DANISH RESEARCH
CENTRE FOR
MAGNETIC RESONANCE

DTU
Health Tech

Hvidovre
Hospital

Field calculations with SimNIBS

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GLOBAL EXCELLENCE IN HEALTH

Overview

Terminology:

- Electric field & current density
- Field strength, normal component: What are they, and which should we report?
- from TDCS to TACS (and TRNS)

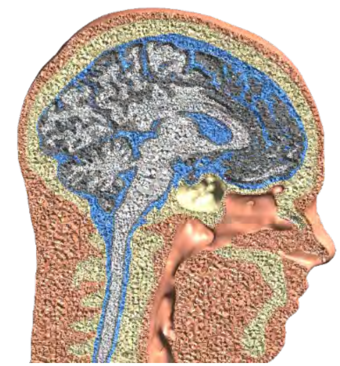
Segmentation accuracy and fields

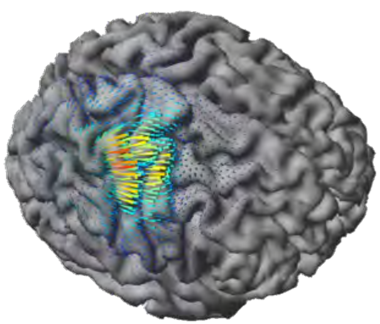
- MR images to get robust segmentations

SimNIBS Workflow

Upcoming features: TES optimization, TMS optimization

Practical Exercise: Overview





Electric field and current density

Ohm's law $\vec{j} = \sigma \vec{E}$

$\vec{j}$ current density in **A/m²**

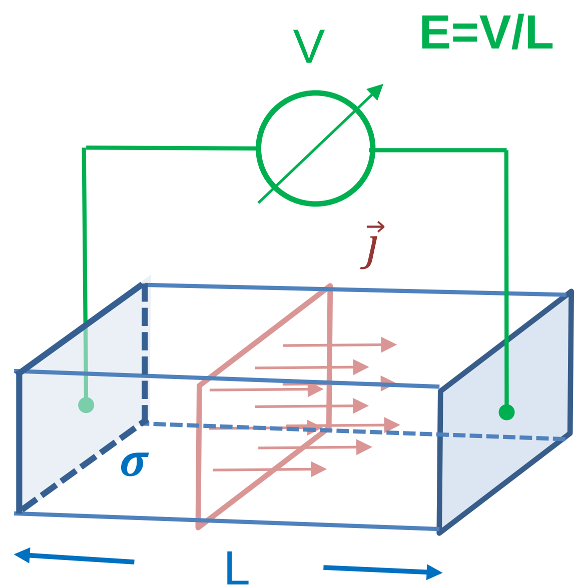
how much current flow per area unit

$\vec{E}$ electric field in **V/m**

which potential (i.e. energy) difference per length unit

σ conductivity in **S/m**

fundamental property of a material that quantifies how well it conducts electric current

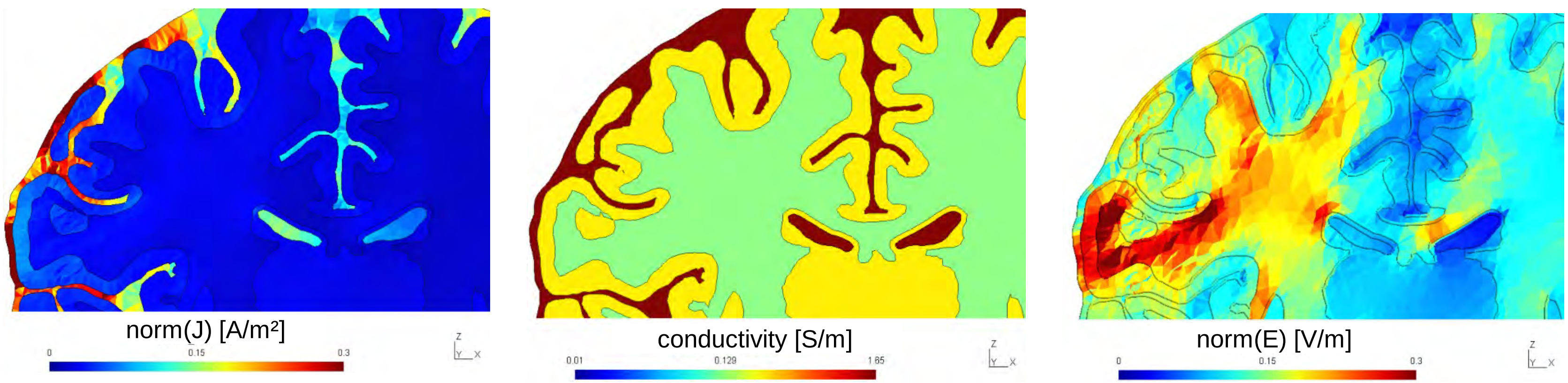


Example: Current flow from left to right in homogeneous conductor

σ is the inverse of the resistivity ρ: σ=1/ρ
ρ is in Ω·m

Electric field and current density

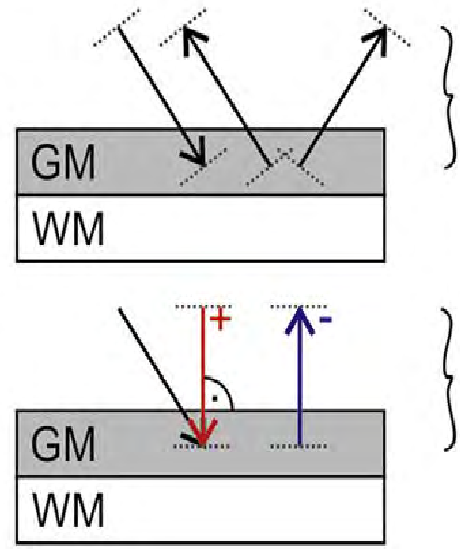
$$\vec{j} = \sigma \cdot \vec{E}$$



1 mA “standard” M1 montage, coronal cut at the level of M1, only CSF, GM and WM

- J and E are interchangeable.
- We usually report E, because nerve membrane polarization is dependent on E (or its spatial derivative)

Electric field strength vs normal component



length of **E**;
electric field strengh
vector norm of **E**
→ **normE, or E_norm**

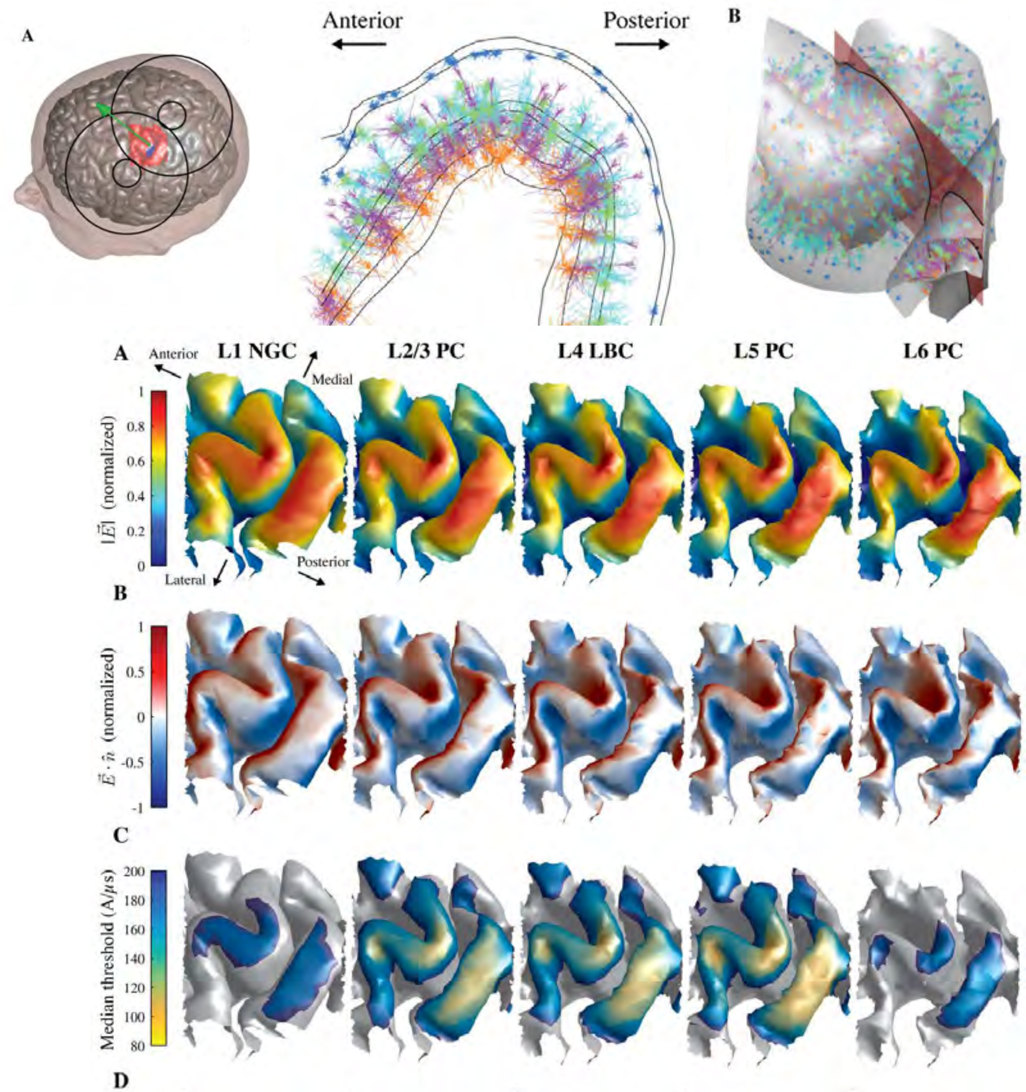
normal component **nE**;
part of E orthogonal to cortex
→ **E_normal**

Note: Naming for J follows the same convention: normJ vs J_normal

Interpretation of simulated electric fields: TMS

Mechanism-of-action

- TMS likely stimulates the **cortical sheet**
- Rough approximation: **Field strength** is the dominant factor determining neural excitation (Thielscher, NI, 2011; Bungert, Cer Cortex, 2016)
- This might be due to a preferential **activation of axon terminals** *(Aberra et al., bioRxiv, 506204)*
- Opposing hypothesis (Fox, HBM, 2004): **Normal component** of the electric field relative to the cortex is important

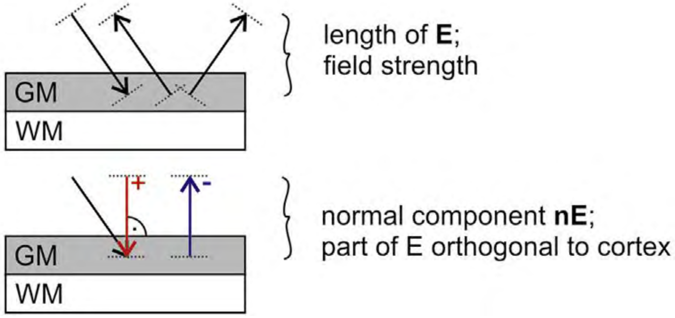


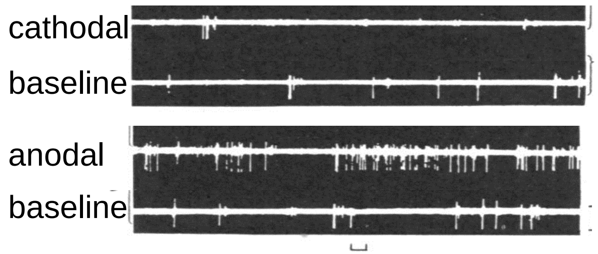
(Aberra et al., bioRxiv, 506204)

Interpretation of simulated electric fields: TES

Normal component of the field is thought to be relevant for physiological effects

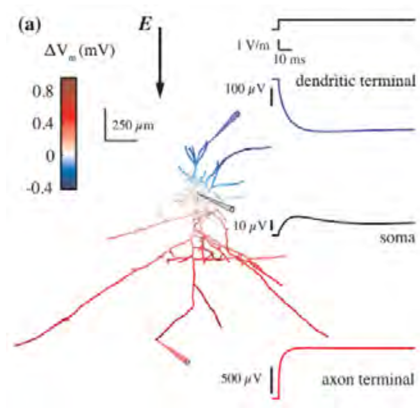
- Polarity-dependent stimulation effects on **cortical sheet**
- Fields **parallel** to the somato-dendritic axis polarize soma and dendrites of pyramidal cells: **Hyperpolarization near the anode and depolarization near the cathode**





This view is simplified

- Electric fields **perpendicular** to the apical–dendritic axis polarize **axon terminals;** occurs also for interneurons
- Seen, e.g. as modulation of responses to orthodromic stimulation



(Bindmann, J Phys,1964; Bikson et al J Physiol 2004; Rahman J Physiol. 2017; Aberra et al J. Neural Eng. 2018)

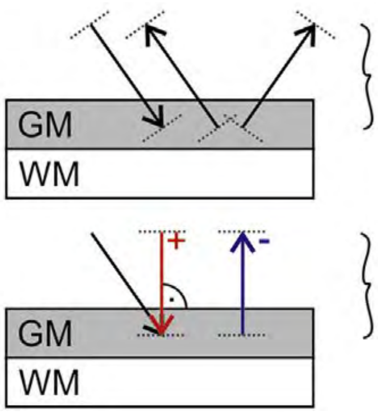
Electric field strength vs normal component

Example: Bipolar F3-F4 electrode montage

Observations:

- **normE**: Highest field strengths close to the midline in the medial frontal cortex and not under the electrodes

- **E_normal:** Complex spatial stimulation pattern: Cathodal – anodal – cathodal – andodal



length of **E**;
field strength

vector norm of **E**

→ normE, or E_norm

normal component **nE**;
part of E orthogonal to cortex

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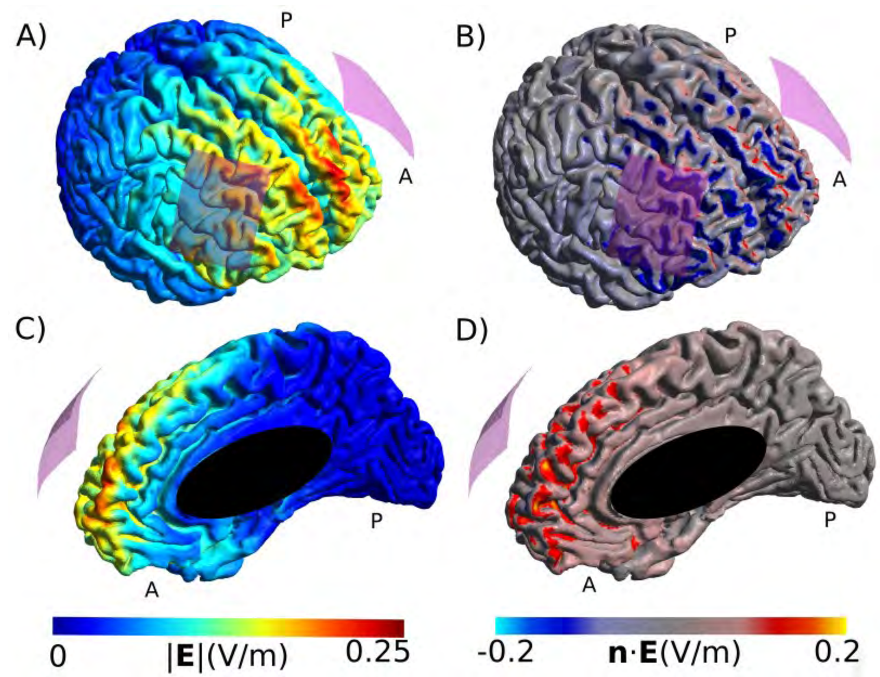
Field strength | Normal component



(Karabanov, Front. Neuroscience, 2019)

From TDCS to TACS (and TRNS)

Quasi-static regime at low frequencies:

- **Electric field separates into spatial and temporal components**. The spatial component can be determined using Laplace's equation for the electrostatic field

$$\boldsymbol{E}(\boldsymbol{p},t) = \boldsymbol{E}(\boldsymbol{p})I(t)$$

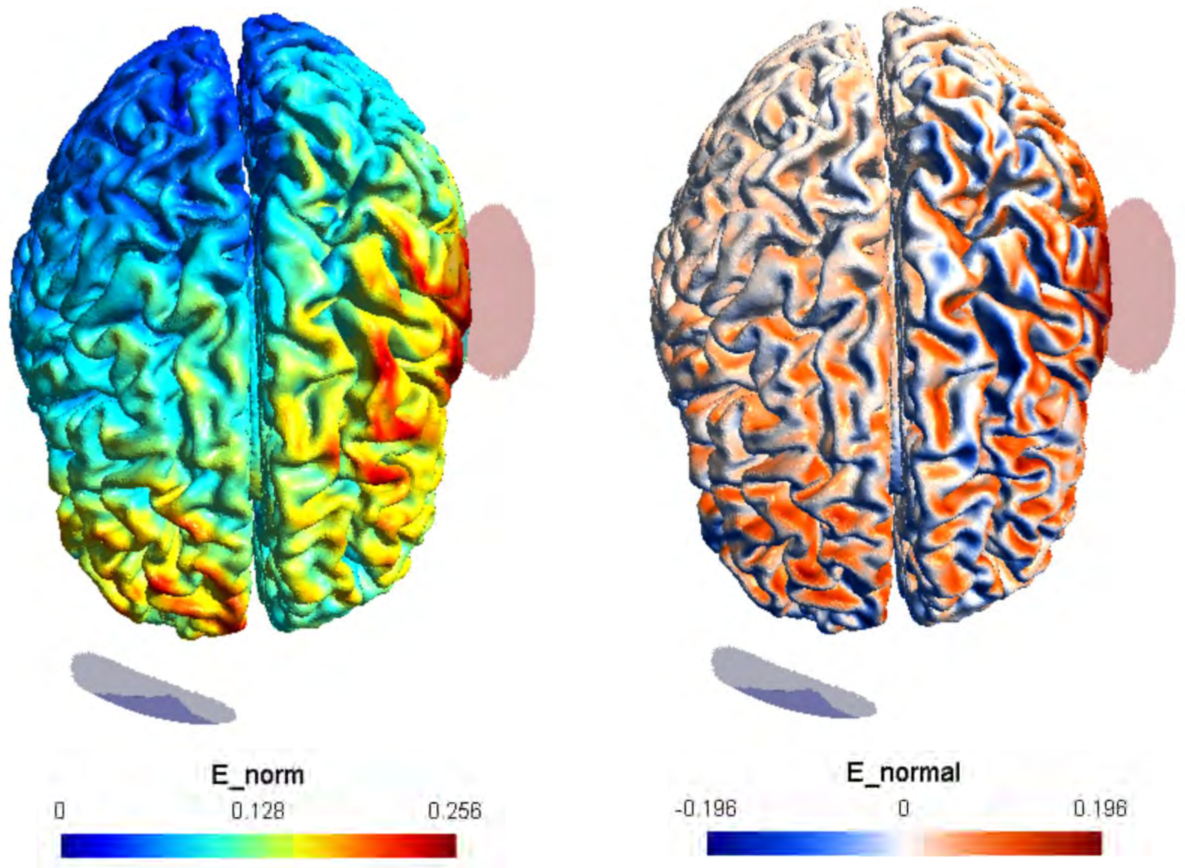
- Numerical field calculations (FEM) to get the spatial component.
- Multiplication of spatial component with temporal waveform gives electric field

- For > 2 electrodes, the field is the vector sum of the fields of the electrode pairs

$$\boldsymbol{E}(\boldsymbol{p},t) = \sum_{i=1}^{N} \boldsymbol{E}_i\,(\boldsymbol{p},t) = \sum_{i=1}^{N} \boldsymbol{E}_i\,(\boldsymbol{p})\,I_i(t)$$

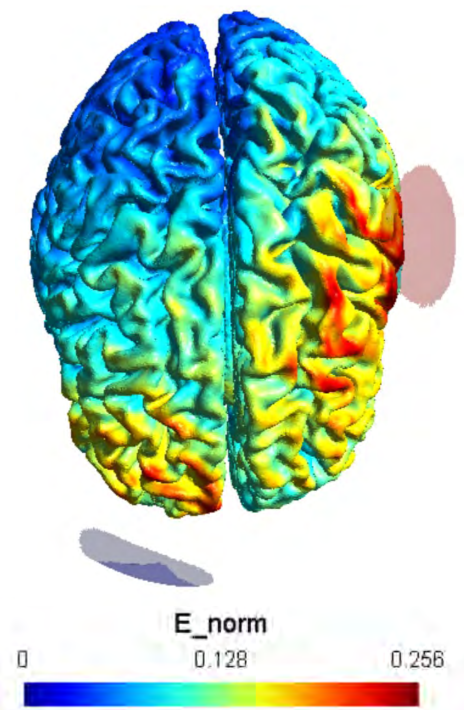
From TDCS to TACS (and TRNS)

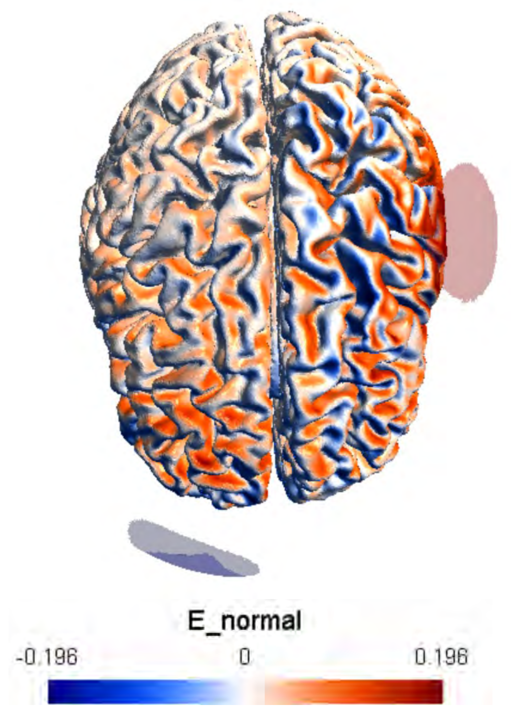
Example: “Classical” M1 montage, 1 mA, anodal TDCS

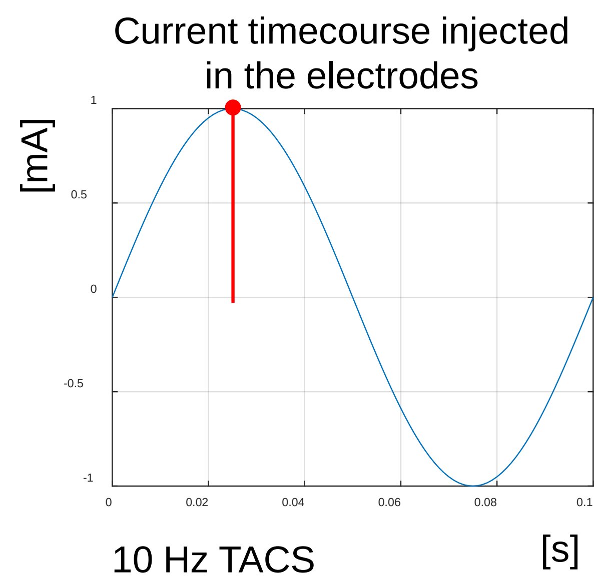


From TDCS to TACS (and TRNS)

Example: “Classical” M1 montage, 1 mA, 10 Hz TACS



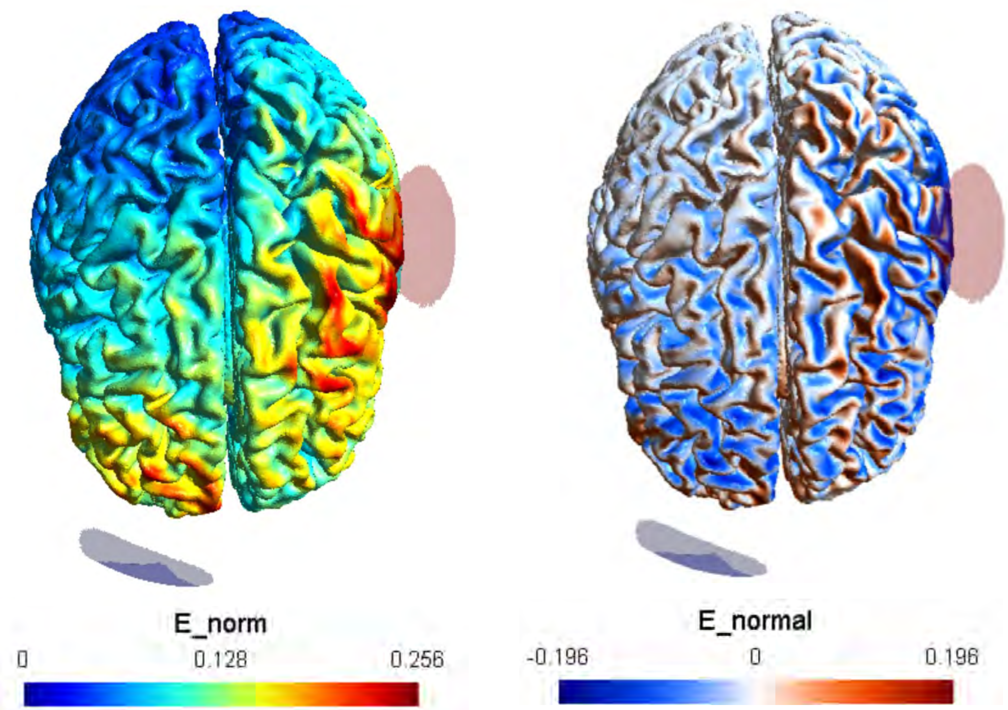


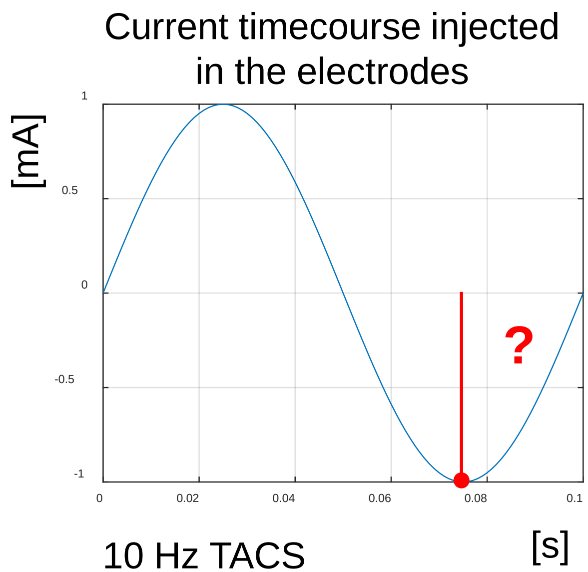


$$\boldsymbol{E}(\boldsymbol{p},t) = \boldsymbol{E}(\boldsymbol{p})\Big|_{1\ \mathrm{mA}} \cdot \sin(2\pi \mathrm{f} t)$$

From TDCS to TACS (and TRNS)

Example: "Classical" M1 montage, 1 mA, 10 Hz TACS



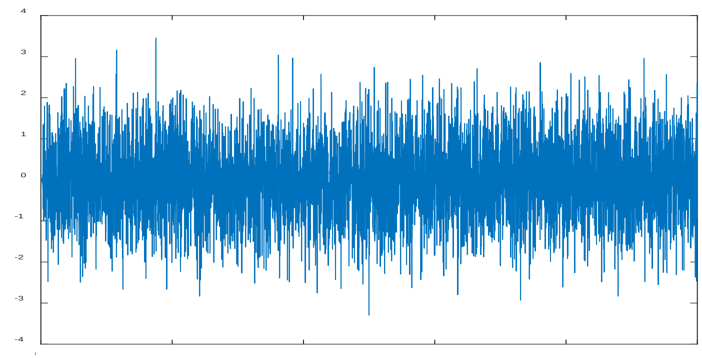


$$\boldsymbol{E}(\boldsymbol{p},t) = \boldsymbol{E}(\boldsymbol{p})\Big|_{1\ \mathrm{mA}} \cdot \sin(2\pi f t)$$

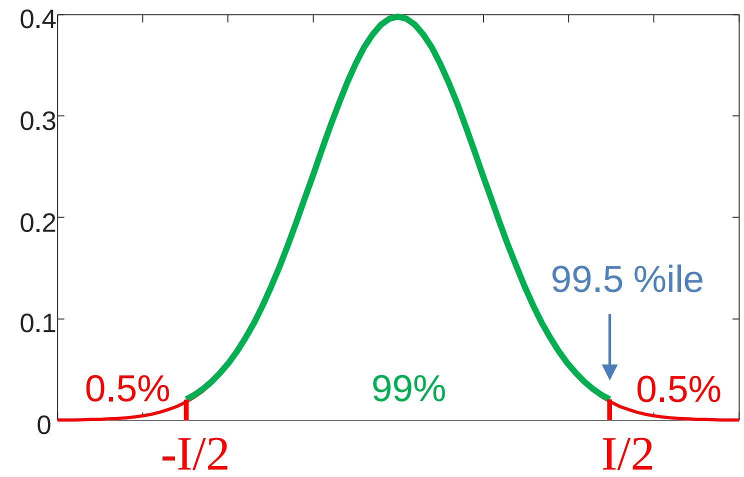
→ Repetitive change between hyper- and depolarization
→ Regions with **same color** change polarity **in-phase**
→ Regions with **opposite color** change polarity **anti-phase**

TRNS

Suggestion: Report the power of the noise signal



NeuroConn user manual: “noise” mode
“The random current levels are statistically normally distributed over time. … The signal form noise has a bandwidth from 0 to 250 Hz.
…
Current I [µA]: 99% of the generated current levels are within the interval [-current/2] und [+current/2].”



The noise power corresponds to the variance (=SD²) of the Gaussian noise.

$$Z = \frac{X - mean}{SD} \qquad SD = \frac{I/2}{Z(99.5\%ile)} \approx \frac{I}{5.15}$$

→ Simulate for I/5.15, and report this as the noise SD of the induced E-field