Gain enhancement of implanted antenna using lens and parasitic ring

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This Letter presents methods for improving the gain and efficiency of a microstrip patch antenna operating at 2.45 GHz implanted in the fat layer of the human body. Simulations using CST Microwave Studio are verified by measurements carried out in an anechoic chamber using a cut of fresh pork meat which has close electromagnetic characteristics to the human body. Using a glass lens and a parasitic ring placed on the skin the implanted antenna gain can be enhanced by almost 8.5 dB.

Introduction: Various implantable antenna designsfor medical applications have been reported [1–3]. Implantable antennas have been studied with a great interest as communication tools to transfer data to external receivers recording patient status. The antennas are embedded under the human skin to improve the quality of life of patients living with diseases such as diabetes, cardiac arrhythmia and retinitis pigmentosa, blood pressure, temperature etc. In most cases, the antenna should have a high gain to guarantee communication between the human body and the external devices but the body absorbs microwaves and hence significantly reduces the gain. Antenna gain enhancement methods for free space applications have been included using metamaterials at millimetre waves [4] or using a square aperture superstrate [5]. In [6], the performance of an implanted antenna was enhanced by up to 10 dB using a parasitic monopole and a matching printed grid surface placed on the skin of the patient. This Letter presents a simple way to improve the antenna gain using a parasitic ring and glass hemispherical lens placed on the skin.

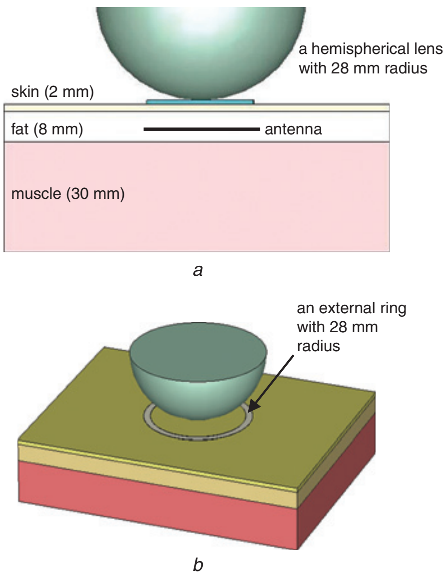

Fig. 1 *Geometry of proposed design*

a Antenna in simplified biological human body tissue model with hemispherical lens
b Implementation of ring with lens

Antenna design: A patch antenna was designed at 2.45 GHz as the implant antenna using CST Microwave Studio. The antenna is embedded inside the fat layer of a simplified biological tissue model which consists three layers of human tissues: skin, fat and muscle. The electrical properties of these body tissues at 2.45 GHz are listed in Table 1. The patch antenna was designed on 0.8-mm-thick FR4 substrate with dimensions of $34 \times 30 \times 0.8$ mm^3. A lens with a parasitic ring resonator (see Fig. 1) was placed on the skin. The microstrip antenna is embedded midway in the 8-mm-thick fat layer below the skin as shown in Fig. 1. The impedance matching and the radiating characteristics of the implanted antenna were simulated and measured. Measurements were carried out in an anechoic chamber and the patch antenna was embedded in a piece of pork meat with similar skin, fat and muscle dimensions to the human model in Fig. 1. Pork meat has similar but not identical electromagnetic characteristics to the human body. However, the thicknesses of the various layers in the meat sample were only approximate and the layers were not completely uniform in thicknesses.

Table 1: Electromagnetic prosperities of human body tissue at 2.45 GHz [7]

	Permittivity ε_r	Conductivity σ, S/m	Loss tangent δ
Skin	37.952	1.4876	0.28184
Fat	5.2749	0.10672	0.14547
Muscle	52.668	1.773	0.24205

Fig. 2 shows the simulated and measured reflection coefficient for the implanted antenna. Measurement and simulation are in good agreement with a bandwidth of about 70 MHz at 2:1 voltage standing wave ratio (VSWR). The simulated antenna gain was −9 dBi.

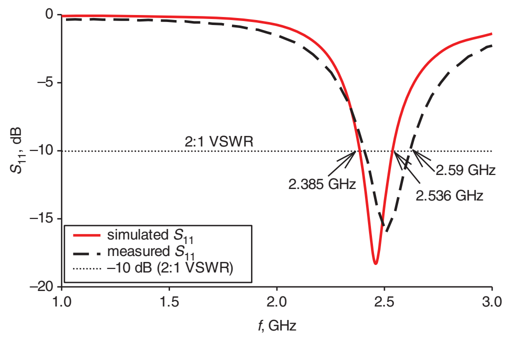

Fig. 2 *Measured against simulated reflection coefficient of implanted antenna*

Gain enhancement using lens: To improve the implanted antenna performance, an external hemispherical glass lens was designed and investigated using CST software, to be placed on the skin over the implanted antenna, see Fig. 1. The hemispherical lens material used was Pyrex glass of permittivity 4.82 and its radius was 28 mm. The simulation results showed that there was a significant gain enhancement when the hemispherical lens was implemented of about 6.5 dB.

Gain enhancement using parasitic ring: Studies were carried out to further improve the implanted antenna gain and efficiency by coupling the existing EM wave to an external parasitic ring. The ring had a radius of 28 mm and 3 mm wide and was printed on a layer of felt which has a thickness of 1.1 mm, relative permittivity of 1.38 and loss tangent of 0.02, see Fig. 1. It was found that placing the parasitic ring over the skin increased the gain by 2.12 dB compared with the antenna without parasitic ring.

Gain enhancement using ring and lens: The lens and parasitic ring were combined together. The simulations indicated that there should be a significant gain enhancement of almost 8.5 dB compared with the implanted antenna alone.

Measurements: The resonant frequency of the implanted antenna was not affected by placing the lens and/or parasitic element on the skin over the antenna. Radiation patterns were measured for three scenarios in the *E* and *H* planes: namely, the implanted antenna alone, the antenna with the lens and the antenna with lens and parasitic ring and these are plotted in Fig. 3 normalised to the lens/ring pattern. From Fig. 3, it is seen that the antenna gain improves by about 6 dB when the lens is placed and further improves by about 2 dB when combined with the parasitic ring, in line with the simulation results. The radiation pattern levels at the rear of the antenna are not accurate due to the stand used to support the antenna and meat sample. However, the specific absorption rate (SAR) for the antenna would be expected to decrease as more energy is effectively drawn out of the body. Numerically, results show an SAR reduction of up to 40%.

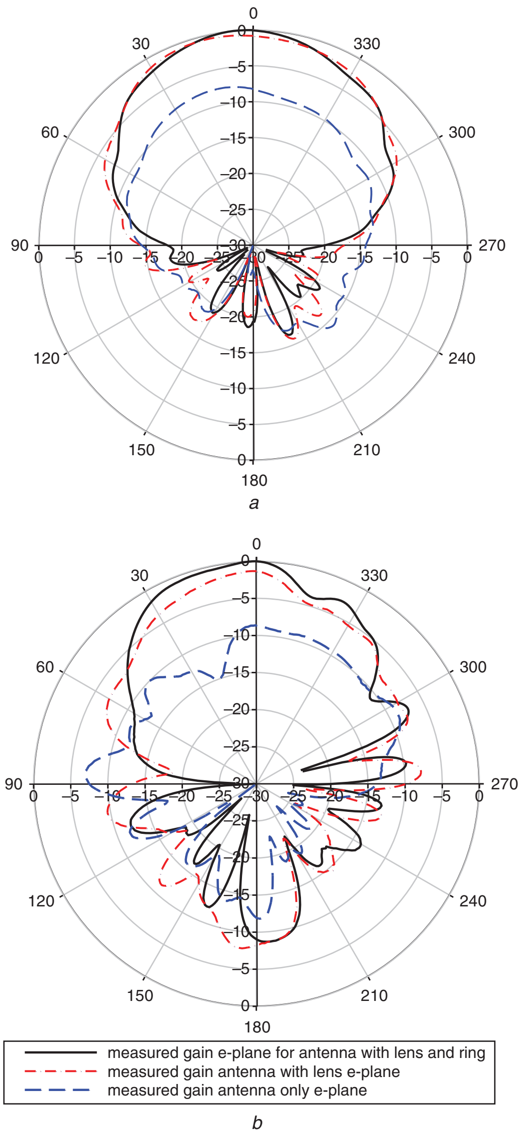

Fig. 3 *Measured radiation patterns in two planes for implanted antenna with/without lens and/or ring at 2.45 GHz*

a E-plane
b H-plane

Conclusions: This Letter has presented a simple method to improve the gain of the implanted antenna. Simulations and measurements show that a combined external hemispherical lens with a parasitic ring placed on the skin above the implanted antenna can increase antenna gain out of the body by up to 8.5 dB and hence provide better communication ability and reduced power consumption for the implant. Moreover, it can also reduce SAR values to satisfy the safety standards for medical implant applications.

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One or more of the Figures in this Letter are available in colour online.

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