EXPOSURE ASSESSMENT OF WIRELESS DEVICES FREQUENCIES ABOVE 6 GHz

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Introduction

• Millimeter-wave (mmW) frequencies between 10-300 GHz are the new frontier for wireless communications that promise orders of magnitude higher bandwidths and transfer rates.

• The short wavelength associated with high frequencies increases the number of challenges associated with dosimetric measurements.

Challenge #1: Shallow Penetration Depth

1.9 GHz

10 GHz

- Coupling
- Alteration of the field
Challenge #1: Shallow Penetration Depth

1.9 GHz

20 GHz

- Loss of isotropy of the probes near the boundary.
Challenge #2: The Use of Multi-Array Systems

Challenge #3: Discerning Spatially mmW Power Deposition

- Currently power density is used for compliance above 6 GHz.
- Power density does not provide any spatial information on the distribution of energy.

Technology Requirements to Address these Challenges

1. Spatially untangle the energy deposited inside tissue.
2. Conduct measurement in a reasonable time.
3. Be able to characterize arrays.
4. Have small uncertainty.
Emerging Methods for Local Exposure Assessment

• Several methods have been proposed to quantify mmW exposure distribution
  – Single point or 2D infrared (IR) temperature measurements on thin “skin” phantoms\textsuperscript{1,2}
  – High-resolution magnetic resonance (MR) thermometry measurements on gel based water phantoms\textsuperscript{3}

• Currently, quantifying mmWave power absorption with sufficient spatial resolution and accuracy is particularly challenging for conventional electric field probe systems\textsuperscript{4} due to small penetration of the energy

1- Alekseev S.I. et al 2009 Bioelectromagnetics
2- Alekseev S.I. et al 2011 Biofizika
3- Alon L et al. 2015 BIOEM
4- Schmid D et al 1996 IEEE Transactions on Microwave Theory and Techniques
Magnetic Resonance Thermal Imaging (MRTI)

- MR thermometry has been used extensively for real-time noninvasive *in vivo* temperature monitoring
  - Laser-induced interstitial thermotherapy (LITT)
  - High-intensity focused ultrasound (HIFU)
  - RF ablation
  - Microwave heating for thermal ablation
Magnetic Resonance Thermal Imaging (MRTI)

ΔT = \frac{\phi_2 - \phi_1}{\alpha \gamma B_0 TE}

- \Delta T: Post-heating difference temperature map
- \phi_1, \phi_2: Reference and Post-heating images
- \alpha: Temperature dependency of the chemical shift
- \gamma: Gyromagnetic ratio
- B_0: Field strength
- TE: Echo Time

Phantom relevant

MR spin/system relevant

Sequence relevant (TE: Echo Time)

Images from Nick Todd, http://slideplayer.com/slide/3362796/
Mobile Phone Exposure Assessment with MRTI

A specific anthropomorphic mannequin (SAM) phantom was filled with dielectric water-based gel

Density = 1000 kg/m$^3$
Heat capacity = 2940 J/kg-K
Thermal conductivity = $0.347 \text{ W/m}^\circ \text{ C}$
$\alpha = 0.01 \text{ PPM/}^\circ \text{ C}$

An LG 920CU (LG Electronics, Seoul, South Korea) cell phone transmitting at maximum power at 1900 MHz GSM band

The maximum temperature change was 1.73 °C in close proximity to the cell phone antenna.
The maximum 10-g average SAR was 0.54 W/kg.
Experimental Setup

• Commercial Siemens whole-body 3T Magnetom Skyra scanner
• 20-channel head array for signal reception

• Acrylic cylindrical gel phantom (gelatin, water and sugar) with a radius = 8.25 cm and height = 21.6 cm
Experimental Setup

- YAV7.1 signal generator (Istok, Fryazino, Russia) operating at 42.25 GHz
- Millitech AMP-22-01120 power amplifier (Millitech, Northhampton, MA, USA)
- 3.1-meter long waveguide whose tip was placed orthogonally to the phantom

Measured output power density = 600 W/m² (3x ICNIRP limits)
Measurement Details

- One reference and multiple post-heating gradient echo (GRE) image were acquired with the following parameters:
  - TE = 15ms
  - TR = 54ms
  - Resolution = 2 mm³
  - Acquisition time = 7 seconds

Oil phantom used for MR thermometry reference

Waveguide illustration

Dielectric phantom used for thermometry
Image Acquisition Timeline

- mmWave Exposure
  - OFF
  - ON

- MR Measurements
  - Control Measurement
  - Reference Measurement
  - Heating Measurements

- Characterize the noise behavior of the measurements
- Analyze the sensitivity of the measurements

NYU Langone Medical Center
Temperature Change Results with MRTI

Temperature Maps

Temperature Profiles

Measurement of noise statistics

Measurement of Sensitivity
Maximum Temperature Change vs Time

0.35
0.3
0.25
0.2
0.15
0.1
0.05
0

0
2 Minutes
4 Minutes
6 Minutes
8 Minutes

Start
Measurement Noise Behavior

Noise Standard Deviation 0.0198
In Vivo
In vivo setup (42.25 GHz)

Output power density = 600 W/m²
(3x ICNIRP LIMIT)
In vivo results

Maximum = 1.3 °C
In vivo results – 5 minute exposure

Maximum = 4.75 °C
Discussion

• We demonstrated that the heating due to mmWave exposure can be measured directly using MRTI

• MRTI provides high temporal sensitivity and high spatial resolution
  – Small increments in the maximum temperature change is traced accurately
  – 3D temperature map for local exposure assessment is measured within seconds

• MRTI provides a frequency independent exposure assessment
Discussion

• Temperature penetration inside the phantom increases with heating time, due to heat diffusion effects.
  – This transient behavior could potentially result in precise measurements further inside the phantom shell \( \rightarrow \) exposure assessment for higher frequencies than presented here.
Exposure Assessment Of Wireless Devices at Frequencies Above 6 GHz
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