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Comparative Study of Rectenna for Electromagnetic Energy Harvesting*

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Abstract

In this paper, we present the review of energy harvesting contained in electromagnetic waves. An overview of existing energy harvesting techniques is discussed, which will motivate researchers to design antenna in the field of electromagnetic energy harvesting. It also focuses on a characteristic of patch antenna for designing Rectenna.

Keywords: *Wireless power transmission, Radio frequency (RF), Energy harvesting, Rectenna*

1. Introduction

In our daily life, wireless technology has become a popular means of transmitting signals from the use of satellite in space to the use of cell phones. Anybody, anywhere and anytime wireless technology has provided the easiest way to us. In the present situation where the production of energy is reliant on gas and oil industry whose price is irregular daily, the wireless energy concept may be used as alternative energy. Awareness regarding need to reduce our reliance on fossil fuels has led to the development of surrounding self-regenerating energy source.

Many researches and efforts are being conducted to develop a technique to supply power to the electrical and electronics equipment using energy harvesting technology. In this modern era, electronic appliances grow along with radiation, although most radiation from these electronic devices is harmless, the radiated energy is not being utilized, and thus a device capable of harvesting energy can be built.

The wireless energy transfer is a process that takes place in any system where electrical energy is transmitted from a power source to an electrical load, without involving wires. Wireless transmission is ideal in cases where instantaneous or continuous energy transfer is needed, whereas wired connections are inconvenient, hazardous, or impossible [1]. Though the physics of both are related, this is different from wireless transmission for the purpose of transferring images such as television broadcasting, where the percentage of the received power is only important if it becomes too low to successfully recover the signal. With

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wireless energy transfer, the efficiency is a more critical parameter and creates important differences in this technology [2].

2. Ambient Energy Sources and Techniques

Energy sources surrounding everywhere around us in the environment are available in the form of light, thermal, wind, mechanical, or electromagnetic energy. Energy harvesting, power harvesting or energy scavenging is the process of collecting and capturing ambient energy in order to make new things possible and to remove the expense, inconvenience and pollution that results from frequent replacement of batteries in small devices. Wireless power transmission has received significant attention in the past demonstrating efficient RF to DC conversion capability for direct, high power transmission applications. Recently, considerable many research efforts have been done to harvest ambient energy from solar energy, microwave energy to employed existing communication networks [3-6].

Ambient RF energy is pervasive, especially for mobile and Wi-Fi networks. ABI Research and iSupply estimate that mobile-phone subscriptions have surpassed 5 billion, and the ITU estimates there are over 1 billion mobile broadband subscriptions. RF energy can be harvested from mobile phones in close proximity, potentially providing power-on-demand for short-range sensing applications. Other sources of RF energy such as Wi-Fi routers and wireless end devices (*i.e.*, Laptops) are also plentiful. At short range, such as within the same room, users can harvest a small amount of energy (microwatts) from a typical WI-Fi router transmitting at 50 mW to 100 mW. For long-range operation, higher-gain antennas are needed to harvest RF energy from mobile base stations and broadcast radio towers [7].

Antenna as the communication device is used for transmission and/or reception of data by utilizing the different frequency ranges. Frequency ranges and power at different frequency spectrum from 10 kHz to 30MHz are given in detail in [8]. The output power of RF devices is limited due to safety and health concern offered to EM radiation by regulations such as Federal Communications Commission (FCC), USA [9]. The maximum theoretical available power for RF energy harvesting is 7.0 μW and 1.0 μW for 900 MHz and 2.4 GHz frequencies respectively for a free space distance of 40 meters. The path loss of signals can be different in an environment other than free space [10]. The diagram of various microwave power sources along with their typical density levels is shown in Figure 1.

Energy harvesters do not provide enough amount of power to produce mechanical movements or temperature changes (like cooks, refrigerators, *etc.*) because there are no such technologies that can capture energy with that much of great efficiency. But these technologies can provide the amount of energy sufficient enough for low-power devices that can operate separately. Another advantage with this type of technology is that, unlike the production of large-scale power, we can get the free energy source from the electromagnetic energy of transmitting mobile stations, radio, and TV broadcasting antennas.

A number of studies and a los of surveys have already been done in this literature. In [11], a new method to find a maximum power point of sensor nodes using renewable energy has been proposed in order to extend the sensor node's life. A maximum power point refers to a point, at which a sensor node’s power becomes a maximum through the proper ratio between a voltage and a current. In [12], Through SPICE simulation, different piezoelectric harvester interface circuits are demonstrated and compared. In [13], a new way of representing and interacting with energy in electric products, specifically home appliances has been developed.

3. Rectenna Concept and Brief Literature Review for Electromagnetic Energy Harvesting

Rectenna is an acronym for RECTifying antenna as shown in Fig.2 [6]. It is a particular type of antenna that rectifies the incoming electromagnetic waves into DC current. Usually, a rectenna consists of a mesh of dipoles and diodes for collecting microwave energy from a transmitter and then converted it into electric energy. The elements are commonly arranged in a mesh pattern giving a district appearance from most antennas. A simple rectenna can be made from a schottky diode placed between antenna dipoles. Antennas can be considered as the backbone in the wireless communication without which the world would not have reached till this age of technology. The rectification of microwave signal to DC power has been proposed and researched since the 1950s [14] in the context of high power beaming. It has been proposed for helicopter powering [15], solar power satellite (SPS) [16], the SHARP (Stationary High Altitude Relay Platform) System [17], and recently for RFID system. In 1999, the Korea Electro technology Research Institute conducted a study on the wireless power transmission system, where they were able to achieve single rectenna conversion efficiency of 75.6% and an overall system efficiency of 33% [18] .There are many research work related to rectenna elements. The antenna can be any type such as dipole [4,19], Yagi-Uda antenna [20, 21], microstrip antenna [22, 23], monopole [24], loop antenna [20, 25], coplanar patch [26], spiral antenna [27], or even parabolic antenna [28]. The rectenna can also take any type of rectifying circuit such as single shunt full-wave rectifier [29-34], full-wave bridge rectifier [34-37], or other hybrid rectifiers [22]. The circuit, especially the diode is used to determine the RF-DC conversion efficiency. Silicon Schottky barrier diodes were usually used before for the previous rectennas but these days new diode devices like Silicon Carbide and Gallium Nitride (SiC and GaN) are expected to increase the efficiency. The rectennas with FET (Field Effect Transistor) [38] or HEMT (High Electron Mobility Transistor) [39] appear in recent years. The world record of the RF-DC conversion efficiency among developed rectenna is approximately 90% at 4W input of 2.45 GHz microwave [35]. Other rectennas have approximately 70–90% at 2.45GHz or 5.8GHz microwave input. The comparative summary of rectenna designs for electromagnetic energy harvesting is shown in Table 1 [40].

In 2009, students of Singapore of the Nanyang Technology University conducted a study in which they attempted to use wireless energy technology to remotely power sensors with low amount of energy. They used patch antennas to receive the signal and rectenna was used to rectify the power. They found that the addition of a low pass filter helped concentrate the power received and improved the overall efficiency of the system [41].

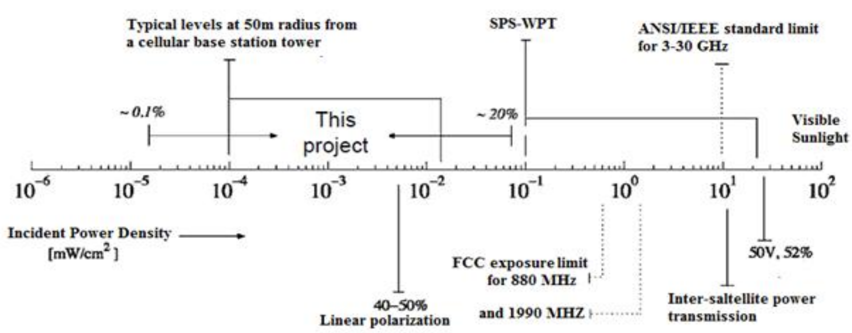

Figure 1. Various microwave power sources and their typical power density levels

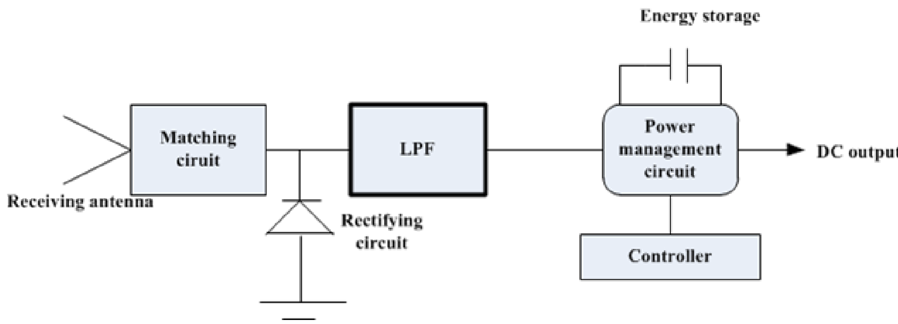

Figure 2. Basic rectenna schematic with the power management system

The RF-DC conversion efficiency η is represented as follows:

$$\eta = ((P_{DC})/(P_{Received})) * 100\% \quad (1)$$

where, $P_{DC} = V_{DC}^2/R_L$, V_{DC} is the output DC voltage at the load, R_L is the load resistance, $P_{Received}$ is the available power at the input of the rectifier.

Table 1. Comparative summary of rectenna designs for electromagnetic energy harvesting

Author(year)	Type	Design	Power input	Results	Application
McSpadden (1998a)	Half-wave dipole rectenna	Half-wave dipole and GaAs IMPATT diode	Not available	85% conversion efficiency across 165Ω resistive load at 2.45GHz	Microwave power transmission
McSpadden (1998b)	Half-wave dipole rectenna	Half –wave dipole and MA40150119 Si Schottky diode	50mW	82% conversion efficiency across 327Ω load resistor at 5.8GHz	Microwave power transmission
Gomez (2004)	E-pHEMT technology rectenna	Microstrip antenna and an E-pHEMT detector	14.12mW	85.4% overall efficiency at 900MHz	Microwave power transmission, Actuators and RFID sensors
Suh and Chang (2002)	Dual-frequency rectenna	Dual-frequency dipole and MA4E1317 GaAsSchottky diode	89.84mW at 2.45GHz ,49.09mW at 5.8GHz	84.4% efficiency at 2.45GHz and 82% at 5.8GHz	Microwave power transmission
Heikkinen and kivikoski (2003)	Dual-frequency rectenna	Shorted ring-slot and HSMS-2862 Si Schottky diode pair	-5dBm	49% efficiency at 2.45GHz and 14% at 5.8GHz	Microwave power transmission
Strasner and Chang (2002)	Circularly polarisedrectenna	DLRA and MA4E1317 detector diode	Not available	80% conversion efficiency at 5.8GHz across a 250Ω load resistor	Microwave power transmission
Strasner and Chang (2003)	Circularly polarisedrectenna	Folded dipole and MA4E1317 schottky diode	$2mW/cm^2$(115mW)	82% efficiency at 5.8 GHz for a 150Ω load	Microwave power transmission
Park (2004)	Circularly polarisedrectenna	Circular sector and HSMS-2820 schottky diode	10dBm	77.8% efficiency at 2.4GHz across 150 Ω load resistor	Not available
Hagerty (2004)	Circularly polarisedrectenna	Equiangular spiral and SMS7630-079 Schottky diode	$0.1mW/cm^2$	20% rectification efficiency	Indoor sensor networks and energy recycling

Ali (2005)	Circularly polarisedrectenna	Patch antenna and MA4E1317 detector	2.55mW/cm^2	57.3% conversion efficiency at 5.5GHz for 300Ω load impedance	Embedded wireless sensor and data telemetry
Ren and Chang (2006)	Circularly polarisedrectenna	Truncated patch and two model MA4E1317 Schottky diodes	Not available	76% efficiency at 5.8GHz for 100Ω loading and 6.22V DC output voltage	Microwave power transmission
Chin (2005)	FG-CPW rectenna	Patch antenna and HSMS-8202 Schottky diode	18dBm	68.5%conversion efficiency at 5.8GHz	Microwave power transmission and RFID sensors
Akkermans (2005)	Probe-fed microstrip patch rectenna	Microstrip patch and HSMS-2852 Schottky diode	0dBm	40% conversion efficiency across 470Ω	Low-power wireless sensor
Zbitou (2006)	Hybrid rectenna	Patch antenna array and HSMS2820 Schottkydide	-20dBm	20% conversion efficiency at 2.45GHz	Not available

4. Rectifier

Rectifier circuits provide a DC output voltage at the load. There are three main options for the rectifier:

• a diode (Figure 3(a))

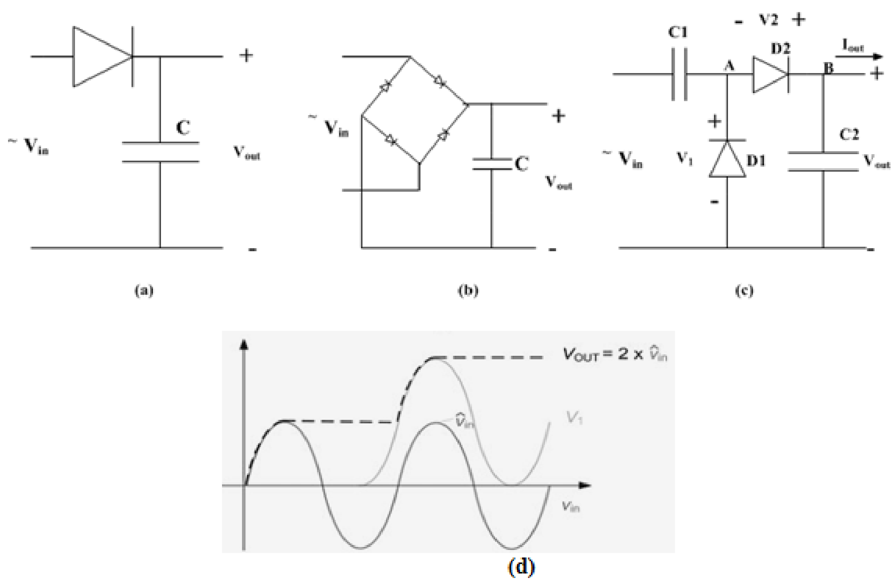

Figure 3. (a) diode, (b) bridge of diodes, (c) a voltage multiplier rectifier and (d) its waveforms during the transient

The diode and bridge diode provide an output DC voltage to the load (V_{OUT}) whose amplitude is lower than that of the incoming signal. The voltage rectifier is a multiplier, as the name indicates, it multiples the peak amplitude of the incoming signal. At long distances, the DC voltage level is not high enough to power an electronic circuit, so the voltage rectifier multiplier is used.

5. Structure of Patch Antenna

Microstrip patch antennas having low profile are growing popularity to be used in wireless applications. They are suitable for embedded antennas in handheld wireless devices for example cellular phone. Compared to the standard dipole and another monopole antenna, patch antennas are cheaper; provide better and high directional gain performance in a small package. Some of the characteristics of microstrip patch antenna compared to dipole antenna is shown in Table 2.

Table 2. Characteristics of microstrip patch antenne

Characteristics	Microstrip Patch Antenna	Printed Dipole Antenna
Profile	Thin	Thin
Fabrication	Very easy	Easy
Polarization	Both linear and circular	Linear
Shape Flexibility	Any shape	Rectangular and triangular
Bandwidth	2-50%	~30%

While designing dipole antenna, there is a problem in coupling between antenna and feed circuit so microstrip patch antenna has been chosen. The microstrip patch antenna is a layered structure consisting of a very thin layer of metallic strips (patch) placed over a thin layer of dielectric substrate with relative permittivity ε_r. The bottom side of the substrate is a conductive layer acting as a ground plane. The dimension of patch is usually a fraction of the wavelength and the thickness of the dielectric substrate layer is usually a small fraction of a wavelength. The shape of the patch could be any geometrical structure, but commonly used are rectangular (square), elliptical (circular or annual ring). Diagram of a rectangular patch antenna and its dimension is given by the patch length (L) and width (W), is given in Figure 4 and Figure 5.

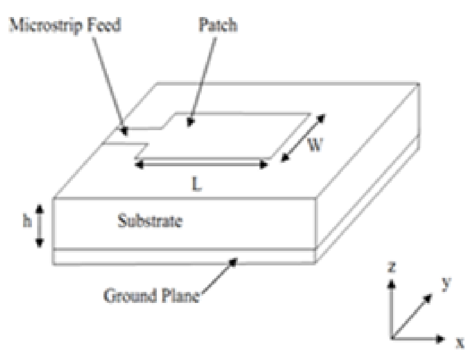

Figure 4. 3D view of rectangular patch antenna

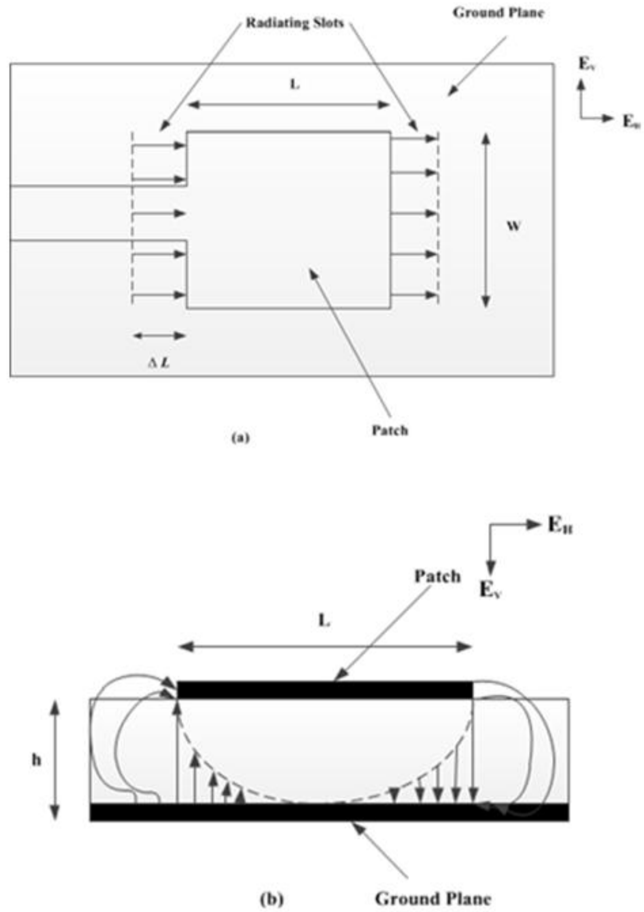

Figure 5. (a) Top and (b) Side view of patch antenna

For a rectangular patch, the length L of the patch is usually $0.3333\lambda_0 < L < 0.5\ \lambda_0$ where λ_0 is the free-space wavelength. The patch is selected to be very thin such that $t \ll \lambda_0$ (where t is the patch thickness). The height (h) of the dielectric substrate is usually $0.003\ \lambda_0 \leq h \leq 0.05\ \lambda_0$. The dielectric constant of the substrate usually falls in the range $2.2 \leq \varepsilon_r \leq 12$. Microstrip patch antennas radiate because of the fringing fields (ΔL) between the ground plane and the patch edge. For better antenna performance, a thick dielectric substrate having a low dielectric constant is necessary as it gives better efficiency, large bandwidth and better radiation. But the size of the antenna is increased so as to design a compact microstrip patch antenna; higher dielectric constants must be used.

5.1. Some Advantages of Patch Antenna

- Light weight and low volume
- Low profile planar configuration which can be easily made conformal to host surface
- Low fabrication cost that can be manufactured in large quantities
- Supports linear as well as circular polarization
- Can be easily integrated with microwave integrated circuits (MICs)

- Capable of dual and triple frequency operations
- Mechanically robust when mounted on rigid surfaces

5.2. Some Disadvantages of Patch Antenna

- Low Gain
- Low efficiency
- Narrow bandwidth
- Surface wave excitation
- Low power handling capacity
- Extraneous radiation from feeds and junctions
- Poor end fire radiator except tapered slot antennas

Microstrip patch antennas have a very high antenna quality factory (Q) where Q represents the losses associated with the antenna and a large Q leads to narrow bandwidth and low efficiency. By increasing the thickness of the dielectric substrate, Q can be reduced. But due to the thickness increases, an increasing fraction of the total power delivered by the source goes into a surface wave. This surface wave contribution can be counted as an unwanted power loss since it is ultimately scattered at the dielectric bends and causes degradation of the antenna characteristics. As a solution, surface waves can be minimized by use of photonic band gap structures. Other problems such as lower power handling capacity and lower gain can be overcome by using an array configuration for the elements.

6. Conclusion

In this paper we try to explain some reviews for electromagnetic energy harvesting. The brief explanation of components of rectenna has been given along with ambient source of energy and comparison between microstrip patch and dipole antenna . Also try to mention comparative summary of design of rectenna for electromagnetic energy harvesting. Electromagnetic energy harvesting is the emerging field in today’s world so most of the researchers are looking for new technology to harvest electromagnetic energy using different types and design of antenna. Many researches have been done and continuously going on for the betterment of future electromagnetic energy harvesting technique.

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