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Orthopaedic Implant Micromotion Sensing Using An Eddy Current Sensor

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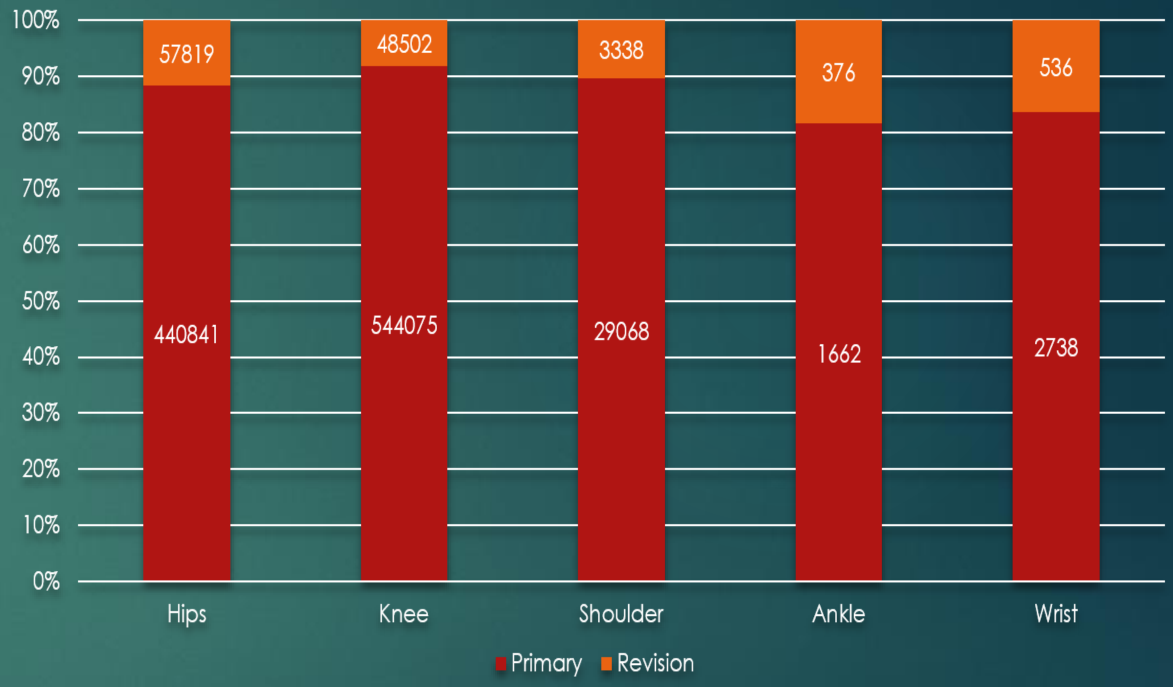
Motivation - Problem

- In Australia, till 2016, about 1.1 million people had Orthopaedic surgeries.
- Out of these, about 100K were revision surgeries.
- In 85% of the cases the major cause of the revision is the Aseptic Loosening and mechanical failure whereas remaining 15 % is due to infection.
- This causes a substantial

a) Financial burden on healthcare system and

b) Physical discomfort to the patient.



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Motivation - Solution

- Measure micro motion of the implant on bone
- *50μm motion is the threshold for decreased bone ingrowth.*
- Detect impending failure of the implant
- Modify post-operative mobilisation to allow for better bone ingrowth if there is excessive initial motion

Need to Develop a Small Implantable Non-contact Micromotion Sensor with the Resolution of 10 μm.

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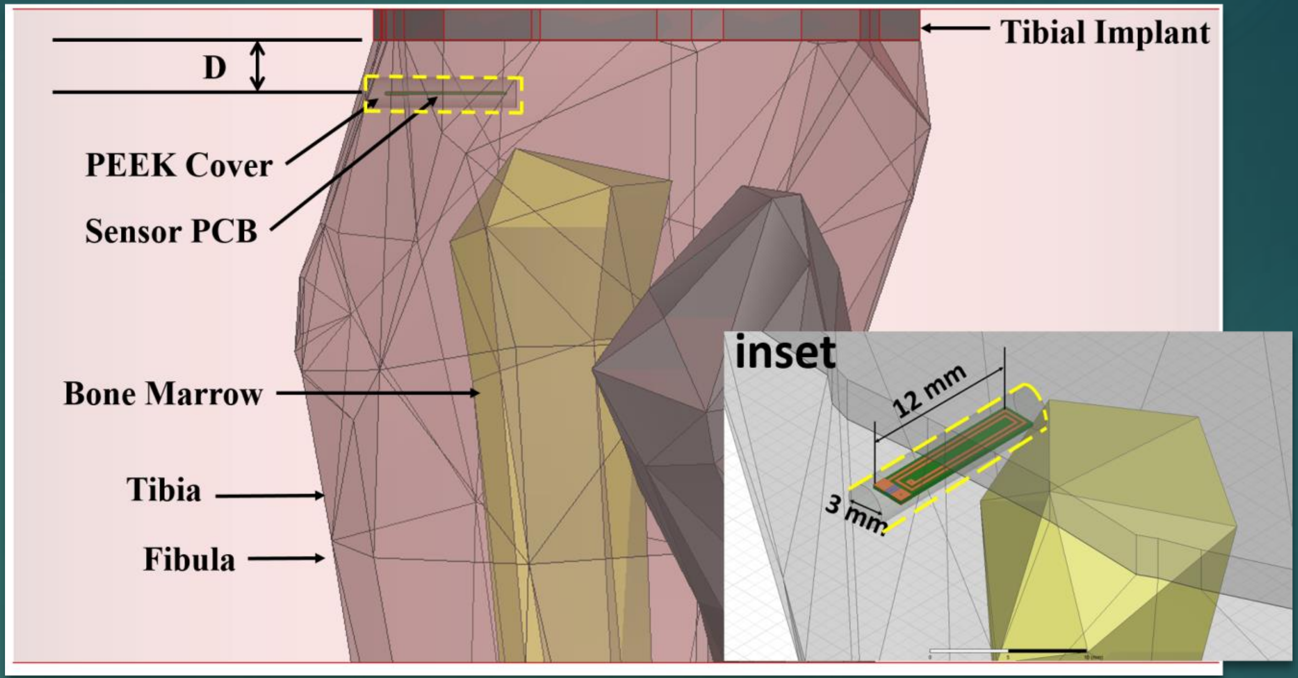
Modelling in Ansys HFSS



A cylindrical hole of diameter 3 mm and length 15 mm is drilled into the tibial bone at a distance D from the tibial implant (target). A two-turn loop is printed on Rogers RT Duroid 6010 substrate and inserted into the hole. The sensor head is encapsulated in a low loss biocompatible material, PEEK. This entire assembly is inserted in a cylindrical muscle phantom of diameter 120mm.

How does the Impedance of the eddy current loop changes with

a) Distance D between Tibial plate and sensor.
b) Frequency of Operation

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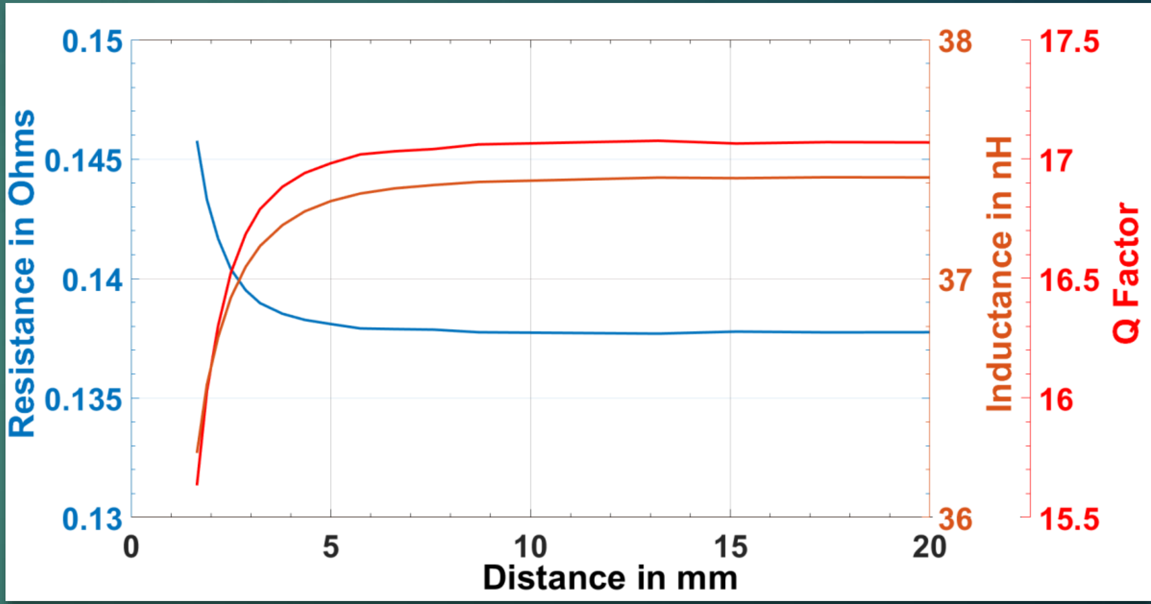
Simulations Results - 1

- At 10 MHz, the response of the eddy current sensor shows a typical behaviour in which inductance increases with the distance while resistance decreases and correspondingly Q Factor increases.



We perform curve fitting on these graphs in the form $y = ax^b + c$

Sensitivity is distance dependant !!!

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Defining Analysis Parameters

- Sensitivity is defined as the relative change in the measured quantity y expressed in dB for 10 μm displacement of the target .

$$S_{10\mu m} = 10\, log_{10} \frac{\Delta y}{y}$$

- Sensitivity range is defined as the distance between target and sensor at which the sensitivity drops to 'x' dB.
- While first definition allows for analysing what is the sensitivity at given standoff distance, the second parameter is useful for working out the stand-off distance given the limitations of the designed circuit.

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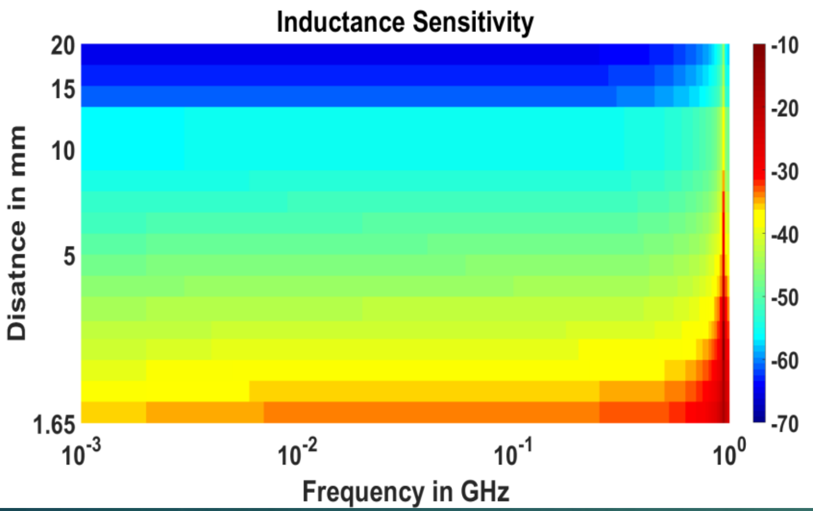
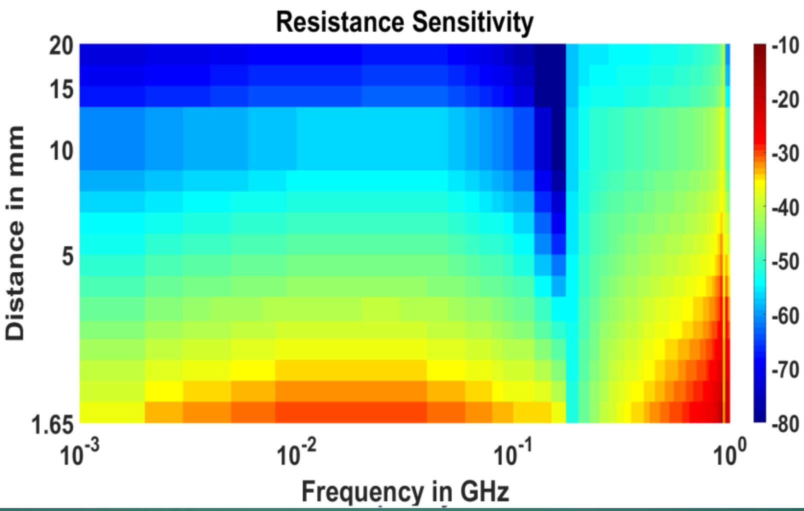
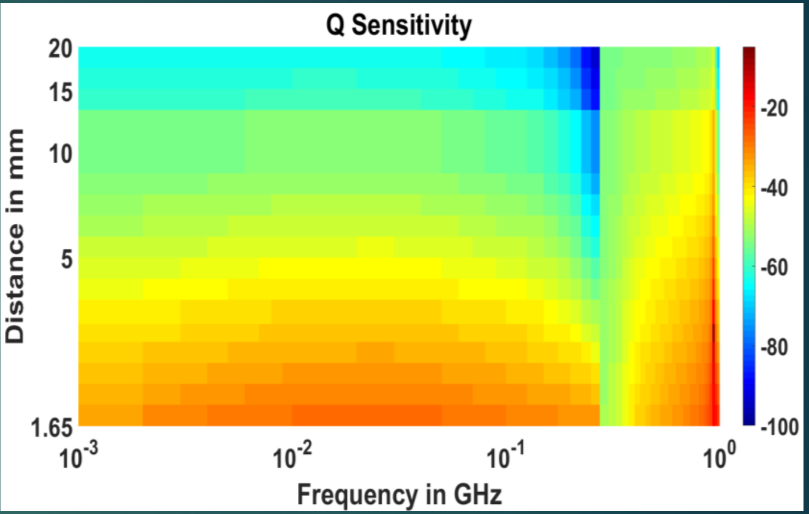
Simulations Results - 2







- As frequency increases the inductance sensitivity also increases. However, the change is very prominent in the vicinity of Self Resonant Frequency (SRF) of 920 MHz.
- The graph for resistance shows that sensitivity has a null around 200 MHz and an optimum value in the range of 20-50 MHz. The Sensitivity peaks at SRF.
- Q factor follows nature of resistance.

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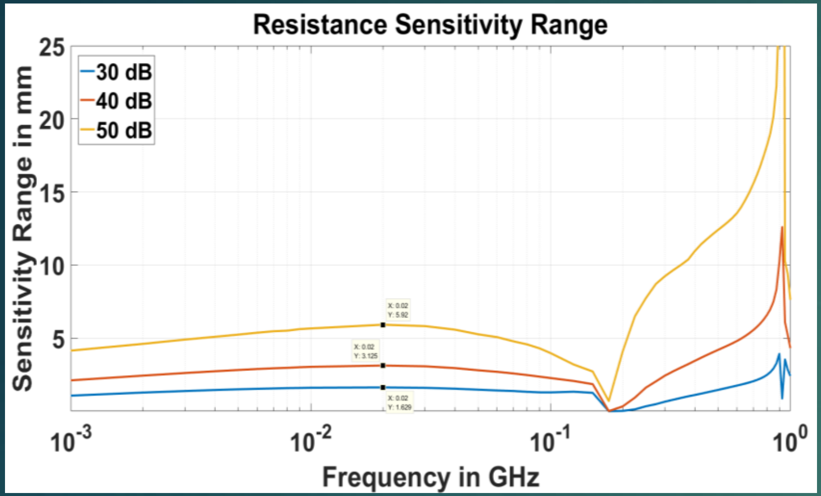
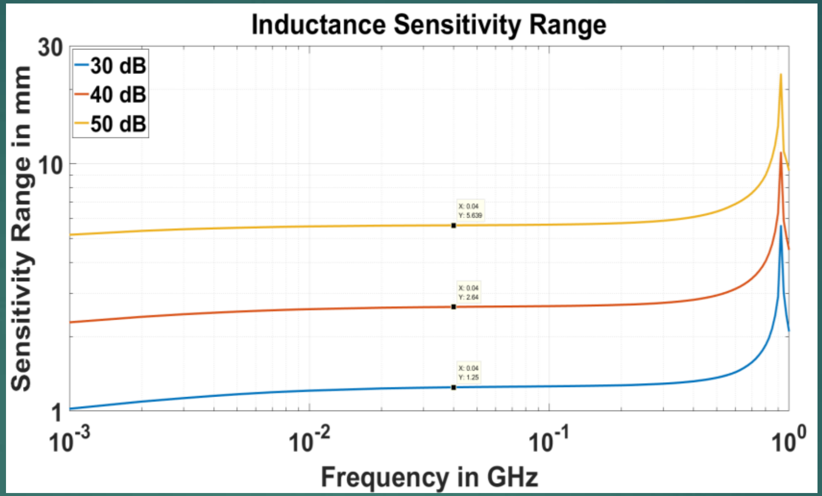
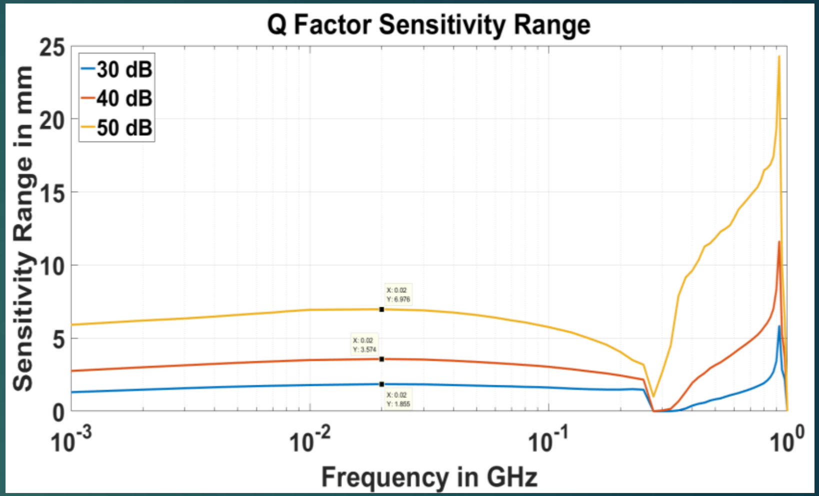
Simulations Results - 2







@ 20 MHz	30 dB	40 dB	50 dB
Inductance	1.25 mm	2.54 mm	5.6 mm
Resistance	1.63 mm	3.15 mm	6.1 mm
Q Factor	1.86 mm	3.57 mm	7.0 mm

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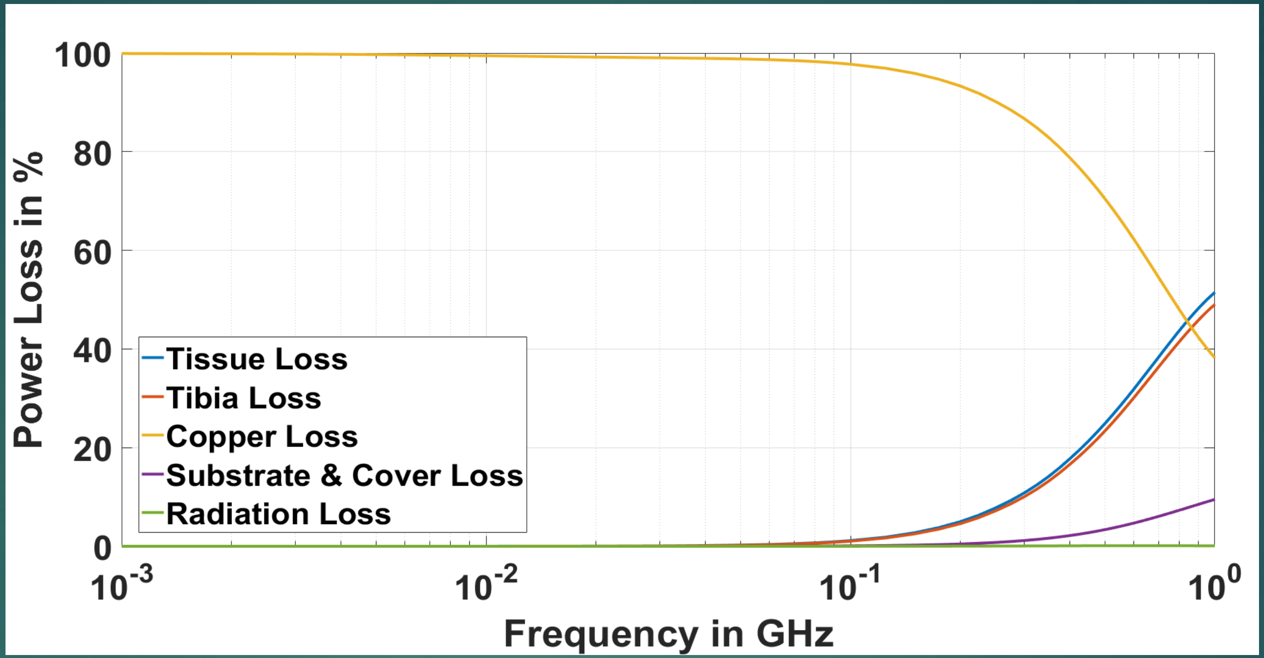
Simulations Results - 3



- Most of the power is lost in Tibial tissue.
- Power Loss in Human body starts manifesting beyond 1 GHz. After 500 MHz, more than 50 % power is lost in tibial tissue.
- About 2-5 % power is lost in substrate and PEEK encapsulation.

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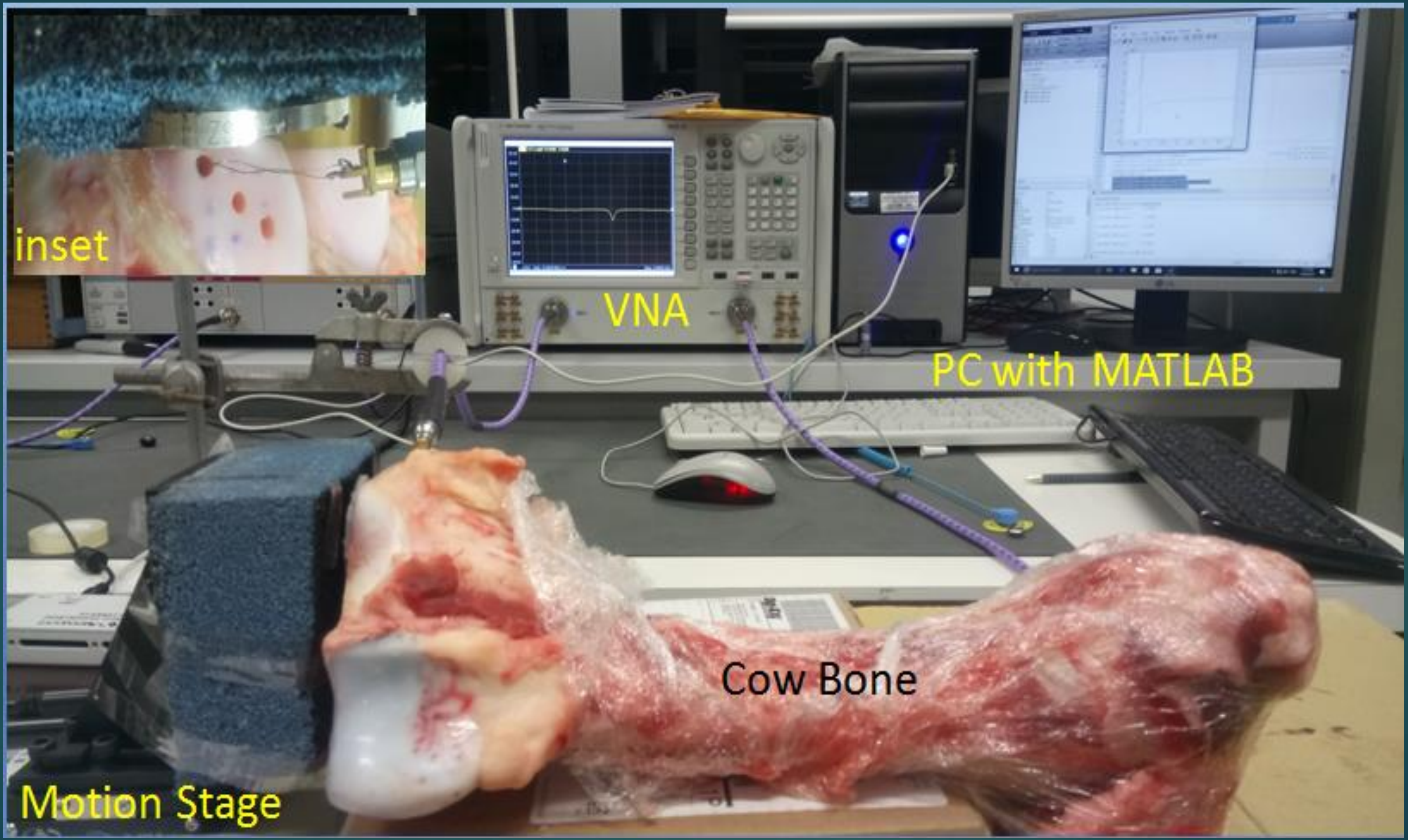
Experimental Setup



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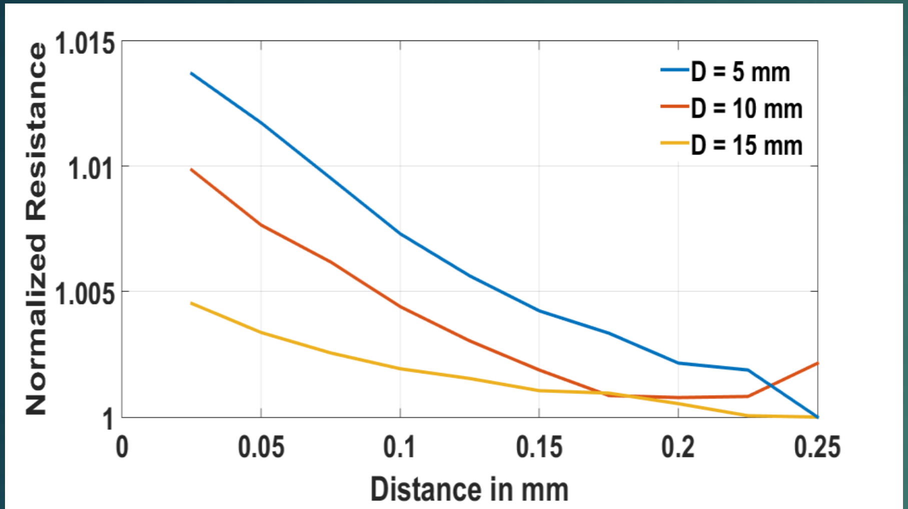
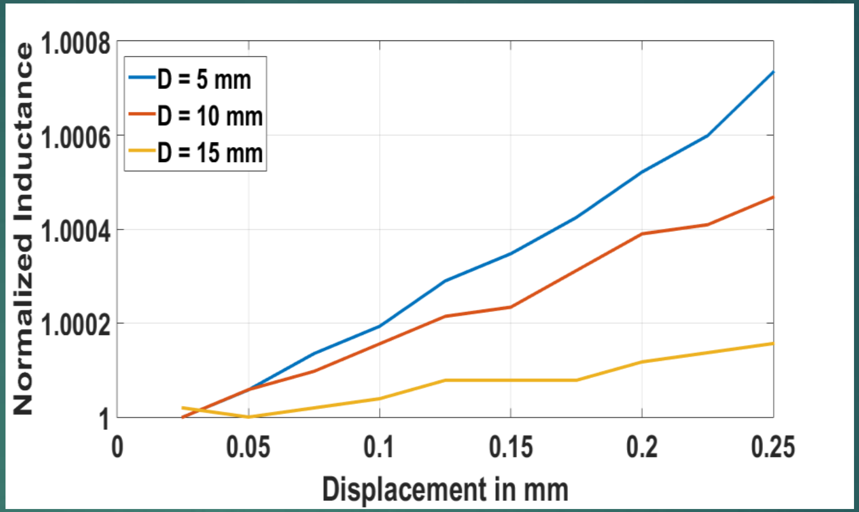
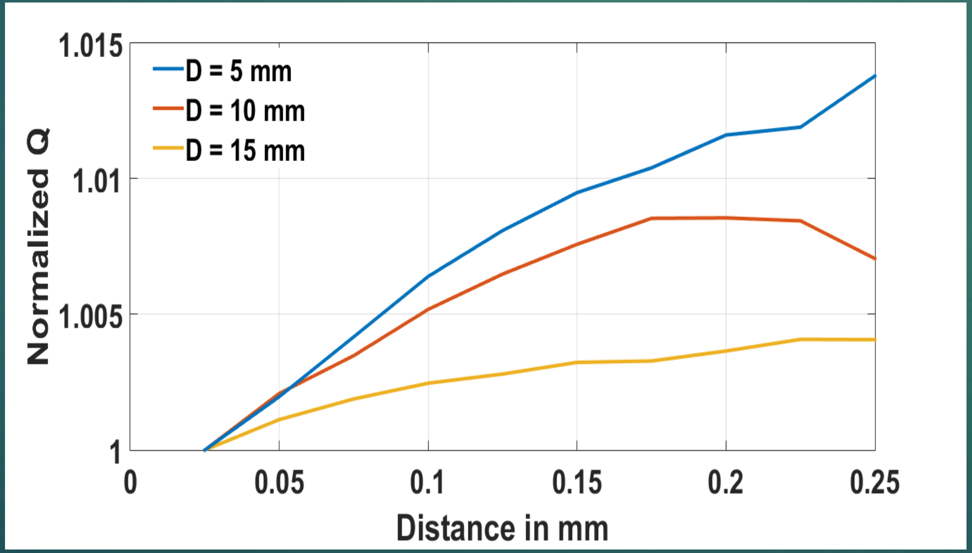
Experimental Results – 20 MHz







- Resistance offers an order of magnitude higher sensitivity than Inductance.
- The sensitivities match fairly well with the simulation results.

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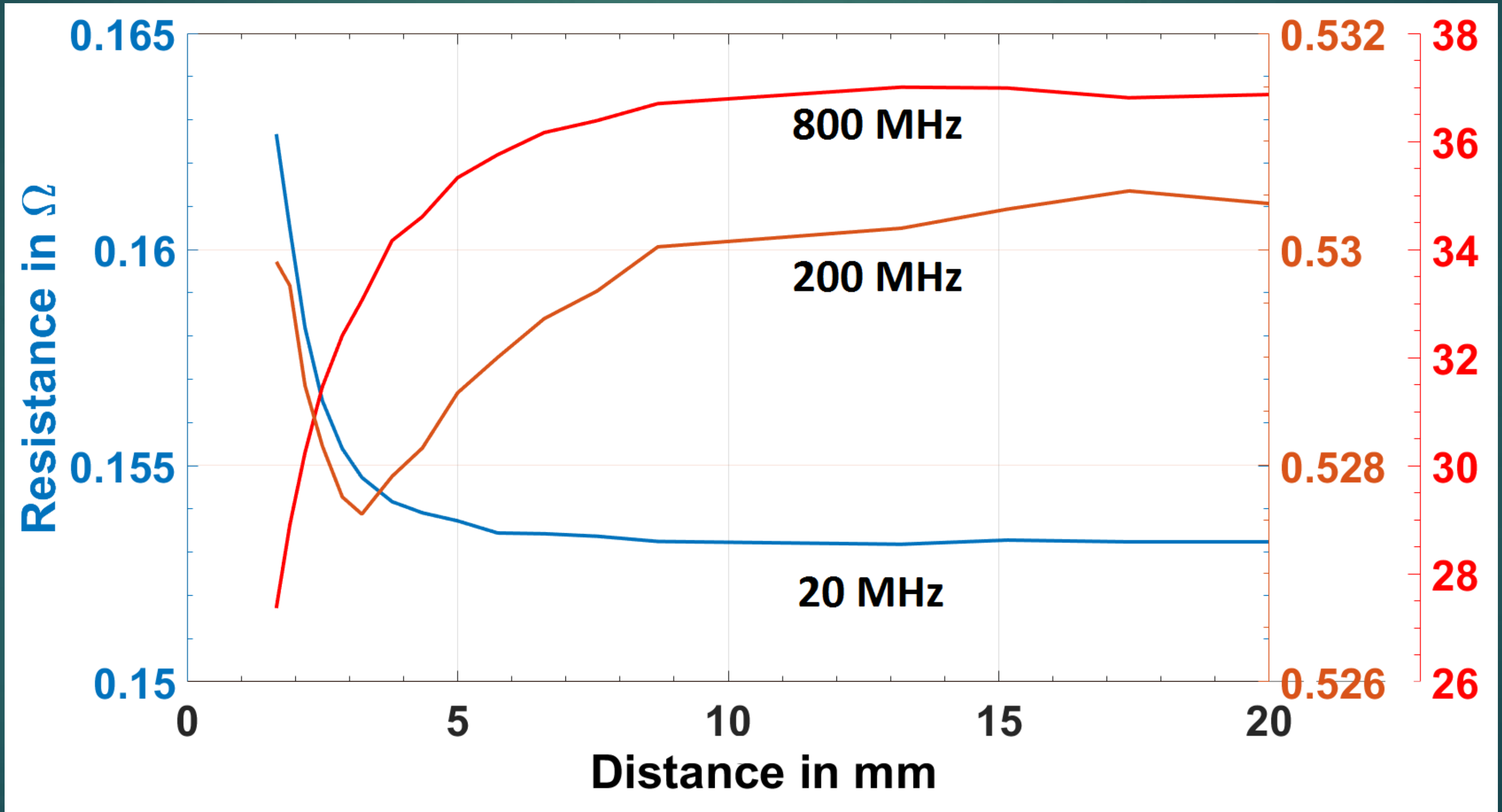
Conclusion

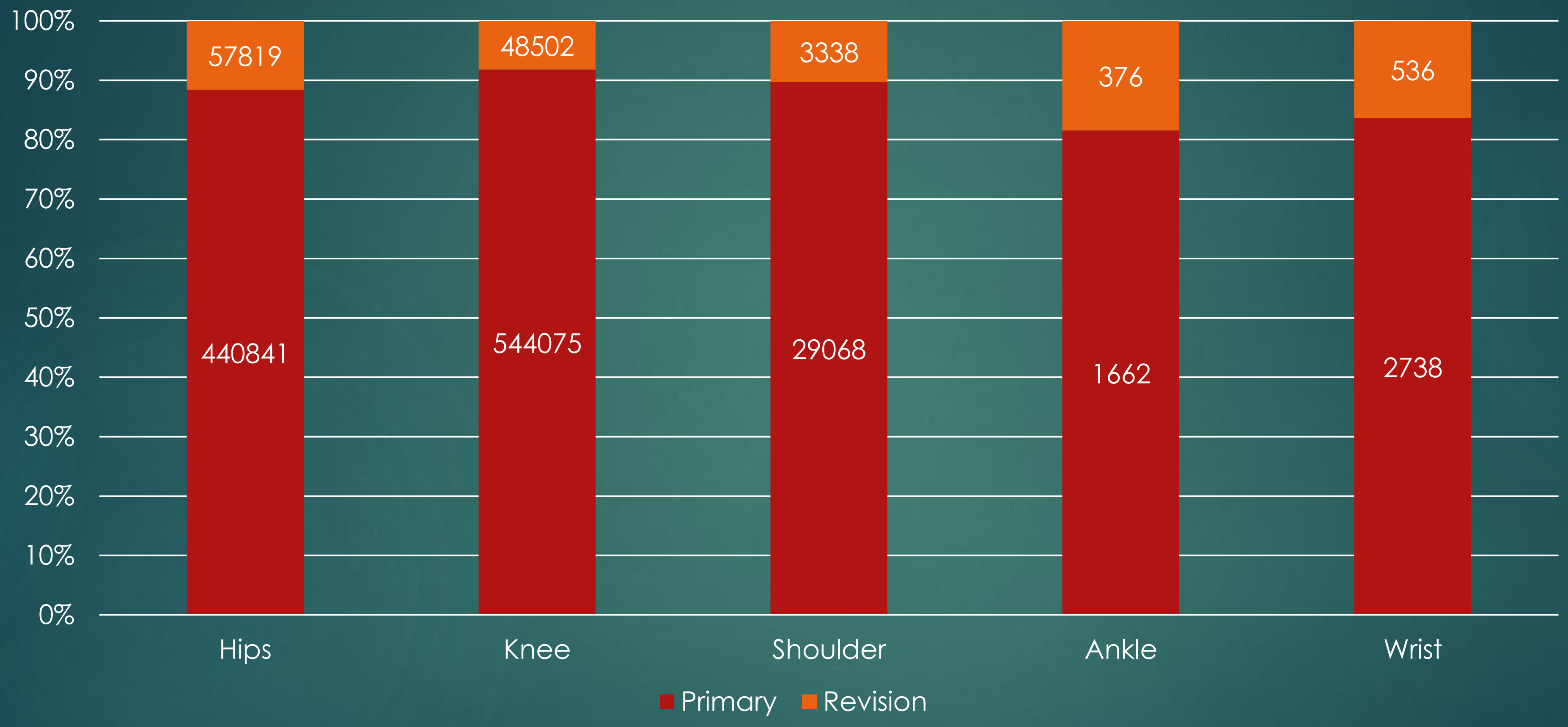
- We developed a good and reliable simulation strategy for Eddy current sensor implanted inside bone.
- As the standoff distance increases, the sensitivity of all the parameters decreases. This is also seen in the simulations.
- As the standoff distance changes from 5 mm to 15 mm, the sensitivity changes almost by an order of magnitude.
- The resistance offers higher change as opposed to the inductance. It is higher by an order of magnitude than inductance. This is also reflected in the Q factor.
- It may not be practical to have standoff distance higher than 5 mm to get the resolution of 10 μm.

Thank You !

Reason for dip in the resistance curve



Rate of revision



Rate of revision – Australian JRR

Table R2 Revision Hip Replacement by Reason for Revision

	Revision of Known Primary		All Revisions	
Reason for Revision	Number	Percent	Number	Percent
Loosening/Lysis	5268	27.6	26876	46.5
Infection	2911	15.3	8455	14.6
Prosthesis Dislocation	3385	17.8	8184	14.2
Fracture	3171	16.6	6214	10.7
Metal Related Pathology	1883	9.9	2239	3.9
Pain	674	3.5	1123	1.9
Wear Acetabular Insert	98	0.5	926	1.6
Implant Breakage Acetabular	108	0.6	526	0.9

Rate of revision – USA JRR