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Wearable fractal integrated antennas for medical applications

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Abstract. Wearable embedded antennas are becoming increasingly vital in modern healthcare, enabling continuous monitoring and communication for medical purposes. Integrated into wearable devices, these antennas facilitate the transmission and reception of crucial health data, such as pulse rate, body temperature, and blood pressure, to healthcare professionals or real-time monitoring systems. This instant data transmission allows for swift interventions, thereby enhancing the quality of healthcare services. The aim of this study is to summarize recent research carried out in prestigious databases, focusing on the specificity and effectiveness of wearable fractal antennas used in medical applications. This synthesis offers valuable insights for researchers and practitioners aiming to develop and implement wearable integrated fractal antennas in the medical field, ultimately improving healthcare and patient outcomes.

1. Introduction

In the rapidly evolving field of medical technology, wearable devices have become increasingly vital for continuous health monitoring and real-time data transmission. Central to the functionality of these devices are antennas, which must be designed to meet the unique demands of wearable medical applications. This introduction explores the critical aspects of miniaturized wearable antennas and the specific requirements for their use in medical applications, highlighting the potential of fractal antennas in this context.

Miniaturized Wearable Antennas [1], [2]

Wearable medical devices require antennas that are not only highly efficient but also compact and lightweight. Miniaturized antennas fulfill this need by providing the necessary performance within a small footprint. The miniaturization process involves innovative design techniques and advanced materials to ensure that the antennas can fit seamlessly into wearable devices without compromising their effectiveness.

Miniaturized wearable antennas must address several key challenges:

- **Size Constraints**: The antennas need to be as small as possible to integrate into the wearable devices discreetly.
- **Performance**: Despite their reduced size, the antennas must maintain high efficiency and reliable signal transmission.
- **Durability**: The antennas must withstand the physical demands of daily wear, including bending, stretching, and exposure to various environmental conditions.

Fractal antennas, with their complex geometric shapes, offer a promising solution for miniaturized wearable antennas. Their design allows for a high surface area within a limited space, providing excellent performance across multiple frequency bands, which is crucial for medical applications that require precise and reliable data transmission.

Requirements for Wearable Antennas in Medical Applications [1], [2]

The design and implementation of wearable antennas for medical applications must adhere to several stringent requirements to ensure optimal performance and patient safety:

- **Flexibility and Comfort**: Wearable antennas must be flexible enough to conform to the human body's shape without causing discomfort. They should remain functional even when subjected to movements and stretching.
- **Biocompatibility**: Materials used in wearable antennas must be biocompatible to prevent skin irritation and allergic reactions. The antennas should be safe for prolonged contact with the skin.
- **Reliable Signal Transmission**: The antennas must provide robust and consistent signal transmission to ensure accurate monitoring and data collection, even in the dynamic environment of the human body.
- **Low Power Consumption**: Wearable medical devices often rely on battery power, making it essential for the antennas to operate efficiently and consume minimal power to extend the device's operational life.
- **Miniaturization**: To ensure that wearable devices are unobtrusive and comfortable, the antennas must

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be miniaturized without compromising their performance or coverage.

- **Multi-band and Wideband Capabilities**: Wearable medical devices may need to operate across different frequency bands. Fractal antennas, with their inherent multi-band and wideband properties, are particularly well-suited to meet this requirement.
- **Specific Absorption Rate (SAR) Values**: SAR is a measure of the rate at which the human body absorbs electromagnetic energy when exposed to a radio frequency (RF) electromagnetic field. For wearable antennas, it is crucial to ensure that the SAR values are within the safety limits set by regulatory bodies to prevent any potential harm to the user. Typically, the SAR limit is 1.6 watts per kilogram (W/kg) averaged over 1 gram of tissue in the United States, and 2.0 W/kg averaged over 10 grams of tissue in Europe. Antenna designs must minimize the SAR to adhere to these safety standards while maintaining efficient performance.

In summary, wearable fractal antennas represent a significant advancement in medical technology, offering the benefits of miniaturization, flexibility, and robust performance. By addressing the specific requirements of wearable medical devices, these antennas pave the way for enhanced health monitoring, improved patient care, and the seamless integration of advanced medical technologies into daily life.

2. Fractal technologies [3], [4], [5], [6]

2.1 Definition

A fractal is a geometric shape with a complex structure generated by the use of fractional rules. Benoît MANDELBROT coined the term «fractal» in 1974 from the Latin word "fractus", meaning broken, irregular.

Fractal geometries are those that could not be defined using Euclidean geometry, such as trees, clouds, mountains, coastlines, lightning and so on. Most of them are self-similar at different levels and the dimensions are fractional numbers.

Fractal geometries have been applied to a variety of fields:

- Medicine: intestines, lung structure, heartbeat...
- Meteorology: lightning structure, turbulence, clouds, ice floes...
- Volcanology: forecasting volcanic eruptions, earthquakes...
- Astronomy: craters on the Moon, description of the structures of the universe, distribution of galaxies...

Fractal geometries have also been used in the field of electromagnetism, especially in antenna design. Several studies have adopted fractal structures and shown that this technique enables multi-band and broadband behavior, as well as improved performance by increasing the number of iterations.

2.2 The fractal dimension

The usual dimensions used are integer values. Taking the example of a straight line with a dimension equal to 1, we can determine all the points on this line by defining a reference (origin) and the position (x) of the point in question. The same applies to two- and three-dimensional geometries: to determine the position of a point in a 2- or 3-D figure, we need to define a reference, and the points are defined by their positions (x,y) and (x,y,z) respectively.

For fractal geometries, the dimension is not necessarily integer, but is expressed using the HAUSDORFF dimension. If a fractal is made up of smaller replicas of itself, its fractal dimension can be calculated using formula (1)

$$d = \frac{\log(n)}{\log(h)} \quad \textbf{(1)}$$

Where the starting fractal is made up of (n) copies whose size has been reduced by a factor of h (for homothety).

Figure 1 shows the three first iterations of SIERPINSKI triangle fractal structure.

Fig. 1. The three first iterations of SIERPINSKI triangle fractal structure

For this fractal structure, the HAUSDORFF dimension is

$$d = \frac{\log(3)}{\log(2)} = 1.58$$

3. The use of fractal antennas to design wearable antennas for medical applications

In recent years a lot of researcher are studied the use of fractal structures to design compact and low profile antennas. In 2017, Omar Masood Khan designed a flamenco fractal antenna with a resonance frequency of 2.4GHz having the dimensions 27.14x20x1.575mm^3. The antenna is printed on a Roger RT5870 substrate with a relative permittivity of 2.22. The antenna has a maximum gain of 1.24dB. But we note that no SAR has been studied fig 2-a [7]. In 2018, Albert Sabban has developed an antenna combining metamaterials and fractal technologies. The antenna is miniature, measuring 45.8x39.1x0.8mm^3, printed on a substrate with a dielectric constant of 2.2. The antenna operates at frequencies from 1.5 to 3GHz, with a maximum gain of 5.5dB. However, no SAR has been studied fig 2-b [8]. Omar Masood Khan has designed a flamenco fractal antenna operating on several frequencies: 0.928, 3.56, 6.85, 8.12 and 10.56 GHz. The antenna has a size of 37x59.04x1.575mm^3 printed on a Roger RT 5870 substrate with a relative permittivity of 2.33. The SAR level is 0.989 W/kg averaged over 1g, which complies with the US standard fig 2-c [9].

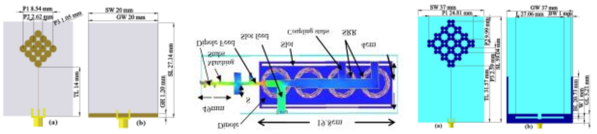
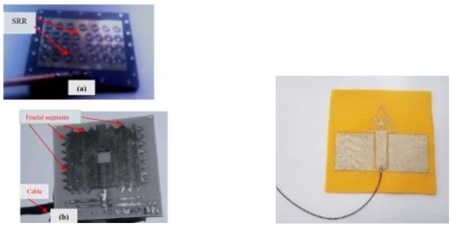

(a) (b) (c)

Fig. 2. The antennas developped by Omar Masood Khan (a and c) and Albert Sabban (b)

In 2019, Albert Sabban has conceived an antenna combining metamaterials and fractal technologies. It is operational for the 3.46GHz frequency with a high gain of 7.8dB. The antenna has a dimension of 36x20x3.2mm^3. Also suitable for 5G mobile networks. No SAR study has been performed fig 3-a [10]. Nikolay T. Atanasov has designed a flexible fractal antenna printed on polar fleece operating on 2.43GHz. The author did not specify the antenna dimensions. The SAR level is 0.0971 W/kg averaged over 1g, which complies with the US standard fig 3-b [11].



(a) (b)

Fig. 3. The antennas designed by Albert Sabban (a), Nikolay Atanasov (b)

Evangelista has designed three iterations of KOCH fractal antenna, with a resonance frequency of 2.22 and a maximum gain of 5.5, printed on a substrate with a dielectric constant of 4. The antenna has a size of 48x42mm. No SAR has been given fig 4-a[12]. Ali Arif has designed an antenna printed on the Roger RT Duroid 5880 substrate with a relative permittivity of 2.2. The antenna has a modified KOCH-type fractal shape with slot insertion. It has a size of 39 x 39 x 0.508 mm3. It operates in the 2.4Ghz band with a maximum gain of 2.06dB. The SAR has been well studied for several configurations and the antenna is conform to all international standards fig 4-b[13].

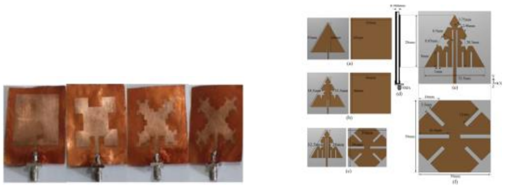

(a) (b)

Fig. 4. The antennas developped by Evangelista(a) and Ali Arif (b)

Mohamed Ahmed has developed three fractal antennas. The first is a square fractal antenna with four resonance frequencies 1.57, 2.7, 3.4 and 5.3 Ghz and a size of 70x46x1.6mm^3, printed on FR4 with a relative permittivity of 4.4 (fig 5-a). The second one is a Sierpinski carpet fractal antenna with three resonance frequencies 1. 7, 5.3 and 5.8 GHz, printed on Dry Jeans with a dielectric constant of 1.78, size 70x70x0.6 mm^3 (fig 5-b) and the third is a Crown fractal antenna operating on the three resonance frequencies 3.3, 5.8 and 6.7 GHz, with a size of 57x50 x0.6 mm^3, also printed on the same substrate as the second antenna. These three antennas are also suitable for GNSS, Wifi and Wimax applications (fig 5-c). The study also focused on SAR reduction[14].

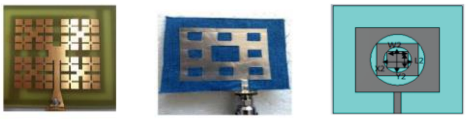
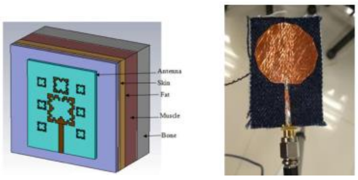

(a) (b) (c)

Fig. 5. The antennas developped by Mohamed Ahmed

In 2021, R.Singh has studied a Minkowski island fractal antenna operating at three resonance frequencies: 2.4, 3.5 and 5.2 GHz. Its size is 32x40x1.6mm^3, printed on a substrate of relative permittivity 4.3. The SAR study shows that it complies with international standards (fig 6-a)[15]. Ashraf has developed a fractal antenna with ultra-wideband behavior covering the 2.2 to 5 GHz band. The minimum gain of the antenna in this band is 2.32dB. Its size is 32.4x48.6x0.74mm^3, printed on denim's jeans. The maximum SAR value has not exceeded the safety limit imposed by the international standards(fig 6-b)[16].



(a) (b)

Fig. 6. The antennas developped by Singh (a) ans by Ashraf (b)

In 2022, KHAN has developed a modified MOORE fractal antenna operating in the two bands 1.38 to 1.8 GHz and 2.25 to 4.88 GHz. the maximum gain is 2.2dB. This antenna is sized 60x85x4mm3 printed on a Rogers 5880 with permittivity 2.2. The calculated SAR complies with international standards (fig 7-a)[17]. In 2023, Heshmatzadeh has studied an antenna combining two fractal structures Koch and Sierpinski. The antenna operates at a resonant frequency of 2.4Ghz with a size of 17.6x17.6x1.6 mm^3.The antenna is printed on FR4 substrate with 4.4 as relative permittivity. No SAR has been studied (fig 7-b)[18].

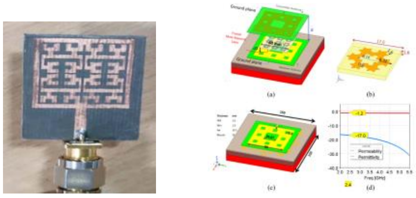

(a) (b)

Fig. 7. The antennas developped by Khan (a) ans by Heshmatzadeh (b)

4. Conclusion

In conclusion, the exploration of miniaturized wearable antennas, specifically fractal antennas, reveals their substantial potential in advancing medical technology. Our review of articles published since 2017 has highlighted the significant strides made in the design and implementation of fractal antennas for medical applications. The critical parameters of size, materials, gains, frequency bands, and SAR compliance have been meticulously analyzed, underscoring the unique advantages offered by fractal antennas.

Fractal antennas stand out due to their compactness and efficiency, meeting the stringent size constraints of wearable medical devices without sacrificing performance. The innovative use of advanced materials ensures durability and biocompatibility, making these antennas suitable for continuous and safe contact with the human body. The multi-band and wideband capabilities of fractal antennas provide reliable and precise signal transmission across various frequency bands, essential for accurate health monitoring.

Moreover, the ability of fractal antennas to maintain low Specific Absorption Rate (SAR) values aligns with international safety standards, ensuring user safety and regulatory compliance. This is crucial for the widespread adoption of wearable medical devices, which must operate efficiently while minimizing potential health risks.

The advancements in fractal antenna technology signal a transformative impact on the medical field, offering enhanced patient care through improved monitoring and data collection. As the demand for wearable medical devices continues to grow, the integration of fractal antennas will play a pivotal role in the development of more sophisticated and effective health monitoring solutions.

Future research and development efforts should focus on further optimizing fractal antenna designs, exploring new materials, and enhancing performance metrics to meet the evolving needs of medical applications. By continuing to address these key areas, fractal antennas will remain at the forefront of wearable medical technology, contributing to the betterment of healthcare and patient outcomes.

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