EMF Energy Absorption
Mechanisms in the mmW Frequency Range

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Background

• The compliance of wireless devices up to the 4th generation is tested against the basic restrictions by measuring SAR.

• The dielectric properties of the tissue simulants for the SAR measurements were determined by evaluating the plane-wave absorption in large numbers of head- and body-tissue combinations.

• For body tissue, constructive interference from the fat-muscle interface was observed that can lead to an increase of the psSAR of up to 3dB for far-field like exposure.

• For head tissue, no such effects could be identified.

• Compliance testing for mmWave frequencies no longer uses a dosimetric approach.

• The skin can no longer be regarded as bulk tissue for the characterization of the absorption of EM fields.
Objectives

• propose a stratified skin model for the analysis of EM energy absorption in the mmWave frequency range

• identify the skin layering structure that maximizes absorption

• quantify EM energy absorption and the induced temperature increase for plane-wave exposure

• characterize the near-field of a set of generic wireless devices with phased array antennas operating at 28GHz and 100GHz

• quantify the induced temperature increase based on the incident E-field and the real part of the power density averaged over surfaces of 1cm², 4cm² and 100cm²
Stratified Skin Model – Biophysical Properties

- Unperfused epidermis modeled as stratum corneum and viable epidermis
- Cole-Cole tissue properties:
  - Low water content for stratum corneum and hypodermis
  - High water content for viable epidermis, dermis and muscle
- Adiabatic thermal boundaries as conservative estimate of live conditions
Stratified Skin Model – Layer Thicknesses

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>thick SC</td>
<td>20 - 700µm</td>
</tr>
<tr>
<td>thin SC</td>
<td>10 - 20µm</td>
</tr>
<tr>
<td>viable epidermis</td>
<td>60 - 120µm</td>
</tr>
<tr>
<td>dermis</td>
<td>0.4 – 2.4 mm</td>
</tr>
<tr>
<td>hypodermis</td>
<td>1.1 – 5.6 mm or ∞</td>
</tr>
<tr>
<td>muscle</td>
<td>∞</td>
</tr>
</tbody>
</table>

- two body regions distinguished depending on stratum corneum thickness:
  - thick stratum corneum: fingers, palm, soles of the feet
  - thin stratum corneum: everywhere else on the body

- large variability for stratum corneum thickness of the hands depending on individual manual activities

- hypodermis or muscle as terminating layer
Power Transmission Coefficient

- Plane wave power transmission always > 45%, may exceed 90%
- Enhanced absorption due to constructive interference below 15GHz
- Enhanced absorption due to impedance matching above 15GHz
SC Thickness for Maximum Transmission

![Graph showing SC thickness for maximum transmission across different frequencies.](image-url)
Temperature Increase

- Temperature increase $\Delta T$ for adiabatic boundary conditions normalized to an incident power density of $10\text{W/m}^2$

- $\Delta T$ in layered tissue up to 4 times higher than in homogeneous tissue due to increase in power transmission coefficient and reduced perfusion (epidermis, fat)
Generic Transmitters – 28GHz

- **F28b** – generic phone with 16 PIFA elements on the back of the ground plane operating at 28GHz
- **F28t** – generic phone with 16 PIFA elements on the bent top of the ground plane operating at 28GHz
- **N28** – generic phone with four folded feeding ports and 30 parasitically coupled notch antenna elements operating at 28GHz
Generic Transmitters – 100GHz

- **P100b** – generic phone with 16 patch antenna elements on the back of the ground plane operating at 100GHz

- **P100t** – generic phone with 16 patch antenna elements on the top of the bent top of the ground plane operating at 100GHz
Farfield Patterns of the Generic Transmitters

- **direct beam**: F28b, F28t, N28, F100b, F100t
- **deflected beam**: F28b, F28t, N28, F100b, F100t

Normalized far-field in dB:
-0, -5, -10, -15, -20
Positioning of the Generic Transmitters

- close distance: 1.7mm between ground and tissue corresponding to $\lambda/6$ at 28GHz (N28: 4.2mm distance because of case)
- far distance: increased by 8mm
Calculation of the Temperature Increase

- fields averaged over square surfaces of 1cm\(^2\), 4cm\(^2\) and 100cm\(^2\)
  - absolute value of the E-field vector
  - real part of the Poynting vector
  - normal component of the real part of the Poynting vector

- temperature increase simulated applying the antenna power required to reach an incident power density of 10W/m\(^2\)

- close and far distance, direct and deflected beam, homogeneous and layered (worst-case) skin, adiabatic boundary conditions
ΔT Averaged Over 1cm² – Homogeneous Skin

- similar ΔT for av. E-field and av. total Poynting vector
- generally higher ΔT for av. normal Poynting vector
- ΔT dependent on device and distance
$\Delta T$ Averaged Over $1\text{cm}^2$ – Layered Skin

- $\Delta T$ generally higher by about a factor of 2
- Otherwise, similar characteristics as for homogeneous tissue
ΔT Averaged Over 4cm² – Homogeneous Skin

- ΔT generally higher than for an averaging surface of 1cm²
- reduced correlation between temperature increase and power density
- otherwise, similar characteristics as for homogeneous tissue
ΔT Averaged Over 20cm\(^2\) – Homogeneous Skin

- ΔT higher than for an averaging surface of 1cm\(^2\) and 4cm\(^2\)
- Significantly reduced correlation between temperature increase and power density
Correlation of $\Delta T$ and Power Density

- Standard deviation of $\Delta T$ with power density increases with size of averaging area indicating higher dependence of $\Delta T$ from device type.
- Improved correlation for normal av. Poynting vector in layered tissue for an averaging area of $1\text{cm}^2$. 
Summary and Conclusions

• Layered modeling of the skin yields an increase of the induced $\Delta T$ by up to a factor of 4 in comparison to homogeneous skin mainly in the palms and fingers. This can be attributed to impedance matching and reduced perfusion in the outer skin layers.

• Normalization of the temperature increase to the normal av. Poynting vector yields a higher temperature increase in comparison to the total av. Poynting vector, but shows a better correlation, i.e., larger independence of the incident field.

• The observed temperature increase remains under 1K if an averaging area of 1cm$^2$ is used and the averaged power density does not exceed the exposure limit for the general public of 10W/m$^2$.

• At distances $>\lambda/6$ (1.7mm at 28GHz), the impact of reactive fields is negligible. Further evaluations may be necessary for lower frequencies (10GHz).