Modeling of the Test Fixtures to Improve the HBC Channel Interpretation

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Presentation Outline

• Human Body Communication - HBC
• HBC Channel modeling
  ▪ Primary channel model
• HBC Channel measurements
  ▪ Measurement system and results
• Test Fixture modeling
  ▪ Extended Model
• Final Considerations
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HBC – Human body communication

- Electrostatic coupling to the body using electrodes (galvanic and capacitive).

HBC – Human body communication

- Electrostatic coupling to the body using electrodes (galvanic and capacitive).
- Low frequency operation (<100 MHz).
- Advantages over other BAN options:
  - Higher data security.
  - Higher coexistence.
  - Lower channel attenuation.
  - Lower power consumption.

Capacitive HBC characterization and modeling

- Required for link budget analysis (Tx output power, Rx sensitivity, operating frequency).
- Literature review:
  - Different author find different attenuation levels and frequency profile.
  - Most models cannot fully reproduce the measured channel frequency profiled.
  - Obtained models are not complete or where not validate correctly.
  - Correct channel path is not preserved.
  - Neglecting of the influence of test fixture.
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Primary channel

- Primary channel partitioning:
  - Intrinsic channel.
  - Extrinsic channel.
- Secondary channel: external structures (environment and test fixture).
Intrinsic channel

- Network based on unit blocks equivalent circuit offers good compact alternative [Xu et al., 2011].

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Extrinsic channel

- Return capacitances: empirical exp. and 3D EM simulations EM 3D.
Extrinsic channel

- Body leakage capacitances.
- Inter-electrode and electrode skin impedances.
## Primary channel

<table>
<thead>
<tr>
<th>$R_{arm}$</th>
<th>65 Ω</th>
<th>$R_{chest}$</th>
<th>500 Ω</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_{arm}$</td>
<td>25 pF</td>
<td>$C_{chest}$</td>
<td>3.5 pF</td>
</tr>
<tr>
<td>$C_{leak-a}$</td>
<td>0.7 pF</td>
<td>$R_{torso}$</td>
<td>600 Ω</td>
</tr>
<tr>
<td>$C_{leak-t}$</td>
<td>15 pF</td>
<td>$C_{torso}$</td>
<td>4 pF</td>
</tr>
<tr>
<td>$C_{injec}$</td>
<td>5.5 pF</td>
<td>$R_{injec}$</td>
<td>250 Ω</td>
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</tbody>
</table>

### Intrinsic channel

- $C_{ret}$: 870 fF
- $C_e$: 11.3 pF
- $C_{X-20}$: 25 fF
- $C_{X-30}$: 16 fF
- $C_{X-140}$: 1.25 fF

Diagram of the intrinsic channel showing the connections between $R_{arm}$, $R_{chest}$, $R_{torso}$, $C_{arm}$, $C_{chest}$, $C_{torso}$, and $C_{injec}$.
Primary channel model

- High pass profile.
- Low frequency dependence on distance.
- Attenuation levels between 50-100 dB.

RX (30 cm)
RX (15 cm)
TX
RX (140 cm)
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Measurement system

• R&S ZVB VNA.
• Baluns FTB-1-1.
• Cables RG 316.
• 2 x 2 cm² electrodes.
• SOLT calibration at the balun’s transitions.
Channel measurements

- Pass band profile.
- Independence of $d$ in lower frequencies.
- Attenuation levels between 10-50 dB.
Measurements and model comparison

- 30 cm propagation distance.
- Differences on freq. profile.
- Over 45 dB higher attenuation.
- Balun’s effect [Sakai et al, 2013].

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Test fixture modeling

- DUT and test fixture transitions.
  - Modified cables transitions model.
  - Baluns: model extraction.
Extended model

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### Intrinsic channel

- $C_{iw}$: 27.2 pF
- $L_1$: 420 nH
- $C_{dis}$: 12.3 pF
- $L_m$: 200 uH
- $C_t$: 6 nH

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</tr>
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<tbody>
<tr>
<td>$C_{ret}$</td>
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<tr>
<td>$C_e$</td>
<td>11.3 pF</td>
</tr>
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<td>25 fF</td>
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Extended model

- Reproduces the band pass profile.
- Low frequency independence of d.
- Around 45 dB lower attenuation.
Measurements and Extended model comparison

- Good extended model fit below 70 MHz
- Differences < 5.5 dB.
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Final Considerations

- Contributions:
  - Proposal of a systematic primary channel partitioning that facilitates HBC understanding and modeling.
  - Proposal of extended model that includes the test fixture.
  - Verification of test fixture influences.
  - Validation of primary channel model and identification of challenges for transceiver design.

- Ongoing studies:
  - Methodology to de-embed the test fixture from measurements.
Thank You