Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: [A Statistical Path Loss Model for MICS]
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Abstract: [This contribution describes a simple statistical model representing the path loss for communication to/from an implant or between two implant inside a human body. It consists of detailed characterization of path loss model parameters with the center frequency of 403.5 MHz i.e. MICS band.]

Purpose: [This information is intended for the IEEE 802.15.6 to adopt the path loss model and use it in link budget calculations for validation of throughput and range requirements of TG6 PHY proposals as related to MICS]

A Statistical Path Loss Model for MICS

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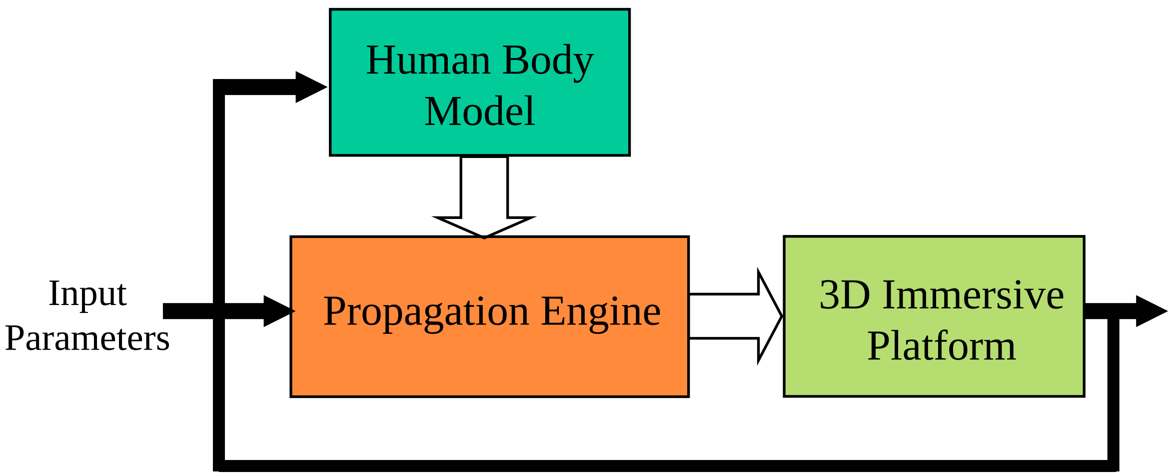
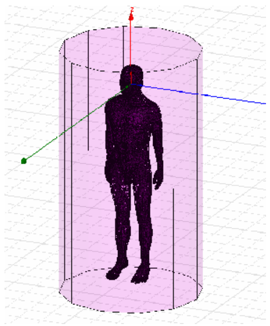
Medical Implant Communication Service (MICS)

- Unlicensed band allocated for communication between an implanted medical device and an external controller
- Allocated frequency 402MHz to 405MHz. Primary reasons for selecting these frequencies are:
  - Better propagation characteristics for implants
  - Reasonable sized antenna for implants
  - Worldwide availability
  - Limited threat of interference to primary users

Background: A 3D Immersive Platform to Study MICS Channel Propagation

As in-body measurement and experimental study is difficult (if not impossible), a 3D simulation & visualization scheme is proposed to study the propagation characteristics of MICS





System Components in the NIST 3D Immersive Platform

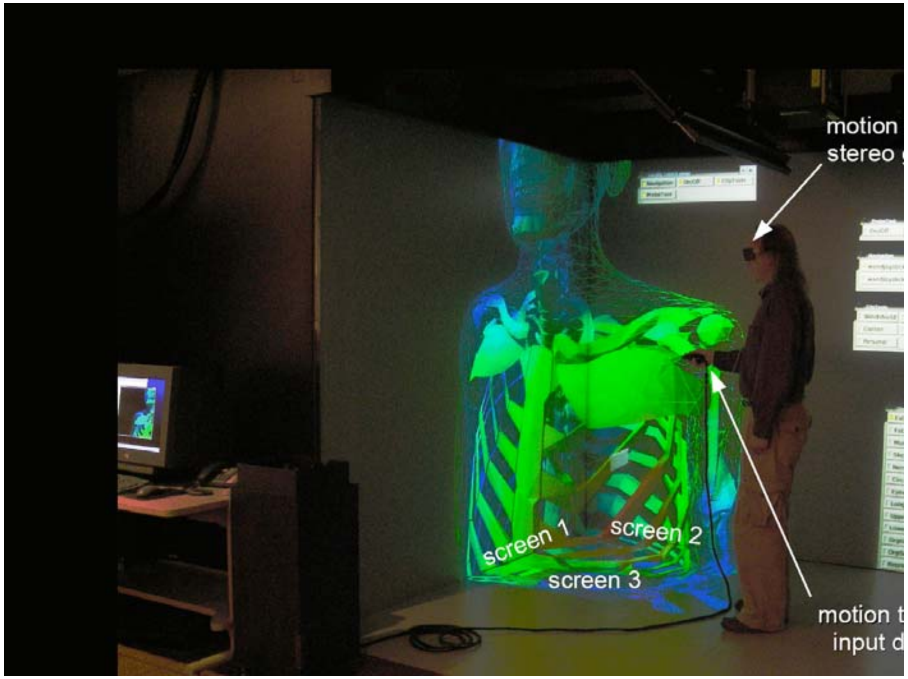
Human Body Model

- Dielectric properties of 300+ parts in a male human body
- Frequency-dependent biological material
- Properties are user-definable if changes are desired
- Accuracy of 2mm

Propagation Engine

- 3D full-wave electromagnetic field simulation (HFSS)
- Capable of calculating a variety of outputs

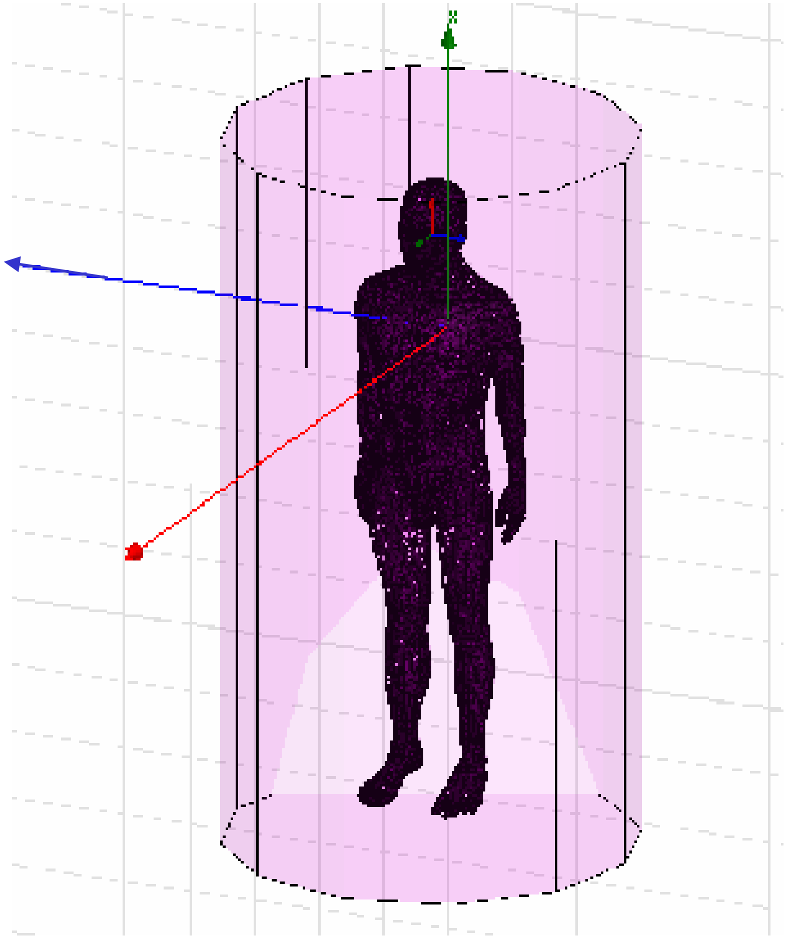
3D Immersive & Visualization Platform



A User in the NIST Immersive Visualization Environment

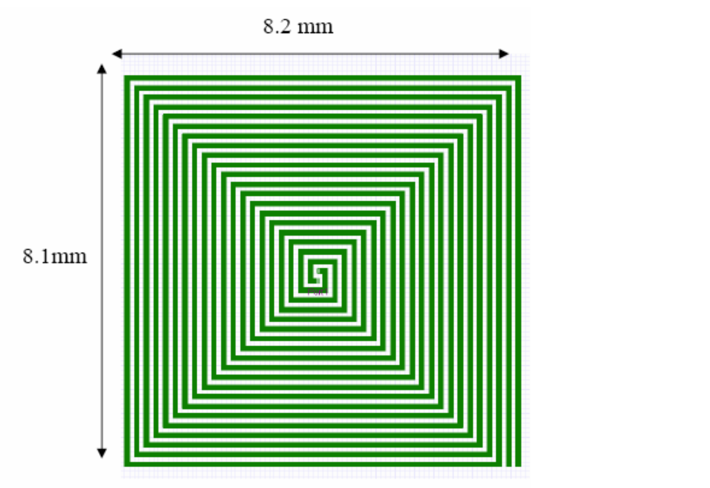
Input Parameters

- ❑ Antenna characteristics
- ❑ Antenna Location
    - Various deep tissue and body surface applications
- ❑ Antenna Orientation
    - Facing parallel to the body surface
- ❑ Operating Frequency
    - 403.5 MHz
- ❑ Transmit Power
- ❑ Resolution
- ❑ Range
- ❑ Output Parameter
    - e.g. Received power

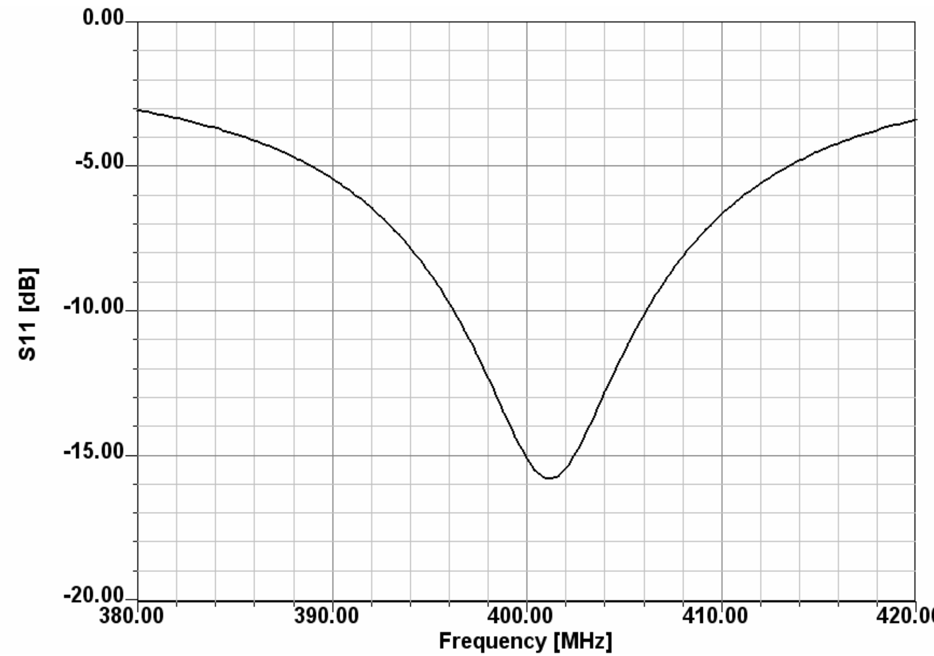


Antenna Used in The Simulation

- Size: 8.2 x 8.1 x 1 mm
- Metallic Layer: Copper, t=0.036 mm
- Substrate: D51 (NTK),
  ε_r =30, $\tan\theta$ = 0.000038, and t=1mm
- The metallic layer is covered by RH-5
  ε_r =1.0006, $\tan\theta$ = 0, t =1mm

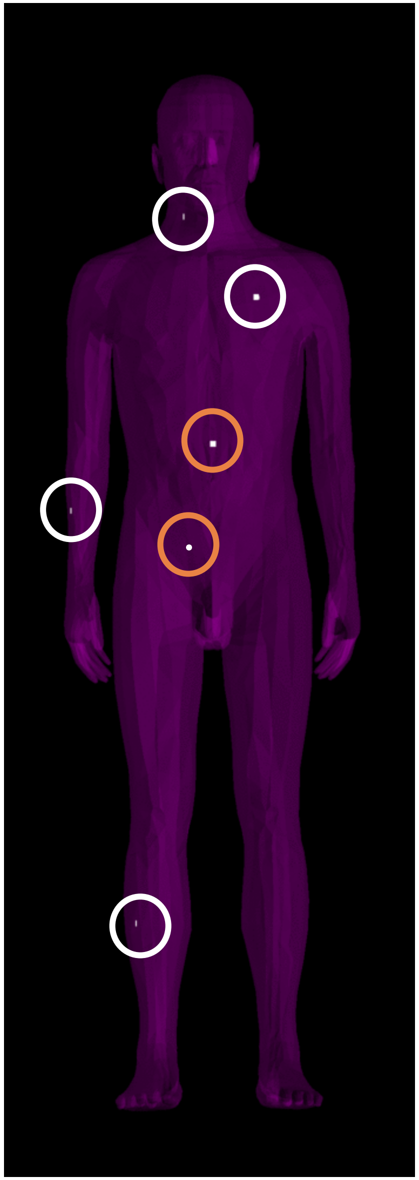


Return Loss of the Antenna



Simulated Scenarios

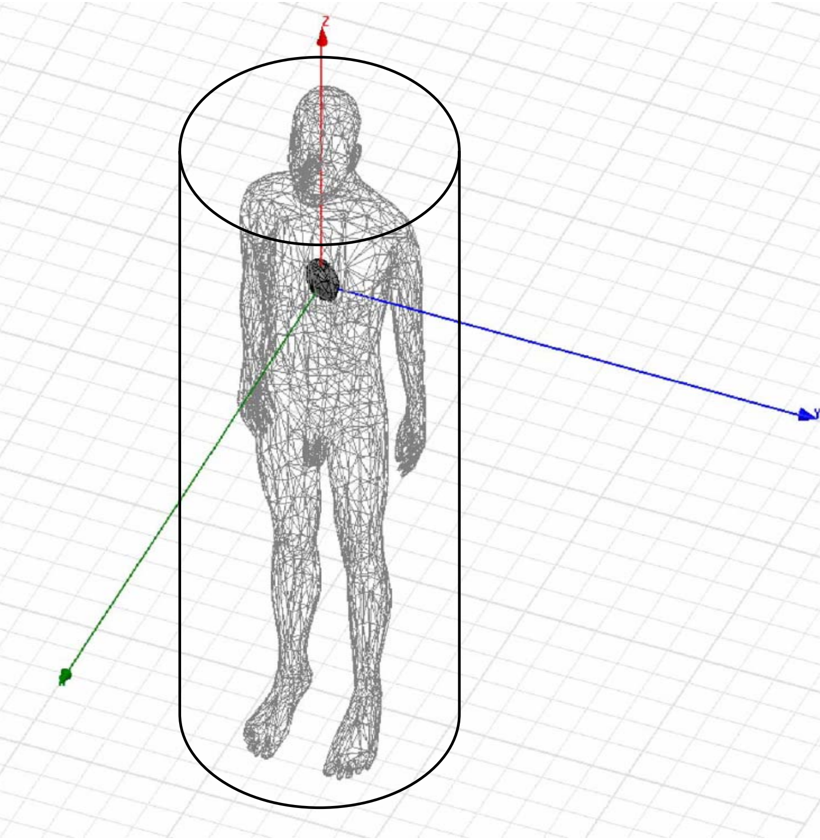
- **Near Surface Implant:**
    - ICD and Pacemaker (Left Pectoral Muscle)
    - Vagus Nerve Stimulation (Right Neck & Shoulder)
    - Motion Sensor
        - Right Hand
        - Right Leg
- **Deep Tissue Implant:**
    - Endoscopy Capsule
        - Upper Stomach (95mm below body surface)
        - Lower Stomach (118mm below body surface)



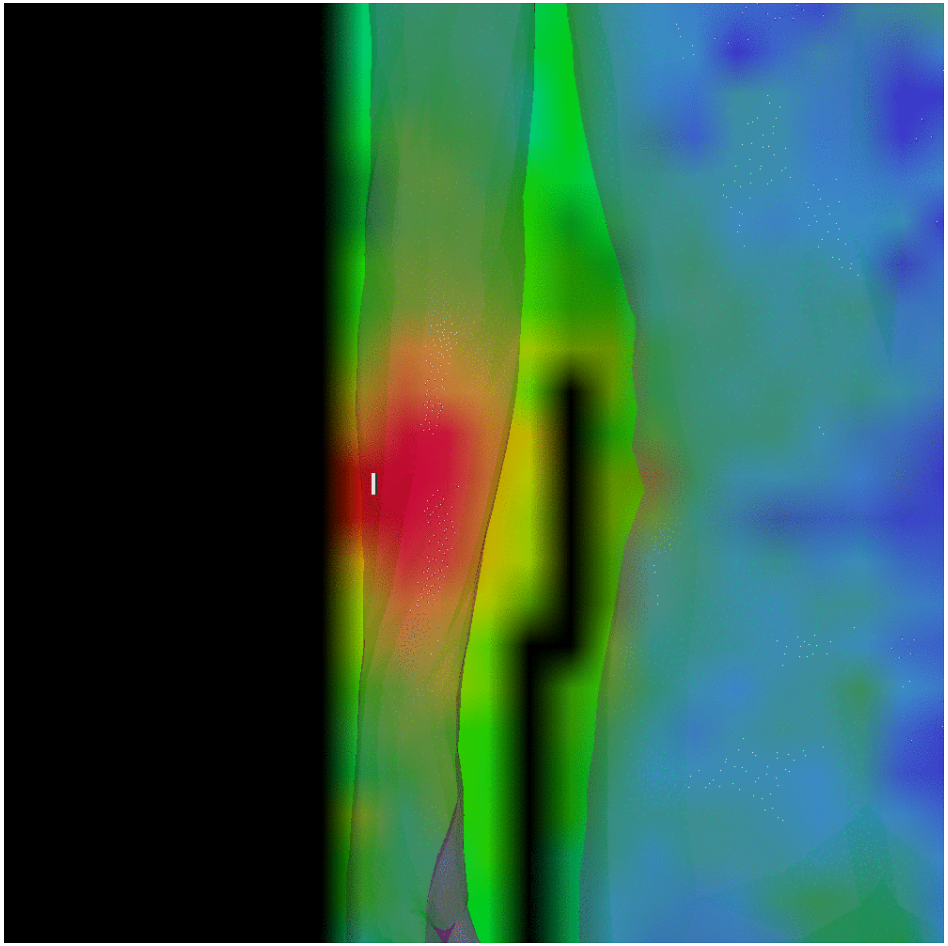
Methodology

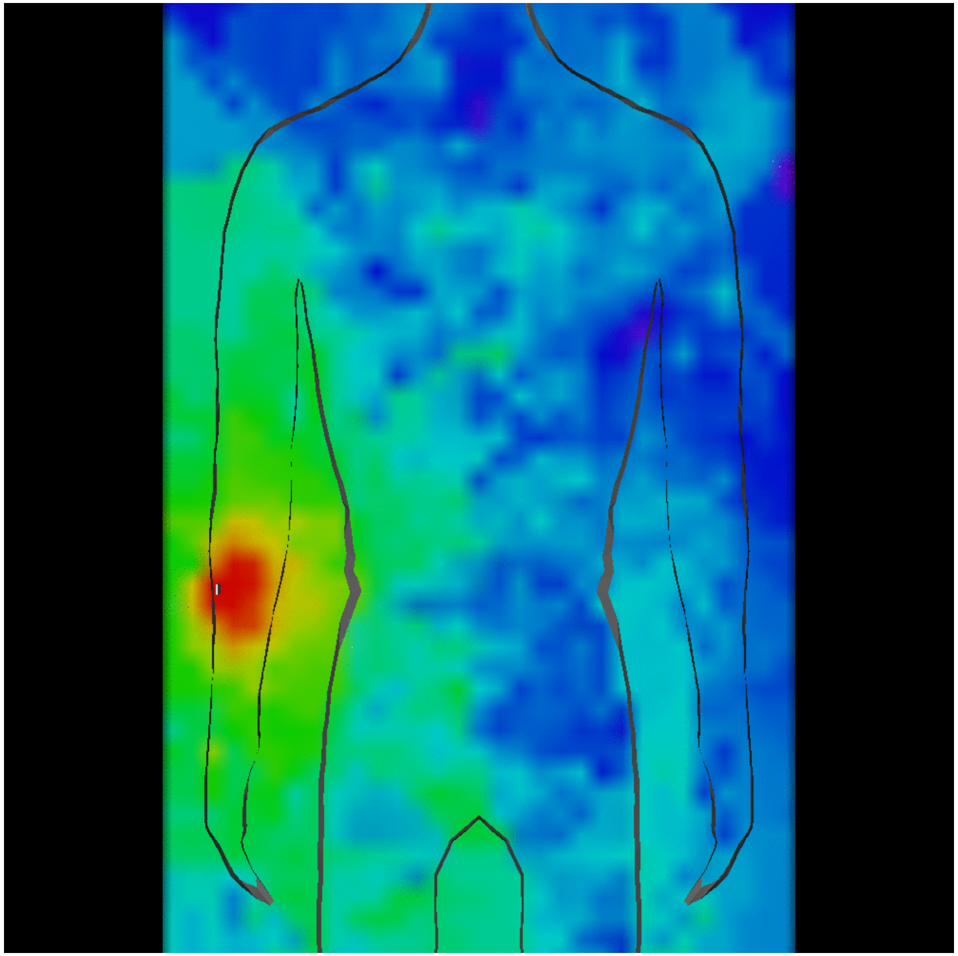
❑ Per scenario (i.e. TX location), the received power was calculated for a grid of points within a cylinder area around the body as shown. Then, the resulting data was filtered into 3 sets:

- ❑ In-body propagation: The sets of points that completely reside inside the body
- ❑ In-body to body surface propagation: The set of points that reside within a definable distance (2mm, 10mm, 20mm, 50mm) from the body surface
- ❑ In-body to out-body propagation: The set of points that reside further away from the body surface

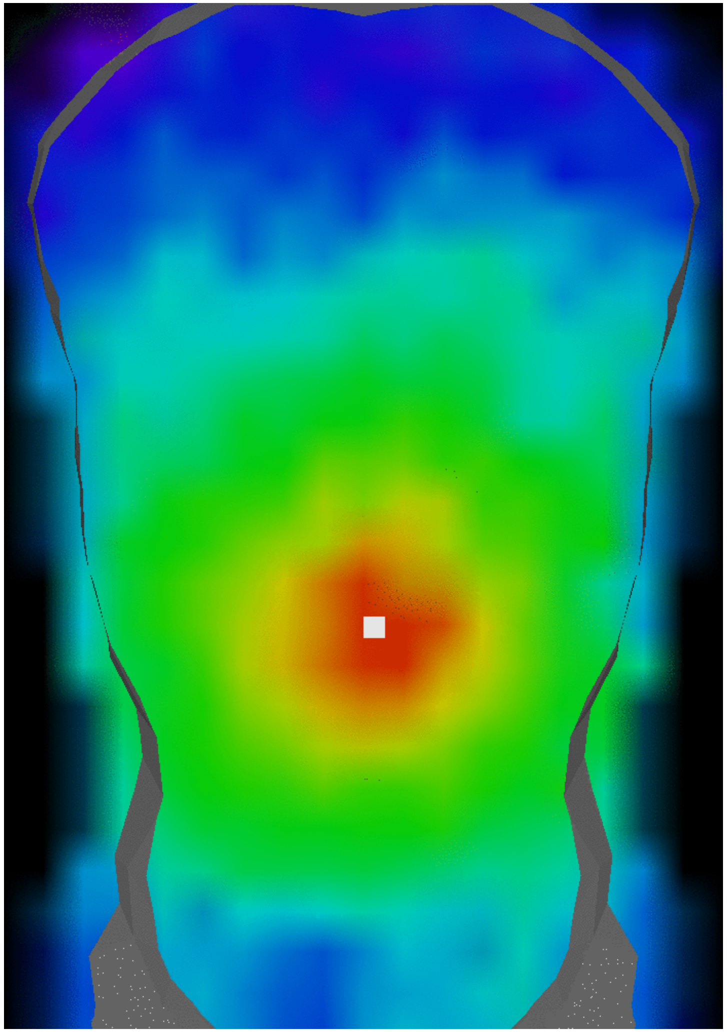


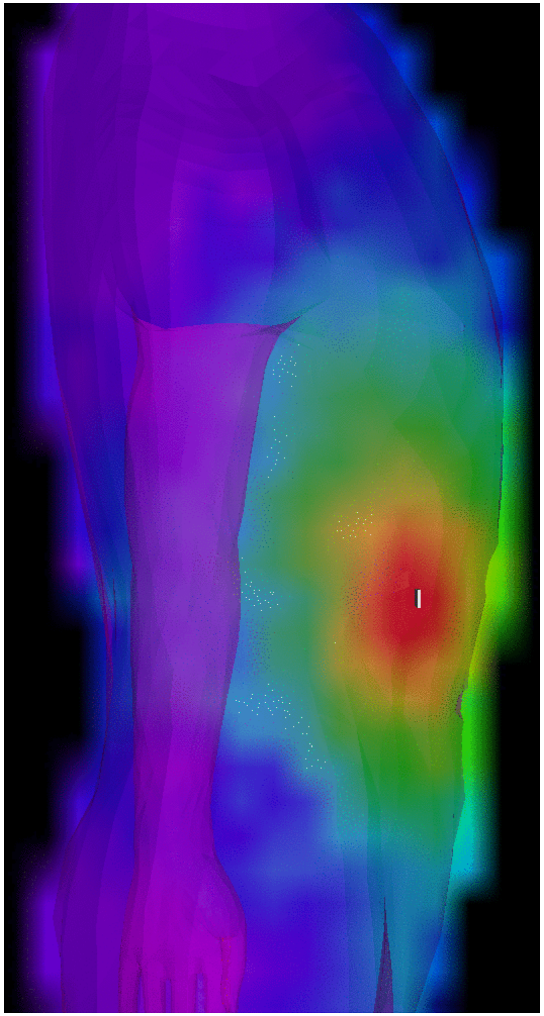
Sample Result (Right Arm)





Sample Result (Upper Stomach)





The Path Loss Model

Path loss is defined as: $PL(d) = \frac{G_T G_R P_T}{P_R}$

Where G_T : *Transmit Antenna Gain*

G_R : Re*ceive Antenna Gain*

P_T : *Transmit Power*

P_R : Re*ceived Power*

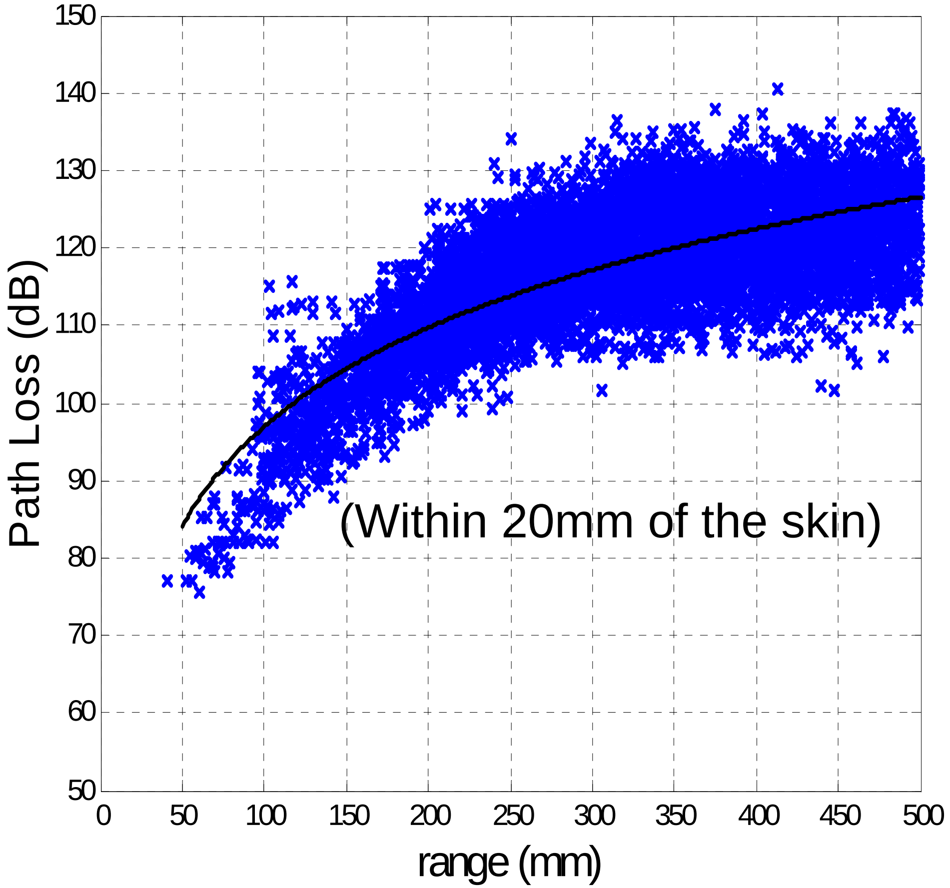
Path Loss (PL) versus distance (d) can be represented by:

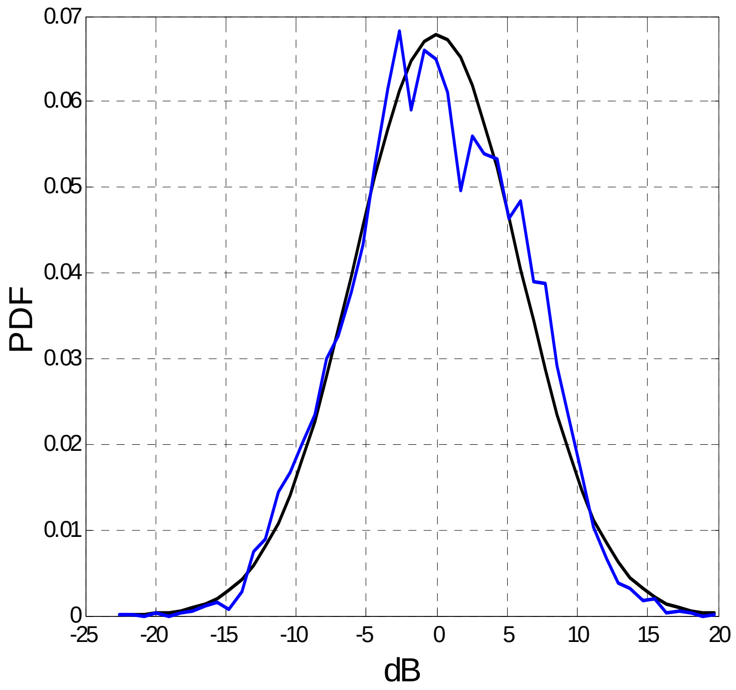
$$PL(d) = PL(d0) + 10n \log 10(d / d0) + S \qquad d \geq d0$$

Where:

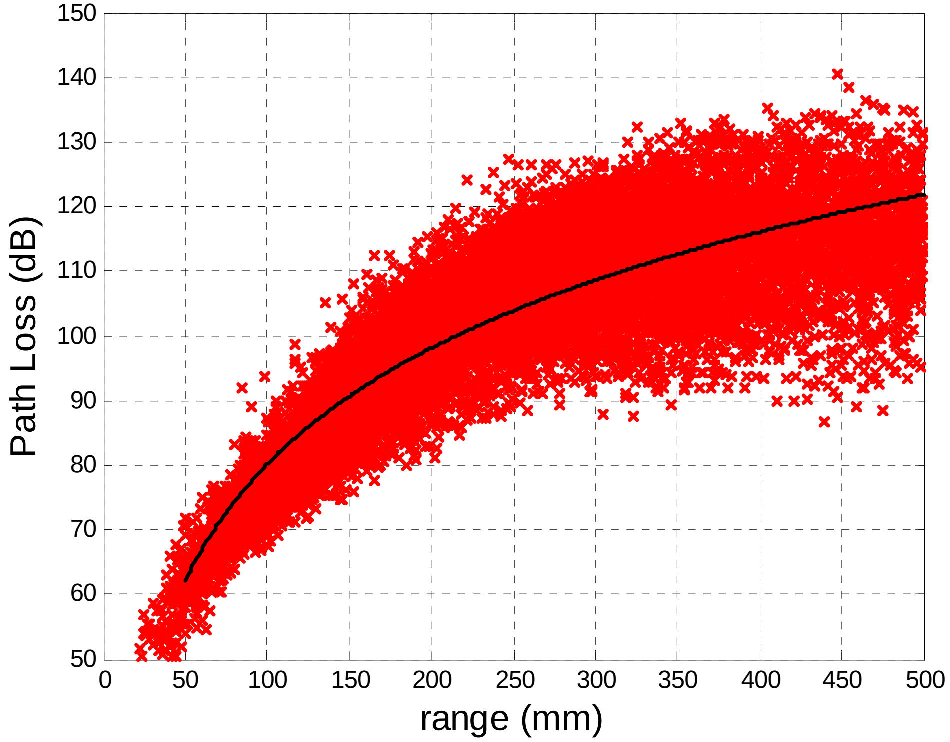
*d*o is a reference distance (e.g., do = 50mm)
S is the random scatter around the regression line

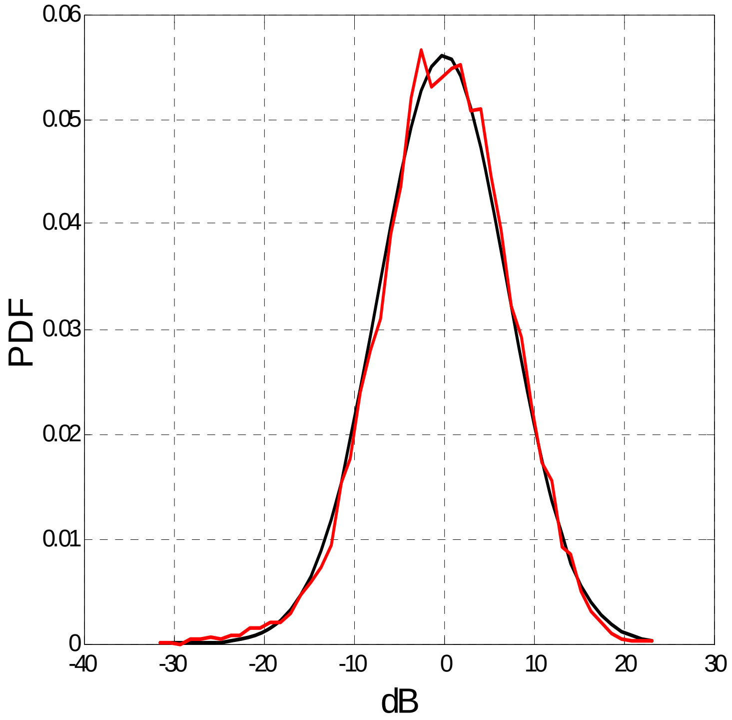
Path Loss vs. Distance Scatter Plot (Deep Tissue Implant to Body Surface)



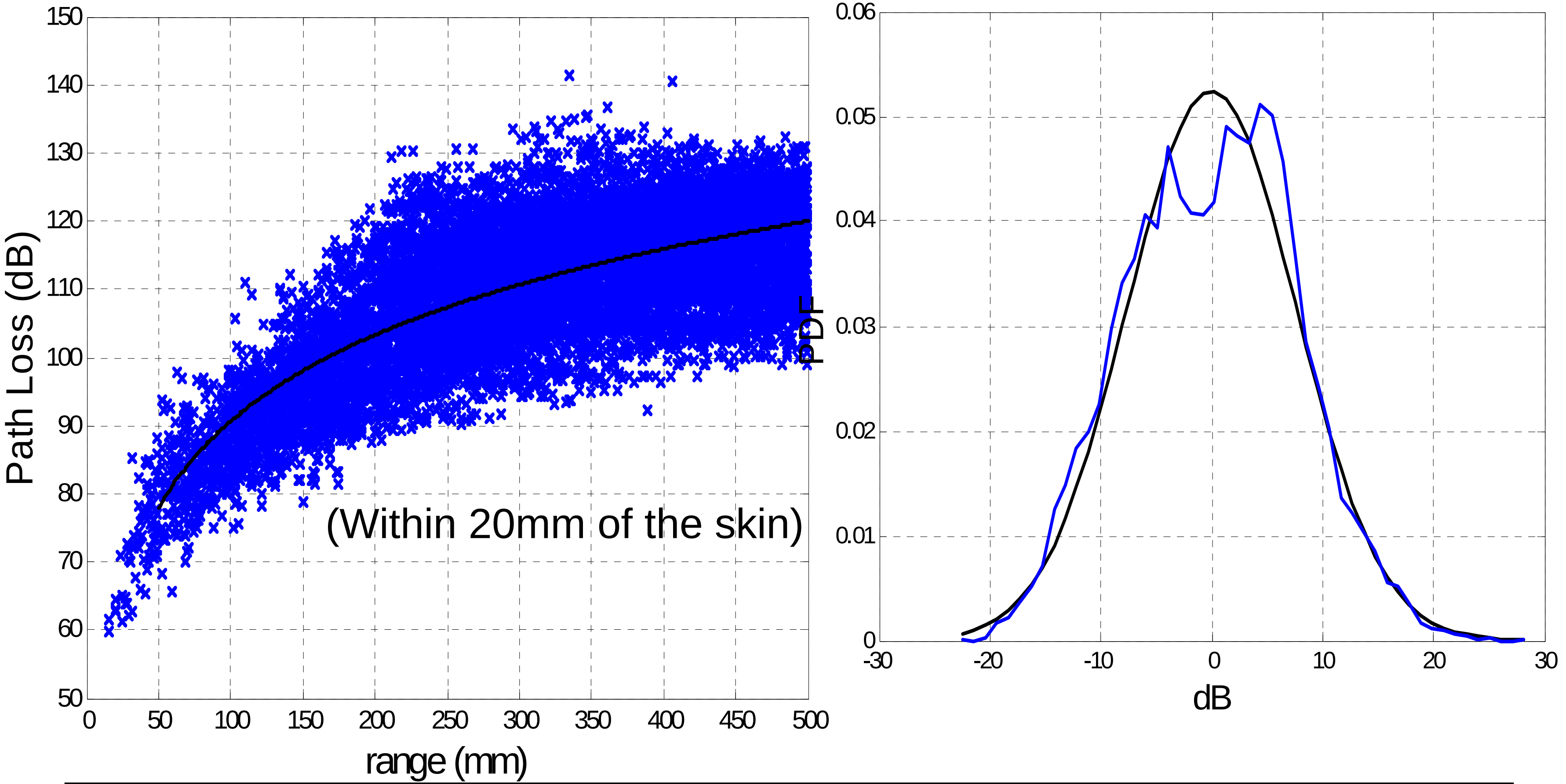


Path Loss vs. Distance Scatter Plot (Deep Tissue Implant to Another Implant)

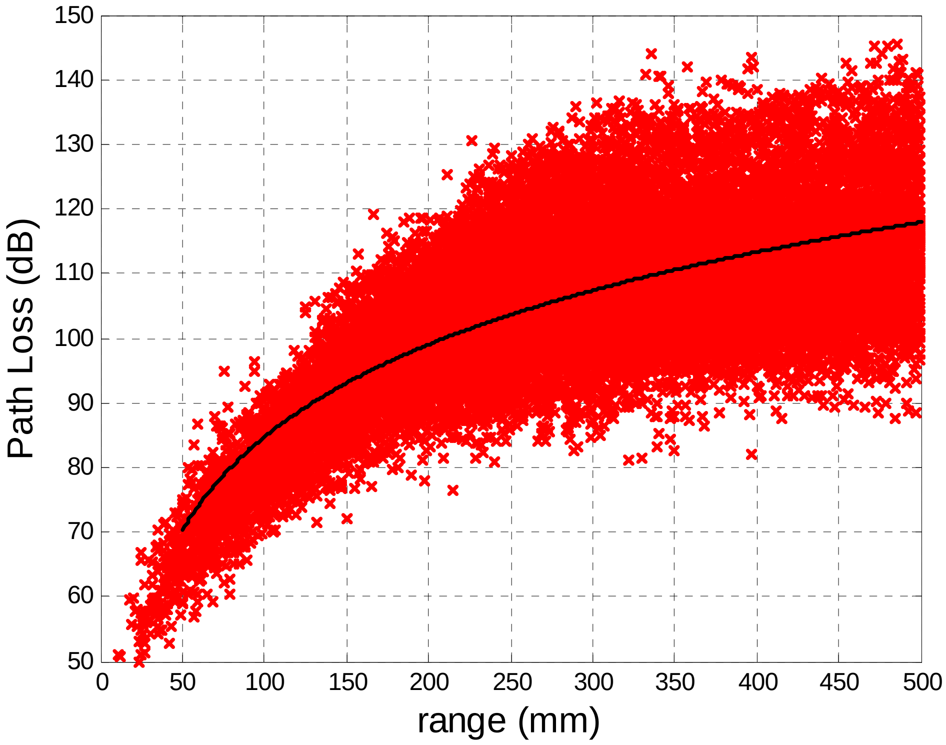


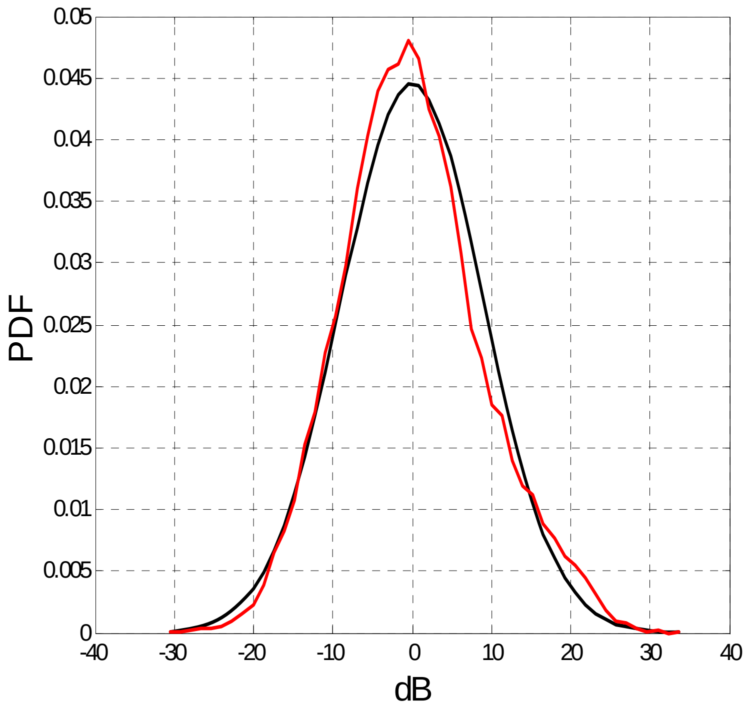


Path Loss vs. Distance Scatter Plot (Near Surface Implant to Body Surface)



Path Loss vs. Distance Scatter Plot (Near Surface Implant to Another Implant)





Path Loss Model Parameters

Implant to On-body	$PL(d_0)$ (dB)	n	$\sigma_s (dB)$
Deep Tissue	84.20	4.24	5.88
Near Surface	77.98	4.20	7.61

Implant to Implant	$PL(d_0)$ (dB)	n	$\sigma_s (dB)$
Deep Tissue	62.15	5.97	7.11
Near Surface	70.39	4.75	8.95

$$PL(d) = PL(d_0) + 10n \log_{10}(d / d_0) + S \qquad S \sim N(0, \sigma_S) \qquad d_0 = 50mm$$

Conclusion

- Extensive simulation to characterize the MICS path loss has been performed and a statistical path loss model at 403.5 MHz is presented.
- The model is based on 4 near surface implants and 2 deep tissue implants applications for a typical male body.
- Path loss model key parameters for specific application can also be obtained.
- The result is a general statistical path loss model which upon availability of physical experiment/measurements needs to be validated or adjusted.

References

- Doc: 15-08-0351-00-0006-MICS Channel Characteristics-Preliminary Results
- Doc: 15-08-0033-00-0006-channel-model-for-body-area-network
- Doc: 15-08-0034-06-0006-ieee-802-15-6-regulation-subcommittee-report-doc

Acknowledgement

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