Miniaturized Planar Inverted F Antenna for Tri-Band Bio-Telemetry Communications

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Abstract— A tri-band miniaturized Planar Inverted F Antenna (PIFA) design for bio-telemetry communications is investigated in this work. This smaller antenna effectively covers the three bands namely the Medical Implant Communications Service (MICS) band, the Industrial, Scientific, and Medical (ISM) band and a third band which is devoted to make the implanted device to work as and when required. The operating frequency ranges of the three bands are chosen as 402 MHz (MICS band), 2.45 GHz (ISM band) and 433 MHz (third band). Inorder to achieve size reduction of the antenna meandered configuration, high dielectric constant, grooving slots and layer stacking methods are being used. It is shown that the antenna has compact size of 25.4 mm (10 mm by 10 mm) on a whole. Experimental results shows that a bandwidth of 5 MHz is obtained when the antenna operates in the MICS band, when the antenna proposed operates in ISM band it obtained 100 MHz bandwidth and it showed 18 MHz bandwidth while operating in the third band (433 MHz). It is found that the efficiency of the PIFA proposed at each bands are 71.33%, 81.61% and 73.7% respectively.

Index Terms— Planar Inverted F Antenna, bandwidth, miniaturization, three band operation, MICS band, ISM band, third band.

1 Introduction

With the rapid development of wireless communication, the multi-frequency antenna has become one of the most important devices and attracted much interest. The growth and proliferation of wireless communications can be felt in almost every aspect of our lives. Apart from mobile telephony, wireless local area network (WLAN), and Bluetooth recently attention is also being placed on implantable wireless applications. During the last few decades bio-medical engineering has experienced a remarkable growth. The design of bio-implantable devices that help the people to improve their health care and quality life has attracted a lot of interest. This has led to the design of small, reliable and low-power-consuming biomedical devices that can be implanted inside a patient's body by means of a surgical operation. Contrary to traditional, external medical devices, these implanted devices can sense data from inside the human body in real-time, offering a unique opportunity for early diagnosis and treatment of diseases. Before designing an implantable device one needs to know about bio-telemetry.

Recently, biomedical telemetry between the device(s) implanted inside the human body and exterior equipment has drawn a great attention for both medical diagnosis and therapy [1], [2]. Bio- Telemetry provides wireless communication from outside the body to inside it, or vice versa. Biotelemetry is a vital constituent in the field of medical sciences. It entails remote measurement of biological parameters. When considering biotelemetry systems, the study of the communication devices used for establishing a wireless link between the implanted device and the external base station becomes essential. In this sense, the implanted system must fulfill two main requirements: miniaturization and good radiation performances. In the most complicated scenario, implanted devices communicate with the external world in terms of both powering and telemetry. Powering is the delivering of energy to the implant from the external world in order to make it work. Telemetry includes data transmission from the implanted device to an external one, and vice versa. Antennas are one of the most important components in wireless communication systems as they play a vital role in implantable devices. Among all the components, the antenna is one of the most challenging to scale down in size because the size of the conventional antennas depends on the operating frequency of the required applications, which is usually in the MHz or low GHz range.

Miniaturization and bio-compatibility of the antenna, broadening of bandwidth to avoid drift in frequency and optimization of the performance of radiation are the main design constraints of any antenna [3], [4].Designing antennas that are to be implanted within the human body are challenging. Size limitations and the harsh environment of the human body create extra work for the antenna designer. Precision needs to be present at such small device sizes. Body tissues have a much higher relative permittivity than the air. This in turn will lead to a slower propagation velocity and therefore a smaller wavelength. The high relative permittivity [5] of bodily tissues will create shorter wavelengths and antennas can be designed for these shorter wavelengths. In other words the antenna implanted within the body is electrically larger. This will help designers create the antenna to be implanted within the body, but this also means that an antenna designed in for implant use will not operate the same in the free space realm.

This paper investigates a new miniaturized antenna design [6] with meandered and stacked configurations used for bio-telemetry communications that operates in three different bands 402 MHz (MICS), 2.45 GHz (ISM) and 433 MHz). The antenna chosen for our design is the well-known Planar Inverted F Antenna (PIFA).

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2 RELATED WORKS

Different kinds of schemes are available for manufacturing bio-compatible implantable antenna. Tutku Karacolak, Aaron Z. Hood (2008) [7] designed a small sized dual band antenna that covers the two bands namely the MICS and ISM bands. The dual-band design allows the implant to switch between sleep and wake-up modes, thereby it conserves energy and extend the lifetime of the implant. In order to test the performance of the antenna, they have developed skin mimicking gels to mimic the electrical properties of real human skin. The fabricated antenna is embedded in these gels and tested in-vitro (externally) using a network analyzer. The test shows a good result for MICS band but while operating the antenna in the ISM band the skin mimicking gel showed a more conductive result. Erdem Topsakal (2009) designed a small sized dual band antenna for medical wireless telemetry. The antenna is intended for wireless medical monitoring of the physiological parameters such as glucose, pressure, temperature. The antenna is designed by using particle swarm optimization in combination with an in-house finite element boundary integral simulation code. The drawback with this kind of antenna is that it can be used only for animals that are of same breed, age, sex [8].

Another type of ultra wide-band antenna for bio-telemetry systems was designed by Fatima Zengin, Even Akkaya (2011) [11]. This antenna was designed for operation in the ISM (2.4-2.48 GHz) band. The bandwidth of this antenna is low and also there was a drift in the frequency range when the antenna is tested in a skin mimicking gel. A broadband non-superstrate implantable CPW-fed monopole antenna operating at the Medical Implant Communication Service (MICS) frequency band (402-405 MHz) was developed by Tsung-Fu Chien, Chien-Min Cheng (2010) on a microwave dielectric ceramic substrate with high dielectric constant and high quality factor. Jaehoon Kim, and Yahya Rahmat-Samii (2004) device a planar inverted f antenna for implantation in the head. In both the cases the resulting antenna structure seems to be bulkier [12].The high relative permittivity of bodily tissues will create shorter wavelengths and antennas can be designed for these shorter wavelengths. In other words the antenna implanted within the body is electrically larger. This will help designers create the antenna to be implanted within the body, but this also means that an antenna designed in for implant use will not operate the same in the free space realm.

Implanted communication systems utilize either the MICS or ISM bands. Designing antennas for implant applications can be difficult to the harsh environment of the human body. There are many tradeoffs that need to be considered when designing for implanted communication systems. These tradeoffs include radiated power, power consumption, efficiency and size. This paper is organized in such a way that section III tells about the significance of the triple bands and the choice of the antenna. Section IV includes the antenna a detailed design procedure for the miniaturized bio-implantable antenna which is carried out in Advanced Design System (ADS) software. Followed by section V, holding the simulation results and discussions of the design. Later on section VI gives some concluding remarks about the results.

3 SIGNIFICANCE OF TRIPLE BAND

There are two main bands of interest with implantable medical communication systems. These bands are known as the Industrial, Scientific and Medical (ISM) band and the Medical Implant Communication Service (MICS) band.

3.1 MICS Band

Medical Implant Communication Service (MICS) is the name of a specification for using a frequency band between 401 and 406 MHz in communication with medical implants. The standard is defined by the U.S. Federal Communications Commission (FCC) and European Telecommunications Standards Institute (ETSI) [13], [14]. It allows bi-directional radio communication with a pacemaker or other electronic implants. The maximum transmit power is very low, EIRP=25 microwatt, in order to reduce the risk of interfering with other users of the same band. The maximum used bandwidth at any one time is 300 KHz, which makes it a low bit rate system compared with Wi-Fi or Bluetooth. If the system uses separate frequencies for up- and down-link, the two link bandwidths must not add up to more than 300 kHz. This implies that in order to get high data throughput a half-duplex scheme should be adopted, where only one device transmits at a time. If full duplex is necessary, the available bandwidth for each direction will be less, and this implies a lower data bandwidth for each direction. Note that in the case of a half-duplex solution the up- and down-link do not have to share the same frequency band. Separate Receive and Transmit bands, each with a bandwidth of 300 kHz, may be used as long as they are not used simultaneously. The main advantage is the additional flexibility compared to previously used inductive technologies, which required the external transceiver to touch the skin of the patient. The frequency band specified for MICS is already in use. The Meteorological Aids Service (METAIDS), which primarily is used by weather balloons transmitting data down to the earth, uses the same spectrum allocation today. For this reason the MICS system is specified to be used only indoors.

3.2 ISM Band

The ISM-band is a potential band to be used for medical implant communication. This band is designated to be in 2.45 GHz. It is the same band that is used today by a variety of services, e.g., Wi-Fi and Bluetooth, both used by computer equipment. In addition, cordless telephones and household microwave ovens operate in this frequency band. The ISM bands are defined by the ITU-R. The band is limited to 100 mW radiated power. Because communication devices using the ISM bands must tolerate any interference from ISM equipment, unlicensed operations are typically permitted to use these bands, since unlicensed operation typically needs to be tolerant of interference from other devices anyway. Worldwide Digital Cordless Telecommunications or WDCT is an ISM band technology that uses the 2.4 GHz radio spectrum.

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3.3 Third Band

Implanted devices need energy in order to sense or stimulate. The amount of energy required for the implant to work is small but cannot cease; if the implanted device runs out of energy, it would become useless and have to be substituted by surgical operation. Early implanted devices were interfaced with wires through the skin in order to receive energy. This way of powering soon proved to be ineffective since it restricted the movements of the patient and increased the chances of infection. Adding a battery to the implanted device is also a prohibitive solution. No matter how small the battery might be, the total size of the implant increases, limiting the possible implant locations. Moreover, battery life is limited and even rechargeable batteries have a limited number of recharge cycles before they become completely useless. One might suggest energy harvesting as being the solution to the powering problem. However, while this makes use of the external environment as a source of energy (temperature, wind, water etc), these sources of energy are unavailable in the case of implanted devices. The use of implanted and external antennae to wirelessly transmit energy to the implant appears to be a suitable alternative. Antennas that will potentially be used inside of implanted communication systems will need to consume very small amounts of power. Systems will typically only be consuming power during data transmission and periodic polling for signals from a transmitting unit. To facilitate this, the system will sleep when it is not transferring data to remote stations. A wakeup signal will be sent from the remote transceiver when it needs to communicate with the implanted device. Inorder to facilitate this, the third frequency band operating at 433 MHz is used for the design.

4 DESIGN PROCEDURE FOR MINIATURIZED BIO-COMPATIBLE PIFA

Since there is triple band operation the choice of the antenna should be precise. For the ISM band a rectangular patch antenna can be used. This type of antenna is attractive because the bandwidth is very narrow. For the MICS band a rectangular patch antenna would be too large, therefore a Planar Inverter F Antenna (PIFA) was designed. This type of antenna is a variant of the patch antenna. So, on a whole the Planar Inverted F Antenna (PIFA) is chosen for this design. This antenna resembles an inverted F, which explains the PIFA name [15].The PIFA typically consists of a rectangular planar element located above a ground plane, a short circuiting plate or pin, and a feeding mechanism for the planar element. PIFA's inherent bandwidth is higher than the bandwidth of the conventional patch antenna (since a thick air substrate is used).The Planar Inverted F antenna is a variant of the monopole where the top section has been folded down so as to be parallel with the ground plane. This is done to reduce the height of the antenna. The planar inverted –F antenna is popular for portable wireless devices because of its small size, and built-in structure. The other major advantages are easy fabrication, low manufacturing cost, and simple structure.

The proposed PIFA consists of four layers with spiral and meandered configurations. Fig. 1 displays the geometry of the proposed implantable antenna, with a total height of 2.54 mm. As said it has four layers out of that the layer 1 is the ground plane, and the remaining three layers form the radiating elements. Each layer has a length and width of 10mm respectively. The shorting pins are nothing but the vias with radius 0.5mm. The antenna is designed and developed purely in Advanced Design Systems (ADS) environment. It is built by using the Rogers RT/Duroid 5880 substrate with a specific relative dielectric constant 'εr' of 9.6 and thickness 'H' of about 0.675 mm. Ground plane is located on the bottom side of the substrate with shorting plates between them. A loss tangent of 0.001 is included for the design of the antenna so as to ensure that there is minimum loss. Fig 2 shows the multilayer PIFA designed in ADS.

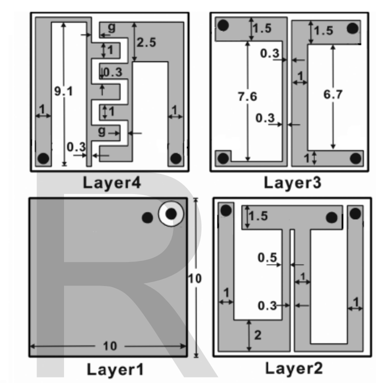

Fig. 1. Geometry of Proposed Multi-Layer PIFA

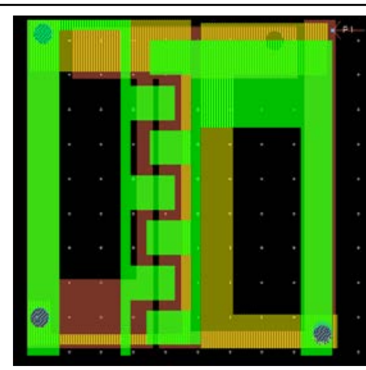

Fig. 2. Multi-Layered PIFA designed in ADS

The 3D visualization of the proposed multi-layer Planar Inverted F Antenna can be clearly seen from the fig 3. And the fig 4 shows the current distribution of in the three layers of the proposed antenna. The value of the parameter 'g' is chosen as 1 mm. Choosing other values for 'g' makes the frequency to shift from the desired range to some other one. So, an optimized value of 1 mm is chosen for the design. The

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meandered configurations on each of the layer are done inorder to increase the capacitive coupling effect so as to achieve size reduction. When the size of the antenna is reduced, the inductance part of the antenna is increased leading to a deviation in the desired frequency range. So, inorder to compensate for this equal amount of capacitance is included in the circuit to cancel the effect of the inductance. And hence meandSered configuration is used along with other options like stacking up the layers and using a high dielectric constant substrate, grooving slots. Having a high dielectric constant substrate makes the guided wavelength underneath the patch to reduce and hence the resonating patch size is also reduced. The reduction ratio is approximately related to the square root of . To reduce the size further slots can be introduced onto the resonating patch. In doing so, the current on the patch or the field underneath the patch will resonate from one edge of the patch and take longer path around the slots to reach the opposite edge. This longer path, in essence, reduces the resonant frequency or the physical size of the antenna. Depending on the length of the slots, a 10% to 20% size reduction can be achieved. Combining all these techniques it is possible to achieve maximum size reduction.

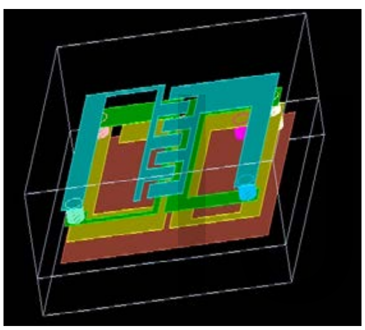

Fig. 3. 3D view of the proposed Multi-Layered PIFA designed in ADS

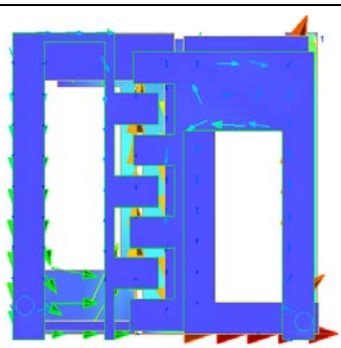

Fig. 4. Current distribution of the proposed Multi-Layered PIFA designed in ADS

5 PERFORMANCE MEASURES

5.1 Bandwidth

Bandwidth (BW) is defined as “the range of frequencies within which the performance of the antenna, with respect to some characteristics conforms to a specified standard”. Bandwidth is often expressed in terms of percent bandwidth, because the percent bandwidth is constant relative to frequency. If bandwidth was expressed in absolute units of frequency, it would be different depending upon the center frequency. The unit of bandwidth is Hertz (Hz).The formula for calculating BW is given in equation (1).

$$BW\ (\%) = \frac{f_h - f_l}{f_c} \ X100 \qquad (1)$$

Where, f_h= the highest frequency in the band with -3dB return loss value

f_l= the lowest frequency in the band with -3dB return loss value

f_c= the center frequency in the band

5.2 Efficiency

Efficiency is one of the most important antenna parameters. A high efficiency antenna has most of the power present at the antennas’ input radiated away. A low efficiency antenna has most of the power absorbed as losses within the antenna, or reflected away due to impedance mismatch. It can be expressed as the ratio of gain to directivity. It is shown in the equation (2) as,

$$Efficiency\ (\%) = \frac{gain}{directivity} X100 \qquad (2)$$

6 SIMULATION RESULTS AND DISCUSSIONS

7.1 Appendices

The triple band operation of the proposed PIFA can be clearly seen from the return loss plot i.e., $|S_{11}|$ shown in fig 5.The operating frequencies of the antenna at which it will operate are shown as a dip at 402MHz (MICS band), 2.45GHz (ISM band) and 433MHz (Third band). At 402MHz frequency range the antenna has a return loss of about -12.008 and at the 2.45GHz range it is having a return loss of nearly -8.263 while it is having a return loss of -23.849 at the frequency range of 2.45GHz.

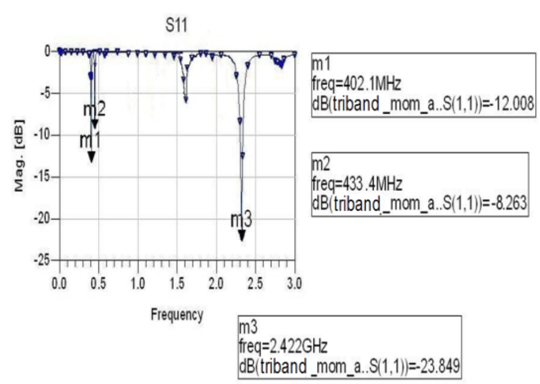

Fig. 5.(a) Return Loss plot of the three bands of the proposed Multi-Layered PIFA designed in ADS

Also at each of the three bands the antenna has separate set of gain, directivity and bandwidth. The gain for each band is given as 6.8652dB (MICS Band), 6.7832dB (ISM Band) and 6.8345dB (Third Band). Similarly, the directivity can be given as 4.922dB, 5.5363dB and 5.0375dB respectively.

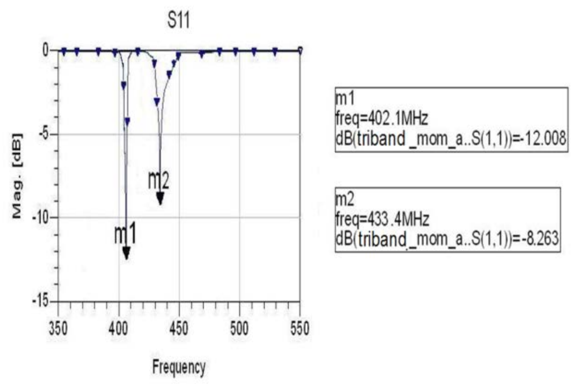

Fig. 5.(b) Return Loss plot of the first two frequencies of the proposed Multi-Layered PIFA designed in ADS

The radiation pattern for each band is given in fig 6. As PIFA is a variant of monopole antenna the radiation pattern obtained is having a single lobe. The bandwidth for MICS band is about 5MHz, for ISM band it is about 100MHz and finally for the third band the bandwidth is about 18MHz. Since, the MICS and Third bands are closely placed they both tend to have a smaller bandwidth when compared to that of the ISM band which ultimately falls in the 2.45GHz range. Also, the efficiency of the proposed antenna at each bands are found as 71.33% (MICS band), 81.61% (ISM band) and finally 73.7% (Third band). Efficiency and bandwidth of the antenna clearly predicts the performance of the proposed multilayer PIFA.

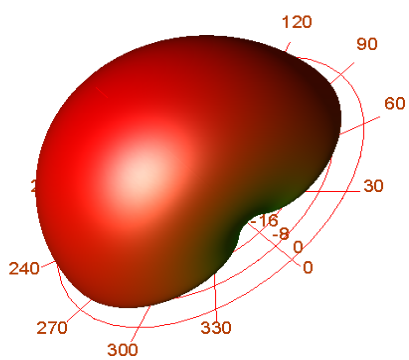

Fig. 6.(a) Radiation pattern for MICS band of the proposed Multi-Layered PIFA designed in ADS

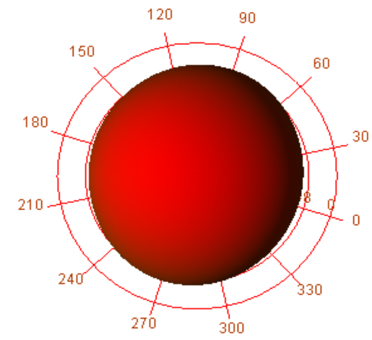

Fig. 6.(b) Radiation pattern for ISM band of the proposed Multi-Layered PIFA designed in ADS

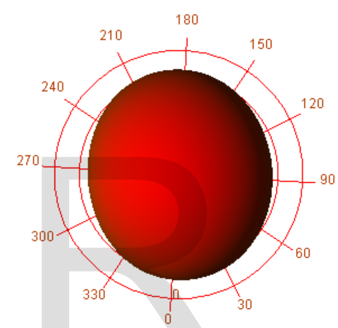

Fig. 6.(c) Radiation pattern for third band of the proposed Multi-Layered PIFA designed in ADS

4 Conclusion

In the present paper, a miniaturized bio-compatible Planar Inverted F Antenna (PIFA) that effectively supports triple band operation was proposed. The bands are MICS (402 MHz), ISM (2.45GHz) and third band (433MHz). The experimental data clearly predicts the antennas' triple band operation. The bandwidth of the antenna at each band is 5MHz (MICS band), 100MHz (ISM band) and 18MHz (third band). The efficiency of the antenna at MICS, ISM and the third bands are 71.33%, 81.61% and 73.7% respectively. This antenna proves to be an effective option for implantable devices to communicate with the outside world. It comes with an additional option that the device can be switched on when the receiver needs to communicate and it will be sleeping when it is not communicating. This can be availed by the use of the third band which operates at the frequency range of 433MHz and this was included so as to improve and extend the lifetime of the implant.

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