Body Wearable Antennas

Simulation Challenges
Antenna examples: RFID, ISM, UWB

Marc Rütschlin
Body Area Networks - Antennas

- BAN enabling technology: antennas
- Stringent requirements:
  - performance
  - form factor
  - legal - SAR
- Important design tool: simulation

Simulation Challenges

1. Large structures
   ⇒ solver choice, hardware constraints?

2. Material properties
   ⇒ how to obtain and define?

3. Construction and body model handling
   ⇒ how to deal with complex geometries?
Simulation Challenge 1: Model Size

- RFID antenna simulated on Intel® Xeon® E5620 2.4 GHz CPU, 4×Tesla 2070 GPUs

<table>
<thead>
<tr>
<th></th>
<th>RFID 870 MHz</th>
<th>ISM 2.4 GHz</th>
<th>UWB 6 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>mesh</td>
<td></td>
<td>11.1</td>
<td></td>
</tr>
<tr>
<td>[million cells]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>memory</td>
<td></td>
<td>4.3</td>
<td></td>
</tr>
<tr>
<td>[GB RAM]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>simulation time [min]</td>
<td>18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HPC options</td>
<td></td>
<td>GPU</td>
<td></td>
</tr>
</tbody>
</table>

- ε_r = 42
- 3 mm
- 1.8 m
- 34 λ
- RF
- RFID 870 MHz
- ISM 2.4 GHz
- UWB 6 GHz
Simulation Challenge 1: Model Size

- $\varepsilon_r = 42$
- ISM antenna
- 1.8 m
- $93 \lambda$
- 4 mm
- $\lambda$

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<tbody>
<tr>
<td>mesh [million cells]</td>
<td>11.1</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>memory [GB RAM]</td>
<td>4.3</td>
<td>63</td>
<td></td>
</tr>
<tr>
<td>simulation time [min]</td>
<td>18</td>
<td>51</td>
<td></td>
</tr>
<tr>
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simulated on Intel® Xeon® E5620 2.4 GHz CPU, 4×Tesla 2070 GPUs
# Simulation Challenge 1: Model Size

**ε_r = 42**

<table>
<thead>
<tr>
<th>Frequency</th>
<th>RFID 870 MHz</th>
<th>ISM 2.4 GHz</th>
<th>UWB 6 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>mesh [million cells]</td>
<td>11.1</td>
<td>120</td>
<td>940</td>
</tr>
<tr>
<td>memory [GB RAM]</td>
<td>4.3</td>
<td>63</td>
<td>650?</td>
</tr>
<tr>
<td>simulation time [min]</td>
<td>18</td>
<td>51</td>
<td>?</td>
</tr>
<tr>
<td>HPC options</td>
<td>GPU</td>
<td>more GPU</td>
<td>MPI + GPU</td>
</tr>
</tbody>
</table>
Simulation Challenge 2: Materials

“A simulation model is only as good as its material property definitions!”

phantom model  voxel model  antennas
Materials: Homogeneous Phantom

- Relatively simple: homogeneous $\varepsilon_r = 42$, $\sigma = 1 \text{ S/m}$
- Dispersive!
- SAT format models from
  - CST examples
  - External software like Poser® or MakeHuman.org
  - www.sam-phantom.com
Materials: Voxel Models

- Complex body models with realistic materials
- Dispersive; aging effects
- Models from
  - CST Voxel Family
  - Visible human voxel data (HUGO)
  - Other voxel sources (standard import format)
Simulation Challenge 3: Geometry

- Deformation of antennas
  - bending, crumpling, stretching, ...
- Positioning of antennas on body
Example 1: RFID Antenna

- 870 MHz RFID slot antenna
- Why RFID?
  - low power = low SAR
  - no battery required
  - problem: human body absorber
- Aim here:
  show effect of deformation and proximity to body on antenna performance and SAR

$Z_{\text{chip}} = 15 - j80 \, \Omega$
$\varepsilon_{r,\text{felt}} = 1.17$
$\sigma_{\text{felt}} = 2 \times 10^{-4}$

Effect of Bending

influence of bending in both directions on S11 of RFID tag

variation of radius of curvature from 20 to 100 mm around both axes

slot orientation

horizontal plane

vertical plane

flat tag
Comparing 4 cases:
1. antenna only
2. antenna on full h-body
3. antenna on part of h-body
4. antenna on voxel model

Effect on Antenna S11

![Graph showing S11 magnitude for different cases](chart.png)
Effect of Body on Farfield

bent antenna only

antenna on full homogeneous body
Voxel Body vs. Homogeneous Body?

antenna on voxel body

antenna on full homogeneous body
Do we need the whole body?

antenna on partial homogeneous body  \[ \text{ok?} \]  antenna on full homogeneous body
Do we need the whole body?

antenna on partial homogeneous body  antenna on full homogeneous body
Do we need the whole body?

insets: partial body model simulation
Farfield Cut-planes

Farfield Directivity Abs (Theta=90)

Farfield Directivity Abs (Phi=0)

vertical plane

horizontal plane

antenna position
RFID Read Range

receiver sensitivity: -15 dBm
max. read range: 1 m

receiver sensitivity: -60 dBm
max. read range: 182 m
Specific Absorption Rate

- Antennas affect body
- SAR: legal requirement
- Questions:
  - which body model?
  - which standard?
  - input power?
  - antenna deformation?
  - antenna positioning?

See application note on support website!
SAR: Voxel vs Homogeneous Model?
Power Loss: Voxel vs. Homogeneous

Homogeneous body model

Voxel model
SAR: Voxel vs Homogeneous Model

Homogeneous body model

0.25 W accepted power
max. SAR: 0.667 W/kg

Voxel model

0.25 W accepted power
max. SAR: 0.883 W/kg

internal structure: different distribution
SAR: Positioning of model

Homogeneous body model

Voxel model

0.25 W accepted power max. SAR: 0.667 W/kg

0.25 W accepted power max. SAR: 0.988 W/kg

antenna position shifted by just 2 mm
SAR of Homogeneous vs. Reduced

Full homogeneous body model

0.25 W accepted power
max. SAR: 0.667 W/kg

Partial homogeneous body model

0.25 W accepted power
max. SAR: 0.644 W/kg
Example 2: ISM Patch Antenna

- 2.4 GHz circularly polarised (CP) patch antenna
- Why CP?
  - reduce multipath effects in scattering rich environments
- Aim here:
  - more detailed SAR study
  - multiple antennas - MIMO - a good idea?

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\[ \varepsilon_{r,\text{foam}} = 1.52, \tan\delta_{\text{foam}} = 0.012 \]

\[ \varepsilon_{r,\text{textile}} = 1.85, \tan\delta_{\text{textile}} = 0.015 \]

Multiple Antennas

Four antennas positioned around body

all antennas excited simultaneously

realised gain at 2.4 GHz
MIMO Output

Weighting Function (shown at left):
- Vertical component: mean: 0°, sigma: 20°
- Horizontal component: mean: 0°, sigma: 20°

Cross-Polarisation Rate XPR = 0 dB

<table>
<thead>
<tr>
<th>Port no.</th>
<th>$S_{xy}$ at 2.4 GHz</th>
<th>Correlation coefficient</th>
<th>Diversity gain</th>
<th>Multiplexing efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ⇔ 2</td>
<td>-52 dB</td>
<td>$3.8 \times 10^{-7}$</td>
<td>10 dB</td>
<td>55 %</td>
</tr>
<tr>
<td>1 ⇔ 3</td>
<td>-55 dB</td>
<td>$3.8 \times 10^{-7}$</td>
<td>10 dB</td>
<td>60 %</td>
</tr>
<tr>
<td>2 ⇔ 3</td>
<td>-54 dB</td>
<td>$3.8 \times 10^{-7}$</td>
<td>10 dB</td>
<td>62 %</td>
</tr>
<tr>
<td>3 ⇔ 4</td>
<td>-80 dB</td>
<td>$3.8 \times 10^{-7}$</td>
<td>10 dB</td>
<td>67 %</td>
</tr>
</tbody>
</table>

Built-in postprocessing template
Example 3: UWB Antenna

- 3-6 GHz UWB slot antenna
- Why UWB?
  - low power
  - slot: shielding of body
- Aim here:
  - challenges in high frequency simulation of on-body antennas

1.8 m
233 λ

Antenna Performance

UWB antenna S11 comparison

Broadband farfield of flat antenna

frequency range: 3.5-6 GHz
Simulation of a Reduced Volume

variation in S11 for different volumes

Box 1: 200x200x200 mm
52 million mesh cells
18 GB RAM

Box 2: 300x400x400 mm
184 million mesh cells
52 GB RAM

Box 3: 600x200x400 mm
280 million mesh cells
72 GB RAM
Simulation of a Reduced Volume
directivity at 5.65 GHz for different volumes

Box 1: 200x200x200 mm
52 million mesh cells
18 GB RAM

Box 2: 300x400x400 mm
184 million mesh cells
52 GB RAM

Box 3: 600x200x400 mm
280 million mesh cells
72 GB RAM
UWB Antenna Fidelity

Cross Correlation peak

Group delay

Antenna in free space

Antenna on body

Time in ns

Frequency in GHz
Conclusion

- **Challenging topic** with many subtleties
- **Simulation an essential tool** for looking at
  - different antennas at different frequency ranges
  - external and internal field related quantities ⇒ different body models and sizes as required
  - different output quantities (SAR, MIMO, UWB fidelity, …)
Thank you for your attention!

Questions?