Energy Harvesting Using a Cheap Easy-to-Fabricate FM Rectenna

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Abstract- **Energy harvesting techniques are emerging as environmental friendly energy sources, which form a promising alternative to existing energy resources. These include rectennas, solar cells, harvesting human energy and wind power. GHz/THz rectennas already exist and have some characteristics such as small size and wideband. These rectennas have a lot of disadvantages such as power fading, complicated design procedure and high fabrication technology. Thus, the present paper suggests using FM rectennas to solve these problems and by using fractals we will keep the advantages.**

The present paper discusses the design and implementation of a rectenna prototype operating in the FM range. Using Fractal antennas (which offer broadband/multiband operation) and simple tricks from circuit design, God's willing, proves to be a successful strategy for obtaining useful power from a cheap easy to fabricate rectenna that can be even made in home by interested users. The paper includes theoretical discussion, simulation results and practical prototype results.

Keywords: **rectennas, fractals, rectifying circuits, antennas, energy harvesting.**

I. INTRODUCTION

Energy harvesting techniques are emerging as environmental friendly energy sources, which form a promising alternative to existing energy resources. These include energy harvesting from rectennas, passive human power, wind energy and solar power.

Energy harvesting from human power is used to generate useful power by portable equipments are wearable devices in which digital systems are integrated in everyday personal belongings, like clothes, watch, glasses, etc. Human body can be considered as a storehouse of energy. There exist two possibilities: power can be scavenged from the user's everyday actions or can be intentionally generated by the user. This method has a lot of advantages. It allows the decrease in both size and power consumption of complex digital systems.

The power harvesting can be stored in capacitors, rechargeable batteries, etc. The disadvantages of this method arise because the portable products are powered by rechargeable batteries and they will remain as the main source for this kind of consumer products. However the disadvantage of batteries is the need to rather place or recharge them periodically. Typical candidate applications are extracting power from pedaling which can generate power up to 1.6 mJ, from typing which can generate pewer up to 2 mJ with every push of the button of 15 N and power from body heat which can recoverable 2.8-4.8 W of power.[1]

Another method to harvest energy is offshore wind energy where researchers are developing new technologies to provide electricity offshore. The new Spar-WARP wind machine developed by ENECO can produce and store clean, safe electricity offshore in many areas where there is sufficient wind speed. Most offshore areas provide good sites for wind technology. A good land site usually has mean wind speeds of 13 to 17 mph, while typical offshore mean wind speeds range from 15 to 20 mph [2].

The WARP, which stands for Wind Amplified Rotor Platform, is designed to further amplify wind by as much as 50 to 80 percent, and has many advantages for providing electricity in offshore areas. It can be installed in any depth of water—on a foundation in shallow water or on a floating platform tethered to the bottom by cable in deep water.

A third method to harvest energy the solar power may be used. Solar energy is an environment energy available to power portable devices. A photovoltaic system generates electricity by the conversion of the sun's energy into electricity.

Photovoltaic systems are found from the Megawatt to the milliwatt range producing electricity for a wide range of applications: from wristwatch to grid-connected PV systems.

The examples of consumer products that contain PV solar cells are: calculators, radios, headphones, laptops, battery chargers, etc. [1]

Moreover, we can use solar rectennas to harvest solar power but those rectennas are operating at GHz/THz and have a lot of disadvantages such as power fading, complicated design procedure and high fabrication technology. Thus, it has been suggested to use FM rectennas operating at FM range of frequencies using fractal antennas not to harvest solar power but to harvest electromagnetic waves instead of all those energy harvesting techniques because those FM rectennas are simpler and cheaper to construct. To maintain rectennas advantages, fractal antennas are used. DC-up converter circuits can be used to raise the voltage harvested by the rectenna.

The organization of the remaining of the paper is as follows. In section II, we will explain the rectenna concept and offer a brief literature survey which shows the efforts of some researchers. Section III explains fractal antennas and especially Sierpinski triangle fractals. This section will show the complete rectenna design applied of a fractal antenna called FRACTENT [5]. Finally in section IV the simulation and the practical results of complete rectenna are given including steps of constructing the cheap simple prototype. Simulations are performed using NEC2 software and P-SPICE software.

II. RECTENNA CONCEPT AND A BRIEF LITERATURE SURVEY

A rectenna is a device that can harvest microwave energy. It can be constructed using an antenna, rectifier circuit, smoothing circuit. A basic rectenna is shown in Fig.1. [1]

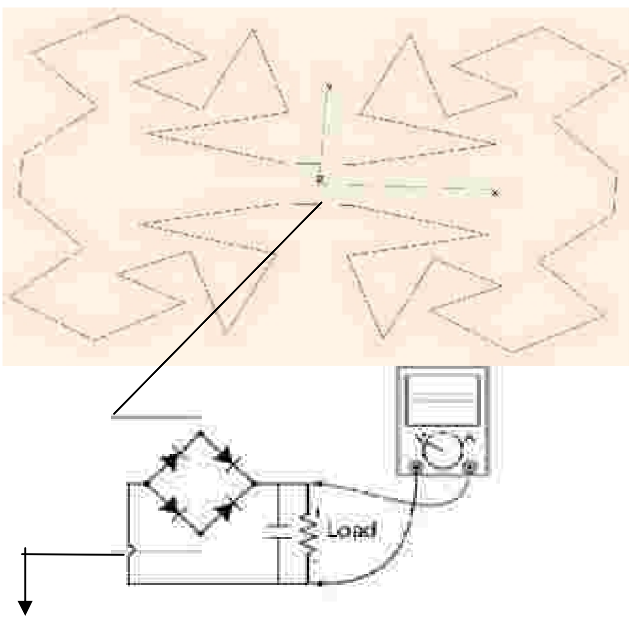

Fig.1 The complete rectenna

Several researchers reported the successful design and implementation of rectenna. J. Hagerty, ET. Al. have developed a new approach for construction of efficient rectenna arrays for arbitrarily polarized incident waves with broad spectral content. The approach has been validated experimentally on a dense grid array that rectifies two orthogonal linear polarizations, and on a self-similar spiral array with alternating right-hand and left-hand circular polarizations. The two arrays operate from 4.5to 8GHz and 8.5to 15GHz and have maximum open circuit voltages of 3.5 and 4.0V, respectively. Their efficiencies increase above 35% and 45%, respectively, for higher incident powers. The grid of rectifiers has excellent reliability and graceful degradation. The limiting factor on the size of the grid rectifier is the current rating on the diodes. Note that in the grid in Fig.2 the four corner diodes are the most critical ones, because one half of the current through the DC terminals passes through each of the diodes. If these 4 diodes are replaced by shorts, the current in the DC leads can be twice as large. The current intensity in the next diodes closest to the terminals is half of that through the four most critical diodes. Any overloaded diodes in the grid are automatically eliminated if they fail as shorts, and the rest of the grid continues to function. If a diode fails as an open, the current will find a path through the other diodes/shorts across the grid. [3]

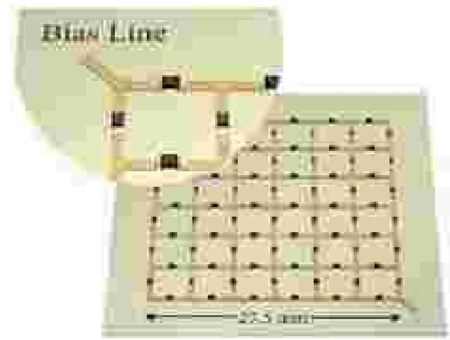

Fig.2 The grid array rectifier

Another researcher Y. Li has developed a 2.45 GHz low power rectenna design for wireless sensor and RFID applications. The system is monolithically integrated onto a single circuit board. A high gain patch antenna array is used to boost the power level at the input of the Rectenna for better power conversion efficiency. Moreover, a hybrid ring coupler is used to divide the power between Rectenna and detector. The system implements a key RF front end for GAP4S wireless sensor system [4].

III. FRACTAL ANTENNAS

Fractals are geometrical shapes, which are self-similar, repeating themselves at different scales. In this chapter we will shown two examples of fractal antenna (Sierpinski triangle antenna and kuch curve antenna), after that we will shown FRACTENT that will using in our FM rectenna.

The Sierpinski triangle, shown in Fig.3, is a common self-similar geometrical figure. It also has been used as a very effective antenna in the GHz frequency range.

The geometric construction of such a triangle is simple. One starts with the black equilateral shape and takes afterwards, in different steps, the middle of the sides and generates respectively 3, 9, 27, 81, triangles which are self similar and exactly scaled down versions of the initiating shape. The same procedure can be observed in Fig.4 where a Koch curve is iterated in 3 steps.

It is interesting to know something about the “Dimension” of such a fractured structure. The term “Dimension” in mathematics has different meanings. The common definition is the “Topologic Dimension” in which a point has the dimension 0, a line has the dimension 1, a surface has the dimension 2 and a cube has dimension 3.

Using Fractal geometry in antennas results in multi-frequency/broadband behavior. This behavior is best illustrated based on discussion of Sierpinski monopoles.

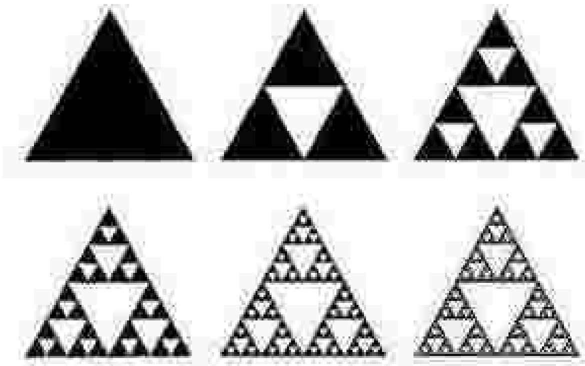

Fig.3 The Sierpinski triangle antenna

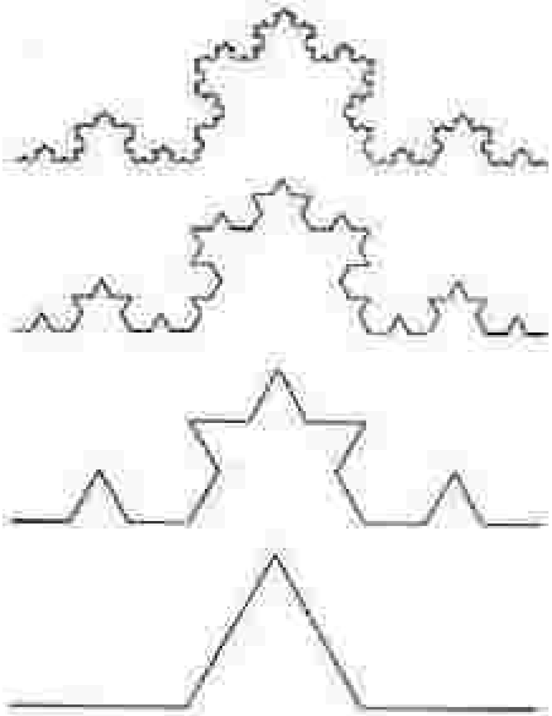

Fig.4 The Kuch curve antenna

The Sierpinski Monopole is shown in Fig.5. This is a monopole antenna resonant at frequencies of 0.44, 1.75, 3.51, 7.01 and 13.89GHz having an input resistance of 50Ω. One can easily see the 5 resonant frequencies of the structure by looking to the 5 circles marking the respective triangles.

The complete rectenna design (antenna+ rectifier and smoothing circuit) has been shown in Fig.1.

The multi broadband response of fractal antennas mentioned earlier make them suitable for use in rectenna applications since they can harvest more power than a single band antenna. The FRACTENT [5] is a particularly interesting antenna geometry as shown in Fig.6.

Since the Fractent operates at FM range, the author was able to construct it using the following simple procedure. First, the Fractent operating was drawn to scale. Second, a common 1-mm copper wire was shaped by hand to take the Fractent shape.

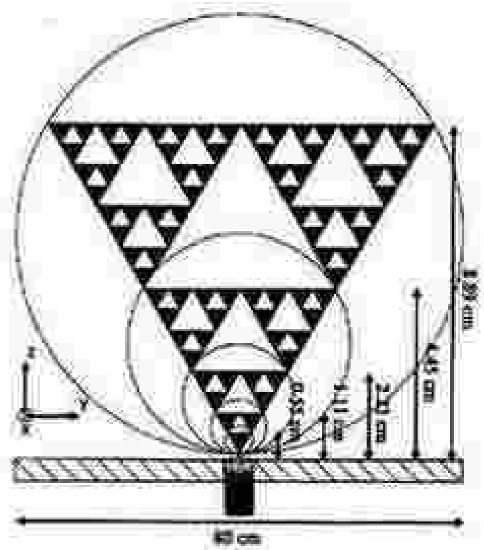

Fig.5 Sierpinski Monopole antenna resonant

Fig.6 Fractent antenna

The performance of FRACTENT has been studied through simulation using NEC2 software and has been validated practically by the author by putting it into operation as an FM antenna. The rectification circuit and smoothing circuit shown in Fig.1

The following design formula has been used Full-wave bridge rectifier with Schottky diode. Schottky diodes have been used duo to their low turn-on voltage and fast response which is necessary at high frequency.

It is important to note that the choice of FM range is important because it allows for easy and cheap rectifier/smoother circuit design and implementation while working in higher microwave frequency range requires more technologically complex methods.

IV. SIMULATION AND PRACTICAL RESULTS

The fractal antenna prototype constructed by the author is shown in Fig.7

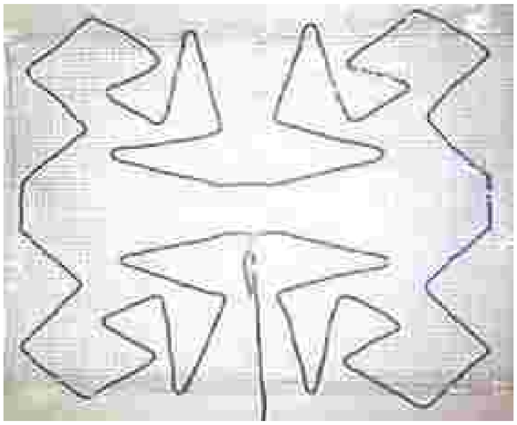

Fig.7 The cheap practical prototype made by the author

We use NEC2 software to simulate this antenna and results at 90 MHz are shown in Fig.8.The antenna radiation pattern is shown in Fig.9. Simple frequency scaling was used to change the dimensions of the antenna so as to transform its bandwidth to 90 MHz.

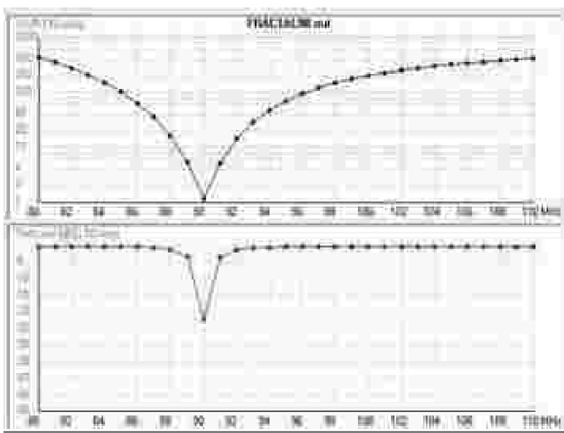

Fig.8 NEC2 simulation results for the practical prototype (VSWR and reflection coefficient in dB)

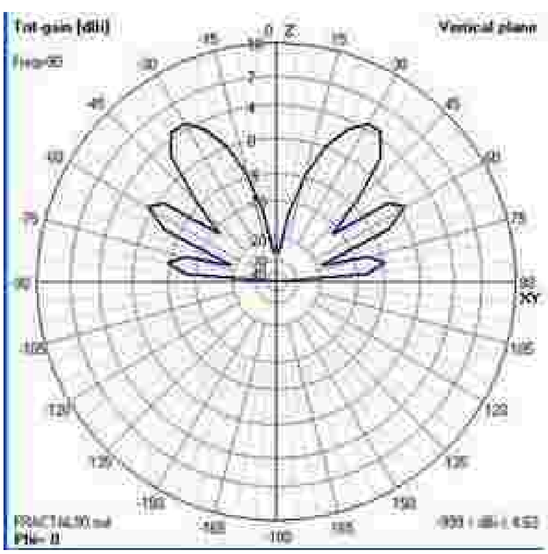

Fig.9 The Fractal antenna radiation pattern in the horizontal plane at 90 MHz

Rectifier circuit simulate on P-SPICE program. The results of P-SPICE program are shown in Fig.10.

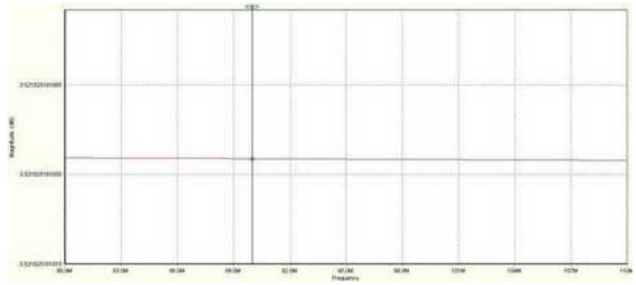

Fig.10 P-SPICE program results for usage rectifier circuit

V. CONCLUSIONS

In this paper, it was shown that energy can be harvested from some sources such as rectennas, human power, solar energy and offshore wind energy. The rectenna concept was the focus of the paper as efficient alternative to common GHz/THz rectennas. To get over the technological difficulties associated with developing rectennas at GHz/THz range, the author developed a new rectenna efficient design that uses fractal antennas operating at FM range. The rectenna operating an FM range is easily constructed using common copper wire, diodes and capacitors, which make them easy and cheap to develop even by inexperienced users without compromising rectenna efficiency. Thus, the developed rectenna is cheap, efficient, simple to implement and environmental friendly.

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