Towards printed wearable antennas for energy harvesting

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Motivation

- In-car wireless sensor networks
Vehicle → Human body
## Parameters of human body

<table>
<thead>
<tr>
<th>Tissue</th>
<th>$\varepsilon_r$ [GHz]</th>
<th>$\varepsilon_r$ [GHz]</th>
<th>$\sigma$ [S/m]</th>
<th>$\sigma$ [S/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tissue</td>
<td>2.40</td>
<td>5.80</td>
<td>2.40</td>
<td>5.80</td>
</tr>
<tr>
<td>Skin</td>
<td>38.063</td>
<td>35.114</td>
<td>1.441</td>
<td>3.717</td>
</tr>
<tr>
<td>Fat</td>
<td>5.285</td>
<td>4.955</td>
<td>0.102</td>
<td>0.293</td>
</tr>
<tr>
<td>Muscle</td>
<td>52.791</td>
<td>48.485</td>
<td>1.705</td>
<td>4.962</td>
</tr>
</tbody>
</table>

- Lossy dielectrics → poor efficiency of slot antennas
- What range of frequencies?
Measurement of available energy

- GSM 1800 – 1.840 GHz
- UMTS 2100 – 2.145 GHz
- WiFi 2400 – 2.445 GHz
- Required bandwidth BW = 28%
Additional requirements

- Energy harvesting conditioned by
  - Omnidirectional radiation patterns
  - Very high radiation efficiency
- Proximity of human body $\rightarrow$ ground plane preferred to shield the body
- Low profile (small distance) from ground plane $\rightarrow$ magnetic antenna preferred
- Dielectric resonator antenna
Dielectric resonator antenna

- Arlon AR600
  \[ h = 1.575 \text{ mm}, \quad \varepsilon_r = 6.15, \quad \tan \delta = 0.003 \]

Dielectric resonator antenna

- Optimum notch angle: 90 °
- Fundamental mode: HEM11
- Impedance bandwidth proportional to height of resonator (min. height for required BW: 25.2 mm)
Towards inkjet printing

- But, the height of the DRA has to be reduced
DRA – impedance matching

![Graph showing S11 vs frequency for simulation and measurement](image)
DRA – patterns @ 1.840 GHz

$\phi = 0^\circ$

$\phi = 90^\circ$
DRA – patterns @ 2.145 GHz

phi = 0°

phi = 90°
DRA – patterns @ 2.445 GHz

\( \phi = 0^\circ \)

\( \phi = 90^\circ \)
DRA – final parameters

<table>
<thead>
<tr>
<th>Frequency [GHz]</th>
<th>Radiation eff. [dB]</th>
<th>Total eff. [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.840</td>
<td>-0.050 (99.4 %)</td>
<td>-0.40 (95.5 %)</td>
</tr>
<tr>
<td>2.145</td>
<td>-0.062 (99.3 %)</td>
<td>-0.45 (94.9 %)</td>
</tr>
<tr>
<td>2.445</td>
<td>-0.083 (99.0 %)</td>
<td>-0.39 (95.6 %)</td>
</tr>
</tbody>
</table>

- **Radiation efficiency:** dielectric and conduction losses
- **Total efficiency:** Radiation efficiency increased by mismatch loss
Towards inkjet printing

- Available inks Sigma-Aldrich
  - http://www.sigmaaldrich.com
- Silver nanoparticle inks
- Photovoltaic inks
- Dielectrics inks
- Semiconductor inks
- ...

Conclusions

- Dielectric resonator antennas
  - Acceptable parameters
  - Height of resonator to be reduced
  - Feeding to be redesigned

- Inkjet printing
  - Wide spectrum of inks available
  - The whole harvesting system can be printed
  - Special inks rather expensive

- Prototype of printed harvester under development
Thank you for your attention

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