A proper resistive match over a wide range of power levels has to be maintained. The radiation of harmonics on the device input must be inhibited. Aspects concerning the reliability, size and cooling have to be taken into account. Therefore different RF to DC converters is examined and their feasibility for this application is evaluated [5].

1) Seven Stage Voltage Multiplier:

The seven stage voltage multiplier circuit design implemented in this paper is shown in Figure 2.9. Starting on the left side, there is a RF signal source for the circuit followed by the first stage of the voltage multiplier circuit. Each stage is stacked onto the pre1vious stage as shown in the Figure 3. Stacking was done from left to right for simplicity instead of conventional stacking from bottom to top.

The circuit uses eight zero bias Schottky surface-mount Agilent HSMS-285X series, HSMS-2850 diodes. The special features of these diode is that, it provides a low forward voltage, low substrate leakage and uses the non- symmetric properties of a diode that allows unidirectional flow of current under ideal conditions [6]. The diodes are fixed and are not subject of optimization or tuning. This type of multiplier produces a DC voltage which depends on the incident RF voltage. Input to the circuit is a predefined RF source. The voltage conversion can be effective only if the input voltage is higher than the Schottky forward voltage.

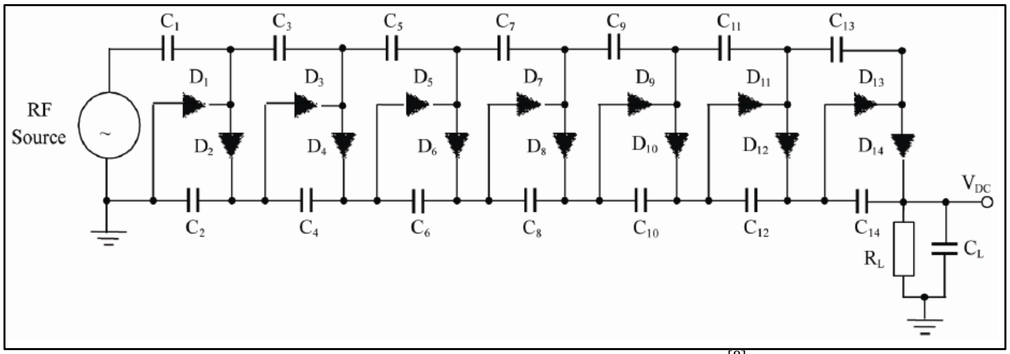

Fig. 3: Schematic of 7 Stage Voltage Multiplier [8]

The other components associated with the circuit are the stage capacitors. The chosen capacitors for this circuit are of through-hole type, which make it easier to modify for optimization, where in the optimization was accomplished at the input impedance of the CMOS chip for a three stage voltage multiplier. [10] The circuit design in here uses a capacitor across the load to store and provide DC leveling of the output voltage and its value only affects the speed of the transient response. Without a capacitor across the load, the output is not a good DC signal, but more of an offset AC signal.

In addition to the above, an equivalent load resistor is connected at the final node. The output voltage across the load decreases during the negative half cycle of the AC input signal. The voltage decreases is inversely proportional to the product of resistance and capacitance across the load. Without the load resistor on the circuit, the voltage would be hold indefinitely on the capacitor and look like a DC signal, assuming ideal components. In the design, the individual components of the stages need not to be rated to withstand the entire output voltage [2]. Each component only needs to be concerned with the relative voltage differences directly across its own terminals and of the components immediately adjacent to it. In this type of circuitry, the circuit does not change the output voltage but increases the possible output current by a factor of two. The number of stages in the system is directly proportional to the amount of voltage obtained and has the greatest effect on the output voltage.

D. Software Used:

HFSS is a commercial finite element method solver for electromagnetic structures from Ansoft. The acronym originally stood for High Frequency Structural Simulator.

It is one of several commercial tools used for antenna design, and the design of complex RF electronic circuit elements including filters, transmission lines, and packaging.

Advanced Design System (ADS) is an electronic design automation software system produced by Keysight, a division of Keysight Technologies. It provides an integrated design environment to designers of RF electronic products.

It has been used for simulating the Voltage Multiplier Circuit.

III. PROPOSED WORK

Table 1 presents the dimensions of the proposed antenna.

Table – 1
Parameters of Proposed Antenna

Parameters	***Value***
Material	***Copper***
Dielectric Material	***FR4***
Dielectric Constant	***4.3***
Width of Substrate	***30 mm***
Length of Substrate	***40 mm***
Width of Patch	***13 mm***
Length of Patch	***18.5 mm***
Width of Partial Ground	***13.2 mm***
Width Slot	***5.2 mm***
Length of Slot	***1 mm***

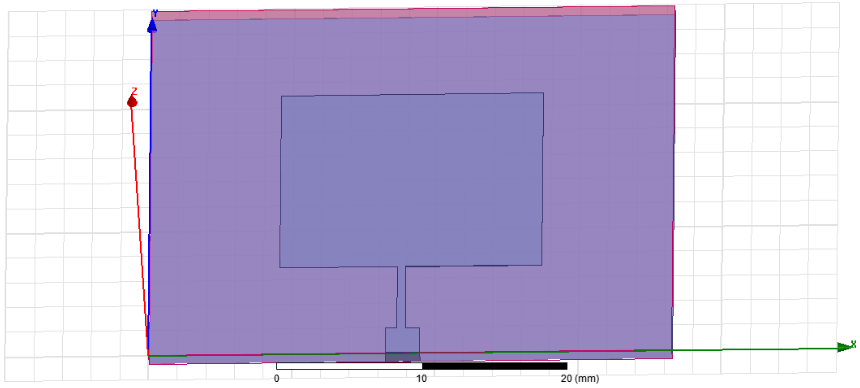

Fig. 4: Proposed Antenna at 5GHz frequency

Here results are achieved for three different feeding points which are 16.5 mm, 17mm and 18mm.

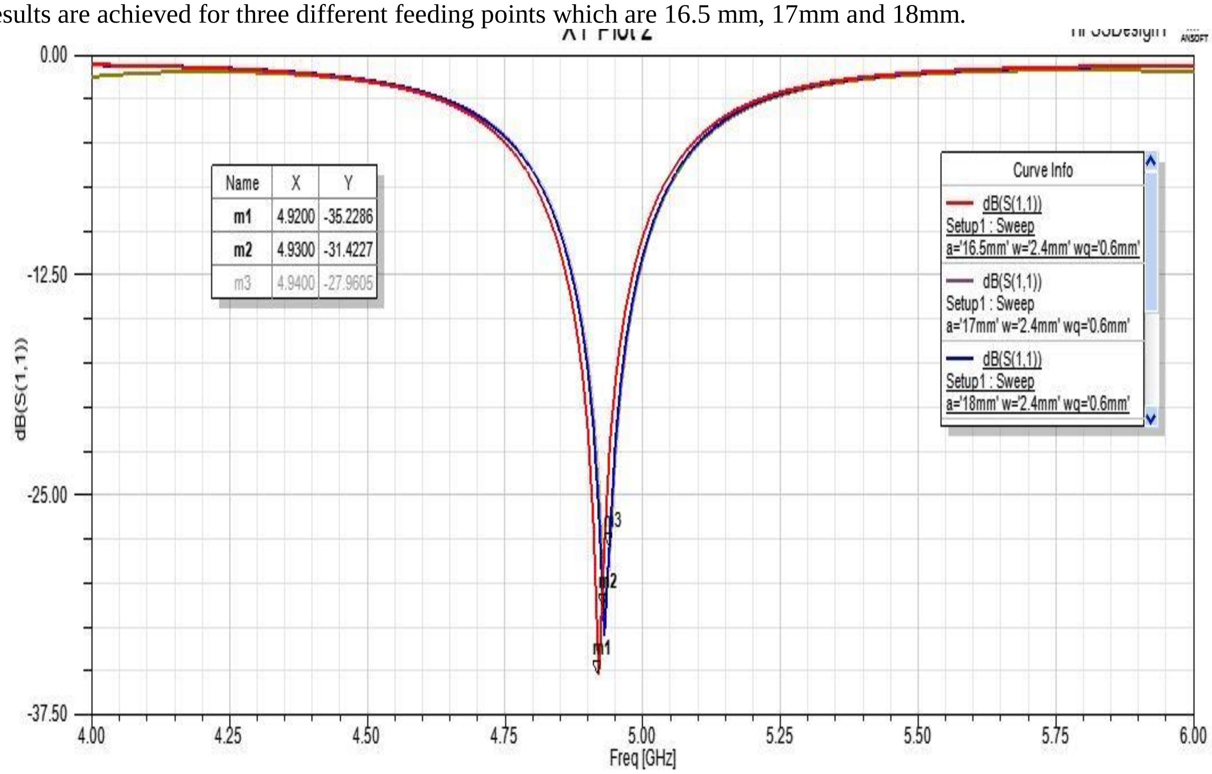

Fig. 5: Combined Return Loss at 5 GHz frequency

By introducing slots and partial ground in proposed antenna, bandwidth can be improved.

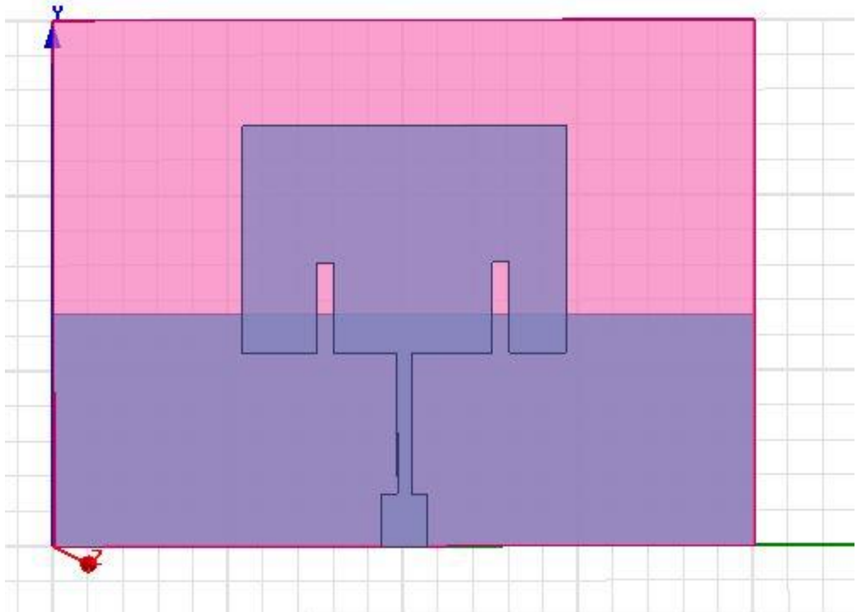

Fig. 6: Proposed Slotted Antenna with Partial Ground at 5 GHz frequency

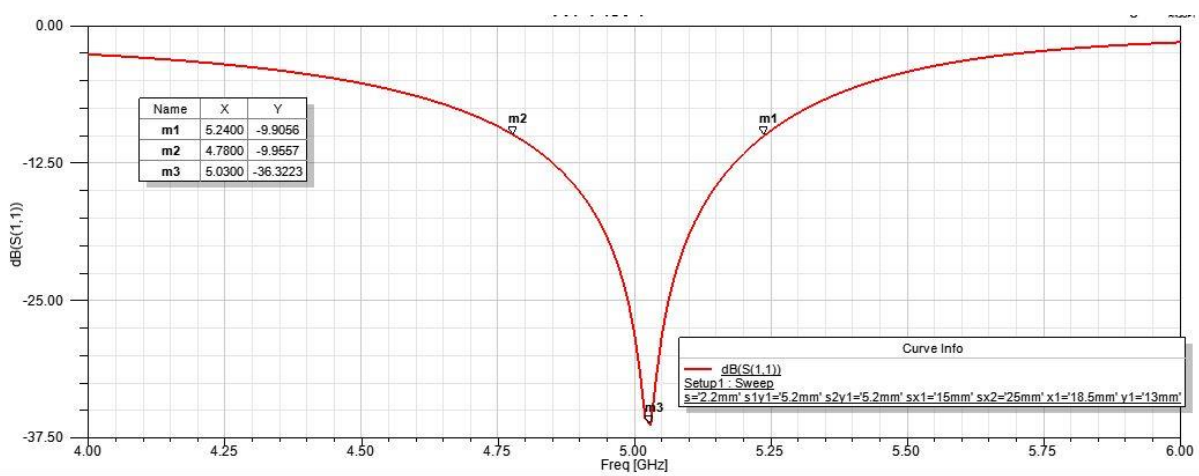

Fig. 7: Return Loss

The most negative return loss for slotted antenna with partial ground achieved is -363223 at 5.0300 GHz frequency.

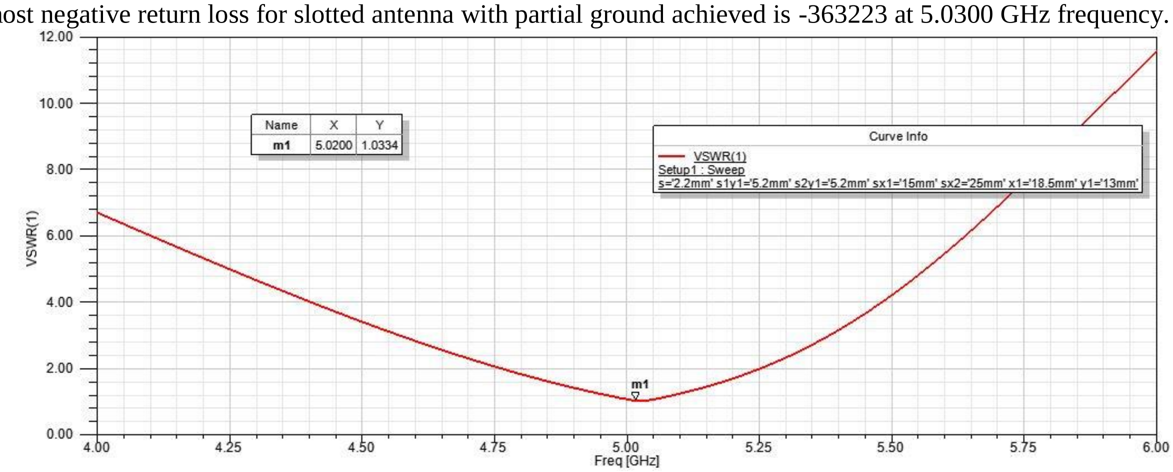

Fig. 8: VSWR at 5 GHz frequency

Table – 2
Comparison between Slotted and Non-Slotted Antenna

Antenna Design Type	*Resonant Freq. (f_r) GHz*	*Return Loss (dB)*	*10 dB BW MHz*	*VSWR*
Non-slotted	***4.9200***	***-35.2286***	***150***	***1.04***
Slotted	***5.0300***	***-36.3223***	***450***	***1.0334***

Simulation of voltage Multiplier circuit is carried out using ADS software.

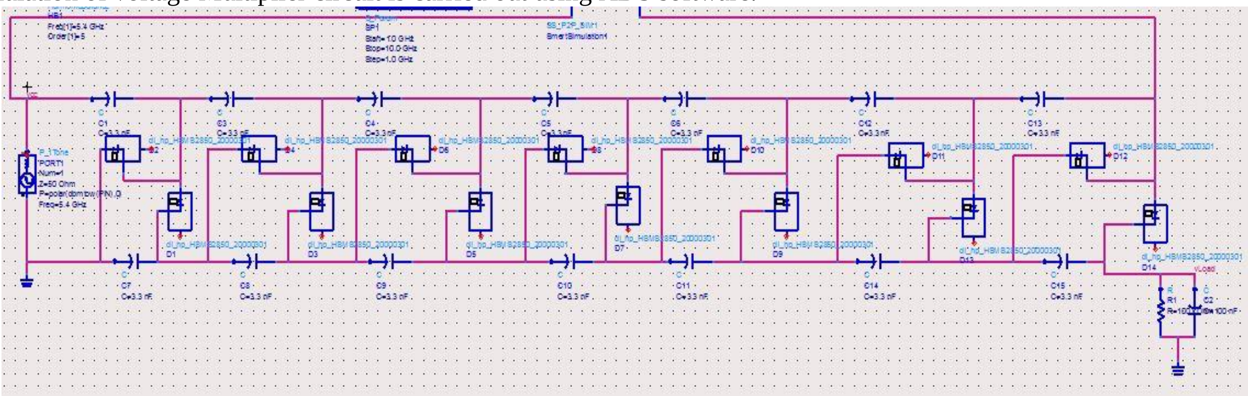

Fig. 9: Simulated Result of 7 Stage Voltage Multiplier

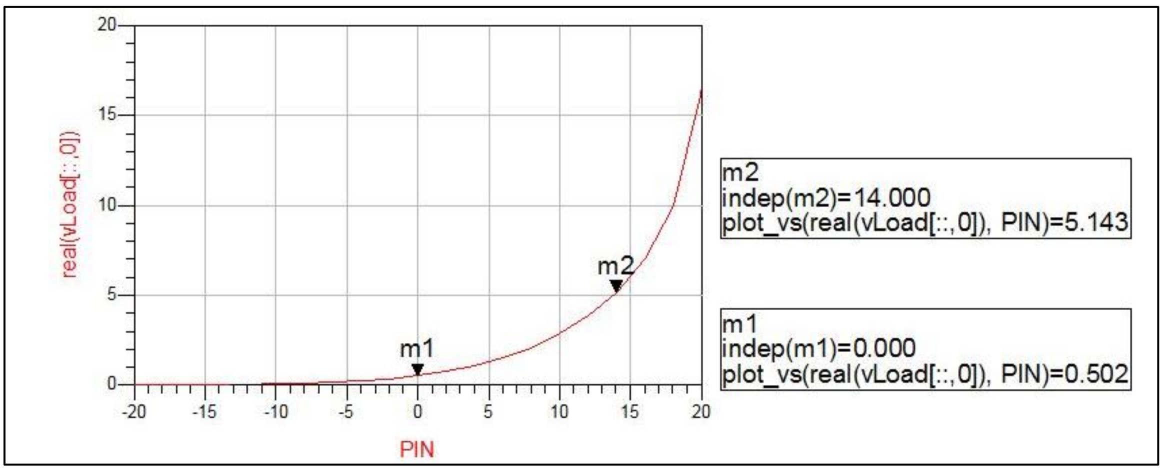

Fig. 10: Output Power is double than input power

Further results are carried out near a WIFI router.

Table – 3
Measured Results of proposed system

Received Signal frequency (GHz)	*Received signal power(dBm)*	*Received signal power (µw)*	*Received signal (mV) rms*	*DC output voltage obtained (V) from Voltage Doubler*	*LED status*
4.75	***-30.78***	***0.86***	***6.45***	***0.88***	***ON***
4.8	***-30.45***	***0.9***	***6.84***	***0.97***	***ON***
4.85	***-29.98***	***1***	***7.23***	***1.22***	***ON***
4.9	***-29.75***	***1.06***	***7.34***	***1.56***	***ON***
4.95	***-28.5***	***1.41***	***8.84***	***1.76***	***ON***
5	***-27.5***	***1.78***	***9.2***	***1.95***	***ON***
5.05	***-27.2***	***1.91***	***9.87***	***2.15***	***ON***
5.1	***-29.1***	***1.23***	***7.53***	***1.68***	***ON***
5.15	***-30.16***	***0.96***	***6.9***	***1.05***	***ON***
5.2	***-31.8***	***0.96***	***4.7***	***0.6***	***OFF***

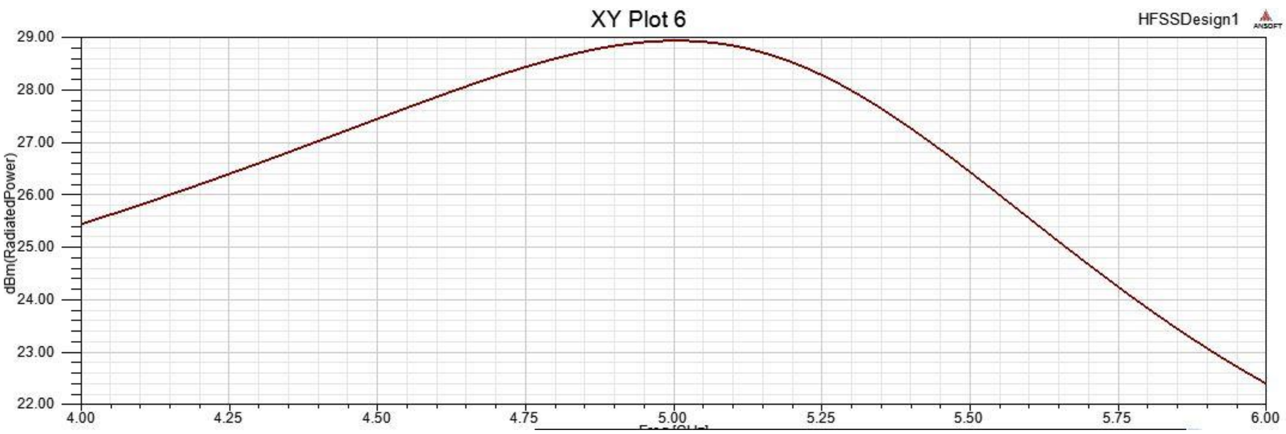

Fig. 11: Frequency vs. Radiated Power (DBM)

IV. RESULT AND DISCUSSION

Therefore, we can conclude that compared to the conventional rectangular patch antenna, slot loading antennas give the better performance in resonant frequency, return loss in the cost of bandwidths. Initially, the return loss was -35.2286 dB with 150 MHz bandwidth but after introducing slots and partial ground, the return loss achieved is -36.3223 dB with 450 MHZ bandwidth which almost thrice as the bandwidth received before. Meanwhile the VSWR remains almost equal to 1 which is an ideal case but in hardware implementation all the parameters may vary. Resonance frequency reduction has also been achieved up to 36% as well as size reduction of more than 60%. Furthermore, it also gives increased Bandwidth which is necessarily required in the system. Moreover, while testing the system near a WiFi, the maximum output achieved is 2.15 V at 5.05 GHz frequency which can be further improved by varying the size of slots or partial ground or increasing the stages of voltage doubler circuit.

V. CONCLUSION

In this paper, we carried out an energy harvesting system to achieve power low enough to drive a low power device on. After designing two antennas, it’s been observed that by introducing slots and partial ground to Microstrip Patch Antenna more efficient results can be achieved. The maximum output voltage received was 2.15 V at 5.05 GHz which turned on the LED. It can be further improved by adding more stages in voltage double circuit or reducing the resonant frequency.

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