Application of Focused Impedance Method (FIM) to Determine the Volume of an Object within a Volume Conductor

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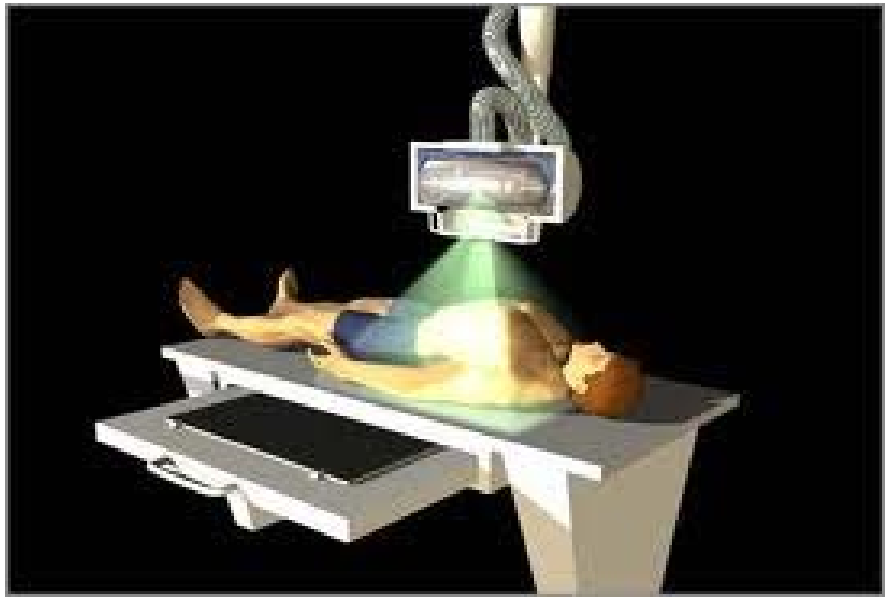
Investigating an organ inside the body

Tool: Knife

Surgery

Investigating an organ inside the body

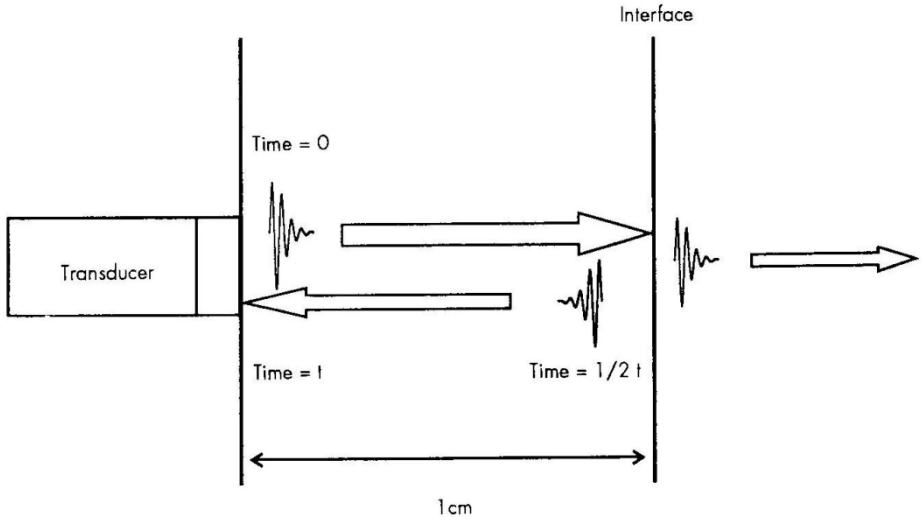
Tool: Radiation



Property: Interaction of radiation with matter

Investigating inside the body

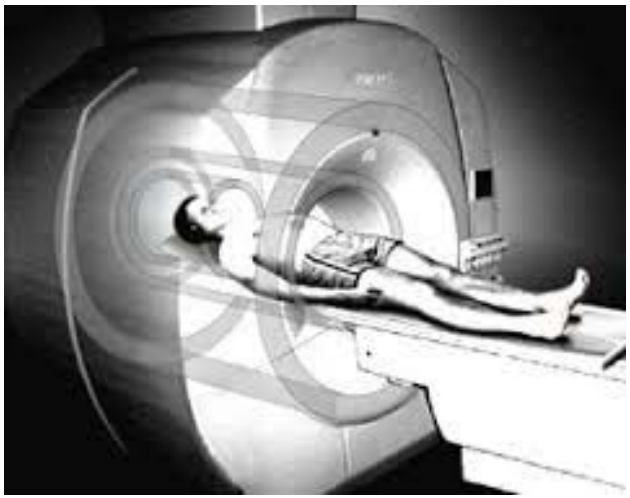
Tool: Ultrasound

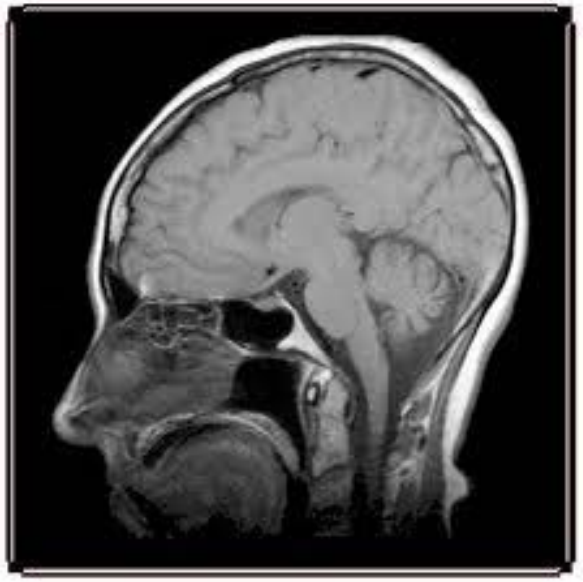


Property: Reflection and transmission from an interface

Investigating inside the body

Tool: Magnetic filed

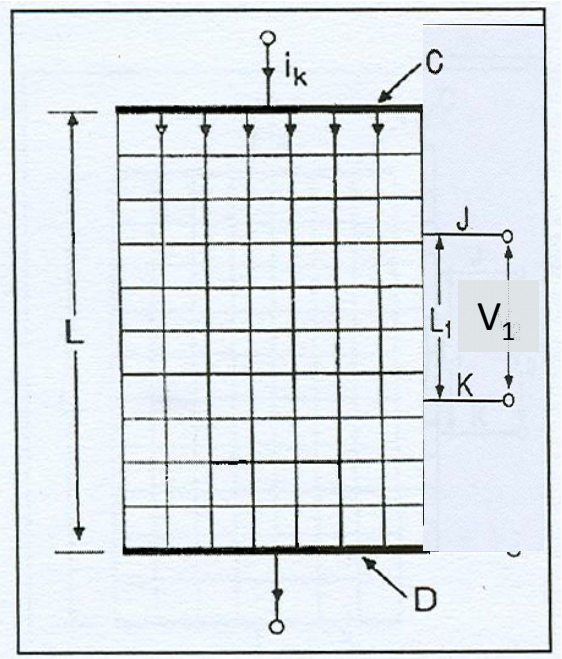


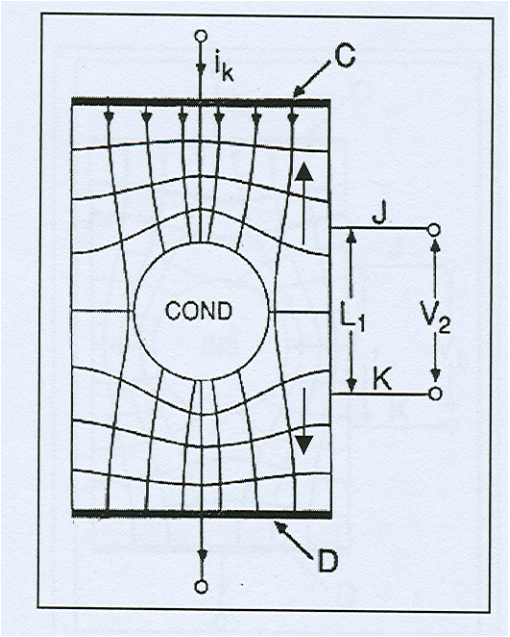


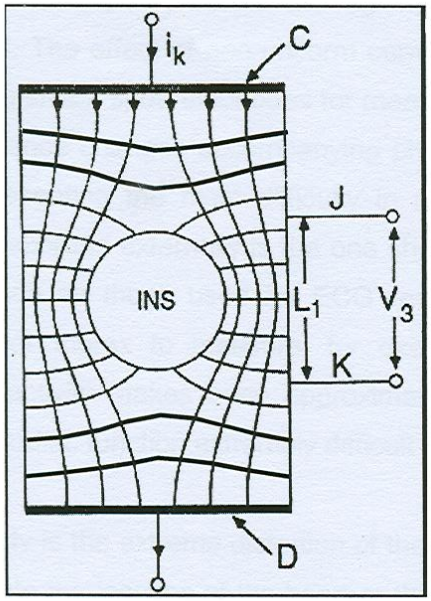
Property: nuclear magnetic resonance

Investigating inside the body

What about using *electric field*?



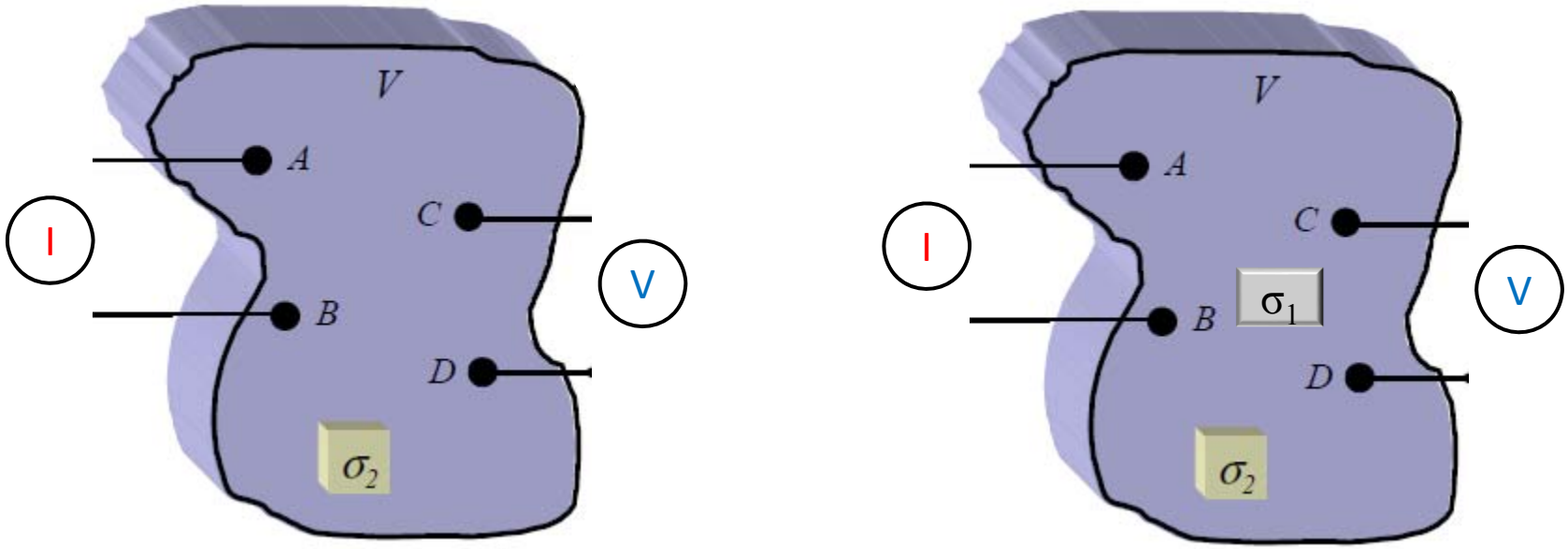




Property: volume, position, conductivity, permittivity

Can we use electrical impedance to determine ***volume of an embedded object***?

Electrical Impedance Technique



Transfer Impedance, Z=V/I

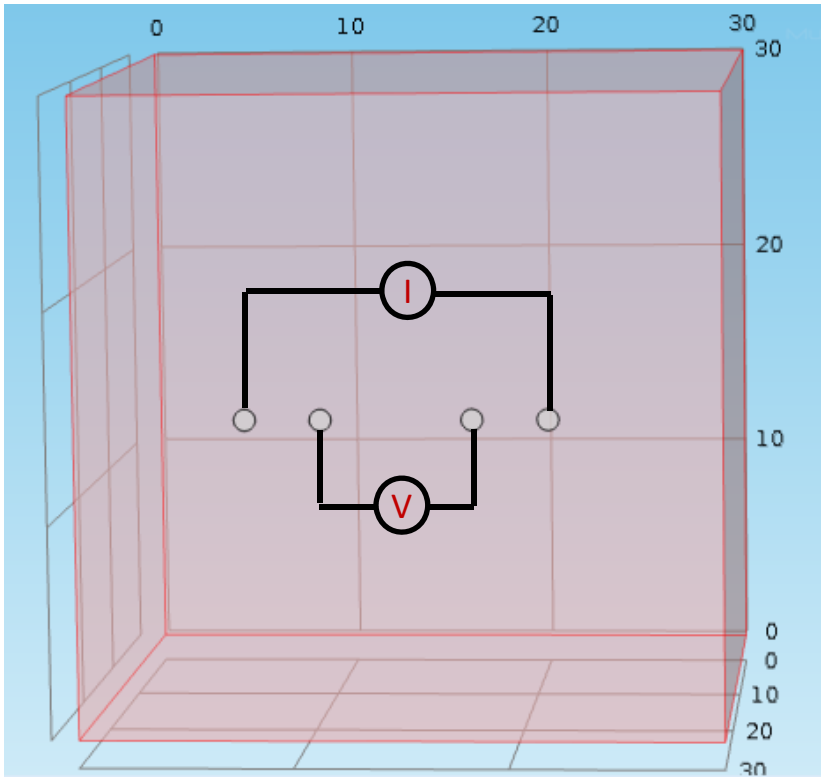
Sensitivity

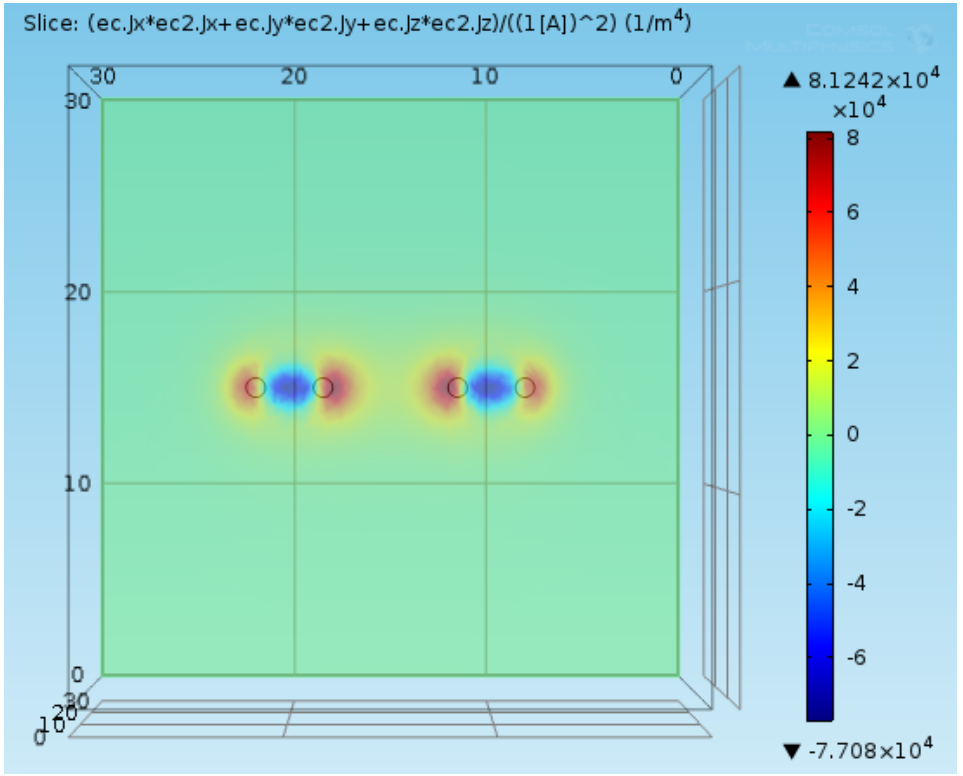
The extent to which a change in conductivity of a point within the volume conductor contributes to the measured transfer impedance

$$Sensitivity = \frac{J_1 . J_2}{I^2}$$

Tetra-polar Electrical Impedance Method

Sensitivity at depth 2cm, using COMSOL





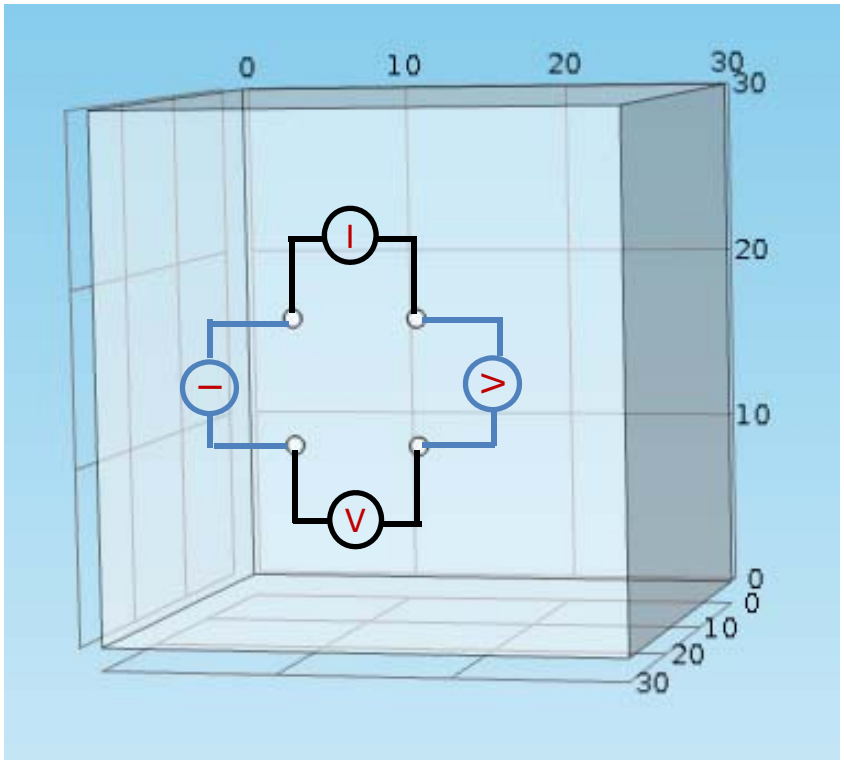
Electrode separation:
drive: 14cm, receive: 7cm

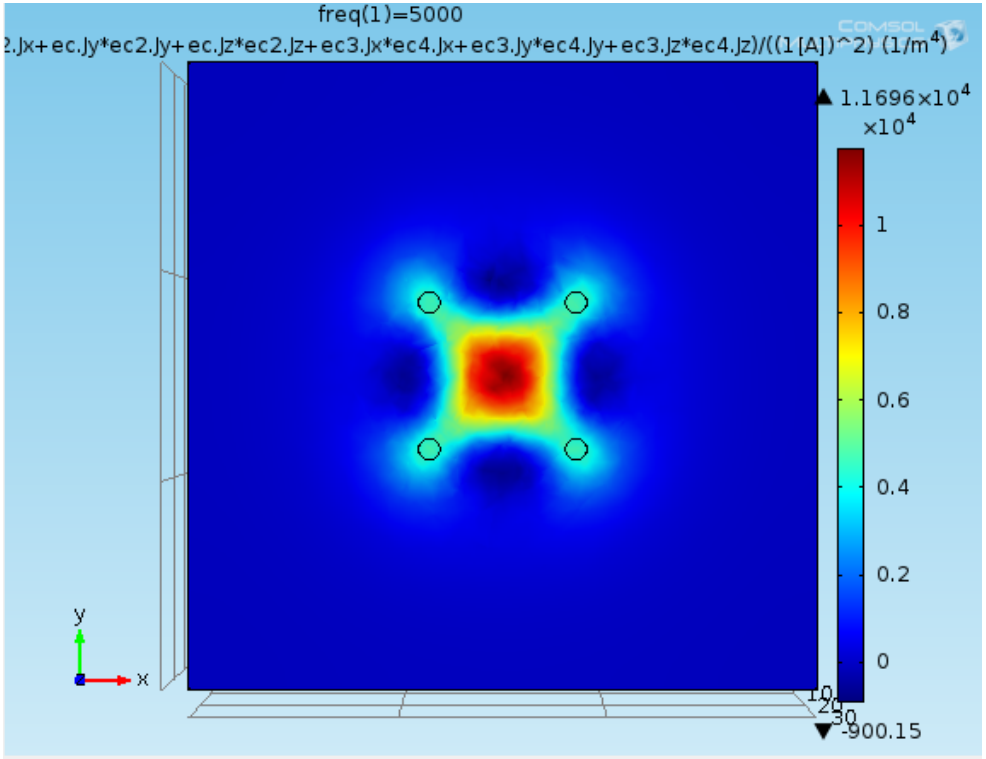
$$Tetrapolar\ Sensitivity = \frac{J_{ec} \cdot J_{ec2}}{I^2}$$

- Sensitive zone is wide
- can not focus a particular organ
- Has large negative sensitivity

Focused Impedance Method (FIM)

Sensitivity at depth 2 cm using COMSOL



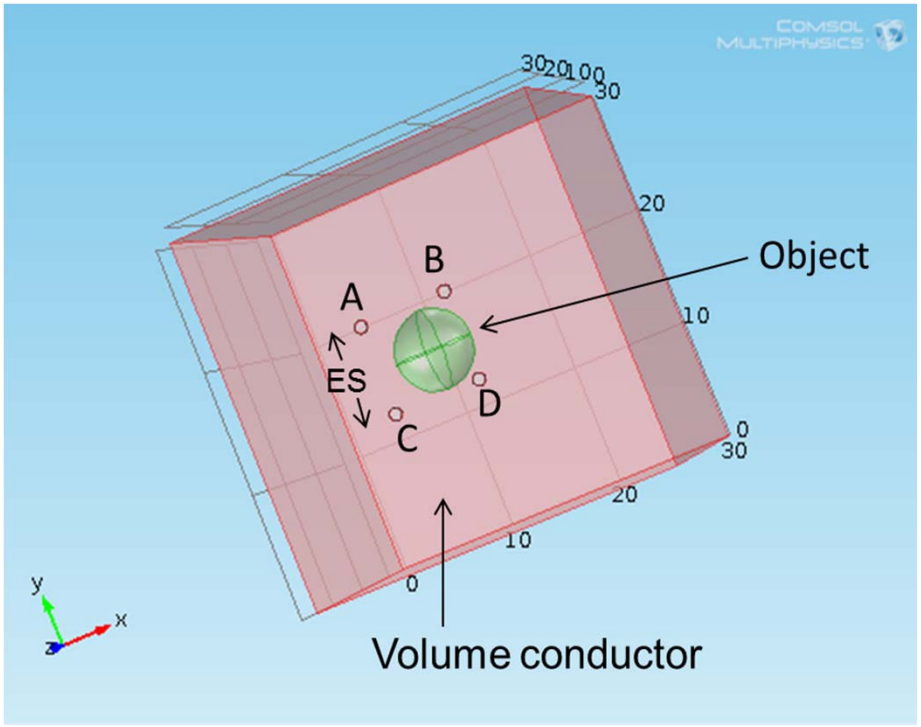


- Electrodes placed at the corners of a square
- Electrode separation 7 cm

$$FIM\ Sensitivity = \frac{J_{ec} \cdot J_{ec2} + J_{ec3} \cdot J_{ec4}}{I^2}$$

- Sensitive zone ***focused***
- can focus a particular organ
- Reduced negative sensitivity

Materials and Methods



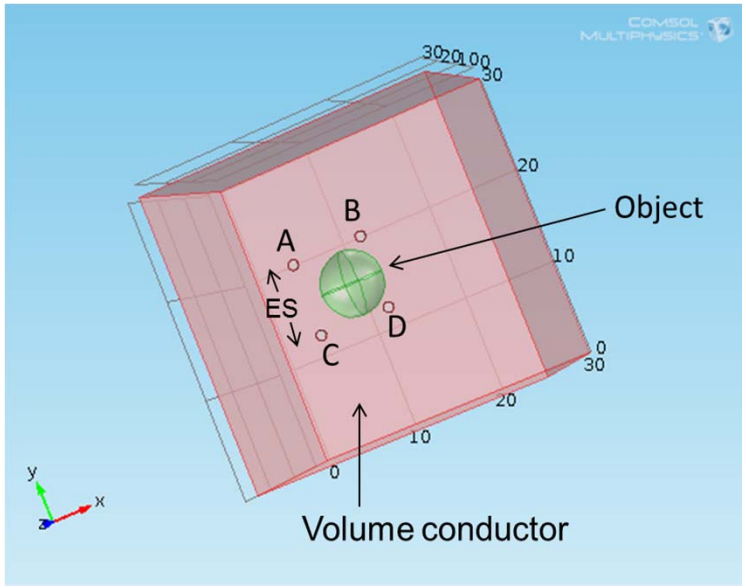
Sequence 1	Sequence 2
Drive: A B (I amp) Receive: C D (V_1 volt)	Drive: A C (I amp) Receive: B D (V_2 volt)

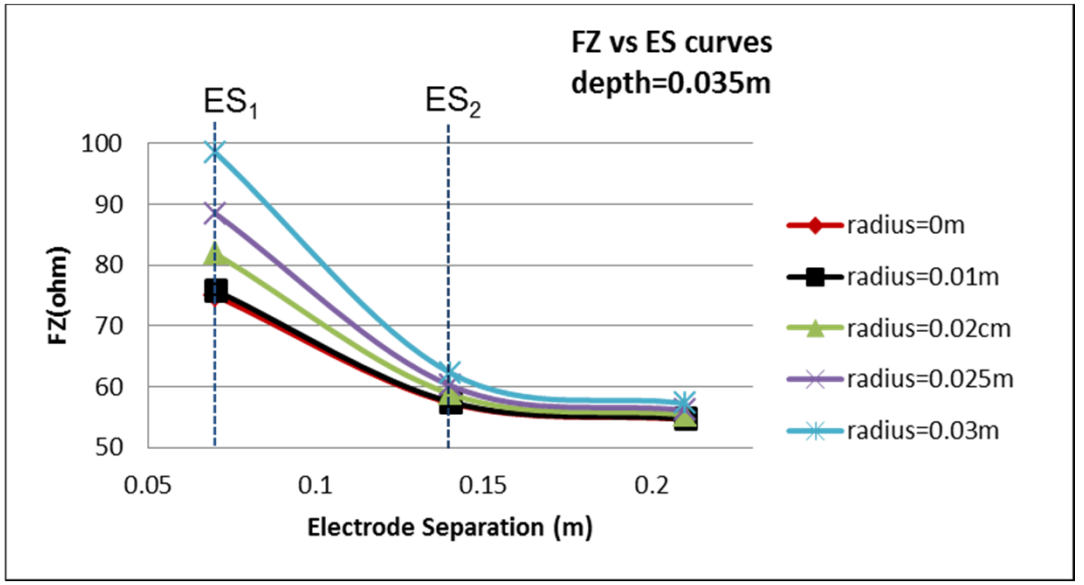
- A cubic tank of edge 30 cm filled with saline was modeled as a volume conductor in COMSOL Multiphysics with electrodes placed on one of the sides, centrally
- Drive current introduced using electric current interface of AC/DC module in COMSOL Multiphysics
- Resulting voltage measured using boundary probes

Focused Impedance, $\mathbf{FZ} = \frac{V_1}{I} + \frac{V_2}{I}$

Results and Observations

Relation between *FZ* and *ES*

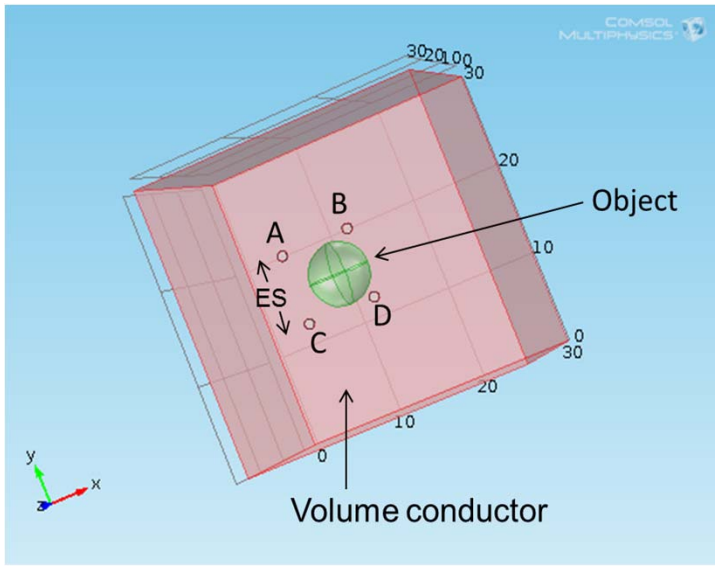


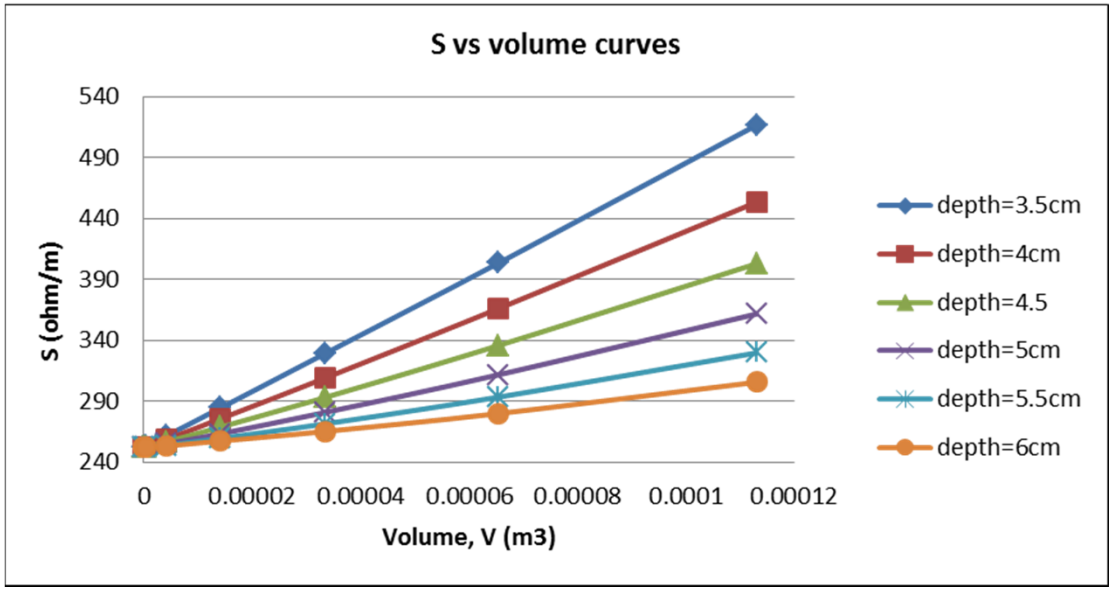


- Focused Impedance *FZ* decreases with increasing Electrode Separation *ES*
- The decrease is rapid in the segment between ES_1 and ES_2 in the curve
- The decrease is more rapid for object having larger volume

We define $$S = \frac{|\Delta FZ|}{ES_2 - ES_1}$$ ------(1)

Any relation between *S* and the object volume *V* ?

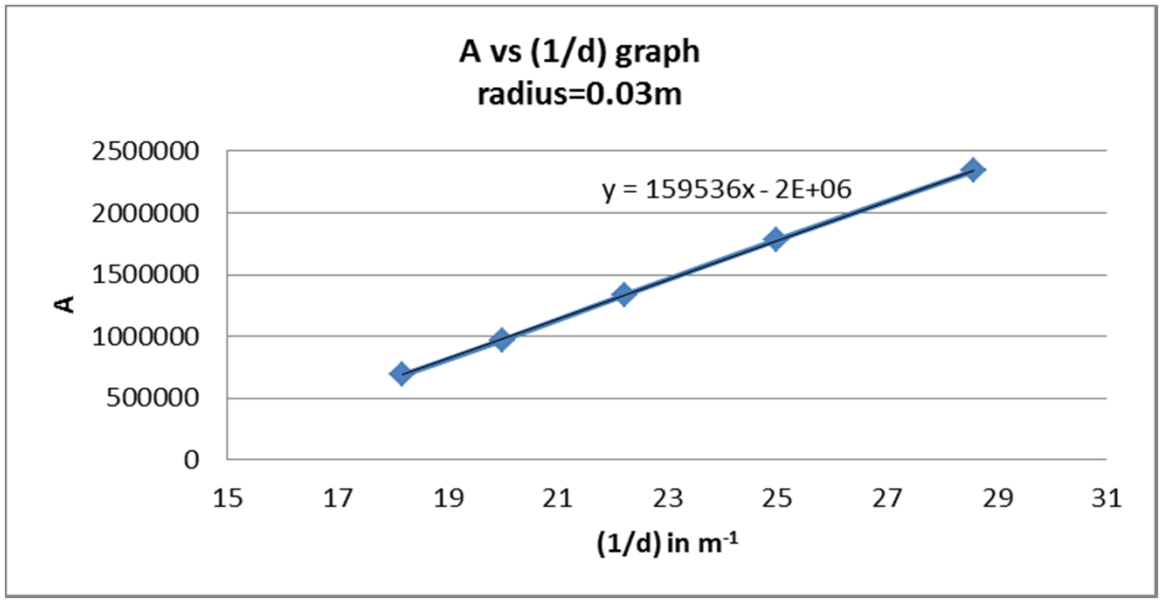




The parameter *S* is linearly proportional to the object volume *V*.

$$S = AV + C \quad \text{-----(2)} \quad \textit{when d is constant}$$

Any relation between ***A*** and the object depth ***d***?



The slope ***A*** is inversely proportional to the depth ***d***.

$$A = \frac{K}{d} + B$$ ------ (3)

when V is constant

Combining all

$$S = \left(\frac{K}{d} + B\right) V + C \text{ -------(4)}$$

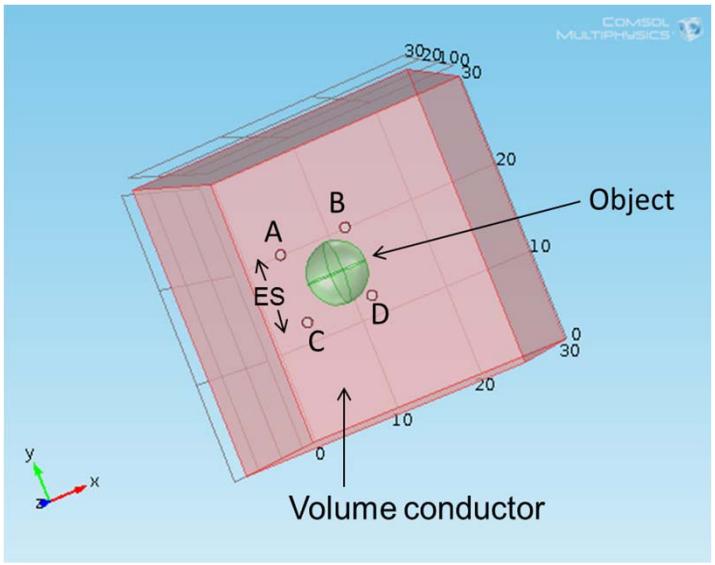
$$\mathbf{V = \frac{S - C}{\frac{K}{d} + B}} \quad \textbf{-------(5)}$$

$$S = \frac{|\Delta FZ|}{ES_2 - ES_1}$$

Constants:
K = 159536, B = – 2211400, C = 252.118

Volume *V* can be obtained by measuring FZ at two electrode separations if depth *d* and the values of the other constants are determined through experimental procedures.

Verification



$$V = \frac{S - C}{\frac{K}{d} + B} \quad \text{-------(5)}$$

Comparison of the actual object volume to the calculated volume from simulated FIM measurements taken in the COMSOL model

Simulated Radius m	Depth m	Calculated Radius m	% error
0.030	0.045	0.03002	0.07
0.025	0.035	0.02489	0.44

Volume of the object can be obtained with an error less than 1%.

Conclusion

- The present work has put forward a new technique for measurement of the volume of an object embedded within a volume conductor using 4-electrode FIM
- COMSOL Multiphysics simulation allowed development of this method.
- Verification carried out using COMSOL simulation as well as in practical phantom
- Next: verification inhomogeneous volume conductor and then in human body
- FIM is noninvasive, non ionizing

The new technique for volume measurement using FIM will have applications in many areas in Biomedical Physics & Engineering, in Geology

Thank You