(This article was presented to the 28th National Chemistry Congress and submitted to JOTCSA as a full manuscript)

Preparation of a Human Skin-Mimicking Gels for *In Vitro* Measurements of the Dual-Band Medical Implant Antenna

Erdinc Doganci[1]*, Mustafa Hikmet Bilgehan Ucar[2]*, Adnan Sondas[2]

[1]Department of Chemistry and Chemical Processing Tech., Kocaeli University, Kocaeli, Turkey
[2]Department of Information Systems Engineering, Faculty of Technology, Kocaeli University, Kocaeli, Turkey

Abstract: The purposes of this study are to design a small size implantable antenna and to present a complementary recipe for a human skin-mimicking material for *in vitro* testing of implantable antennas operating at MICS (Medical Implant Communications Service, 402–405 MHz) and ISM (Industrial, Scientific and Medical, 2.4 GHz–2.48 GHz) bands. Approximate electrical properties of human tissues at MICS and ISM bands were obtained by mixing deionized water, sucrose, sodium chloride (NaCl), and poly(acrylic acid) (PAA or Carbomer) with different content percentages. To test the antenna *in vitro*, skin mimicking gels were made that to show electrical properties real skin tissue (relative permittivity (ε_r) and conductivity (σ)) for the operation frequencies of ISM and MICS bands. For the antenna performance evaluations the measurements of the antenna (return loss (S_{11})) have been performed by placing in to the skin mimicking gels. The measurements were taken in the 1 GHz - 5 GHz frequency band. The measurement and simulation results are quite good agreement except some discrepancy in S_{11} levels and frequency bands.

Keywords: Skin-mimicking gel; carbomer; implantable antennas; MICS-band; ISM-band.

Submitted: July 22, 2016. **Revised:** August 17, 2016. **Accepted:** October 14, 2016.

Cite this: Doğancı E, Uçar M, Sondas A. Preparation of a Human Skin-Mimicking Gels for In Vitro Measurements of the Dual-Band Medical Implant Antenna. JOTCSA. 2006;3(3):583–96.

DOI: 10.18596/jotcsa.72855.

*Corresponding authors. edoganci@kocaeli.edu.tr; Tel: +90 262 349 43 (E.D.) and mhbucar@kocaeli.edu.tr; Tel: +90 262 303 22 61 (M.H.B.U.).

INTRODUCTION

Recently, wireless telemetric systems have attracted much attention because of the needs for enable early detection of diseases and continuous monitoring of physiological parameters such as oxygen level, sucrose level, heart rate, blood pressure, and bodily temperature in medical technology (1-5). Antennas are crucial parts of these telemetric systems because they supply communication between the patient and the external environment. Implantable antennas have recently been getting extensive interest in several wireless data telemetry applications such as cardiac pacemakers, brain pacemakers, nerve signal recorders, artificial eyes, cochlear implants, implantable drug pumps, and glucose sensors with the developments in telecommunications and telemedicine (5-8). However, designing antennas for implantable telemetric systems is a quite challenging problem for researchers because of impedance matching, biocompatibility, low power requirements, antenna miniaturization, and high losses in the tissue. These factors play a vital role in the design for overall system reliability (9-14). In addition, the body tissue temperature and placing the antenna inside a biological tissue can be added significant complexity to the problem. Because the antenna resides in the human body consisting of many loss media with a very high permittivity such as skin, muscle, blood, and bone. The human body has electrical properties (such as relative permittivity and conductivity) that are frequency dependent (15-17). For this reason, antenna placed in the human body is designed as based on electrical properties of the human tissue.

Commonly, antenna engineers developed their antenna designs according to the specifications (such as operating bands, size, *etc*.) in simulators, and here we use Computer Simulation Technology (CST) Microwave Studio. After obtaining the optimum antenna design, it should be measured via testing devices using the Vector Network Analyzer (VNA) to observe radiation parameters [S_{11}, Antenna Gain (G) and Directivity (D)]. The most critical antenna parameter is the S_{11} both in simulation and measurement. In the S_{11} measurements, the VNA transmits a small amount of power to your antenna and measures how much power is reflected back ($S_{11}=10\ \log_{10}\ (P_i/P_r)$ (in decibels; dB), here P_i, P_r stand for incident and delivered power, respectively) to the VNA, hence it is known as the reflection coefficient. For example if the S_{11}=0 dB, then all the power (100%) is reflected from the antenna and nothing is radiated, or if the S_{11}=-10 dB, then ~30% is reflected from the antenna and 70% is radiated at the designed frequency band. In the antenna radiation considerations, it is desired that almost the entire power fed to the antenna should be radiated at the resonant (operation) frequency. In this context, in the antenna's S_{11} performance evaluations, $|S_{11}|<-10$ dB standard (with 50Ω system impedance) is sufficient [18].

Moreover, measurement set up should be same as the simulations. The numeric analysis of the implant antennas is executed in a tissue medium which has electrical properties of the skin (ε_s, σ_s). In this context, to provide realistic measurement set up, there are two possible ways to create the medium which the implant antenna operates. One uses real tissue (*in vivo*), the other uses skin-mimicking gels (*in vitro*). *In vivo* measurement is not practical during the design process and it also needs some ethical permission from the Food and Drug Administration (FDA). Conversely, *in vitro* measurement is crucial to verify the proper of these antennas. Hence we used skin-mimicking gels (*in vitro*) in antenna measurements. *In vitro* testing of these antennas requires the development of materials that can mimic the electrical properties of the human skin. Recently, an implantable dual-band antenna operating at MICS and ISM bands was designed and fabricated for in body wireless data telemetry [13].

The aim of this study is to propose a complementary for human tissue gels that mimic both relative dielectric constant (ε_r) and conductivity (σ) of the human tissue at both MICS and ISM bands in the light of recent studies. Sucrose, NaCl, deionized water, and carbomer were used to formulate the desired gels. The gels were prepared via mixing different percentages of different biocompatible chemicals for tissue samples in the literature (13, 17, 19). In the literature, agarose, a polysaccharide polymer material, was widely used to ensure the formation of gel of the mixture and in our study we used carbomer instead of agarose for this aim. Carbomer is a generic name for homopolymer of acrylic acid having high molecular weight, which is cross-linked, or bonded, with any of several polyalcohol allyl ethers. In our study, we have focused on the use of these polymers due to very good mucoadhesive properties. Carbomer, which is a type of anionic polymer, is water-soluble at neutral pH. It is well known as anionic polyelectrolyte that the side chains of PAA would lose their protons and obtain negative ions. It is recognized as a binder when placed in water due to its ability to absorb water and swell into many times their original size and weight. Carbomers are frequently used as thickening, dispersing, suspending, and emulsifying agents in paints, pharmaceuticals, cosmetics, and personal care products including skin, hair, nail, makeup products, as well as dentifrices [20]. Also, due to obtainable biocompatible matrices for medical applications, these polymers are convenient such as gels for skin care or skin disease treatment products. Recently, for the development of polymeric matrices, investigations aimed towards the clarification of the conformational changes of the polymeric gel during neutralization, light irradiation, and embedment of gold nanoparticles [21, 22]. To the best of our knowledge, this is the first report on the implantable antenna application of a human skin mimicking gel containing carbomer as polymer to solidify the liquid blend to simplify measurements. These gels were created by adding Carbomer in the liquid solution and waiting the blend until a clear solution forms overnight. Thus, they will not be dissolved in one-another during *in vitro* testing. There was a very good agreement between the electrical properties of the proposed material and the human skin at ISM and MICS bands.

MATERIALS AND METHODS

Materials

Carbomer (Rheocare C Plus, commercial, BASF), Sodium chloride (NaCl, Aldrich, ≥99%), water (deionized, Sigma-Aldrich) and sucrose (commercial) were used as received.

Physical Measurements

Numeric analysis of the proposed antenna design and the skin mimicking gels were carried out using CST Microwave Studio simulation software which is a well-known electromagnetic (EM) simulator based on Finite Integration Technique (FIT) in the time domain. Also return loss (S_{11}) measurements of the implant antennas in the proposed skin mimicking gel medium were carried out using Rohde & Schwarz ZVB8 Vector Network Analyzer (VNA).

Preparation of Human Skin-Mimicking Gel

Table 1 shows the amount and percentages of content of gels used to build the proposed complementary recipes for human skin-mimicking materials for the MICS and ISM bands. Firstly, sucrose, deionized water and NaCl (only MICS band) were added to an 80-mL beaker equipped with a magnetic stirrer and stirred for 20 minutes. These human skin-mimicking gels were formed by adding dry carbomer in liquid solution. A clear solution was obtained by heating the mixture at 80 °C for 1 h and then the mixtures were solidified by cooling to room temperature to simplify measurements. The individually prepared human skin-mimicking gels for MICS and bands ISM are shown in Figure 1a and Figure 1b, respectively.

Table 1. Suggested ingredients for human skin tissue.

Frequency	Ingredients (%)
ISM	Sucrose 53%, Deionized water 47%, Carbomer for 0.5 g in 40 mL solution
MICS	Sucrose 56.18%, NaCl 2.33%, Deionized water 41.49%, Carbomer for 0.5 g in 40 mL solution

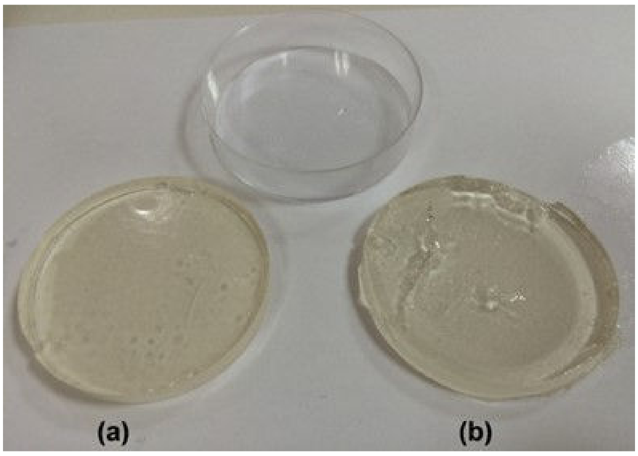


Figure 1. The individually prepared human skin-mimicking gels according to suggestions listed in Table 1 for the concerned frequency bands of (a) MICS, (b) ISM gel form view.

Design of Microstrip Implantable Antenna

The microstrip implantable antenna which is shown in Figure 2 was designed using concentric square split-ring elements with inserting a metallic pad between the rings. Also note that the antenna is excited via SMA type coaxial connector.

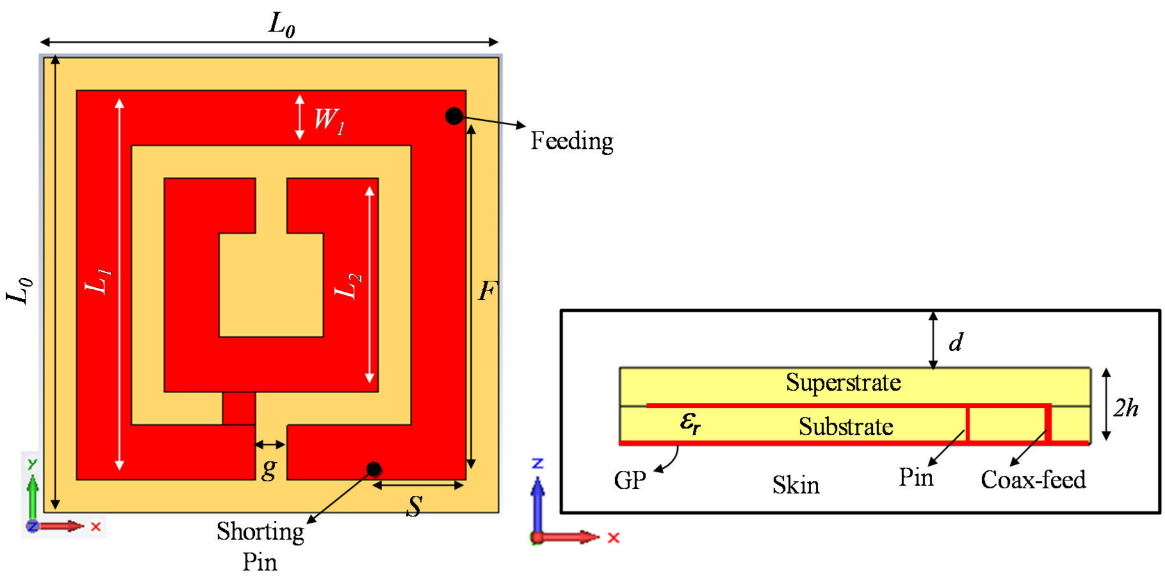


Figure 2. The proposed microstrip implantable antenna design: (L_0=14, L_1=12, W_1=1.7, g=1, S=2.8, F=11.2, h=1.27 (all in mm), ε_r=10.2).

The radiating elements were placed on a ground backed thin substrate (Rogers RO3210) with a thickness of h=1.27 mm and electrical properties of ε_r=10.2 and tan δ=0.003. Besides, the outer ring element and the ground plane were connected each other by means of shorting-pin with a radius of 0.2 mm. The radiating element is sandwiched between two substrate layers to prevent the connection between tissue and the metallic elements. The proposed antenna located in the tissue covers the two bands, namely MICS (402 – 405 MHz) and ISM (2.4 – 2.48 GHz) bands. We also note that numerical analysis of the proposed implantable antenna design and the skin mimicking gels were carried out using CST Microwave Studio simulation software which based on finite Integration technique in the time domain.

The simulated return loss (S_{11}) characteristic of the implant antenna is given in Figure 3. As can be seen, the antenna provides an impedance bandwidth of 30 MHz (392-422 MHz) and 300 MHz (2.25-2.55 GHz) covering the MICS and ISM standards respectively. Note that S_{11} ≤-10 dB standard with 50Ω system impedance is considered.

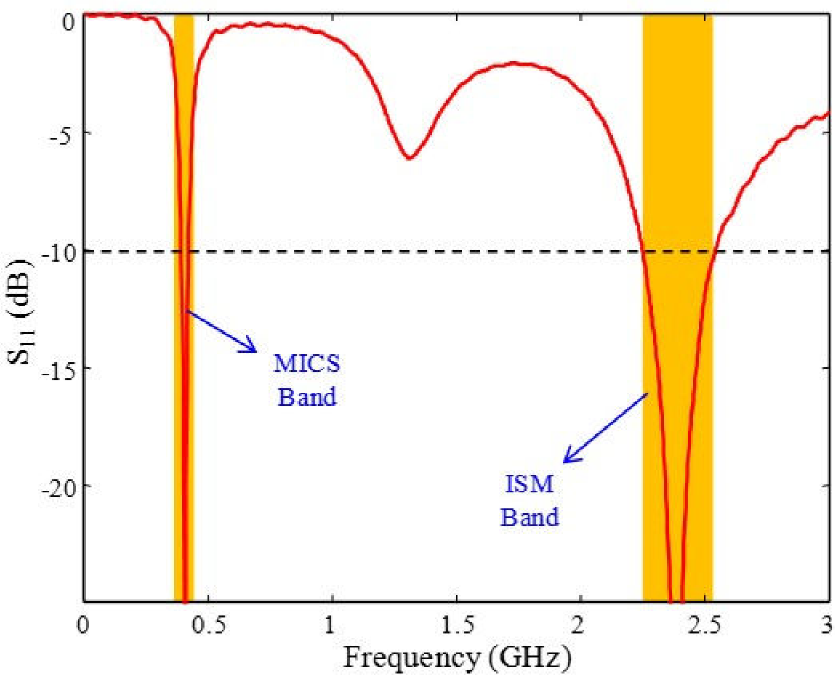


Figure 3. The simulated return loss characteristics of the implantable antenna design.

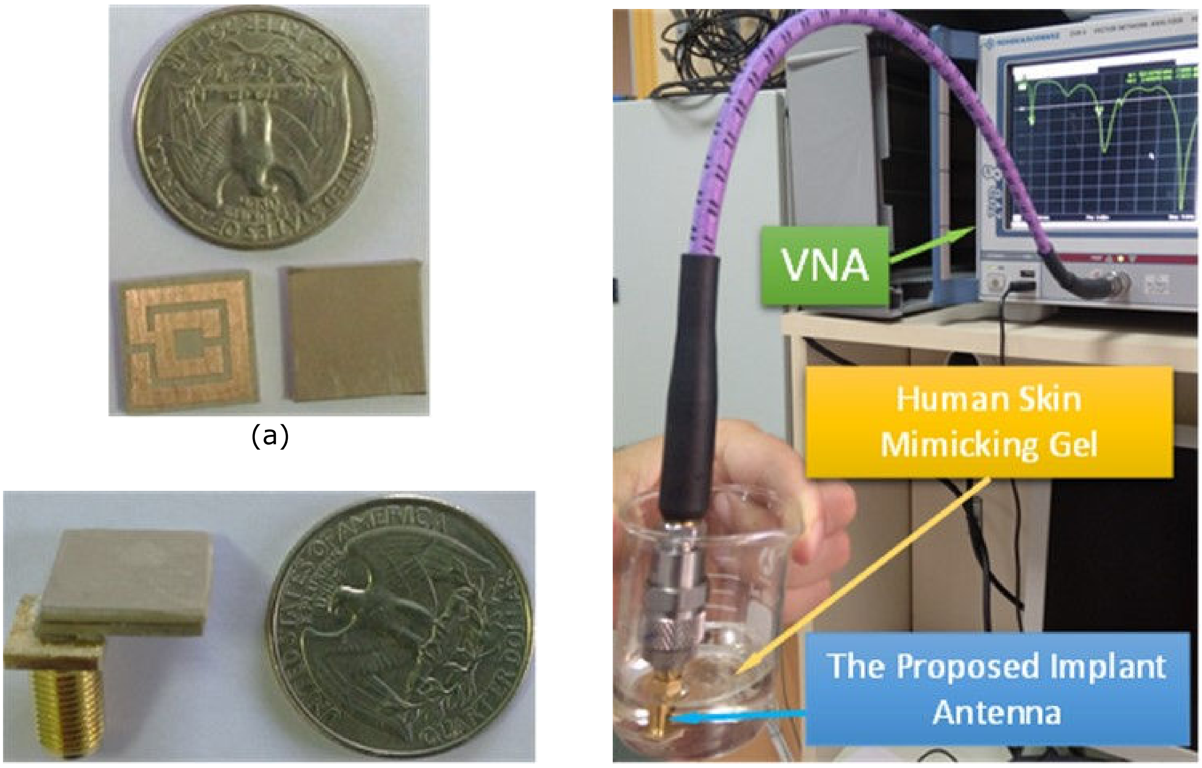
RESULTS AND DISCUSSIONS

Characterization of Human Skin-Mimicking Gel

The numeric analysis of the implant antennas is realized in a tissue medium which has electrical properties of human skin (ε_s, σ_s). In this context, we used human skin-mimicking gels which are significant for *in vitro* testing of implantable systems to provide realistic measurement for the fabricated antenna. For *in vitro* testing of dual band implantable systems, characterizations of human tissue-mimicking gels examine the interaction between tissues and electromagnetic waves. For preparation of these gels, many recipes have been proposed in the literature and used in SAR measurements, cardiac pacemakers, microwave imaging systems, implantable antennas, and ultrasound measurements (23-29). The characterization of skin-mimicking materials must be made for *in vitro* measurements because the implanted antenna must work through the human skin. To create human skin-mimicking gels we used materials which are usually made of low toxic, edible, and easily obtainable substances such as sucrose (sucrose), salt (NaCl), carbomer, and deionized water. Sucrose is used to lower the dielectric constant of water whereas salt is used to increase the conductivity of the mixture. ε_r decreases significantly as sucrose concentration increases in the mixture. Besides, there is only a small increase in σ as the sucrose concentration increases and also an increase in NaCl content concentration decreases ε_r and significantly increases σ [30, 31]. Carbomer has been used as a gelling agent. To see the practical performance of the antenna, the gels were prepared by mixing different content percentages of different chemicals for human tissue samples suggested in the references [32, 33].

Results of the Measurement

We fabricated the antenna design and located in two different skin mimicking gel at MICS and ISM bands for the purpose of realistic antenna measurement. The fabricated antenna and the measurement set up are given in Figure 4. As seen, the fabricated antenna is located in the gel and the return loss measurements were carried out using Rohde & Schwarz ZVB8 VNA.



(a) (b) (c)

Figure 4. (a) The fabricated layers (b) perspective view of the implant antenna design and (c) the S_{11} measurement set up.

The measured and the simulated return loss characteristics of the implant antenna are displayed in Figure 5. As seen in the figure, the measurement and simulation results agree quite well except some frequency and S_{11} level differences mainly due to fabrication, material tolerances, and unknown electrical properties of skin-mimicking gel. Of importance is that for the realistic antenna measurements individually prepared gels for the MICS and ISM operation bands are sufficient. On the other hand, those results show the estimated dual-band (MICS and ISM bands) performance.

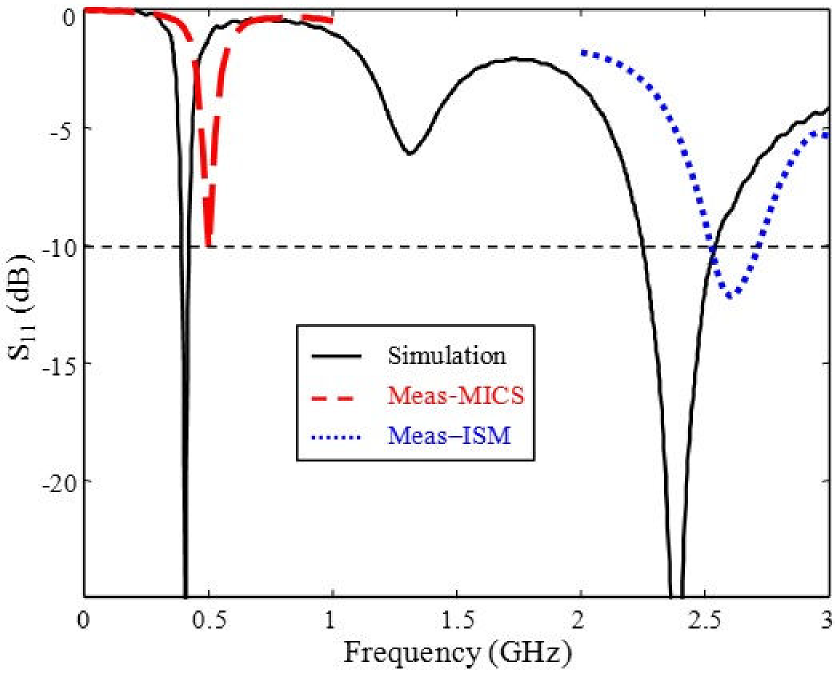


Figure 5. The return loss (S_{11}) characteristics of the antenna: simulation versus measurement.

CONCLUSION

In this study, we prepared two different human skin-mimicking gels and designed a small size dual band implantable micro-strip antenna for medical applications covering ISM and MICS bands in the light of recent studies. We developed gels to mimic the electrical properties of real human skin tissue and used these gels for *in vitro* testing of the proposed dual-band implantable antenna. The recipe for the skin mimicking gels is composed of carbomer, sucrose, NaCl, and deionized water at several percentages. We note that numerical analysis of the proposed antenna carried out using CST Microwave Studio software. It has been shown that the measurement and simulation results agree with each other except for some discrepancy in S_{11} levels and frequency bands. These differences mainly due to antenna fabrication, material tolerances and unknown electrical properties of skin-mimicking gel. Currently, we are working to acquire perfect complementary recipe using alternative materials instead of sucrose, carbomer, agarose, *etc*. to match both the ε_r and σ of human skin for the ISM and MICS bands.

ACKNOWLEDGMENTS

This work has been supported by the Scientific Research Projects Unit of Kocaeli University (KOU-2015-87HD).

REFERENCES

[1] Asili M, Green R, Seran S, Topsakal E. A small implantable antenna for medradio and ISM bands. IEEE Antennas and Wireless Propagation Letters. 2012, 11: 1683-1685. DOI:10.1109/LAWP.2013.2241723.

[2] Beach RD, Conlan RW, Godwin MC, Moussy F. Towards a miniature implantable in vivo telemetry monitoring system dynamically configurable as a potentiostat or galvanostat for two- and three-electrode biosensors. IEEE Trans. Instr. Meas. 2005, 54 (1): 61-72. DOI:10.1109/TIM.2004.839757.

[3] Beach RD, Kuster FV, Moussy F. Subminiature implantable potentiostat and modified commercial telemetry device for remote glucose monitoring. IEEE Trans. Instr. Meas. 1999, 48 (6): 1239–1245. DOI:10.1109/19.816143.

[4] Yilmaz T, Karacolak T, Topsakal E. Characterization and testing of a skin mimicking material for implantable antennas operating at ISM band (2.4 GHz-2.48 GHz). IEEE Antennas and Wireless Propagation Letters. 2008, 7: 418-420. DOI:10.1109/LAWP.2008.2001736.

[5] Furse CM. Design of an antenna for pacemaker communication. Microw. RF. 2000, 39 (3): 73-76. URL: http://www.eng.utah.edu/~cfurse/Publications/Micorwaves%20and%20RF%20paper.pdf.

[6] Cavuoto J. Neural engineering's image problem. IEEE Spectr. 2004, 41 (4): 32-37. DOI: 10.1109/MSPEC.2004.1279191.

[7] Schuster JW, Luebbers RJ. An FDTD algorithm for transient propagation in biological tissue with a Cole-Cole dispersion relation. Antennas and Propagation Society International Symposium, IEEE.1998, 4: 1988-1991. DOI:10.1109/APS.1998.701597.

[8] Weir RF, Troyk PR, DeMichele G, Kuiken T. Implantable myoelectric sensors (IMES) for upper-extremity prosthesis control-preliminary work. Engineering in Medicine and Biology Society, Proceedings of the 25th Annual International Conference of the IEEE, 2003, 2: 1562-1565. DOI:10.1109/IEMBS.2003.1279658.

[9] Budinger TF. Biomonitoring with wireless communications. Annual Review of Biomedical Engineering. 2003, 5 (1): 383-412. DOI: 10.1146/annurev.bioeng.5.040202.121653.

[10] Gosalia K, Humayun MS, Lazzi G. Impedance matching and implementation of planar space-filling dipoles as intraocular implanted antennas in a retinal prosthesis. IEEE Transactions on Antennas and Propagation. 2005, 53 (8): 2365-2373. DOI:10.1109/TAP.2005.852514.

[11] Jaehoon K, Rahmat-Samii Y. Implanted antennas inside a human body: simulations, designs, and characterizations. IEEE Transactions on Microwave Theory and Techniques. 2004, 52 (8): 1934-1943. DOI:10.1109/TMTT.2004.832018.

[12] Karacolak T, Cooper R, Topsakal E. Electrical properties of rat skin and design of implantable antennas for medical wireless telemetry. IEEE Transactions on Antennas and Propagation. 2009, 57 (9): 2806-2812. DOI:10.1109/TAP.2009.2027197.

[13] Karacolak T, Hood AZ, Topsakal E. Design of a dual-band implantable antenna and development of skin mimicking gels for continuous glucose monitoring. IEEE Transactions on Microwave Theory and Techniques. 2008, 56 (4): 1001-1008. DOI:10.1109/TMTT.2008.919373.

[14] Soontornpipit P, Furse CM, You Chung C. Design of implantable microstrip antenna for communication with medical implants. IEEE Transactions on Microwave Theory and Techniques. 2004, 52 (8): 1944-1951. DOI:10.1109/TMTT.2004.831976.

[15] Karacolak T. Implantable antennas for wireless data telemetry: Design, simulation, and measurement techniques. Electrical and Computer Engineering, Mississippi State University, Mississippi State, Mississippi, 2009:1-123. ISBN: 9781109516692.

[16] Topsakal E. Antennas for medical applications: Ongoing research and future challenges. Electromagnetics in Advanced Applications, 2009. ICEAA '09. International Conference on, 2009: 890-893.DOI:10.1109/ICEAA.2009.5297319.

[17] Zengin F, Akkaya E, Turetken B, San SE. Design and realization of ultra wide-band implant antenna for biotelemetry systems. General Assembly and Scientific Symposium, 2011 XXXth URSI, 2011: 1-4. DOI:10.1109/URSIGASS.2011.6051320.

[18] Bird TS. Definition and misuse of return loss. IEEE Antennas and Propagation Magazine. 2009, 51 (2): 166-167. DOI: 10.1109/MAP.2009.5162049.

[19] Yilmaz T, Characterization of tissue mimicking materials for testing of implantable and on body antennas. Electrical engineering, Mississippi State University, Mississippi, 2009: 1-69. URL: http://gradworks.umi.com/14/67/1467229.html.

[20] Orwoll RA, Yong CS. Poly(acrylic acid). J.E. Mark (Ed.) Polymer Data Handbook. Oxford University Press, Inc., Oxford, England, 1999: 252–253. ISBN: 978-0195107890.

[21] Todica M, Pop CV, Stefan R, Nagy M, Garabagiu S. Spectroscopic investigation of some poly (acrylic acid) gels with embedded gold nanoparticles. Studia Universitatis Babes-Bolyai, Chemia. 2015, 60 (1): 19-28. URL: http://chem.ubbcluj.ro/~studiachemia/issues/chemia2006_2015/Chemia2015_1.pdf.

[22] Todica M, Stefan R, Pop CV, Papuc I, Stan O, Olar EL. UV-VIS and fluorescence investigation of some poly(acrylic) gels. Studia Universitatis Babes-Bolyai, Chemia. 2015, 60(1):7-17.URL: http://chem.ubbcluj.ro/~studiachemia/issues/chemia2006_2015/Chemia2015_1.pdf.

[23] Ballen M, Kanda M, Chou CK, Q. Balzano. Formulation and characterization of tissue simulating liquids used for SAR measurement. Proc. 23rd Annu. Bioelectromagn. Soc. Meeting. 2001, 14 (3): 80.

[24] Chou CK, Chen GW, Guy AW, Luk KH. Formulas for preparing phantom muscle tissue and various radio frequencies. Bioelectromagn. 1984, 5: 435-441. DOI:10.1002/bem.2250050408.

[25] Fukunaga K, Watanabe S, Yamanaka Y. Dielectric properties of tissue equivalent liquids and their effects on specific absoption rate. IEEE Trans. Electromagnetic Compatibility. 2004, 46 (1): 126-129. DOI:10.1109/TEMC.2004.823624.

[26] Lazebnik M, Madsen EL, Frank GR, Hagness SC. Tissue-mimicking phantom materials for narrowband and ultrawideband microwave applications. Phys.Med. Biol. 2005, 50: 4245–4258. DOI:10.1088/0031-9155/50/18/001.

[27] Peyman A, Gabriel C. Tissue equivalent liquids for SAR measurement at microwave frequencies. Proc. 24th Annu. Bioelectromagn. Soc. Meeting. 2002, P-53: 184–185.

[28] Stuchly SS. Specific absorption rate distributions in a heterogeneous model of the human body at radio frequencies. Nat. Tech. Inform. Ser. PB 87-201 356/AS. 1987, 89. URL: https://nepis.epa.gov/Exe/ZyPDF.cgi/2000TRUE.PDF?Dockey=2000TRUE.PDF.

[29] Stuchly SS, Kraszewski A, Stuchly MA, Hartsgrove G, Spiegel RJ. RF energy deposition in a heterogeneous model of man:Far-field exposures. IEEE Trans. Biomed. Eng. 1987, BME-34 (12): 951–957. DOI:10.1109/TBME.1987.325934.

[30] Kumar SA, Shanmuganantham T. Design and analysis of implantable CPW fed bowtie antenna for ISM band applications. AEU - International Journal of Electronics and Communications. 2014, 68 (2): 158-165. DOI:10.1016/j.aeue.2013.08.003.

[31] Xia W, Saito K, Takahashi M, Ito K. Performances of an implanted cavity slot antenna embedded in the human arm. IEEE Transactions on Antennas and Propagation. 2009, 57 (4): 894-899. DOI:10.1109/TAP.2009.2014579.

[32] Karacolak T, Topsakal E. Electrical properties of nude rat skin and design of implantable antennas for wireless data telemetry. Microwave Symposium Digest, IEEE MTT-S International. 2008, 907-910. DOI:10.1109/MWSYM.2008.4632980.

[33] Kiourti A, Nikita KS. Miniature scalp-implantable antennas for telemetry in the mics and ism bands: design, safety considerations and link budget analysis. IEEE Transactions on Antennas and Propagation. 2012, 60 (8): 3568-3575. DOI:10.1109/TAP.2012.2201078.

Türkçe Öz ve Anahtar Kelimeler

Çift Bantlı Medikal İmplant Antenin *In Vitro* Ölçümleri için İnsan Derisini Taklit Eden Jellerin Hazırlanması

Erdinc Doganci, Mustafa Hikmet Bilgehan Ucar, Adnan Sondas

Öz: Bu çalışmanın amaçları küçük boyutlu ve vücuda yerleştirilebilir bir anteni tasarlamak ve MICS (Medikal İmplant Haberleşme Servisi, 402-405 MHz) ve ISM (Endüstriyel, Bilimsel ve Medikal, 2,4 GHz-2,48 GHz) bantlarında çalışan, vücuda yerleştirilebilir antenlerin *in vitro* testi için insanda deriyi taklit eden bir malzeme oluşturan bir reçete sunmaktır. MICS ve ISM bantlarında insan dokusunun yaklaşık elektriksel özellikleri deiyonize su, sakkaroz, sodyum klorür (NaCl) ve poli(akrilik asit) (PAA veya carbomer) içeriği farklı yüzdelerde karıştırılarak incelenmiştir. Anteni *in vitro*'da denemek için, deriyi taklit eden jeller yapılmıştır, böylece gerçek deri dokusunun elektriksel özellikleri taklit edilmiştir (relatif permittivite (ε_r) ve kondüktivite (σ)). Çalışma ISM ve MICS bantlarının çalışma frekanslarında yürütülmüştür. Anten performansı değerlendirmesi için, anten deri taklit eden jellerin içine yerleştirilerek ölçümler (geri dönüş kaybı (S_{11})) yapılmıştır. Ölçümler 1 GHz – 5 GHz frekans bandında alınmıştır. Ölçüm ve simülasyon sonuçları çok iyi uyum göstermektedir, yalnızca S_{11} seviyeleri ve frekans bantlarında bir miktar uyumsuzluk görülmüştür.

Anahtar kelimeler: Deriyi taklit eden jel; carbomer; vücuda yerleştirilebilir antenler; MICS-bandı; ISM-bandı.

Gönderme: 22 Temmuz 2016. **Düzeltme:** 17 Ağustos 2016. **Kabul:** 14 Ekim 2016.