Dielectric Properties of Human Skin In Vivo in the Frequency Range 20 – 38 GHz for 42 Healthy Volunteers

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ABSTRACT

With the increasing use of microwave radiation for communications and radar, it is necessary to know dielectric properties of various human tissues for evaluation of potential hazards to humans. Dielectric properties of human skin in vivo were measured in the frequency range of 20 - 38 GHz on 42 healthy volunteers (21 men and 21 women) in the palm region. Measurement system consists of a vector network analyzer and a waveguide sensor. Results are reported for complex permittivities (mean and standard deviation), depths of penetration and emissivities in 20 – 38 GHz range for 42 healthy volunteers.

INTRODUCTION

Over the last ten years, high frequency microwaves (10-30 GHz) and millimeter wave (30-100 GHz) application technology has advanced significantly with the development of low-cost, high-performance components and the opening up of new frequency bands in the microwaves (mw) and millimeter wave (mmw) ranges. Applications such as local multipoint distribution services (LMDS), hand-held traffic radars, satellite communications and automotive anti collision radars are increasing being used in mw and mmw frequency ranges.

LMDS system is a broadband wireless point-to-multipoint communication system operating above 20 GHz, which can be used to provide digital two-way voice, data, internet and video services [1]. Also, handheld traffic radar usually operates at k-band (24.15 GHz) [2] and automobile anti-collision radars operate in the frequency range of 24 –77 GHz.

With the increasing use of mw and mmw radiation in communications and radar, it is necessary to know dielectric properties of various human tissues for evaluation of potential hazards to humans. At mw and mmw frequencies ranges, the absorption of electromagnetic radiation is mostly restricted to the skin because of submillimeter depths of penetration [3]. Therefore, the knowledge of dielectric properties of human skin in vivo is of prime importance for quantifying hazardous effects of mw and mmw radiation.

In the past, the dielectric properties of human skin in vivo were measured by Ghodgaonkar et al in the frequency range of 26.5-60 GHz using slotted line [4]. In the frequency band of 8 - 18 GHz, the dielectric properties of human skin in vivo are reported by Hay-Shipton et al [5]. Grant et al [6] have reported the dielectric properties of human skin in the frequency range of 50 MHz - 2 GHz using an open-ended coaxial line sensor technique. In this research, we are using a measurement system which consists of a vector network analyzer (VNA) and a waveguide sensor. The waveguide sensor consists of coaxial cables, coaxial-to-rectangular waveguide transition and Teflon^{TM} impedance transformer. The dielectric properties of human skin in vivo were measured in the frequency range of 20 - 38 GHz. Complex reflection coefficients were measured by pressing the palm region of human skin in vivo against the waveguide sensor. Complex permittivities (ε^*) are calculated from complex reflection coefficients (S_{11}) by implementing a formulation of an open-ended rectangular waveguide radiating in to the half-space of lossy dielectric material [7]. In this paper, complex permittivities are calculated for 42 healthy volunteers in the age group of 21 to 40 years. Then, depths of penetration and emissivity for human skin in vivo are calculated based on measured complex permittivities.

MEASUREMENT SYSTEM

The measurement system is as shown in Fig. 1. It consists of a VNA Wiltron 37269B and a waveguide sensor. For the frequency range of 20 to 38 GHz, two waveguide sensors (operating in the K-band 18 – 26.5 GHz band and Ku-band operating in 26.5 – 40 GHz range) were used. The waveguide sensor consists of coaxial cables, a coaxial-to rectangular waveguide transition and Teflon^{TM} impedance transformer as shown in Fig. 1. The impedance transformer which is quarter wavelength at mid-band is used to reduce the reflectivity of human skin in vivo. The measurement system was calibrated up to the rectangular waveguide end of the coaxial-to-waveguide transition by implementing LRL (line-reflect-line) calibration technique in rectangular waveguide. In the LRL calibration, first line is a through connection, the second line is a precision waveguide of length equal to quarter wavelength at mid-band. The reflect standard is a waveguide shorting plate. The time-domain gating function of VNA is used to further reduce the residual post-calibration errors.

CALCULATION OF COMPLEX PERMITTIVITY

Fig. 2 shows the sample arrangement for the calculation of complex permittivity ($\varepsilon^* = \varepsilon' - j\,\varepsilon''$) from measured reflection coefficients. For implementation of a formulation of an open-ended rectangular waveguide radiating into the half-space of lossy dielectrics material [7], it is necessary to make following two assumptions regarding human skin in vivo.

1. It is modeled as a homogeneous lossy dielectric material.
2. Reflections from muscle and fat layers can be neglected

Human skin consists of two layers: (a) epidermis (b) dermis. The range of thickness of the epidermis and dermis for adult males and females are 0.03 - 1.4 mm and 0.86 - 3 mm, respectively [7]. For the palm region, the approximate thickness of the epidermis and dermis are 0.429 mm [8] and 3 mm [8, 9], respectively. The palm region of the human body was chosen for measurements because the skin is thick in this area and has a relatively smooth surface. Because of the first assumption, the measured dielectric data will correspond to average properties of epidermis and dermis. Due to the second assumption, calculation of dielectric properties is justified above 18 GHz where the total (epidermis and dermis) thickness of skin (3.5 mm) is greater than 3 depths of penetration. At a distance of 3 depths of penetration, the electric field reduces to $1/e^3$ (less than 5 %) of its original value. In this paper, emissivities and depth of penetrations are calculated based on mean values of complex permittivies of human skin in vivo. Emissivity is defined as the in power absorption coefficient of human skin in vivo.

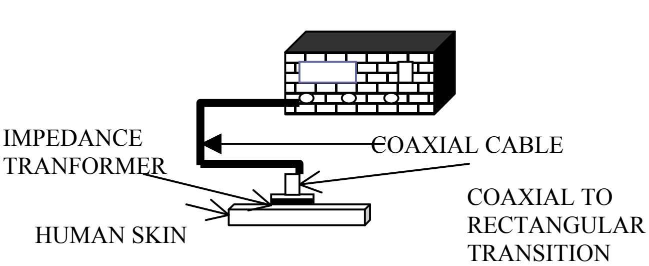

Fig. 1: Measurement system for S_{11} measurements of human skin in vivo.

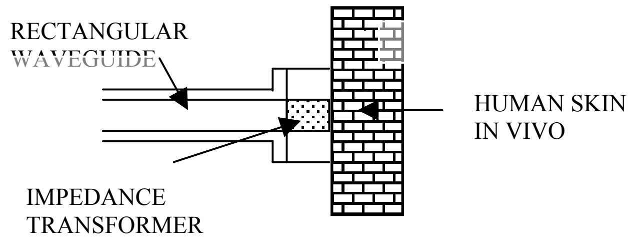

Fig. 2: Specimen arrangement for calculation of S_{11}

VOLUNTEERS AND PROTOCOL

In this research, the protocol for dielectric measurement of human skin in vivo of volunteers was approved by the Universiti Teknologi MARA (UiTM) Research Ethics Committee. We performed measurements in the right hand palm regions of 42 human volunteers. Inclusion and exclusion criteria for volunteers are as follows.

<u>Inclusion criteria for volunteers</u>
a) Human subjects will be in the age group of 18 to 40 years.
b) Human subjects should be male or female from Malays cohort.
c) Human subjects should have a good medical record and no pre-historical illness.
d) Human subjects should have taken no medicine in the past 3 days.
e) Human subjects should not have any wounds or burns in the area around the exposure area (i.e. palm region)

<u>Exclusion criteria for volunteers</u>
Children and pregnant women will not be chosen as human subjects.

Total number of volunteers was chosen to be 42 in order to get statistically significant results after considering errors in measured complex permittivities and subject to subject variation of dielectric properties.

EXPERIMENTAL RESULTS

We have done measurements on 42 healthy volunteers (21 women and 21 men) in the age group of 21 - 40 years. Fig. 3 and Fig. 4 show the mean values of dielectric constant and loss factor on the right hand plam region of 42 volunteers. The standard deviation for dielectric constant of 42 volunteers is in the range of 0.9 (38 GHz) to 1.3 (20 GHz). The standard deviation for loss factor of 42 volunteers is in the range of 1.4 (38 GHz) to 1.8 (20 GHz). Fig. 5 and Fig. 6 give emissivity and depth of penetration for mean values of complex permittivities for 42 volunteers.

CONCLUSION

From the graphs of Fig. 3 and Fig. 4, dielectric constants as well as loss factors decreases with increase in frequency. From Fig. 5, emissivity varies from 55 % to 70 % for human skin in vivo. From Fig. 6, depth of penetration varies from 1.05 mm at 20 GHz to 0.78 mm at 38 GHz for human skin in vivo. At 22 GHz, the mean dielectric constant of 42 volunteers is 6.04 and the mean loss factor for 42 volunteers is 14.39. Ghodgaonkar et al [4] reported that the dielectric constant is 8.6 and the loss factor is 12.2 at 28 GHz for human skin in vivo. Considering difference in frequencies and sample size, there is a close match with the data reported in reference [4].

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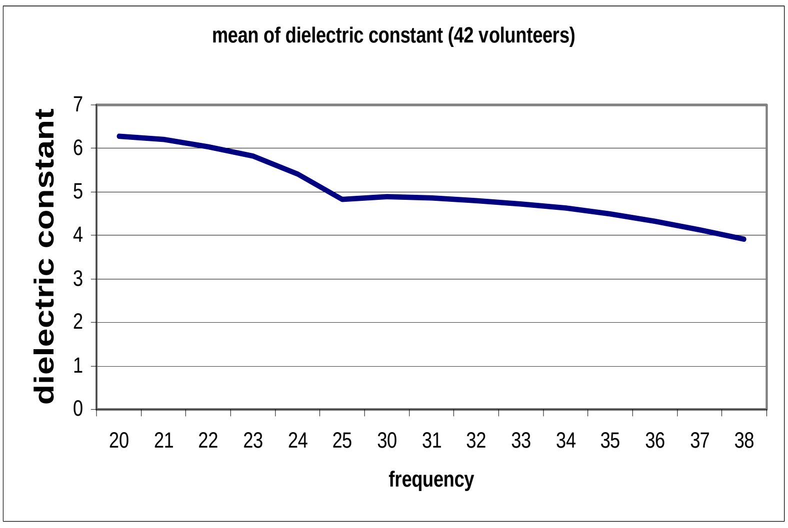

Fig. 3 Mean value of dielectric constant of human skin in vivo for 42 volunteers

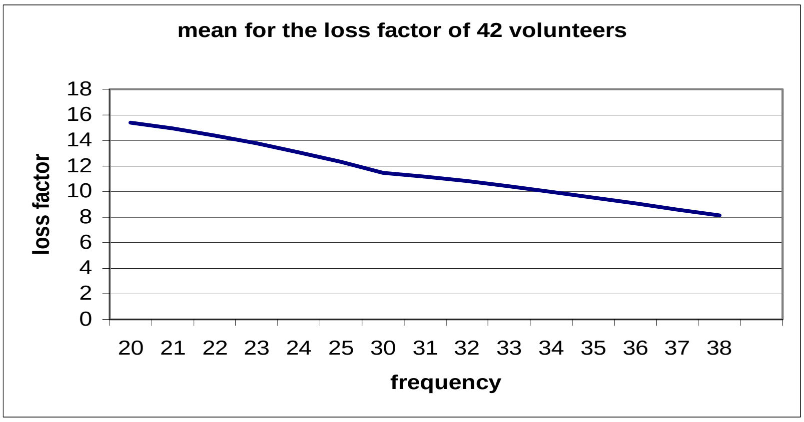

Fig. 4 Mean value of loss factor of human skin in vivo for 42

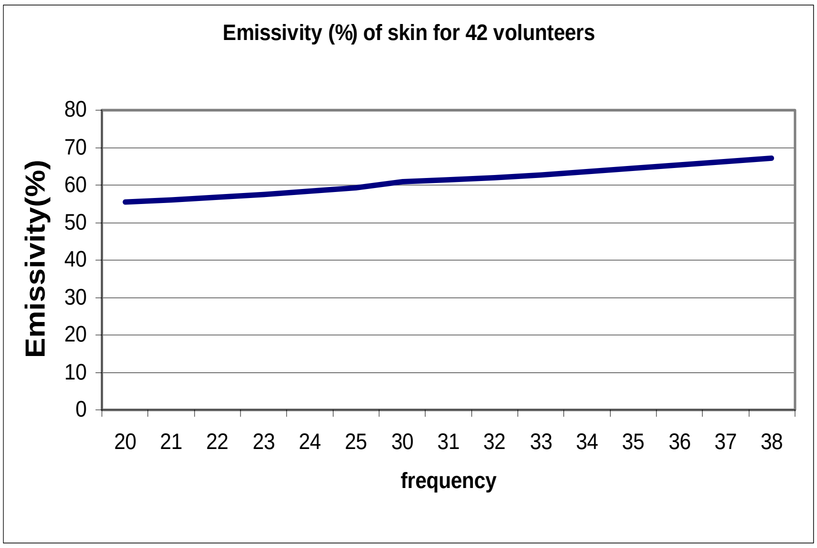

Fig. 5 Emissivity (%) of human skin in vivo from mean values of ε* for 42 volunteers

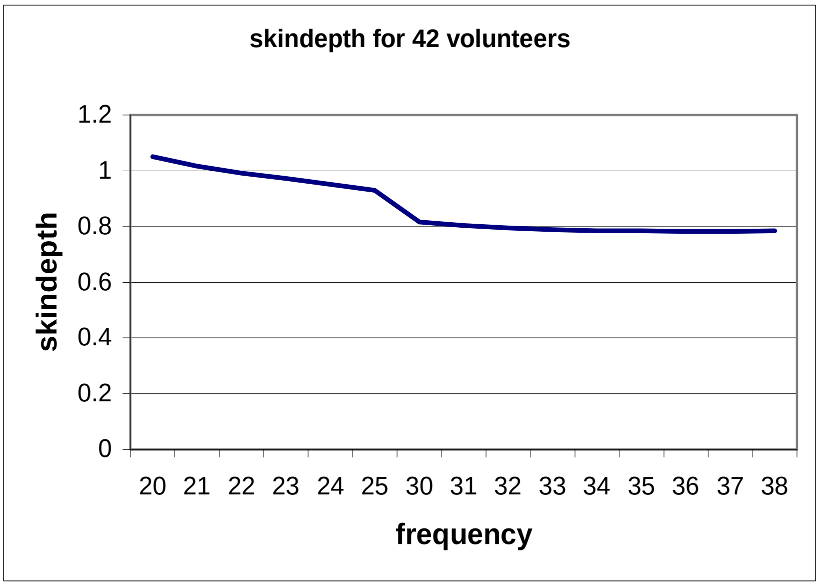

Fig. 6 Depth of penetration of human skin in vivo from mean values of for 42 volunteers