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Designing Polymer Thick Film Intracranial Electrodes for use in Intra-Operative MRI Setting

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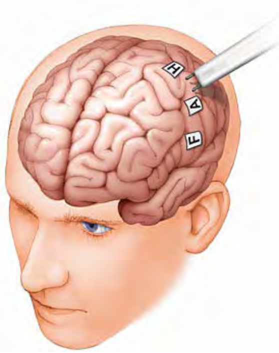
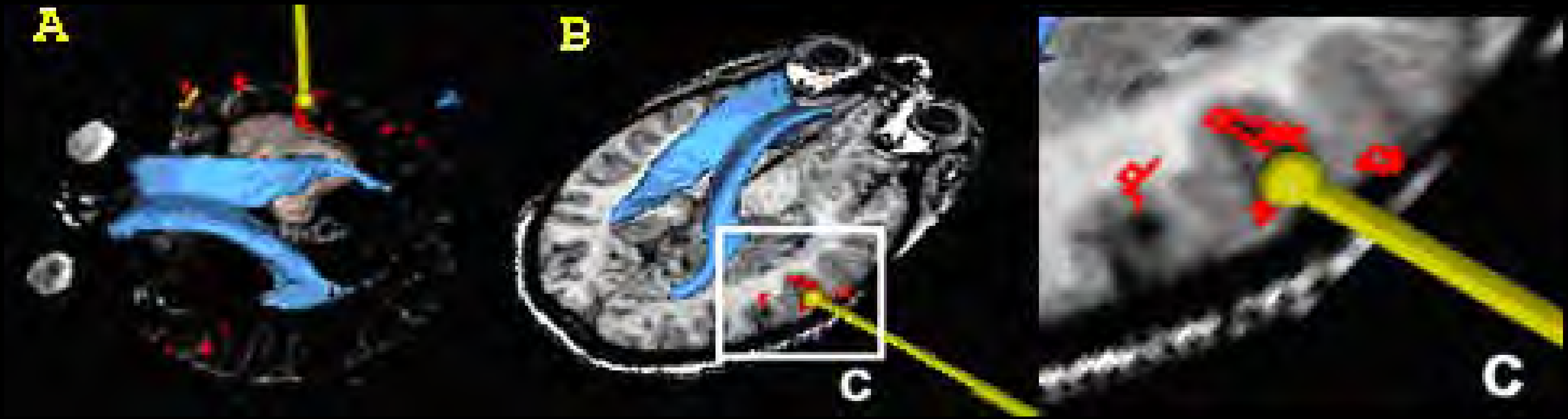


MRI guided Brain Tumor Surgeries

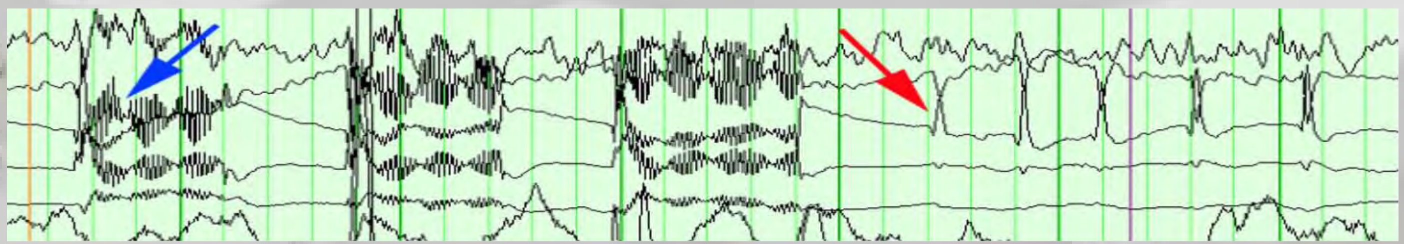
- **The American Cancer Society (ACS) estimated 18,820 new cases of brain cancer 2006 and 12,820 deaths (in US).**
- **Maximal surgical excision is the best current treatment option for primary brain tumors.**
- **Complete surgical excision can reduce the risk of progression to higher grade.**
- **Determining the optimal limits of the resection by visual inspection can be problematic, especially when operating in eloquent cortex.**
- **MRI-Guided Brain Tumor Removal With Cortical Mapping**

Cortical Stimulation during MRI



Intra-operative validation of fMRI of speech/language function in a left-handed patient with a right temporal brain tumor. The patient performed an object-naming task. fMRI data were overlaid on the anatomical images using the 3D Slicer software (SPL). The patient's anatomy (with ventricles in blue) and tumor (in gray, panel A) are visualized with the fMRI-activated areas (in red). The tip of the cortical stimulator is visualized as a yellow wand (seen best in close-up panel C). Intraoperative stimulation of the putative speech areas (as defined by fMRI) caused speech arrest during picture naming, verifying the fMRI localization and right hemisphere language dominance.

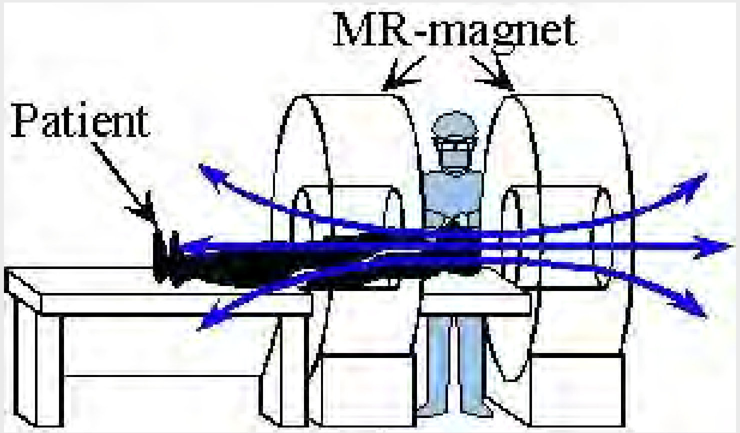
MRI guided surgeries and electrocortical stimulation (ECS):

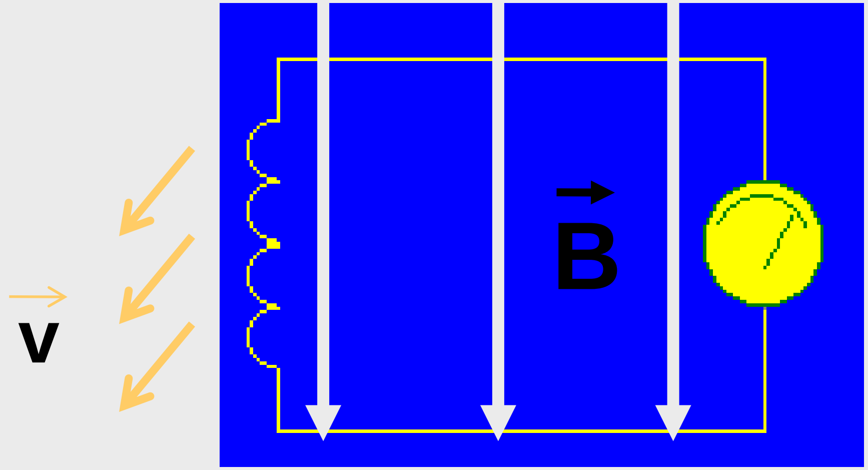


- **ECS permits the investigation of brain function at the time of surgery since it mimics a temporary surgical lesion and is the current gold standard for limiting deficits due to the surgical procedure**

- **However, artifacts introduced by the magnetic field in both the electrophysiological and MRI signals have prevented the concurrent use of such techniques in MRI-guided surgeries, reducing the effectiveness of ECS in neuro-oncological surgeries. .**

Faraday's Induced Noise

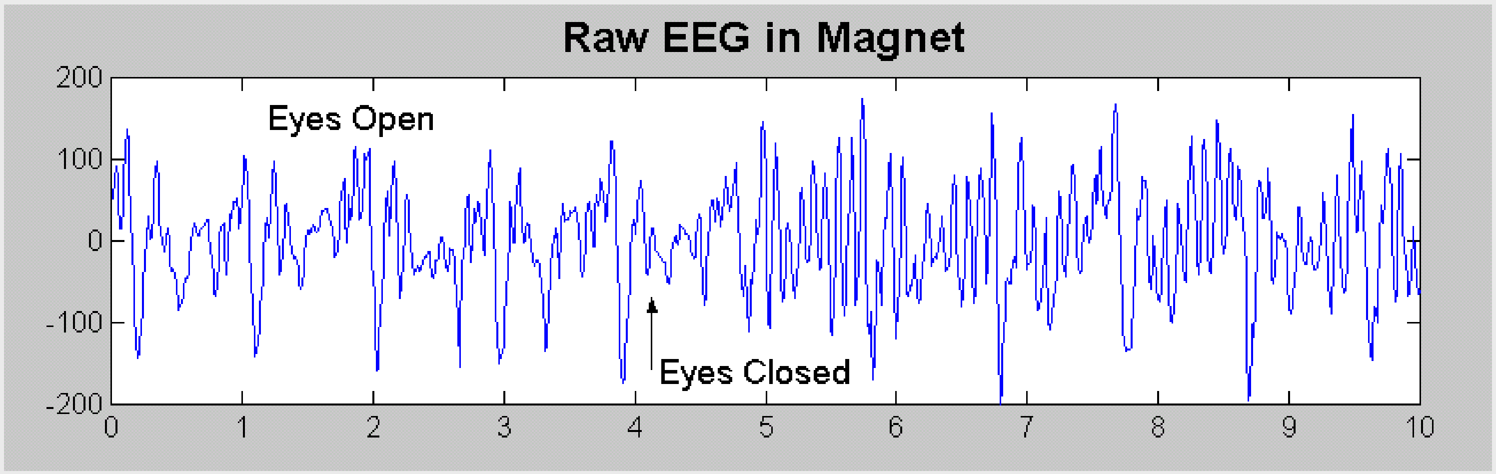




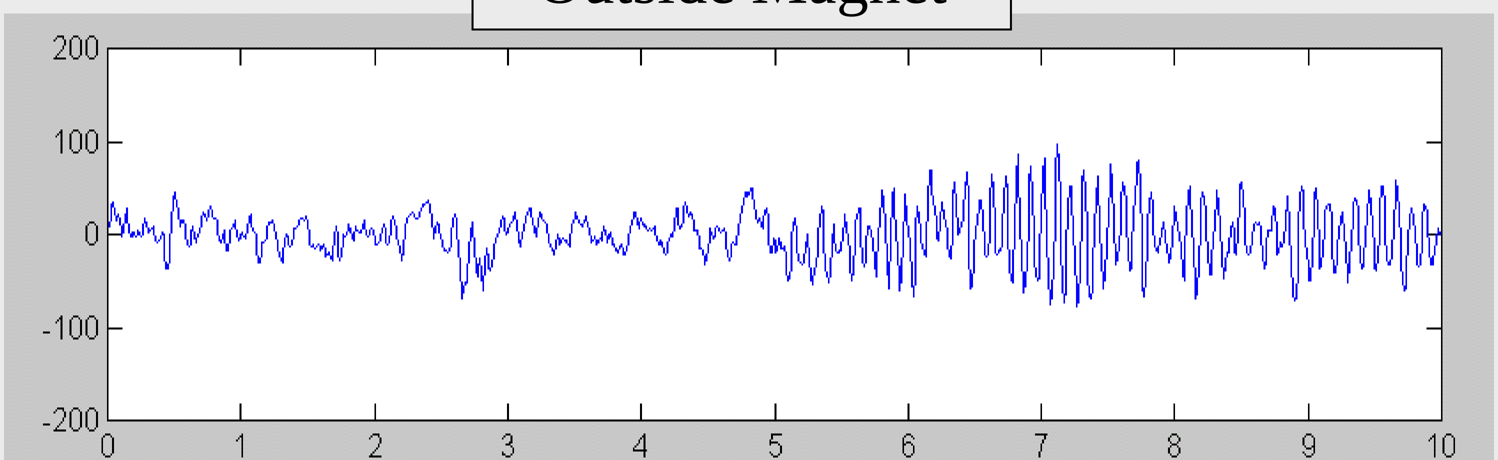
$$\varepsilon = N \frac{\partial \phi}{\partial t}$$

- Faraday's induced noise:
  - Motion of the EEG electrodes and leads generates noise
- Physiological Motion is Primary Noise Source
  - Heart beat (ballistocardiogram), breathing, subject motion

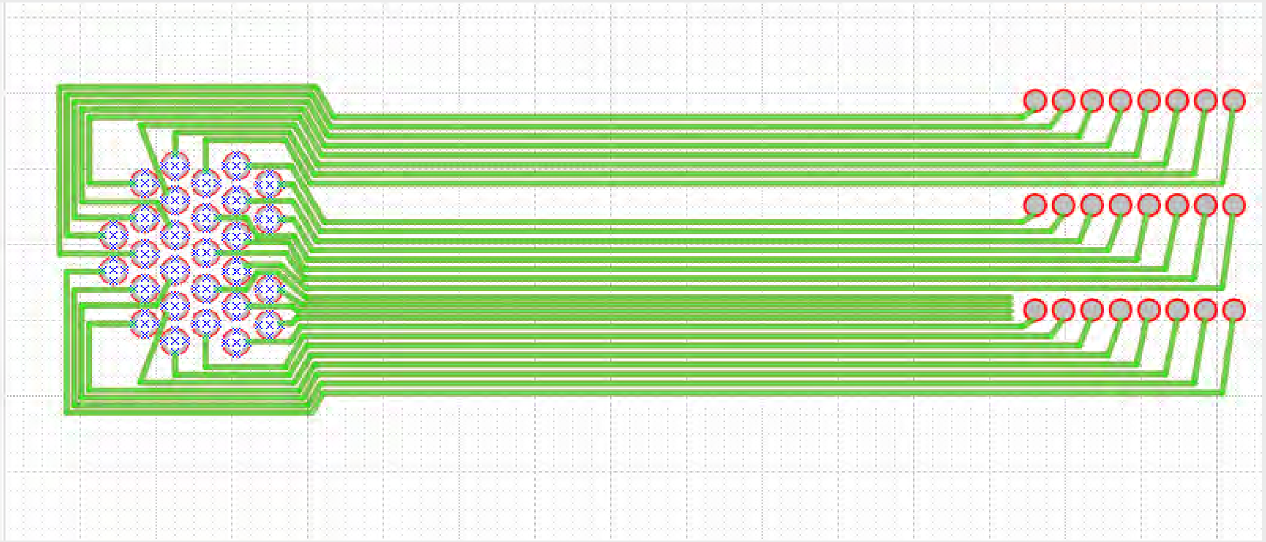
Example of EEG (scalp) Ballistocardiogram Noise



Outside Magnet



The goal is to design leads with advantageous electrical properties based on Polymer Thick Film (PTF) to help reduce ballistocardiogram noise.



We will study the reduction of induced Faraday currents using Magnetic Quasi Static approximation since the velocities of the pulsating intact brain are small (1.5-2 mm/s << c) and the geometry size are smaller than the wavelength ($3\ 10^8$m).

Magnetic Quasi Static Approximation (MQS):

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{H} = \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t} + \mathbf{J} \cong \mathbf{J}$$

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$$

$$\nabla \cdot \mathbf{H} = 0$$

Macroscopic Properties of the Material:

$$\mathbf{B} = \mu_0 \left(\mathbf{H} + \mathbf{M} \right)$$

$$\mathbf{J} = \sigma \left(\mathbf{E} + \mathbf{v} \times \mathbf{B} \right)$$

$$\mathbf{E} = -\Delta V - \frac{\partial \mathbf{A}}{\partial t}$$

The Lorentz Term:

$$\mathbf{J} = \sigma_m \mathbf{E} + \sigma_m \mathbf{v} \times \mathbf{B}$$

$\sigma_{118-43} = 400 S/m$ $\sigma_{GelFilm} = 0.33 S/m$

$\sigma_{119-28} = 0.08 S/m$

MQS in Cylindrical Coordinates:

$$\sigma_m \frac{\partial A_\Phi}{\partial t} + \nabla \times \left(\frac{1}{\mu_0 \mu_r} \left(\nabla \times A_\Phi - \mathbf{B}_0 \right) \right)$$

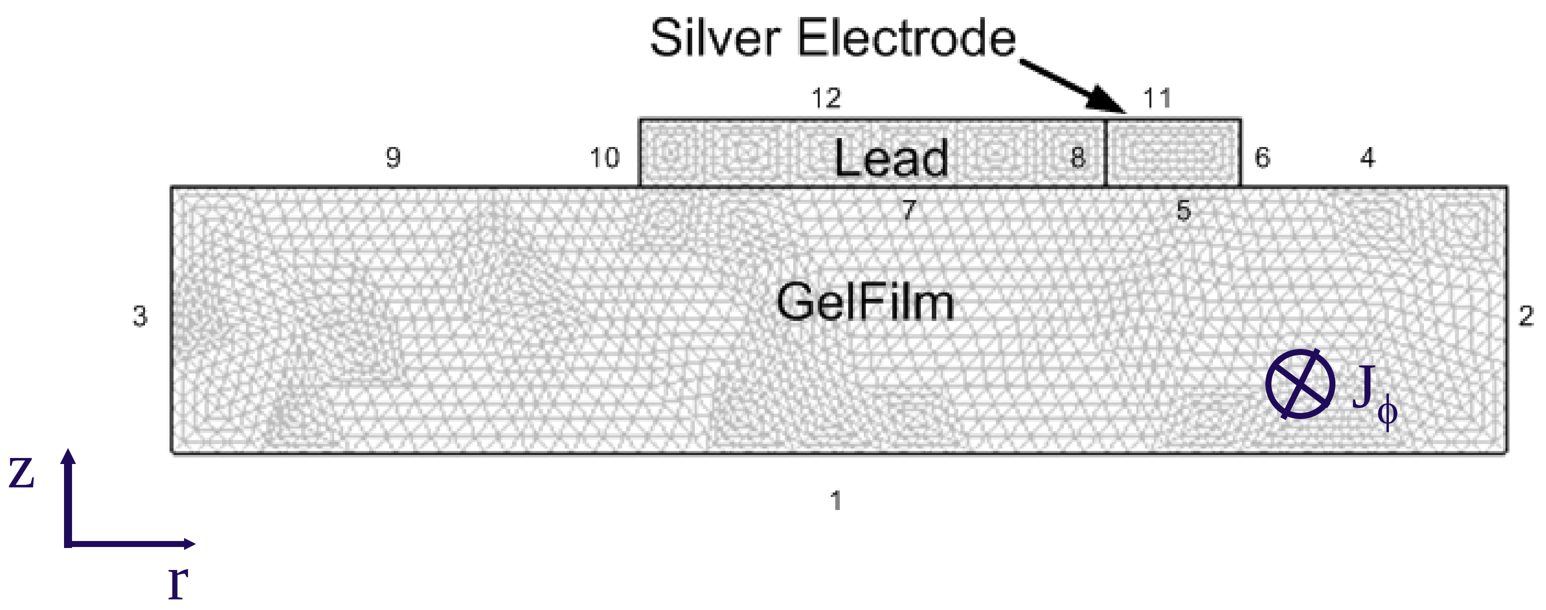
$$+ \sigma_m \mathbf{v} \times \left(\nabla \times A_\Phi \right) = 0$$

Approximations/Limits:

1. COMSOL Multiphysics 3.2 with EM module
2. Transient Analysis of MQS not available in 3D
3. 2D simulations with limited physical accuracy
4. Faraday's induced currents were modeled using the Lorentz term (non realistic).

Model:
Resistive Leads Vs Metallic Leads

$$v_z(t) = 0.01 \cdot \omega_0 \cos(\omega_0 t - \pi/2)$$

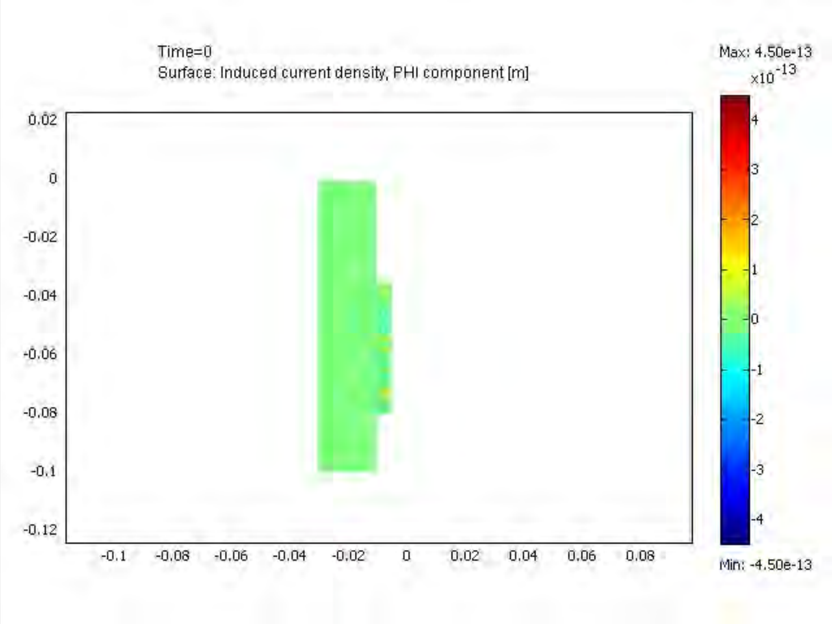


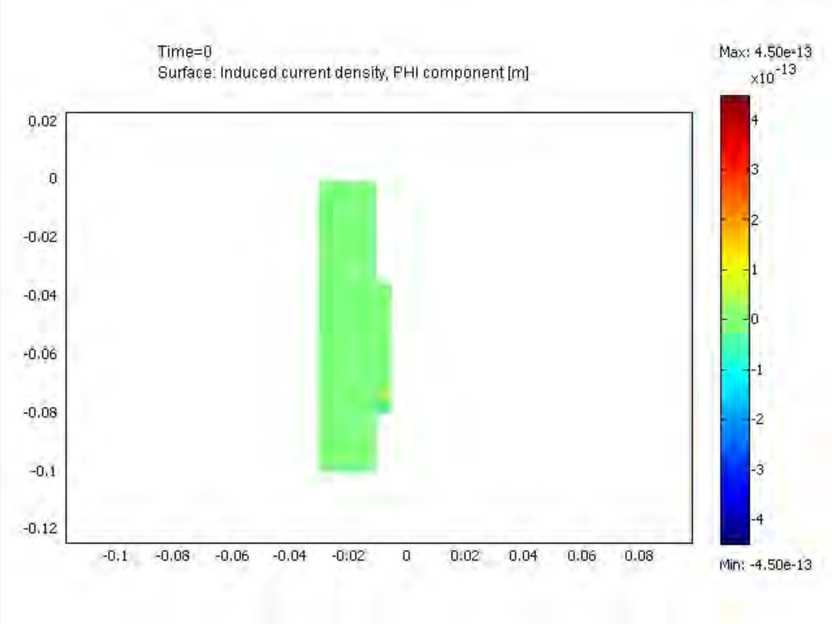
$\mathbf{B_0}$=1 Tesla

Simulation Parameters:

1. Application Modes: Moving Mesh (ale) and Perpendicular Induction Currents Vector Potentials (emqa).
2. Magnetic insulation in all external boundaries.
3. Time steps of 10ms.
4. Max mesh size of 100μm in all domains.

Results


Time=0
Surface: Induced current density, PHI component [m]
Max: 4.50e-13
x10^-13
Min: -4.50e-13


Time=0
Surface: Induced current density, PHI component [m]
Max: 4.50e-13
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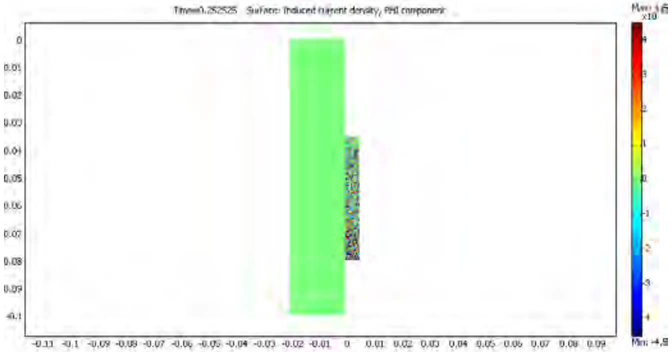
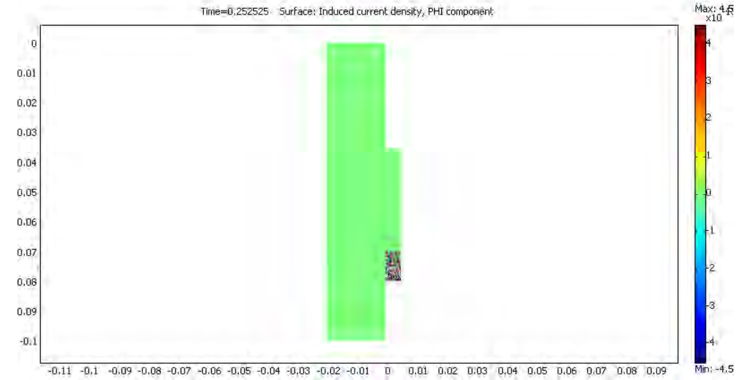
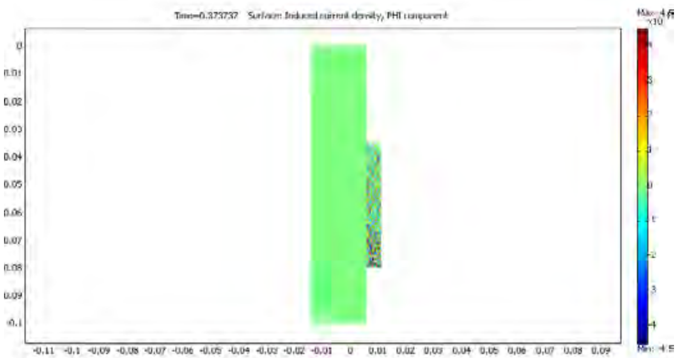
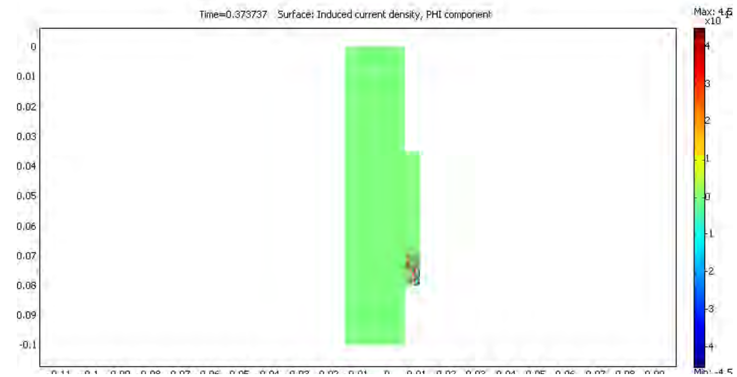


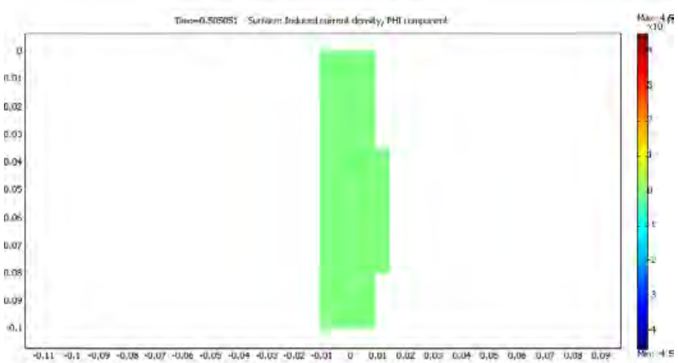
$$\varphi = \frac{\pi}{2}$$



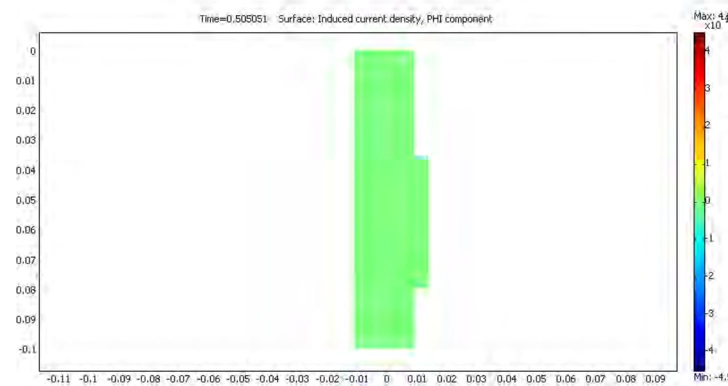


$$\varphi = \frac{9\pi}{10}$$

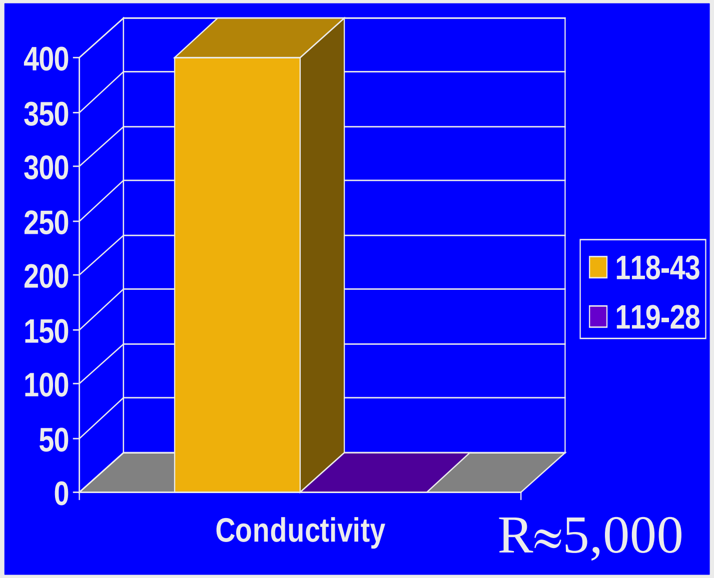


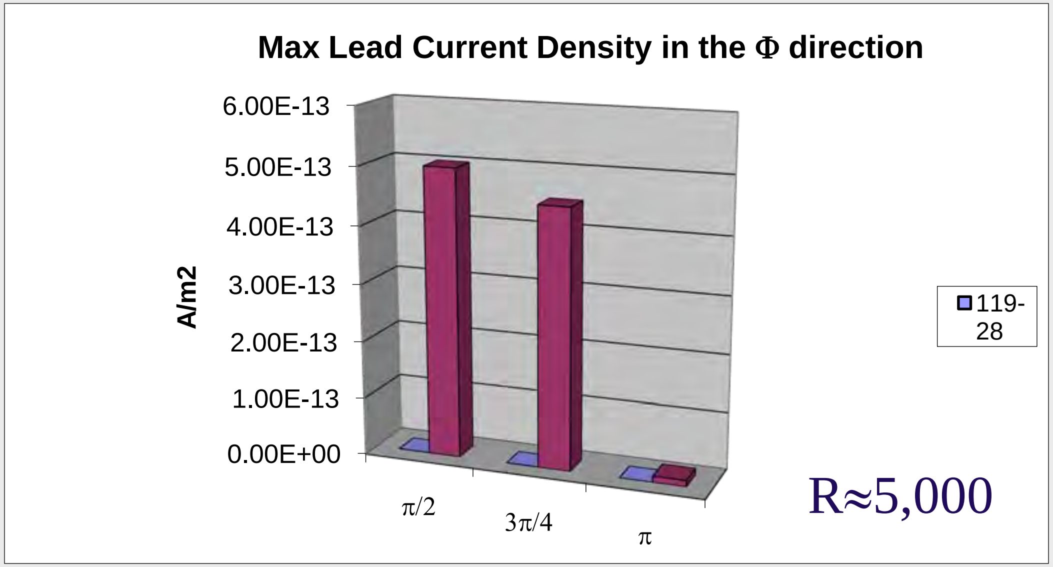


$$\varphi = \pi$$

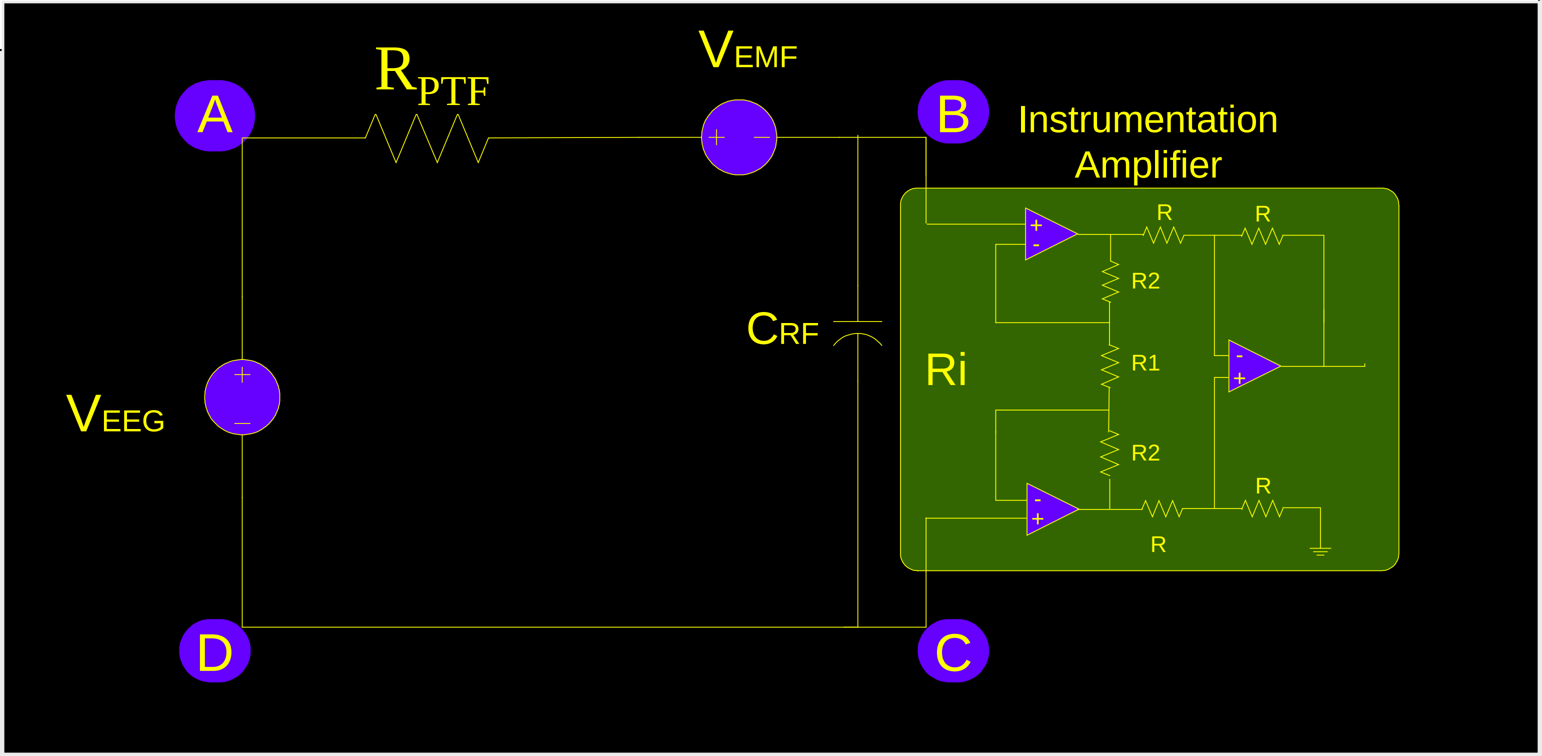


Comparison of Results





PTF and the SNR increase



$$I = \frac{1}{R_{leads}} \oint_{\Omega} \vec{E}\, d\vec{s} = -\frac{1}{R_{leads}} \frac{d\Phi}{dt}$$

$(R_{leads} << Ri)$

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