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Investigation of Fractal Antenna for RF Energy Harvesting System

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Abstract: In this paper a fractal antenna for RF energy harvesting system has been proposed. In this design stacked structure of three layers with air medium has been presented. This antenna is specially designed for TV transmission as well as GSM mobile application in band of 700 GHz and 900 GHz respectively. Electromagnetic energy can be harvested and renewable energy can be generated using rectifier and DC motor, that can be a source of electrical power. As proposed antenna has significant amount of efficiency, so antenna will work very efficiently for harvesting RF energy from unbounded media. Proposed antenna has been designed and simulated using IE3D EM simulator.

Key words: Fractal antenna, VSWR, return loss, RF energy, renewable.

Introduction

Using wireless device, RF energy harvesting can only be possible by using the antenna. Antenna should have very high efficiency. There are two type of efficiencies used for usable antenna, first is antenna efficiency, which includes mismatching impedance at the input terminals arising due to mismatching of characteristic impedance of TL and input impedance of antenna. Second is radiation efficiency which includes structure of antenna losses i.e. conduction and dielectric losses (Balanis, 2005). Energy harvesting is an important application in which energy can be harvested from different sources such as ambient RF electromagnetic signals, solar energy and vibration.

This paper focuses on harvesting energy from RF sounding signals at 700 GHz and 900 GHz frequency. RF energy harvesting system (Hasan and Giri, 2012) basically consists of antenna and rectifier. The function of rectifier is to convert the signals received by antenna to a DC voltage. There are many different types of antennas (Nambi and Wentworth, 2005) which can be used for energy harvesting system. However, paper presents the array type of antenna as it has the advantage of providing a higher gain and better antenna performance. There have been many researches about array antenna starting by studying a single patch (Hazila and Aljund, 2005), mircostrip antenna. Once the single patch designed has the suitable gain and good performance, array antenna can be designed. The single patch is first optimized to achieve a high gain and good performance in terms of radiation pattern, bandwidth and return loss.

The design of array antennas in the prior literatures evaluates the performance of array antenna base on patch's shape (Sai Sandeep and Sreenath Kashyap, 2012) of the array antenna; for example, circular patch array can achieve gain of 10.7 dBi and return loss of –10 dB, whereas, rectangular patch can achieve gain of 10.6 dBi and return loss of –26 dB. Other literature

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review (Olgun et al., 2010), of array antenna uses Roger RT duriod 5880 substrate to achieve gain of 11.54 dBi and return loss of –30 dB, by using Roger RT5880. The performance of array antenna is better and the gain is increased. However, Roger RT5880 substrate is more expensive which makes the overall design costly (Sharif Ahmed et al., 2015).

This paper presents the evaluation performance and results comparisons of 4×1 array and 2×2 array. These two array structures consist of four patches fabricated on the substrate of FR4 so that the design has the benefits of having better performance and lower cost compared to previous literatures. These arrays antennas use quarter wave technique in order to improve the matching impedance of designed array antennas. Once the design of array antenna is done, it can be implemented with the rectifier circuit to produce a DC voltage. The output DC voltage of energy harvesting system can be utilized to energise low power devices such as wireless sensors and radio frequency identification (RFID) tags, which makes the system work more efficiently (Weiglhofer and Lakhtakia, 2003). Block diagram of RF energy system is shown in Figure 1. RF energy collected by antenna has to process through impedance matching network and rectifier; and renewable energy has been achieved by DC motor.

Figure 1: Block diagram of RF energy harvesting system.

Fractal Geometry

Fractal means broken or irregular shape. A fractal geometry can be generated by making repeated changes in the previous geometry. Fractal was inspired by nature like mountain, tree leaf. It was introduced by Mandelbrot (1983). Multiband antenna with fractal geometry was investigated (Puente-Baliarda et al., 1998; Lizzi et al., 2012). First stage starts with a square shaped geometry. Next stage can be generated by removing similar square from the centre of the original geometry and this construction procedure can be extended to infinite number of stages. It is clear from geometry that iterative process can be used to construct many number of stages (Kumar and Singhal, 2010, 2012). A Sierpinski's Carpet antennas of different iteration has been shown in Figure 2.

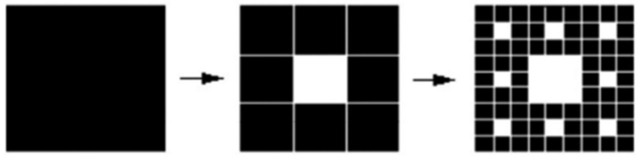

Figure 2: Fractal geometry antenna with different iterations.

Antenna Design and Analysis

First iteration of fractal antenna is proposed as shown in Figure 3. There are three layers of antenna proposed of different dimensions. Top layer was made fractal geometry to get double band antenna. Proposed antenna has been fed with proximity feeding technique of microstrip line of 50 Ohm. Spacing between layers is taken 2 mm to have proper coupling. The substrate has very important role in coupling of electromagnetic wave between layers. In this design, air medium has been taken for better coupling. Design starts with ground of physical size 200 mm × 200 mm. The proposed square antenna of physical size 166 mm × 166 mm, 100 mm × 100 mm and 50 mm × 50 mm of first layer, second layer and top layer respectively with fractal geometry. To make fractal geometry, a slot of size about 17 mm × 17 mm has been cut on top layers. As fractal antenna has feature of self symmetry, the slot cut on the top is of a square shape of one third of the top patch. First two layers have truncated corners to get better result. Feeding line of 50 Ohm impedance has been designed to get maximum power transfer from coaxial cable, through which power is fed to the antenna. Proximity feeding technique has been chosen to maximize band width, so that maximum RF energy can be harvested to get maximum electrical energy.

Results and Discussion

Most suitable simulated results of proposed antenna are presented. A VSWR vs frequency plot as shown in Figure 4, shows two bands ranging from 650 MHz-763 MHz and 890 MHz-1090 MHz at centre frequencies 700 MHz and 1000 MHz respectively. Matching of impedance plays important role in antenna designing. Return loss vs frequency plot is mentioned in Figure 5, which shows losses due to mismatching of impedance. Matching gets better as return loss value increases. In Figure 5 maximum value of return loss for respective bands are 24 dB and 32 dB which show good impedance matching. Comparison with existing work (Bakkali et al., 2016) about impedance matching of feed. Proposed antenna has better matching. So, the maximum power transfer can be achieved and it can improve overall efficiency of antenna. This design is better for reception of RF wave. Antenna efficiency plot is shown in Figure 6. Proposed antenna has efficiency 97 percent and 98 percent for lower and upper bands. Lower band works for TV reception and upper band works for mobile application. 3D gain radiation pattern is shown in Figure 7. Antenna should have highest gain so that RF wave can travel maximum distance. Presented antenna has maximum gain about 3.17 dBi, which is good enough to work antenna properly. Proposed antenna has been simulated using IE3D EM simulator.

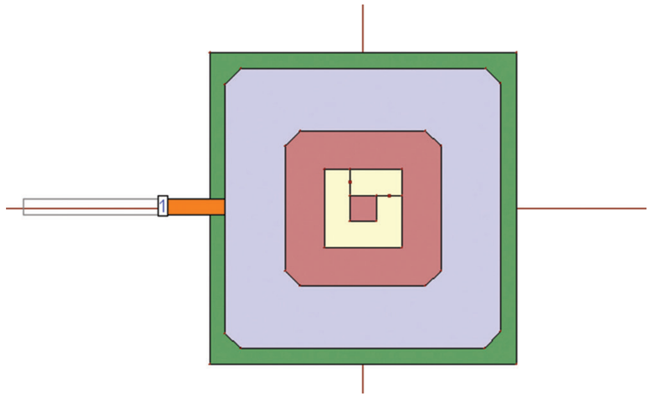

Figure 3: Stacked fractal antenna of 1st iteration.

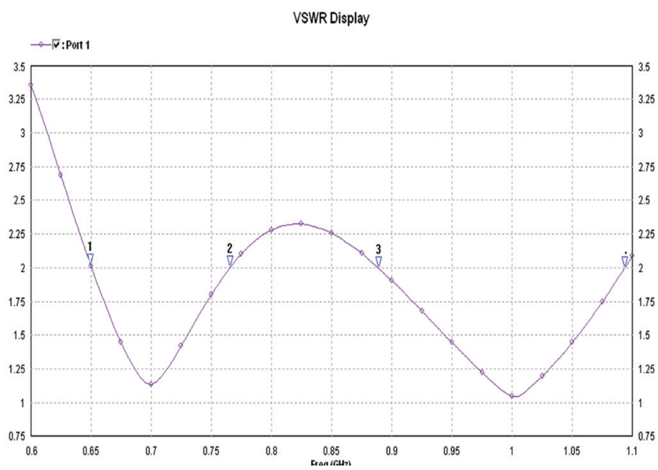

Figure 4: VSWR vs frequency plot.

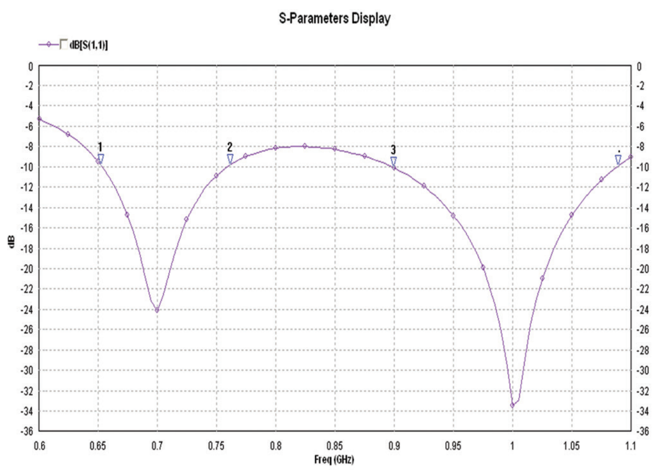

Figure 5: Return loss vs frequency plot.

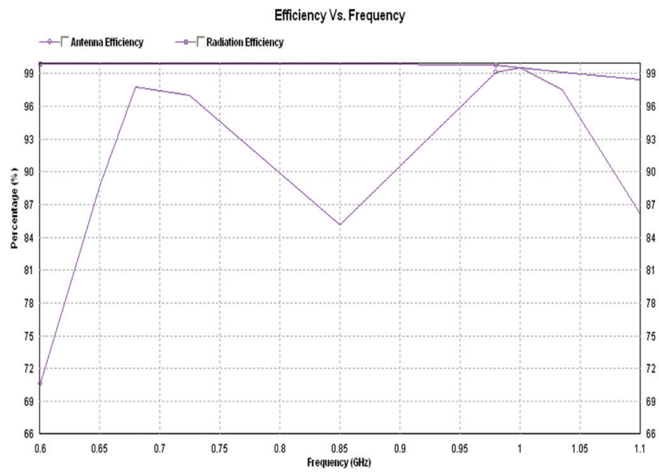

Figure 6: Efficiency vs frequency plot.

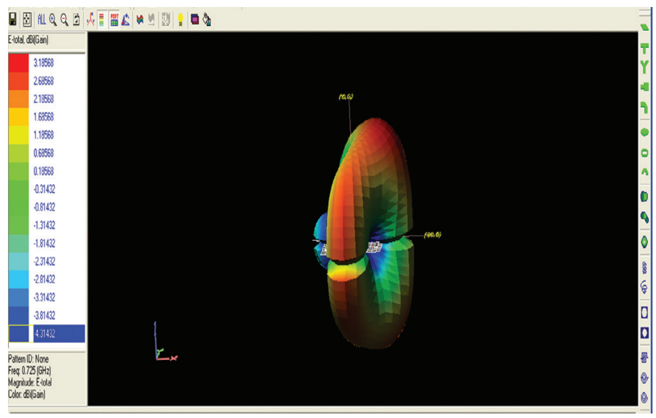

Figure 7: 3D-Antenna gain plot.

Conclusion

In this paper, a fractal geometry antenna is presented for RF energy harvesting system. Proposed antenna has got two bands of 650 MHz-763 MHz and 890 MHz-1090 keeping band width of 113 MHz and 100 MHz respectively. At lower bands RF waves work for TV reception and at upper band RF waves work for GSM mobile application. Since antenna has better efficiency above 90 percent for both bands, this antenna can have better harvesting of RF energy. From the return loss result, it can be seen that better impedance matching has been achieved.

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