Analysis of MMW Exposure of a Clothed Skin with Oblique Incidence Angles

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Millimeter wave (MMW) frequency bands are promising for future wireless communication system owing to the potential high transmission data rate. MMW transmitters utilized close to human body, such as mobile phone, tablet terminal and laptop, increase the concerns on human exposure to electromagnetic fields (EMFs). International safety guidelines [1] have recommended the power densities at inside the human body (Absorbed Power Density; APD) and incident into the human body (Incident Power Density; IPD), respectively, as the metrics of basic restriction and reference level at frequencies from 6 to 300 GHz. The EMF power deposition for bare [2-3] and clothed skin [4] was investigated in previous work. However, the EMF exposure including both impacts of cloth materials and incidence angles were not sufficiently investigated. In this study, we aimed to analyze the EMF exposures of a clothed human skin tissue with an obliquely incident plane wave at 60 GHz. The effects of the air gap between the cloth and the bare skin tissue were examined considering various incidence angles and polarizations.

Figure 1 shows the analytical model composed of cotton material, air gap, epidermis, dermis, subcutaneous fat, and muscle used to represent the skin tissue in the abdomen [2]. The dielectric properties of skin tissue and cotton material at 60 GHz reported by [2] and [4] were used, respectively. An obliquely incident plane wave from air to the clothes surface with the angle of θ_0 is assumed. Two polarization components of the incident waves are considered individually, defined as TE and TM waves, whose electric-field vectors are perpendicular and parallel to the incident plane (*yz*-plane), respectively. The absorbed power density within the skin surface was calculated for an incident power density of 26.6 W/m^2, i.e., the reference level for local exposure of the general public at 60 GHz, as indicated in ICNIRP 2020 and IEEE C95.1 2019.

Figure 2 indicates the results of absorbed power density inside the skin surface as a function of the air gap thickness with different incidence angles and polarizations. An oscillatory behavior with a peak to valley variation of 5 dB for the case of normal incidence as the increase of air gap thickness can be observed. This indicates that the variation of an air gap between the cloth material and skin can decrease or increase the electromagnetic field power deposition in the human tissues, as reported in [4]. In addition, with the increase of oblique incidence angle, both the entire level and the fluctuation of the APD will be obviously reduced. Particularly, for TM wave incidence at θ_0 = 60 deg., the APD within the skin surface shows an almost flat profile, indicating that the increase of oblique incidence angle will reduce the variation of the APD due to the air gap effects. Furthermore, all the results of the APD cannot exceed the basic restriction for local exposure (20 W/m^2), demonstrating that the current safety guidelines are appropriate for preventing the excessive exposure at millimeter wave bands even when considering the impacts caused by oblique incidence and cloth materials.

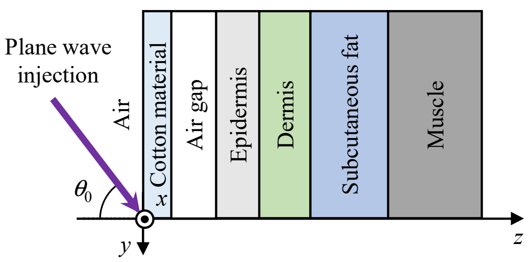

Figure 1. Six-layer skin model of the abdomen tissue considering cloth material and air gap.

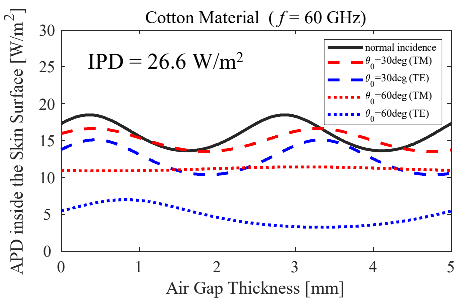

Figure 2. APD within the skin surface as a function of the air gap thickness with different incidence angles and polarizations.

References

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