SEMARAK ILMU
PUBLISHING
202103268166(003316878-P)

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Energy Harvesting Fractal Antenna for Charging Low Power Devices

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ARTICLE INFO

Article history:
Received 3 October 2023
Received in revised form 22 January 2024
Accepted 7 March 2024
Available online 8 April 2024

Keywords:

RFEH; Fractal antenna; Multi-band; ITS

ABSTRACT

Radio frequency energy harvesting (RFEH) is a prospective technique that uses electromagnetic waves which waste in the air to create energy. This cutting-edge technology offers the ability to wirelessly charge battery-free gadgets, making it a potential alternative energy source for use in the future. Fractal antenna systems are a type of antenna that is characterized by their self-similarity and ability to operate over a wide range of frequencies. The proposed design combined two popular fractal shapes in one design. This one design combines the advantages of the other two designs. This research presents a novel multi-band fractal slot antenna design and optimization method for RFEH systems. The fractal antenna designs that were simulated using the CAD design suite, as well as the final design and performance that captured multiple bands are described. The rectifying and matching networks are next evaluated, and the ADS (Advanced Construct System) software is used to construct and simulate each circuit. Additionally, the voltage regulator, energy storage, and application are addressed along with the required voltage to completely function a wireless sensor node, which may be utilized in many applications including wearable technology and intelligent traffic systems (ITS) that control roads to improve environmental quality. Finally, experimental results demonstrated good agreement with simulations that had a high radiation efficiency and gain.

1. Introduction

Harvesting ambient energy to power portable electronics or low power wireless sensors is becoming more and more popular. The energy needed to run portable electronics like wireless sensors, Bluetooth devices, cell phones, hearing aids, and medical implants can be partially or entirely supplied by RF energy harvesting. In an RF energy harvesting system, as an antenna receives the incident RF signal, a multi-stage rectifier converts the entering RF signals into an output DC voltage while an impedance matching circuit maximizes power transfer from the receiving antenna to the rectifier [1]. Energy harvesting is the process of extracting energy from the environment to power devices. One method of energy harvesting is by fractal antennas, which are specially designed to capture and convert electromagnetic waves into usable electrical energy [1,2].

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https://doi.org/10.37934/araset.43.1.211226

A fractal antenna for energy harvesting is a type of antenna that is based on fractal geometry, which is a mathematical concept that involves the repetition of a simple pattern at different scales. The fractal structure of the antenna allows it to have a large surface area in a compact form, which increases its ability to capture electromagnetic energy. Additionally, the fractal shape of the antenna can also help to increase its ability to capture energy from a wide range of frequencies. Fractal antennas are particularly well-suited for charging low power devices, such as wireless sensors and IoT devices, because they can efficiently capture and convert the low-level electromagnetic energy that is available in these environments. For example, a fractal antenna can capture energy from ambient sources such as radio waves, microwaves, or even light waves. This allows the devices to be powered continuously, without the need for a battery replacement or charging. There are several types of fractal antennas, such as Sierpinski fractal antenna, Sierpinski gasket fractal antenna, and Koch fractal antenna, each with its own unique properties that make it better suited for specific applications. For example, Sierpinski fractal antenna has a wide bandwidth and high gain, making it suitable for wireless communication, while a Koch fractal antenna has a more compact structure, making it more suitable for energy harvesting in portable devices [3]. Overall, fractal antennas have the potential to revolutionize the way low power devices are powered, by allowing them to be continuously charged using ambient energy sources. They are relatively simple to construct, low-cost and can be integrated into existing devices, making it an attractive solution for a wide range of applications. The latest generation of wireless networks can now be powered using radio frequency (RF) energy transfer and harvesting techniques. It is advantageous to serve applications with quality of service (QoS) needs since this developing technology enables proactive energy replenishment of wireless devices [4]. Due to design limitations, fabrication challenges, and technical developments, fractal antenna design has become a bottleneck for some researchers. To meet the demands of technology applications, antenna design is essential. In 1975, Benoit Mandelbrot developed fractal geometry and its dimensions. Mandelbrot described the fractals as symmetries, which are invariances under expansions and contractions [5]. Fractal geometry has arisen and is inspired by fractals found in nature, such as the structure of trees, leaves, mountains, waves, clouds, snowflakes, and the pattern of coastlines, among others. For the antenna design, a fractal is a complicated geometry that has been divided up into pieces, those are all scaled-down versions of the entire building. Fractal antenna architecture has recently entered more complex, high-end applications like the cube satellite terminal and other wireless ones [6].

In this paper, a new distinct shape for the energy harvesting antenna is presented by relying on cutting-edge design methodologies to absorb the highest energy from many frequencies simultaneously using the fractal antenna, where can significantly enhance antenna array performance using fractal geometric methodologies. The usage of an array fractal antenna (FA) enhances multi-beam and multi-band features and enhances the behaviour of the array factor, but one of the research challenges of FA's is among huge antenna elements at higher level frequencies, such as four to N iterations [7]. The rest of this research is organized as follows: Section 2 presents the related works. Section 3 describes the methodology in detail. The results of the proposed system are discussed in section 4 and finally, section 5 concludes the paper.

2. Related Work

For wearable technology, wireless sensor networks, and portable devices, batteries are the main obstacle. Batteries can't supply enough power for prolonged usage, necessitating frequent and inconvenient charging or replacement. Self-sustainable technology is an alternative approach that has attracted a lot of interest from the scientific community with the goal of increasing the energy density of energy storage systems [8]. It integrates low energy harvesting, energy storage, and power management technologies. Many studies [9-12] have shown that there are numerous ways to increase output power and deliver a steady supply of energy, including effective charge boosting strategies to satisfy power and continuous demands. In [9], A new multi-band fractal slot antenna with a partial ground plane has been reported for RF energy harvesting systems working in frequency bands ranging from 1-6 GHz, including GSM, UMTS, WLAN, LTE, and 5G networks. The performance of the proposed antennas was measured and compared to one another in the lab to decide which had the best characteristics. In [10], the study focused on the design, distribution management networks, effectiveness, compatibility with other components, costs, and environmental impact of self-sustaining power units. Its technical elements, financial impact, and environmental impact are analysed to appropriately choose the most suitable energy storage for the self-charging power unit. In [11], the author's attention was drawn to issues with cold start issues and tracking maximum power points in relation to voltage step-up energy management. This review aims to fill an unidentified gap in self-sufficient technology by evaluating a variety of integrated designs of low-powered energy harvesting devices with energy storage and power management systems. In [12], the author combined fractal and metamaterial techniques to produce a tiny microstrip antenna with dual-band capabilities. To do this, a slot antenna is created using the Sierpinski carpet and Minkowski fractals, after which the slot portion of the antenna is covered with a metamaterial unit cell. The proposed antenna detected further resonance frequencies at 1.9, 2.4, 3.2, and 5.3 GHz.

According to the works discussed above, this research focuses on a new RFEH with multi-bands and high accuracy. Table 1, review of literature on various performances for previous designed related works.

Table 1
Analysis of related work performances

No. of Ref.	Band of Freq.	Size of Antenna (mm)	Frequencies (GHz)	Gain of Antenna (dBi)	Max. Efficiency At −20 dBm (%)
[13]	triple	145 × 145	1.8, 2.15, 2.45	4.33,4.22,3.88	67
[14]	quad	245.1 × 150	0.84, 1.86, 2.1, 2.45	N/A	30, 22, 33, 16.5 @ −25, −5
[15]	triple	200 × 200	1.84, 2.14, 2.45	9, 11, 11	25.3, 27.9, 19.3
[16]	quad	160 × 160	0.85, 1.81, 2.18, 2.4	3.95, 4.45, 4.42, 4.82	48

3. Design Methodology

The RF-EH relies on the scavenging of RF signals in the vicinity of the system; there are two types of RF signal sources: ambient and specialized [7].

An antenna is used in an RF harvester to collect RF energy, which is then sent into a matching network to ensure maximum power delivery to the rectifier, the energy harvester's main component, which converts the RF power to DC power before feeding into a microcontroller (MCU) and sensor (s). Using the block diagram shown in Figure 1, the operation of an RF harvester is condensed.

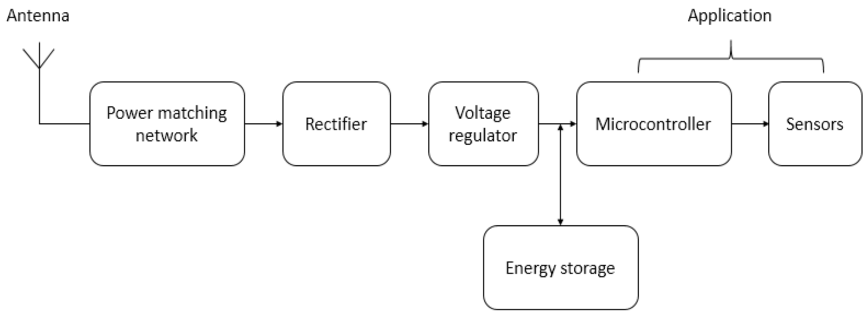


Fig. 1. Block Diagram for Suggested RF-EH System

3.1 Design of Fractal Antenna

The creation of a fractal antenna utilizing the MATLAB and CAD tools is shown in Figure 2.

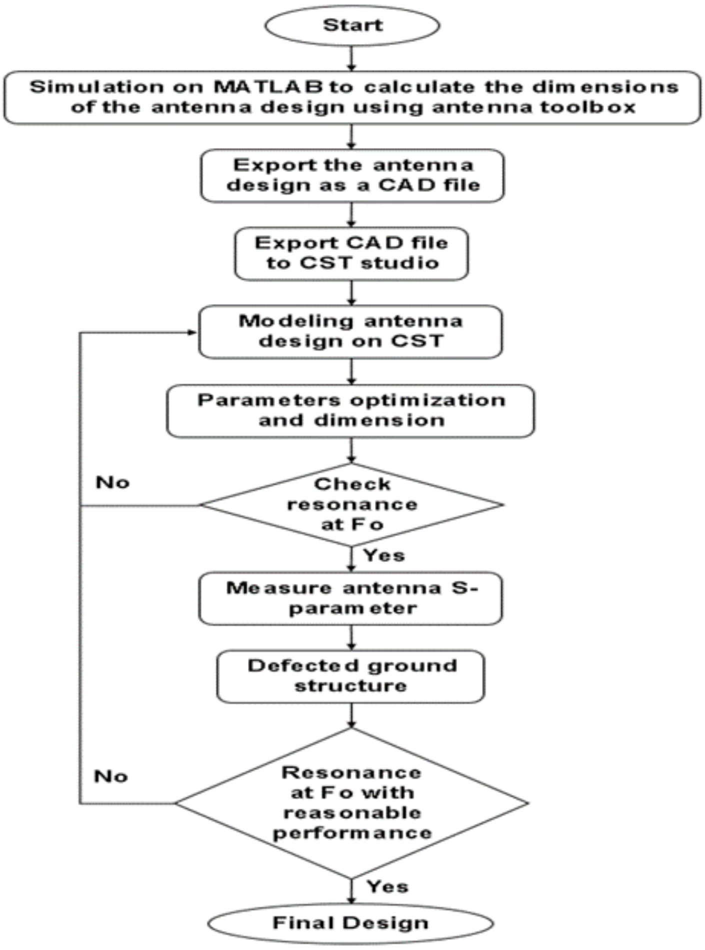


Fig. 2. Flowchart of design process for fractal antennas

The proposed design of fractal antenna is shown in Figure 3.

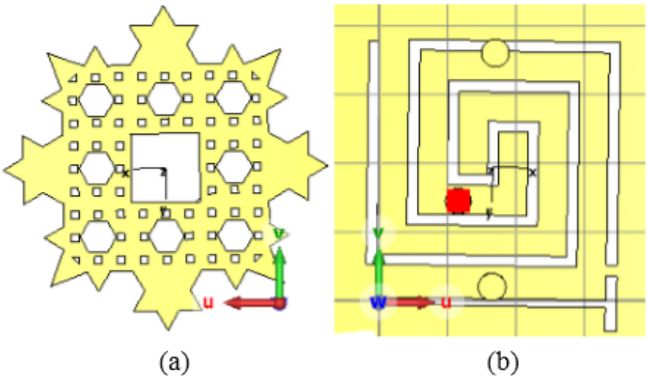


Fig. 3. Simulation of the proposed fractal antenna design. (a) Upper layer (b) Ground layer

Our proposed design offers 4 frequency bands 1.8 GHz- 2.4 GHz- 3.2 GHz- 4.3 GHz- 5.2 GHz. It also proposes superior performance and novel design. The dimensions of a fractal antenna are typically obtained through a recursive process, in which a basic antenna structure is iteratively modified to create a more complex and self-similar structure. The most used method for designing fractal antennas is the Iterated Function System (IFS) algorithm. The IFS algorithm uses a set of mathematical transformations, called contractive mappings, to generate a self-similar fractal pattern. The fractal pattern is then mapped onto the surface of the antenna to obtain the desired shape. There are some of the most used fractals in antenna design along with their corresponding equations:

3.1.1 Koch snowflake fractal

The Koch snowflake fractal is a self-similar fractal pattern that can be generated using the following recursive algorithm 1:

Algorithm 1: The Koch snowflake fractal

i. Start with a line segment.
ii. Divide the line segment into three equal segments.
iii. Replace the middle segment with two-line segments that form an equilateral triangle.
iv. Repeat steps 2-3 for each of the remaining line segments.

The Koch snowflake fractal can be mapped onto the surface of the antenna to obtain the desired shape. The dimensions of the Koch snowflake fractal antenna can be obtained using the following equations:

Length of each line segment: $L(n) = L(0) / 3^n$
Perimeter of the Koch snowflake fractal: $P(n) = 4L(n) * (1 + 2\sqrt{3})^n$
Width of the antenna at each iteration: $W(n) = W(0) / 2^n$

3.1.2 Sierpinski gasket fractal

The Sierpinski gasket fractal is a self-similar fractal pattern that can be generated using the following recursive algorithm 2:

Algorithm 2: The Sierpinski gasket fractal

i. Start with a triangle.
ii. Divide the triangle into four smaller triangles by connecting the midpoint of each side.
iii. Remove the central triangle.
iv. Repeat steps 2-3 for each of the remaining triangles.

The Sierpinski gasket fractal can be mapped onto the surface of the antenna to obtain the desired shape. The dimensions of the Sierpinski gasket fractal antenna can be obtained using the following equations:

Side length of the triangle: $L(n) = L(0) / 2^n$
Area of the triangle: $A(n) = (L(n) / 2) * (L(n) * \sqrt{3} / 2)$
Width of the antenna at each iteration: $W(n) = W(0) / 2^n$

3.1.3 Minkowski fractal

The Minkowski fractal is a self-similar fractal pattern that can be generated using the following recursive algorithm 3:

Algorithm 3: The Minkowski fractal

i. Start with a square.
ii. Divide each side of the square into three equal segments.
iii. Remove the middle third of each side.
iv. Replace each middle segment with two-line segments that form a square.
v. Repeat steps 2-4 for each of the remaining line segments.

The Minkowski fractal can be mapped onto the surface of the antenna to obtain the desired shape. The dimensions of the Minkowski fractal antenna can be obtained using the following equations:

Side length of the square: $L(n) = L(0) / 3^n$
Perimeter of the Minkowski fractal: $P(n) = 8L(n) * (1 + 4\sqrt{2})^n$
Width of the antenna at each iteration: $W(n) = W(0) / 3^n$

3.2 Design of Matching and Rectifier Circuit

Matching circuits are a crucial component in energy harvesting systems that charge low power devices using fractal antennas. They are used to ensure that the impedance of the antenna and the load (the device being charged) are matched, which maximizes the amount of energy that can be transferred from the antenna to the load. There are two main types of matching circuits that are commonly used in energy harvesting systems: L-matching circuit and T-matching circuit. An L-matching circuit is a simple matching circuit that consists of an inductor and a capacitor connected in series between the antenna and the load. The values of the inductor and capacitor are chosen to match the impedance of the antenna and the load. The L-matching circuit allows the antenna to efficiently transfer energy to the load, even if the load impedance is different from the impedance of the antenna. A T-matching circuit is another type of matching circuit that is widely used in energy harvesting systems. It is like the L-matching circuit, but it includes a resistor in series with the inductor, which is connected in parallel with the capacitor. The T-matching circuit is used to match the impedance of the antenna and the load, and it allows for a more precise control over the impedance match. It is important to note that the matching circuit must be carefully designed and optimized for the specific energy harvesting application, in order to ensure that the maximum amount of energy is transferred from the fractal antenna to the load. The design of the matching circuit depends on various factors such as the impedance of the antenna, the load impedance, the frequency of the electromagnetic waves, and the available energy [18]. So, in energy harvesting systems that use fractal antennas to charge low power devices, matching circuits are essential. The antenna impedances and the load are matched with the help of these components, maximizing the amount of energy that can be transferred from the antenna to the load. L-matching circuits and T-matching circuits are two types of matching circuits that are frequently utilized. The design of the matching circuit must be carefully optimized for the specific energy harvesting application to ensure maximum energy transfer. A rectifier circuit is an essential component in RF (radio frequency) energy harvesting devices that use fractal antennas to convert electromagnetic waves into usable electrical energy. The antenna's alternating current (AC) output is transformed into direct current (DC), which can be utilized to operate a device or charge a battery, via the rectifier circuit.

The performance of the rectifier circuit in RF energy harvesting devices depends on several parameters, including:

i. Rectification efficiency: This is the ratio of the DC output power to the RF input power. A high rectification efficiency means that more of the energy from the antenna is being converted into usable electrical energy [19].
ii. Power conversion efficiency: This is the ratio of the output power of the rectifier circuit to the input power. A high-power conversion efficiency means that more of energy is being converted into usable electrical energy, and less is being lost as heat.
iii. Input impedance: This is the impedance of the antenna as seen by the rectifier circuit. A good match between the impedance of the antenna and the rectifier circuit is important to ensure that the maximum amount of energy is transferred from the antenna to the rectifier circuit.
iv. Load impedance: This is the load's impedance as it appears to the rectifier circuit. A good match between the impedance of the load and the rectifier circuit is important to ensure that the maximum amount of energy is transferred from the rectifier circuit to the load.
v. Voltage and current ripple: This are the fluctuation in the DC output voltage and current caused by the rectification process. Low ripple means that the DC output voltage and current are stable, which is important for applications that require a stable DC power supply.
vi. Bandwidth: The range of frequencies over which the rectifier circuit can efficiently rectify. For fractal antennas, the bandwidth should be wide enough to cover the range of frequencies that the fractal antenna is able to capture.
vii. Temperature: This parameter is important to consider when designing rectifiers as they are sensitive to temperature changes. High temperatures may cause the rectifiers to degrade [20].

Therefore, the rectification efficiency, power conversion efficiency, input impedance, load impedance, voltage and current ripple, bandwidth, and temperature are all important parameters to consider when designing a rectifier circuit for RF energy harvesting devices that use fractal antennas.

The optimal values of these parameters depend on the specific application and the requirements of the energy harvesting system. According to the previous section, we use a simple T-matching circuit and voltage doubler circuit to achieve the optimal value of the previous parameters, all these methods will be discussed in upcoming sections.

Figure 4 shows a matching circuit that operates at 900 MHz with an input impedance of 50Ω and a load resistance of 100KΩ.

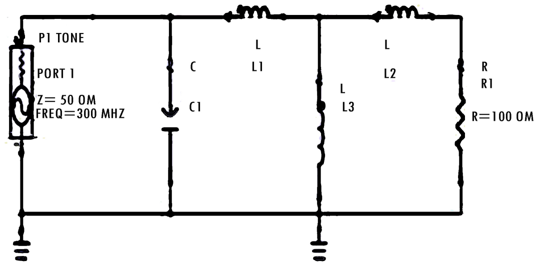


Fig. 4. Matching circuit

The next sections cover the parameters that determine circuit component selection as well as design strategies for performance efficiency.

3.2.1 Diode selection

The energy harvesting circuit's ability to function with low RF input power is one of the most important requirements. Because the peak voltage of the ac signal obtained at the antenna is often substantially lower than the diode threshold, it is desirable to employ diodes with the lowest turn-on voltage possible [21]. Additionally, since the energy harvesting circuit operates at extremely high frequencies, it is necessary to employ diodes with a very quick switching time. Metal-semiconductor junctions are used in Schottky diodes [22]. In this study, we use four distinct Avago Technologies diodes: the HSMS - 2800, HSMS - 2820, HSMS - 2850, and HSMS - 2860. In addition to delivering a forward voltage drop of as little as 0.15V, this allows the junction to operate substantially faster. For the energy harvesting circuit, these diodes have been modelled. In their data sheets, Agilent provides the modelling parameters for these diodes. In the Advanced Design System (ADS), these parameters are used for internal modelling. For modelling purposes, the diode is transformed into an analogous circuit utilising passive components that are represented by the SPICE characteristics in Table 2.

Table 2
Diodes Model Spice Parameters

Parameters	Units	HSMS-2800	HSMS-2820	HSMS-2850	HSMS-2860
C_{JO}	pf	1.6	0.7	0.18	0.18
E_G	E_v	0.69	0.69	0.69	0.69
B_V	V	75	15	3.8	7.0
I_S	A	3E-8	2.2E-8	3E-6	5E-8
I_{BV}	A	E-5	E-4	3E-4	10E-5
R_S	Ω	30	6	25	5
P_B (V_J)	V	0.65	0.65	0.35	0.65
P_T (X_{TI})	-	2	2	2	2
N	-	1.08	1.08	1.06	1.08
M	-	0.5	0.5	0.5	0.5

3.2.2 Number of stages

The number of rectifier steps has a considerable impact on the output voltage of the energy harvesting circuit. A modified voltage multiplier is used at each stage in this series arrangement. The number of stages used in the energy harvesting circuit directly relates to the output voltage. The output voltage, as well as the number of permitted steps, are nevertheless constrained by practical considerations. Here, as the number of stages increases because of the parasitic effect of the individual capacitors in each stage, the voltage gain falls and eventually disappears [23]. Each independent stage can be viewed as a single battery with an open circuit output voltage (Vo), load resistance (RL), and internal resistance (Ro). Eq. (1) is used to express the output voltage (Vout).

$$V_{out} = \frac{V_O}{R_O + R_L} R_L \tag{1}$$

The output voltage (Vout) achieved by connecting n number of these circuits in series with a load (RL) and changing the RC value will result in a longer time constant, which keeps the two-fold multiplication effect in this seven-stage voltage doubler design [24]. According to Eq. (2), the system's stage count has the biggest impact on the DC output voltage.

$$V_{out} = \frac{nV_O}{nR_O + R_L} \tag{2}$$

3.2.3 Effect of RF input power

Due to the presence of diodes, a nonlinear electrical component, the energy harvesting circuit displays nonlinearity [25]. This implies that depending on how much power is taken in by the antenna, the energy harvesting circuit's impedance varies. Since the circuit and antenna need to be matched for the maximum amount of power transfer to occur, impedance matching is frequently performed at a particular input power. This illustration shows how RF input power, which ranges from -40 to 0 dBm, affects the energy harvesting circuit's impedance. Agilent's Advanced Design System (ADS) software is used to simulate the energy harvesting circuit. To calculate the steady state solution of a nonlinear circuit, we employ the harmonic balancing analysis in this study. To design the 7-stage voltage doubler using diodes HSMS-2800, HSMS-2820, HSMS-2850 and HSMS-2860 for RF energy harvesting circuit, the following components in Table 3 were used.

Table 3
Components used in voltage Doubler circuit

Name of Components	Label	Value
Stage Diodes	$D_1 – D_{20}$	HSMS-2800, HSMS-2820, HSMS-2850, HSMS-2860
Stage Capacitors	$C_1 – C_{20}$	3.3 nF
Filter Capacitor	C_L	100 nF
Load Resistor	R_L	100 KΩ

The 7-stage circuit can achieve its maximum power when the HSMS-2850 diode is used. Additionally, the maximum output voltage for a one-stage circuit is 1.109v at 0 dBm. 6.222 v at 0 dBm can be attained for the 7-stage circuit using the HSMS-2850 diode, though. So, the 7-stage HSMS-2850 is better suited to the RF energy harvesting circuit that can be used in wireless sensor networks. Figure 5 to Figure 9 shows multi-stages voltage doubler rectifier for (one, three, five, seven) stages and their simulation curves results [26].

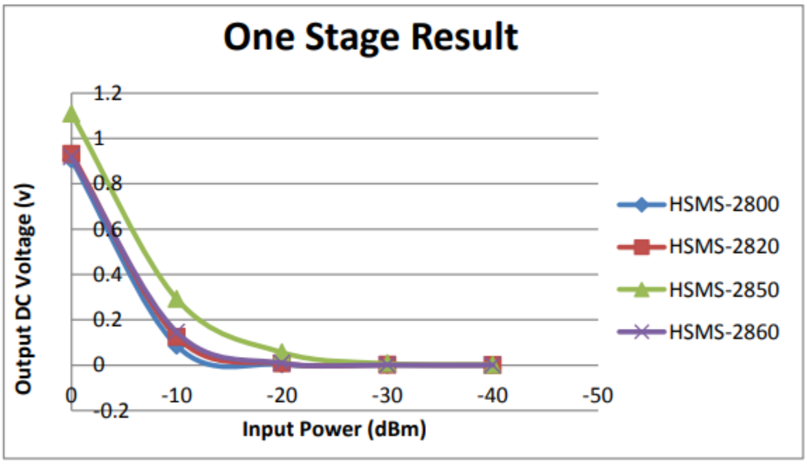


Fig. 5. Simulation results of one stage voltage doubler circuit curves

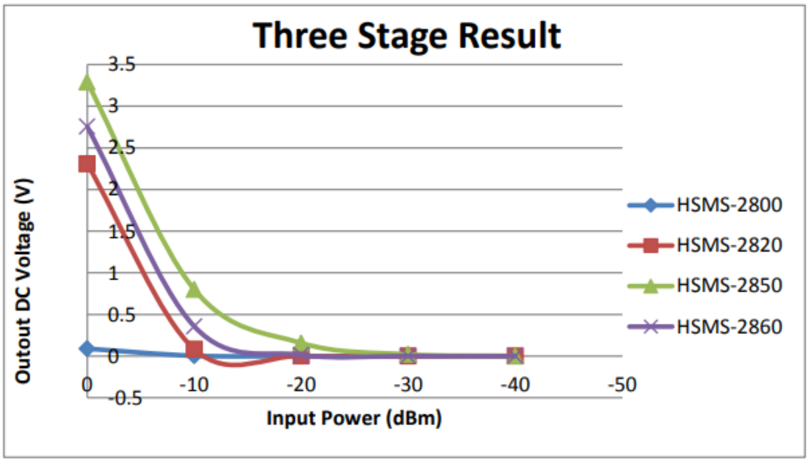


Fig. 6. Simulation results of three stage voltage doubler circuit curves

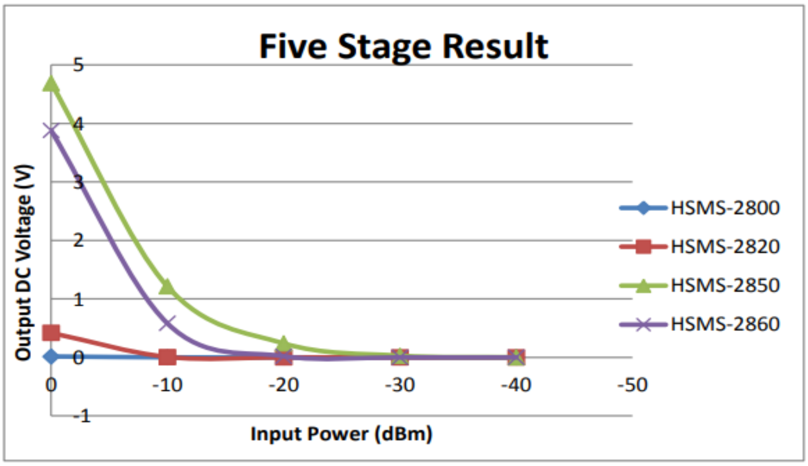


Fig. 7. Simulation results of five stage voltage doubler circuit curves

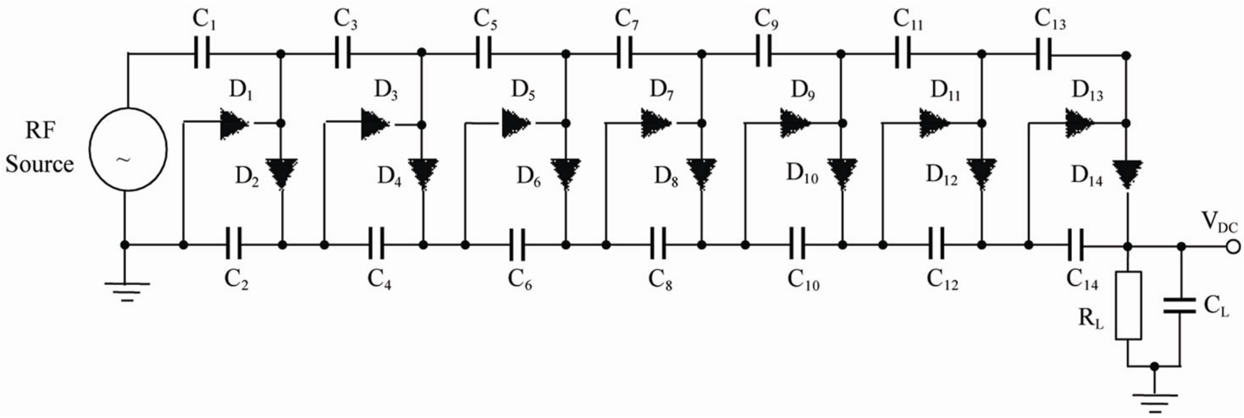


Fig. 8. Seven stage voltage doubler circuit

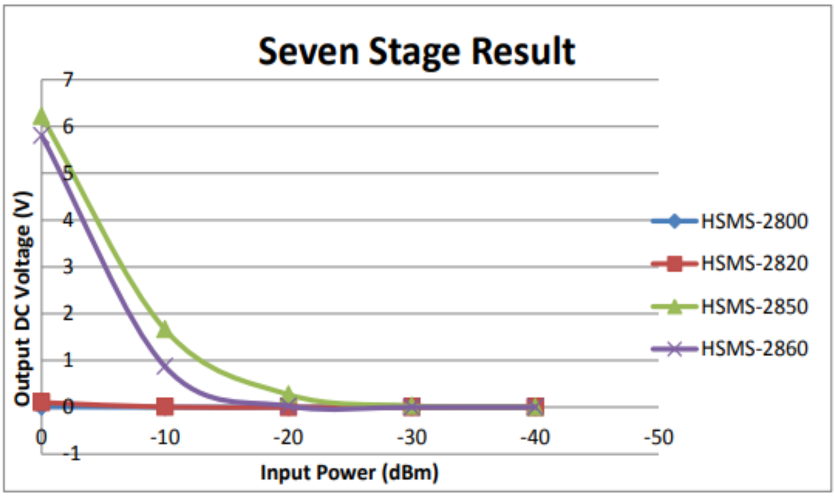


Fig. 9. Simulation results of seven stage voltage doubler circuit curves

3.3 Voltage Regulator and Energy Storage

3.3.1 Voltage regulator

Figure 10 illustrates the DC-DC Booster Adjustable Step-Up Converter Module, which includes the voltage regulator XL6009. The XL6009 regulator was specifically created for use with portable electronic equipment.

Fig. 10. DC-DC Step Up Boost Module

3.3.2 Energy storage

As ambient RF signals may not be sufficient to directly power WSN or other low-powered devices, gathered energy signals must first be stored in the system, which requires energy storage [2,27]. The Super Capacitor that was selected has a capacitance of 0.1 F and a voltage of 5.5 V. The value of the capacitance was determined using Eq. (3) to determine the minimum capacitance needed for the WSN to operate in both active and sleep mode, where Vcap is the capacitor's voltage, Vth is the capacitor's threshold voltage, and Econ is the energy consumption of the sensor used.

$$C_{min} = \frac{2E_{con}}{V_{cap}^2 - V_{th}^2} \tag{3}$$

According to [28], the lower the capacitance, the shorter the discharge time, so 0.1 F was more than adequate for the system, as the computed Cmin was 0.018 F.

4. Results and Discussions

In this part, the results of multiple antennae design for harvesting energy would be analysed to determine the optimum design capable of absorbing energy from the most frequencies at the same time to identify a viable contribution for future work. The recommended antenna was constructed in the lab, and measurements of its radiation pattern and return loss were made. The modelled antenna radiation pattern at frequencies is shown in Figure 11.

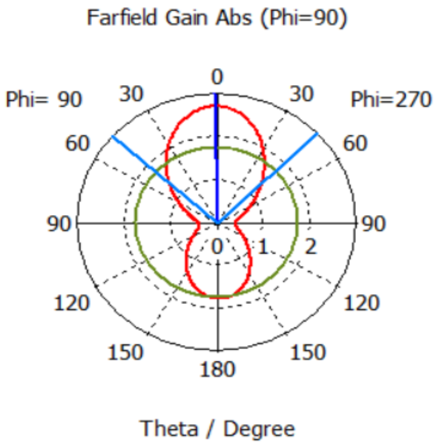
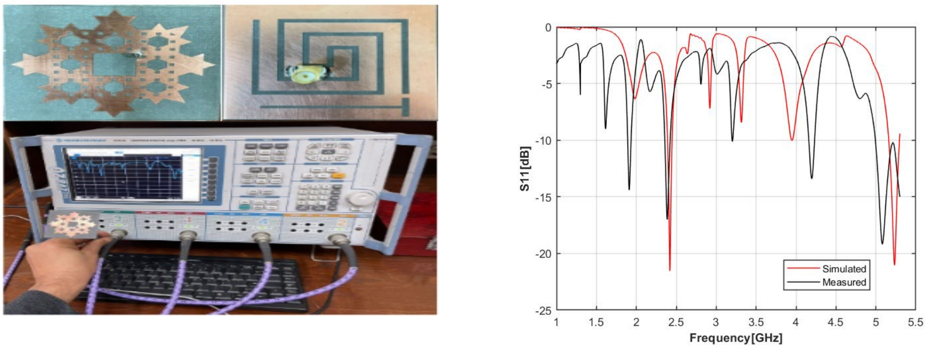


Fig. 11. The modelled antenna radiation pattern at frequencies

On the other hand, Photographs of the finished antennas are shown in Figure 12 which illustrate the measured and simulated return loss of an antenna for frequencies ranging from 1 to 5 GHz. At lower frequencies, there was a good deal of agreement between simulation and measurements; while there were some variations at higher frequencies because of the inadequate testing environment, they were nevertheless bearable and helped to support the idea of this research. A full anechoic chamber can be used to eliminate the inconsistencies, which can be due to the inaccurate testing environment. It is crucial to keep in mind that the purpose of this work is to provide a step-by-step guide for creating and optimizing multiband fractal slot antennas for RF. energy harvesting applications and how to make the antenna resonance is aligned with the required ambient RF systems. The suggested method can be used to create multiband fractal slot antennas for 5G networks, other forthcoming wireless communication systems, and mobile communication systems [30-32].



(a) (b)

Fig. 12. (a) A photo of the constructed antennas' front and rear sides as well as the experimental measurement setup. (b) Measured return loss (S11) for the constructed fractal antenna in comparison to the simulated on

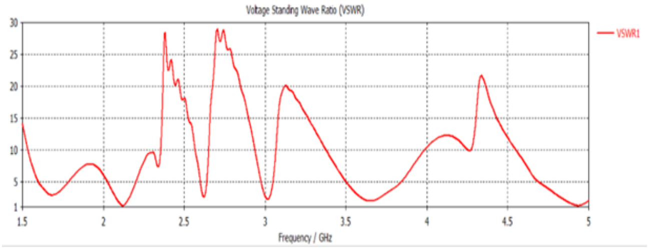


Fig. 13. Proposed antenna VSWR

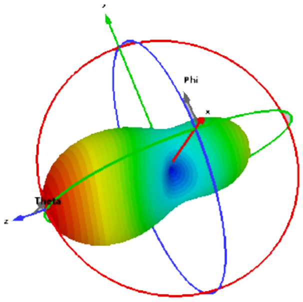


Fig. 14. 3D radiation pattern of proposed antenna

5. Comparison of Performance

Fractal antennas are a type of antenna that uses self-similar or repeating geometric patterns to increase the performance of the antenna. In the following section, the peak gain, VSWR, return loss, size, and bandwidth of several fractal antennas have been compared and reviewed based on different published papers. The following table summarizes the results of these published papers.

Table 4
Comparison of proposed antenna with other existing papers

Authors/Ref.	Year	Comparison Metrics				
		Peak Gain (dB)	VSWR	Return Loss (dB)	Size (mm)	Bandwidth
L. Wang. [33]	2021	3.34	-	-30	61 x 87.5	2.5–3.8-5.3 GHz
Lee, Woosol *et al.,* [34]	2021	6.12	-	- 33.6	28 x 28	2.45 GHz
Y. Zhu *et al.,* [35]	2018	5.2	1.1	-27	20 x 20	3.1-12.2 GHz
Raza *et al.,* [36]	2019	4.2	1.2	-10	30 x 30	2.4-2.5 GHz and 5.2-5.8 GHz
Goyal *et al.,* [37]	2020	7.62	1.6	-20	40 x 40	2.4-2.5 GHz
K. Singh *et al.,* [38]	2020	5.43	2.0	-10	30 x 30	Operate in three frequency bands
Proposed System	2023	5.9	1.4	-20	40 x 40	Operate in four frequency bands

There are some discrepancies between the published results for the fractal antennas. For example, the peak gain of the fractal antennas ranges from 4.2 dB to 7.62 dB, which is a significant difference. The same is true for the VSWR and return loss, which can vary by a factor of two or more. These discrepancies can be due to several factors, including differences in the simulation and measurement techniques.

6. Conclusions

The power industry may enter a new era of clean and sustainable energy thanks to our revolutionary design, which can harvest energy from multi-band sources including GSM, Wi-Fi, and WI-Max. This paper provided a systematic process for the original design and optimization of multiband fractal slot antennas for RFEH applications. First, a high-performance simulation was run to capture several bands while designing a fractal antenna. To obtain the most precise results, a rectifier and matching circuit were selected. Finally, the voltage regulator and energy storage were chosen in accordance with the amount of power required to run a simple WSN that was also constructed with a simple microcontroller and a sensor to detect temperature and humidity that can be utilized in ITS.

Acknowledgement

This research was not funded by any grant.

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