DESIGN OF A SEIRPINSKI GASKET FRACTAL ANTENNA WITH THE DEFECTIVE GROUND STRUCTURE AIMING AT THE REDUCTION OF SPECIFIC ABSORPTION RATE FOR SKIN IMPLANTS

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ABSTRACT

The development of Implantable Medical Devices (IMDs) is one of the most important aspects towards establishing an advanced health care system. Nowadays, the devices which are designed to monitor physiological data inside the human body have great promises to provide major contributions to disease prevention, diagnosis and therapy thus reducing hospitalization terms and improving the patient’s quality of life.

The proposed work is to design a Seirpinski gasket fractal antenna with Defective Ground Structure aiming at the reduction of Specific Absorption Rate for Skin Implants. The project is structured by the way that the Seirpinski gasket acting as the radiating element which helps in attaining the multiband behaviour of the antenna. By using the fractal structure the antenna size is reduced considerably. Periodic defects at the ground helps in side lobes suppression so that the antenna can radiate only in the intended direction which is very much desirable for a Skin Implantable Antenna. Their performance has been analyzed in terms of Specific Absorption Rate, Voltage Standing Wave Ratio, Return loss and Radiation efficiency by placing the antenna inside the three layered skin model. The antenna operates at ISM band of 2.45GHz and MICS band of 402MHz so that when 2.45GHz is unavailable as it is used for other miscellaneous applications like Bluetooth, Wi-Fi etc. This antenna can use the MICS band which is exclusive for medical implants reducing the interference.

The proposed work fulfills the requirements given by the International Telecommunication Union Standards for a Skin Implantable Antenna.

Index Terms: Defective ground structure, Specific Absorption Rate (SAR), Seirpinski gasket fractal, ISM band, MICS band, International Telecommunication Union Regulation Standards (ITU-R).

1. INTRODUCTION

The increasing demand for non-invasive surgical operations has made the use of Implantable Medical Devices (IMDs) as part of medical procedures highly attractive. Consequently, current invasive procedures to elicit physiological and biological data may be avoided by using implantable devices. Implantable antennas are electrically small antennas similar to typical antennas used for common wireless applications such as mobile phones, but with the additional complication that the implant will be located in a complex lossy medium. Most of the research on implantable antennas for medical purposes has focused on therapeutic applications such as hyperthermia, balloon angioplasty, etc. or on sensing applications. In both cases, the antennas works in its near field and propagation over a certain distance is not an issue.

In Biomedical Telemetry applications [3]-[15] on the other hand, the system is unlikely to be in the near field therefore it should have the capacity to transmit data over a longer distance. In this case, features like the radiation efficiency and the bandwidth are essential in order to provide transmission over a large enough range with a high enough data rate to be able to operate in wider environments like those experienced in the day-to-day life of the user. Currently, the application of the implantable antenna for building a communication link between the implanted devices and outside the human body is receiving more attention. As already mentioned above, the integrated implantable antenna is a key and critical component of RF-linked implantable medical devices, which enables bidirectional communication with the exterior monitoring/control equipment.

In this paper, the main aim is to reduce the Specific Absorption Rate in the implantable antenna which is a serious issue which is overcome by the use of Defective Ground Structure, a recent ongoing development approach for designing low profile antennas such as microstrip and dielectric resonator antennas [17]-[20]. The paper also focuses on the implantable antenna complying with the antenna less than 1 m (Body area network antenna).

The defect in a ground is one of the unique techniques to reduce the overall size of the antenna. So, antenna size with DGS is reduced for a particular frequency as compared to the antenna size without the defect in the ground. DGS is realized by introducing a shape defected on a ground plane thus will disturb the shielded current distribution depending on the shape and dimension of the defect. The disturbance at the shielded current distribution will influence the input impedance and the control flow of the antenna. It can also control the
excitation and electromagnetic waves propagating through the substrate layer. DGS have the characteristics of the stop band slow wave effect and high impedance. DGS is basically used in microstrip antenna for different applications such as antenna size reduction, cross polarization reduction, mutual coupling reduction in antenna arrays, harmonic suppression etc.

2. PROPOSED METHOD

2.1 DESIGN OF SEIRPINSKI GASKET FRACTAL ANTENNA

The equations to calculate the resonant frequency of a simple equilateral triangular patch without any degree of Seirpinski gasket fractal is given below,

\[
f_r = \frac{2c}{3a_{\text{eff}} \sqrt{\varepsilon_{\text{eff}}}} (m^2 + mn + n^2)^{1/2}
\]

\[
a_{\text{eff}} = a + h (\varepsilon_r)^{-1/2}
\]

\[
\varepsilon_{\text{eff}} = \varepsilon + \frac{1}{2} + \frac{\varepsilon_r - 1}{4} \left[ 1 + 12h / a_{\text{eff}} \right]^{1/2}
\]

Where

- \( a \) = length of the equilateral triangular patch
- \( h \) = thickness of the substrate
- \( c \) = velocity of light
- \( \varepsilon_r \) = relative dielectric constant

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>DIMENSIONS</th>
</tr>
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<tbody>
<tr>
<td>Length of a side of equilateral patch</td>
<td>51.5mm</td>
</tr>
<tr>
<td>Substrate used</td>
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<tr>
<td>Relative permittivity of the substrate</td>
<td>10.2</td>
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<tr>
<td>Thickness of the substrate</td>
<td>0.635mm</td>
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</tbody>
</table>

Table -1: Proposed Seirpinsk Gasket fractal dimensions

Figure 1: Layout of the Seirpinski Gasket first iteration

2.2 DESIGN OF DEFECTIVE GROUND STRUCTURE

DGS is an intentionally designed defect on the ground plane and depending on the shape and dimension of the defect on ground plane it will disturb the shielded current distribution. This defect creates additional effective inductance (\( L \)) and capacitance (\( C \)) which is given by the equation below,

\[
L = \mu \frac{h}{\mu}
\]

\[
C = \frac{w \varepsilon_0 [\varepsilon_{\text{r1}} + 1]}{\pi} \cosh^{-1}\left( \frac{w + g}{g} \right)
\]

Where

- \( L \) = Inductance of the defect
- \( C \) = Capacitance of the defect
- \( W \) = Width of the defect
- \( g \) = Gap between the defects
- \( f_r \) = resonant frequency
- \( h \) = Height of the defect
- \( \varepsilon_0 \) = Dielectric permittivity in free space
- \( \varepsilon_{\text{r1}} \) = Dielectric permittivity of the substrate

Figure 2: Layout of Defective Ground Structure

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>DIMENSIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of the DGS</td>
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</tr>
<tr>
<td>Width of the DGS</td>
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<tr>
<td>Radius of the circle</td>
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<td>Gap between the successive DGS</td>
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<tr>
<td>Substrate used</td>
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<tr>
<td>Thickness of the substrate</td>
<td>2 mm</td>
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<tr>
<td>Relative permittivity of the substrate</td>
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</tr>
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</table>

Table -2: DGS dimensions
Figure 3: Layout of Seirpinski Gasket second iteration

Step 1: The Seirpinski gasket fractal acts as the radiating element with inset feed provided at the patch (Fig 1).

Step 2: Square periodic defects are placed as the ground (Fig 2). Both the ground and the patch are assigned with the Perfect electric conductors (Perf E1 and Perf E2).

Step 3: Waveport with the incident power of 1W is assigned at 21mm along the X-axis which is the default value provided by the software tool.

Step 4: Air box of 10cm is placed over the antenna and radiation boundary is assigned to it (Rad 1).

Step 5: Antenna is placed inside the skin model and their performance has been estimated (Fig 4, 5 & 6).

3. ITU-R STANDARDS FOR A SKIN IMPLANTABLE ANTENNA

Wireless implantable devices operate in several frequency bands depending on the data rate, working range, power transfer capability, and the different standards of different countries. This project focuses on the EM radiation occurring in the 2.45 GHz ISM band. EIRP limitations and frequency spectrum allocations are reported based on the information available from ITU [2]. Power limitations are also set to prevent hazardous heating of the biological tissue. The maximum power for the transmission from any implantable device must comply with the peak spatial-average SAR limitations.

In the presence of biological tissues, the main drawback of the power dissipation in the lossy surrounding media is the generated heat which may be hazardous. The Specific Absorption Rate has therefore been introduced for the analysis of EM waves in biological tissues. The evaluation of SAR is a way to compute the dissipation of EM power per unit mass (with different averaging techniques or peak values), in order to estimate the heating of the tissues that may have harmful effects.

\[ \text{SAR} = \frac{1}{2} \frac{\sigma}{\rho} |E|^2 \]

Where

- \( E \) is the RMS electric field
- \( \rho \) is the sample density (Kg/m³)

The limitations of a skin implantable antenna operating at 2.45GHz and 402MHz are

- EIRP should be 20 dBm or 100 mW and -16dBm or 25µw for 2.45GHz and 402MHz respectively.
- SAR per 1-g averaging should not be more than 1.6W/Kg according to the FCC limit.
- SAR per 10-g averaging should not be more than 2W/Kg according to the European union limitation.
4. PERFORMANCE ANALYSIS OF SKIN IMPLANTABLE ANTENNA FOR SEIRPINSKI GASKET FIRST ITERATION

Figure 7: Return loss graph for first iteration

Figure 8: VSWR at 2.43GHz and 402 MHz

Figure 9: Radiation pattern

4.1 INFERENCE

Periodic DGS placed beneath the Seirpinski fractal perturbs the electromagnetic fields around them so that the trapped electric fields give rise to Capacitive effect(C) while the surface currents around the defect cause an Inductive effect(L) in turn results in resonant characteristics of a DGS. The Periodic DGS follows the boundary of the patch resulting in the rejection of the TM_{02} mode which is responsible for producing the XP radiations in the rectangular patch. It signifies suppressing the XP radiations in H-plane while leaving the primary radiation relatively unaffected.

The Seirpinski gasket fractal geometry acts as the radiating element. This fractal structure is responsible for the multiband behavior of the proposed antenna design. This fractal shape increases the overall electrical length of the antenna and the resonant frequency is lower than that of conventional monopole, loop and patch type antenna. The current distribution of the fractal is such that most of the current density concentrates on the joints and edges of different triangle clusters that make up the Seirpinski gasket. Thus providing a good return loss of 21.1dB and 14.5dB at 2.45GHz and 402MHz respectively(Fig 7), VSWR < 2 at both the frequencies(Fig 8), SAR is 1.33W/Kg which is low when compared to the maximum limit given by the European Union provided by the ITU-R standards for...
Skin implantable antenna (Fig 11). The radiation efficiency of the antenna is 91% (Fig 10).

5. PERFORMANCE ANALYSIS OF SKIN IMPLANTABLE ANTENNA FOR SEIRPINSKI GASKET SECOND ITERATION

![Return loss graph for Seirpinski Gasket antenna second iteration](image)

**Figure 12:** Return loss graph for Seirpinski Gasket antenna second iteration

![Seirpinski gasket fractal](image)

**Chart -1:** 1st iteration Vs 2nd iteration of Seirpinski gasket fractal return loss graph

5.1 INFERENCES

Comparing the results of first iteration and second iteration of the Seirpinski gasket fractal antenna from Fig 2 the first iteration provides very good return loss at both the desired frequencies namely 2.45GHz and 402MHz while the second iteration shows a poor return loss at 402MHz (Fig 12). VSWR is greater than 2 at 402MHz and the radiation efficiency obtained is also less compared to the first iteration.

6. CONCLUSION

Skin implantable antenna with defective ground structure aiming at the reduction of Specific Absorption Rate is designed to operate at ISM band of 2.45GHz and MICS band of 402MHz. Their performance has been analyzed in terms of SAR, VSWR, Return loss and Radiation efficiency to match with the limit provided by the European Union given in the ITU-R standards for Skin Implantable Antenna.

The ultimate aim of this work is to reduce the size of the antenna for which Seirpinski fractal geometry has been used as the radiating element. Periodic defects have been used as the defective ground structure which operates at both ISM band of 2.45GHz and MICS band of 402MHz successfully. The performance analysis gives the return loss value as 21.1dB and 14.5dB at 2.45GHz and 402MHz respectively with 91% radiation efficiency and VSWR < 2. The SAR value is 1.33W/Kg which is less than the European Union limit provided by the ITU-R standards for Skin Implantable Antenna.

Thus the antenna of smaller size, high radiation efficiency and lower cross polarization and SAR value amicable with the European Union limit are obtained successfully.

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