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Modeling of Retinal Electrical Stimulation Using a Micro Electrode Array Coupled with the Gouy-Chapman Electrical Double Layer Model to Investigate Stimulation Efficiency

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leti

cea

energie atomique • energies alternatives

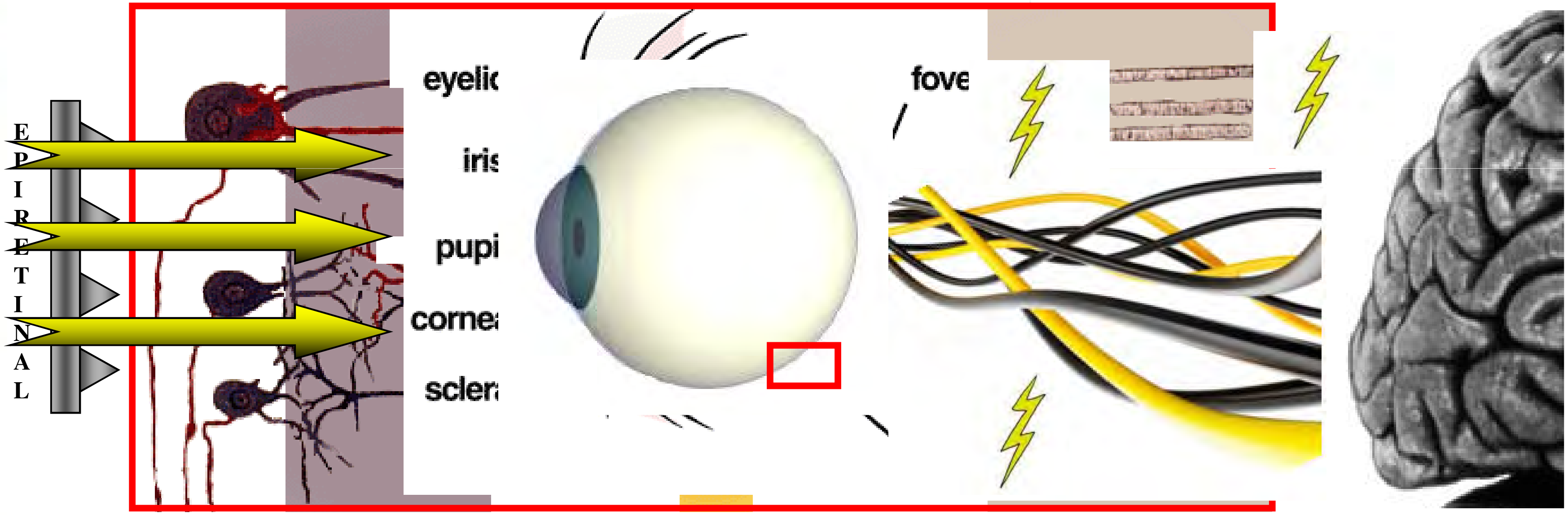
Outline

- Why electrical stimulation in the eye?
- Objectives
- Electrokinetic Equation
- Validation: Impedance Spectroscopy
- Hodgkin-Huxley for Retinal Ganglion Cell
- Looping Fast Fourier Transform in COMSOL
- Conclusion and Future Work

Why electrical stimulation in the eye ?

Essential and sophisticated transducer

Retinitis Pigmentosa (RP) and Age-Related Macular Degeneration (AMD)



Ganglion Cells (RGC) | Amacrine Cells | Bipolar Cells | Photoreceptors

=> New stimulation target depending on the prosthesis location

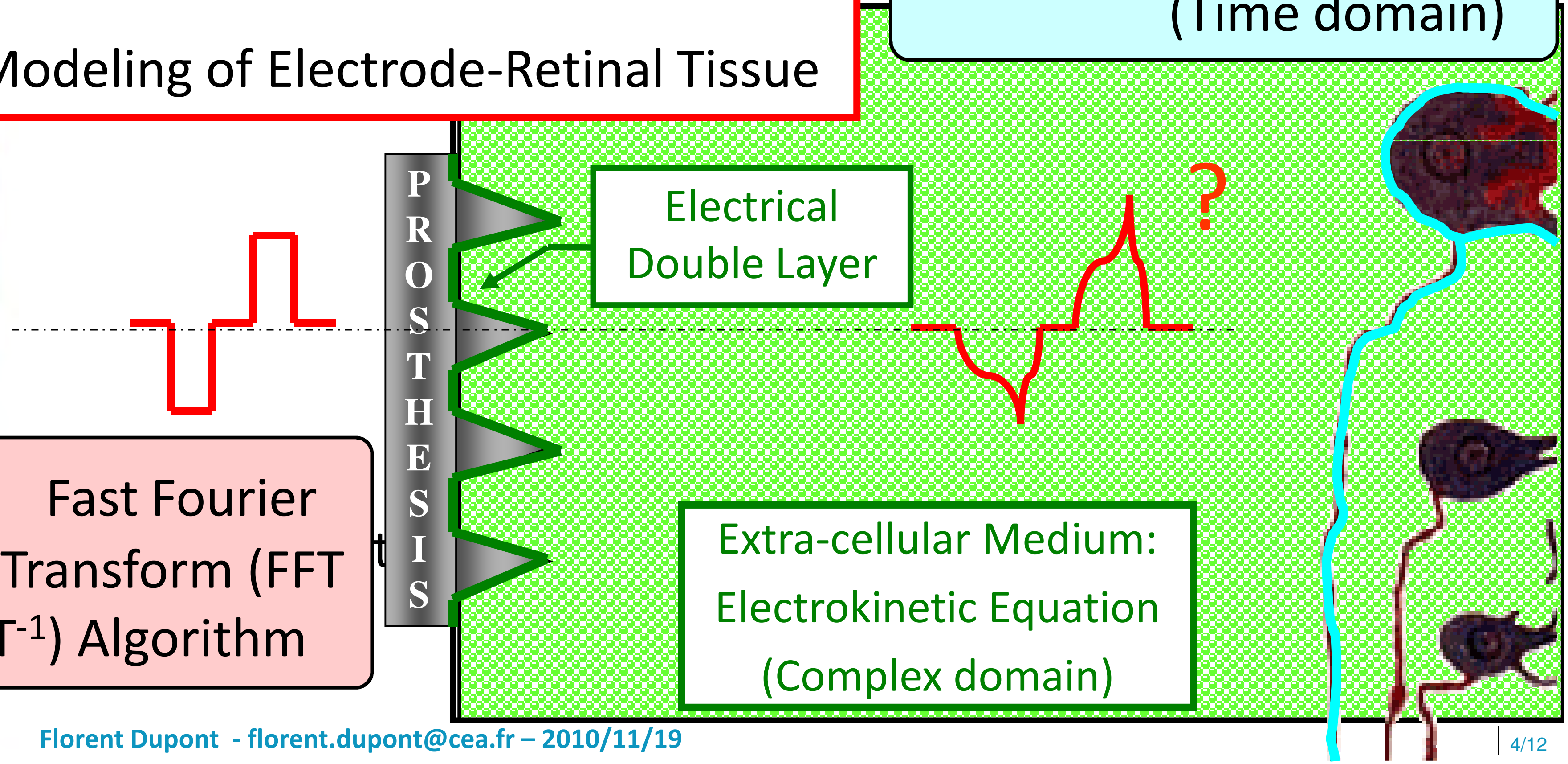
Study Objectives

PhD subject: Design of a Programmable Multipoint Stimulation ASIC for Neural Applications

⇒ Safe and Energy Efficient Waveform

⇒ Modeling of Electrode-Retinal Tissue

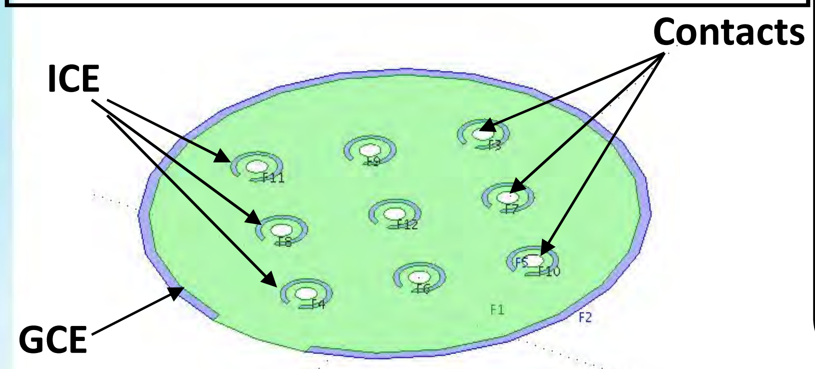
Cells Electrical activity modeling: Hodgkin-Huxley model (Time domain)



Fast Fourier Transform (FFT & FFT^{-1}) Algorithm

Electrokinetic Equation

CEA MEA-RETINE (Micro Electrode Array):
Nine Platinum Contacts **(Ø35µm)**,
nine **Individual Counter Electrodes** (ICE)
and a **General Counter Electrode** (GCE)



3D geometry => large computation time

EDL Capacitance

$$C_{EDL} = \frac{\varepsilon_0 \varepsilon_{r_{H_2O}}}{L_{Debye}}$$

Gouy-Chapman Model

$$\vec{\nabla}.\left(-\sigma^* \vec{\nabla} V_0^*\right) = 0$$

Linearity hypothesis → ***Complex domain***

$$\sigma^* = \sigma + i\omega\varepsilon$$

$$V(t) = V_0^* e^{i\omega t}$$

Boundary Conditions

Homogeneous Neumann

$$-\sigma^* \vec{\nabla} V_0^* . \vec{n} = 0$$

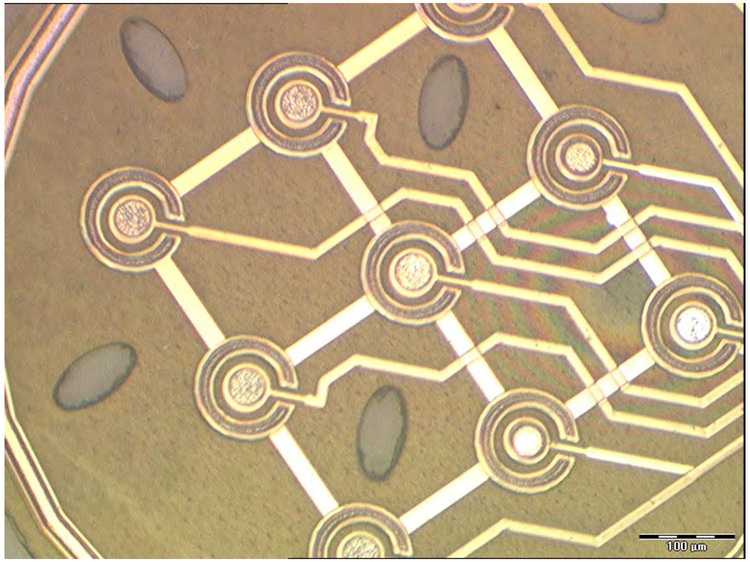
Robin (EDL)

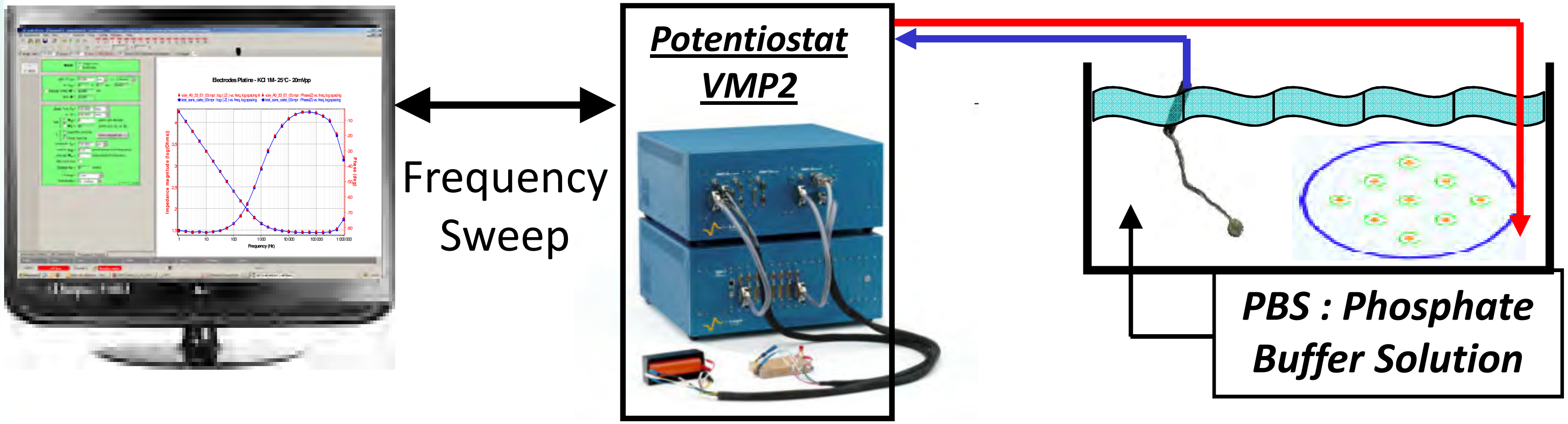
$$-\sigma^* \vec{\nabla} V_0^* . \vec{n} = -i\omega C_{EDL} \Delta V$$

Model Validation: Impedance Spectroscopy

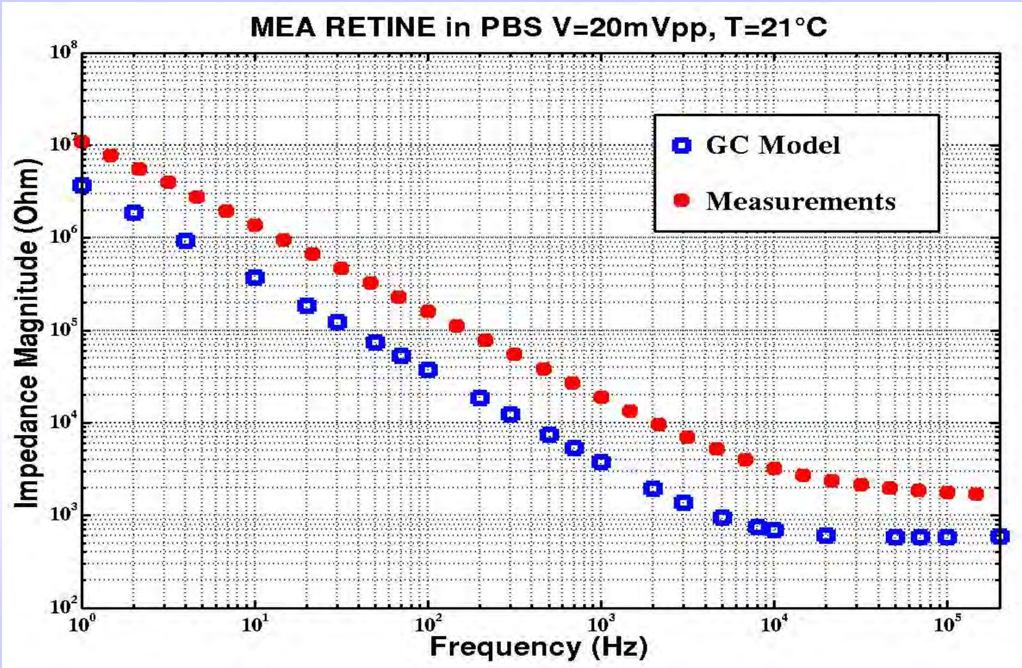
CEA MEA-RETINE

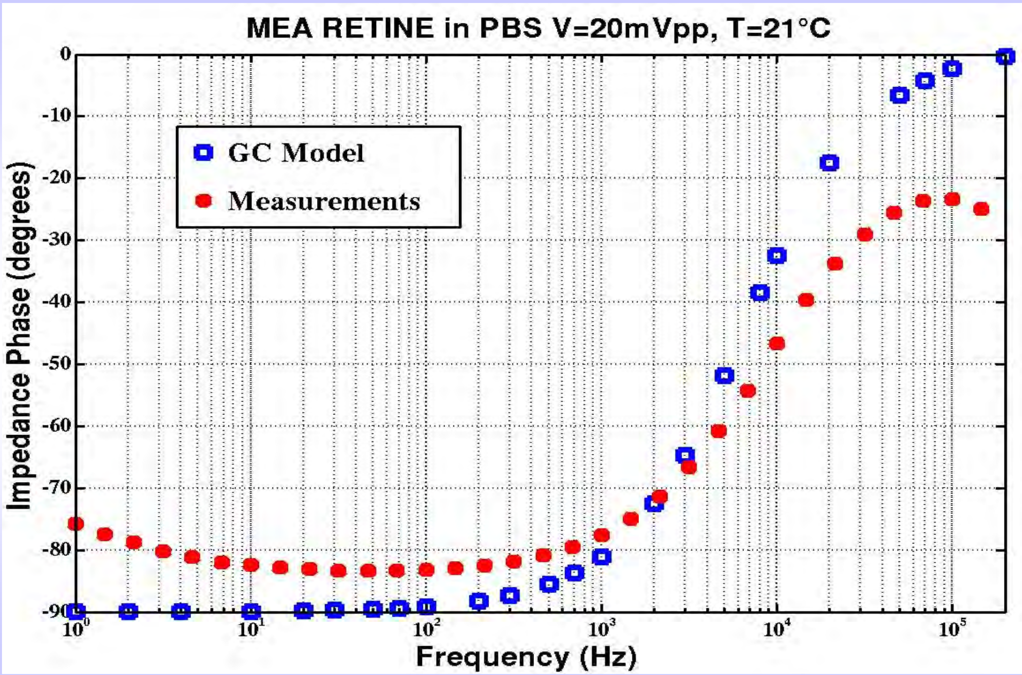
F.Sauter, V.Agache





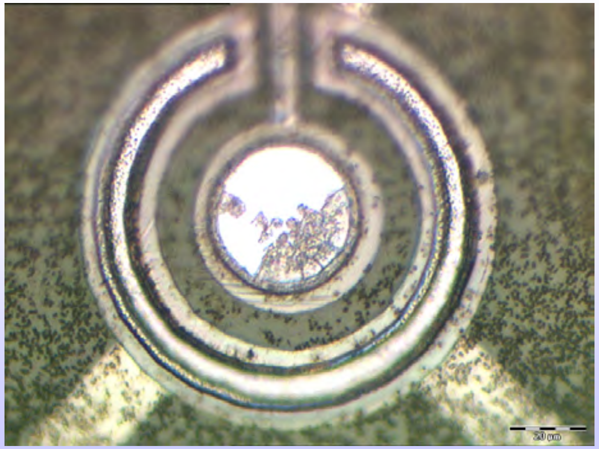
Test setup for characterization



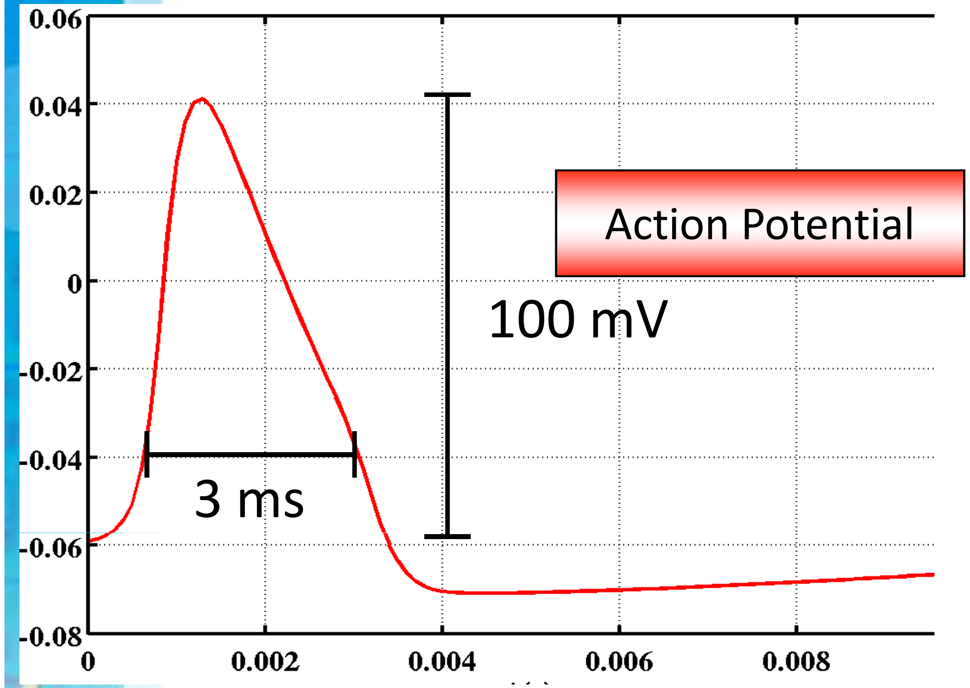


Results

- Behavior similar to RC series
- Etching Process Problem



Cell's response: Time Domain Hodgkin Huxley Model



Transmembrane potential (V_m)

- Rest V_m= -60/-70mV
- Triggering Threshold at V_m= -50mV
- Large amplitude and auto-regenerated

Hodgkin-Huxley (HH) Neuron Electrical Activity Model

$$\frac{a}{2\rho_i}\frac{\partial^2 V_m}{\partial x^2} = C_m\frac{dV_m}{dt} + \bar{g}_{Na}m^3h(V_m - E_{Na}) + \bar{g}_K n^4(V_m - E_K) + \bar{g}_L(V_m - E_L)$$

Propagation term **+** ***Transmembrane potential temporal equation***

$$\frac{dm}{dt} = \alpha_m(1-m) - \beta_m m$$

$$\frac{dh}{dt} = \alpha_h(1-h) - \beta_h h$$

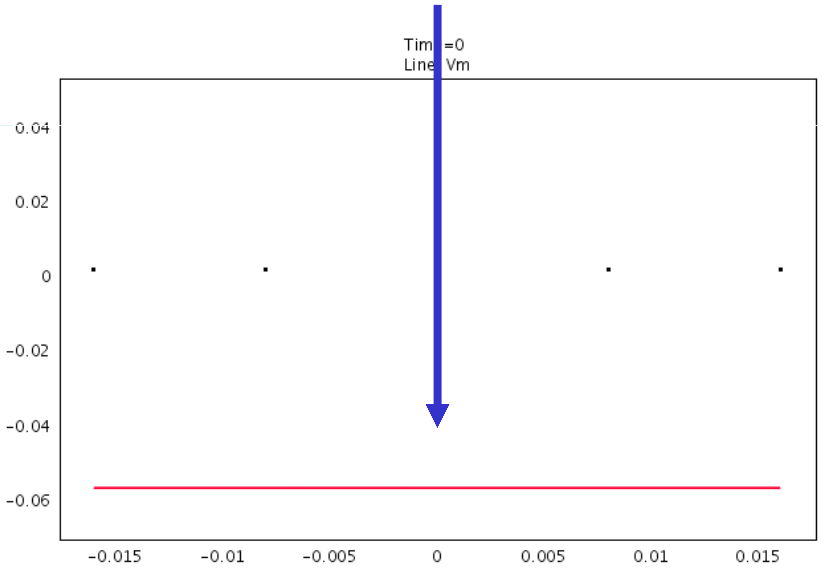
$$\frac{dn}{dt} = \alpha_n(1-n) - \beta_n n$$

Coefficient Temporal Equations

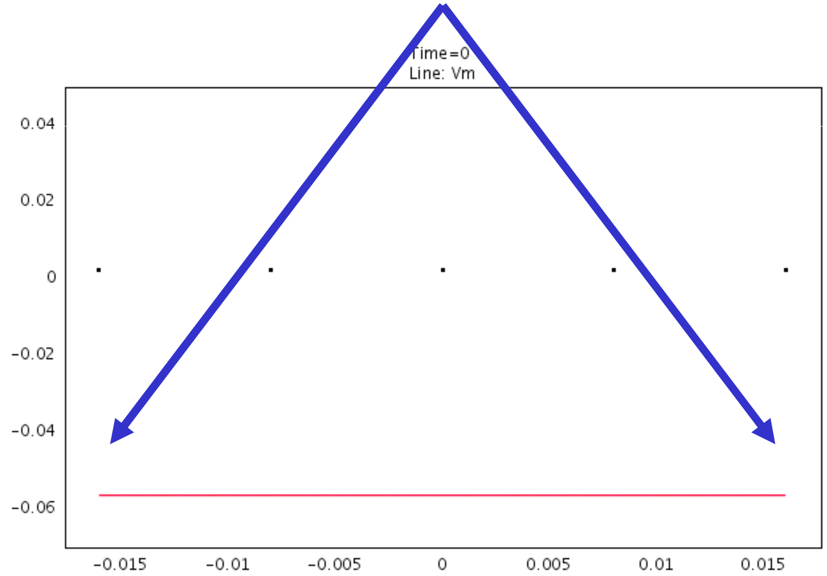
Hodgkin-Huxley Model for RGC

⇒ 1D modeling for the RGC membrane

Stimulation application point



Stimulation application points



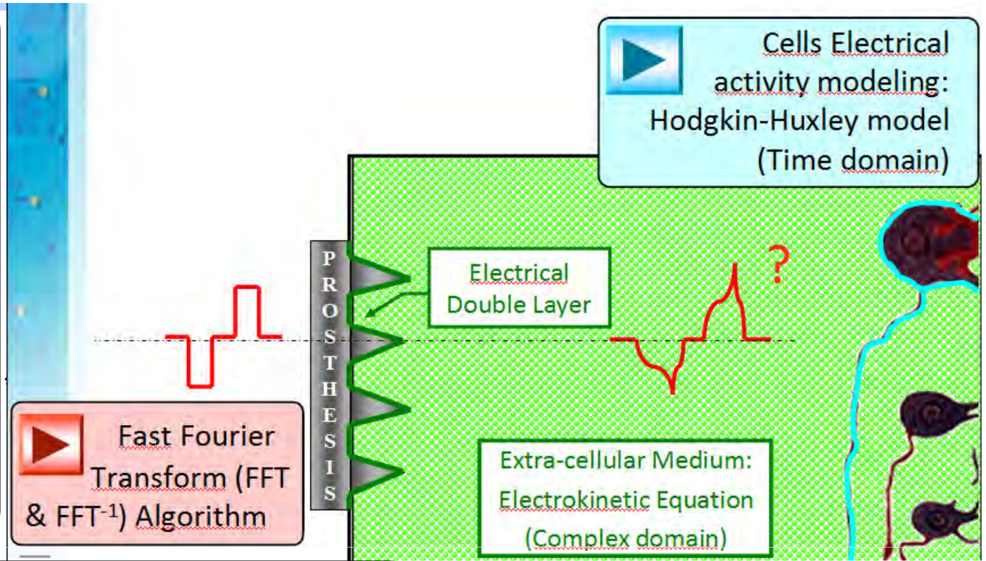
⇒ Creation of action potentials

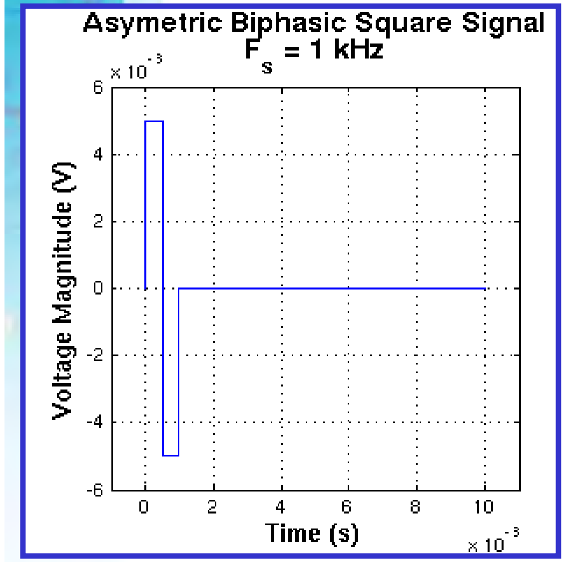
⇒ Inhibition of existing action potentials

Looping Fast Fourier Transform with COMSOL

MATLAB script

- Stimulus creation and sampling
- Fast Fourier Transform
- COMSOL Multiphysics script
- Post-processing





Time domain

FFT^{-1} Algorithm

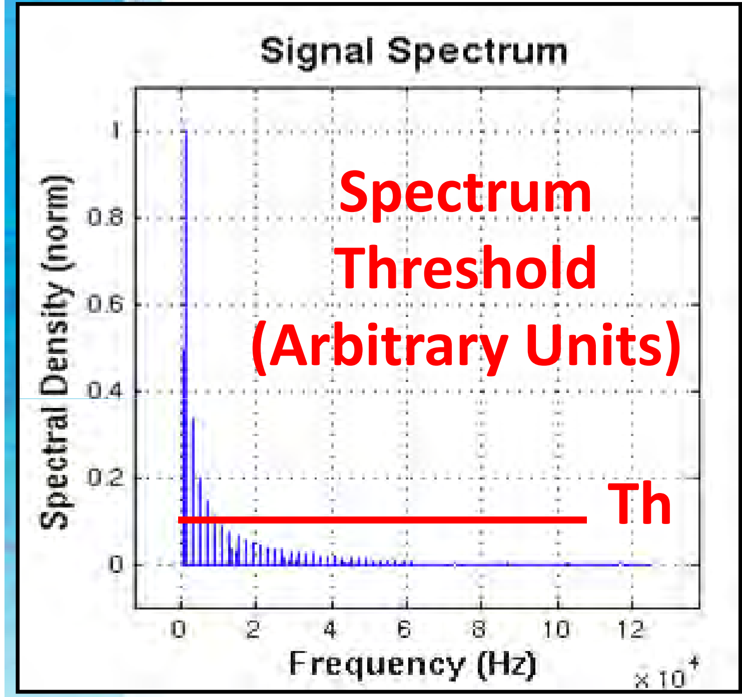
$$x[n] = \frac{1}{N}\sum_{n=0}^{N-1} X[m] e^{-i2\pi m\frac{n}{N}}$$

$$N \equiv 0(2), \quad m \in [0, N-1]$$

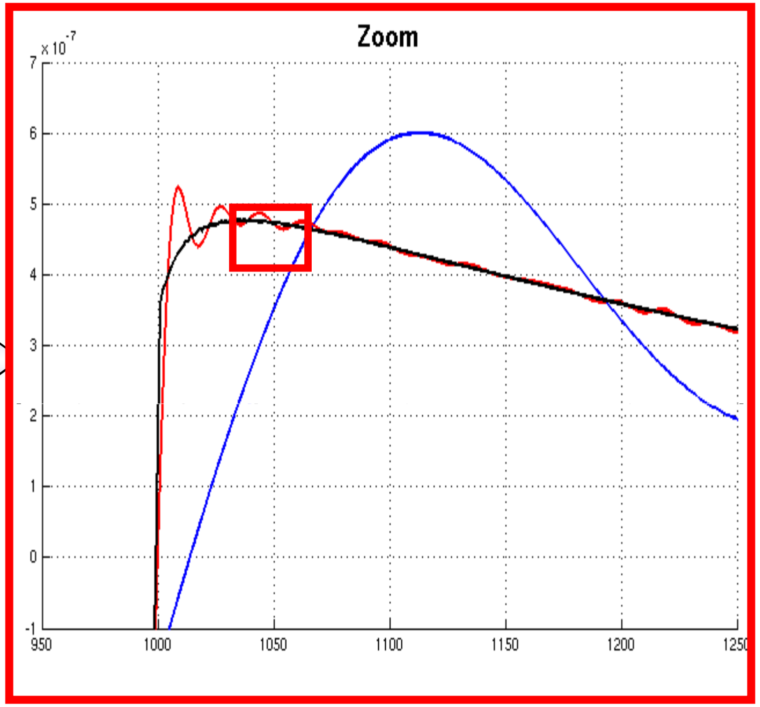
Frequency domain

FFT Optimization

Decreasing the loop number without degrading the signal



FFT^{-1}



Blue line	$Th=10^{-4}$ -> 24 harmonics
Red line	$Th=5.\ 10^{-6}$ -> 309 harmonics
Black line	$Th=10^{-7}$ -> 2642 harmonics

- $Th = 10^{-6}$ -> 95% of computation time saved
- Applicable to different stimuli

=> ≈ 90-95% saving in computation time

Conclusion

- Modeling used as a prediction tool
- Coupling FFT (MATLAB) with COMSOL
- Fast Fourier Transform (FFT)
  - ➔ Select data spectrum
  - ➔ Reducing the number of harmonics (threshold)
- Complete numeric FEM Test Framework

Future Work

- Tests of different waveform/electrode shapes
- Tests with multi-signal patterns