Effect of Thickness Inhomogeneity in Fat Tissue on In-Body Microwave Propagation

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***Abstract*—In recent studies, it has been found that fat tissue can be used as a microwave communication channel. In this article, the effect of thickness inhomogeneities in fat tissues on the performance of in-body microwave communication at 2.45 GHz is investigated using phantom models. We considered two models namely concave and convex geometrical fat distribution to account for the thickness inhomogeneities. The thickness of the fat tissue is varied from 5 mm to 45 mm and the *Gap* between the transmitter/receiver and the starting and ending of concavity/convexity is varied from 0 mm to 25 mm for a length of 100 mm to study the behavior in the microwave propagation. The phantoms of different geometries, concave and convex, are used in this work to validate the numerical studies. It was noticed that the convex model exhibited higher signal coupling by an amount of 1 dB (simulation) and 2 dB (measurement) compared to the concave model. From the study, it was observed that the signal transmission improves up to 30 mm thick fat and reaches a plateau when the thickness is increased further.**

***Index Terms*—microwaves, dielectric properties, fat tissue, concave, convex, intra-body communication, fat channel, phantom.**

I. Introduction

In recent years, various efforts have been initiated toward the realization of a wireless body area networks (WBANs) by developing numerous implanted devices for a physiological monitoring system that sense, transmit, and record data. The wireless communication linking of an implant with external devices can improve diagnoses and therapy. In MedRadio, the frequency band 401 – 406 MHz is designated for radio-frequency (RF) biomedical telemetry. However, there are also applications that demand continuous monitoring at high data rate, for example, real-time videoendoscope capsules [1]. Also, brain-machine interfaces used to record neural signals to control prosthetic arms inherently need higher information transfer rates [2], [3].

The wireless communication, particularly in biomedical implants, becomes challenging due to the requirement for small sizes and larger transmission bandwidth. Therefore, opting GigaHertz frequencies corresponding to the Industrial, Scientific, and Medical (ISM) band (2.4 – 2.45 GHz), is a solution to achieve smaller antenna sizes and higher data rates.

Channel characterization and feasibility of in-body to on-body communication need to be investigated more to improve the communication performance of implanted devices. The use of the human body tissue itself as a transmission medium to communicate the health information serve as a promising technique for intra-body area networks (i-BANs). Microwave intra-body communication through the fat channel is a new technique that uses a specific human tissue as a communication channel [4]–[6]. This new technique has the ability to communicate through the fat channel with a substantial resiliency up to 60 % of blockage of the channel height [7].

In this paper, inhomogeneous fat tissue thickness is proposed to assess its impact on the transmission channel quality. The proposed models are characterized at 2.45 GHz. Two separate, concave and convex models comprised of the three-layer (skin, fat, muscle) tissue-equivalent phantom are used to analyze and verify the performance of the channel, both numerically and experimentally.

II. Numerical Modeling and Results

A multilayer 3D computational model was created in the Computer Simulation Technology (CST) software with the thickness of the skin, fat, and muscle are 2 mm, 25.36 mm, and 30 mm, respectively as a reference model (fat channel model). The thickness of the skin tissue was chosen based on the average thickness of the human body [8]. The fat thickness of this study was chosen by referring to the rectangular waveguide probe's height which was used to launch the electromagnetic signal through the fat tissue. The rectangular waveguide probes consisted of topology optimised planar antenna (TOPA) and was optimised to operate in the fat tissue [9]. The probes are aligned laterally in the fat layer with a distance of L = 100 mm between the transmitter (TX) and the receiver (RX). Based on the reference model, we investigate the influence of fat tissue thickness and the distance between the transmitter/receiver and the starting and ending of concavity/convexity (*Gap*) on the microwave propagation at 2.45 GHz. To exemplify that, two separate concave and convex model were proposed. The concave model is defined by having a surface that curves inwards in the middle, while the convex model is defined by having a surface that curves outwards.

Fig. 1 shows the two proposed models which comprise of three-layer tissues and a pair of rectangular waveguide probes with a 50 Ω subminiature version A (SMA) connector. We compare the scattering parameters (S-parameter) of the inhomogeneous fat thickness models to the S-parameter of the reference model, mentioned above. Fig. 1(a) shows the concave model. The simulation was done by varying two parameters, which are the fat thickness, T_{fat_min} and the *Gap*. The T_{fat_min} is varied from 5 mm to 25.36 mm by 5 mm step, and the *Gap* is varied from 5 mm to 25 mm by 5 mm from the probes. According to the convex model as shown in Fig. 1(b), the simulation was performed by varying the fat thickness, T_{fat_max} and the *Gap*. The T_{fat_max} is varied from 25.36 mm to 45 mm thickness of fat, by 5 mm step, and the *Gap* is varied from 5 mm to 25 mm by 5 mm from the probes. The variation of the T_{fat_min} and T_{fat_max} are based on an elliptical shape and the fat thickness is defined from the center (L = 50 mm) of the transmission channel. The variation in the parameters are studied to assess the transmission channel quality of the microwave propagation through the fat channel.

Fig. 2 shows the dependence of the transmission channel quality on the fat thickness and the *Gap* between the probes for the concave model and the convex model. The simulated results of the reflection coefficient, S_{11} is shown in Fig. 2(a). Overall, the S_{11} response shows a good channel matching below -12 dB. As can be seen, there could be variations in the channel matching with respect to the *Gap* distance. Since a good matching is obtained in all cases, this discrepancy is not significant for the channel propagation. The simulated results for the transmission coefficient, S_{21} for the concave and convex model as a function of fat thickness and the *Gap* are depicted in Fig. 2(b). As can be seen, the S_{21} magnitude of the concave model appears to gradually increase with increasing the thickness of fat from 5 mm until it reached a maximum value of 25.36 mm. As can be seen in Fig. 2(b), the presence of the *Gap* has a very little impact on the signal coupling between the two sides of the fat channel. When the fat thickness is above 30 mm, the S_{21} slightly decreases and hits a plateau. However, the signal coupling does not show significant reduction with the thicknesses in the convex model compared to the concave model. The decrease in signal coupling in the concave model is a consequence of signal path blockage by the muscle tissue.

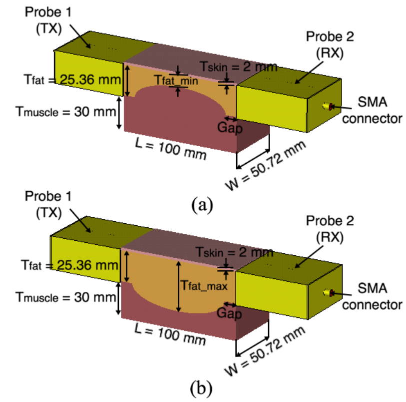


Fig. 1. The models used for the numerical modeling studies. (a) concave, (b) convex. The models consists of the skin, fat, and muscle tissue from the bio-model materials in the CST software.

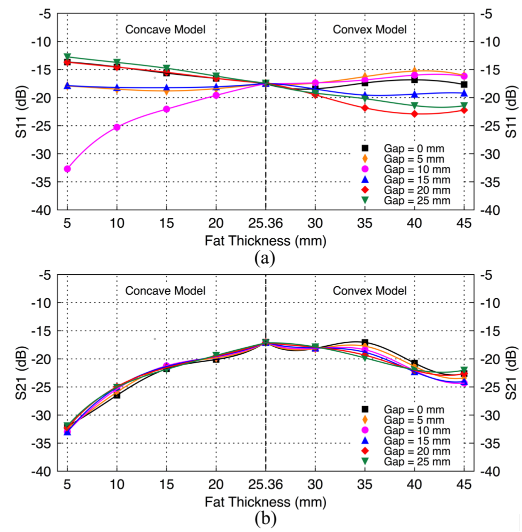


Fig. 2. Dependence of the transmission channel quality on the *Gap* and the fat tissue thickness. The simulated scattering parameters results for concave and convex model at 2.45 GHz.

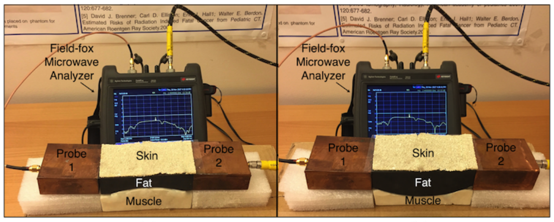
III. Experimental Setup and Results

In order to validate the applicability of the fat channel to predict the optimum performance and to evaluate the consistency of the measurements, the three-layer tissue-equivalent phantom with two different model were investigated as shown in Fig. 3. The thickness of the fat tissue in the concave model is 20 mm, and in the convex model is 35 mm with 10 mm *Gap* in both cases. Table 1 shows the dielectric properties used in this study at 2.45 GHz. The measurement was carried out using a Field-fox Microwave Analyzer to observe the signal coupling between the two waveguide probes. Calibration was validated against a calibration kit prior to measurement. The distance between the two waveguide probes (L = 100 mm) and the width (W = 50.72 mm) of the channel were kept constant for both measurement conditions.

Fig. 4 shows the S-parameters comparison between simulation and measurement results corresponding to the reference fat channel model and the selected concave and convex fat channel, mentioned above. The solid line represents the measured results, and the dashed line represents the simulated results. Fig. 4(a) shows the S_{11} comparison between the reference fat channel, the concave, and the convex model. The simulated and measured S_{21} of the concave and convex model were compared as shown in Fig. 4(b). We note that generally the change in the fat thickness alters the coupling coefficient S_{21}. In simulation, the coupling coefficients through the reference fat channel, the convex channel, and the concave channel are -8.48 dB, -10.70 dB, and -12.05 dB, respectively. In experimentation, the corresponding values are -8.53 dB, -10.01

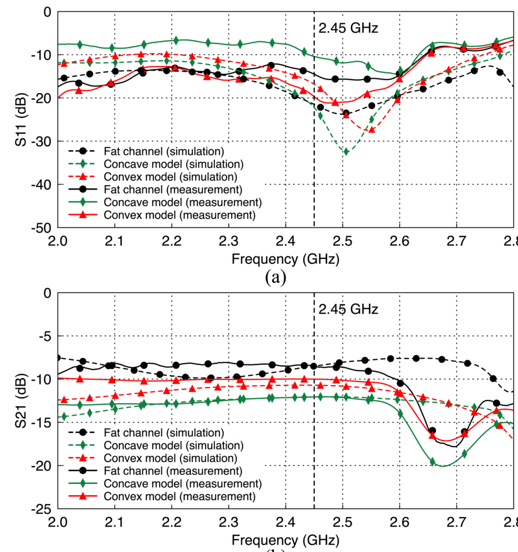
TABLE 1
COMPARISON OF DIELECTRIC PROPERTIES OF THE PHANTOM, AND HUMAN TISSUE AT 2.45 GHZ

	Phantom			**Human [10]**		
Tissue	Relative permittivity (ε_r)	Loss tangent ($tan\ \delta$)	Conductivity (σ)	Relative permittivity (ε_r)	Loss tangent (tan δ)	Conductivity (σ)
Skin	38.003	0.215	1.113	38.007	0.283	1.464
Fat	4.708	0.015	0.0096	5.280	0.145	0.105
Muscle	48.038	0.217	1.423	52.729	0.242	1.739



(a) (b)

Fig. 3. The experimentation setup. The models are based on the phantom materials consists of the skin, fat, and muscle tissue. The fat thickness for the concave model is 20 mm, and for the convex model is 35 mm. The *Gap* is 10 mm.



(b)

Fig. 4. A comparison of the simulated and measured scattering parameters for the concave and the convex models at 2.45 GHz. The solid line represents the measured results, and the dashed line represents the simulated results.

dB, and -12.06 dB, respectively. Compared to the reference fat channel, we note that the coupling coefficient decreases by ∼2 dB for the convex channel and by ∼4 dB for the concave one. The little disagreement between simulated and measured results may be accounted for by differences in geometries and dielectric properties between the physical phantoms and the theoretical models. Our results shows that the thick fat layer is suitable and reliable to propagate microwave signals through the fat tissue.

IV. CONCLUSION

In this paper, a comparison of the microwave propagation through concave and convex fat tissue models has been presented. Three-layer inhomogeneous tissue phantoms - concave and convex fat models were proposed, where we can demonstrate the feasibility of a stable and reliable intra-body communication channel. The results presented in this paper show that the *Gap* does not affect the transmission. The signal transmission seems to be flat from 15 mm to 35 mm of the fat thickness with attenuations no bigger than 4 dB. This finding is potentially good for information transmission. However, with the fat thickness lower than 15 mm, the absorption signal in the channel is greater, but still good enough to support other transmission applications. Finally, we find the performance of the fat channel under a change in the thickness of fat tissue is acceptable and feasible for microwave communication.

ACKNOWLEDGMENT

This work was supported in part by the Ministry of Higher Education Malaysia, Eurostars project under Grant E-9655-COMFORT, Swedish Vinnova project under Grant BDAS (2015-04159) and by the SIP "Smartare Elektroniksystem", a joint venture of VINNOVA, Formas and Energimyndigheten, and a strategic collaborative eScience program by Swedish Research Council under Grant eSSENCE.

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