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A HYBRID PLANAR INVERTED-F SPIRAL ANTENNA FOR IN-BODY WIRELESS AREA NETWORKS

Nowadays, in hyperthermia and biotelemetry, antennas implanted in a human are widely used. A number of numerical analyses and measurement setups should be evaluated in order to make practical use of antennas inside a human body, the resonance characteristics of the implanted antennas and their radiation signature outside the body. What most important is: antennas should be designed with an in-depth consideration given to its surrounding environment. A wireless body area network (WBAN) consists of nodes that communicate wirelessly and are located on or in the body of a person. One should have a good command of propagation loss within a human body for the development of WBAN for implants within a human body. The human body is a lossy medium hence a considerable attenuation of the waves, traveling from the transmitter to the receiver takes place.

In this paper, a hybrid planar inverted-F spiral antenna of 8 x 8 x 3 mm^3 is presented for the in-body operation in the 402...405 *MHz* Medical Implant Communication Service band. The antenna has a two-layer structure, involving a substrate and a superstrate. For reasons of compatibility with the human body, it is covered with a biocompatible silicon layer. When operating in-body, the proposed antenna has about 50 *MHz* bandwidth when the return loss (parametr S_{11}) is -10 *dB*. The simulated return loss is about -42 *dB* at 403 *MHz*. The calculations are employed in a three-layer model for the human tissues involved. A prototype was fabricated and measured.

Keywords: Wireless Body Area Network, telemetry system, implantable antenna, Archimedean spiral antenna, planar-inverted F antenna (PIFA), CST Microwave Studio.

Introduction. The concept of Wireless Body Area Networks (WBAN) involves modern technology that is promising in bringing health care into quite a new level of personalization. WBAN systems can easily be installed in medical environments. A WBAN consists of nodes that communicate wirelessly and can be located on or in the body of a person [1]. It helps doctors to get data on a patient's physiological state, such as temperature, blood pressure, and cardiac rate [2,3]. These physiological data are transferred to remote stations through medical gateway wireless boards. The gateway nodes are usually connected to the sensor nodes in the local area network.

It is crucial to understand that this high data rate technology has to be low power, on the one hand because of the possible close proximity to the body, which yields exposure issues, on the other hand, because of the limited battery power available.

There are two possible antenna environments in WBANs: in-body and on-body [4,5]. The in-body systems are especially challenging for several reasons.

First, the antenna should be designed, taking into consideration the properties of the body tissue. Factors such as high tissue conductivity, impedance matching, low power requirements, and biocompatibility play an important role in the design [6]. Second, the implanted sensor must be able to communicate with equipment external to the body. This means that the loss in the "body" channel becomes really crucial. Third, the implanted device should be small, thus the device must have an integrated antenna.

Some in-body antennas for the MICS band (402...405 *MHz*) have been investigated in [7-10]. In these studies, the characteristics of the antennas, such as input impedance, radiation pattern, and Septic Absorption Rate (SAR) around the antenna are presented. However, the antennas in these papers are still rather large, creating problems when they have to be implanted into the human body. For example, [7] proposes a rather large PIFA to be combined with a cardiac pacemaker for use in a MITS (Medical Implant Telemetry System). In [8], spiral and planar inverted-F (PIFA) antennas are presented. A six-layer model has been used (brain, CSF, Dura, bone, fat, and skin) in the simulations. The size of the spiral is 40 mm × 32 mm × 8 mm, and the size of the PIFA is 32 mm × 24 mm × 8 mm. This is still quite large. In [9], a dual band serpentine antenna, operating both in the MICS and ISM frequency bands is presented. The antenna is to be implanted under the skin. Its size is 22.5 *mm* x 22.5 *mm* x 2.5 *mm*. The realized gain of the antenna is -30 *dB* for a human skin thickness of 4 *mm*. In [10], two types of antennae, a spiral and a serpentine, are presented. Both antennae are of the size 26.6 *mm* x 16.8 *mm* x 6 *mm*. For a depth of 14 *mm* below the skin surface, the realized gains are -35 *dB* and -43 *dB*, respectively. Although there are also proposals for smaller implantable antennas, they are designed for the higher frequency bands [11-21]. An overview of the state-of-the-art on implantable antennae, together with their main characteristics, is given in Table 1.

Antenna design. The new type of Hybrid Planar Inverted-F Spiral Antenna for the MICS frequency band is presented in Fig. 1. It is based on a 2-arm Archimedean spiral antenna. This antenna type is widely used for its low profile, high efficiency, circular polarization, stable impedance characteristics, and very broad band [22,23]. One of the arms is an active element, fed by a probe, and the other arm is passive. The passive element is connected to the ground with a shorting pin. This feature is the same as in a Planar Inverted-F Antenna (PIFA). In order to guarantee biocompatibility, the Rogers RO3210 ($\varepsilon_r = 10.2$) material with 1.5 *mm* thickness has been used. The width of the microstrip line is 0.2 *mm*. The maximum radius of the active element $r_{acmax} = 3.45\ mm$ and minimum radius is $\mathrm{r_{acmin}} = 1.73\ mm$. The maximum radius of the passive element is $\mathrm{r_{psmax}} = 2.2\ mm$, and the minimum radius is $\mathrm{r_{psmin}} = 0.85\ mm$. The overall size of the antenna is 8 mm × 8 mm × 3 mm.

Table 1

Overview of the state-of-the-art on impantable antennas

Referance	Antenna type	Scope of action (S-simulation, M-measurement)	Substrate and Superstrate materials name and permittivity	Realized Gain (*dB*)	Depth (mm) Tissue	Bandwidth (*GHz*)	Min. Refl. (*dB*)	Pol.	Size (mm^3)	Size/λ_0
1	2	3	4	5	6	7	8	9	10	11
[7]	Planar Inverted F	S	$\varepsilon_r = 10.0$	-30.5	15*mm/muscle*	0.402...0.405	-40.1	Linear	39x30x9	0.053
[8]	Planar Inverted F	S and M	$\varepsilon_r = 10.2$		-----	0.402...0.405	-18	Linear	32x24x8	0.043
	Spiral	S	$\varepsilon_r = 10.2$		-----	0.402...0.405	-16	Ellipt.	40x32x8	0.054
[9]	Serpentine patch	S and M	Rogers RO3210, $\varepsilon_r = 10.2$	-30	4*mm/skin*	0.402...0.405	-20	Linear	22.5x22.5x2.5	0.03
[10]	Microstrip Spiral	S and M	Macor, ε_r =3.1	-35	14*mm/muscle*	0.402...0.405	-24	Ellipt.	26.6x16.8x6	0.036
	Microstrip Serpentine	S and M	Macor, ε_r =3.1	-43	14*mm/muscle*	0.402...0.405	-13	Linear	26.6x16.8x6	0.036
[11]	Planar Antenna	S	$\varepsilon_r = 10.2$	-15	-----	5...10	-15	Linear	9x6x2.7	0.225
[12]	Folded Dipole Wire	S and M	Glass coating, ε_r=5.0	-23.5	2*mm/ skin*	0.951...0.956	-18	Linear	20.3x0.8x0.8	0.064
[13]	Rectangular patch	S	FR-4 (Glass Epoxy Laminates)	-35	10*mm/ breast*	4.11...12	-10	Linear	20x10x1.5	0.67
[14]	Planar dipole	S and M	-----	-----	-----	3.1...10.6	-11	Linear	31x21.6x1.27	1.03

Continue of Table 1

1	2	3	4	5	6	7	8	9	10	11
[15]	Slot Dipole Conformal	S and M	Copper, Nickel, Polyimide, PDMS (Polydimethylisiloxan)	-24	-----	2,4...2,4835	-18	Linear	25.9x8.5x2.5	0.216
[16]	Spiral	S	Quartz	-----	-----	2.45±0.05	-16	Ellipt.	4x2.5x1.1	0.03
[17]	Cavity Slot	S and M	ε_r =2.17	-26.5	*4mm/ skin*	2.45±0.05	-52.77	Linear	4x2.8x1.6	0.03
[18]	Patch		Rogers RT6002	-46.5	*8mm/skin and fat*	31.5±0.315	-30	Linear	6x5.68x0254	0.63
[19]	Cavity Slot	S	-----	-24	*4mm/ skin*	2.45±0.05	-53.25	Linear	8.4x3.2x2.8	0.07
[20]	Loop Antenna	S	Rogers 6010	-20	-----	3.1...10.6	-10	Linear	10x7.5x1.091	0.23
[21]	Teardrop Antenna	S	-----	-40	*8mm/muscle*	3.1...10.6	-10	-----	7.5x2.4x2.4	0.172
	Hybrid Planar Inverted-F Spiral Antenna	S and M	Rogers RO3210, ε_r = 10.2	-42	*26 mm/ muscle, fat and skin*	0.402...0.405	-40	Linear	8x8x3	0.011

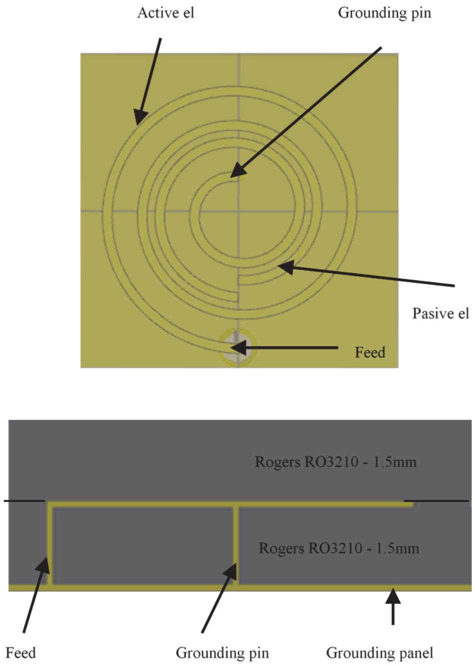


Fig. 1. Topology of Hybrid Planar Inverted-F Spiral Antenna

Characteristics of the antenna in the body. It is clear that the antenna parameters have to be evaluated in the presence of the human tissue. Therefore, during the design, a three layer human model was used [7]. In this model, the antenna is inserted into a layer of muscle covered with fat and skin, like in the human body, see Fig. 2.

Table 2

The dielectric permittivities and conductivities of tissues

Material	ε_r	σ
Skin	46.68	0.64 *S/m*
Fat	5.028	0.045 *S/m*
Muscle	42.8	0.65 *S/m*

The thicknesses of the tissues are: skin 2 *mm*, fat 2 *mm*, and muscle 30 *mm*. The S11 results of the antenna embedded within the three-layer model are presented in Fig. 3. The dielectric permittivities and conductivities of tissues are shown in Table 2 for 433 *MHz* [24].

Simulations have been done with CST Microwave Studio. As seen from Fig. 3, the -10 *dB* bandwidth is about 50 *MHz* (400...450 *MHz*). Fig. 4 shows the simulated gain (a) and radiation pattern (b) at 403 *MHz*. The simulated realized gain at a depth of 26 *mm* is -41.4 *dB* at 403 *MHz*.

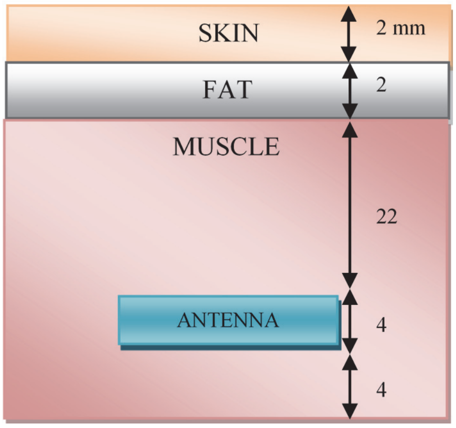


Fig. 2. Three-layer model for human tissue

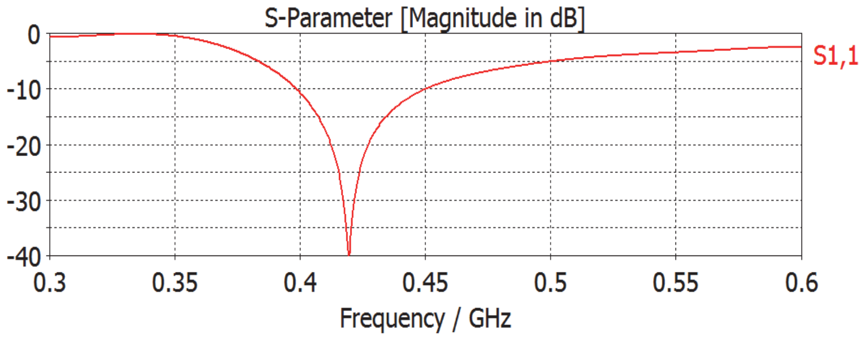
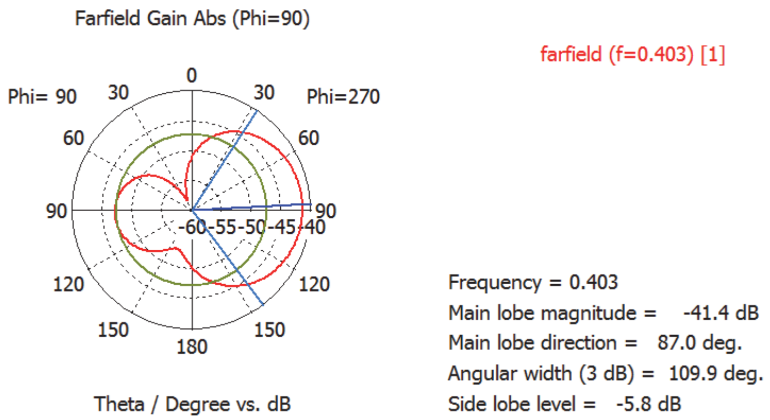
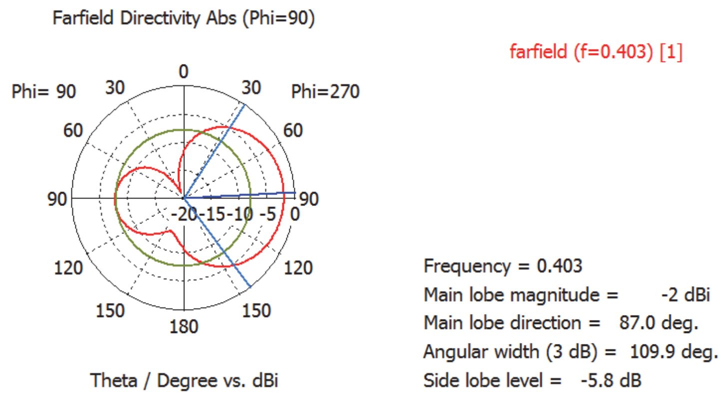


Fig. 3. Simulated S11 with three-layer model for the human tissue

Analyzing the results in Table 1 with the parameters of implantable antennae, it becomes evidently clear that there are a number of advantages. As a main requirement and advantage can be mentioned its small size: the antennae designed for 402...405 *MHz* frequency band have relatively big sizes, in the case when our antenna size is 8x8x3 *mm*. The simulation was made in a human tissue with 26 *mm* depth (muscle fat skin), in this case the antenna's S_{11} parameter is 40 *dB* (Voltage Standing Wave Ratio- VSWR =1.02).



a)



b)

Fig. 4. Realized gain (a) and radiation pattern (b)

Experimental results. The proposed antenna has been manufactured (see Fig. 5), and was measured in different environments in order to inspect its performance. As the antenna is not envisaged to work in an unechoic envirnment, no measerments were implemented in an unechoic environment.

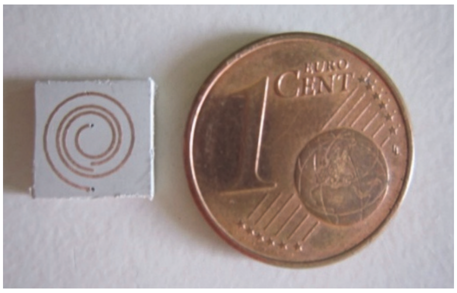


Fig. 5. Top side view of the Hybrid Planar Inverted-F Spiral Antenna

The return loss (parametr S_{11}) simulated and measured in free space is revealed in Fig. 6 (a). The agreement of the results validates the correctness of fabrication. Since the body tissue is removed from the model, a strong resonance appears at 1.895 *GHz* and 1.956 *GHz* in simulation and measurement, respectively. This small difference is due to a) the small tolerances during fabrication, b) the small inaccuracy of the measurement equipment (an HP 8510C), but mainly c) the influence of the testing cables since the antenna is extremely small compared with the wavelength.

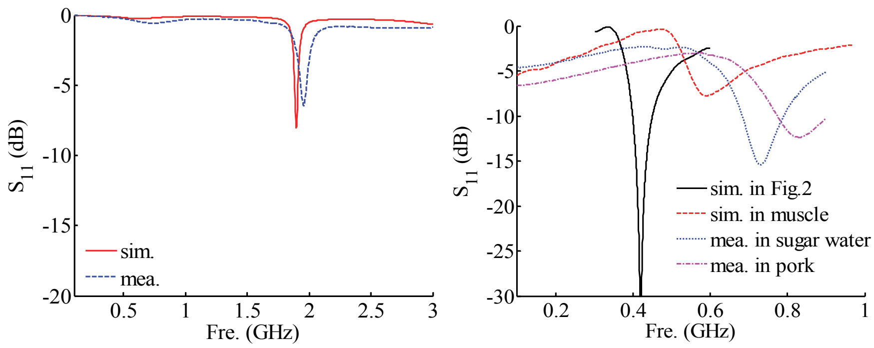
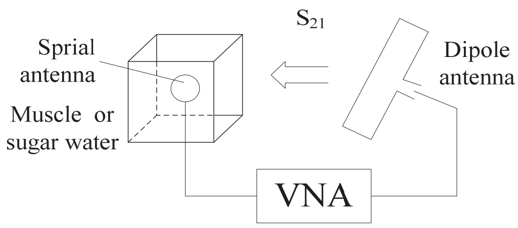


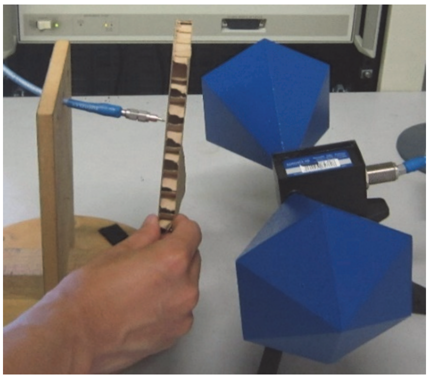
Fig. 6. Simulated and measured reflection coefficient, (a) in free space, (b) in several environments mimicking the body

After the free space measurements, the antenna was measured in two environments that aim at mimicking human tissue (see Fig. 6b). The first one consists of sugar water with the antenna encapsulated in a small plastic bag. A disposable cup with about 150 *mL* sugar water was used and the antenna was placed 3 *cm* below the surface of the water. A strong resonance appears at 730 *MHz* in the measurement. The second environment is a piece of pork with size ca. 5 x 5 x 5 cm^3 with the antenna located in the center. In this situation, the antenna shows a resonance at about 820 *MHz*.

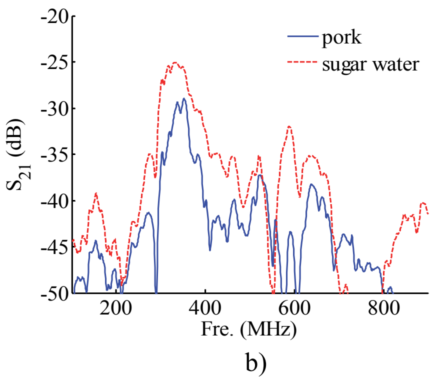
The differences between the measured results and the simulated results in Fig. 6b are mainly caused by the fact that it is very difficult to construct a meat muscle that will have exactly the same material parameters as the human body. It is known that it is often not possible to realize a measurement in a real human tissue. That is why, during the measurement period, the used phantom models consider organic materials equivalent to the human tissue, also using a liquid of water sugar, water salt, etc. [9-12,17].

The last measurement was the transmission between the proposed spiral antenna and a reference dipole antenna. The measurement setup is shown in Fig. 7(a), and the results are shown in Fig. 7(b). The environments were the same as before: sugar water and a piece of pork. The reference dipole antenna was placed about 40 *cm* away in the horizontal polarization.





a)



b)

Fig. 7. Transmission measurement, (a) measurement setup, (b) the measured result

The maximum transmission coefficient (S_{21}) is -25 *dB* for the sugar water and -29 *dB* for the pork around the operating frequency. Although the path loss is highly due to the loss in the environment, it is clear that the proposed antenna can still communicate with the dipole antenna.

Conclusion. In this paper, we have presented a hybrid planar inverted-F spiral antenna. The proposed antenna can be easily used in-body within the framework of a WBAN medical telemetry system, because of its small size (8 *mm* × 8 *mm* × 3 *mm*). The characteristics of the proposed antenna have been investigated in a three-layer human tissue model (muscle, fat and skin). The bandwidth is 50 *MHz* (400...450 *MHz*).

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Հ.Վ. ԱԲՐԱՀԱՄՅԱՆ

F ՏԻՊԻ ԻՆՎԵՐՍՄԱՄԲ ՄԻԿՐՈՇԵՐՏԱՎՈՐ ՀԻԲՐԻԴԱՅԻՆ ՊԱՐՈՒՐԱՁԵՎ ԱՆՏԵՆԱ ՀԵՌԱԲԺՇԿԱԿԱՆ ԱՆԼԱՐ ՑԱՆՑԵՐԻ ՀԱՄԱՐ

Ներկայումս հեռաբժշկական համակարգերում լայնորեն կիրառվում են մարդու օրգանիզմում տեղադրվող իմպլանտային սարքավորումները: Տվյալների հաղորդման համար այդ սարքավորումների բաղկացուցիչ մաս են կազմում իմպլանտային անտենաները: Կատարվել են մարդու մարմնի ներսում իմպլանտային անտենաների գործնական կիրառության համար մի շարք թվային վերլուծություններ և չափումներ, ինչպիսին է, օրինակ, ազատ տարածությունում իմպլանտային անտենաների ռեզոնանսային բնութագրերի և ճառագայթման հաճախականության ճշգրտումը: Ցույց է տրվել, որ իմպլանտային անտենաները պետք է նախագծել՝ հաշվի առնելով շրջակա միջավայրի բնութագրերը: Հեռաբժշկական անլար ցանցում (WBAN) իմպլանտային սարքավորումները, որոնք գտնվում են մարդու մարմնի վրա կամ մարմնի ներսում, հեռահար տվյալներ են փոխանցում: Մարդու մարմնի ներսում իմպլանտային անտենաների նախագծման համար անհրաժեշտ է ունենալ հիմնավոր գիտելիքներ մարդու օրգանիզմում ճառագայթի տարածման կորստի վերաբերյալ: Մարդու մարմինը կորստային միջավայր է, հետևաբար՝ տեղի են ունենում հաղորդչից դեպի ընդունիչ անցնող ազդանշանի զգալի մարումներ:

Ներկայացվել է մարդու մարմնում տեղադրվող բժշկական իմպլանտների կապի ծառայության (MICS) հաճախականային տիրույթի (402...405 *ՄՀց*), 8 x 8 x 3 *մմ*^{3} չափսերով F տիպի ինվերսմամբ միկրոշերտավոր հիբրիդային պարուրաձև անտենա: Իմպլանտային անտենան երկշերտ է՝ բաղկացած ենթաշերտից և հիմնական շերտից: Մարդու օրգանի հետ կենսական համատեղելիության ապահովման նպատակով այն պատված է կենսահամատեղելի սիլիկոնային շերտով: Մարմնի ներսում տեղադրելու դեպքում առաջարկվող իմպլանտային անտենան, մինչև -10 *դԲ* անդրադարձման գործակցի (անտենայի S_{11} բնութագիրը) դեպքում, ունի մոտ 50 *ՄՀց* հաճախականային թողարկման շերտ: Անտենայի անդրադարձման գործակիցը -42 *դԲ* է՝ 403 *ՄՀց* հաճախականության դեպքում: Հաշվարկները կատարվել են մարդու հյուսվածքների համար նախատեսված եռաշերտ մոդելով: Իմպլանտային անտենան մոդելավորվել է CST Microwave Studio մոդելավորման ծրագրով, պատրաստվել է, և կատարվել են չափումներ:

Առանցքային բառեր. հեռաբժշկական անլար ցանց (WBAN), հեռաբժշկական համակարգ, իմպլանտային անտենա, արքիմեդյան պարուրաձև անտենա, F տիպի ինվերսմամբ միկրոշերտավոր անտենա (PIFA), CST Microwave Studio:

Г.В. АБРААМЯН

МИКРОПОЛОСКОВАЯ ГИБРИДНАЯ СПИРАЛЬНАЯ АНТЕННА ИНВЕРТИРОВАННОГО ТИПА F ДЛЯ БЕСПРОВОДНЫХ СЕТЕЙ ТЕЛЕМЕДИЦИНЫ

В настоящее время импланты широко используются в гипертермии и биотелеметрии. Имплантированная антенна является неотъемлемой частью этих устройств для передачи данных. С целью практического использования антенн внутри человеческого тела проведена оценка ряда численных анализов и измерительных устройств, например, резонансных характеристик имплантированных антенн и спецификации частоты излучения вне тела. Показано, что антенны в первую очередь должны быть спроектированы с учетом окружающей среды. Сеть беспроводной сети (WBAN) состоит из узлов, которые передают информацию по беспроводной сети и расположены на теле человека или в нем. Чтобы спроектировать имплантированую антенну WBAN внутри человеческого тела, необходимо иметь представление о потере радиации в организме человека. Человеческое тело представляет собой среду с потерями, поэтому происходит значительное ослабление волн, проходящих от передатчика к приемнику.

Представлена микрополосковая гибридная инвертированная антенна F типа диапазона частот 402...405 *МГц* с медицинским имплантатом (MICS) размерами 8 x 8 x 3 *мм*^{3}. Антенна имеет двухслойную структуру, состоящую из подложки и главного слоя. Для обеспечения жизненно важной совместимости с человеческим телом антенна покрыта биосовместимым силиконовым слоем. Предлагаемая имплантированная антенна при вставке внутри тела имеет полосу частот около 50 *МГц* в случае потери коэффициента отражения до -10 *дБ* (параметр S_{11}). Коэффициент отражения антенны -42 *дБ* на частоте 403 *МГц*. В расчетах использована трехслойная модель для задействованных тканей человека. Изготовлен и измерен прототип микрополосковой гибридной инвертированной антенны F типа.

Ключевые слова: беспроводная телемедицинская сеть (WBAN), телемедицинская система, имплантированная антенна, архимическая спиральная антенна, инвертируемая микрополосковая антенна F типа (PIFA), CST Microwave Studio.