Towards the Design of a Non-Invasive Blood Glucose Monitor

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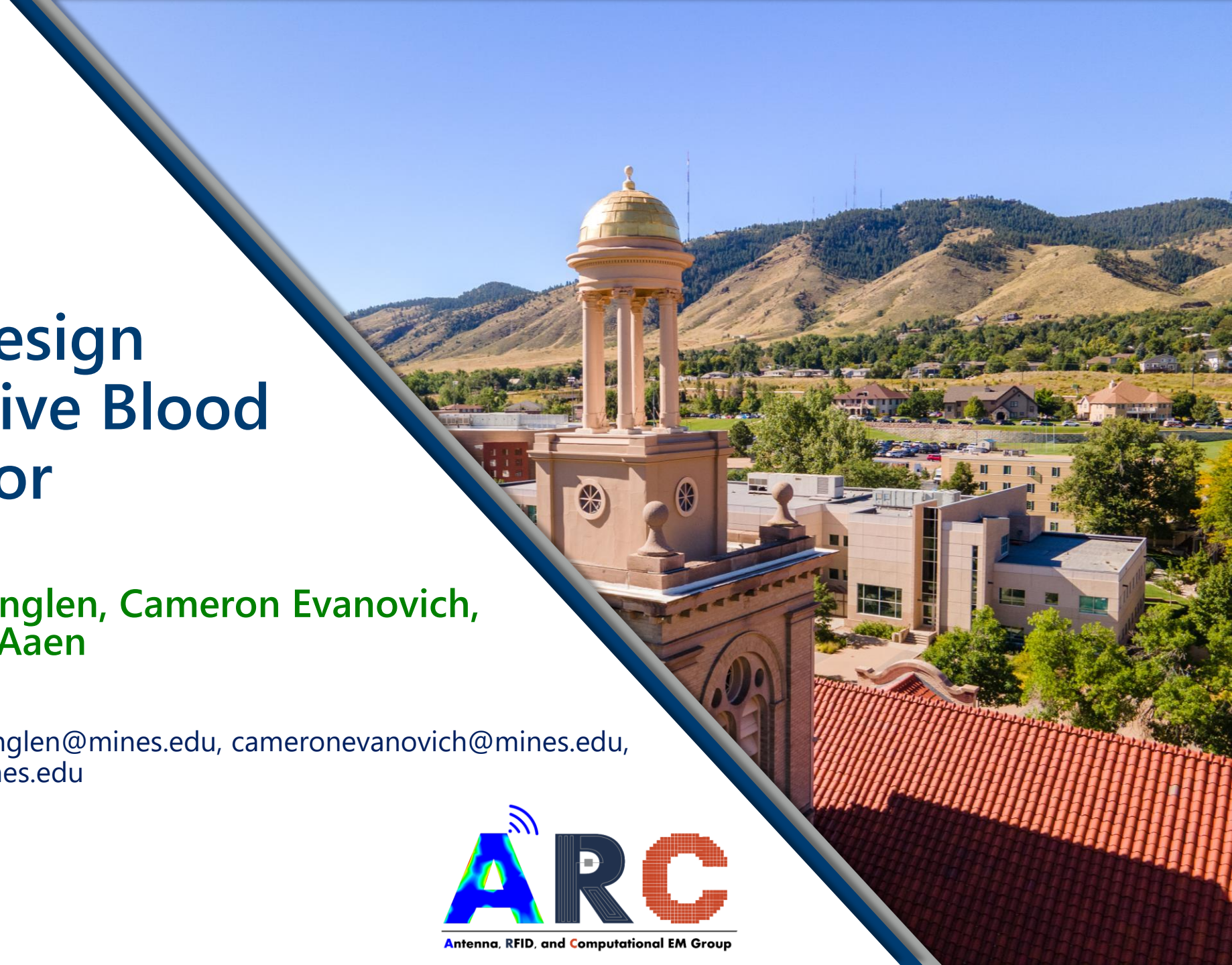


Introduction

Long Term Goals

- Develop antenna-based sensor sensitive to changes in blood glucose levels
- Compact - Comfortable -Reliable Accurate
- Process and communicate those changes to an external device (ie: smartphone)

Why?

- Current continuous blood glucose monitors (CGMs) are invasive, uncomfortable, and single use.
- CGMs are currently the best way to prevent diabetes complications.

Technical Background

- Plenty of environmental factors influence antenna performance
- Sweat, temperature, etc

Challenges

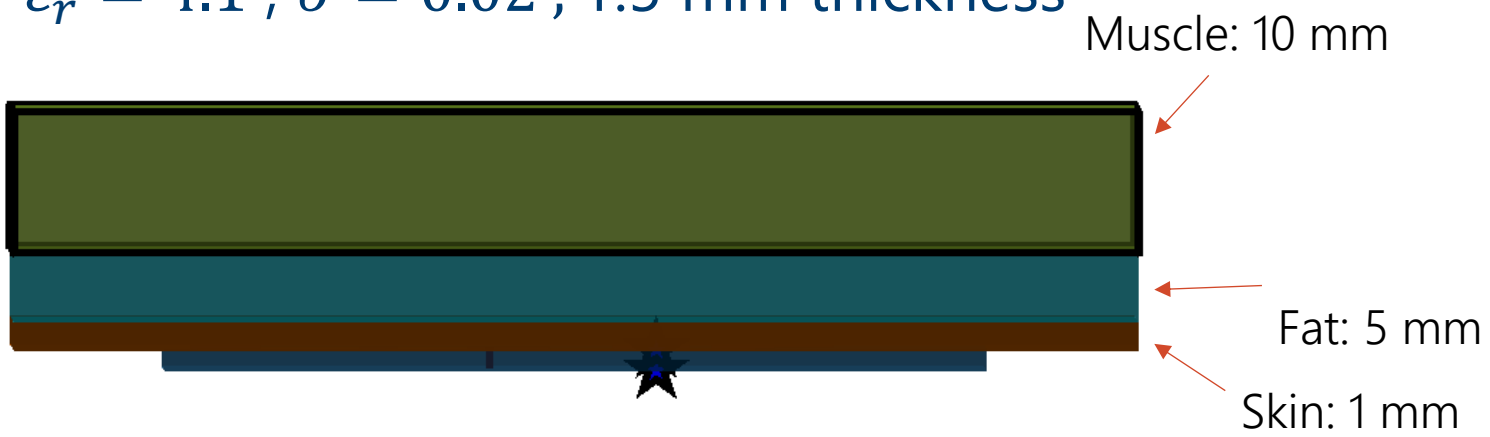
- Other molecules at similar concentrations could impact performance as well
- Cholesterol, Lactic Acid

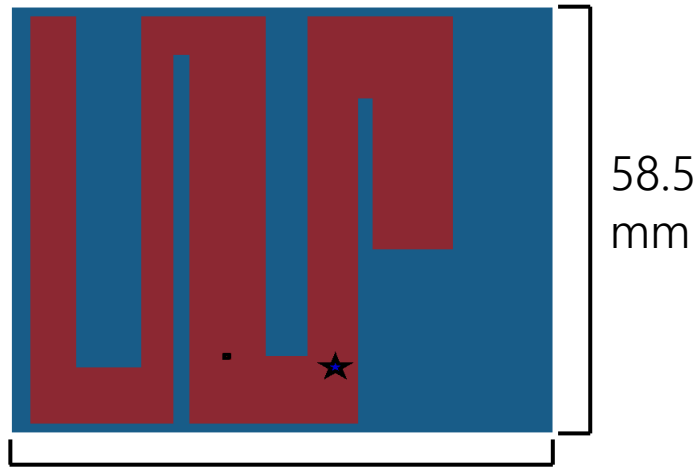
Antenna Design

- Resonant patch antenna on FR4 substrate
- Fabricated antenna made with LPKF milling machine
- Simulated antenna places on skin, Fat and muscle

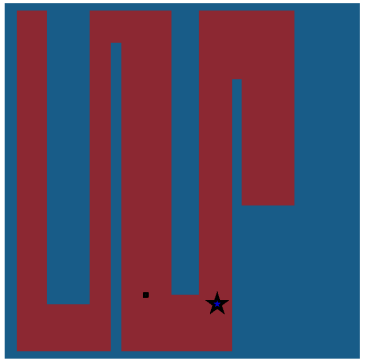
	Fat	Muscle	Skin
$\Delta\epsilon_1$	0.9895	36.54	32.51
$\Delta\epsilon_2$	1.846	2.349	2.499
$\Delta\epsilon_3$	17.87	324.1	125.6
τ_1	4.377e-12	6.47e-12	7.248e-12
τ_2	8.119e-12	1.393e-11	5.272e-12
τ_3	4.127e-09	3.44e-09	1.38e-09
ε_∞	2.67	5.896	4.136

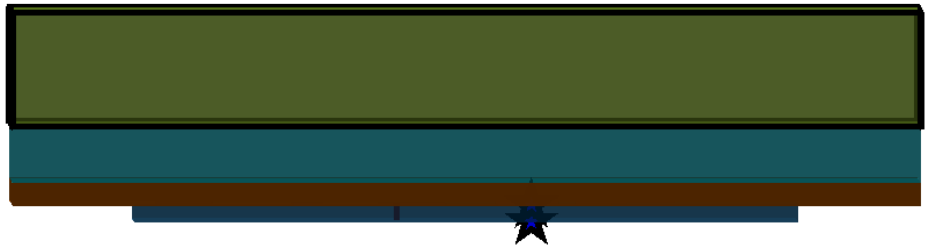
$\varepsilon_r = 4.1$, $\sigma = 0.02$, 1.5 mm thickness

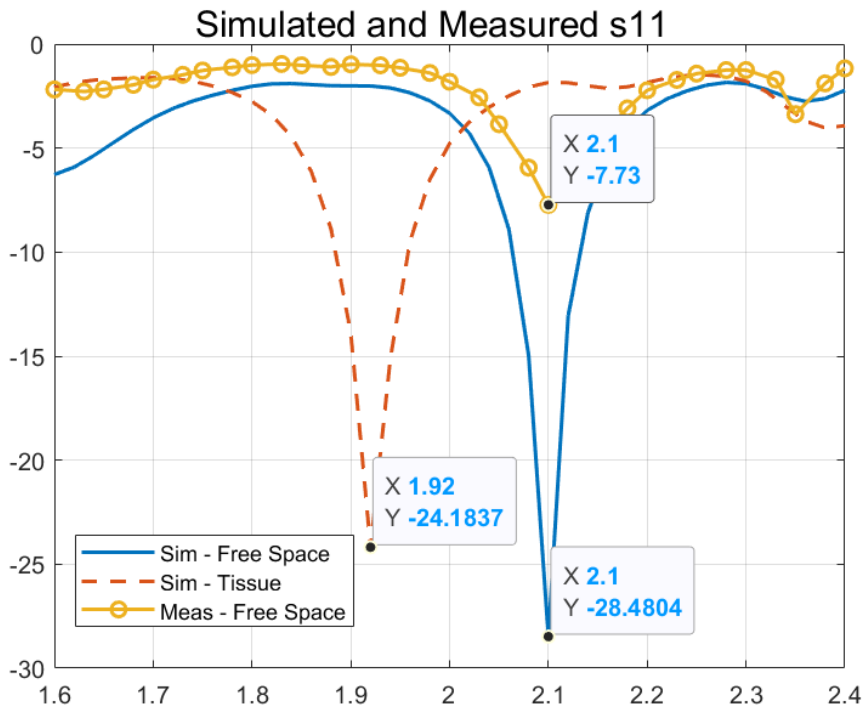


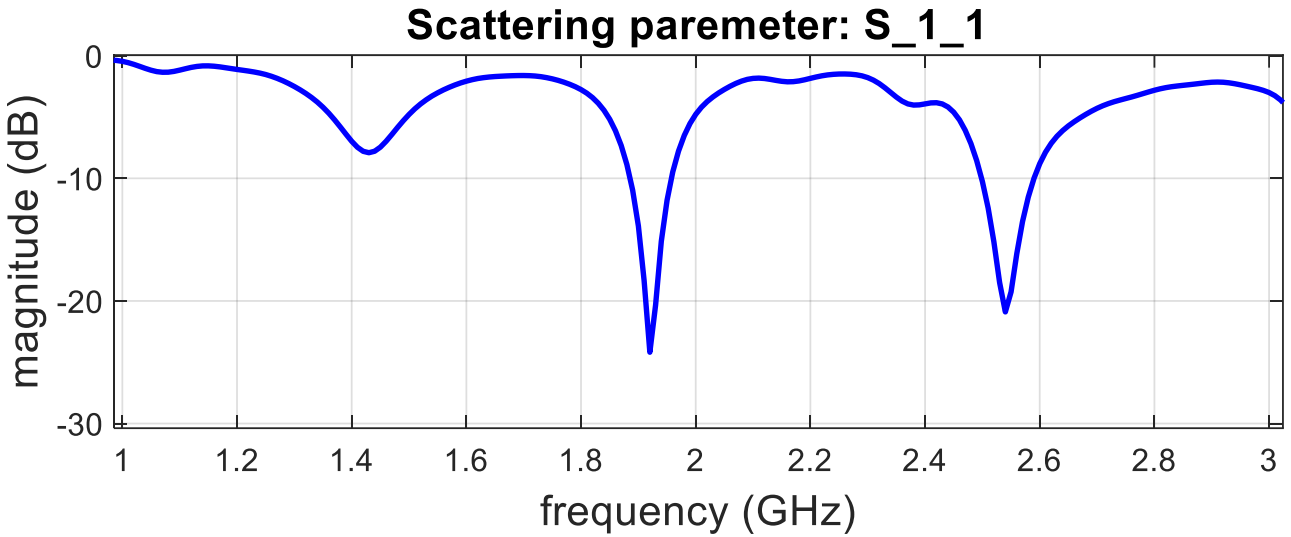


Resonance - Simulation Results



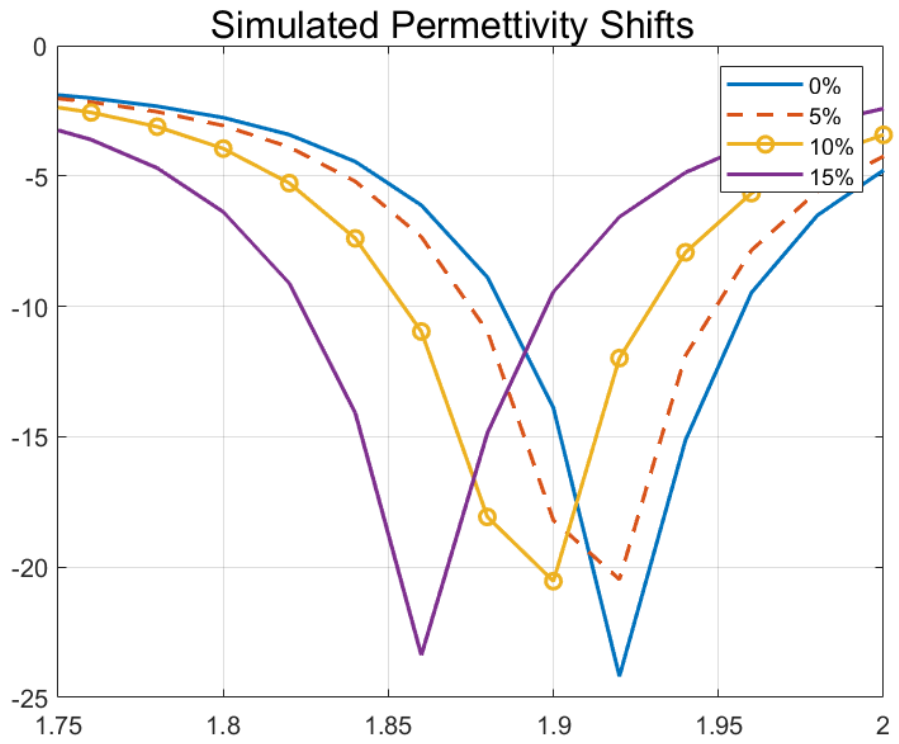


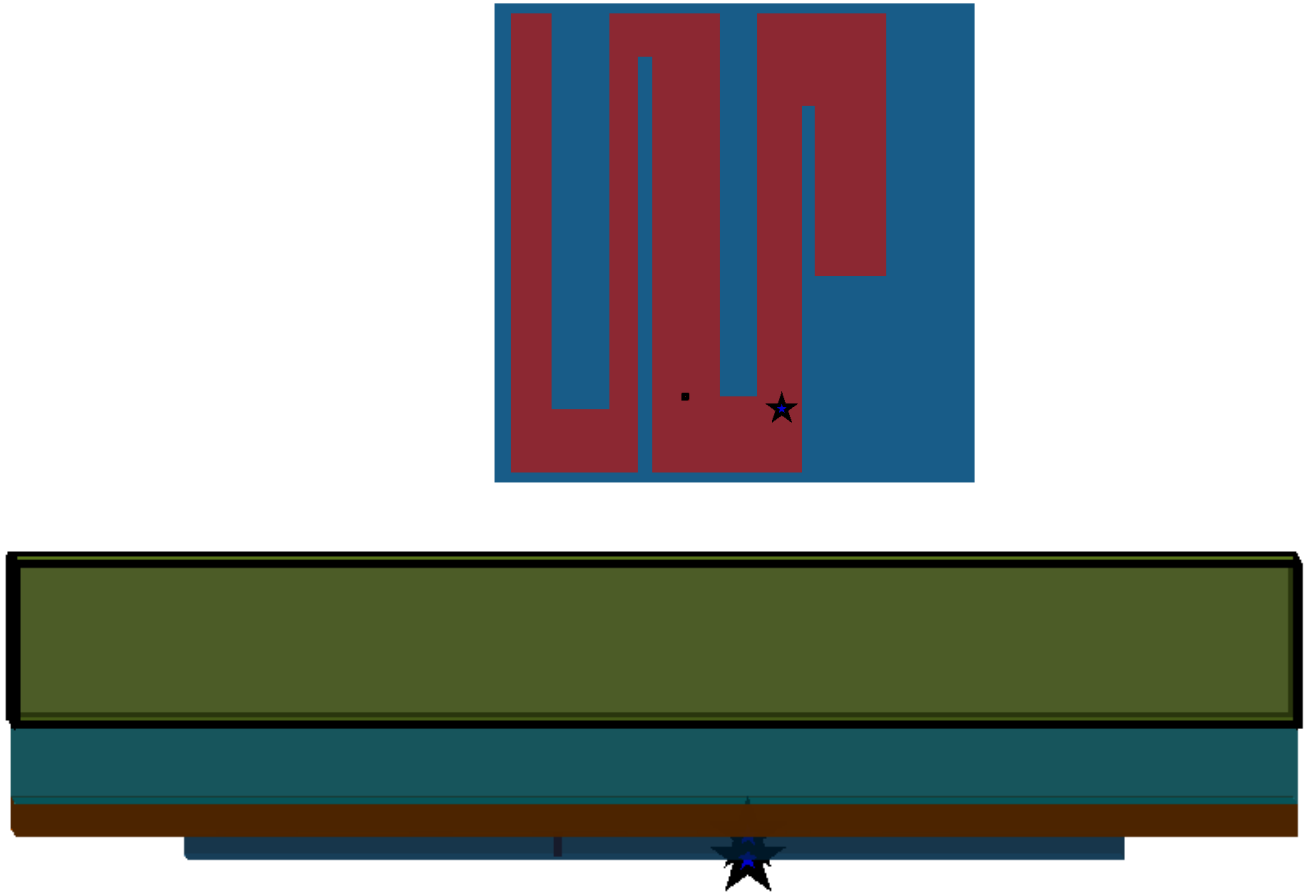




We see similar results between the simulated antenna in free space and the fabricated antenna, however, the fabricated antenna performs significantly worse in free space.

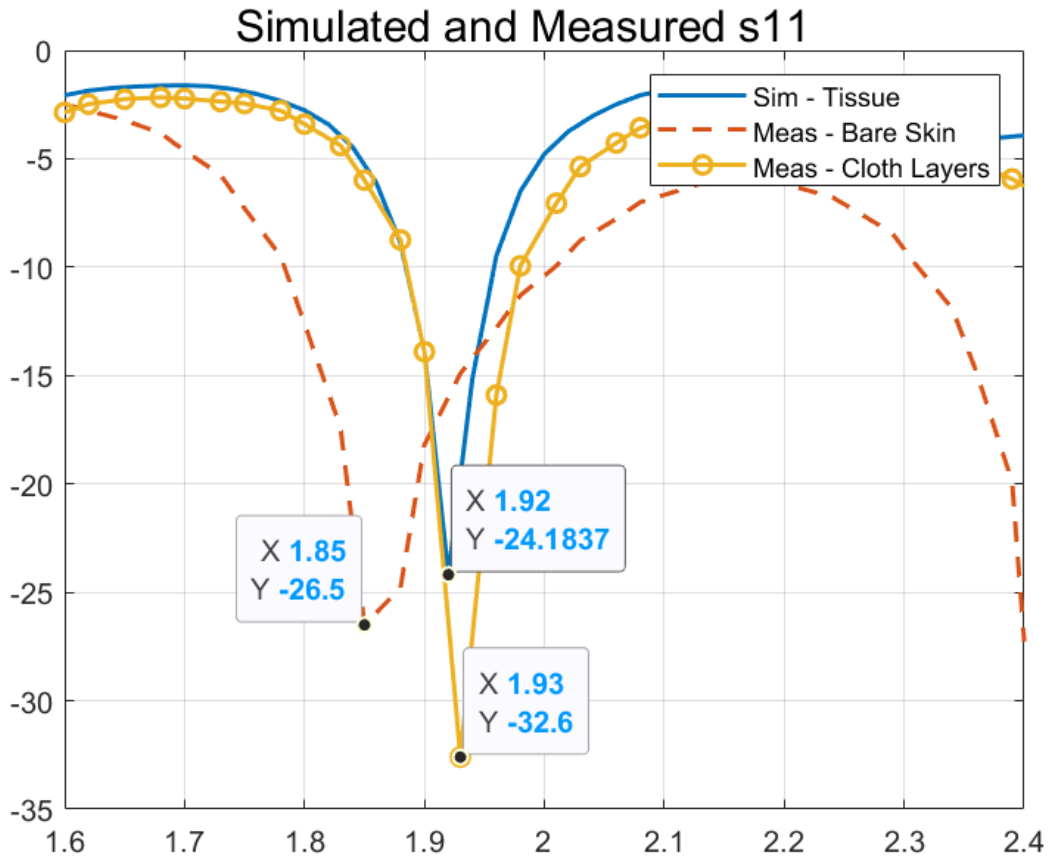
Resonance behavior with Tissue Permittivity Variations

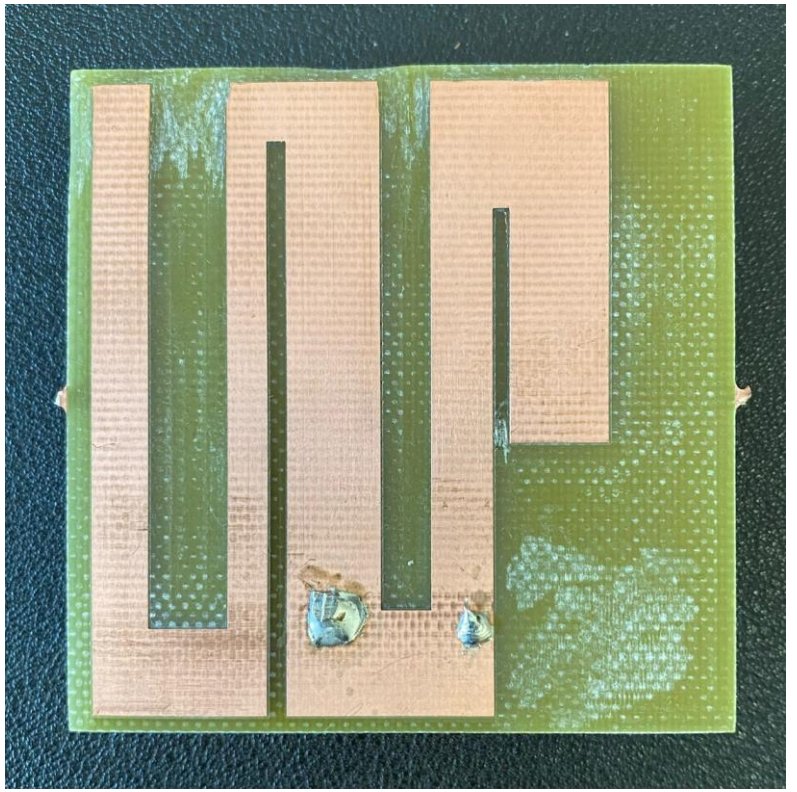




Measurable shifts in resonance is Observed when the tissues permittivity changes ~5%,10%,15%

Resonance with Human Tissues - Simulation and Measurements

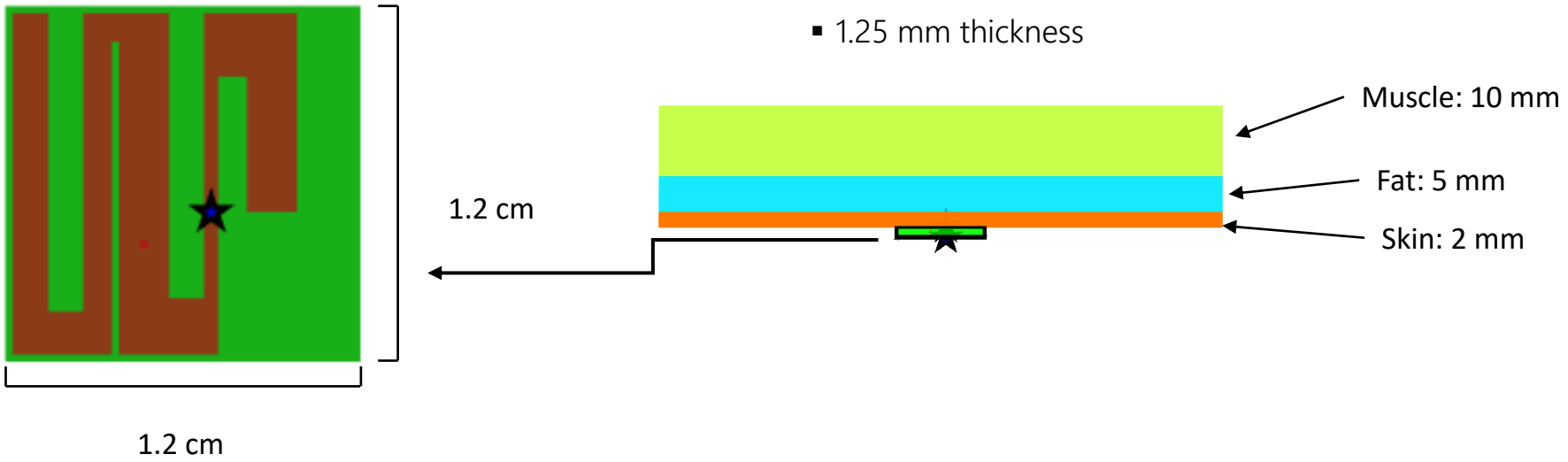




Resonance measurements of the fabricated antenna match closely with simulation results with human tissues model.

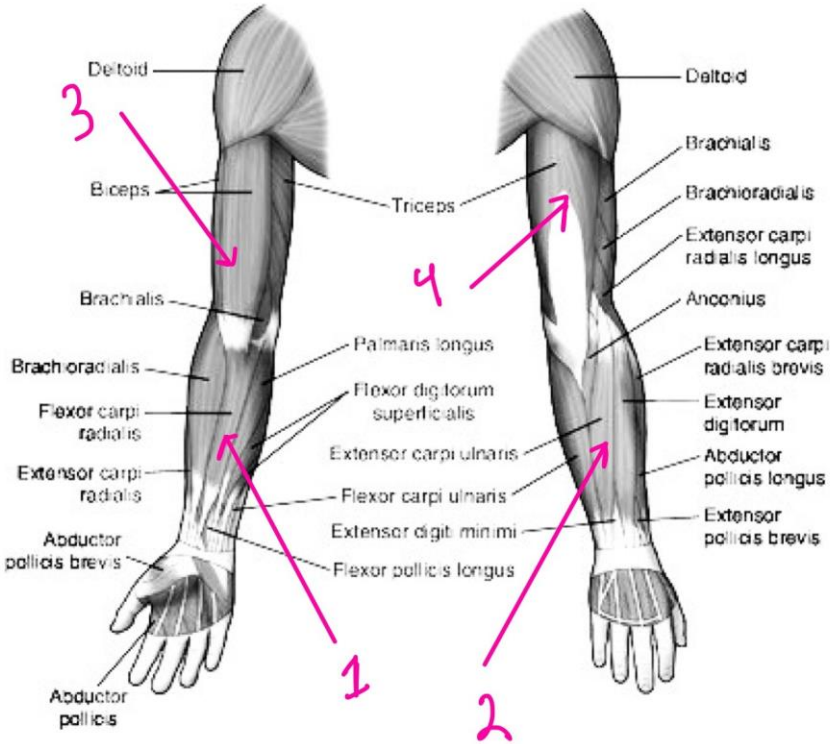
Miniaturized Resonance Patch Antenna

- Substrate: Rodgers
  - $\varepsilon_r = 10.6$
  - $\sigma = 0.002$
  - 1.25 mm thickness

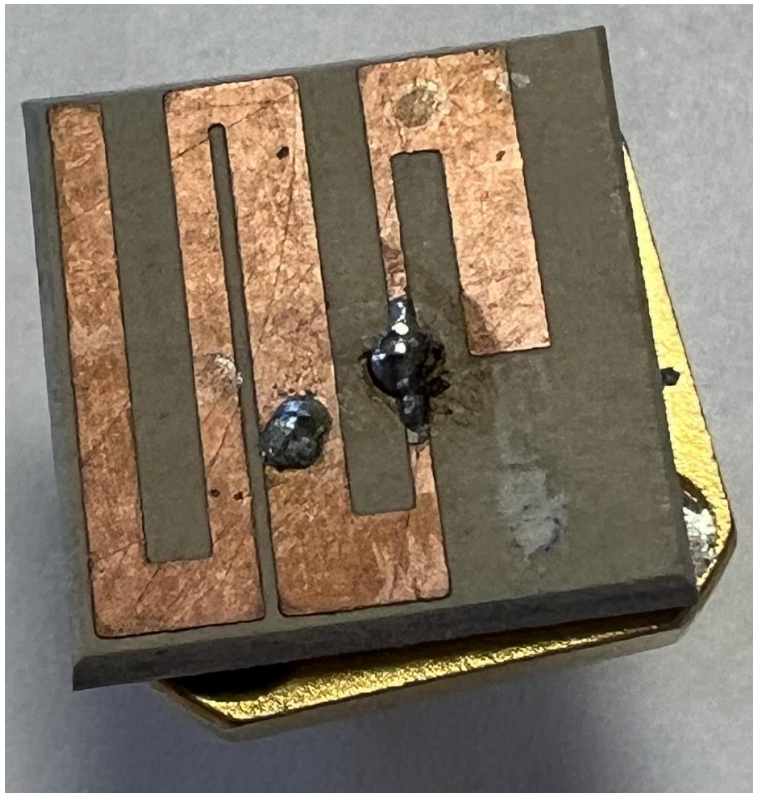


Fabricated Antenna

- **Two** of this antenna design were fabricated and assembled.
- Because of the tolerances in fabrication and soldering, the performance of these two antennas were examined and compared.
- Different positions on the arm were considered for actual measurements as shown below.

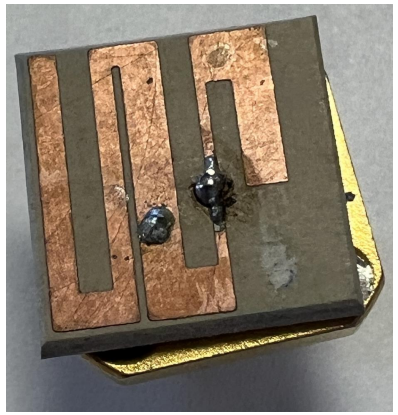


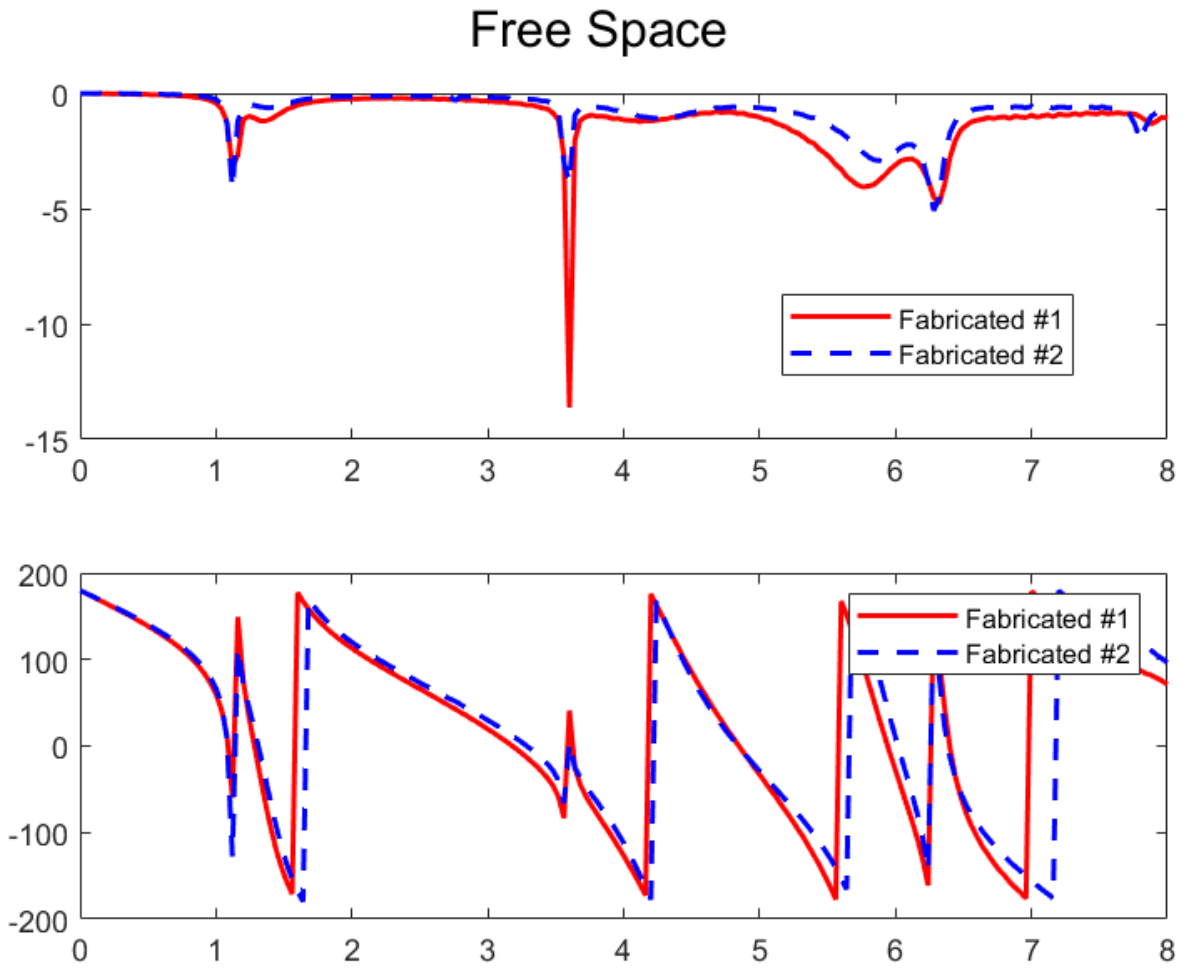
Measurement Locations



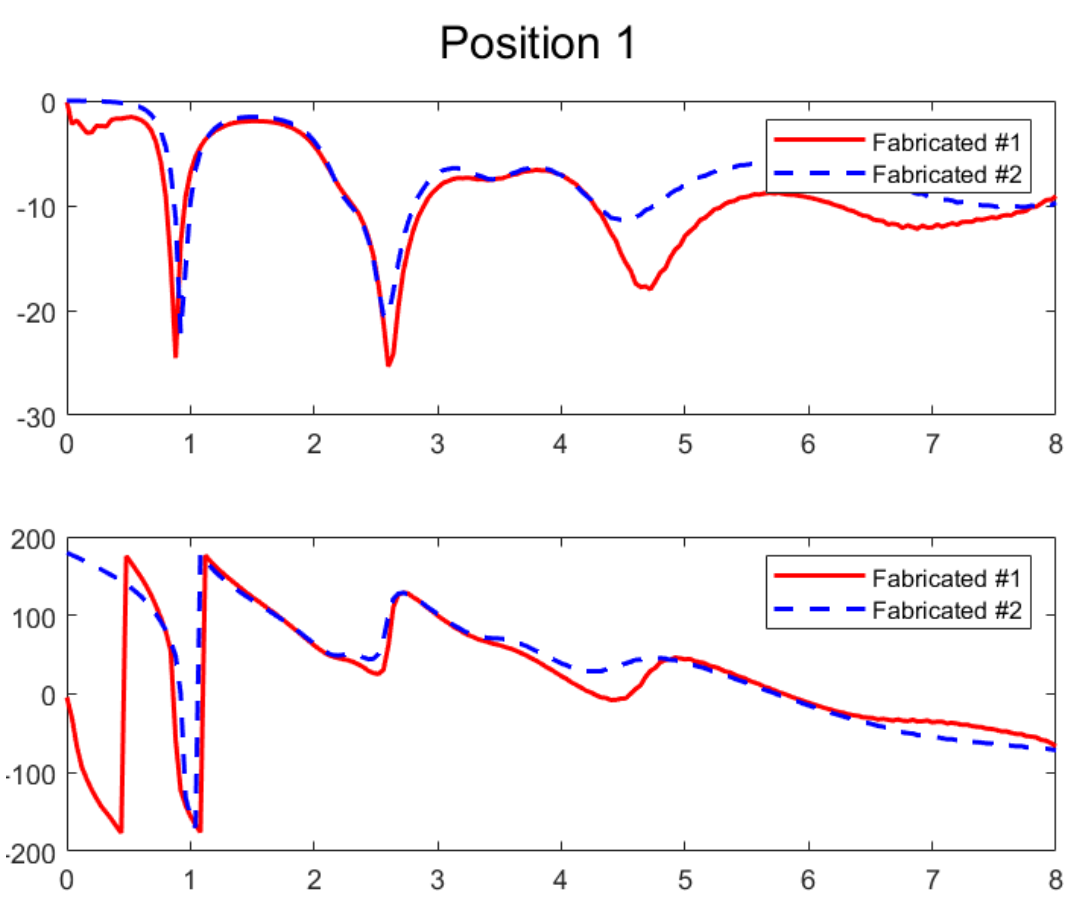
Antennas Reflection in Free Space

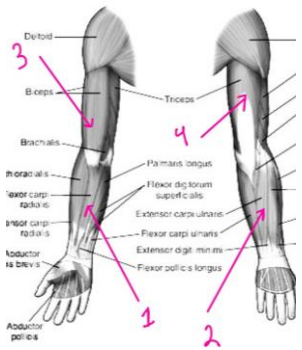
- The antenna #2 works much better in free space than antenna # 1 around 3.7 GHz.
- Neither antenna were designed for free space operation.
- The phase measurements track very well with each other and we see similar performance/resonances

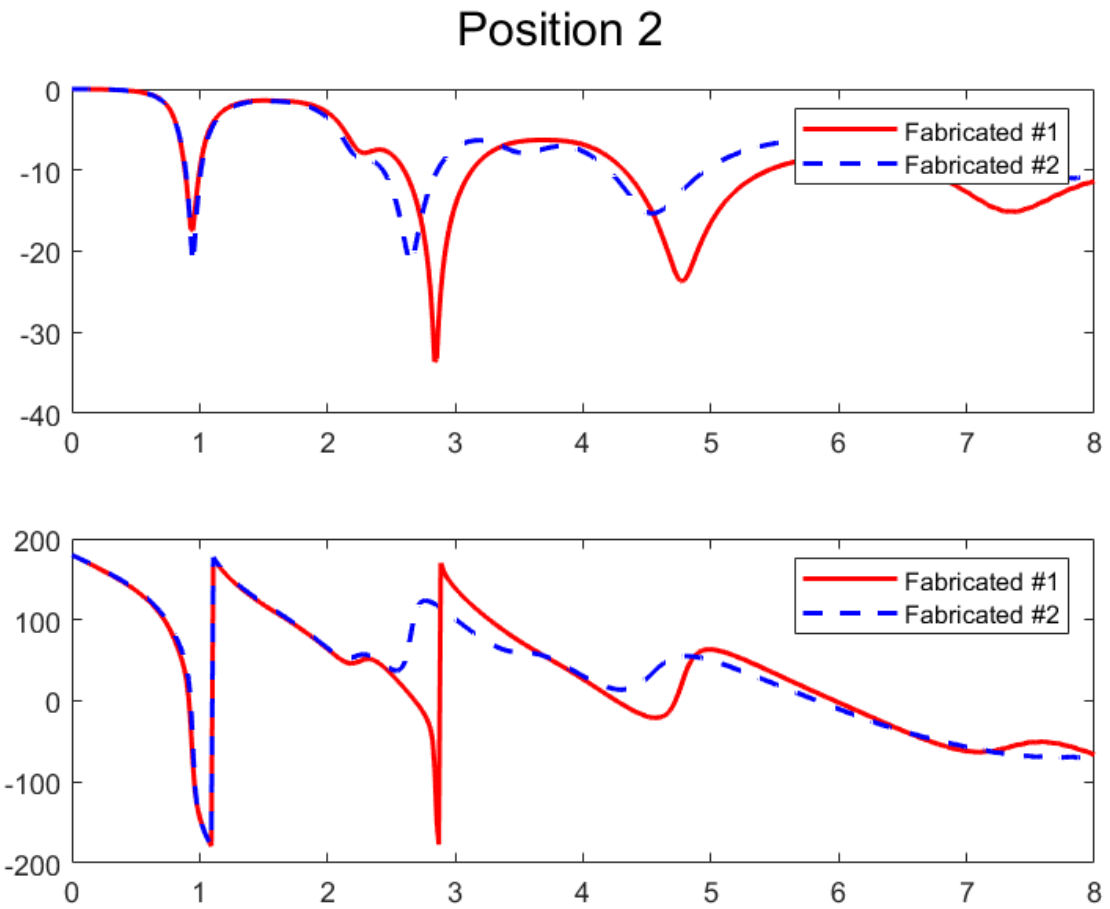




Antennas placed in Position 1

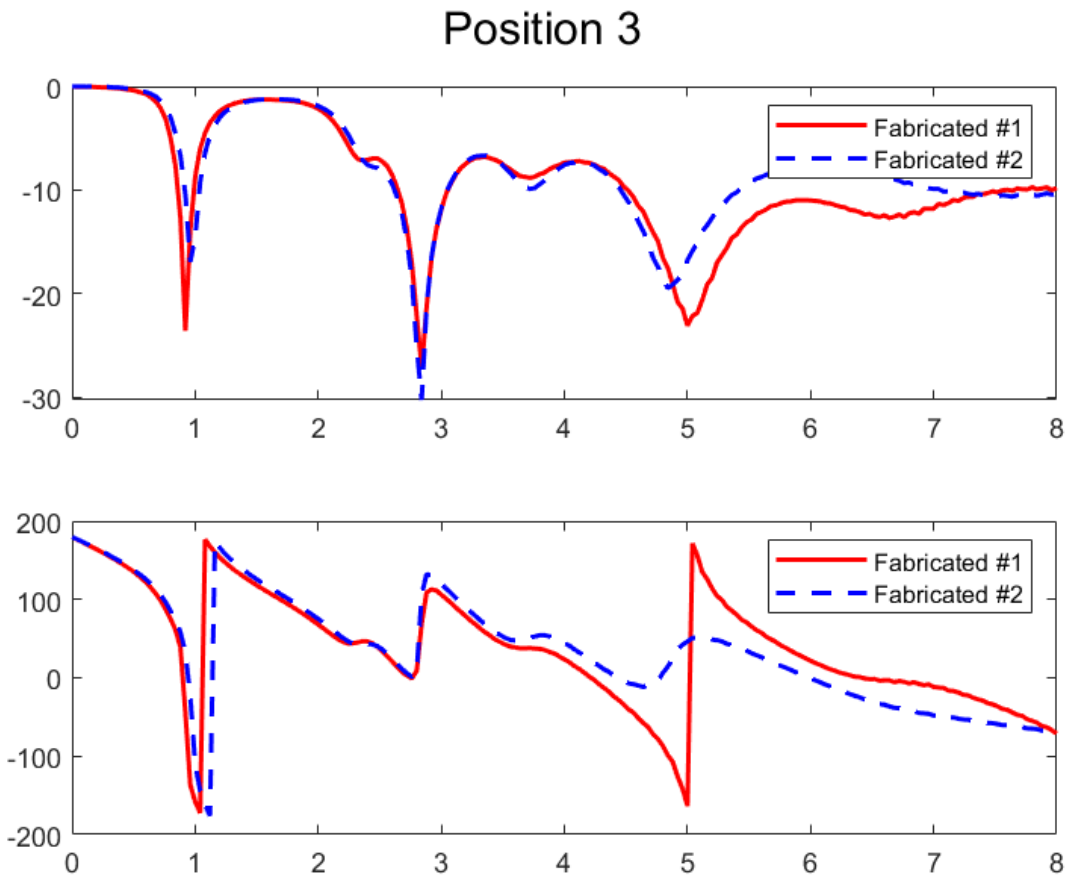


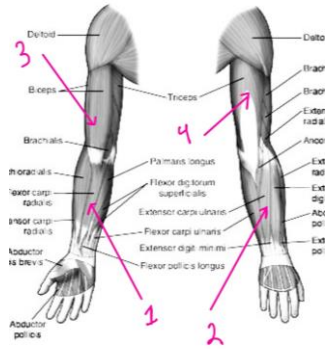


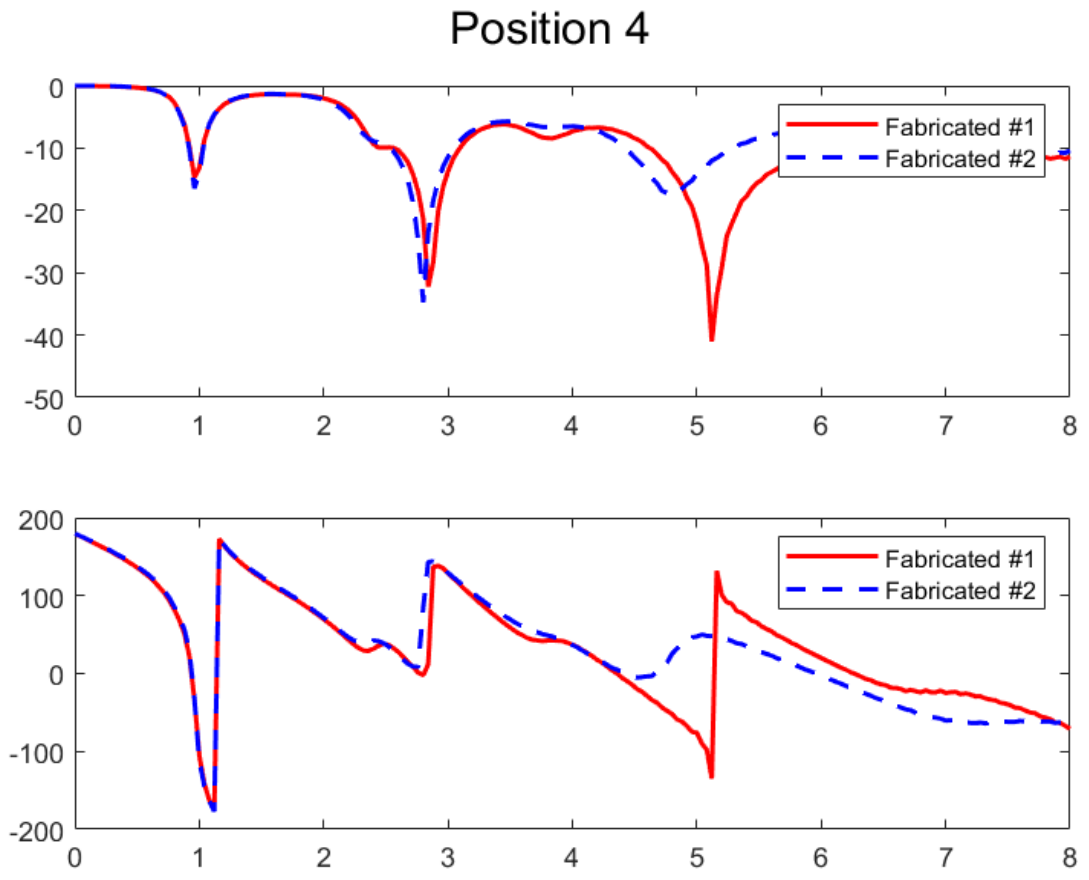


Antennas show consistent and better performance in position 1 relative to position 2.

Position 3

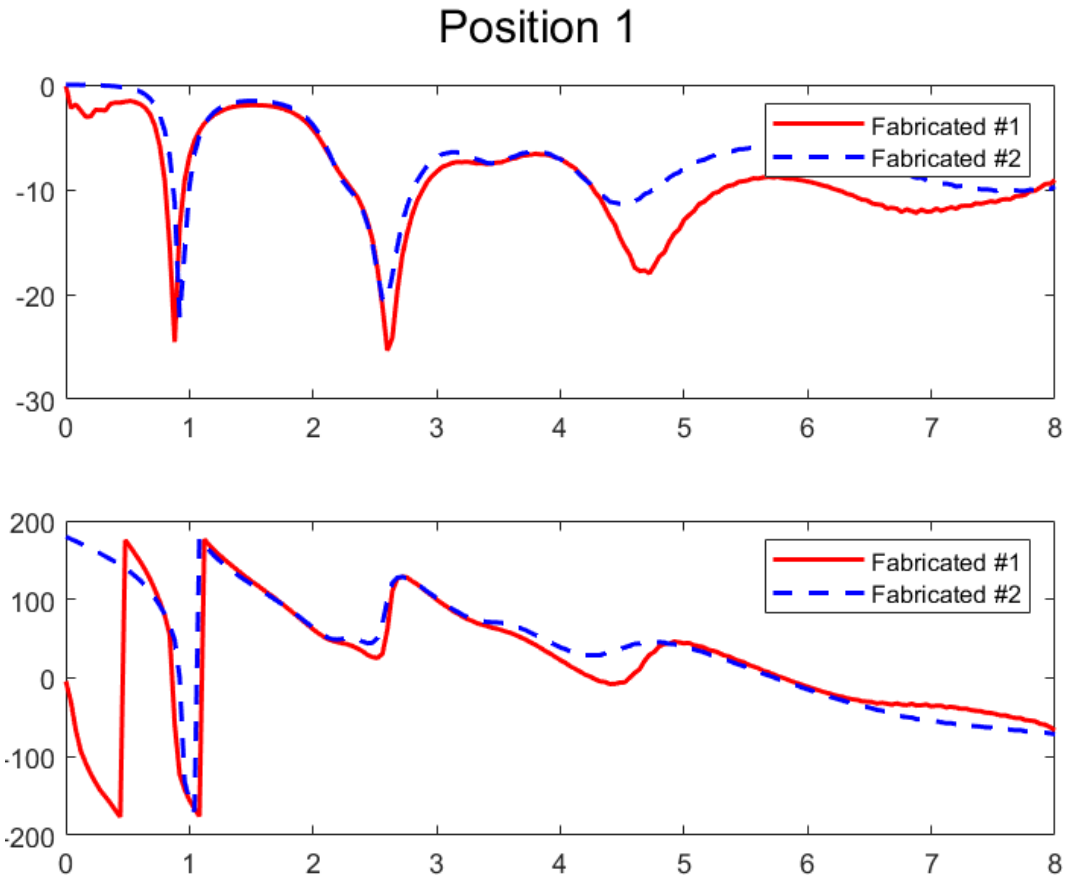


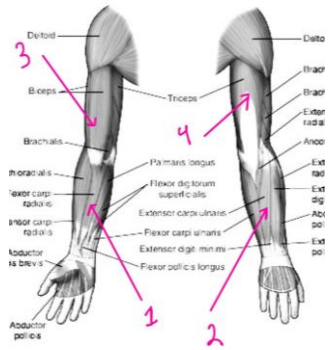


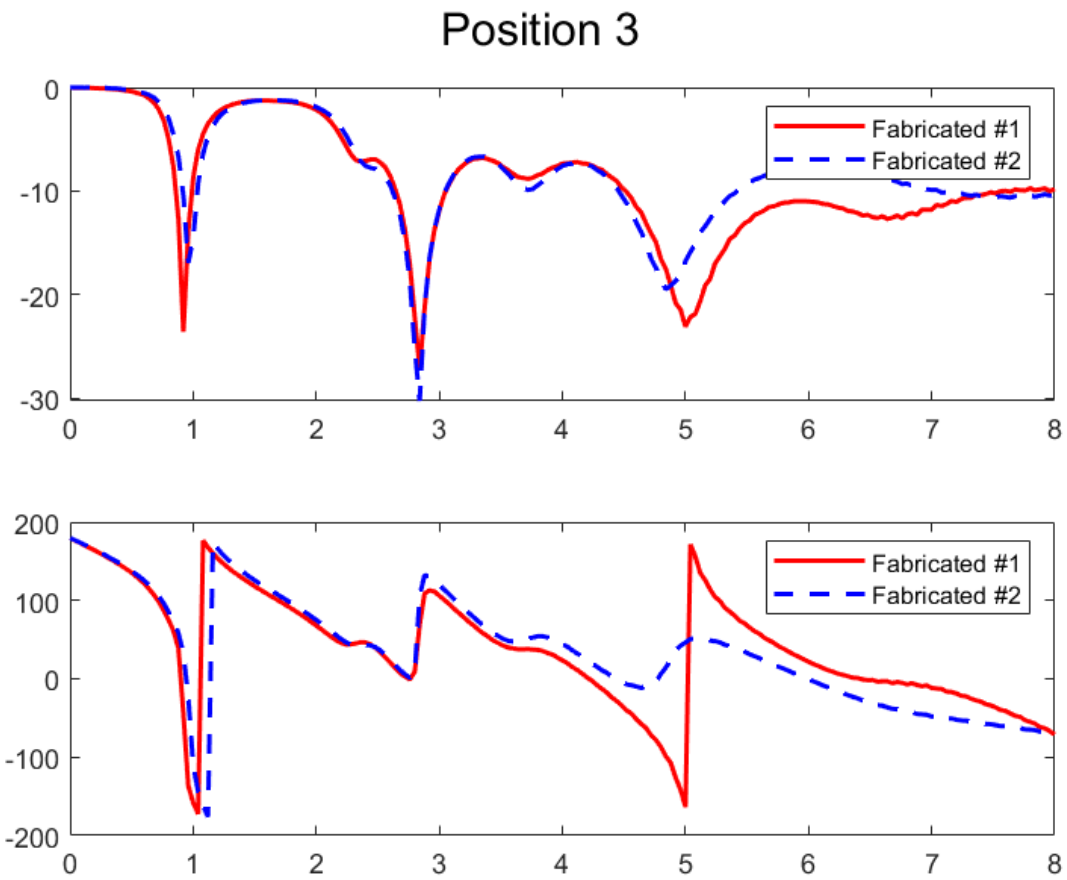


Antennas show consistent and better performance in position 3 relative to position 4.

Position 3





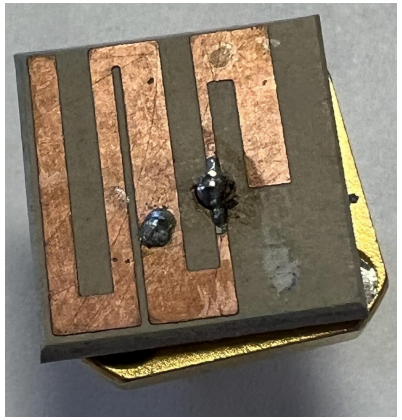


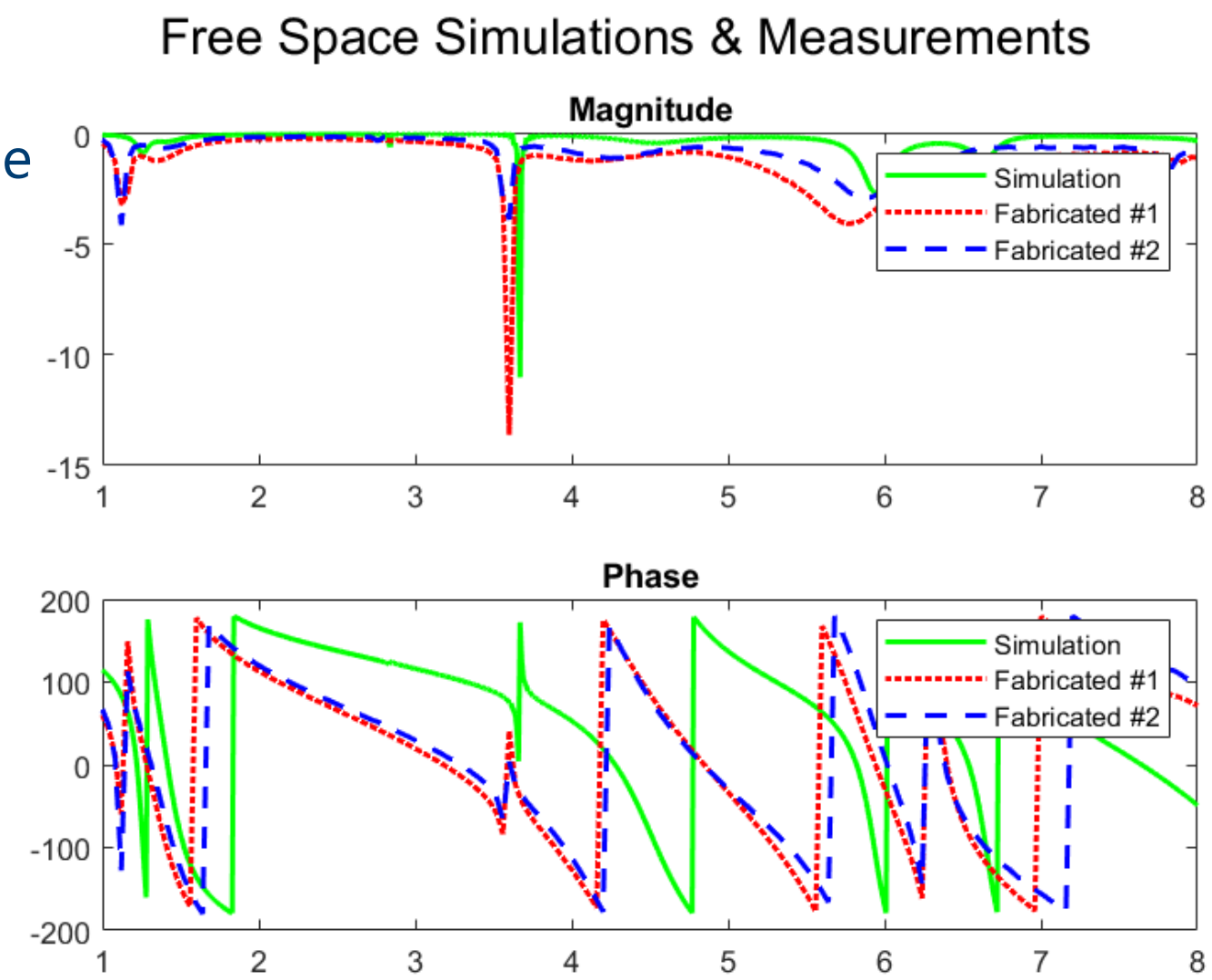
Antennas show consistent and better performance in both positions 1 and 3.

Measurements and Simulations

- We see good alignment with the free space simulations and measurements, however the phase is off in some places

- Overall, is about as good as expected

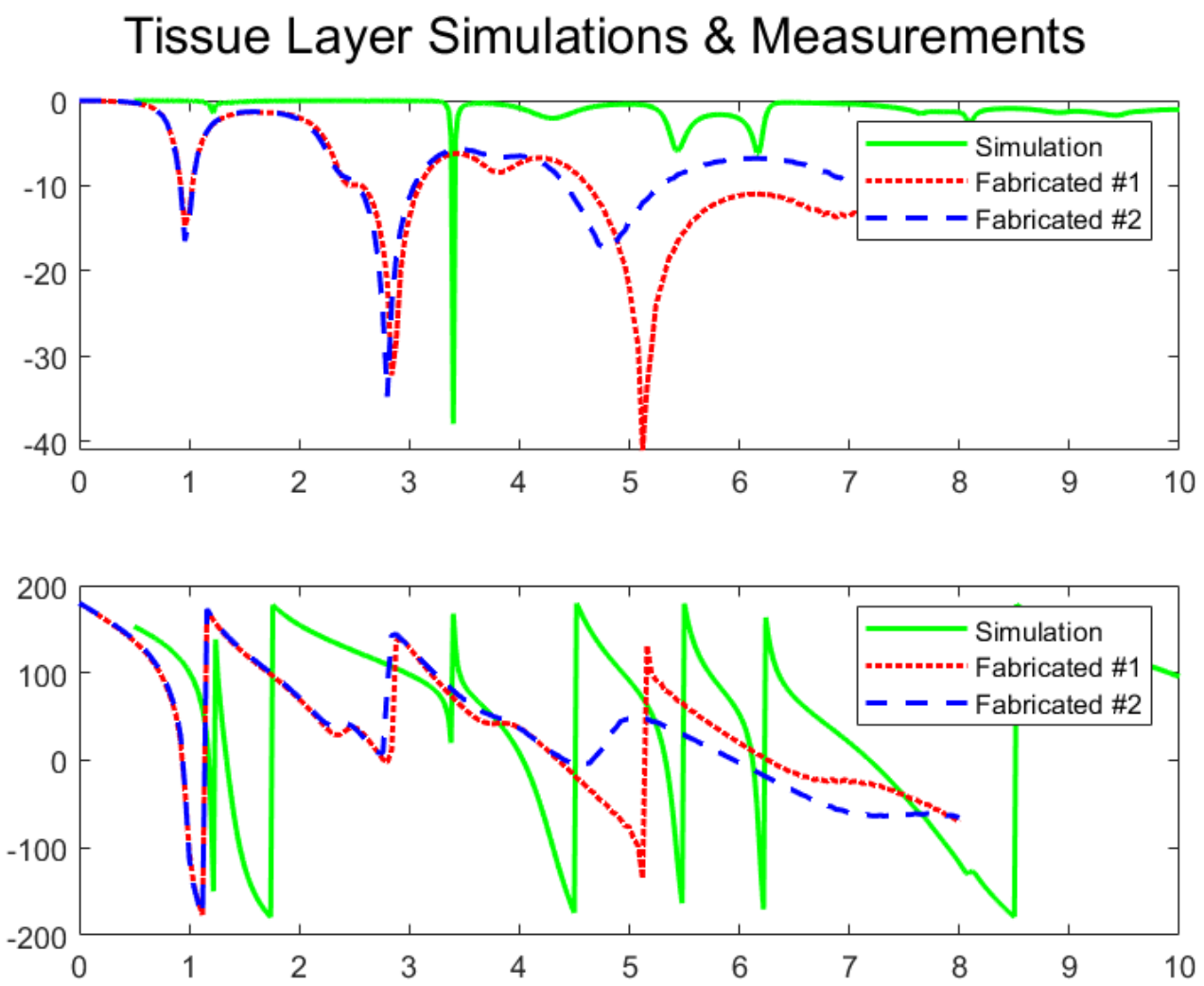




Measurement and Simulations with Tissue Layers

- The fabricated antennas sho different resonances than tho predicted through the simulati with tissues

- These difference can be attribut to the difference between my a actual tissue structure and t tissue layers. Specially the presen of bones that are not considered the simulation.



Conclusions & Future Work

These Antenna designs are a proof of concept that needs further testing.

Future Testing includes comparing measurements with a commercial blood glucose monitor and comparing measurements at different times and days.