Miniature 2.45 GHz Patch Antenna with Defected Ground Structure for Rectenna Applications

A. Taybi[1], A. Tajmouati[1], J. Zbitou[1], A. Errkik[1], L.El Abdellaoui[1], M. Latrach[2]

[1] LMEET, FST of Settat, Hassan 1st University, Settat, Morocco
[2] Microwave Group ESEO Angers, France

Abstract. In the context of miniaturization of microwave systems that this paper is aimed at. We have designed a novel miniaturized 2.45 GHz antenna dedicated to operate for wireless power transmission applications. At first, the antenna was radiating at 5.8 GHz with the optimal dimentions, then, and by conserving the same size, we have switched the operating frequency to 2.45 GHz by using a novel configuration of Defected Ground Structure (DGS). The final structure have been designed and optimized by using Computer Simulation Technology (CST) Microwave Studio .The obtained results confirm the proper functioning of the antenna.

Keywords: Wireless Power Transmission, DGS, Rectenna, CST Microwave Studio.

1 Introduction

The wave of innovations continues to improve day by day and particularly in the field of telecommunications, which are in a period of globalization. Therefore, studies have focused on significant miniaturization, especially for the antenna part to meet modern telecommunications needs. The antenna is an essential part of any wireless device, especially RECTENNA (RECtifying anTENNA) systems. Figure 1 shows a basic block diagram of rectenna system. A rectenna is a device that collects incident electromagnetic radiation and converts it to DC power. The rectenna consists of four elements: a receiving antenna, an input filter, a diode or combination of diodes [1] that performs wave rectification, and an output filter that makes DC energy available at the load. The possibility of using Rectennas for wireless power transmission [2] purposes have been initiated and experimented by W.C Brown [3] by using a model of helicopter powered by microwaves transmited from the ground and received by an attached rectenna. A variety of rectenna designs optimized for conversion efficiency in the industrial, scientific, medical band (ISM) reaching important efficiencies for different values of input power have been reported [4,6].

There are several types of antennas depending on geometry, gain, beam shape and bandwidth. Patch antennas [7,9] (Figure 2) are widely used for microwave applications mainly for those involving wireless power transmission. It has the advantage of low weight and is made by engraving a printed circuit board. Due to their manufacturing technology, they can be integrated as close as possible to electronic circuits, occupying a reduced volume and conforming to different types of surfaces. Their main advantage is their low manufacturing cost.

Otherwise, the operating frequency has a significant weightiness on the antenna's size. Several operating frequencies of the rectenna have been considered and investigated.

ICCWCS 2019, April 24-25, Kenitra, Morocco

DOI 10.4108/eai.24-4-2019.2284085

Components of microwave power transmission have traditionally been focused on 2.45 GHz and recently moving up to 5.8 GHz, which has a smaller antenna aperture area than that of 2.45 GHz.

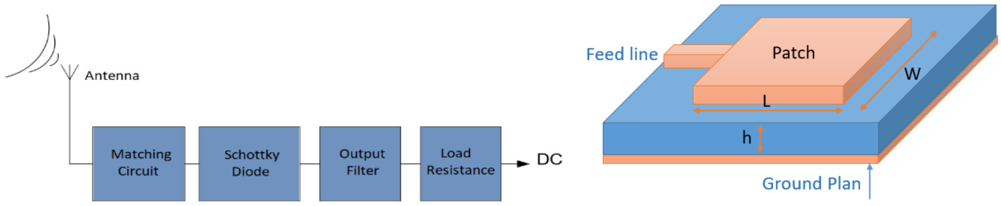

Fig. 1. (a) Block diagram of rectenna circuit (b) Rectangular microstrip antenna configuration

Many research topics have been devoted to benifits from small size and performant antennas, hence, Defected Ground Structure (DGS) [10,12] is becoming an effective and efficient technology for the miniaturization of patch antennas. DGS is a periodic motif engraved on the ground plan. The name of this technique simply means that a defect is placed on the ground plane which is generally considered an anomaly of a current well.

In this paper, a novel DGS configuration have been employed on a 5.8 GHz antenna's ground plane so that the frequency could be switched to 2.45 GHz without losing in terms of antenna's performances.

2 5.8 GHz initial antenna analysis and design

Owing to technological advances in telecommunications and continuous scientific research concerning printed antennas, and given the multiple requirements in the field of communication, the use of conventional microwave antennas is no longer able to meet these requirements. For this reason, printed antennas replace conventional ones in a number of applications, including rectenna systems. In general, a printed antenna (Fig. 1(b)) consists of a ground plane, one or more substrate layers that may have the same or different permittivities. The surface contains a radiating element of any geometry (rectangular, circular, slit, or more elaborate shapes). Among the many advantages: A low manufacturing cost, lightweight and space-saving, the possibility of networking to improve directivity and the compatibility with hybrid and MMIC (Microwave Monolithic Integrated Circuit) circuits.

2.1 Calculation of Width (W), Length (L) and Effective Dielectric Constant ε_{reff}

- For an effective radiator, practical width of the patch antenna that leads to good radiation efficiencies is given by [13]:

$$W = \frac{C_0}{2F_0}\sqrt{\frac{2}{1+\varepsilon_r}} \qquad (1)$$

  Where C_0 is the free-space velocity of light i.e. 3×10^{-8} m/s and ε_r is the dielectric constant of material.
- The length of the patch determines the resonance frequency thus it is a critical factor for narrowband patch. Since it is not possible to accurately account the fringing field the results are not definite. Below is the equation to calculate the length of the patch :

$$L = \frac{\lambda_{eff}}{2} - 2\Delta L \qquad (2)$$

Where ΔL is the length extension because of fringing field, which can be calculated as follow:

$$\Delta L = 0.412\, h \frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \qquad (3)$$

- The value of effective dielectric constant is less than dielectric constant of the substrate, because of the fringing fields are not confined in dielectric substrate around the periphery of the patch only, but is also spread in the air. The value of this effective dielectric constant is given by [13]:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \qquad (4)$$

2.2 Initial antenna design

The development of rigorous techniques to solve maxwell's equations has introduced and imposed computer tools in electromagnetism. These tools are increasingly used in the analysis and design of microwave devices used in microwave and wireless communications applications. Digital electromagnetic calculation tools are therefore becoming an essential element in the design of a patch antenna due to rapid growth of the computer's processing power. The choice of simulation software therefore depends on the problem to be solved, for example the size, type and material of the structure, the complexity of the geometry. In our case, we have chosen the transient solver of Computer Simulation Technolgy (CST) Microwave Studio [14] which is an electromagnetic simulation software of 3-D passive structure based on the resolution of Maxwell's equations according to the technique of integral equations (Finite Technical Integration).

The proposed patch antenna is depicted in figure 2.

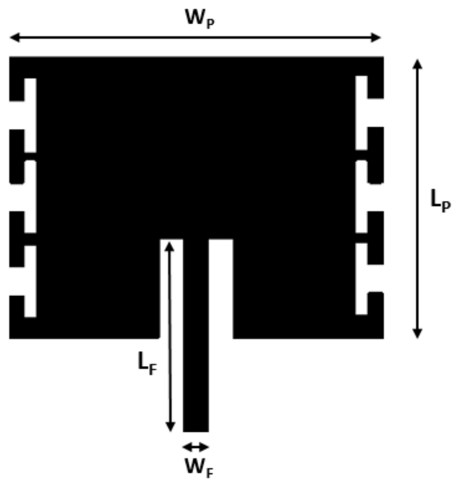

Fig. 2. The proposed patch antenna.

The FR-4 substrate have been used with dielectric permittivity constant 4.4, thickness of 1.6mm and loss tangent of 0.025. We have also chosen to feed our patch antenna with the microstrip-line method since it is easy to fabricate, simple to match by controlling the inset position and rather simple to model. The following figure shows the reflection coefficient of the proposed antenna at the resonance frequency 5.8 GHz. The antenna is well matched at the desired frequency.

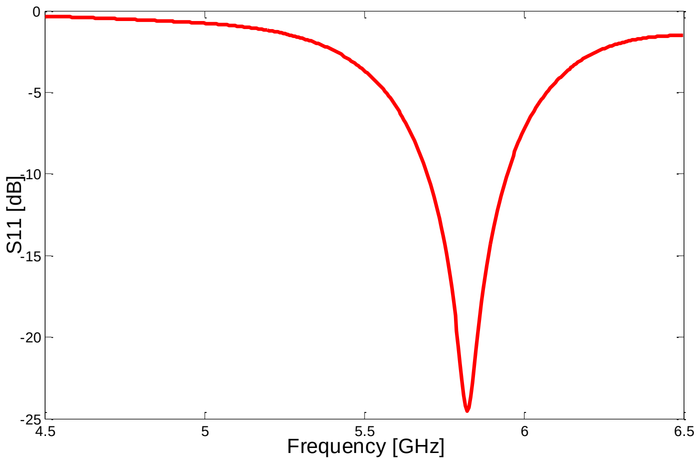

Fig. 3. Simulated reflection coefficient versus frequency.

3 Defected Ground Structure Design

In order to improve the performance of a patch antenna, several processes and techniques have been used, including the DGS technique, which stands for "Defected Ground Structure". This technique consists of applying more or less regular deformations (periodic or not) to the structure of the ground plane. Current research has allowed a greater degree of freedom in the design and location chosen on a ground plan. Whatever these deformations, they have a direct influence on the distribution of electrical charges and currents, which greatly modifies the characteristics of the antenna: the bandwidth, gain, directivity, radiation pattern, etc.. Many forms of DGS unit cells have been proposed in the literature for antenna design. Several types of patterns are illustrated in Figure 4.

Figure 5 shows the structure of the proposed Dumbbell shaped DGS with a ring slot between the two edges of the dumbell. Once investigating the whole parameters of the DGS, with a series of optimizations and simulations, the usage of the structure can be summarized and then etched on the metallic ground plane of the afromentionned microstrip antenna, with the dimentions shown in figure 5: L_{DGS1}, L_{DGS2}, L_1, L_2, L_3, W_1 ,W_2 ,W_3.

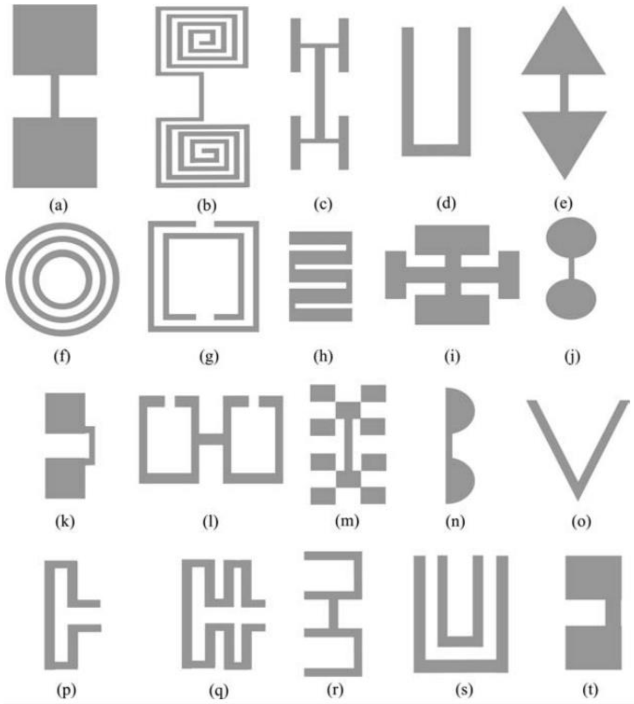

Fig. 4. Different DGS geometries: (a) dumbbell-shaped (b) spiral-shaped (c) H-shaped (d) U-shaped (e) arrow head dumbbell (f) concentric ring shaped (g) split-ring resonators (h) interdigital (i) cross-shaped (j) circular head dumbbell (k) square heads connected with U slots (l) open loop dumbbell (m) fractal (n) half-circle (o) V-shaped (p) L-shaped (q) meander lines (r) U-head dumbbell (s) double equilateral U (t) square slots connected with narrow slot at edge. [15]

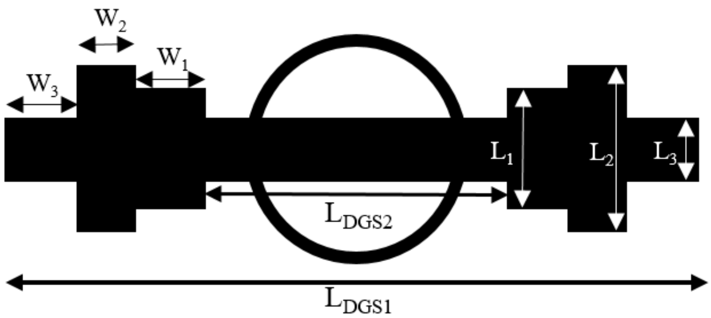

Fig. 5. The proposed Defected Ground Structure.

4 Final Antenna Design with DGS

The aim of this reseach study being the miniaturization of the 2.45 GHz patch antenna, we have assembled the designed 5.8 GHz antenna and the proposed new configuration of Defected Ground Structure on an FR4 substrate with dielectric permittivity constant 4.4, thickness of 1.6mm and loss tangent of 0.025 as shown in the figure 6, the whole system was simulated by using the Transient solver of CST Microwave Studio. The Defected Ground Structure have been placed in an optimized way permitting to obtain the desired results . Figure 7 shows the simulated reflection coefficient of the system, we can conclude from the graph that the resonating frequency is well shifted from 5.8 GHz to 2.45 GHz of the Industrial Scientific Medical band (ISM) with a return loss of -34 db and bandwidth of 260 Mhz. The 2D radiation pattern is given by Figure 7 in the E-plane, which show a stable and bi-directional radiation pattern for the resonant frequency band. The miniaturisation have been achieved with a size reduction of more than 80%.

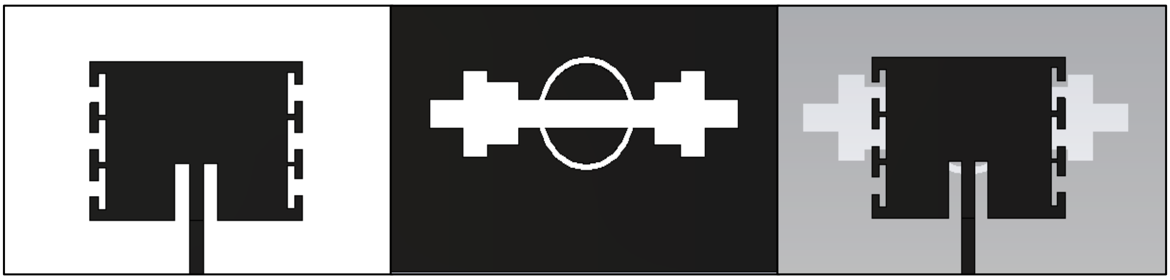

Fig. 6. Final Antenna Design

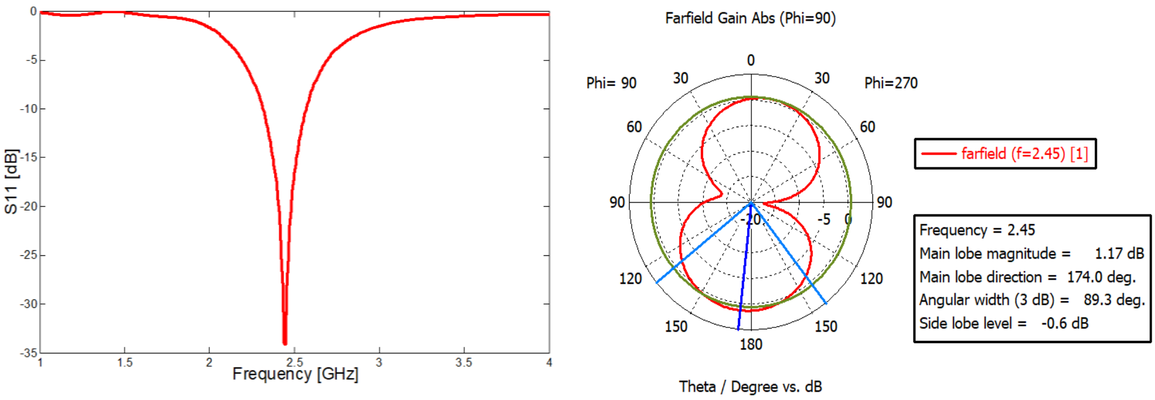

Fig. 7. Simulation results (a) Reflection coefficient versus frequency (b) Antenna 2D Radiation pattern in E-Plane at 2.45 GHz

5 Conclusion

This paper reports the design and simulation of a novel patch antenna with an integrated Defected Ground Structure (DGS) etched in the ground plan. This configuration leads us to ensure a good size reduction compared to a conventional antenna radiating at 2.45 GHz The CST Microwave Studio have been used to design, optimize and simulate the whole system and an FR-4 substrate was adopted. Interresting results have been ontained.

References

[1] "Surface mount RF Schottkybarrier diode HSMS-282X series," AgilentTechnol., Palo Alto, CA, Tech. Data, 2001.

[2] K. M. Z. Shams and M. Ali, "Wireless power transmission to a buried sensor in concrete "IEEE Sensors Journal, vol. 7, no. 12, pp. 1573–1577, 2007.

[3] W. C. Brown. The history of power transmission by radio waves. IEEE Trans. Microw. Theory Techn. Sep. 1984; MTT-32(9): 1230-1242.

[4] Jamal Zbitou, Mohamed Latrach "Hybrid Rectenna and Monolithic Integrated Zero-Bias Microwave Rectifier,"IEEE Transactions On Microwave Theory And Techniques, Vol. 54, No. 1, January 2006

[5] A. Taybi, A. Tajmouati, J. Zbitou, A. Errkik, M. Latrach, L. El Abdellaoui. A New Configuration of a High Output Voltage 2.45 GHz Rectifier for Wireless Power Transmission Applications. Telecommunication, Computing, Electronics and Control Journal (TELKOMNIKA). October 2018; 16(5): 1939-1946.

[6] Seung-Tae Khang, Dong-Jin Lee, In-Jun Hwang, Tae-Dong Yeo, and Jong-Won Yu, Microwave Power Transfer With Optimal Number of Rectenna Arrays for Midrange Applications. IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, VOL. 17, NO. 1, pp. 155-159 (2018).

[7] Kai-Fong Lee , Shing Lung Steven Yang, Ahmed A. Kishk. Dual- and Multiband U-Slot Patch Antennas. IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, VOL. 7, pp. 645-647 (2008)

[8] Fu-Jhuan Huang, Tzong-Chee Yo, Chien- Ming Lee, and Ching Hsing Luo, "Design of Circular Polarization Antenna With Harmonic Suppression for Rectenna Application," IEEE Antennas Wireless Propag. Lett., Vol. 11, pp. 592-595,2012.

[9] C. Y. D. Sim, M. H. Chang, and B. Y. Chen. Microstrip-fed ring slot antenna design with wideband harmonic suppression. IEEE Trans. Antennas Propag. Sep. 2014; 62(9): 4828-4832.

[10] Lin Dang, Zhen Ya Lei, Yong Jun Xie, Gao Li Ning, and Jun Fan. A Compact Microstrip Slot Triple-Band Antenna for WLAN/WiMAX Applications. IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, VOL. 9, 2010.

[11] Debatosh Guha, Senior, Chandrakanta Kumar, and Surendra Pal. Improved Cross-Polarization Characteristics of Circular Microstrip Antenna Employing Arc-Shaped Defected Ground Structure (DGS). IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, VOL. 8, 2009

[12] Chandrakanta Kumar, Senior Member, IEEE, Mahammad Intiyas Pasha, and Debatosh Guha, Senior Member, IEEE. Defected Ground Structure Integrated Microstrip Array Antenna for Improved Radiation Properties. IEEE Antennas and Wireless Propagation Letters. (2016).

[13] C. A. Balanis, "Antenna Theory, Analysis and Design,"John Wiley & Sons. Third Edition, New York, 2005.

[14] Computer Simulation Technolgy (CST) Microwave Studio. www.cst.com

[15] Debatosh Guha, Yahia M.M. Antar. MICROSTRIP AND PRINTED ANTENNAS NEW TRENDS, TECHNIQUES AND APPLICATIONS. John Wiley and sons Ltd.