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Fractal Fusion: A Breakthrough in Compact Antenna Design for Bio-Telemetry

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Abstract

Since the Internet of Things (IoT) enabled medical diagnostic system requires unprecedented precision and automation for better health care delivery, therefore in such systems, the performance of antennas for efficiently transferring data (vital functions of the human body) is an important task. To address these concerns, a mechanically robust, novel hybrid wearable on-body antenna inspired by Moore's fractal based geometry and conventional rectangular loop for a diagnostic health monitoring system is proposed. The structure developed involves the etching of Moore's curve onto a conventional rectangular patch and subsequently encasing it in a rectangular loop along with a defected ground structure. The proposed antenna exhibits dual-band with bandwidth ranging from 1.38 - 1.8 GHz and 2.25 - 4.88 GHz respectively, covering WMTS, ISM, and Personal Communication band besides covering a portion of UWB band also. The two operating bands of the antenna offer a fractional bandwidth of 38.5% and 73.7% respectively. It is observed that the average specific absorption rate (SAR) over the multi-layer phantom is 0.025 W/kg for an input power of ≈ 24 dBm. In comparison to the recently reported wearable antennas, the design proposed has a compact footprint of 0.135 λ_0 x 0.093λ_0 x 0.004λ_0 besides offering a dual- band of operation, peak gain of 2.2 dBi, overall radiated efficiency of 95% and SAR below 0.025 W/kg. The design is fabricated using Rogers 5880 substrate (semi-flex) of thickness 0.75 mm. The experimental results validate the simulated results making the proposed antenna a promising candidate for the bio-medical application. On analysing the performance of the proposed antenna onto the human body (human body loading), it is concluded that the proposed antenna structure is appropriate for bio-telemetric application in diagnostic health monitoring systems wherein data is relayed from all bio-sensors to remote control systems as well as its content.

1. Introduction

From the last two years, our society at large is facing the disastrous outcomes of the pandemic. It is an undeniable The associate editor coordinating the review of this manuscript and approving it for publication was Masood Ur-Rehman . fact that the healthcare sector is the worst hit and there has been tremendous pressure on its resources. People working in the biomedical field are not only trying to fix the challenge arising due to the unexpected situation but also aim to provide a steady solution for the future whenever such a critical situation arises. In light of this situation, a lot of work has been done to decrease the workload of doctors by reducing the number of visits of patients to the hospitals. This has been achieved by ensuring proper tele monitoring of vital functions of critical patients and a timely diagnosis by the healthcare professionals. In a biomedical diagnostic system, an antenna is not only a vital part of the system but it defines the overall efficacy of the system. A schematic of the biotelemetry-based diagnostic health monitoring system is illustrated in designing an antenna for on-body application is a herculean task. In such scenarios, the RF waves interact with different tissues of the body resulting in internal reflection and scattering phenomena which makes the impedance matching a hectic issue. Not only this, the placement of the antenna once fixed over a human body is liable to change whenever any body movement occurs. This results in a change in the resonant frequency, impedance bandwidth, and reflection coefficient. To alleviate the shifting of operating frequencies in such scenarios, it is always better to design a wideband antenna. Taking into consideration above mentioned challenges, there is a dire demand for the design of a robust, compact, conformal, multiband/ wideband antenna for body-worn applications. A CPW-fed octagonal shaped UWB antenna for WBAN application is reported in. When the reported antenna is operated in close proximity to a human body, the radiation pattern of the antenna being bidirectional increased the specific absorption rate. To address this concern, authors in have employed a full ground plane that is placed beneath the substrate layer to avoid the effect of radiations emitting from the antenna on the human body. A Bow-Tie antenna for biomedical applications is reported. When this antenna is placed over the skin, it operates in the frequency range of 0.5-2 GHz. However, the reported prototype is fabricated on a rigid PCB, which limits its application for the cases where conformity is required (on-body affixation). In authors have reported a biconical antenna for the body area network as it provides a directional pattern with minimum back radiation. The serious drawback of This antenna is its larger size which inhibits its usage in large-scale integration. Furthermore, in the researchers reported that a big ground plane in an antenna shields the body from the electromagnetic (EM) radiation arising out of it by reducing the backward radiation. Nevertheless, antennas with large ground planes resulted in an increase in size and loss of flexibility in the wearable antenna. A pliable on-body antenna is presented in which is compact, conformal, and has a unidirectional radiation pattern. The prospective antenna operates in the frequency band of 0.55-3 GHz when placed at different parts of the human body. In this antenna, the maximum SAR values remain well below 0.8 W/kg (10 g) for the maximum input power limited to 10 dBm. In a unidirectional antenna meant for head imaging is reported. The dimensions of the prototype are 60 × 85 × 4 mm3 and work in the operational frequency range of 1.1-1.9 GHz. For the same application, an improved compact antenna is reported in operating in the frequency band of 1- 4.3 GHz. A triple band implantable antenna meant for bio telemetric application is proposed in, wherein the performance of the design is reported to have been achieved by utilizing the split ring resonators loaded with meandered lines in the radiating patch of the antenna. The fractional bandwidth achieved in all three operating bands of the antenna reported in is less than 20% signifying the fact that the design is a narrowband antenna. In a flexible and compact circularly polarized monopole antenna is proposed for wearable applications. To achieve good performance in terms of gain and Specific Absorption Rate (SAR), the antenna is backed by an Artificial Magnetic Conductor (AMC) that acts as a reflector. A conformal wideband patch antenna backed by AMC for better SAR, impedance matching and high efficiency is reported. However, such types of designs as proposed in have larger sizes and a higher degree of complexity. A low-profile Koch curve-inspired hybrid antenna is proposed for on-body WBAN applications. By virtue of fractal geometry with meandering slits and defected ground plane, the effective size has been miniaturized and bandwidth improvement has been achieved in the reported design. In nutshell, it is observed that apart from the slot and traditional patches, versatile antenna designs for body worn applications with improved efficiency and performance have been recently reported. Keeping these challenges in mind, there is a dire need for new antennas that are more suitable for on-body operations

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2. LITRATURE SURVEY

1. Wireless Body Area Networks: A Survey

Recent developments and technological advancements in wireless communication, Microelectromechanical Systems (MEMS) technology and integrated circuits has enabled low-power, intelligent, miniaturized, invasive/non-invasive micro and nano-technology sensor nodes strategically placed in or around the human body to be used in various applications, such as personal health monitoring. This exciting new area of research is called Wireless Body Area Networks (WBANs) and leverages the emerging IEEE 802.15.6 and IEEE 802.15.4j standards, specifically standardized for medical WBANs.

2. Dual-band reconfigurable antenna with a very wide tunability range

A new technique for designing dual-band reconfigurable slot antennas is presented. Dual-frequency operation is achieved by loading a slot antenna with two lumped variable capacitors (varactors) placed in proper locations along the slot. Loading the slot antenna with lumped capacitors shifts down the resonant frequencies of the first and second resonances of the antenna. However, these frequency shifts depend not only on the values of the capacitors, but also on their locations along the slot antenna

3. Tunable coplanar patch antenna using varactor

The operating frequency of a coplanar patch antenna is tuned using a varactor mounted at one of the radiating edges. The coplanar patch antenna is tunable from 4.92 GHz at 0 V to 5.40 GHz at 19.5 V with a return loss better than 14 dB in this frequency range. The antenna provides a return loss better than 32 dB in the tunable frequency range of 5.16 to 5.40 GHz.

4. MEMS-based reconfigurable antennas

In this paper, two frequency reconfigurable antennas using the ON/OFF states of a microelectromechanical system (MEMS), are presented. A multifrequency planar inverted-F antenna (PIFA) is designed with a L-shaped open slot upon its main plate. As a proof-of-principle, an ON state RF MEMS switch, modeled by a piece of copper (1x1 mm/sup 2/), is inserted into the slot to achieve frequency switching (While OFF state is modeled without the piece of copper).

5. Multifunctional reconfigurable MEMS integrated antennas for adaptive MIMO systems

Multi-input multi-output systems with associated technologies such as smart antennas and adaptive coding and modulation techniques enhance channel capacity, diversity, and robustness of wireless communications as has been proven by many recent research results both in theory and experiments.

6. Reconfigurable antenna structure for a wideband cognitive radio

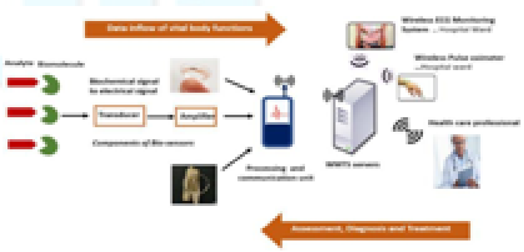
In this paper the design of a single feed antenna that can be tuned to a frequency in the range 450 MHz to 2.2 GHz is discussed. A reconfigurable patch antenna structure is proposed and the frequency tuning is performed by switching in and out coplanar patches, switching in and out shorting posts and varying the voltage across a varactor diode

7. An RF electronically controlled impedance tuning network design and its application to an antenna input impedance automatic matching system

A novel design is proposed for an electronically tunable impedance unit. The prototypes include lumped elements, but no electromechanical control methods. The devices can tune many different complex impedances at minimum manufacture costs. Two antenna input impedance automatic matching systems are also presented, based on the tuning network. One includes a simplified version of the generic tuner, which can achieve good matching levels between the antenna and the power module with low losses.

3. Tables, Figures

3.1 BLOCK DIAGRAM



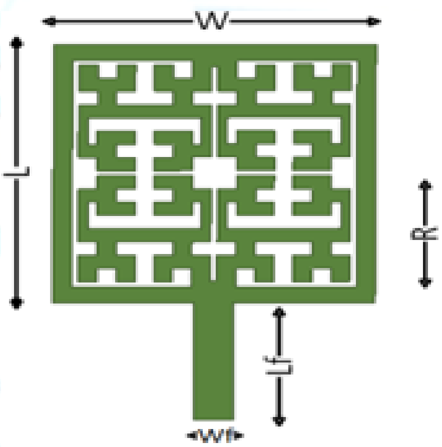
This work is attributed to the development of an antenna for EM medical diagnostic systems and here forth we have chosen Moore's fractal-based antenna for this crucial application. The final design achieved in this work has undergone a number of evolutionary stages to achieve its optimal performance. Illustrates the schematic diagram of the proposed hybrid antenna fabricated on a 0.75 mm thick Rogers 5880 substrate with a loss tangent of 0.0009 and relative permittivity of 2.2. It is worth to mention that the Rogers RT/Duroid 5880 is a high-frequency laminate made from a PTFE composite reinforced with glass microfibers. Furthermore, Rogers 5880 has an extremely low dielectric constant, low coefficient of thermal expansion, low dissipation factor and is remarkably resistant to corrosion, moisture and abrasion. Also, the Dielectric constant of the material remains constant over a wide frequency range. The glass-microfiber-reinforced PTFE laminate is ideal for single-bend applications. All these features make it an ideal material for forming, bending, broadband and high-frequency applications. The prospective antenna consists of a top radiator that is evidently a hybrid version of the fractal-based Moore's antenna. The term hybrid used for the radiating element holds true in the context that the geometry of the antenna is a mixture of fractal concept and the conventional rectangular loop. To build the design, Moore's curve of n = 4 is etched onto a rectangular patch succeeded by a rectangular loop

TABLE 1. Parameters of the geometrical layout of proposed design.

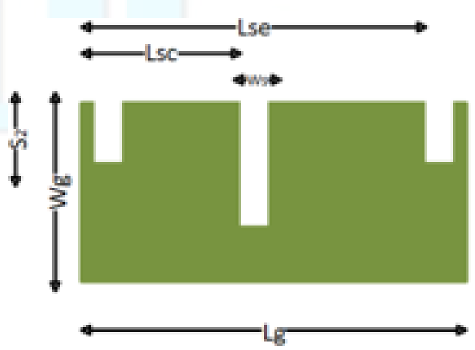
Parameter	Value (mm)	Parameter	Value (mm)
L	19.5	W_g	6.5
W	17	L_g	20
R	8	S1	5
W_f	2.51	S2	2.2
L_f	8.83	W_s	1
Lsc	9	Lse	18

Within which it is enclosed. The fractal is excited through the rectangular loop (the fractal is connected to the loop through the patches at the diametrically opposite sides) that is connected to the feedline. Furthermore, the ground of the proposed antenna is partial and the three slots are embedded within it for achieving impedance matching and suppressing the back lobe radiation. For the size reduction of the antenna, we employed Moore's fractal geometry which in turn lowered the operating frequency of the antenna by increasing its electrical length that results in achieving the required compactness.

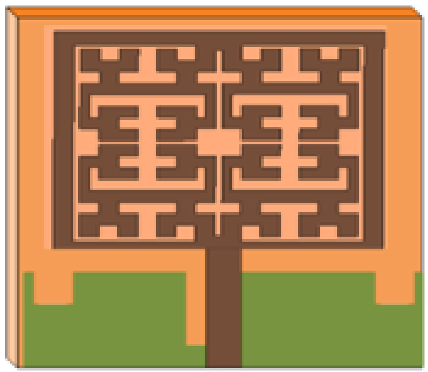
It is a well-established fact that the dimensions of the ground if modified can change the antenna impedance and therefore can help in selecting the desired band of operation. The overall planar size of the prototype is 0.135λ0× 0.093λ0 where λ0 is the wavelength of the lowest resonating frequency. The radiating element is fed by a rectangular feedline of length Lf and width Wf . All the optimized parameters of the geometrical layout are tabulated in Table 1. The width, length, and position of the slots etched in the ground have been optimized for achieving better performance.



(a)



(b)



(c)

4.Conclusions

A compact, robust and flexible body-worn antenna is proposed for biotelemetry in biomedical diagnostic systems. The fractal-based design increased the length of current flow thereby ensuring that the antenna is of optimal size and is operating at a lower frequency of interest. The antenna offers dual-band operation (1.38-1.8 GHz and 2.25-4.88 GHz) covering WMTS and ISM bands simultaneously; making it an ideal candidate for interoperability in biomedical applications. The hybrid antenna reported in this paper offers a fractional bandwidth of about 38.5% and 73.7% in the dual bands 1.38-1.8 GHz and 2.25-4.88 GHz respectively. The back lobe has been minimized to some extent in this work by inserting the vertical slots in the ground. The peak gain of 2.2 dBi has been achieved in the free space and 1.1 dBi when the proposed design is placed on the phantom. The specific absorption rate is well below 0.025 W/kg for an input power of ≈ 24 dBm which is generally used for SAR measurement in the case of mobile application devices. The prospective antenna has an edge over the recently proposed antennas due to its compact size, interoperability, and above all its low specific absorption rate for high power input. Mathematical models of entities involved in this work are also discussed to provide insight into the designing of the radiating element of the antenna and phantom respectively. To validate the simulated results, the device was fabricated and its performance was evaluated using Keysight N5247A Microwave Network Analyzer. To the best of our knowledge, the proposed design is the most compact antenna that offers the lowest SAR for maximum power input and dual-band covering most of the bands allocated for biotelemetry. This work can be extended to investigate the device for imaging applications. Also, the device (because of its minimized size) can be employed in an array configuration for further improvement of gain.

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