Project: IEEE P802.15 Working Group for Wireless Specialty Networks

Submission Title: Statistical Pathloss Model for UWB Wireless Capsule Endoscopy
Date Submitted: July 11th, 2022
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Re: In response to call for technical contributions to the TG6ma Channel Models

Abstract: This document contains an UWB Pathloss Model for Wireless Capsule Endoscopy (WCE) communication. It is intended to support the IEEE802.15.6ma Channel Models for WCE usecase.

Purpose: Statistical Pathloss Model for UWB Wireless Capsule Endoscopy in IEEE802.15.6ma

Wireless Capsule Endoscopy

- A Wireless Capsule Endoscopy (WCE) is an ingestible capsule equipped with a miniaturized camera and electronics to transmit images.

- It provides a minimally-invasive alternative imaging technology for the entire Gastrointestinal (GI) tract of the human body.

- Current commercially available capsules operate at Medical Implant Communication Service (MICS) and Industrial, Scientific and Medical (ISM) bands.

Source: https://www.medtronic.com/covidien/en-us/products/capsule-endoscopy/pillcam-colon-2-system.html

Disclaimer: Commercial products identified in this presentation is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the products are necessarily the best available for the purpose.

Next Generation WCE

- Next generation of endoscopy capsules (i.e., medical micro-robots) are expected to deliver higher quality images or even videos as well as more diagnosis and therapeutic functionality.

- This will require a communication link with higher data rates.

- Ultra Wideband (UWB) technology is an attractive candidate to high data rates for future WCE applications. The low complexity of a UWB transceiver also implies less power consumption.

- A statistical pathloss model that describes the attenuation between the capsule and the on-body receiver is typically needed as part of the PHY layer design

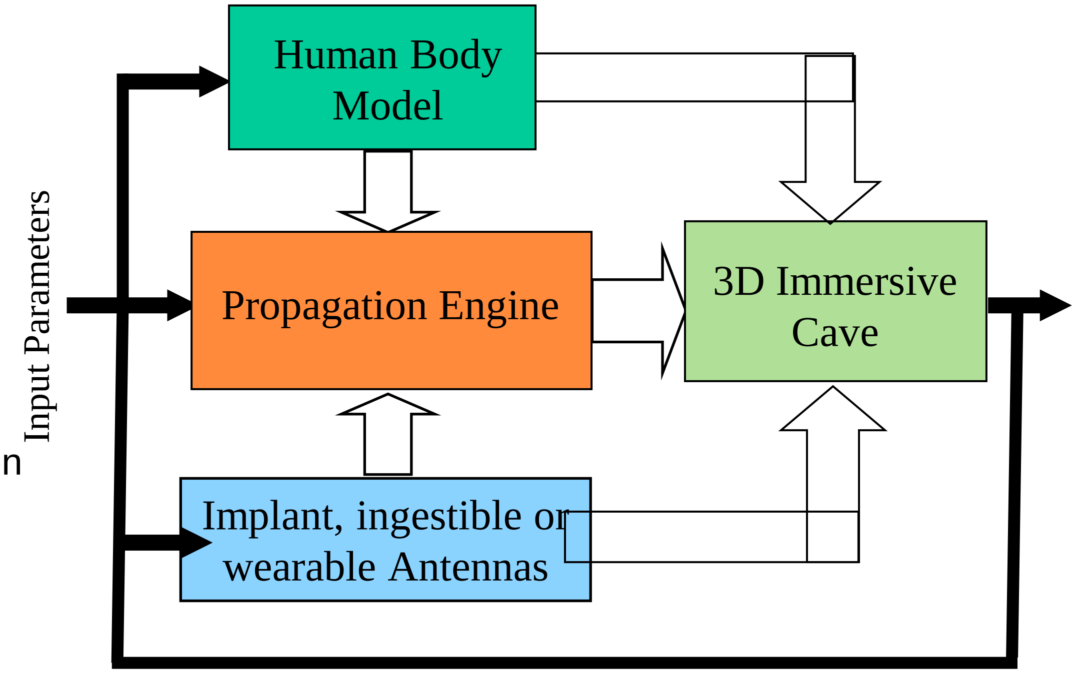
UWB Measurements

- Developing statistical pathloss models requires sufficient sample measurements. However, physical measurement is not quite possible for such applications.

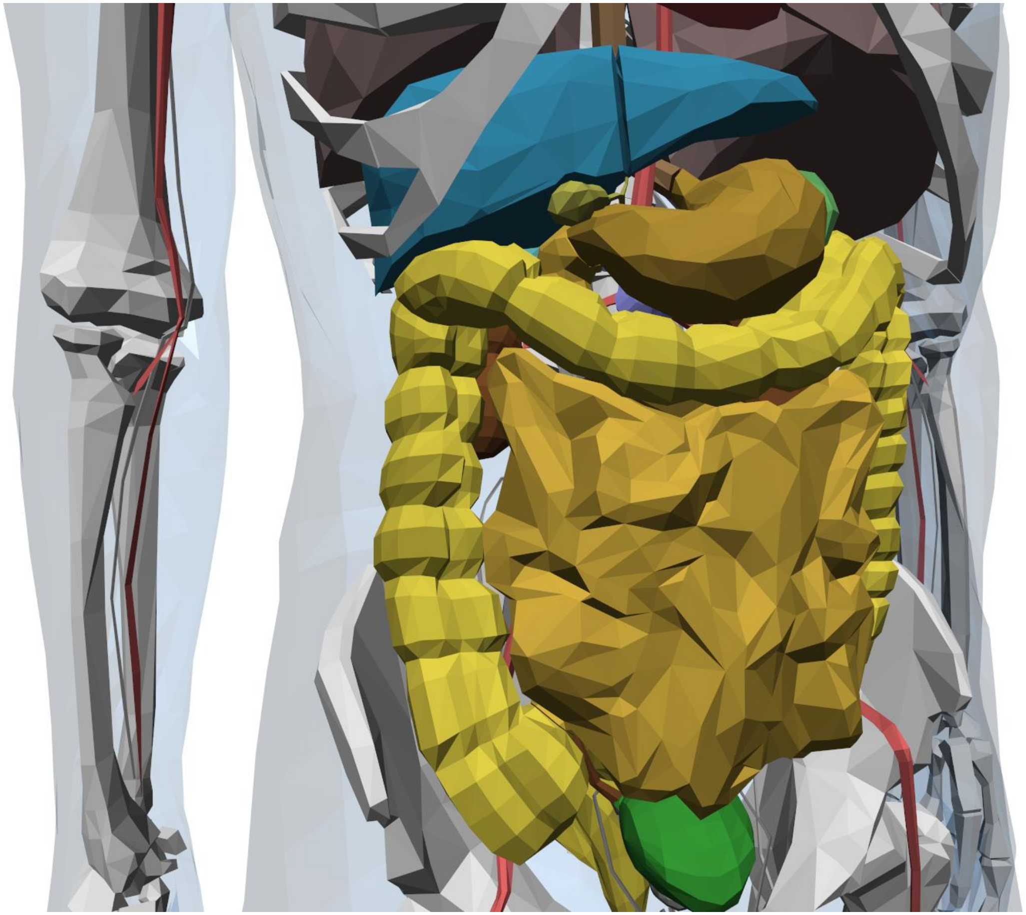
- Possible approaches are:
  - Measurements using animals
  - Liquid phantoms
  - Computational human body models

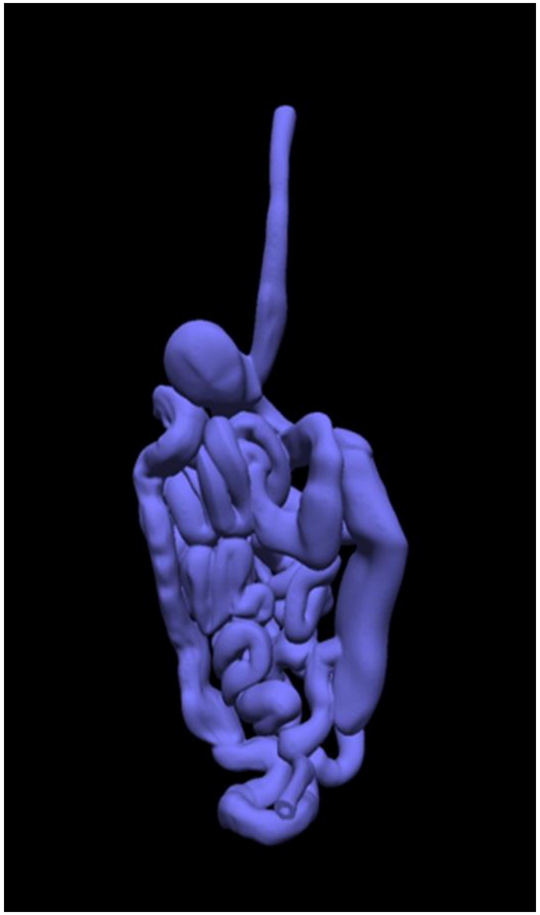
NIST 3D Immersive Platform to Study RF Propagation from Implants

- ❑ **NIST 3D immersive environment**
- ❑ **Human Body Model**
- ❑ **Propagation Engine**
  - ❖ 3D full-wave electromagnetic field simulation (HFSS)
  - ❖ Capable of calculating a variety of outputs
- ❑ **Antennas**



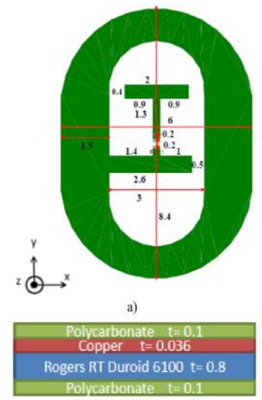
Enhanced Body Model for WCE Propagation Study

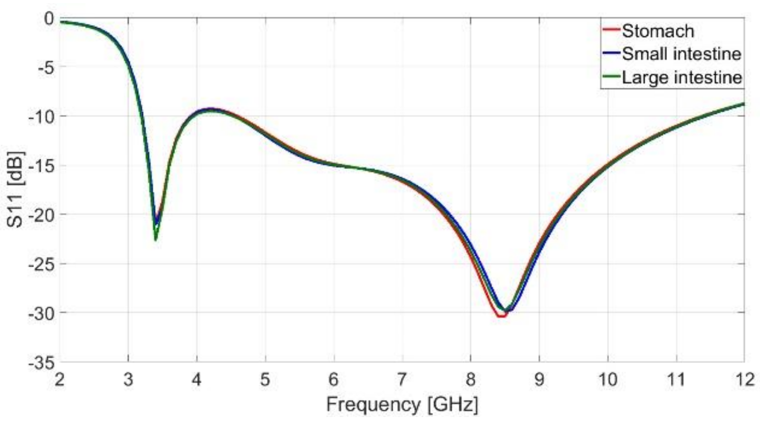


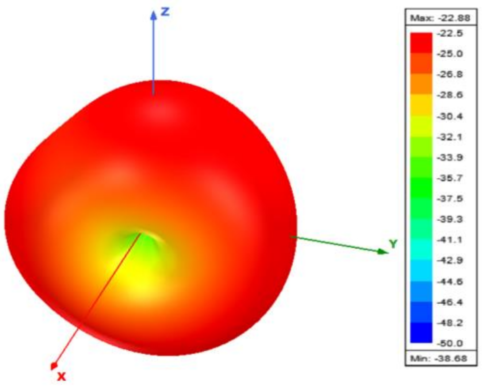


Capsule Antenna

- The transmitter antenna inside the capsule is a total band UWB antenna and it is single side metallic layer planar antenna with the size 8.4 x 6 x 1.036 mm.





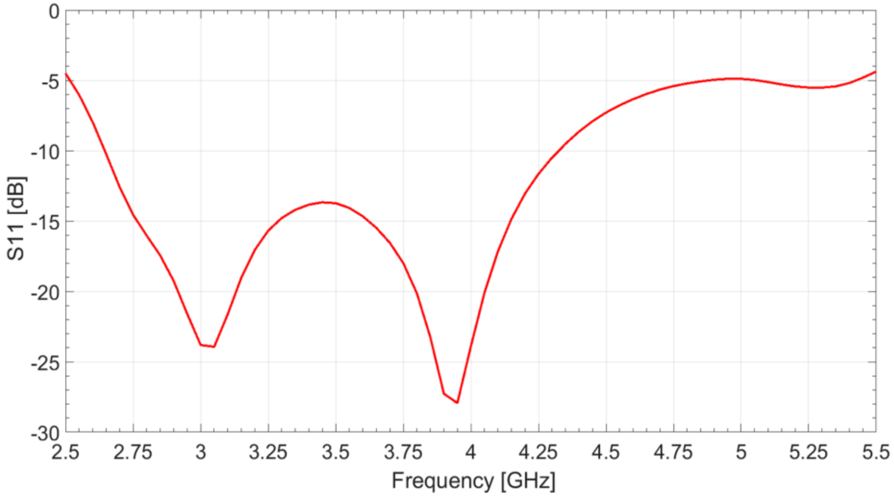


WCE antenna radiation pattern at 3.6 GHz

Ref: K. Yekeh Yozdandoost, "Antenna for Wireless Capsule Endoscopy at Ultra Wideband Frequency," *IEEE 27th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC*), 2016.

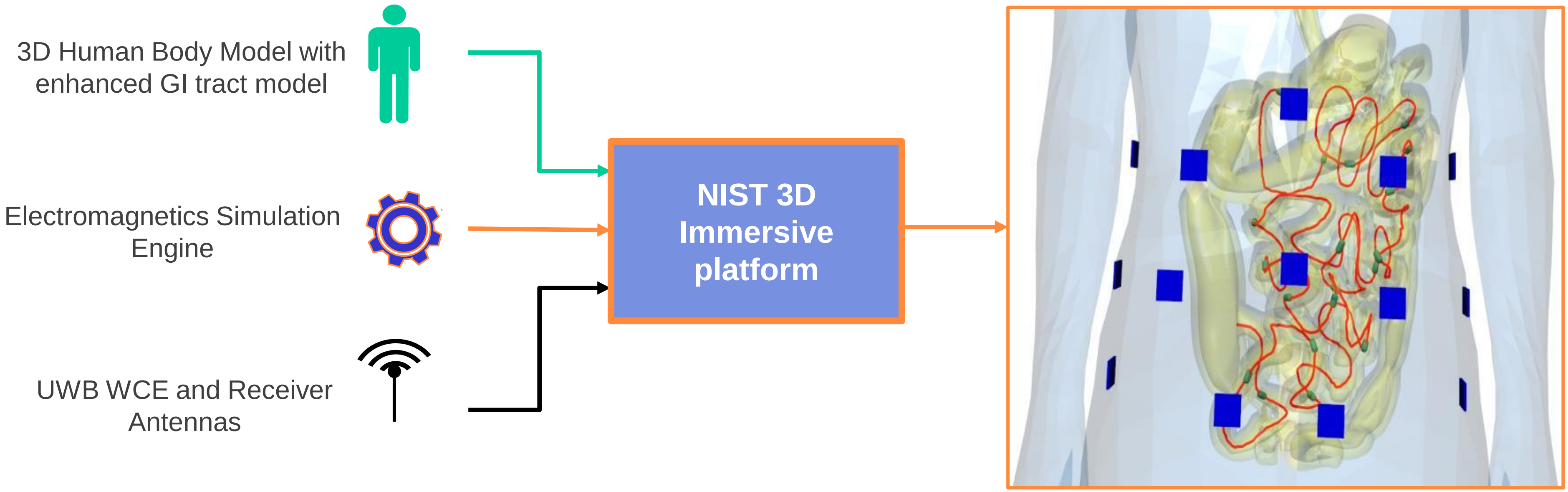
On-body Antenna

- The on-body antenna is a L-shape lower band (3.1 – 5.1 GHz) UWB planar antenna with linearly polarized radiation and size 25 x 24 x 1 mm.
- A RH-5 dielectric substrate with a thickness of 14 mm is also used between the antenna elements and the skin.



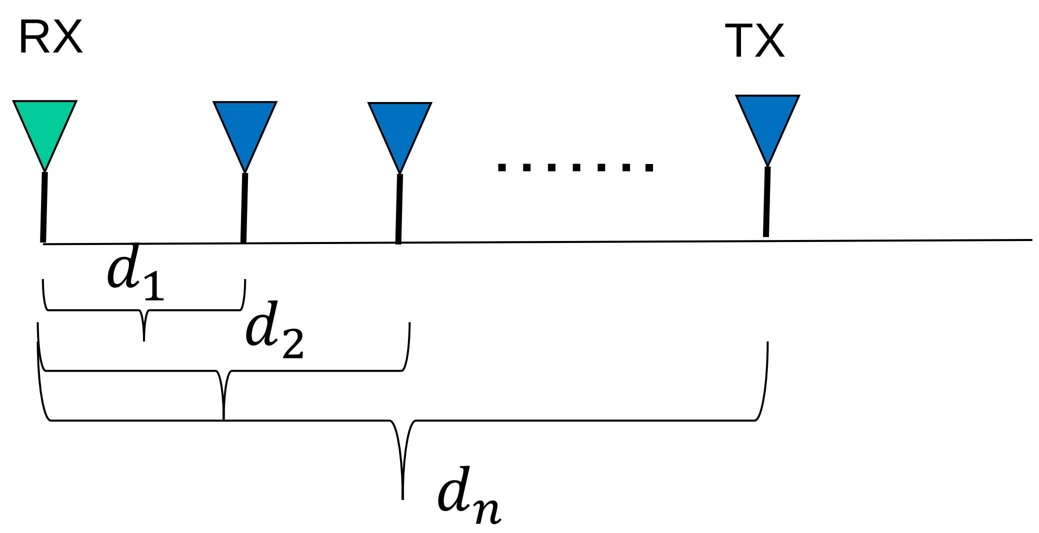
Ref: K.Y. Yazdandoost, K. Takizawa, R. Miura, "UWB antenna and propagation for wireless endoscopy," IEEE 25th Annual International Symposium on Personal, Indoor, and Mobile Radio Communication, 2014.

Immersive Computational Platform to Study WCE Communication Channel



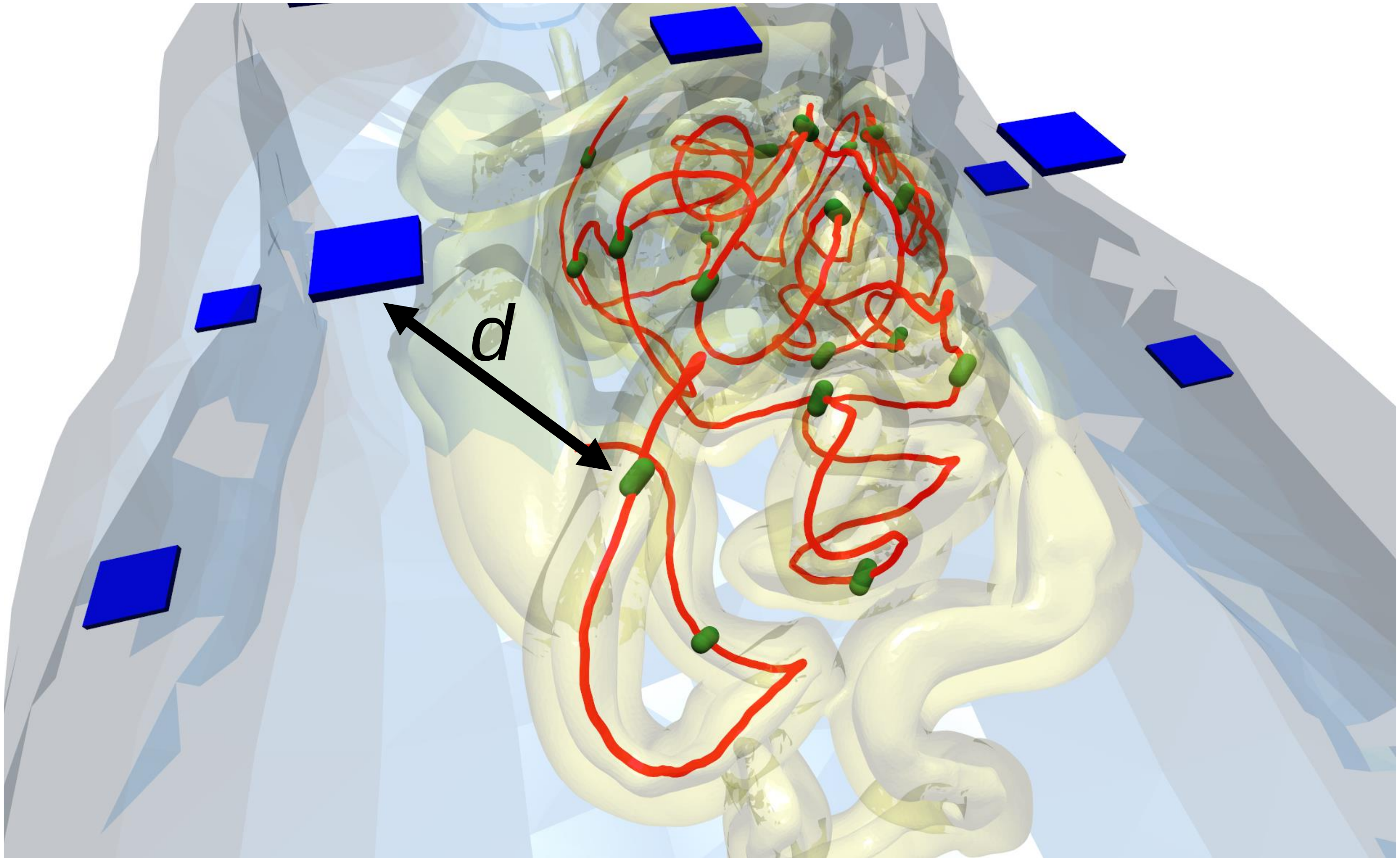
Sample Point Measurement

- To obtain a statistical pathloss model sufficient measurements samples representing all distances between the receiver and transmitter are required.

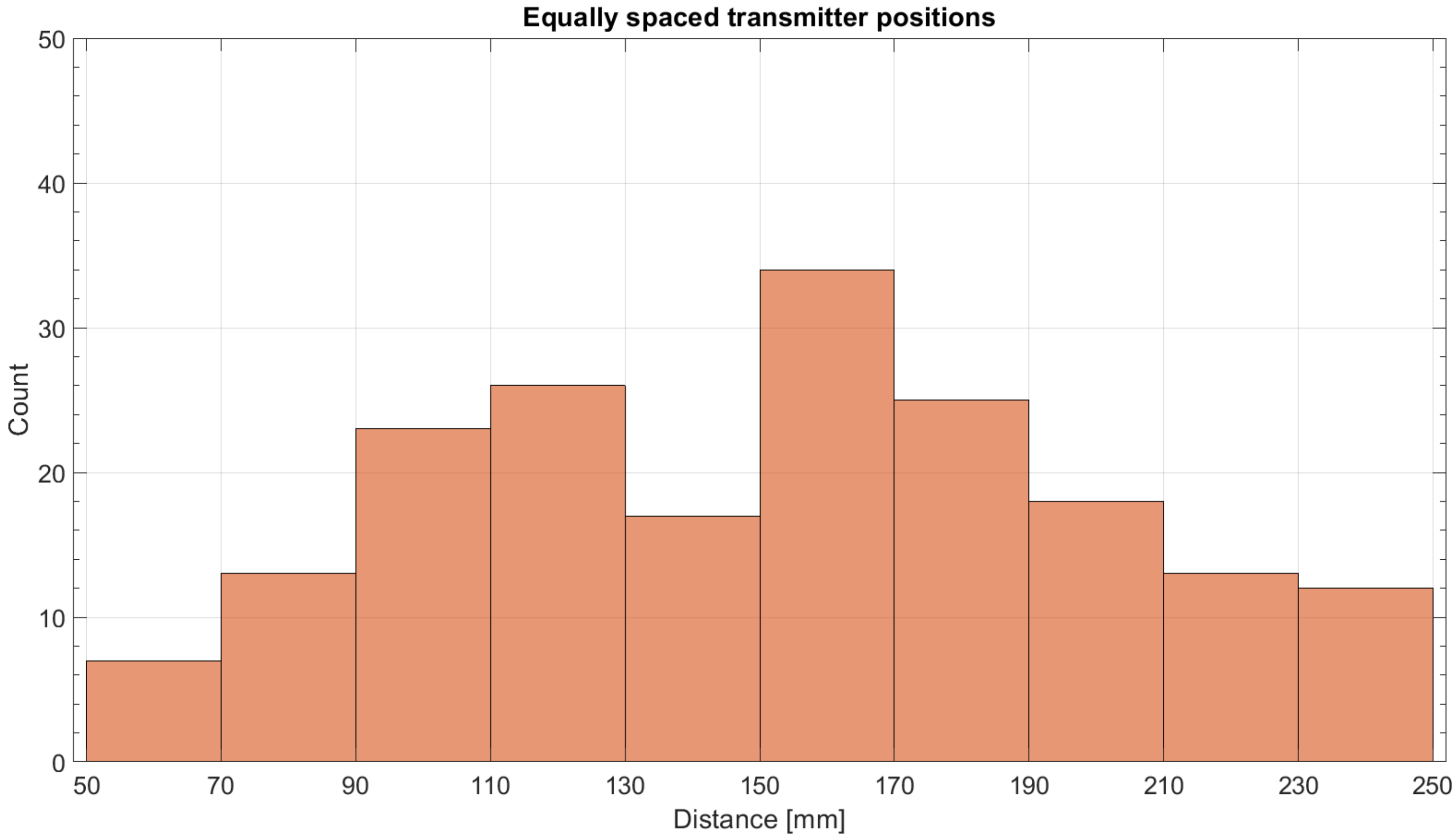


- Due to computational and environmental complexity of the WCE channel, we have a limit in the number of sample measurement point.

Sample Point selection for WCE channel measurement

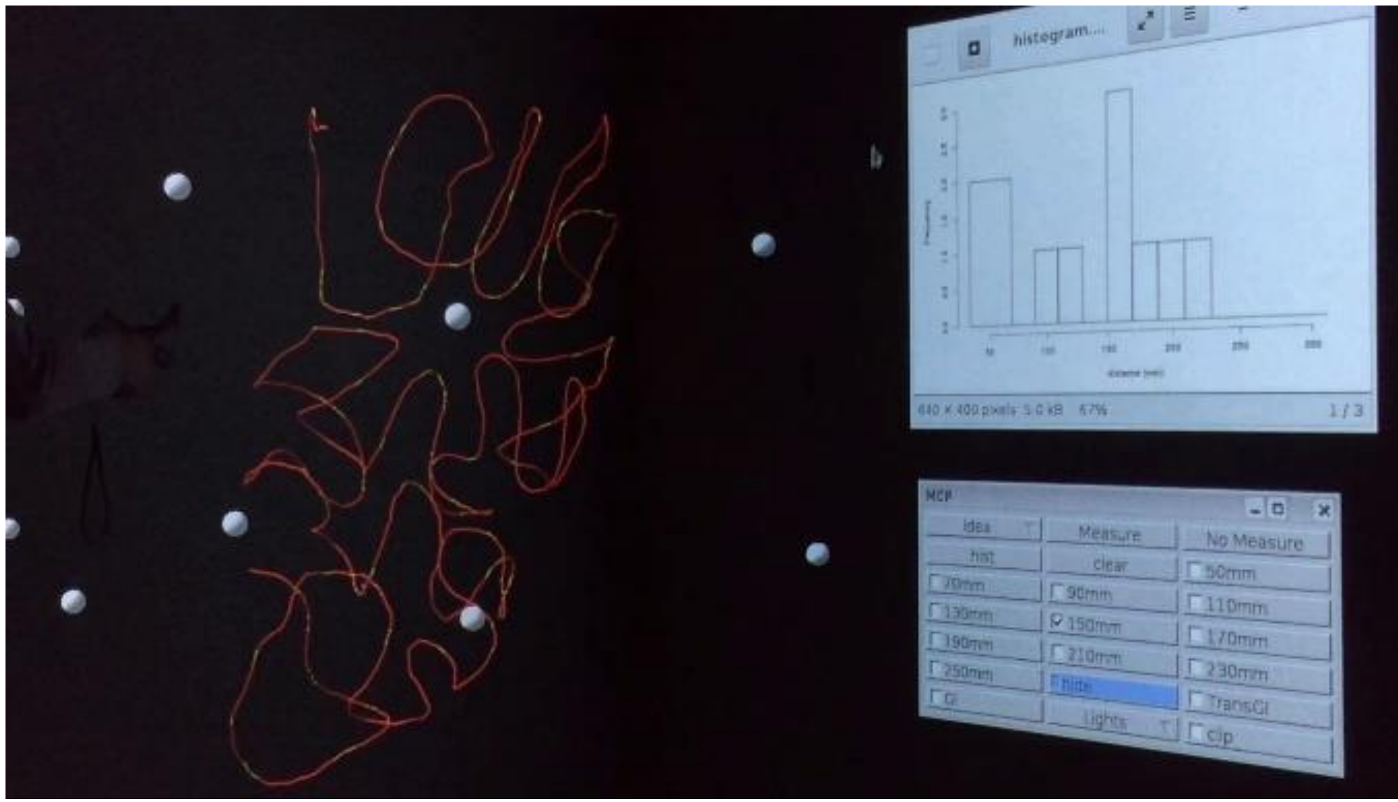


Distance Distribution for equal spacing of the WCE along the GI tract

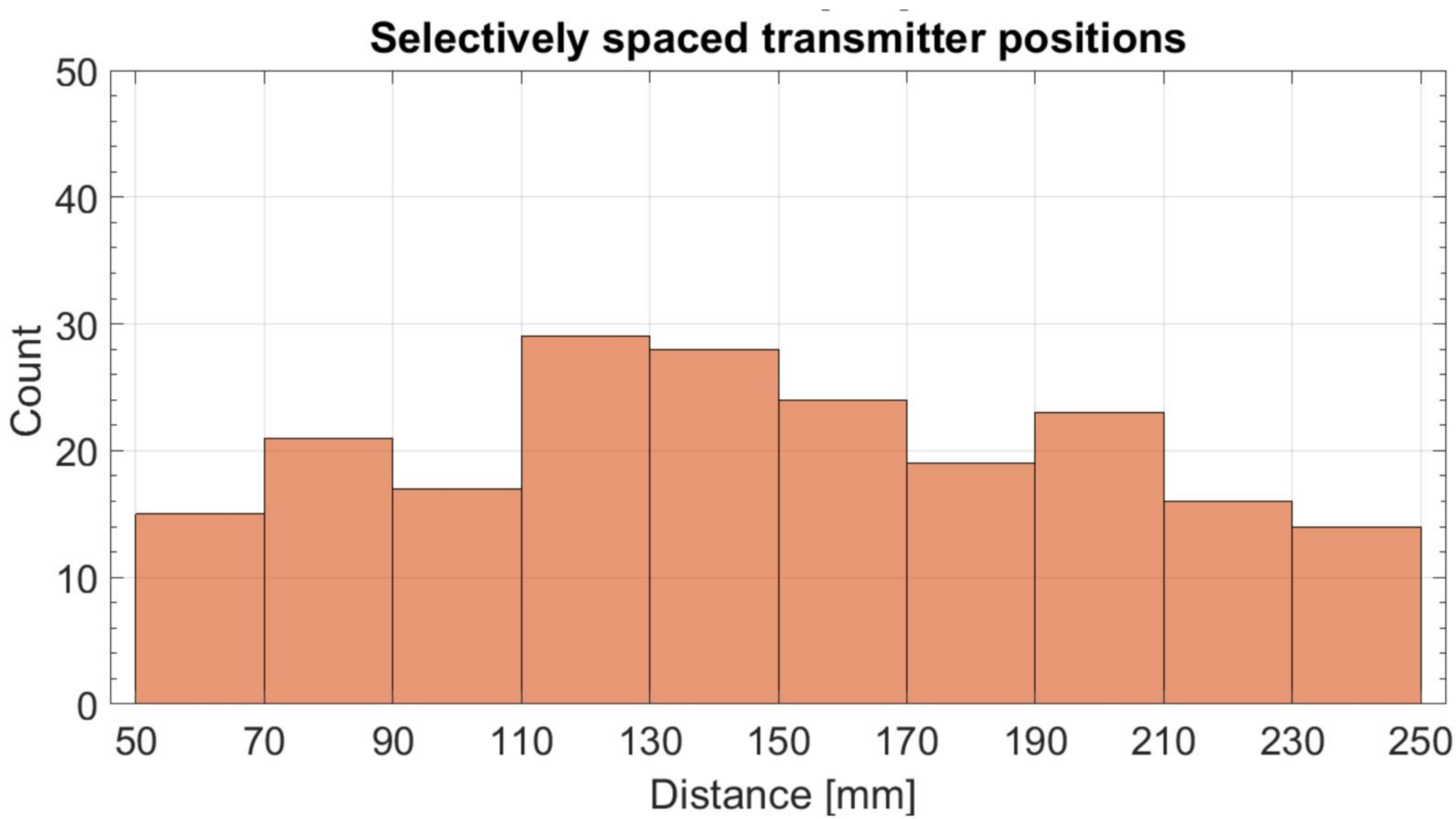


WCE Location Selection for Pathloss Measurement

In order to enable point selection inside the GI tract, we developed an interactive tool in the NIST CAVE. The tool consists of several different modules that aims to converge to a set of WCE sample locations with more unform distribution.



Distance Distribution after using the Interactive Placement Strategy



Statistical Pathloss Modeling

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

$$PL(d) = PL(d_0) + 10n\, log_{10}\left(\frac{d}{d_0}\right) + S \qquad d \geq d_0$$

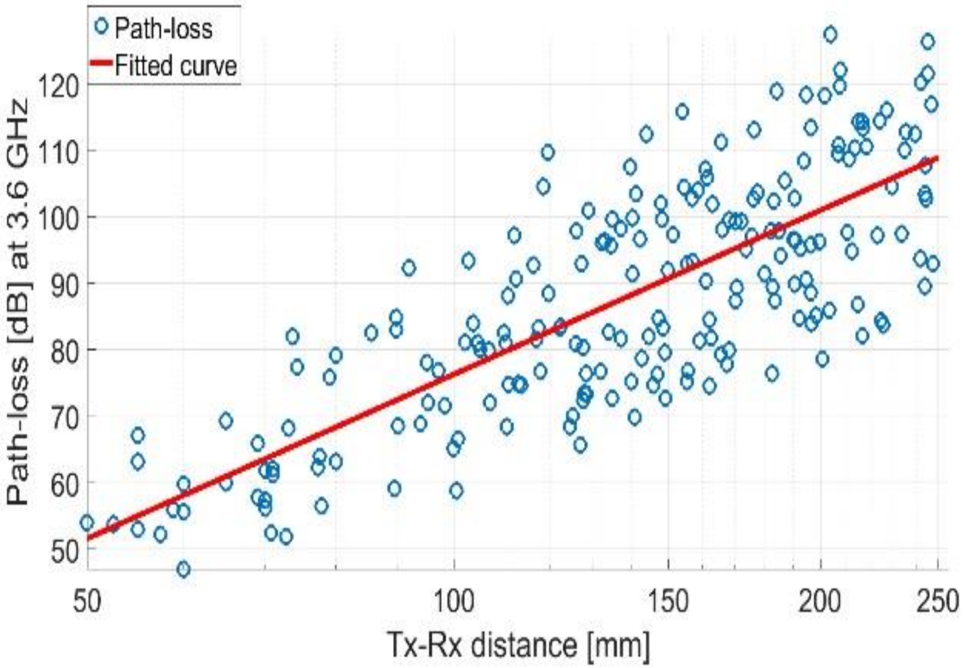
Where:

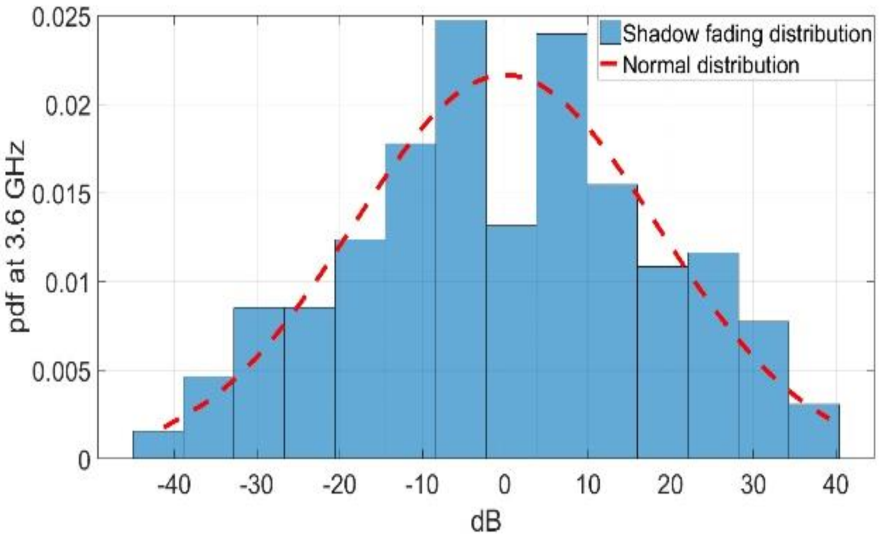
*d*o is a reference distance

n is the pathloss exponent

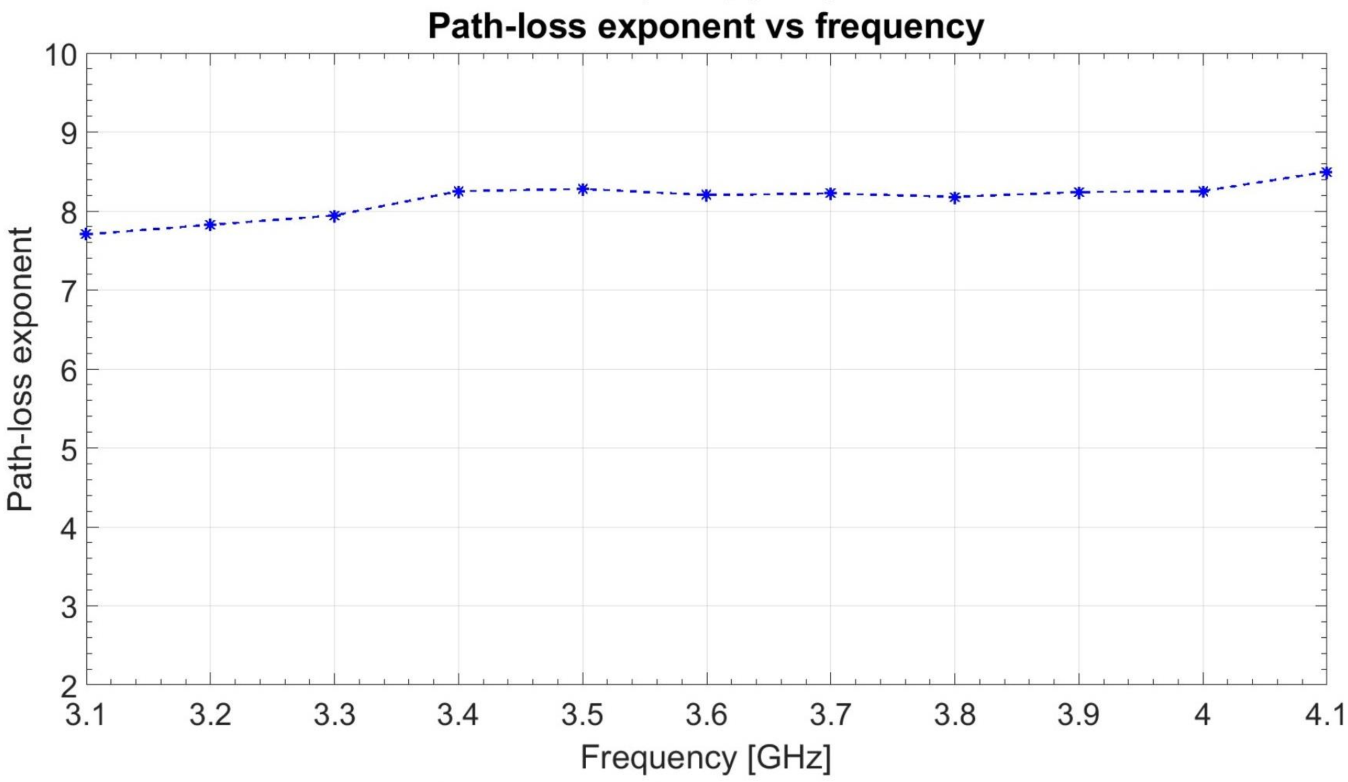
S is the random scatter around the regression line

Statistical Pathloss Modeling

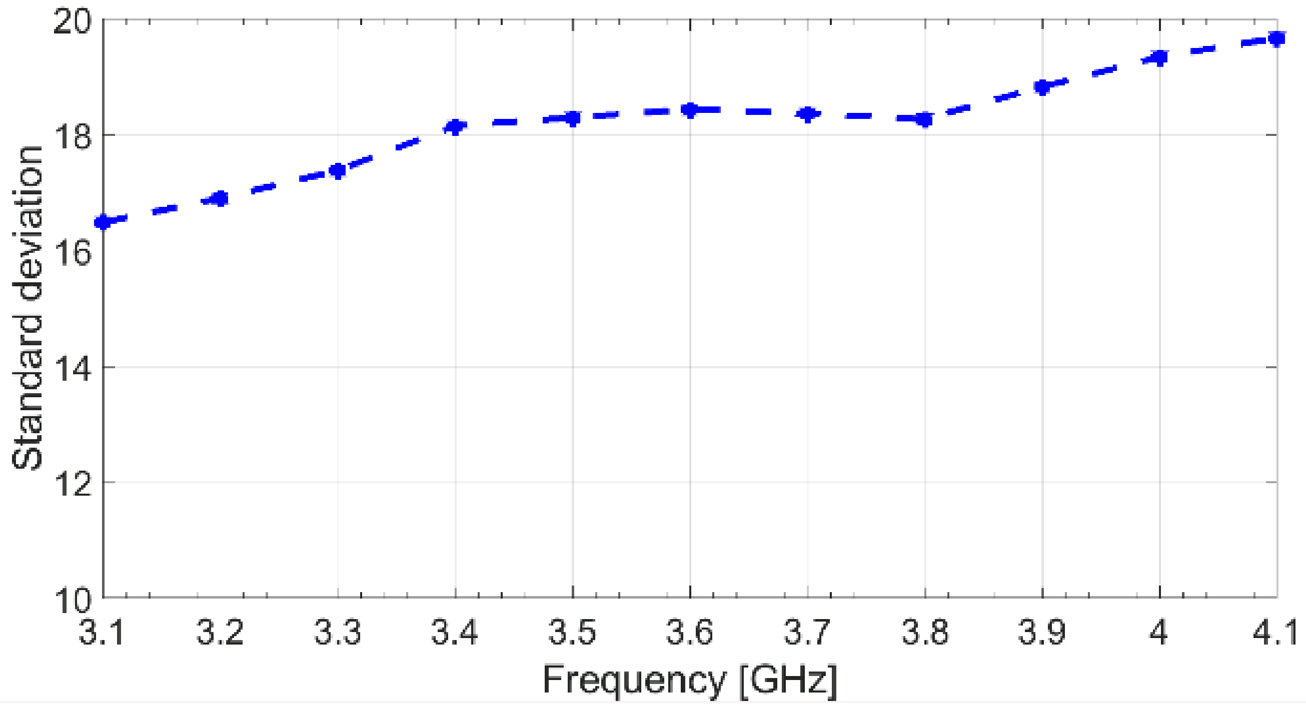




Pathloss Exponent vs. Frequency



Standard Deviation of the Shadow Fading vs. Frequency



Statistical Pathloss Model for UWB WCE

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

$$PL(d) = PL(d_0) + 10n\, log_{10}\left(\frac{d}{d_0}\right) + S \qquad d \geq d_0$$

Where:

d_o is a reference distance

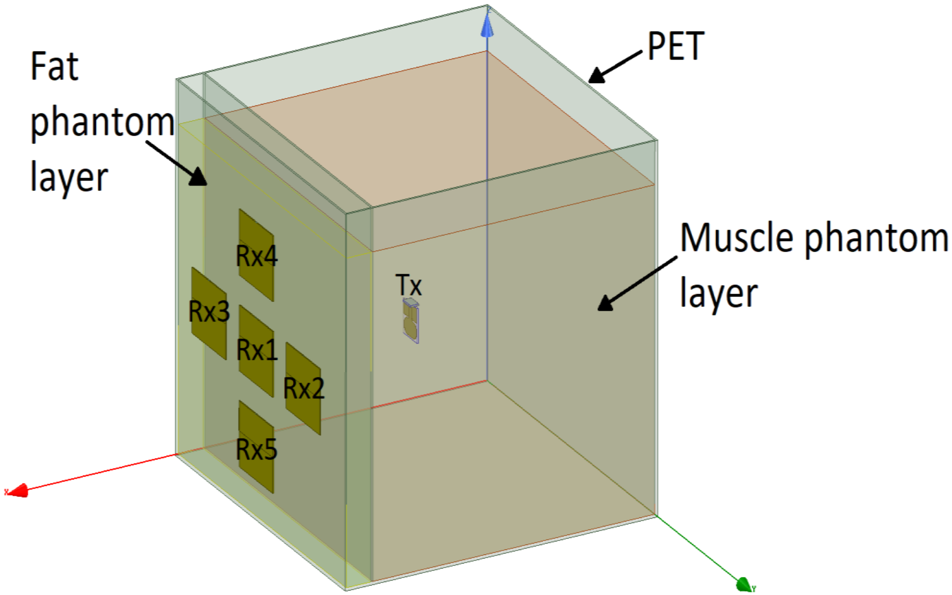
n is the pathloss exponent

S is the random scatter around the regression line with Normal Distribution with standard deviation σ_s

$PL(d_0)$	**n**	**σ_s**
51.9	**8.14**	**18.19**

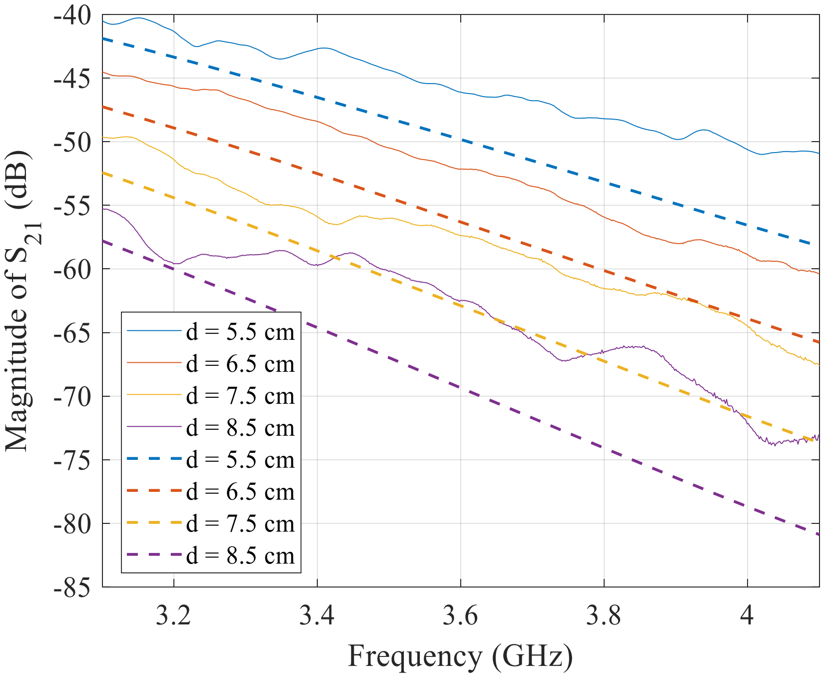
*Detailed results submitted to the IEEE Access Journal: K. Krhac, K. Sayrafian, D. Simunic and K. Yazdandoost, "UWB Channel Characterization in Wireless Capsule Endoscopy Communication“.

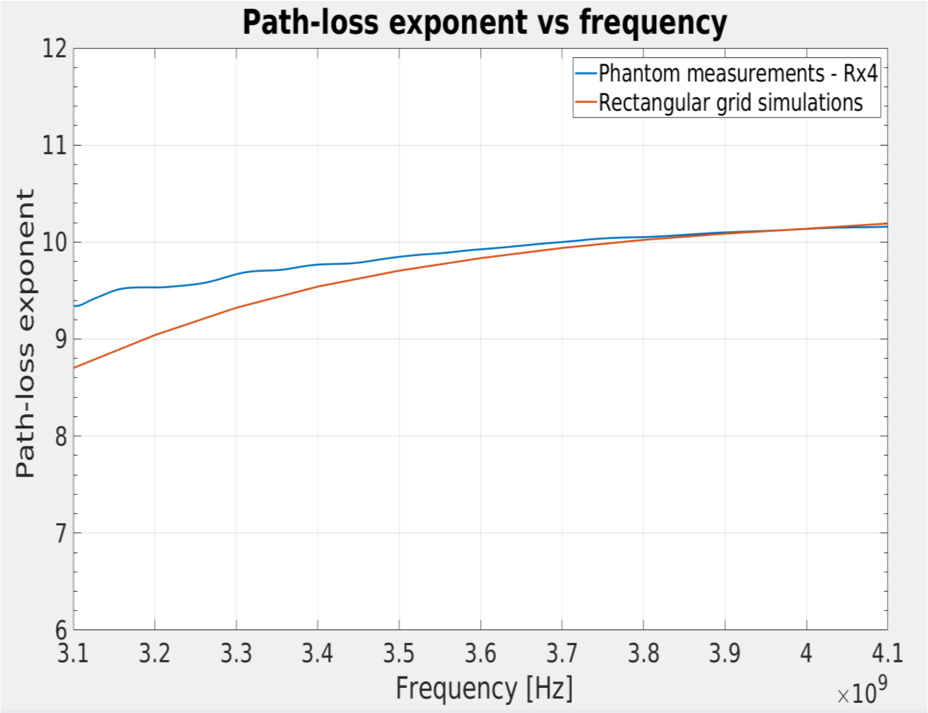
Verification with Liquid Phantom



Ref: S. Perez-Simbor, K. Krhac, C. Garcia-Pardo, K. Sayrafiarr, D. Simunic and N. Cardona, "Impact of Measurement Points Distribution on the Parameters of UWB Implant Channel Model", IEEE Conference on Standards for Communications and Networking (CSCN), Paris, 2018

Verification with Liquid Phantom





Summary and Conclusion

- A statistical pathloss model is presented to support the UWB WCE use-case at 3.1 – 4.1 GHz
- Detailed time domain analysis is also underway to provide information on possible multipath behavior in an UWB WCE Channel
- A standard UWB radio can contribute to enhancing interoperability among WCE and other wearable device manufacturers