THz Time Domain Characterization of Human Skin Tissue for Nano-electromagnetic Communication

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***Abstract*—This paper presents an experimental investigation of excised human skin tissue material parameters by THz Time Domain Spectroscopy in the band 0.1 - 2.5 THz. The results are used to evaluate the channel path loss Nano-electromagnetic communication. Refractive index and absorption coefficient values are evaluated for dermis layer of the human skin. Results obtained illustrate the effect of hydrated tissue on channel parameters and provide the optimum distance, which can be utilized for effective communication inside the human skin.**

Keywords—Nanonetwork, nano-electromagnetic communication, pathloss, terahertz time domain spectroscopy, skin tissue.

I. INTRODUCTION

Nanotechnology has amassed great appreciation in the field of biomedical sciences, since its proposition. With diverse applications, nanodevices are consistently evolving and hold the future for next generation of medical diagnostic techniques. Such devices, being small in size, have been theorized to be operational in optical frequencies spanning from 0.1 - 10 THz. This range of frequencies, know as the Terahertz (THz), encapsulates the vital information of human body, biomolecules, and medical imaging. Nano-network is one of the novel paradigms of electromagnetic (EM) communication technology that promises to edify the present-day health monitoring systems. The growing need for wireless medical devices stems for remote and continuous monitoring of the patients' health, while delivering informative, interactive, non-invasive, and reliable systems [1]. The usability of such nanodevices is only possible with proper communication amongst them through an effective channel model.

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Since, a high date rate can be achieved for transmission distance in the order of few tens of millimeters by terahertz communications in air, EM communication at THz band has been considered as a promising paradigm for dealing with the data exchange in nano-networks. Studies show that using the EM paradigm; the capacity can reach as high as Tera-bits per second (Tb/s) at the level of millimeter. An IEEE framework 1906.1 is dedicated to maintain and define the standards of nano-scale communication, where molecular and electromagnetic communication are the two modes of communication. The existing database on human skin is restricted up to GHz, while a very few with expansion up to THz frequencies have been published, but are scarce and inconsistent. In order to enrich the database with the parameters of biological tissues in the THz band, emphasis is given on spectroscopy and modeling of biological tissues. THz Time Domain Spectroscopy (TDS) has a typical range of 0.1 – 4 THz, which provides an opportunity of broader spectral analysis. It is coherent detection technique, which allows retrieving of both phase and amplitude data, thereby contributing to extracting both refractive index and absorption coefficient. Traditional diagnostic devices were restricted to the MHz-GHz frequncy range. However, novel nano-materials, such CNT (carbon nano-tubes) and Graphene have unfolded new technologies, showcasing capabilities to work in THz band [2-3]. In addition, the THz spectrum region is considered as safe for such applications as compared to conventional microwave frequencies [4].

The transmission schemes for nano-communication have been investigated in the presence of lossy air medium, where it was found that THz communication is feasible for a transmission distance in the order of few tens of mm [5]. The focus of this paper is on channel modeling of nano-electromagnetic communication in human skin tissue in the THz band, taking into account the effects of path loss and noise, and addressing channel capacity.

The rest of the paper is organized as follows: Section II presents the experimental settings with a detailed description of the biological sample, for human skin tissue, and subsequently THz-TDS. Data processing methods and techniques are described in Section III. Section IV, discusses the channel performance based on numerical studies. Finally, conclusions are drawn in Section V.

II. EXPERIMENTAL METHODOLOGY

A. Sample Preparation

Human skin is 60-70% composed of water, which leads to high absorption of THz radiation during the measurement. Efforts have been made to air dry the excess liquid media, which is usually done for preservation and actual moisture content of the tissue is kept intact. Skin in the human body is a protective layer, sensor of multiple parameters such as pressure, temperature, *etc.* Epidermis is the thin outer layer (as shown in Fig.1) and its deepest layer is Basal membrane, which is responsible for preparing new keratinocytes and replacing the old ones. The thickest (~3 mm) of all is the dermis lying just beneath epidermis, as illustrated in Fig. 1. The sample is freshly excised breast tissue from a female patient of around 40-45 years old. The tissue is measured within 48 hours of excision and preserved in a media to maintain the morphology. A standard optical microscopy, as shown in Fig. 1, is used to illustrate the structure of skin; this is given to acknowledge the reader with the complexity of skin. More information about skin morphology can be found in the previous paper by the authors [6]. The next section in this paper aims to characterize real human skin via THz-TDS, while evaluating material properties and applying measured results to the numerical model for nano-communication channel. Biological studies are performed in collaboration with the Subcutaneous Group of the Blizard Institute at QMUL.

B. THz Time Domain Spectroscopy of Human Skin

THz-TDS at Queen Mary University of London (QMUL) has a typical range of 0.1- 4 THz, which provides access to broader spectral analysis. The TDS system is a carefully designed assembly of the following components - Ti:Sapphire is the femtosecond pulsed laser with adjustable wavelength range of 750 - 850 nm; pulse repetition rate of 80 MHz and peak power is about 1 W. The samples are placed in a holder wedged between two TPX (Polymethylpentene) layers of 2.71 mm thickness. These optical pulses are split with the aid of a beam splitter into two beams namely: pump and probe. Generation is made possible with the usability of photoconductive antenna illuminated by the pump beam resulting in a transient photocurrent. The pump beam travels through a time-delay stage resulting in a delay of Δt relative to probe beam.

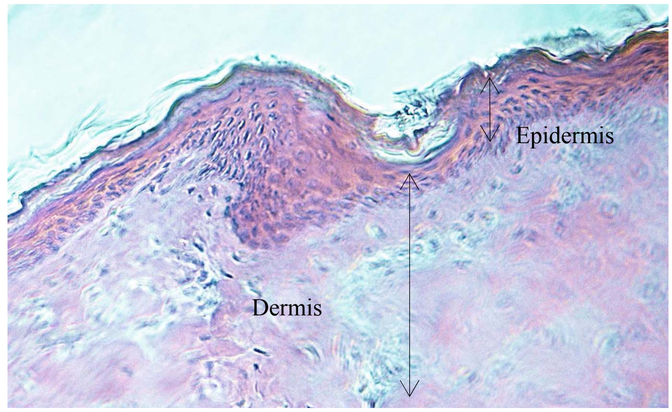

Fig.1 Microscopic image of real human skin presenting the two defined layers: Epidermis and Dermis. The sample sections were stained using Haematoxylin (purple/blue stain) and Eosin (red/pink stain), used for identifying nuclei and cytoplasm respectively. Stratum Corneum (SC) traces were visible in the microscopy, however the thickness is not quantifiable [6].

The TDS pulses are generated and detected via mode locked laser. The lock-in amplifier locks and records the detected THz data for all three samples – air, TPX, and skin and is aided by a computer-generated program written in LabView®[6,7].

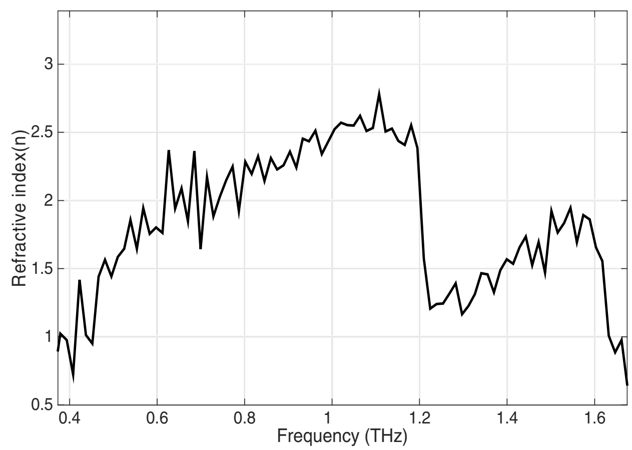

Fig.2 Measured Refractive index as a function of frequency. The refractive index for freshly excised breast tissue at 1 THz is 2.5

III. SKIN MATERIAL PARAMETERS

The measured time domain data obtained via THz Time domain spectroscopy contains both magnitude and phase information of the sample under test. The extraction procedure is made possible by iteratively solving the transfer function equation [8].

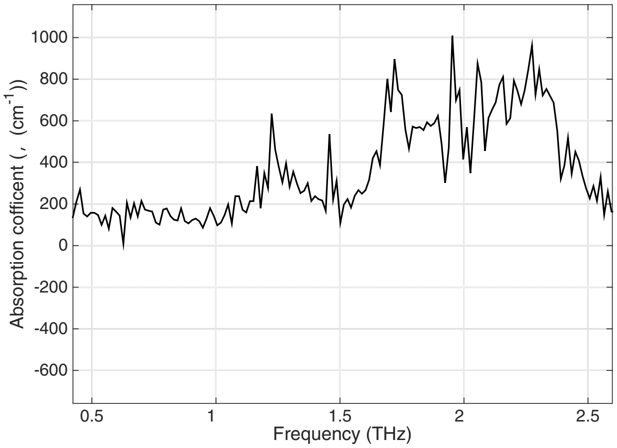

Fig.3 Measured absorption coefficient using THz-TDS. The alpha at 1THz is 97.37 cm^{-1}, considering the losses due to atmospheric water vapors.

IV. CHANNEL PATH LOSS

The extracted material parameters are then utilized to numerically present the channel path loss based on modified Friis equation [6]. The path loss can be divided as: the spreading path loss and the absorption path loss. The absorption path loss is as a result of material dynamics, sample's composition, and molecular behavior. On the other hand, spreading pathloss is introduced by the expansion of the wave in the medium. More information on channel parameters is provided in details in previous papers by the authors [6,9].

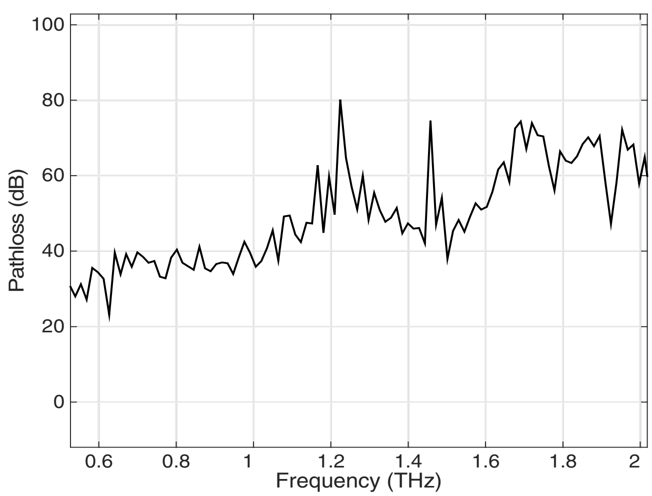

Fig.5 Total path loss as a function of distance and frequency for human skin. The path loss is as a result of absorption and spreading pathloss. These parameters significantly influence the propagation schemes. The pathloss noted at 1 THz is 35dB and the average value is 35.014 dB

V. CONCLUSION

Nano-electromagnetic communication is a potential solution for operation of future healthcare diagnostic nanodevices. The investigation of material properties via THz TDS aims to fulfill the imperative need to understand communication possibilities inside the human body. This study suggests that absorption due to water; propagation distance, and frequency range affects the path loss. Human skin is a complex layered structure, and further studies are currently underway to include such biological parameters for channel improvement.

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REFERENCES

[1] Victor Shnayder, Bor-rong Chen, Konrad Lorincz, Thaddeus R. F.Fulford-Jones, and Matt Welsh.; “Sensor Networks for Medical Care”, Harvard University Technical Report TR-08-05, April 2005.

[2] I. F. Akyildiz and J. M. Jornet, "Electromagnetic Wireless Nanosensor Networks," Nano Communication Networks, vol. 1, pp. 3-19, 2010.

[3] I. F. Akyildiz, F. Burnetti and C. Blazquez, "Nanonetworks: a new communication paradigm," Computer Networks, vol. 52, pp.2260-2279, 2008.

[4] Nuss, M. C., and Orenstein, J., Terahertz time-domain spectroscopy, in Millimeter and sub-millimeter-wave spectroscopy of solids, Grüner, G., ed., Topics in Applied Physics 74. Berlin: Springer, 1998.

[5] H. H. Mitchell, T. S. Hamilton, F. R. Steggerda, and H. W. Bean The Chemical Composition Of The Adult Human Body And Its Bearing On The Biochemistry Of Growth J. Biol. Chem. 1945 158: 625-637.

[6] Nishtha Chopra, Ke Yang, Qammer H. Abbasi, Khalid Qaraqe, Mike Philpott and Akram Alomainy, “THz Time Domain Spectroscopy of Human Skin Tissue for In-Body Nano-networks”, IEEE Transactions on THz Science and Technology (Accepted, 2016).

[7] Nishtha Chopra, Ke Yang, Jamie Upton, Qammer Hussain Abbasi, Khalid Qaraqe ,Mike Philpott, Akram Alomainy, “Fibroblasts Cell Number Density based Human Skin Characterization at THz for In-body Nanonetworks”, Elsevier Nano Communication Networks (Accepted, July 2016)

[8] Timothy D. Dorney, Richard G. Baraniuk, and Daniel M. Mittleman, "Material parameter estimation with terahertz time-domain spectroscopy," J. Opt. Soc. Am. A 18, 1562-1571 (2001).

[9] Q. H. Abbasi, H. El Sallabi, N. Chopra, K. Yang, K. Qaraqe, and A. Alomainy, "Terahertz Channel Characterization Inside the Human Skin for Nano-scale Body-Centric Networks", IEEE Transactions on THz Science and Technology (Accepted, March 2016)