IEEE WAMICON 2013

SAR and BER Evaluation Using a Simulation Test Bench for *In Vivo* Communication at 2.4 GHz

Thomas Ketterl
Gabriel E. Arrobo
Richard D. Gitlin

Department of Electrical Engineering
University of South Florida

UNIVERSITY OF SOUTH FLORIDA

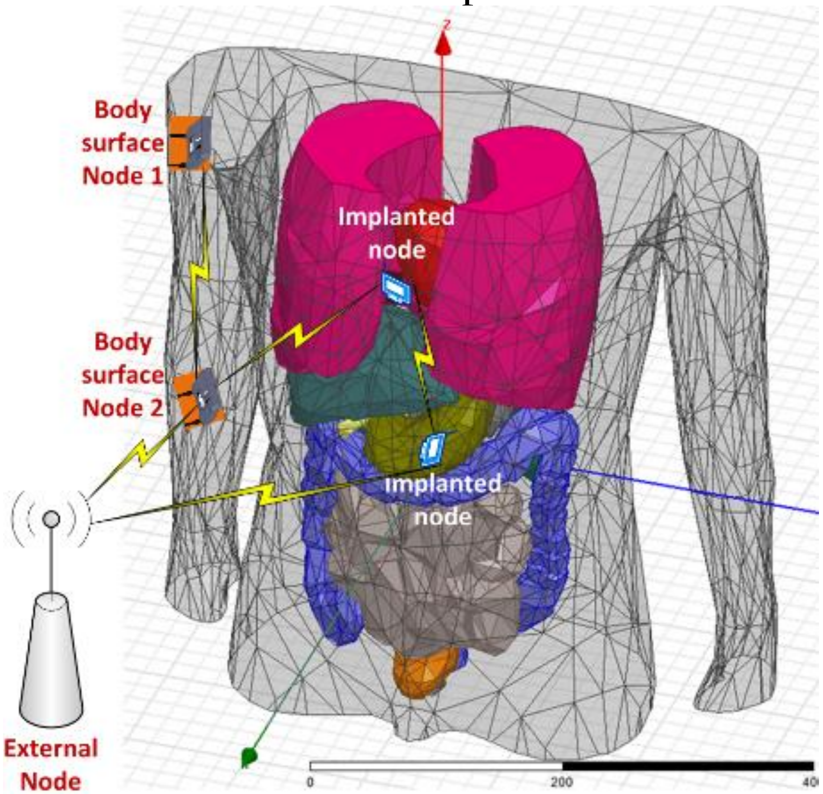
Outline

- Introduction to in vivo wireless communication
- High Data Rate *in vivo* Communication
- Human Body Model in HFSS
- SAR Limit vs. BER
- Simulation Test Bench using ANSYS Designer and HFFS
- Test Bench Simulation Results
- Summary

Introduction

In vivo Wireless Information Networking Laboratory

The *i*WINLAB group focuses on studying novel *in vivo* channel models and signal processing that will facilitate the creation of new communications protocols accommodating the limitations of implanted devices

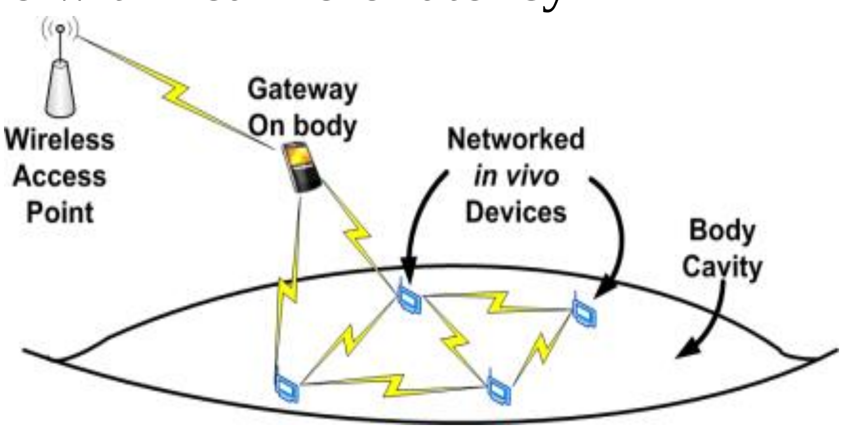


Also focus in the design and implementation of the wirelessly controlled and communicating Miniature Anchored Robotic Videoscope (MARVEL) video system (i.e., a camera) and other embedded devices that are expected to create a paradigm shift in minimally invasive surgery.

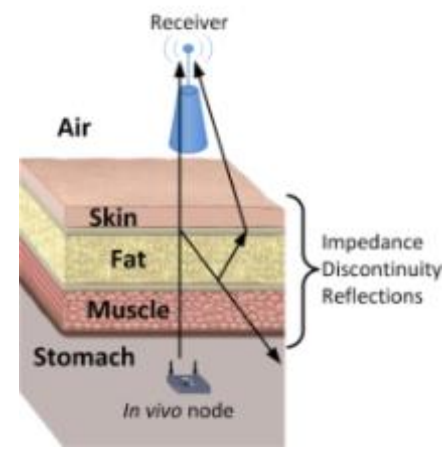
The *In vivo* Wireless Channel

- The *in vivo* channel is very different from the classic wireless RF multipath communication medium.
- There is a need for accurate in vivo channel models to optimize transceiver systems and communication protocols/algorithms for high data rate communication.
- Applications include communication between networked in vivo sensors and HD video transmission for minimally invasive surgical procedures
- In vivo wireless transmission for medical applications needs to be reliable and occur in real-time with near zero latency

Minimally Invasive Surgery (MIS)



In vivo wireless networking

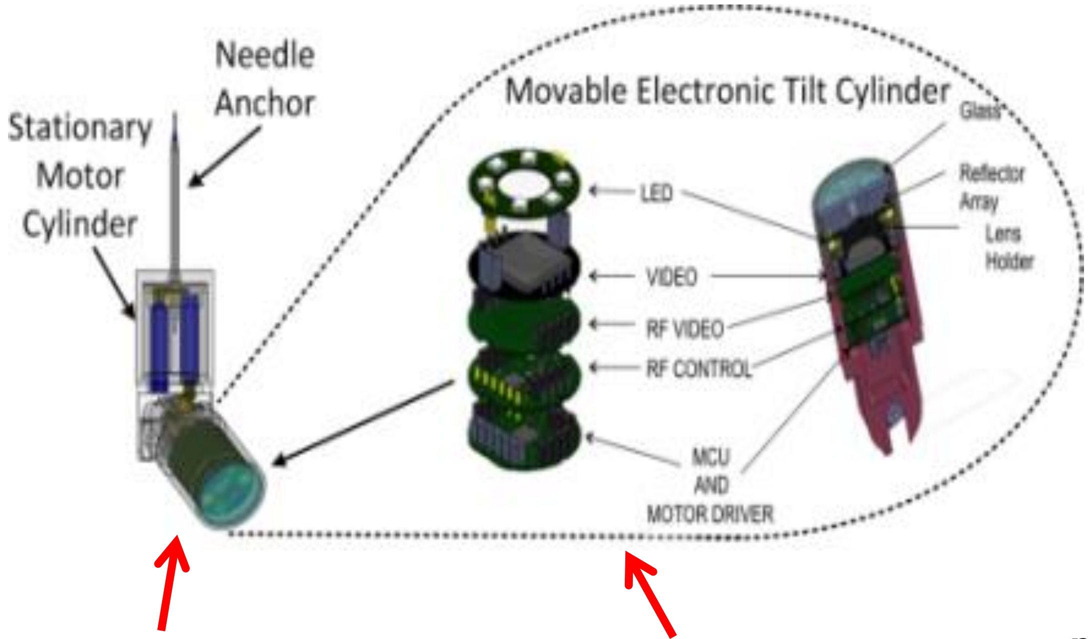


In vivo multipath RF channel

In Vivo Wireless HD Video Transmission

- Wirelessly Controlled and Communicating *In Vivo* Networked Devices: *MARVEL*
  - The implemented device is a Miniature Anchored Robotic Videoscope (*MARVEL*), a wirelessly controlled and communicating video system that provides the spatial and visual advantages of open-cavity surgeries, while being faster, better, and less expensive..

- Current laparoscopic camera modules require HD video capabilities
- There cannot be any noticeable delay in video transmission => low latency =>low compression => high data rates - > 500 Mbps
- Have to operate at higher ISM bands – 2.5 or 5 GHz



MARVEL CAD model and exploded circuit board stack

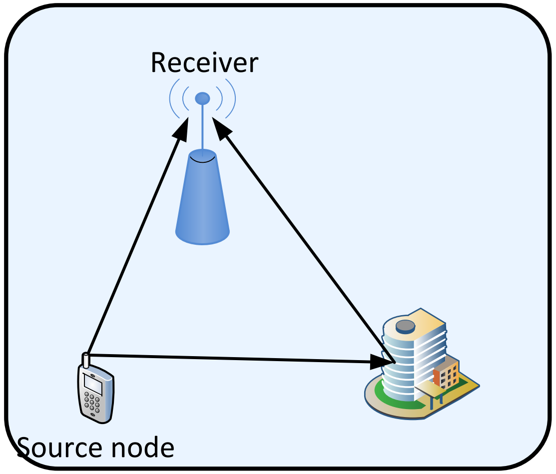
MARVEL units in a porcine abdominal cavity

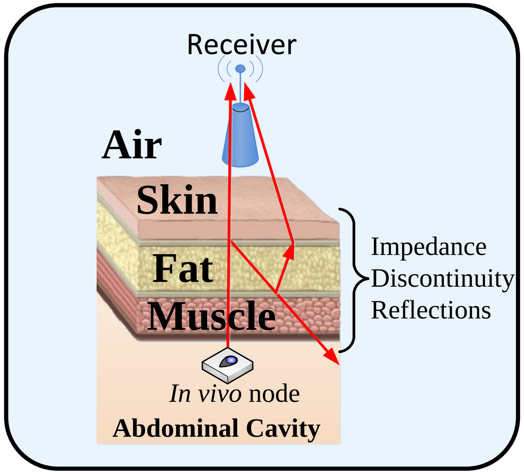
Image of internal organs captured by MARVEL unit

In vivo Wireless Channel Characterization and Signal Processing

- Well-studied wireless environments include: cellular, WLAN, and deep-space
- The *in vivo* channel is a "new frontier" in wireless propagation and communications
- Many new research issues:
  - Media characterization and communications optimization
  - New communications, networking, and security solutions for embedded devices of limited complexity and power
  - Near-field effects (at low operating frequencies) and multi-path scattering (at high operating frequencies) with propagation through different types of human organs and internal structures between closely spaced transmitter and receiver antennas.

Classic Multi-Path Channel



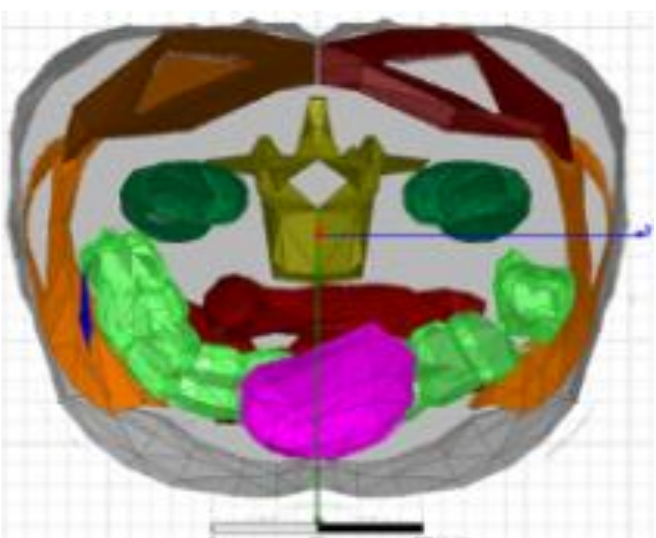


In Vivo Multi-Path Channel

Characterizing *in vivo* wireless propagation is critical in optimizing communications and requires familiarity with both the engineering and the biological environments.

In Vivo Simulation

- ANSYS HFSS 15.0.2, is a 3D full-wave electromagnetic field simulator that utilizes a full-wave frequency domain electromagnetic field solver based on the Finite Element Method (FEM) was used to compute the electrical behavior of RF components, and the ANSYS human body model.
- ANSYS provides a human body model of a detailed adult male with over 300 muscles, organs, and bones with a geometrical accuracy of 1 mm.
- Frequency dependent material parameters (conductivity and permittivity) for each organ and tissue are included in the models which were derived for human tissues from 20 Hz to 20 GHz...

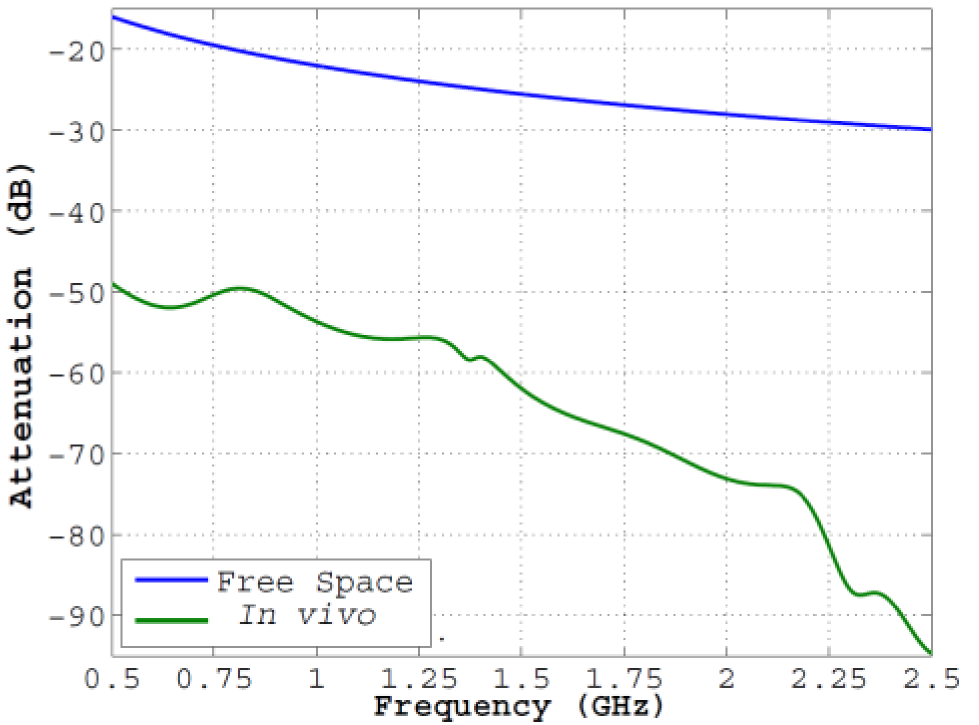


Top-down view of the human body showing locations of internal organs, muscles, and bones

Human body model

Free Space and *In Vivo* Attenuation

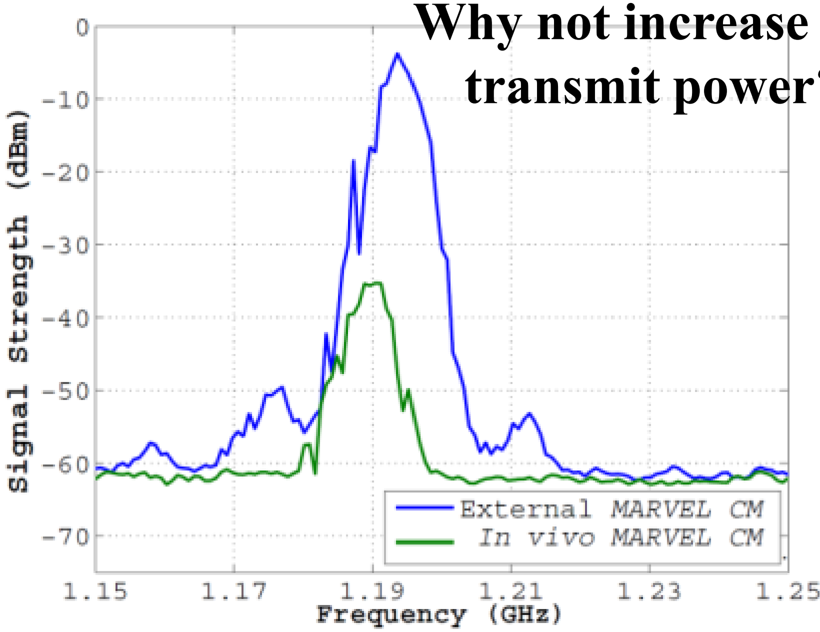
- Simulated attenuation in HFSS, where a signal travels from a monopole placed inside the abdomen to an external monopole with a 30 cm transmission path (9cm of the path are inside the body).
- Antenna effects have been removed in software by simultaneously matching each antenna port impedance in Agilent ADS.
- Signal loss shown in plot for *in vivo* attenuation and free space loss.
- Attenuation drop-off rate is not constant and is seen to increase more rapidly above 2.2 GHz.



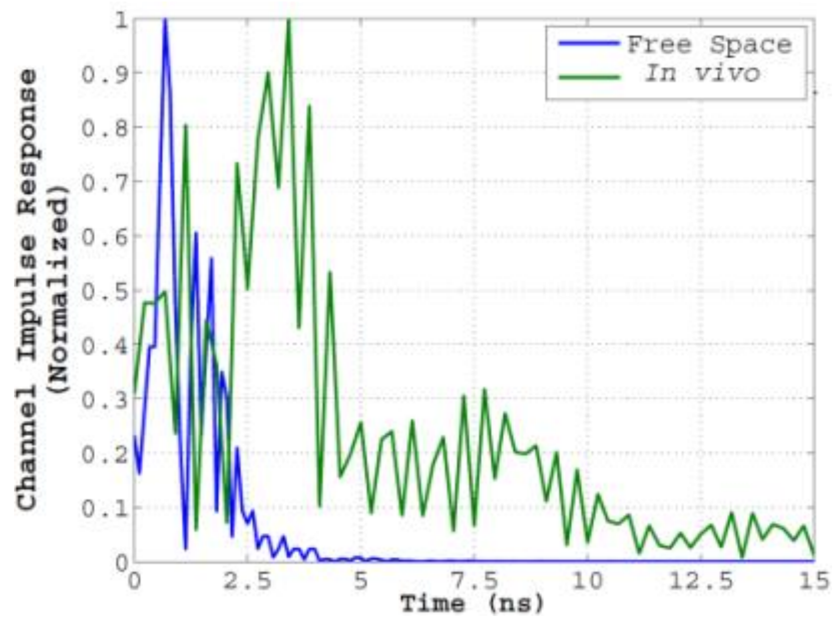
In Vivo Attenuation and Dispersion

- The carrier frequency was ~1.2GHz and the video signal bandwidth is 5MHz. The FM modulation bandwidth was about 11MHz. Transmitter was located inside the abdominal cavity. The receiver was placed ~ 0.5m from the transmitter in front of the abdomen.
- It can be seen that there is about a 30 dB difference in signal strength between the *in vivo* and the external measurement, which shows that there is approximately 30 dB of attenuation through the organic tissue. This seems to be in good agreement in what is shown in the prior chart.
- *In vivo* time dispersion is much greater than expected from the physical dimensions.

Why not increase the transmit power?



MARVEL Camera Module (CM):
Vivarium Experiment

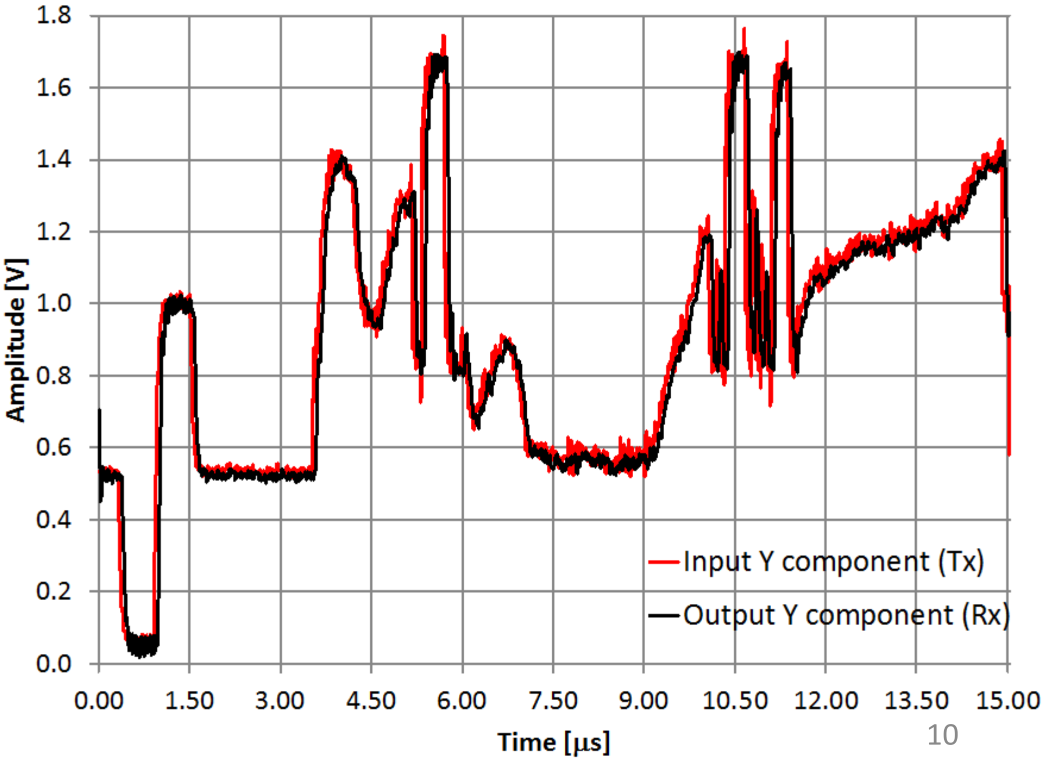


Normalized channel impulse response for the human body for free space and scattered environments.

Simulated Impulse Response used in System Simulators

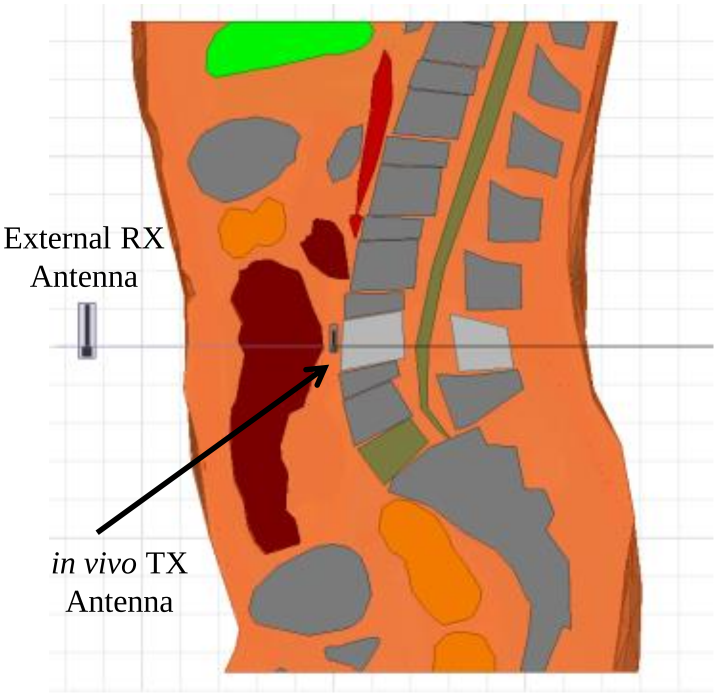
Analog HD Video Transmission: Simulation Results

- We used captured data from a HD Video camera with Y, Pb, Pr outputs for the drive signals in the simulation.
- Y, Pb, Pr components were FM modulated to carrier frequencies of 1.0, 1.03, and 1.06 GHz, respectively.
- The transmitter output and receiver inputs are linked to the human body model and antennas in HFSS to model the channel response of the in vivo wireless link.
- A comparison of the input Y component (red) at the transmitter (Tx) and reconstructed output Y component (black) at the receiver (Rx) is shown in the figure.
- Very little latency between the input and output signal is observed in the simulation; ~0.1us.



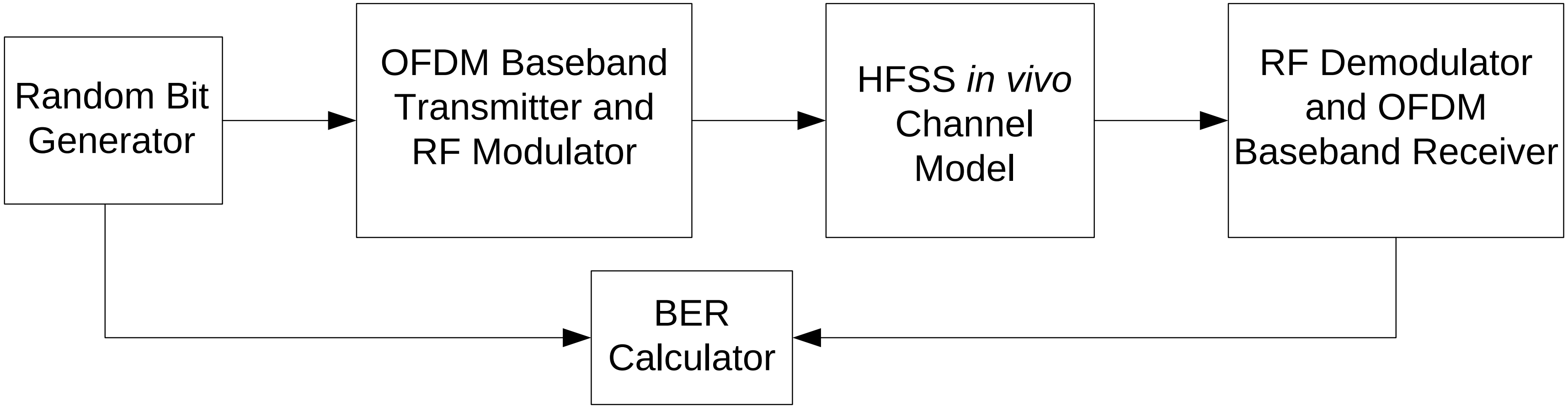
SAR and BER for *In Vivo* Communications

- WBANs must transmit at low power to protect the patients against harmful health effects associated with the radiofrequency (RF) emissions as well as to extend the node's battery lifetime.
- The <u>specific absorption rate</u> (**SAR**) is the rate at which the RF energy is absorbed by a body volume or mass and has units of watts per kilogram (W/Kg).This sets a limit on the transmitted power.
- The SAR limit is frequency dependent, since it depends on the conductivity of the material, which changes with frequency in human organs/tissues
- Due to this limitation on the specific absorption rate, it is not possible to increase the transmission power beyond a certain level to overcome transmission errors.
- By networking the *in vivo* nodes via relay nodes, it is possible to transmit the *in vivo* sensors' information to external nodes while keeping the SAR within allowed limits.
- The figure shows the location of the *in vivo* and *ex vivo* antennas for our software-based experiments.



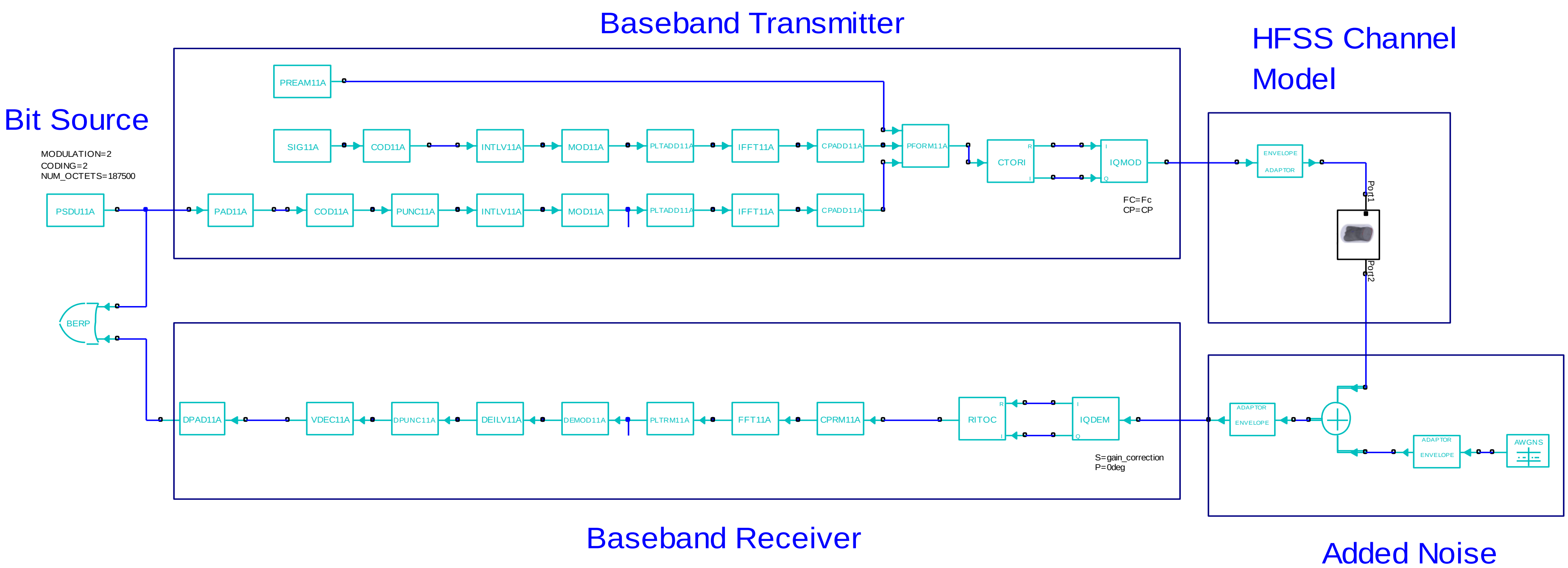
Software Test Bench

- Utilized Dynamic Link capabilities between ANSYS HFSS and Designer
- As a proof of concept, a 802.11G transceiver system model with varying bit rates in Designer was used and dynamically linked to the HFSS simulated channel model
- Data rates of 9, 18, and 36 Mbps were used in the simulation
- Simple monopole antennas, optimized at 2.4 GHz were used for the external and internal antennas in the HFSS simulation
- Frequency sweep of 500 MHz to 3 GHz in HFSS



Software Test Bench

- 802.11g Transceiver Example in ANSYS Designer
- Random Bit Generator
- Calculates BER using NEXXIM System Transient Solver
- Additive Gaussian White Noise Generator



Actual simulation schematic in Designer used for the BER calculations

Software Test Bench

Test Bench Design Steps:

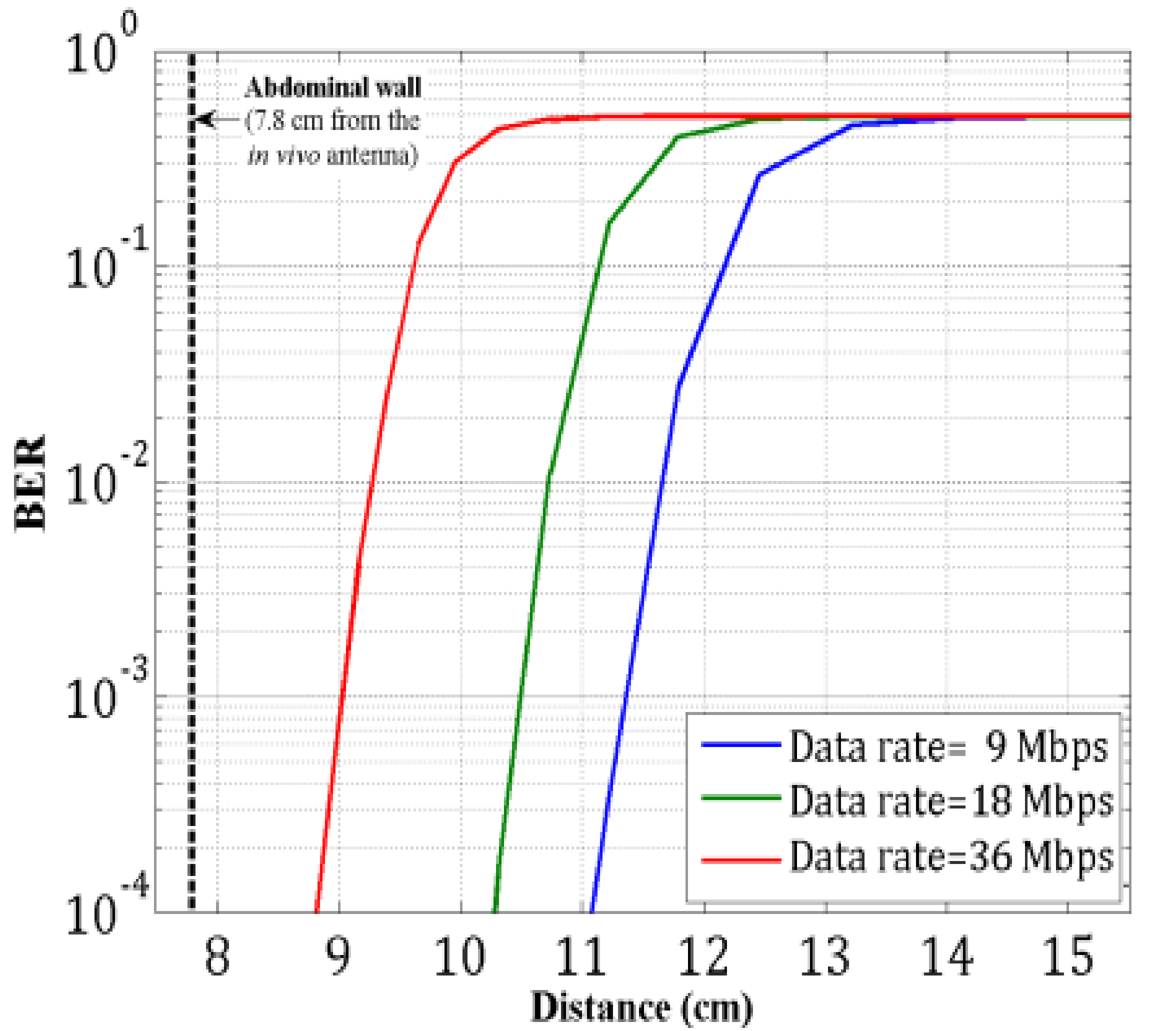
1. The transmit and receive antennas are placed with the human body model into the HFSS design.
2. Field solutions and S-parameter calculations are derived in HFSS over the desired frequency band (and bandwidth).
3. The maximum local SAR levels from the transmit antenna are evaluated in HFSS as a function of frequency. From these data, the maximum allowable power levels can be derived and used in the Designer system simulations.
4. The communication system is set up in Designer.
5. The wireless channel model, derived in the previous HFSS simulation, is used in the Designer system simulations through the direct link between HFSS and Designer.
6. A BER calculation is performed in Designer at various noise levels, using the required power levels (derived in step 2).

SAR and BER for *In Vivo* Communications

Frequency (GHz)	Max Local SAR @ Transmit Power of 0.412 mW (W/kg)
2.402	1.585
2.412	1.562
2.422	1.539

- Above table shows simulated SAR levels for different frequencies in the 2.4 GHz band. These values were found in HFSS using the maximum allowable transmit power (0.412 mW) that assures the SAR limit of 1.6 W/kg across the communication band is met.
- The *in vivo* antenna is located 7.8 cm from the abdominal wall (~laparoscopic surgery). Distance to the external antenna for BER calculations was varied between 8.8 and 17.8 cm.
- With this TX power we simulated a 802/11g OFDM transceiver using a Gaussian noise level of -101dBm, the thermal noise with 20MHz BW.

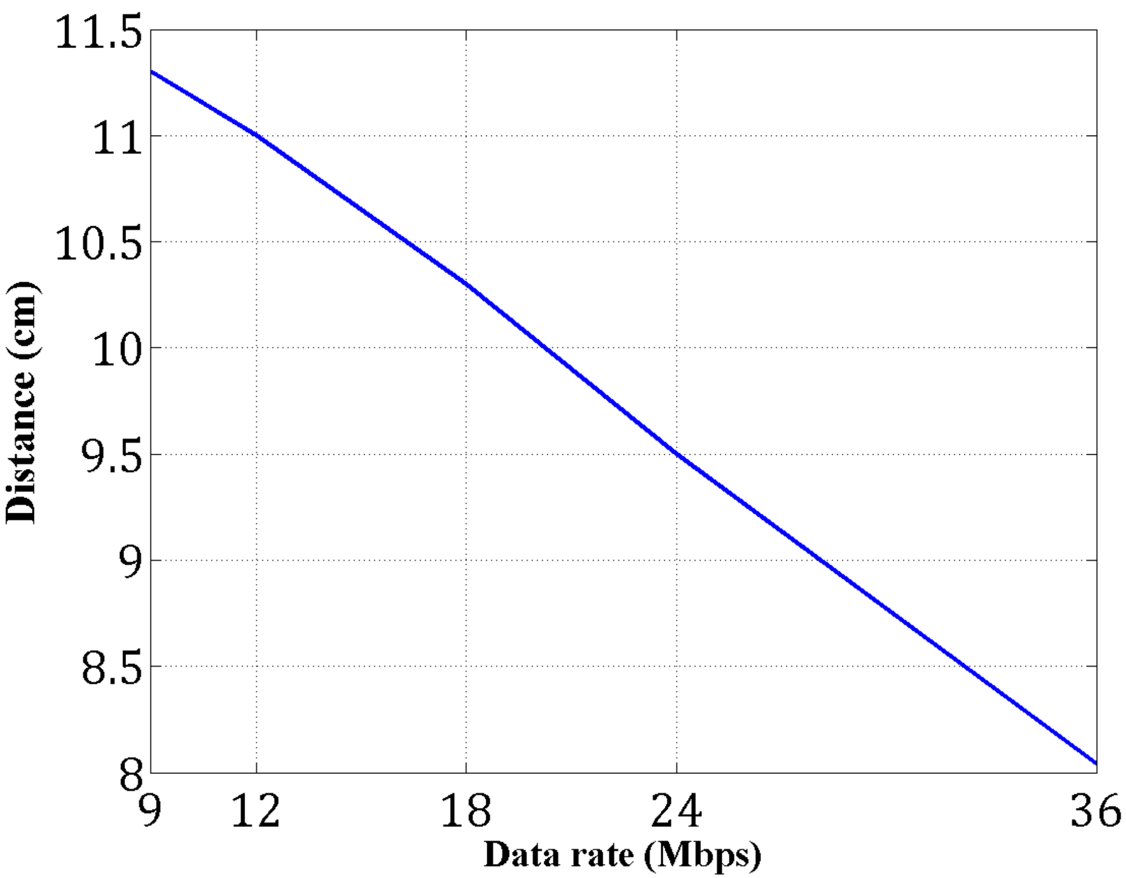
- The figure below shows the BER as a function of distance between the *in vivo* and *ex vivo* antennas.



SAR and BER for *In Vivo* Communications

Achievable distance, as a function of bit rate, between *in vivo* and external antennas for a BER of 10^{-6}.

- At high data rates, receiver must be placed very close to the body; this means that a relay network will be required for transmission over longer distances; i.e. across an operating room.

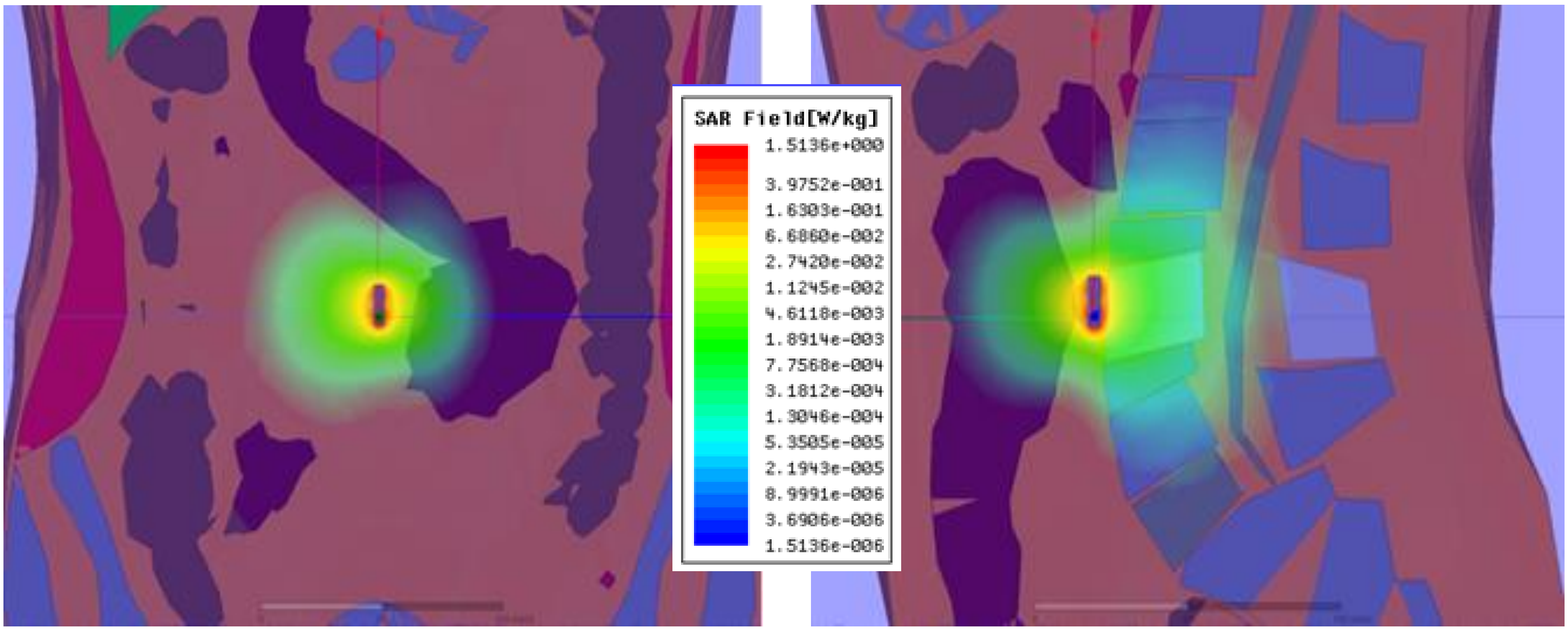


We can use the test bench to optimize various components of the wireless transceiver:

- Test new and improved digital communication algorithms/protocols
- Optimize RF front end components
- Simulate with actual circuit component models

SAR and BER for *In Vivo* Communications

- The figures show the front (left) and side (right) cross-sectional views of the total SAR generated at 2.412 GHz inside the abdomen at a transmit power of 0.412 mW.



SAR distribution can be controlled in HFSS by optimizing the antenna type, architecture and/or antenna placement inside the body

Summary

- Introduced *in vivo* channel model research being performed at USF's iWINLAB
- Discussed the importance of accurate *in vivo* channel models for high data rate communication
- Demonstrated an easy to use simulation test bench for transceiver hardware and communication software optimization to achieve high BER while maintaining SAR specifications
- The need for relays becomes very likely when transmitting from *in vivo* at high data rates