Design and Simulation of a Compact 5.4GHz H-shaped Slot Antenna for RF Energy Harvesting Systems

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Abstract. in this paper, a compact H-shaped slot antenna is proposed. The antenna contains one H-shape slot which is fed through microstrip line, an open circuited stub is connected for proper impedance matching. The H-shaped slot is used for bandwidth enhancement. The antenna is designed to radiate at 5.4 GHz with a bandwidth of 1.6GHz. The antenna has an omni-directional pattern across the frequency band. The gain of the antenna is 4.35dBi at 5.4GHz. Since, the proposed antenna satisfies all the characteristics of energy harvesting systems, it can be used for energy harvesting systems, at 5.4GHz 4G-LTE band. CST microwave studio was used for designing the proposed antenna. An excellent agreement is achieved between simulated and measured results.

1. INTRODUCTION

In recent years the Radio Frequency energy harvesting has been attracting an increasing deal of attention in order to provide power to the electronic devices, including Wireless Sensor Networks. This paper focuses on ambient RF energy available in the ambient environment. One of the best methods for harvesting the Radio Frequency (RF) energy is to use a rectenna. A rectenna is also called as rectifying antenna which consists of receiving antenna, filters and rectifiers. The receiving antenna is presented in this paper.

For energy harvesting systems the antenna should have high gain, high directivity, omnidirectional radiation pattern, large bandwidth and high efficiency. To meet the requirements, various methods have been proposed. Several investigations concentrate on the receiving antenna where it collects input power as much as possible. If the input power received by antenna is maximum then the energy harvested will be also maximum. Several researchers have been using multiband antenna for harvesting from different frequency bands [1, 12, 14], antennas with high gain can also be used for RF energy harvesting [2, 9], combination of Electro Magnetic wave and solar cell is used for energy harvesting [3, 7, 8], and rectenna arrays [4, 6, 9]. In the paper [5, 13], semicircular slot antenna for rectenna was presented. A compact 5.4 GHz antenna for energy harvesting is proposed in this paper. This compact feature can be used in rectenna array design to combine higher microwave power at 4G-LTE band.
2. H-SHAPE SLOT ANTENNA DESIGN ANTENNA DESIGN

Traditional microstrip-fed rectangular slot antenna with a magnetic wall at the slot centre is depicted in Fig.1 (a). The proposed antenna design has an H-shape slot fed by a microstrip feed line and open-circuited stub to adjust impedance matching is depicted in Fig.1(c). The antenna is designed in CST microwave studio. In designing the antenna FR-4 substrate with a dielectric constant (\(\varepsilon_r\)) of 4.4 with thickness of 0.8 mm is used. The antenna is compact for using H-shape slot. The H-shape slot increases the bandwidth (BW) of the antenna. The resonance frequency of the slot is calculated from equation (1), where ‘c’ is the speed of the light and ‘\(\varepsilon_{eff}\)’ is the effective dielectric constant. The dimension of the designed antenna is 92 x 73.5 mm\(^2\). Fig.1(c) and Fig.1 (b) shows the layout and fabricated prototype of the designed antenna respectively; all the structural parameters of the antenna are embellished in Fig.1.

\[
\frac{c}{(\text{slot length} \times \sqrt{\varepsilon_{eff}})} = 1
\]

Fig.1. Proposed antenna layout (a) slot antenna, (b) photo of the fabricated prototype, and (c) H-shape slot geometry L=92mm, L1=44 mm, L2=0.74 mm, L3=38.5 mm, L4=14.9 mm, \(W=73.5\) mm, \(W1=18\) mm, \(W2=2.75\) mm, \(W3=1.53\) mm, \(W4=0.55\) mm.
3. ANTENNA RESULTS

The designed antenna is fabricated using photolithography process and tested using Vector Network Analyzer. The antenna is designed using the FR-4 substrate which is of very low cost. A K connector is used in the measurements which affects the measured results slightly. The measurement setup is shown in Fig. 2.

![Measurement setup](image)

**Fig.2.** Measurement setup

A. S-Parameters of Antenna

Fig. 3 shows the S-parameter plot indicating the reflections from the antenna. It can be observed that the antenna radiates between 4.8GHz to 6.48GHz. Therefore, bandwidth of the antenna is 1.7GHz. Fig. 4 shows the excellent concurrence between the simulated and measured S-parameters for the H-shaped slot antenna.

![S-Parameter plot](image)

**Fig.3.** S-Parameter plot

![Simulated vs measured S-parameters of the antenna](image)

**Fig.4.** Simulated vs measured S-parameters of the antenna

As seen from the figure, it can be noticed that the antenna has a bandwidth for reflection coefficient ≤ -10 dB from 4.8GHz to 6.4GHz. Therefore, the bandwidth of antenna is 1.6GHz.

B. Voltage Standing Wave Ratio (VSWR)

Fig. 5 shows the Voltage Standing Wave Ratio (VSWR) plot of the simulated antenna. It can be noticed that the VSWR obtained at 5.4GHz frequency is nearly 1.21 which indicates that...
the antenna has very less reflections. Fig. 6 shows excellent agreement between simulated and measure VSWR for the H-shaped slot antenna. The antenna has VSWR ≤ 2 from 4.8GHz to 6.4GHz. The antenna efficiency is more than 90% for the entire bandwidth.

![VSWR plot](image1)

Fig. 5. VSWR plot

![Simulated vs Measured VSWR results](image2)

Fig. 6. Simulated vs Measured VSWR results

C. Gain

Fig. 7 shows the polar pattern of the gain. It is observed that at 5.4GHz frequency 4.34dBi gain is obtained.

![3D Polar Plot of Gain](image3)

Fig. 7. 3D Polar Plot of Gain

D. Radiation Pattern

E-plane and H-plane radiation pattern is shown in the Fig. 8. It is observed that the antenna radiates with a gain of 4.35dBi at 5.4GHz. The designed antenna has a relatively stable Radiation Patterns (RP) and around 90% radiation efficiency over the entire frequency range.

![E-plane and H-plane radiation patterns](image4)

Fig. 8. E-plane (Red line) and H-plane (Green line) radiation patterns at 5.4GHz
E. Surface Current Distribution

The surface current distribution (SCD) is shown in the Fig. 9. The red portion indicates the maximum current distribution over the radiating patch.

![SCD of the antenna at 5.4GHz](image)

Fig.9. SCD of the antenna at 5.4GHz

F. Directivity

The Directivity of the designed antenna shown in the Fig.10. The obtained directivity is 6.1dBi.

![Directivity of designed antenna](image)

Fig.10. Directivity of designed antenna

G. Efficiency

Fig.11 and Fig.12 depicts the radiation efficiency and total efficiency of the designed antenna respectively. With the designed antenna 90% efficiency is obtained.

![Radiation efficiency](image)  
![Total efficiency](image)

Fig.11. Radiation efficiency.  
Fig.12. Total efficiency
4. CONCLUSION

This paper presents an H-shaped microstrip slot antenna which resonates at 5.4GHz frequency. The antenna was designed and simulated using CST microwave studio software. The designed antenna has achieved very low return loss and excellent voltage standing wave ratio. The techniques employed for investigating the antenna characteristics shows high efficiency and high accuracy. The fabricated antenna has a bandwidth of 1.6GHz and a gain of 4.35dBi at resonant frequency of 5.4GHz with an Omni directional radiation pattern. Since, the fabricated antenna meets the requirements of energy harvesting systems; it can be used in energy combining techniques.

5. FUTURE SCOPE

The bandwidth of the antenna can be further increased by including multiple slots, but increasing the number of slots increases the complexity in design. Further the directivity of the system can be increased by incorporating array of antennas and also gain can be improved by coupling the slot with another slot antenna.

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