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REGULAR ARTICLE

Radio Frequency Energy Harvesting Receiving Antenna for sub-6 GHz Bluetooth and Wi-Fi Application Bands of 5G Technology

K. Mamta[1,*], R.K. Singh[2,†]

[1] *Dept. of Physics, Nalanda College of Engineering, Chandi, Nalanda-803108, Bihar, India*
[2] *University Department of Physics, Ranchi University, Ranchi-834008, Jharkhand, India*

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Radio frequency (RF) energy harvesting finds application in wireless sensors, RF codes, smart switches, IoT device applications, etc. Contrary to batteries, RF energy harvesting is open to electromagnetic waves coming from different sources and there is no limitation on the dimension and duration of application. A RF energy harvester captures electromagnetic energy from the source to which it is exposed and convert this energy into usable DC voltage. In this paper we propose the fundamental unit of RF harvester, the microstrip patch antenna. Microstrip patch antenna comes with a host of qualities like small size, low price, simple design, less weight, easy fabrication and many more. The proposed microstrip patch RF energy harvest antenna is developed using FR4 substrate with dielectric constant 4.4 and loss tangent 0.009. The substrate comes in between the ground and copper metal patch. Selected target frequency of operations is 2.4 GHz and 5 GHz, which lie in the Wi-Fi band. A microstrip line of width 1.1 mm for 50Ω impedance load matching is used. The antenna is inset-fed. The design and simulation are carried out using High-Frequency Structure Simulator (HFSS) software and the antenna dimensions are due to standard antenna equations. Simulation results achieved gain of 7 dBi at 2.4 GHz with low return loss (S_{11} parameter). The return loss stands near – 13 dB. The gain of the RF harvester at 5 GHz frequency operation is obtained to be 6 dBi with a remarkable low return loss of – 28 dB. With the given results and stable omnidirectional radiation pattern, the proposed antenna design is suitable for energy harvesting application for mm wave application viz. Bluetooth, Wi-Fi, and WiMAX applications, as an alternate energy source meeting the global energy requirement due to increase in demand of power.

Keywords: Energy harvesting, Radio frequency, Microstrip antenna, Gain, Return loss, Receiving antenna.

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1. INTRODUCTION

Wireless power transfer systems employ radio frequency (RF) energy harvesting unit in its receiver segment. Compact antennas are looked for providing power to small handheld devices on the condition of maximum energy capture. Such small handheld RF systems cover different IEEE recommended frequency bands, like 2.4 GHz, 5.1 GHz, 5.8 GHz for Bluetooth and Wi-Fi application and 2.3 GHz, 2.5 GHz, 3.5 GHz, 5 GHz for Wi-MAX application [1-3].

For such intended application, the RF energy harvester put in use the antenna with a characteristic omnidirectional radiation pattern, wide bandwidth and good gain. Energy harvesting devices converts the ex-posed electromagnetic energy into usable DC voltage. Microstrip patch antennas are compact, light-weight, low cost, flat in structure and comes with such characteristics as required for RF energy harvesting and hence are good alternatives for energy harvesting applications [4-6]. Microstrip patch antenna is a triple-layer device. The top layer is the metallic foil radiating patch. The bottom layer is the ground layer and there is a dielectric substrate in between the top and bottom layer. The radiation in the microstrip patch antenna is realized through the fringing fields. The microstrip antenna's radiation is created by the phase-added addition of the fringing E-fields on its border. Contrary to wire antennas, the microstrip patch antenna radiates as if it is a "voltage radiator."

Another point of view in favor of microstrip patch antenna is that they are free from the issues of disposal in landfills, as in case of batteries, which leads to land pollution and the ground water contamination. Further minimizing the use of batteries is also the call of time towards low carbon emission and environment friendliness [7-9]. In view of this, wireless RF power harvesting is considered a promising approach to replace the batteries.

RF harvesting system offers an alternative and

* Correspondence e-mail: mamta.singh548@gmail.com
† rajkrsingh08@gmail.com

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sustainable approach to supply power to low-powered electronic systems [10-11]. Moreover, RF-energy harvesting is a suitable alternative to deliver energy to next-generation wireless networks [12].

The RF energy harvester is the ordinary rectifier circuit that converts RF energy to usable DC power for wireless charging of devices. The antenna, as a transducer, converts the strength of an electric field into a voltage difference and vice versa. On the other hand, the rectifier, converts RF power to DC power with error ac pulsation which can be smoothen out using filters circuit. This is followed by the voltage multiplier circuit which produces a higher output DC voltage level with the given input energy. Following this, batteries or low-loss capacitors are used to store harvested energy. The availability of the ambient RF energy, including those from mobile base stations, radio, TV transmitters, Wi-Fi networks, mobile phones, is an added advantage towards the necessity of self-sustained RF energy sup-ply [13-14]. This is an edge over other conventional energy sources in use, including thermal, solar, vibration, mechanical, and wind energy [15-17]. Although RF energy harvesting systems are designed to catch freely available ambience electromagnetic energy, microstrip patch antenna serves as the source of electromagnetic wave for RF- energy harvesting systems [18-21]. With the use of microstrip patch antenna it is easy to manipulate according to the specifications of the application in hand for the characterization of the electromagnetic waves.

This paper presents a new design of the receiving antenna which is the main part in the RF harvesting energy system with an objective to provide an alternate solution to the existing energy sources in use viz, solar energy, wind energy, etc. Antenna gain is optimized for use in the sub-6 GHz Wi-Fi bands of 5G technology. S_{11} parameter, the return loss, goes below – 13 dB for 2.4 GHz frequencies and – 28 dB for 5 GHz. The radiation shape shows a quasi-omnidirectional stable pattern in Wi-Fi bands. Rest of the paper is organized as follows. Section 2 describes the design and configuration of the proposed radio frequency energy harvesting receiving antenna for the next-generation wireless networks at Wi-Fi bands. Section 3 reports the simulated results and discussions on the performance of antenna. Conclusion is included in Section 4.

2. ANTENNA DESIGN AND CONFIGURATION

The choice of right antenna is very crucial in the design of an electromagnetic energy harvesting system. Among the critical requirements are rectification and storage, the operating frequency and field, the gain and efficiency of the antenna, high output power, bandwidth and its cost. Patch size of the antenna is determined by the frequency bands of interest. Basic block diagram of rectifier antenna is shown in Figure 1, which consists of an antenna delivering power to the matching circuit. Rectifier is used to convert ac voltages into direct voltage. Filter circuit smoothen out any leftover ac voltage pulsation. The rectified and filtered dc voltage goes to the energy storing element.

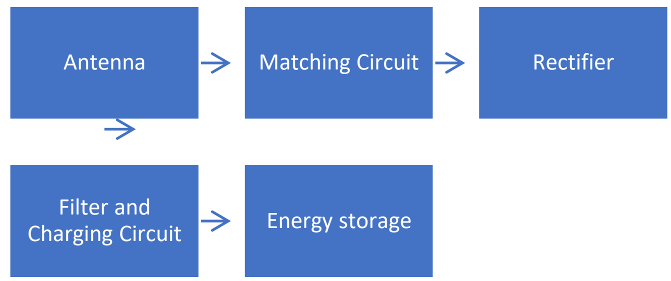

Fig. 1 – Block diagram of the rectifier antenna

We have designed an inset feed microstrip patch antenna ready to have dual-band operation at 2.4 GHz and 5 GHz in the Wi-Fi band, using High Frequency Structure Simulator (HFSS) software, for energy harvesting the Wi-Fi band frequencies (Fig. 2).

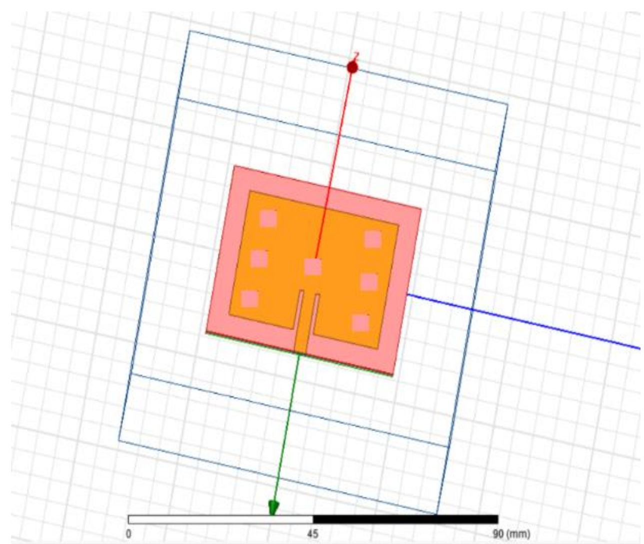

Fig. 2 – HFSS design of rectangular microstrip patch antenna with slots

Some of the basic specifications for the design of antenna, backed by calculation from the standard antenna equation in Table 1, are the thickness of substrate (1.6 mm), material of the substrate (FR4), the thickness of copper as patch (0.035 mm), the relative permittivity of the substrate material (4.4 with the loss tangent 0.009). The performance of the proposed antenna has been evaluated and optimized through Ansoft HFSS.

Design equations for different parameters of the antenna is made available in Table 1, wherein the equations leading to determination of patch width, height, substrate thickness, patch length, length extension and effective dielectric constant can be found.

Table 1 – Antenna design equations

Parameter	Design equation
Patch width, Wp	$Wp = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}}$
Substrate height, h	$h \le \frac{0.3\,c}{2 * 3.14 f_r \sqrt{\varepsilon_r}}$
Patch length, Lp	$Lp = \frac{c}{2\sqrt{\varepsilon_r^{eff}}}\left(\frac{1}{f_r}\right) - 2(\Delta L)$
Length extension, ΔL	$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_r^{eff} + 0.3)\left(\frac{W_p}{h} + 0.264\right)}{\left(\frac{W_p}{h} + 0.8\right)(\varepsilon_r^{eff} - 0.258)}$
Effective dielectric constant, ε_r^{eff}	$\varepsilon_r^{eff} = \frac{1}{2}(\varepsilon_r + 1) + \frac{1}{2}(\varepsilon_r - 1)(1 + 12\ \frac{h}{w_p})^{-1/2}$

Where, ε_r – Dielectric constant of substrate, f_r – resonant frequency, c – velocity of light in free space.

Ground and substrate dimensions conform to 53 × 23 mm. Microstrip patch of dimension 37.4 × 18 mm is taken on which few slots are carved out and labelled as S_1, S_2, S_3, S_4, S_5, S_6 and S_7. The slot S_1 and S_2, of dimension 3.4 × 2.2 mm and at a separation of 9.4 mm, are at the far end from the feed point at a distance of 5.3 mm from the edge of the patch.

From the feed end, identical slots S_6 and S_7 are created, again at a separation of 9.4 mm. In between the slot rows of S_1-S_2 and S_6-S_7, we have another row of identical slots, but this time there are three slots labelled as S_3, S_4 and S_5. Slots S_3 and S_5 are equidistant (3.6 mm) from slot S_4. Feedline connects through a rectangular strip of length 21.8 mm and width 2.2 mm. All slots are 2.1 mm from the both length ends of the patch. Slots S_6 and S_7 are at a distance of 5.4 mm from the end of patch as shown in the schematic Fig. 3

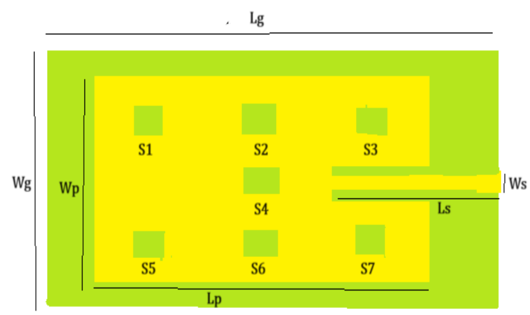

Fig. 3 – Schematic design of antenna

The radiating patch of the antenna uses substrate FR4 (dielectric constant 4.4). A microstrip line of 50Ω impedance is used to match with the load antenna. This ensures supplying of energy to the radiating patch. Dimensions of designed antenna enlisting length and width of ground, length and width of patch, length and width of feedline slot and slot dimensions are mentioned in Table 2.

Table 2 – Patch and slots dimensions

Quantity	Symbol	Dimension in mm
Width of ground	W_g	53
Length of ground	L_g	23
Width of patch	W_p	18
Length of patch	L_p	37.4
Width of feedline slot	W_s	1.7
Length of feedline slot	L_s	21.8
Slot dimension ($l \times b$)	S_1, S_2, S_3, S_4, S_5, S_6, S_7	3.4 × 2.2

3. SIMULATION RESULT AND DISCUSSION

The simulations result of the return loss (S_{11}) is shown in Fig. 4.

From the return loss plot, we observe that the resonance frequency is stable at 2.42 GHz and 5.08 GHz with return loss below – 13 dB and – 28 dB.

In Fig. 5, gain of the designed antenna is shown. The gain stands at 7 dBi (Fig. 5) for the resonance frequency 2.4 GHz band, and at 6 dBi (Fig. 6) at an-other frequency 5 GHz. Antenna with high gain is preferable.

From the gain plot, we infer that a near omnidirectional radiation is realized by the designed antenna for the intended operation frequency in the Wi-Fi bands.

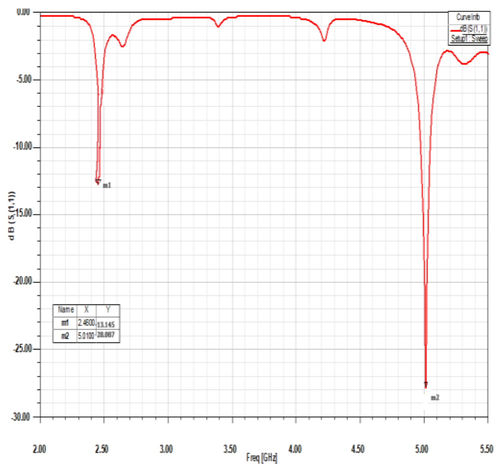

Fig. 4 – Return loss

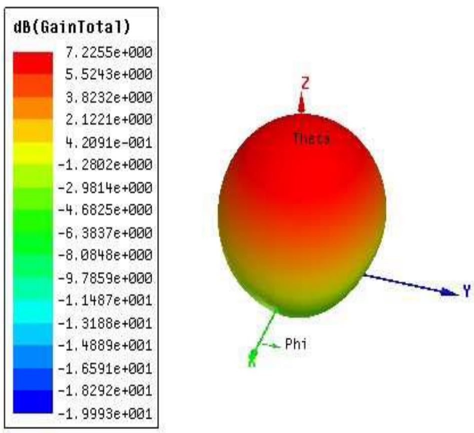

Fig. 5 – Antenna Gain at 2,4 GHz

The results obtained of the compact, low cost, planar, light-weight microstrip patch antenna has potential to provide good performance as receiving antenna in a RF energy harvesting system.

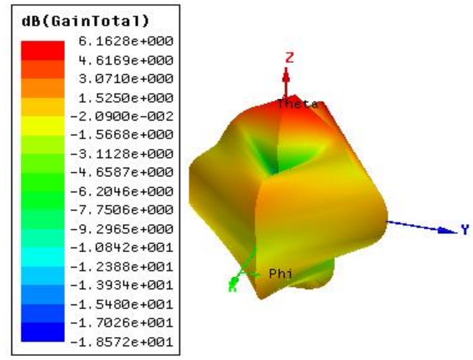

Fig. 6 – Antenna Gain at 5 GHz

4. CONCLUSION

RF energy harvesting has a lot of potential to pro-vide green power indefinitely. This is suitable for wire-less applications. In this paper, we propose a new receiving antenna, with all the qualities and goodness of microstrip patch antenna using High-Frequency Structure Simulator (HFSS) software. Antenna dimensions are based on standard antenna equations. The pro-posed antenna is capable of energy harvesting in the double-band operation frequency 2.4 GHz and 5 GHz, in the sub-6 GHz Wi-Fi bands of 5G spectrum. Microstrip patch design ensures compact size, light weight and eco-friendliness of the antenna. Use of substrate FR4 with dielectric constant 4.4 and loss tangent 0.009 makes it economical. A good quasi-omnidirectional and stable radiation pattern is realized. Antenna gain is improvised with the use of selective slots on the radiating patch. Peak gain varies from 7 dBi to around 6 dBi for the operation frequency 2.4 GHz and 5 GHz. Antenna resonates at 2.42 GHz and 5.08 GHz with low return loss below – 13 dB and – 28 dB with a matching impedance of 50 Ω using inset feed. The designed receiving antenna is suitable for applications in wireless sensors, RF codes, smart switches, IoT device etc. in the sub-6 GHz Wi-Fi bands of 5G spectrum frequency.

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Приймальна антена для збору радіочастотної енергії для діапазонів додатків Bluetooth і Wi-Fi у діапазоні до 6 ГГц технології 5G

K. Mamta[1], R.K. Singh[2]

[1] *Dept. of Physics, Nalanda College of Engineering, Chandi, Nalanda-803108, Bihar, India*
[2] *University Department of Physics, Ranchi University, Ranchi-834008, Jharkhand, India*

Збір радіочастотної (РЧ) енергії знаходить застосування в бездротових датчиках, радіочастотних кодах, розумних комутаторах, додатках пристроїв Інтернету речей тощо. На відміну від батарей, збір радіочастотної енергії відкритий для електромагнітних хвиль, що надходять від різних джерел, і немає обмежень щодо розмірів і тривалість застосування. Збирач радіочастотної енергії вловлює електромагнітну енергію від джерела, якому він піддається, і перетворює цю енергію на корисну напругу постійного струму. У цій статті ми пропонуємо основний блок РЧ-харвестера, мікросмужкову антену. Мікросмугова патч-антена має низку таких якостей, як невеликий розмір, низька ціна, простий дизайн, менша вага, легке виготовлення та багато іншого. Запропонована мікрополоскова антена для збору радіочастотної енергії розроблена з використанням підкладки FR4 з діелектричною проникністю 4,4 і тангенсом втрат 0,009. Субстрат знаходиться між землею та мідною металевою латкою. Обрана цільова робоча частота становить 2,4 ГГц і 5 ГГц, які знаходяться в діапазоні Wi-Fi. Використовується мікросмужкова лінія шириною 1,1 мм для узгодження навантаження з опором 50 Ом. Антена має вбудоване живлення. Розробка та моделювання виконуються за допомогою програмного забезпечення High-Frequency Structure Simulator (HFSS), а розміри антени визначаються стандартними рівняннями антени. Результати моделювання досягли посилення 7 дБ на 2,4 ГГц з низькими зворотними втратами (параметр S11). Зворотні втрати становлять близько – 13 дБ. Коефіцієнт посилення РЧ-харвестера при роботі на частоті 5 ГГц становить 6 дБі з неймовірно низькими зворотними втратами – 28 дБ. Завдяки наданим результатам і стабільній всеспрямованій діаграмі спрямованості запропонована конструкція антени підходить для використання в системах збору енергії для міліметрових хвиль, а саме. Програми Bluetooth, Wi-Fi та WiMAX як альтернативне джерело енергії, яке відповідає глобальним потребам у енергії через збільшення попиту на електроенергію.

Ключові слова: Збір енергії, Радіочастота, Мікросмугова антена, Підсилення, Зворотні втрати, Приймальна антена.