Design and Simulation of Rectenna for RF Energy Harvesting

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ABSTRACT

In recent years, an alternate energy source has become essential as the demand for power increases. In the last energy decades energy obtained from external sources such as thermal energy, solar power, wind energy, and RF energy has been in use for various purposes. To provide unlimited energy for the lifespan of electronic devices, energy harvesting uses inexhaustible sources with no adverse environmental effect. This paper focuses on RF energy harvesting. The receiving antenna captures the RF energy from surrounding sources, such as nearby mobile phones, wireless LANs (WLANs), FMlAM radio signals, broadcast television signals and rectified into a usable DC voltage. One possibility to overcome their power limitations is to extract (harvest) energy from the environment to either recharge a battery, or even to directly power the electronic device. To meet various objectives in last few years, several antenna designs of rectenna have been proposed for use in RF energy harvesting. Among the other antennas, micro strip patch antennas are widely used because of their low profile, light weight, and planar structure.

A key component of this technology is the "rectenna," which is composed of antennas and rectifying circuitry to convert RF energy into dc power. ***This paper presents rectenna based micro strip rectangular patch antenna and rectifier designed at 2.45GHz and return loss is less than or equal to -20dB***

KEYWORDS:
Low power circuits, Micros trip rectangular patch antenna, RF Energy harvesting

I. Introduction

The technique of converting the raw energy source into useful electrical energy is called as energy harvesting. Quoting the Energy Harvesting Forum, energy harvesting is the process of capturing minute amounts of energy from one or more of these naturally-occurring (renewable) energy sources, accumulating them and storing them for later use. A similar viewpoint is reflected by the industrial sector. According to Dr.Peter Harrop, the Founder and Chairman of ID Tech Ex, a large. Company studying on energy harvesting and storage, energy harvesting is the conversion of ambient energy into electricity to drive small or mobile electronic and electrical devices. It is interesting to note that not all renewable source of energy have equivocal support. Wind power, such as the large scale deployment in the Cape Cod region in Massachusetts, US, continues to draw their region of environmental groups that. Argue about its detrimental impact on coastal populations.

Typically, in commercial energy harvesting systems, the energy harvested from renewable resources firstly arrives at boost converters that scale up the voltage, followed by battery management systems where this energy is stored. In this way, it is converted into a useful and regulated form for many small electronic and mobile applications, such as a wireless sensor network, depicted in Fig1

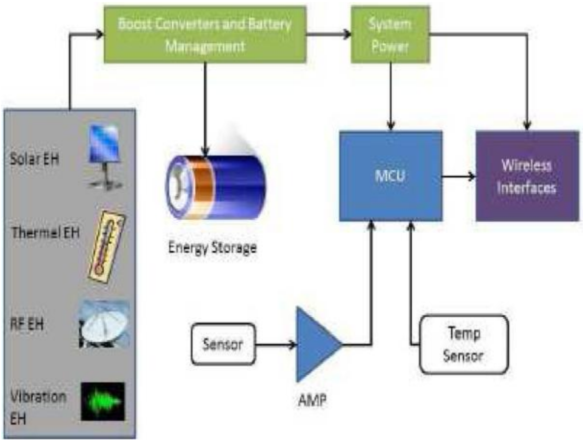

Fig. 1. Energy harvesting systems diagram

As energy harvesting becomes technologically viable, one might wonder what advantages it has over traditional methods of energy generation and storage. Four advantages of energy harvesting that provide useful clues in this context are

- The efficiency of the energy harvesting devices has increased with recent technical developments, especially while capturing energy from ambient sources. Additionally, power consumption of engineered devices is reducing over time, with advancements in microprocessor technology. In combination of the above two facts, energy harvesting is becoming a viable way to drive many low-power applications, potentially replacing current sources of power in the future.
- Energy harvesting can be a maintenance-free alternative to battery technology, which is costly and inconvenient to replace. Thus, lifetime of the appliance may be unlimited if run with well-designed energy harvesting systems. if the source of the energy is guaranteed to available, energy harvesting systems can be used more reliably than battery and plug-based connections.
- Energy harvesting can be used as backup generator in power systems, which helps to improve the reliability and prevent power interruptions.
- Energy harvesting systems can provide mobility to devices, which are dependent on the traditional plug-based electricity sources. Thus, some wired (cable-driven) applications are transformed into wireless applications.

Energy harvesting systems can be classified according to the source which energy is harvested from. The most commonly observed energy harvesting systems are based on the following;

- Mechanical Energy (piezoelectric vibrations, human body movement, etc.)
- Thermal Energy (using geo-thermal energy of the earth, difference in temperatures of two points of a conductor etc.)
- Light Energy (primarily, solar energy)
- Electromagnetic Energy (mainly from radio frequency waves, magnetic coupling)

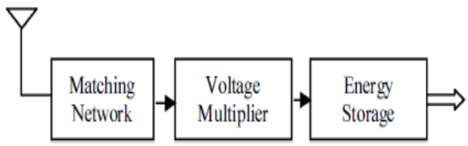

Fig.2.The Principle of RF energy harvesting systems

Of the above types of energy harvesting systems, the scope of our research is limited to Radio frequency (RF) energy harvesting.

Fig.2 shows the components of proposed energy harvesting circuit. The incident RF power is converted into DC power by the voltage multiplier. The matching network, composed of inductive and capacitive elements, ensures the maximum power delivery from antenna to voltage multiplier. The energy store ensures smooth power delivery to the load, and the output of the energy storage section is DC output voltage. RF energy sources can be categorized into three general groups: intentional sources, anticipated ambient sources, and Unknown ambient sources. RF energy harvesting can be implemented as direct power for battery-free systems or battery activation, an auxiliary power source for battery recharging, or remote power with battery backup. A power source combined with energy harvesting can provide wireless devices with low maintenance cost or extended battery life by implementing the ability to receive power or charge the stored energy when needed, or to wake up remote sensors in sleep mode. The possibility of recycling the ambient electromagnetic energy especially in densely populated urban zones is actively being explored. The major component used to convert this RF energy into utilizable DC power is a rectifying antenna, also termed as rectenna. Among various entities of rectenna, antenna is one of the major elements which is responsible for collecting the incoming RF signals of various frequencies. The source of incoming RF energy can be WLAN (2.40Hz, 5.80Hz), WiMax, RFID (microwave band: 2.45, 5.8, 24.1250Hz) and so forth with various frequency ranges. Antennas with resonance at single or multiple applicable frequencies are designed with various ambitions. The variation made in antenna design that was designed with an aim of miniaturizing patch antenna, rejecting unwanted harmonics, and having reconfigure ability in frequency is evaluated in this paper.

In this work, micro strip antenna is proposed. The rectenna has a compact size due to the use of a cross shaped slot at the patch surface. Dual linear polarization is employed in order to be able to receive arbitrarily polarized input RF signals. Then the incoming RF power is collected by the microwave antenna and the incoming electromagnetic wave is rectified into DC current by a rectenna and using rectifying circuit, which can be used by a rectenna. To double the DC output voltage theoretically voltage doubler circuits are used. To increase the conversion efficiency full wave rectifier is used. The design of the rectenna is first presented followed by the antenna miniaturization, rectifier design; finally micro strip patch antenna design is evaluated.

II. RECTENNA

The invention of the rectenna in the 1960s made long distance wireless power transmission feasible. The rectenna was invented in 1964 and patented in 1969 by US electrical engineer William C. Brown, who demonstrated it with a model helicopter powered by microwaves transmitted from the ground, received by an attached rectenna. Since the 1970s, one of the major motivations for rectenna research has been to develop a receiving antenna for proposed solar power satellites, which would harvest energy from sunlight in space with solar cells and beam it down to Earth as microwaves to huge rectenna arrays. A proposed military application is to power drone reconnaissance aircraft with microwaves beamed from the ground, allowing them to stay aloft for long periods. In recent years, interest has turned to using rectennas as power sources for small wireless microelectronic devices.

A rectenna is a rectifying antenna—a special type of antenna that is used to convert electromagnetic energy into directs current (DC) electricity. The incoming electromagnetic wave is rectified into dc current by a rectenna which is a particular type of antenna. The applications like WANs, Wimax, cognitive radio systems, RFID tagging systems the rectennas for wireless power transmission and space solar power transmission has played a very important role in implementing specific functions. Dipole, yagi-Uda, micro strip, monopole, loop, spiral, coplanar patch are examples of different types of antennas. Single shunt full-wave rectifier, a full wave bridge rectifier and hybrid rectifier are types of rectifying circuits which can be used by a rectenna. To double the dc output voltage theoretically, a half wave parallel rectifier and a voltage double structure are used. To increase the conversion efficiency a dual -diode full wave rectifier is used. To decrease the size of micro strip several methods have been suggested.

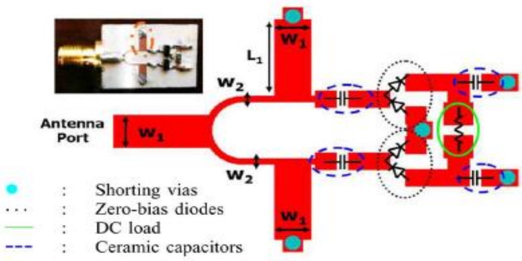

Fig.3. Layout of the rectifier prototype

III. RECTIFIER

A rectifier is an electrical device that converts alternating current (AC), periodically reverses direction, to direct current (DC), current that flows in only one direction, in a process known as rectification. The efficiency of rectifier design is critical for power harvesting. The rectifier is designed at 2.45GHz and simulated using Advanced Wireless Resolution (AWR) software. Toward this goal, we found that a modified version of the single-stage full-wave rectifier, depicted in Fig. 4, provides an efficient rectification scheme the modified rectifier operates as follows. If is the induced voltage at the antenna port, then C1 and D1 (Fig. 4) shift the voltage up at node B. Subsequently, D2 and C2 rectify the voltage at node B (both RF and dc components) to appear across the dc load. Similarly, C3 and D3 shift the voltage down at node C. In turn, D4 and C4 rectify the voltage at node C to appear across the dc load. Upon reaching equilibrium, the rectifier circuit delivers a constant output current and voltage to the dc load. The impedance matching stage (depicted in Fig. 3) is essential in providing maximum power transfer from the antenna to the rectifier circuit. Designing the matching network is not straightforward since the rectifier is a nonlinear load with complex impedance that varies with frequency and input power level. One design approach is to model the rectifier circuit using experimental characterization at the minimum power level required by the application. This can be done by measuring the input impedance (extracted from S_{11}) of the rectifier circuit (with all components) without a matching network at that power level. Using the impedance results from the experimental characterization (i.e., rectifier impedance) and assuming a 50- source load, the matching circuit design is rather straightforward. Using input RF power from -25 to +10 dBm. S_{11} Measurement is conducted by utilizing the at 2.45 GHz.

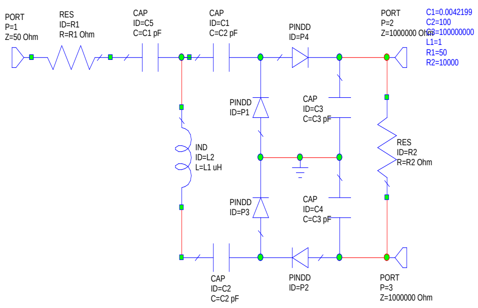

Fig.4. Schematic of the proposed rectifier

Fig.4. Schematic of the proposed rectifier D1–D4 are zero-bias low barrier Schottky diodes (Avago HSMS-2822). These diodes feature high saturation current and do not require additional biasing. C1=C3=100PF, C2=C4=100μF, dc load=10KΩ.

The rectifier was simulated using Advanced Wireless Resolution (AWR). The measured parameter of rectifier is shown in fig.5&6. The frequency at 2.45GHz, the return loss is -13.46 dB and the impedance is -61.21Hz.

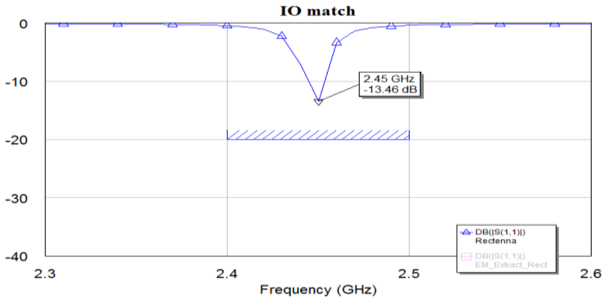

Fig.5. Measured returns loss at 2.45 GHz

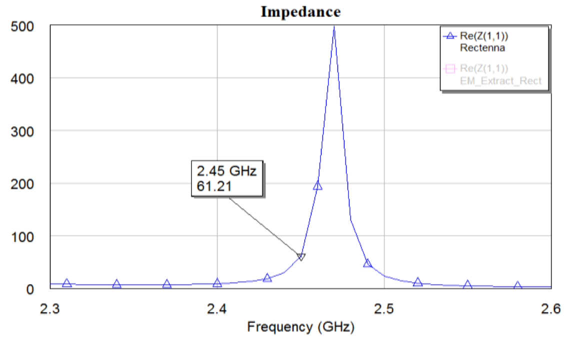

Fig.6 Measured impedance at 2.45GHz

IV. Antenna Design

An antenna is a structure usually made up with a conducting material and is a means of transmitting and receiving electromagnetic signals/radio waves through free space. Antenna is one type of transducer that converts the electrical energy into the electro-magnetic energy in form of electromagnetic waves. Antennas are required by any radio receiver or transmitter to couple its electrical connection to the electromagnetic field.

Micro strip antenna was invented by Bob Munson in 1972 (but earlier work by Dechamps goes back to1953). Micro strip antennas became very popular in the 1970s primarily for space-borne applications. Today they are used for government and commercial applications. These antennas consist of a metallic patch on a grounded substrate. A Micro-strip patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side and is designed at 2.45GHz and simulated using HFSS software. The design involves creating substrate, patch, coaxial feed and assigning E-plane boundary to substrate and patch. Finally plotting the Radiation pattern and S-parameter for the same

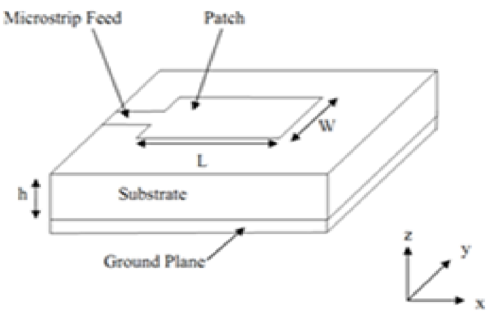

Fig.7. 3D view of rectangular patch antenna

The antenna is first designed separately from the rectifier.Critical to the practicality of batteryless RFIDs is the utilization of a small-size antenna with a broad radiation pattern (e.g., micro strip patch).. The antenna size is W=0.048m &L=0.040 by employing a dielectric substrate($\epsilon r = 2.2$, thickness=62 mil) . The bandwidth was also improved by employing a capacitive coupled probe feed.

The antenna was simulated using High Frequency Structure Software (HFSS). The measured parameter of micro strip patch antenna is shown in fig. The frequency at 2.45GHz, the return loss is -18.2316 db and the gain is 7.9064 db.

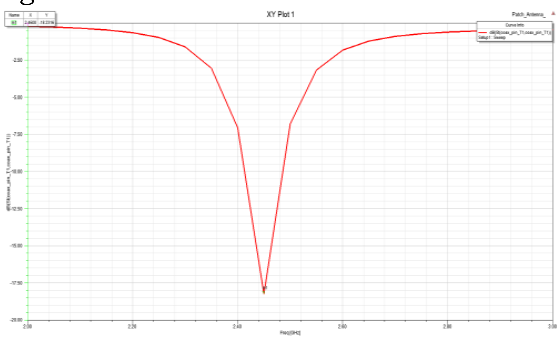

Fig.8. Frequency vs. Return loss

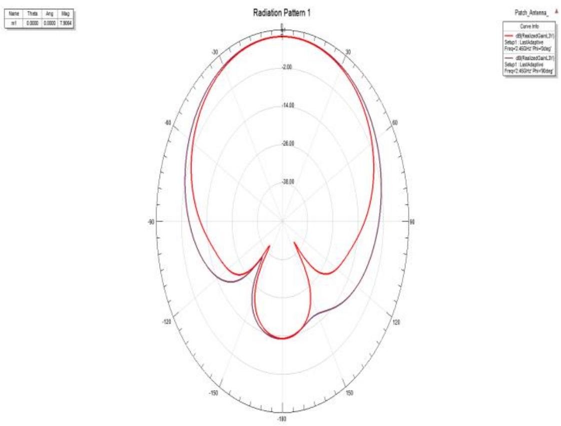

Fig.9. Gain (2D radiation pattern)

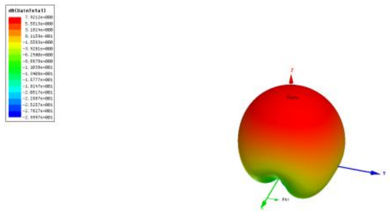

Fig.10. Gain (3D radiation pattern)

V. Conclusion

In this paper, the micro strip patch antenna design for RF energy harvester for low power consumption electrical and electronic devices was introduced. Design of Rectenna is completed using AWR for power harvesting. The simulated results are obtained and they almost met the set goals such as return loss less than or equal to -20db, impedance around 50 ohms. The layout design sent for fabrication. Finally the performance of the fabricated device (Rectenna) is measured on the network analyzer which closely matched with the simulated results. microstrip patch antenna is the simple and easy to fabricated. microstrop patch antenna results are shown using HFSS software.

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