International Journal of Engineering & Technology, 7 (4) (2018) 5484-5488

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET
doi: 10.14419/ijet.v7i4.27031
Research paper

Simulating of RF energy harvesting micro-strip patch antenna over 2.45 GHZ

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Abstract

This paper dealing with simulation a proper antenna design for RF energy harvesting. The energy harvesting technologies are rising gradually in the recent years because of limitation by energy storage and wired power supply. In the last energy decades' energy emitted from external sources such as solar power, wind energy, and RF energy used in the features purposes to provides unlimited energy for the lifespan of electronic appliances, the energy harvesting are never-ending sources because the environment around us is filled daily with different radio signals from ground stations or through mobile towers. This paper focuses on RF energy harvesting over 2.45 GHz that's which emitting from the Wi-Fi band. The receiving antenna picking up the radio signal that in the RF range (2.45 GHz) from the free space then converts it from a radiated electromagnetic wave into an alternating signal and via rectifier converted later into DC voltage, can be store the voltage inside battery or may be feeding the load directly, the position of antenna is most important, in other words the field strength is grater in the vicinity of the earth station than the areas away from the station. In this paper the semiconductor Schottky diode model SMS 7630-005LF choose because low forward voltage between (0.15-0.45) V and a very fast switching action.

Keywords: *Energy Harvesting; Micro-Strip Antenna; Rectifier; Schottky Diode.*

1. Introduction

In our daily life, wireless technology has become a popular means of transmitting or receiving waves, from the use of satellites in space to the use of mobile cell phones. Anybody, in anywhere and anytime wireless technology it began evolve to provide the easiest way and better services to users. In the present situation where the production of energy is reliant on gas and oil whose prices are irregular daily, the wireless energy concept may be can used as alternative energy. Many researches and efforts are being conducted to develop the techniques 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 radiations from these electronic devices are harmless, the radiated energy is not being utilized, and thus a device capable of harvesting energy can be built from any closed area or public places [1].

Energy harvesting is the process of assembling the energy radiated by radio waves transmitted in the free space within a certain frequency range and converted into the form of voltage. The demand for electricity has become very high in recent days and hence the electricity generated by different ways of energy harvesting methods. A technology of capturing and storing the energy from external sources is known as Energy harvesting. Energy harvesters take energy from sources that are present around us and so free for us to use. Energy harvesting, known also as the 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. The Energy harvesting sources are wind, solar, thermoelectric, heel strike, vibration, temperature gradient, electromagnetic, push buttons, acoustic, radio frequency, etc. Radio wave is present in our daily lives in the form of signal transmission from TV, Radio, wireless LAN, Mobile phone etc. The wireless sources transmit very high energy; this energy can be harvested to generate electricity [2].

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. Ambient RF energy is pervasive, especially for mobile and Wi-Fi networks. 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. 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 [3], [4]. The figure.1 illustrate the completed block diagram of energy harvesting antenna

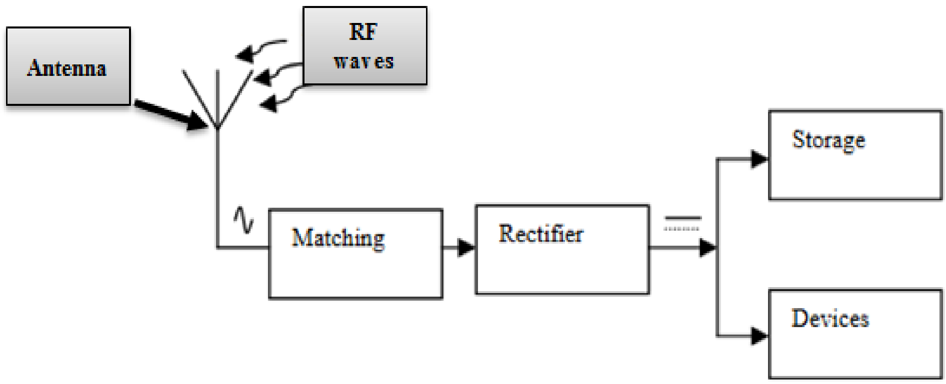

Fig. 1: Completed Block Diagram of Energy Harvesting Antenna.

2. Rectifier circuit

Rectifier circuits are used in rectennas to rectify the AC current induced in the antenna by microwaves. The nonlinear components of rectifying circuits, such as diodes, generate harmonics of the fundamental frequency. These unwanted harmonics cause harmonic reradiation and electromagnetic interference with nearby circuits and antennas and reduce efficiency. The produced DC voltage can be doubled by using a voltage doubler circuit. The output power from the voltage doubler is given to low power devices for charging [5].
Rectifier, also called a charge pump, has three basic types:

- Basic rectifier.
- Voltage doubler.
- Voltage multiplier.

For rectenna application, a rectifier should have high RF to DC conversion efficiency. Typically implemented through one or more diodes, the choice of diode is of prime importance as it can be a major source of loss and its performance determines overall efficiency of the system [6].

3. Micro-strip patch antenna

Micro strip patch antennas are most useful because they can be printed directly onto a circuit board. micro strip antennas are becoming very widespread within the mobile phone market. Patch antennas are low cost, have a low profile and are easily fabricated. Consider the micros-trip the Figure.2 illustrate the micro-strip patch antenna fed by a micro-strip transmission line. The patch antenna, micro-strip transmission line and ground plane are made of high conductivity metal (typically copper). The patch is of length L, width W, and sitting on top of a substrate (some dielectric circuit board) of thickness h with permittivity [7]. .

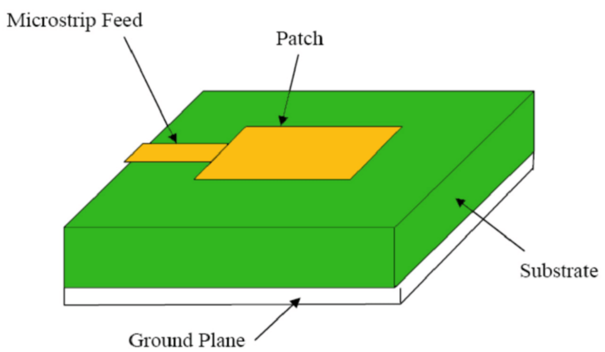

Fig. 1: The Micro-Strip Patch Antenna with Micro-Strip Feed Line.

4. Antenna design

In this part, the essential design characteristics of single Micro-Strip Patch Antenna (MPA) are explained, designed, simulated, and optimized to enhance gain, return loss, bandwidth, and radiation pattern. The results obtained from the simulations are demonstrated [8].
In this work, the Antenna Magus software was used to facilitate the antenna design, to design the single micro-strip patch antenna and [9].
There are many fundamental parameters that should be considered in the simulation software as follows:

- Resonance Frequency (f_o): The resonant frequency of the antenna must be selected according to application used (2.45 GHz).
- Dielectric constant of the substrate (ε_r): The dielectric constants are usually in the range of $2.2 \leq \varepsilon_r \leq 12$. A substrate with a high dielectric constant has been selected since it reduces the dimensions of the antenna.
- Height of dielectric substrate (h): For the MPA to be used in modern applications, it is essential that the antenna is not bulky.

4.1. Rectangular micro-strip patch antenna (MPA)

The antenna design in Antenna Magus Software is not a complex process. In order to design of a rectangular MPA, essential parameters are set as frequency of operation, dielectric constant of the substrate, height of dielectric substrate, Type of material is used as well as input impedance. Table 1, shows the used values in this study.

Table 1: Essential Parameters Values

Resonance Frequency	f_o	**2.45 GHz**
Dielectric Constant	ε_r	**4.25**
Height of Substrate	h	**1.524 mm**
Input Impedance	R_{in}	**50 Ω**
Material Type	FR-4	

After the completion of design inside Antenna Magus, the designed model can be exported to CST MWS. The figure. 3 illustrates the single MPA inside the CST MWS.

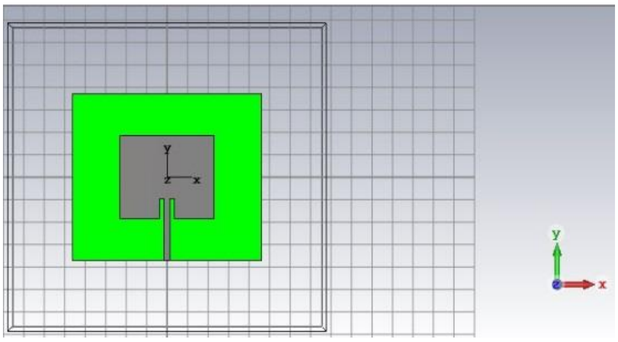

Fig. 3: The Rectangular MPA inside CST MWS.

Optimization is the act of obtaining the best result under given circumstances. In this study, the main interest of optimization is to enhance performance and facilitate the manufacturing process of antennas, where the laser accuracy in manufacturing antennas is 0.01 mm. so, the optimization procedures for antenna are through maximize some parameters and minimize some others [10]. The table.2 presented parameter values were calculated by the Antenna Magus and confirmed through the shown equations below.

Table.2: Parameter Values before and after Optimization for Single MPA

Parameter	Calculated Model(mm)	Optimized Value(mm)
Patch Width (W)	37.5838863292	37
Patch Length (L)	29.1383261927	28
Feed Inset from Edge of Patch (Si)	10.5193230907	9.3
Feed Line Width (W_f)	3.11184311630	3
Feed Line Length (L_f)	33.8534486973	30
Spacing between Feed Line and Patch (Sg)	3.11184311630	1.5

The following equations are used for the purpose of confirming the results obtained through the Antenna Magus simulation software [11].

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1 + 12\frac{h}{w}\right]^{\frac{-1}{2}} \quad (1)$$

$$\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.3)\left[\frac{w}{h}+0.264\right]}{(\varepsilon_{reff}-0.258)\left[\frac{w}{h}+0.8\right]} \quad (2)$$

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} \quad (3)$$

$$L = L_{eff} + 2\Delta L \quad (4)$$

$$W = \frac{c}{2f_r\sqrt{\frac{(\varepsilon_r+1)}{2}}} \quad (5)$$

Where, (ε_{reff}) is the effective dielectric constant, ε_r is dielectric constant of substrate, (h) is height of dielectric substrate. W is width of the patch, (L_{eff}) is effective length, (L) is actual length, and the dimensions of the patch along its length have been extended on each end by a distance (ΔL).The dimensions of the single patch, feed line, and space between them are illustrated in the Figure.4 shown below. Micro-strip patch antennae can be fed by a variety of different methods. The four most popular feed techniques used for the Micro strip patch are

- Inset feed
- Pin feed
- Aperture coupling
- Proximity coupling

Since the current is low at the ends of a half wave patch and increases in magnitude toward the center, the input impedance could be reduced if the patch was fed closer to the center method of doing this is by using an inset feed. In this paper the inset feeding technique used in order to enhancing the impedance matching and to facilitate the fabrication and the coupling of the antenna with the rectifier circuit [12].

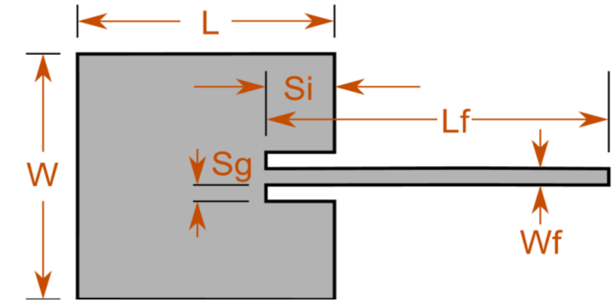

Fig. 4: Dimensions of the Single Rectangular Patch with Feed Line.

After many trials of optimization procedure, the obtained result summarized in table.2, the figure.5 illustrate the final shape of rectangular MPA after optimization operation.

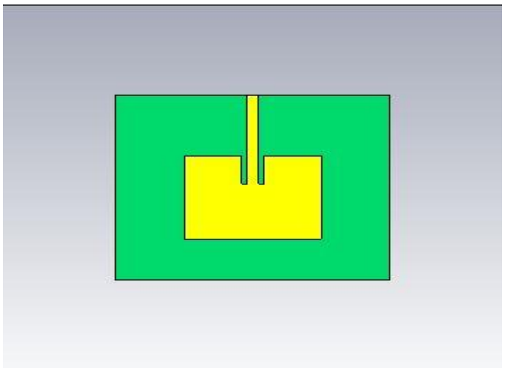
Fig. 5: The Optimized Rectangular MPA.

4.2. Simulation results of single rectangular MPA

The simulated return loss ($S_{1,1}$) of the single before the optimization rectangular MPA from CST MWS is shown in Figure .6, at 2.45 GHz, a return loss of -11.93 dB is achieved. The VSWR, 1.67, can be calculated by using the following equation:

$$S_{1,1} = 20\log(\rho) \quad (6)$$

$$VSWR = \frac{1+|\rho|}{1-|\rho|} \quad (7)$$

Where:
VSWR: Is the voltage standing wave ratio
ρ: is the reflection coefficient and equal to $\rho = 10^{\frac{S_{1,1}}{20}}$.

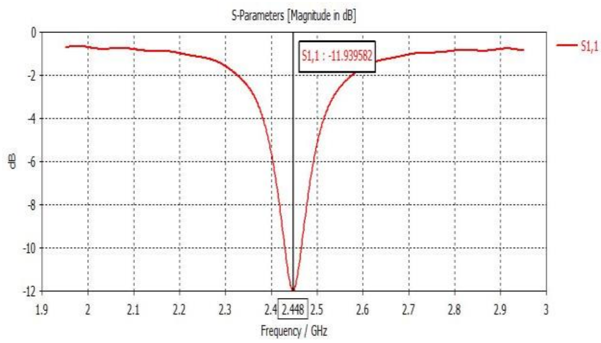

Fig. 6: The Return Loss of Rectangular MPA before the Optimization.

In comparison to the optimized antenna, the return loss after optimization is better, as shown in Figure .7, at 2.45 GHz a return loss approximately -21 dB is achieved and VSWR is 1.19.

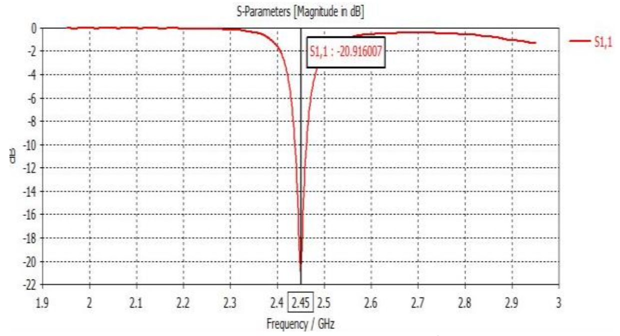

Fig. 7: The Optimized Return Loss of SMPA.

The rectangular MPA are known for their poor gain; this is because the gain is affected by substrate thickness and relative dielectric constant. The Gain is inversely proportional to ε_r and directly proportional to substrate thickness [13].

In the design of rectangular MPA, the gain is 2.87 dB, as shown in Figure .8. Moreover, antenna optimization procedure, the gain is increase to be 6.16 dB as shown in Figure.9.

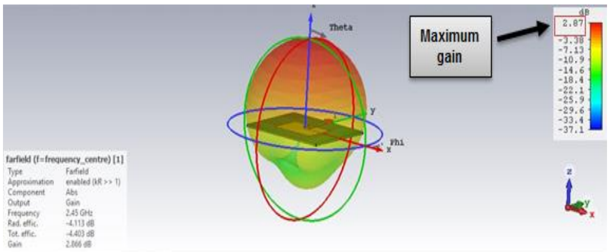

Fig. 8: The Gain of Rectangular MPA before the Optimization.

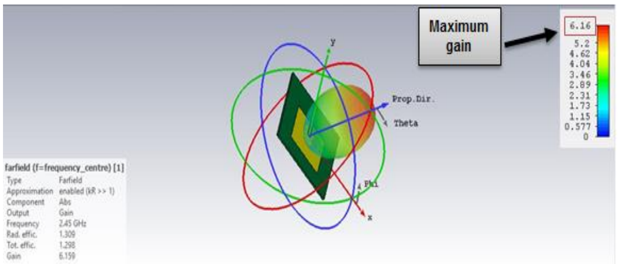

Fig. 9: The Optimized Gain of Rectangular MPA.

The radiation pattern of a single rectangular MPA is described by a single main lobe of moderate beam width. Frequently, the beam widths in the azimuth and elevation planes are similar, resulting in a fairly circular beam, although this is by no means universal. The beam widths can be manipulated to produce an antenna with higher or lower gain, depending on the requirements. The 3 dB beam width, for single rectangular MPA before and after optimization, is about 92^o and same as after optimization as shown in figure .10 and figure.11.

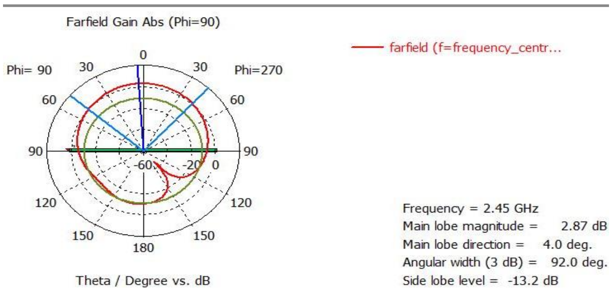

Fig. 10: The Radiation Pattern of Rectangular MPA before the Optimization Operation.

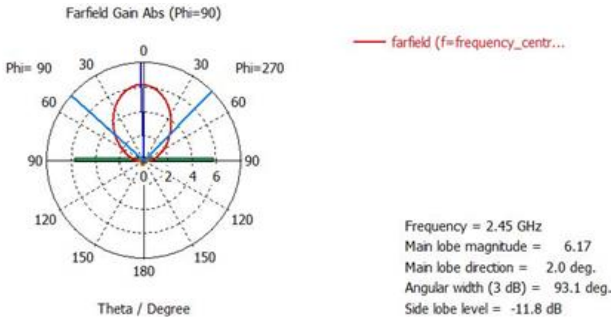

Fig. 11: The Radiation Pattern of Rectangular MPA after the Optimization Operation.

After complete the simulating of the antenna inside the CST MWS, the rectifier circuit is designed and simulated by the CST MWS, which in turn will rectified the received signal through the antenna and turn it into a direct signal (i.e. DC voltage), which will feed the load later. In additional if the signal is a little voltage, can implement amplifier or converter such as boost or buck converter. In the proposed design the voltage doubler select as a rectifier circuit as a traditional and popular circuit to convert the AC signal received from the Antenna to DC output voltage as knows it's a full wave bridge circuit in a way to get voltage for both periods of the positive and negative cycle of the wave. Also we use two stubs for matching purpose in order to match the Antenna impedance with rectifies input impedance which is "50 Ω", the stubs work as a low pass filter in a way to eliminate unwanted harmonic frequencies and just allows the desired level, this matching technique done by changing the dimensions (length & width) of both stubs to matching 2.45 GHz and get best result for return loss [14]. Stubs technique is easy design than LPF also it's reduce the complexity of the circuit so, it selected in this work rather than LPF. The figure.12 illustrate the completed simulation of the antenna, rectifier circuit and subs, (the subs equivalent to low pass filter) inside the CST MWS, the figure.13 illustrate the return loss of the completed simulation. The Schottky diodes are chosen in the implementation of rectifier circuit because of their low voltage threshold (i.e. low voltage drop across the diode terminals) and lower junction capacitance than PN diodes, this low threshold allows for more efficient operation at low powers, and the low junction capacitance increases the maximum frequency at which the diode can operate. A standard Schottky diode model SMS- 7630-005LF choose due to fast forwarding switching. The resistance "Rs" is in series with a variable junction resistance "Rj" in parallel with a variable junction capacitance "Cj" that change as a function of input power, the nonlinearity of Schottky diodes in energy harvesting circuits makes impedance matching a challenging endeavor. So we choose Schottky diode cause have a fast forwarding switching either the low level of received power [15].

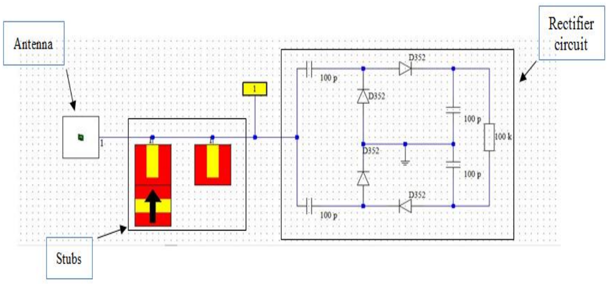

Fig. 12: The Completed Simulation of Antenna and Rectifier Circuit.

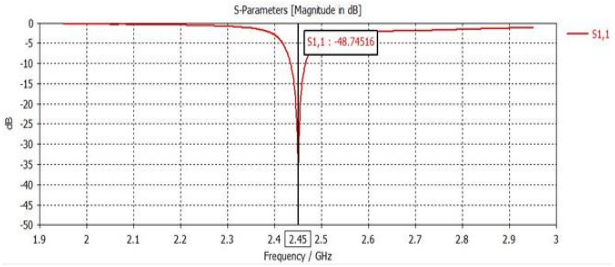

Fig. 13: The Return Loss of the Completed Simulation.

5. Conclusion

The RF energy harvesting technology extend a promising future of the appliances which consumed a low power such electronics devices and wireless sensor networks. In this paper the proposed design of the antenna provides the input for the rectification circuit and it is based on a rectangular patch antenna in order to picking up the radio frequency waves in 2.45 GHz range, the design was simulated based on CST MWS and Antenna Magus, the using of Antenna Magus software to facilitate the design operation. The using of Schottky diode model SMS 7630-005LF makes the antenna with small compact size. The results obtained after the simulations ended was 6.16 dB gain and -48.745 dB return loss, were good result compared to an antenna of this small size.

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