Analysis and Design of Antennas for an Implantable Medical Device System for Functional Electrical Stimulation

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Introduction: Implantable system to re-animate patients who have suffered Stroke, Traumatic Brain Injury, Spinal Chord Injury, by stimulating nerves[1]. Comsol used to analyze far field radiation pattern of implanted device in the human body. Studied effect on radiation pattern of device position and orientation in body. FEA also used to design a circularly polarized antenna for the external control unit along with radome enclosure and case design.

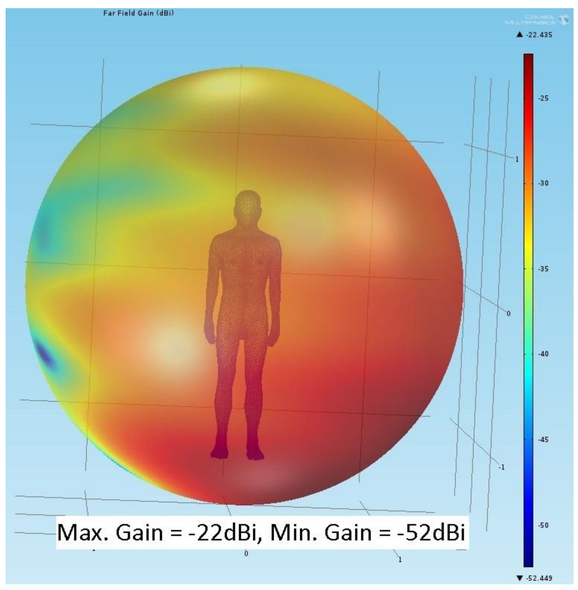


Figure 1. Far Field Gain (dBi)

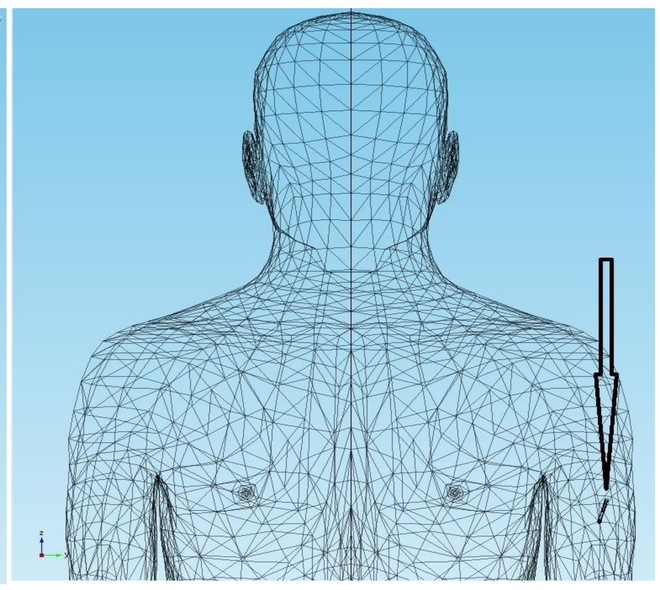


Figure 2. Implant Position

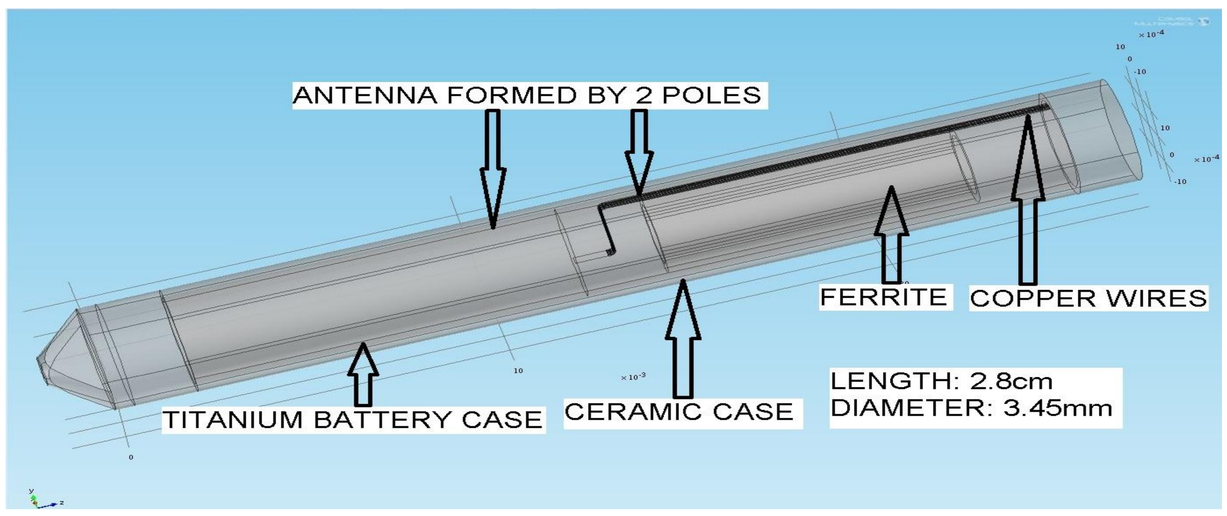


Figure 3. Micro-Stimulator Implant

Simulation Setup: Parameterized frequency domain analysis used to study antenna characteristics in the 400-500MHz range. Device implant position and orientation in the body is parameterized to study various surgical scenarios

$$\nabla \times \mu_r^{-1}(\nabla \times \mathbf{E}) - k_0^2(\epsilon_r - \frac{j\sigma}{\omega\epsilon_0})\mathbf{E} = \mathbf{0}$$

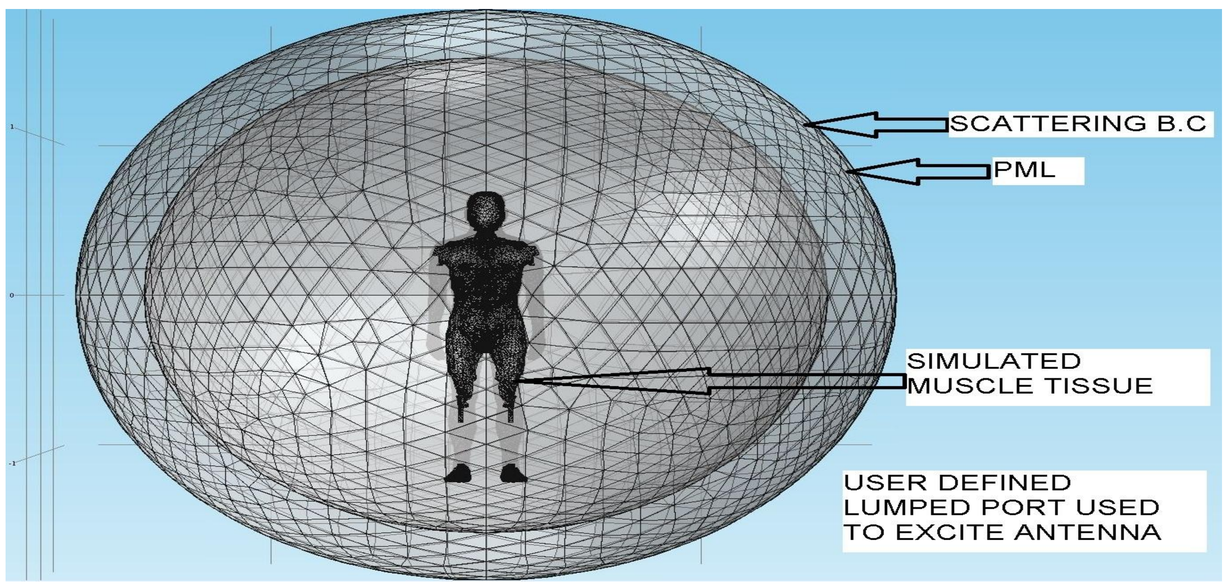


Figure 4. Mesh and Model Setup

Mesh Elements	1.25 Million [Tetrahedrals]
DOF	7.84 Million
Solution Time	40 minutes [per RF channel]
Machine	Quad-Core(3.0GHz, Xeon) Redhat Linux Server, 48GB RAM

Table 1. Model Statistics

	ε_r	μ_r	σ [S/m]
Muscle Tissue [2]	62.5	1	0.9
Copper	1	1	5.99e7
Ceramic	25	1	0
Fair-rite #78	79-j20	0.4-j4.1	0.5
Titanium	1	1	7.4e5

Table 2. Material Properties

Simulation Results and Comparison With Field Trials:

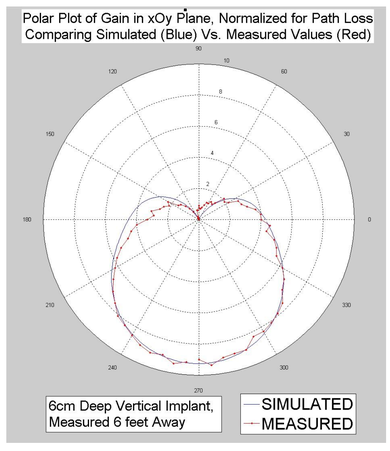


Figure 5. Gain in Azimuthal Plane. Implant in Bucket Filled With Material Simulating Muscle Tissue

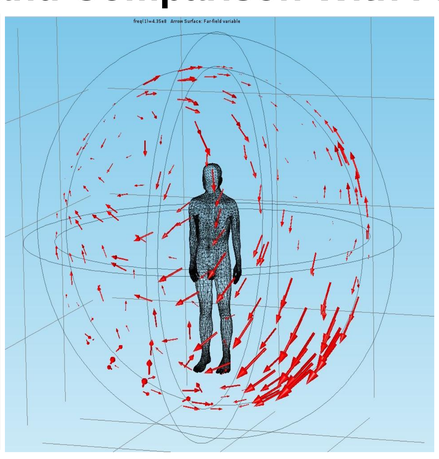


Figure 6. Polarization of E-Field (far)

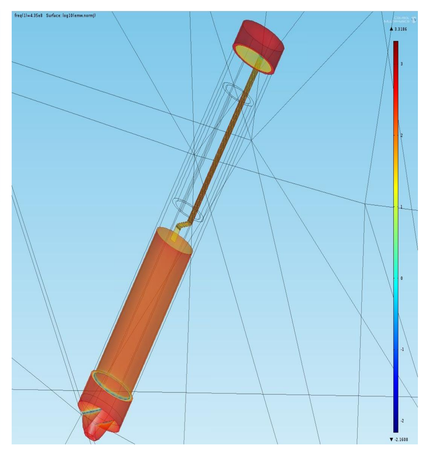


Figure 7. Surface Current Density(Log)

Simulated Z_{in}	28+j6 Ohms
Measured Z_{in}	27+j3 Ohms

Table 3. Feed Point Impedance:435MHz

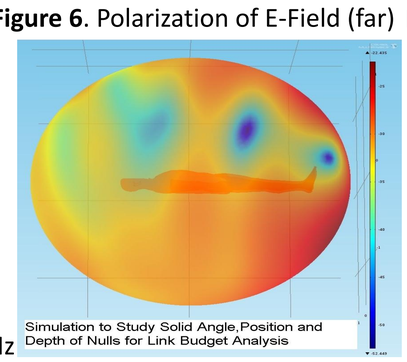


Figure 8. Null Depth and Coverage

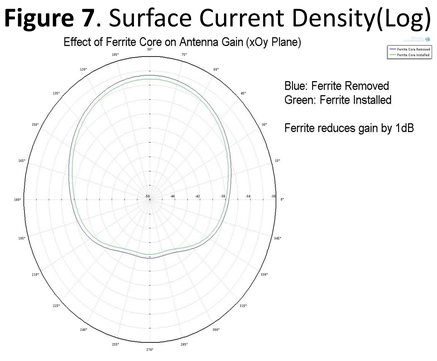
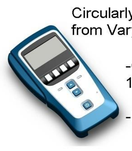


Figure 9. Effect of Ferrite Core on Gain

Design of Circularly Polarized Antenna for External Control Unit:

Circularly Polarized Antenna to Reduce Polarization Loss from Varying Implant Orientation



-Challenge to Design and Match CP Antenna over 10% Fractional Bandwidth at 434MHz

-Electrically Small Antenna:
Large Reactive Part of Feed Impedance
High Q, Approaching Chu-Harrington Limit[3,4]

-Comsol Used to Optimize Antenna Geometry to Lower Antenna Q, Optimize Gain and AR BW

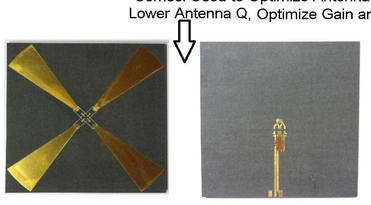


Figure 10. External Control Unit Antenna Design

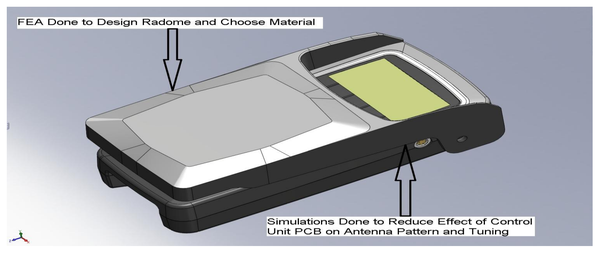


Figure 11. Radome and Case Design

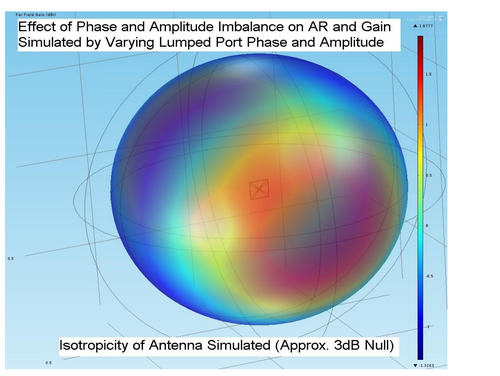
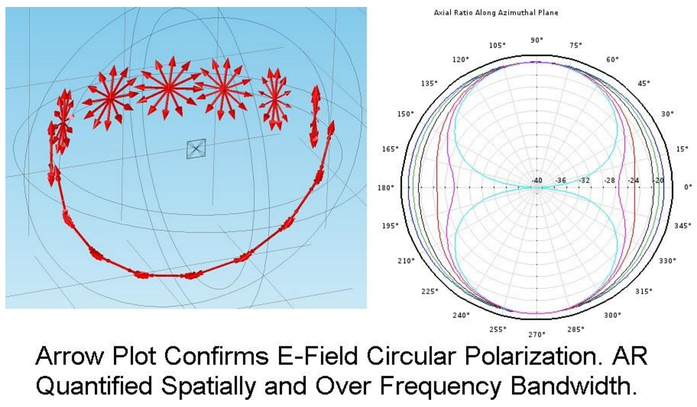


Figure 12. Far Field Gain, Effect of Imbalance



Arrow Plot Confirms E-Field Circular Polarization. AR Quantified Spatially and Over Frequency Bandwidth.

Figure 13. Simulated E-Field Polarization, Axial Ratio

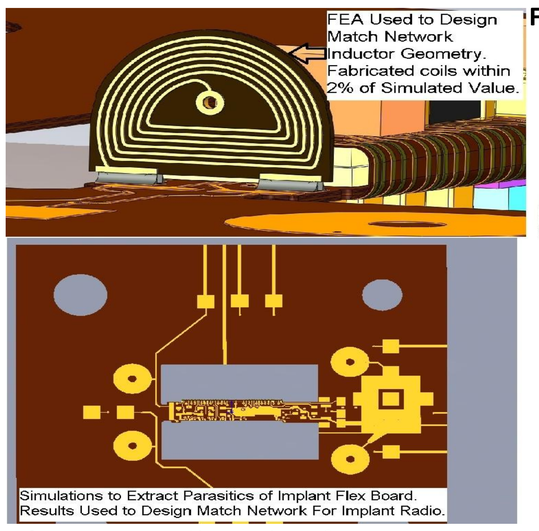


Figure 14. FEA Simulations for Implant Design

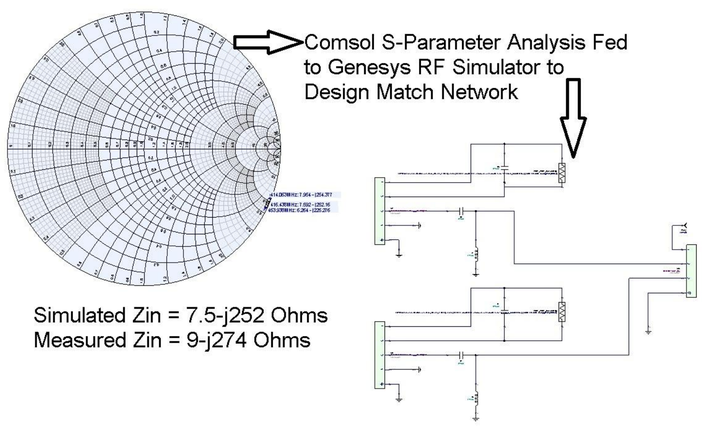


Figure 15. S-Parameter Analysis, Match Network Design

Conclusions: Finite Element Analysis of implanted and external antennas provide accurate results for link budget analysis. Future work will include studying effects of muscles, organs, skeleton - having different electrical properties; Transient simulations to study effect of indoor-multipath environment: fading and intersymbol interference.

References:

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