

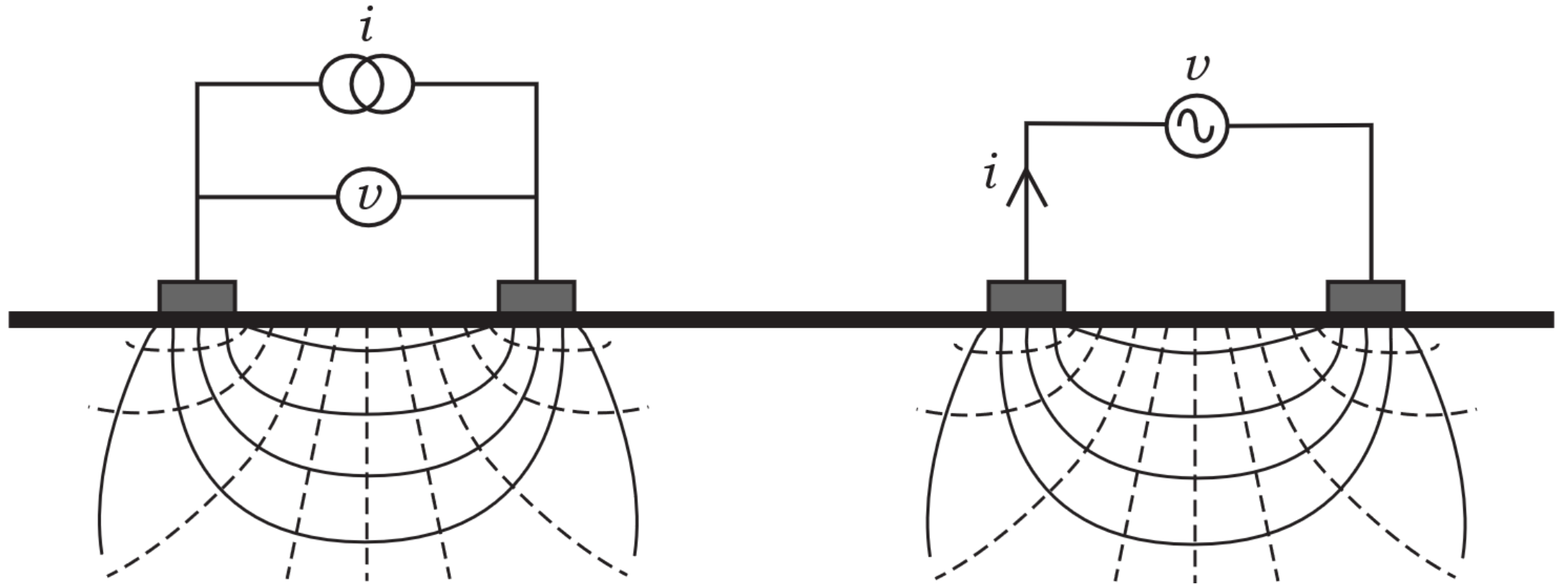


# Impedance measurements on a layered object – some surprising phenomena

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NORWAY

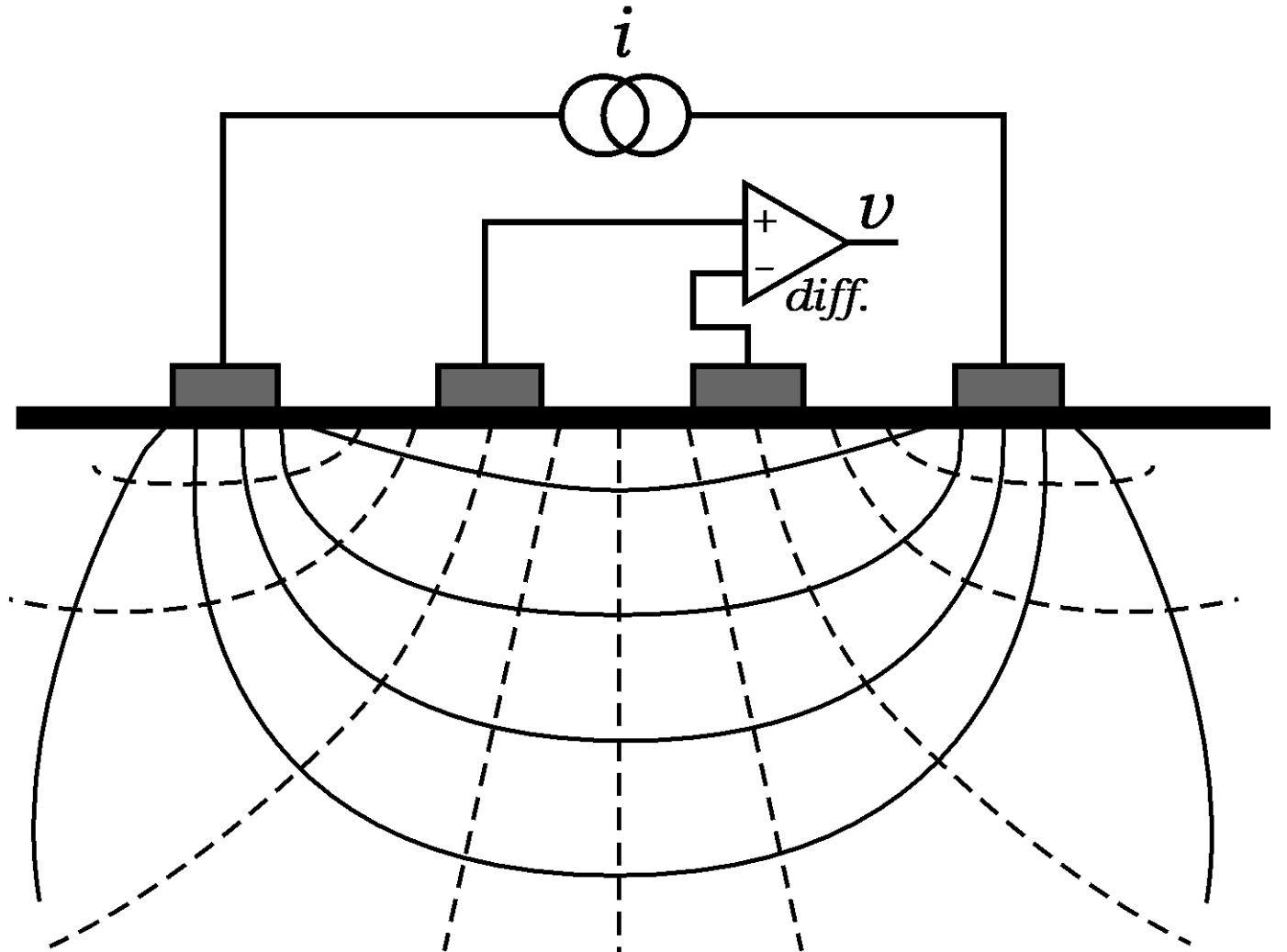


# Impedance measurements: Two-electrode system



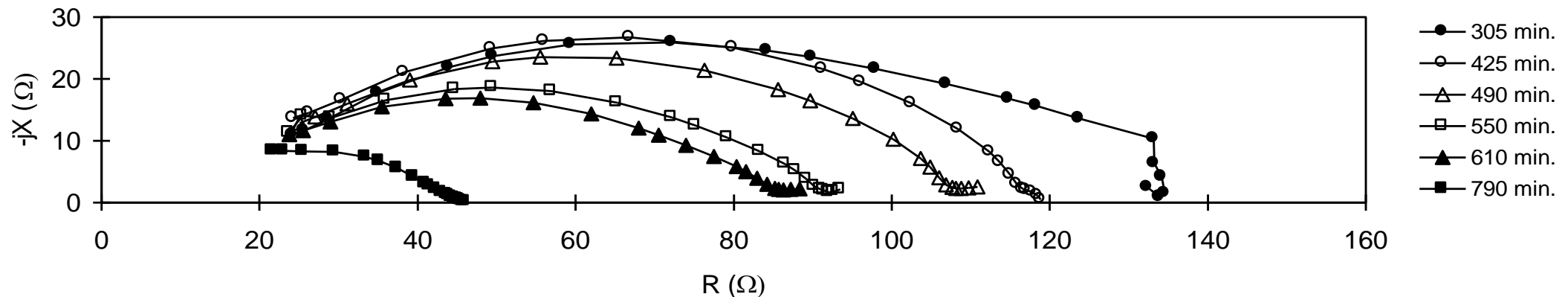
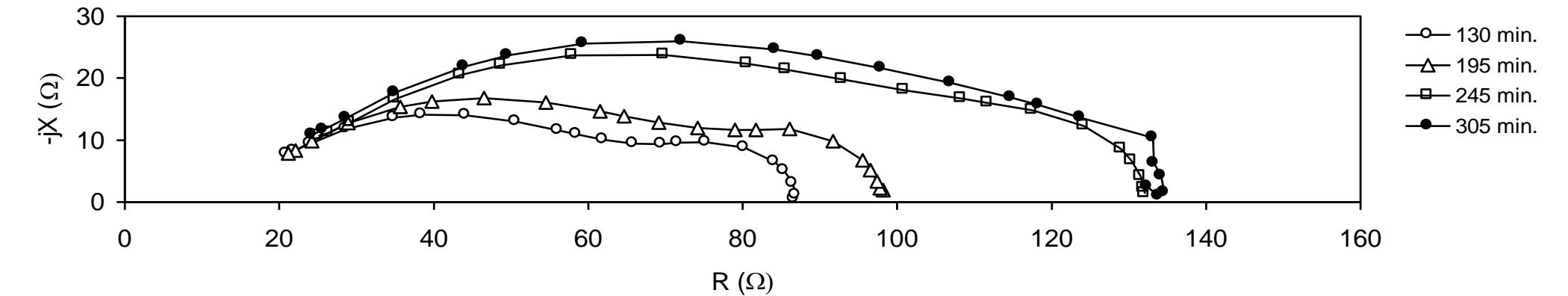
# Impedance measurements: Four-electrode system

- Originates from the invention of the Kelvin bridge in 1861 by William Thomson (Lord Kelvin)
- Two-port network
- Transfer function is per definition an impedance
- Hence, transfer impedance

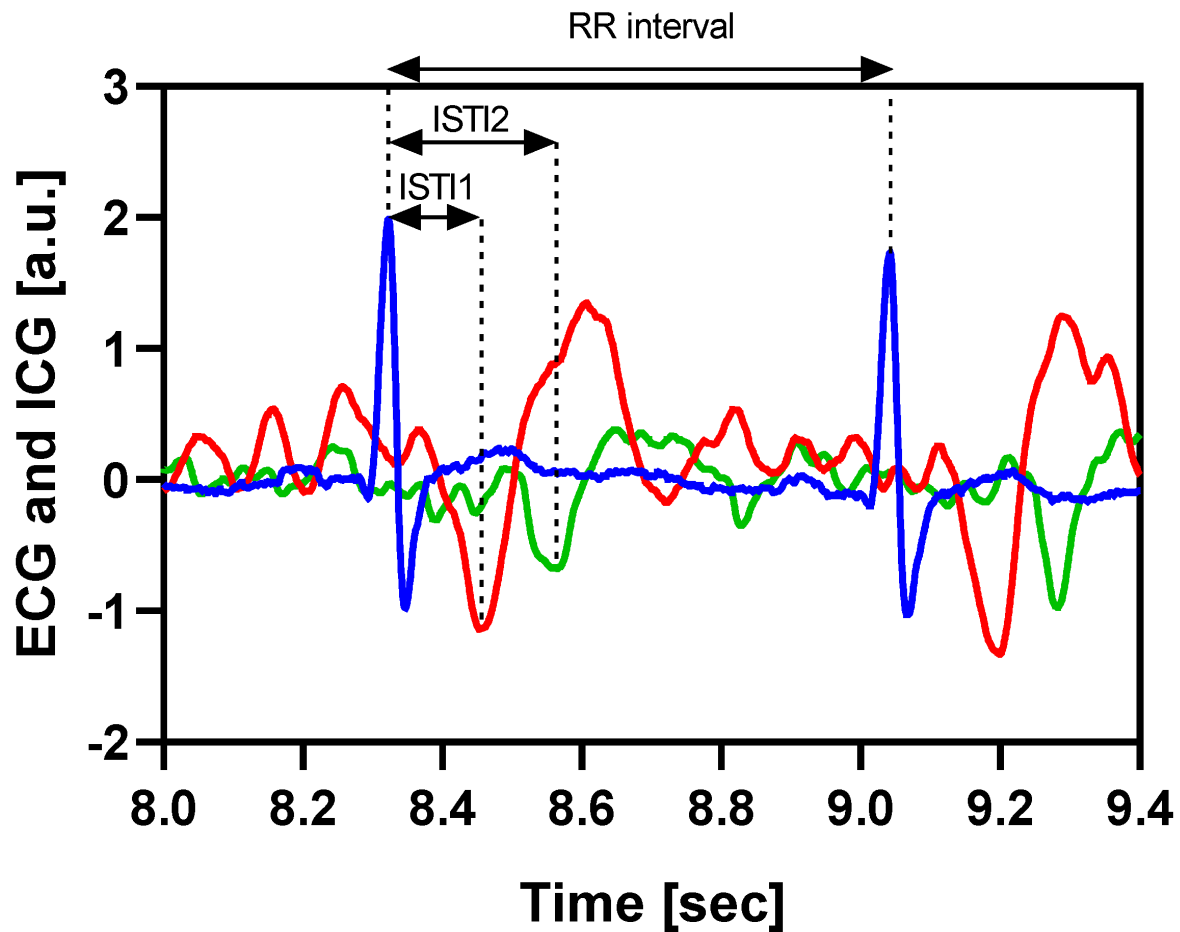


# Example: Fish

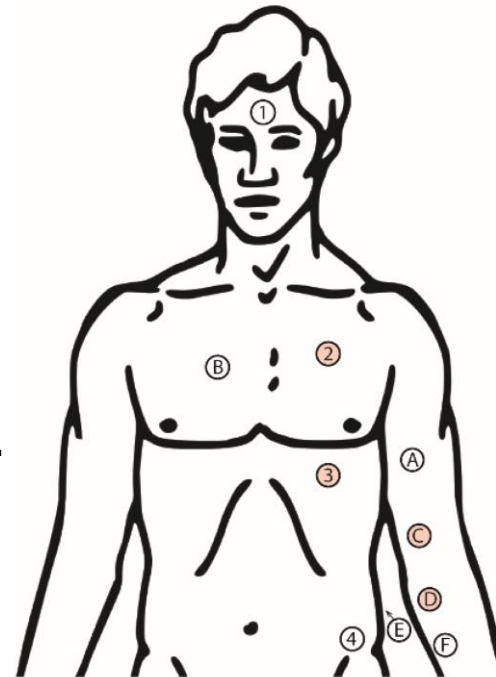
Measured on haddock muscle with surface electrodes



# Example: Pulse wave velocity

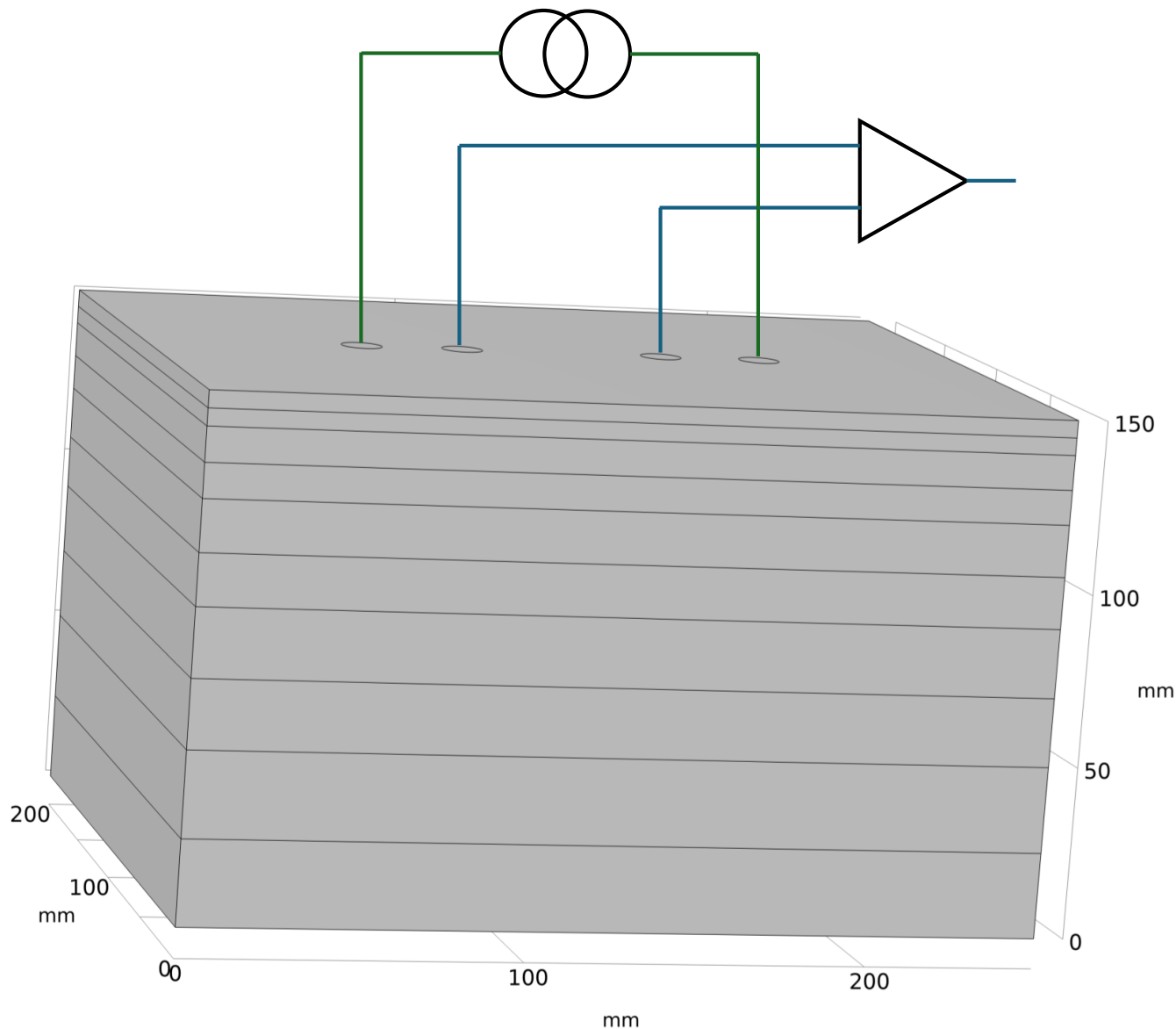


— ECG  
— ICG1  
— ICG2



- ISTI = Initial Systolic Time Interval
- From R-peak in ECG to C-wave in ICG
- Injected  $300 \mu\text{A}$  @  $64 \text{ kHz}$
- ECG and ICG
- 10 subjects 20-30 years old
- 10 subjects > 60 years old
- Velocity significantly higher in older subjects
- Method for measuring degree of

# Theory



- Sensitivity is a negative or positive scalar

$$S = \int_V \frac{\vec{J}_1 \cdot \vec{J}_2}{I^2} \quad [m^{-4}]$$

- Multiplied with the local complex resistivity, it gives volume impedance density,  $\vec{z}$

- Integrated over the whole volume it gives the transfer

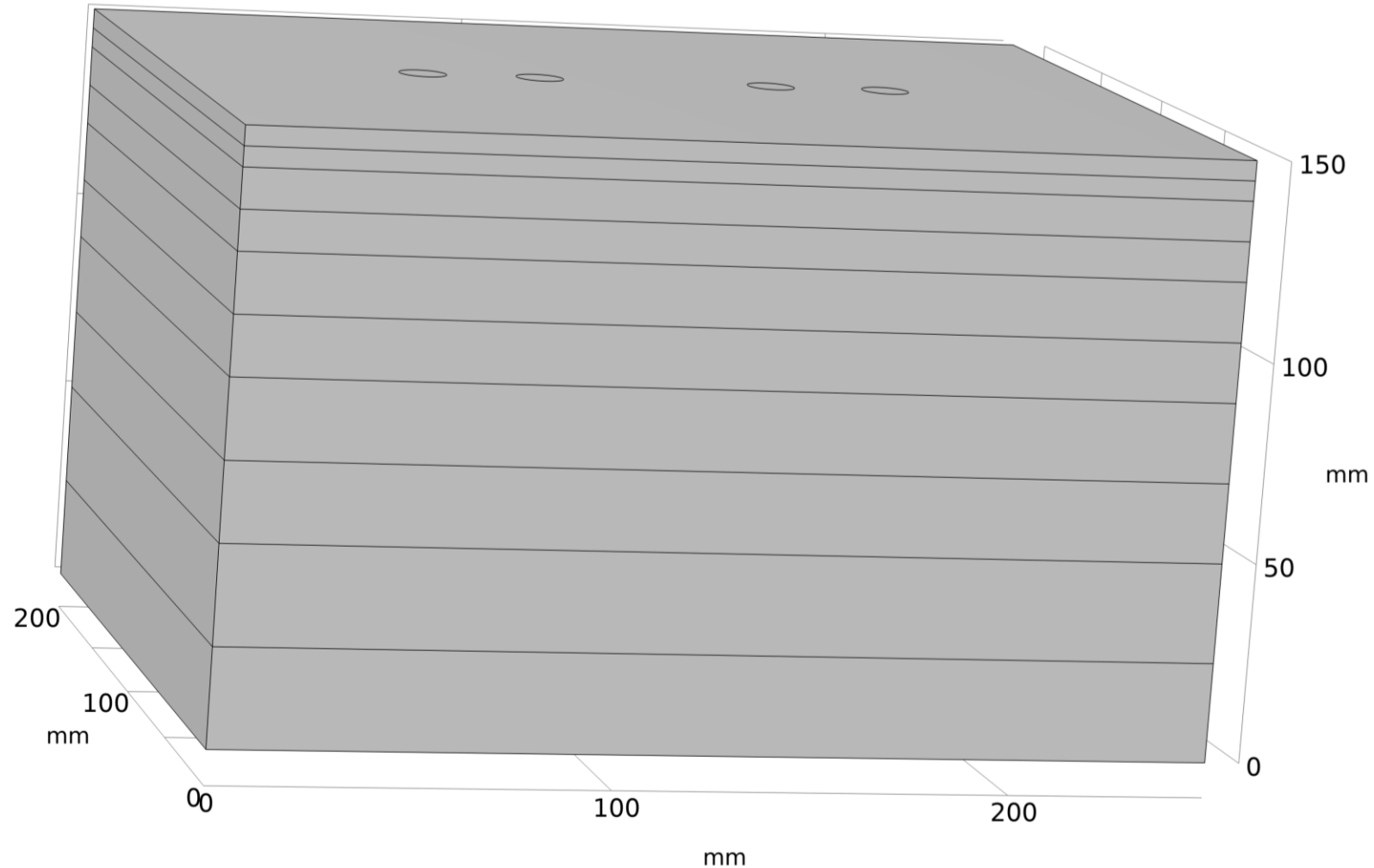
$$\text{imped } \vec{Z} = \int_V \frac{(\vec{J}_1 \cdot \vec{J}_2) \cdot \vec{\rho}}{I^2} dV \quad [\Omega]$$

- Hence, integrating over sub-volumes gives this volume's contribution to the total transfer impedance

- The total transfer impedance is therefore the vector sum of all these contributions, so if

# Measurements on a layered object

The current will flow through the layers partly in series and partly in parallel



VID for each voxel:

$$\vec{z} = \frac{(ec.Jx \cdot ec2.Jx + ec.Jy \cdot ec2.Jy + ec.Jz \cdot ec2.Jz)}{(1[A])^2}$$

Sensitivity

$$\cdot \frac{\left( \frac{ec.Ex}{ec.Jx} + \frac{ec.Ey}{ec.Jy} + \frac{ec.Ez}{ec.Jz} \right)}{3}$$

Complex resistivity

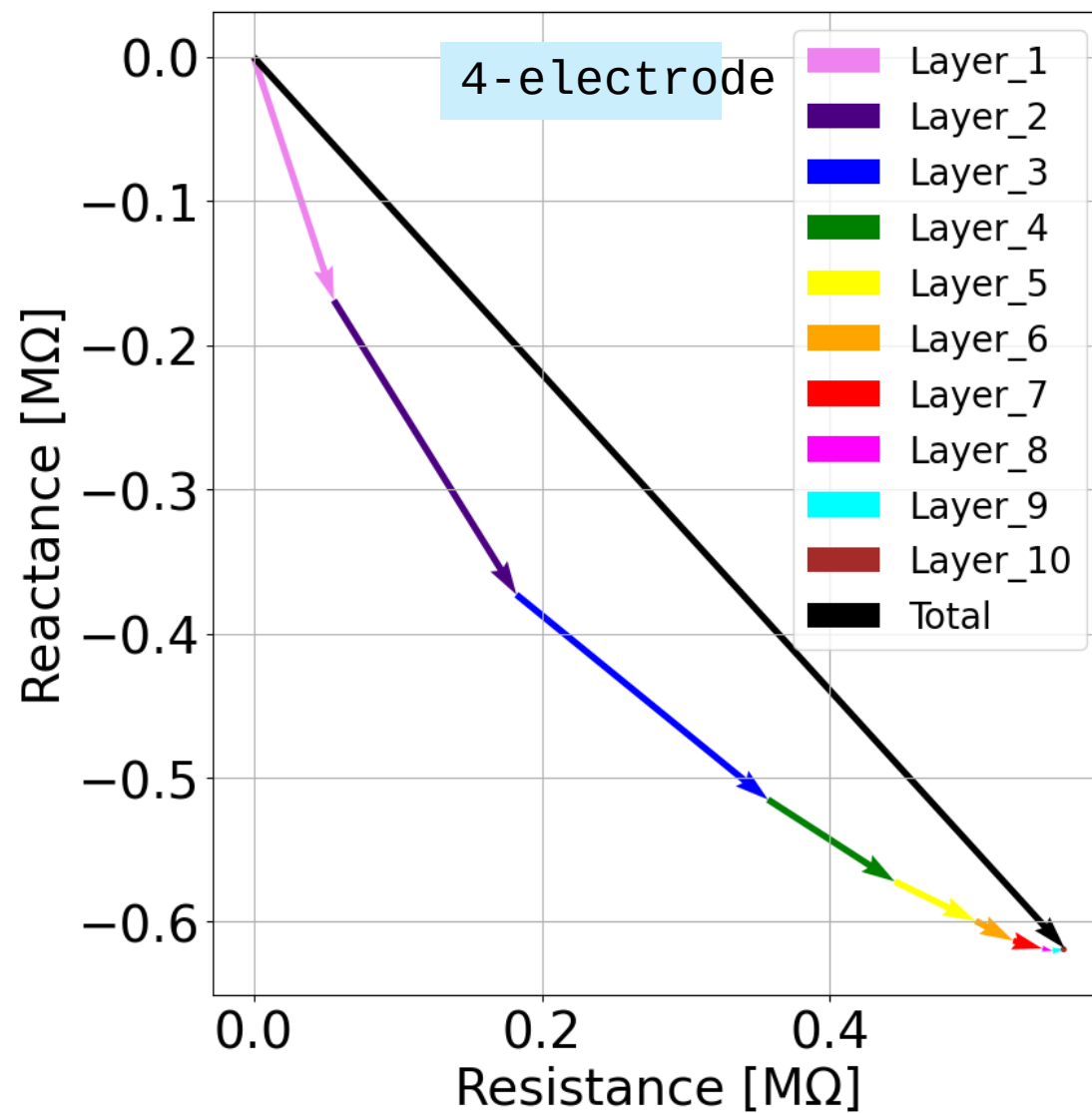
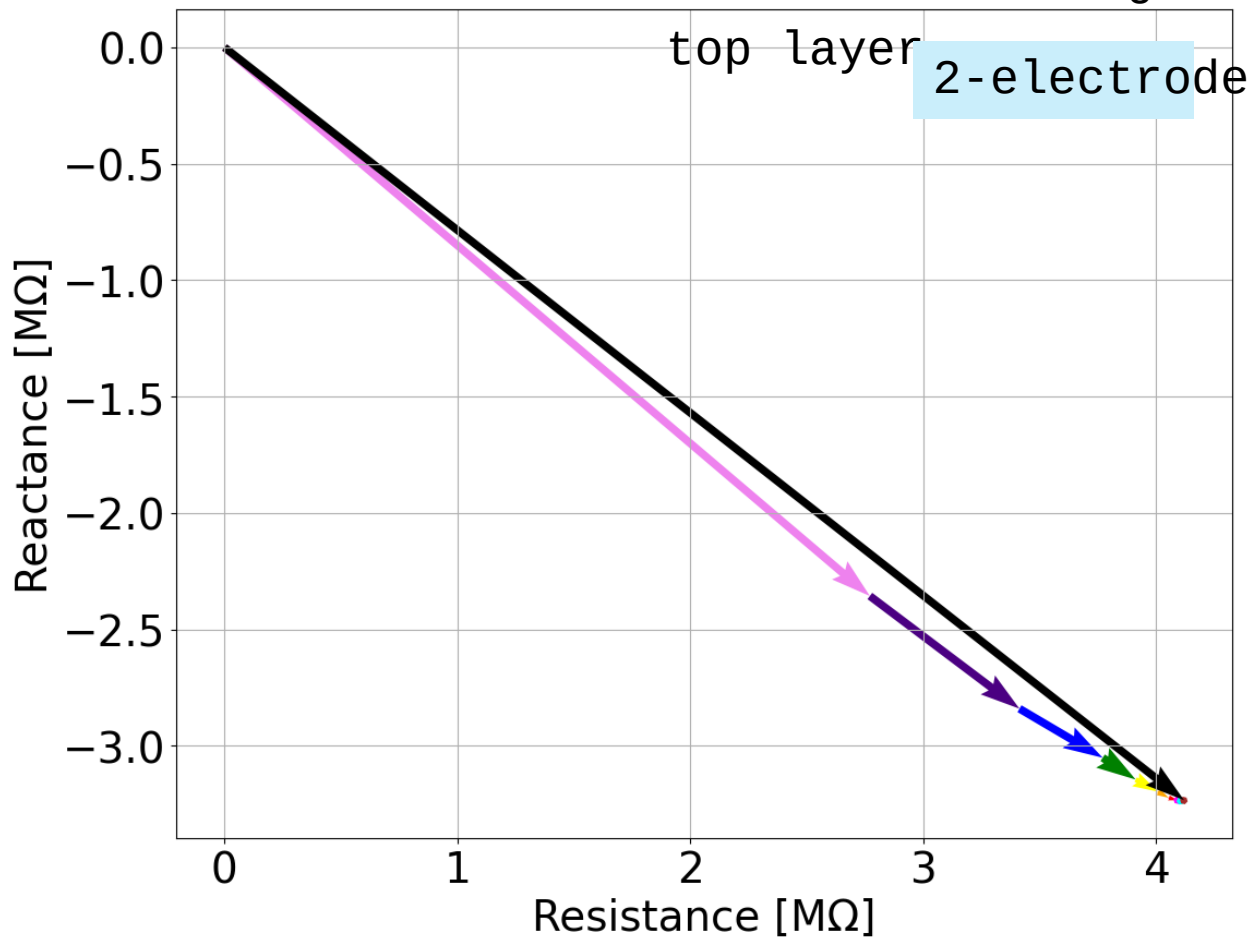
# Four test cases

Test number	1	2	3	4	1	2	3	4	1	2	3	4
Parameters	Thickness [mm]				Conductivity [S/m]				Relative permittivity			
Layer 1	5	7.5	5	15	2e-5	2e-5	2e-4	2e-4	21	21	40	40
Layer 2	5	7.5	5	15	1e-6	1e-6	1e-6	1e-6	5	5	20	20
Layer 3	10	7.5	10	15	2e-5	2e-5	1e-6	1e-6	21	21	20	20
Layer 4	10	7.5	10	15	1e-6	1e-6	1e-6	1e-6	5	5	20	20
Layer 5	15	7.5	15	15	2e-5	2e-5	1e-6	1e-6	21	21	20	20
Layer 6	15	7.5	15	15	1e-6	1e-6	1e-6	1e-6	5	5	20	20
Layer 7	20	7.5	20	15	2e-5	2e-5	1e-6	1e-6	21	21	20	20
Layer 8	20	7.5	20	15	1e-6	1e-6	1e-6	1e-6	5	5	20	20
Layer 9	25	7.5	25	15	2e-5	2e-5	1e-6	1e-6	21	21	20	20
Layer 10	25	7.5	25	15	1e-6	1e-6	1e-6	1e-6	5	5	20	20



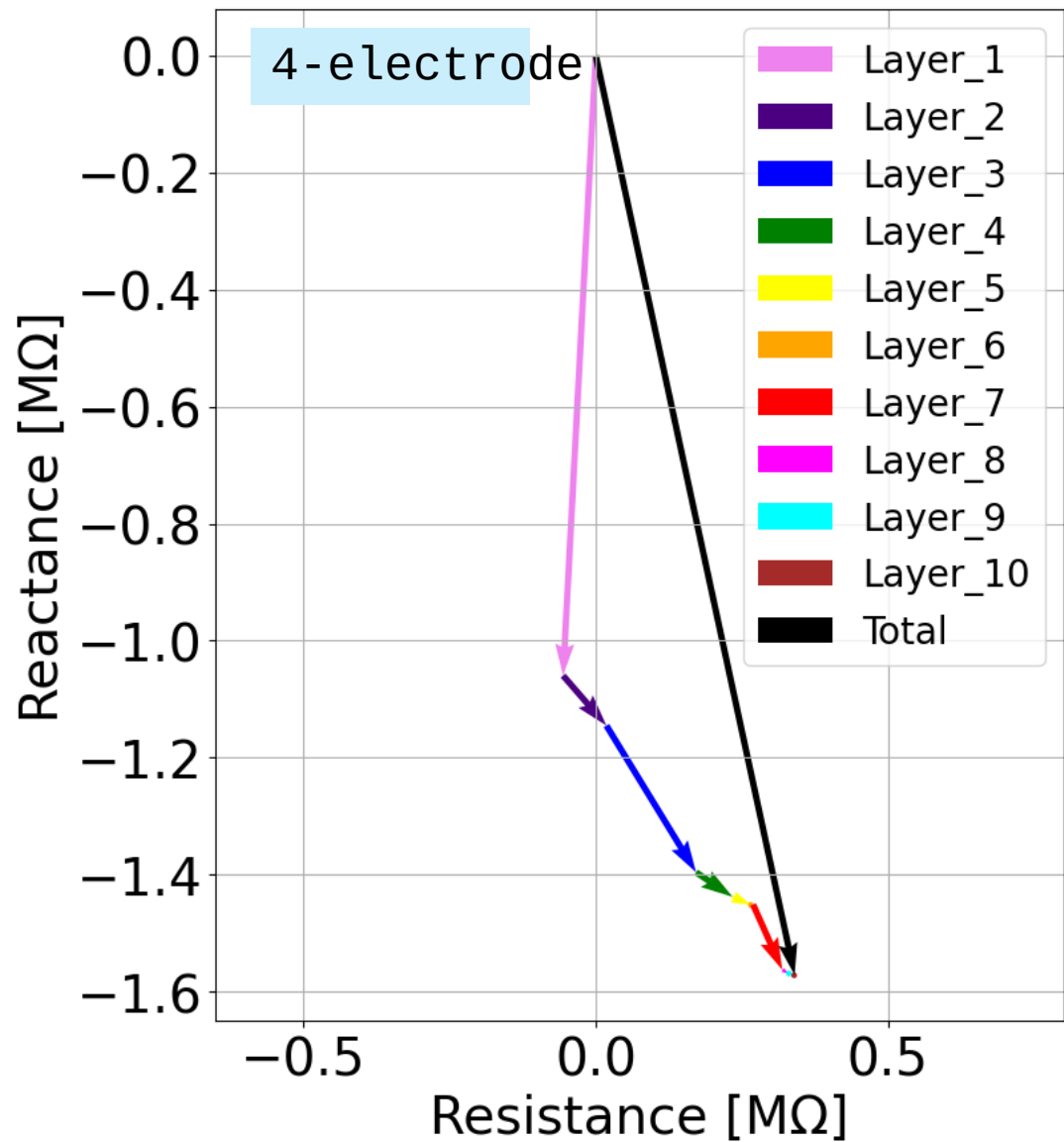
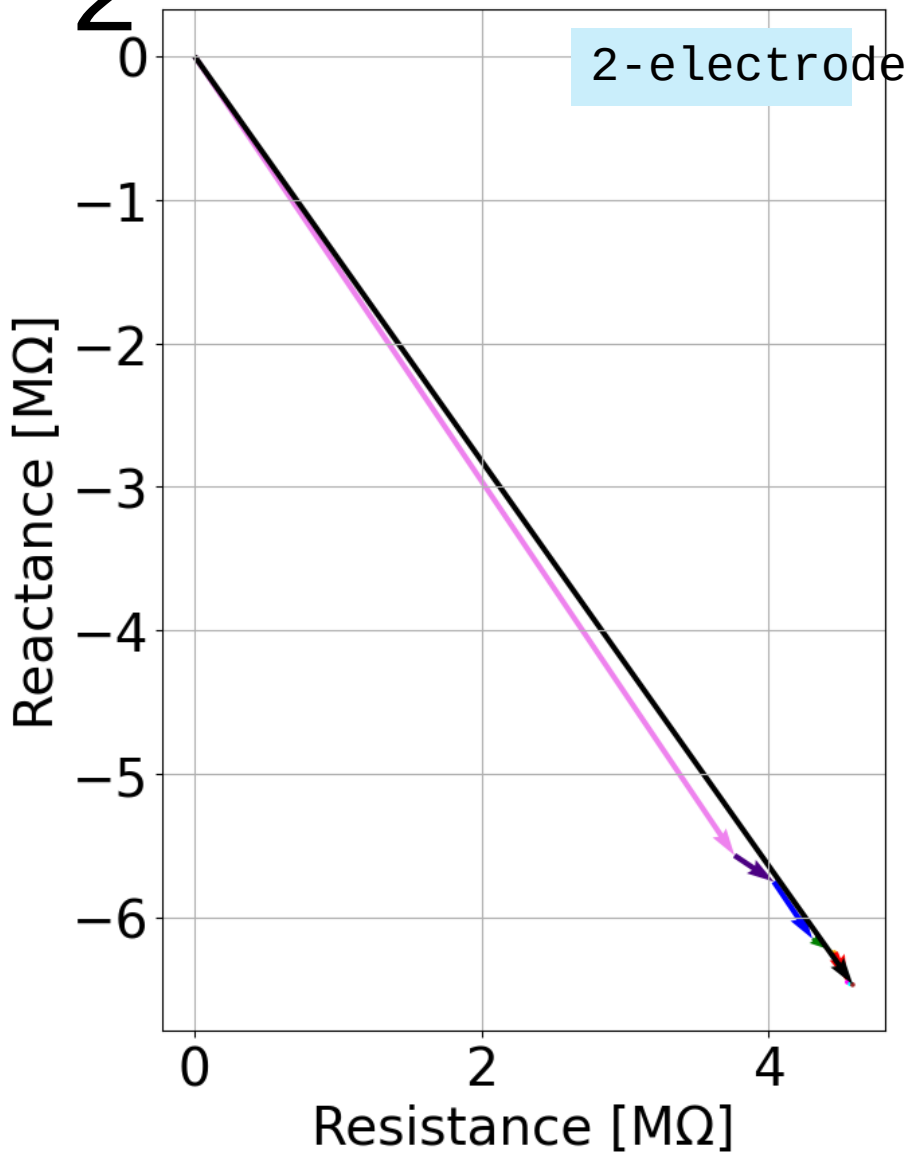
# Test 1

- Increasing thickness
- Alternating properties
- Better conducting top layer



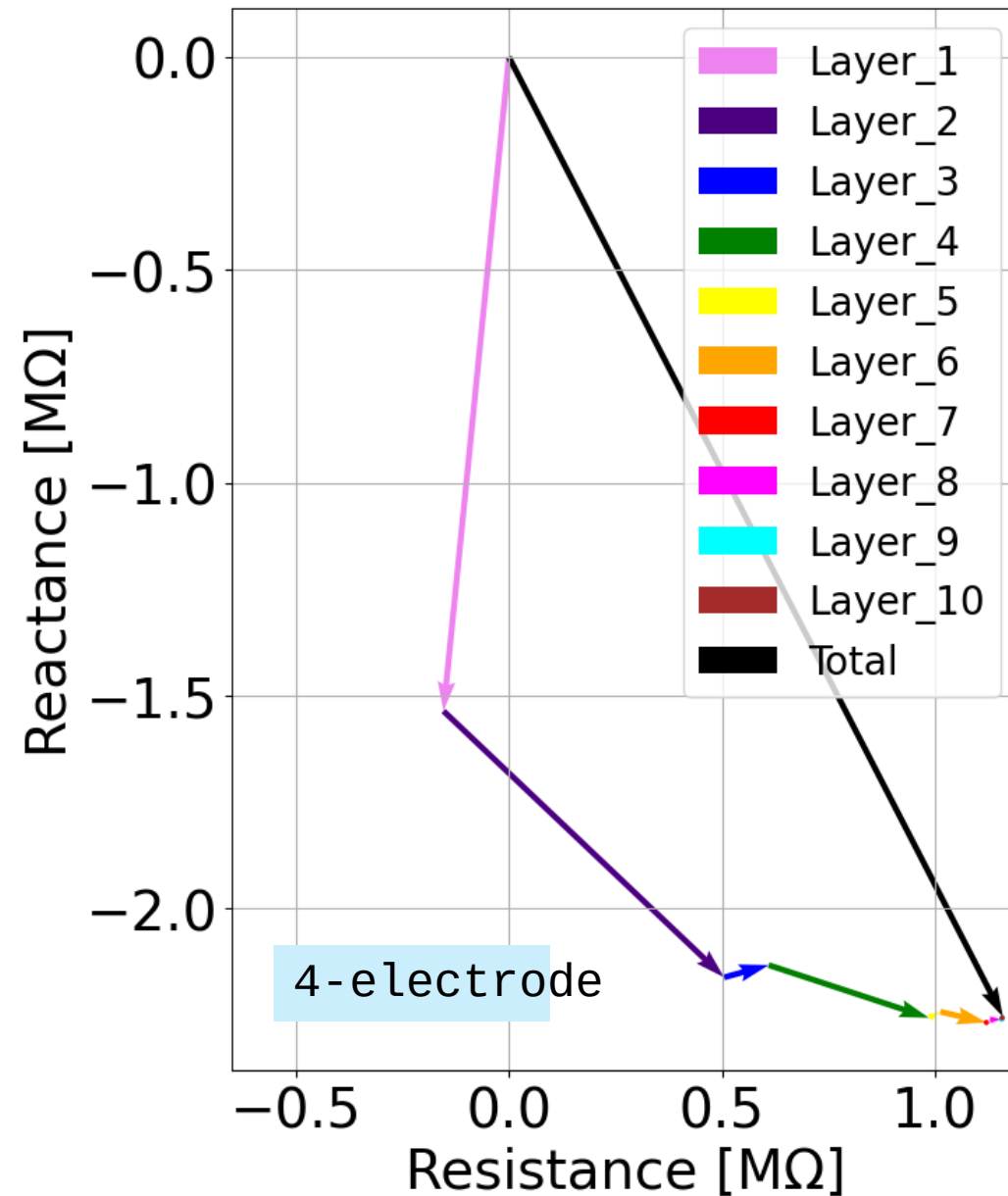
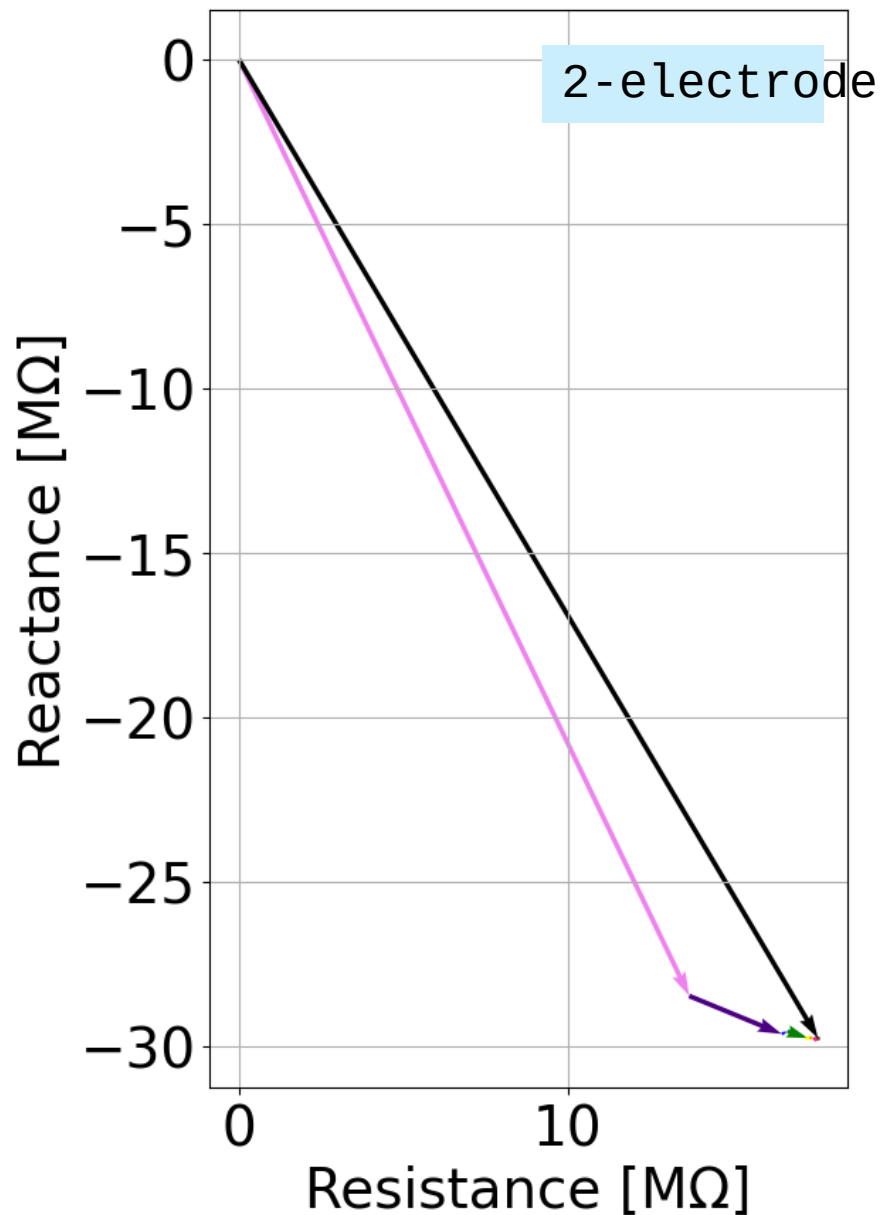
# Test 2

- Equal thickness
- Alternating properties
- Better conducting top layer



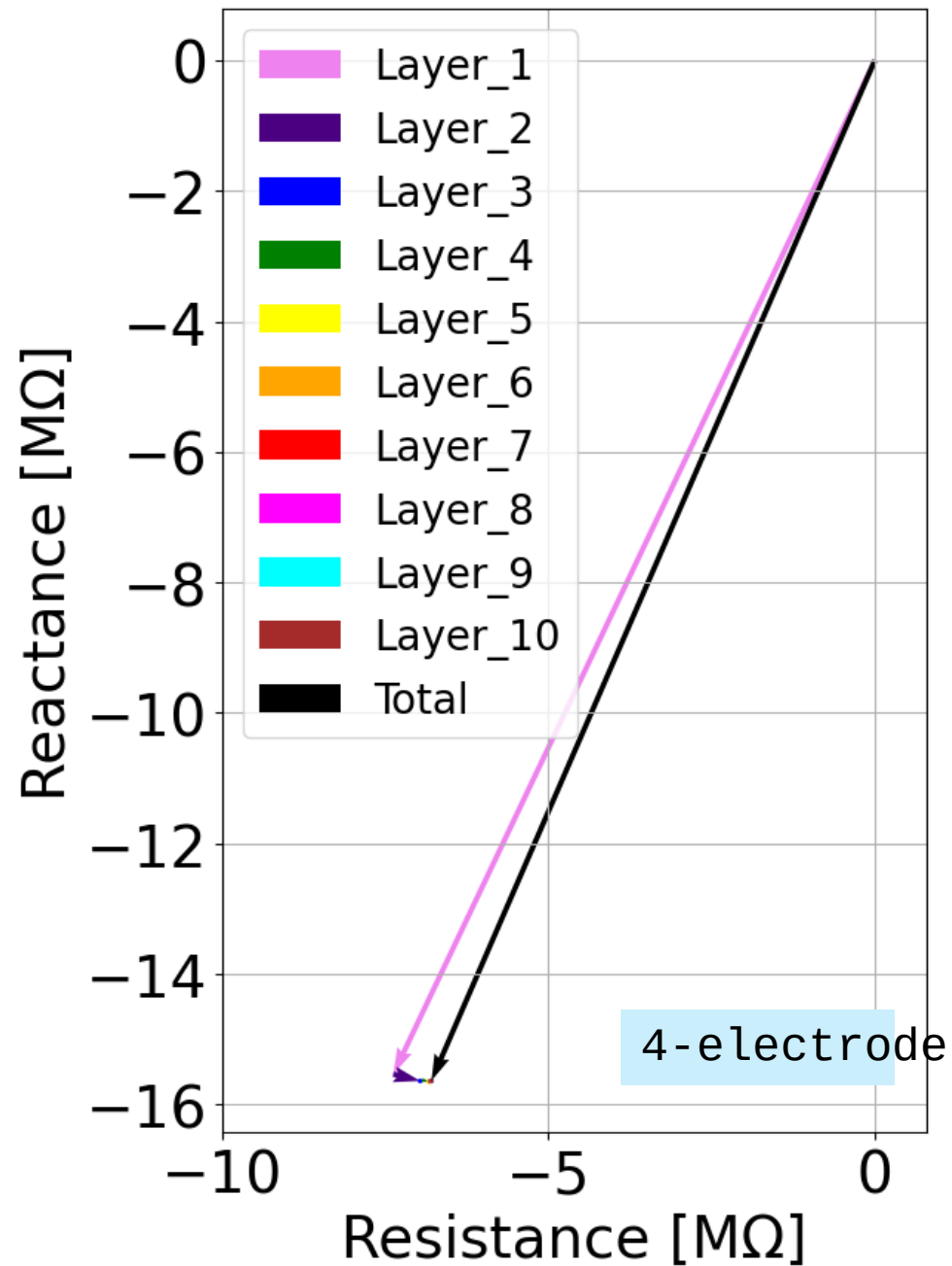
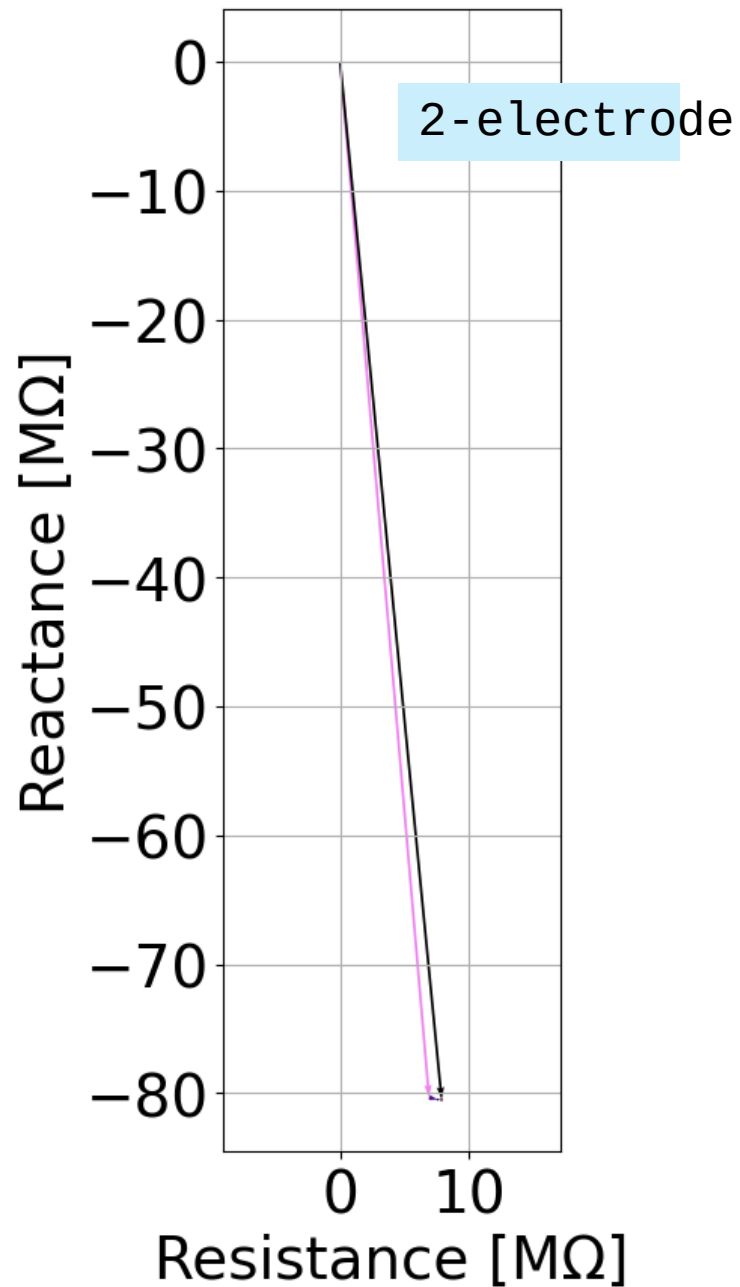
# Test

- Increasing thickness
- Equal properties
- But better conducting top layer



# Test 4

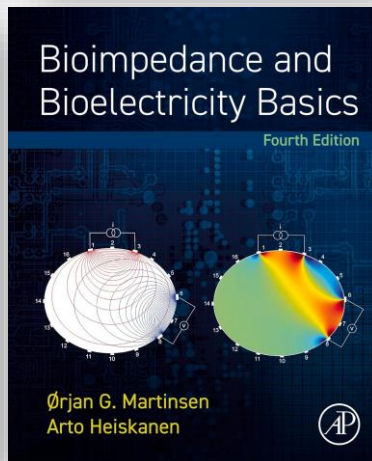
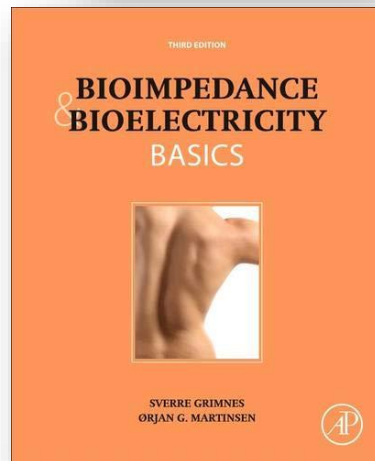
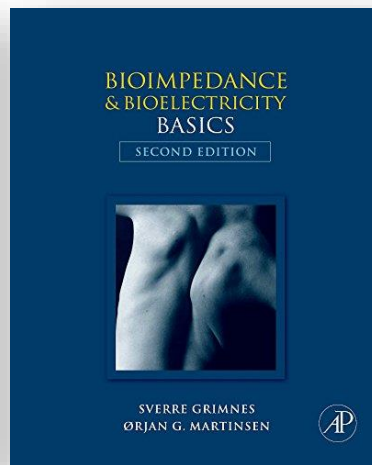
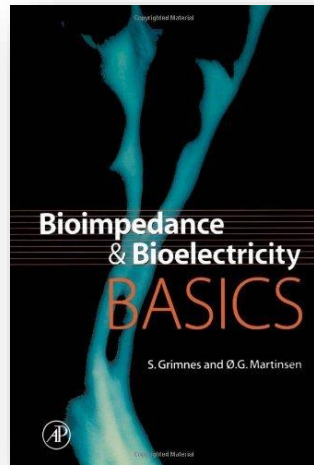
- Equal thickness
- Equal properties
- But better conducting top layer



# Conclusion

- FEM provides a possibility to calculate any sub-domain's contribution
- The total (transfer) impedance is the sum of these contributions
- The nature of a given contribution can be contra-intuitive
- Some reasons:
  - Layers appear electrically both in series and parallel ( $2E + 4E$ )
  - Sub-domains can have negative sensitivity ( $4E$ )

# Oslo Bioimpedance and Medical Technology Group



The screenshot shows the homepage of the Journal of Electrical Bioimpedance on the Sciencedirect platform. The header includes the Sciencedirect logo and navigation links for 'Publish &amp; Distribute', 'Subjects', 'Publications', 'Blog', 'Contact', 'Search', 'EUR', 'English', and icons for a shopping cart and user profile. The breadcrumb trail reads 'Home &gt; Journals &gt; Journal of Electrical Bioimpedance'. The main content area features the journal's cover image, the title 'Journal of Electrical Bioimpedance', and 'Open Access' icons. A 'Metrics' button is on the right. Below this is a dark navigation bar with buttons for 'NEWEST ARTICLES', 'TOP CITED', 'MOST DOWNLOADED', and 'VOLUMES &amp; ISSUES', along with a search bar. The main article list shows three articles, each with an 'Open Access' icon, a date, a title, and authors. The first article is 'Exploring protocol development: Implementing systematic contextual memory to enhance real-time fMRI neurofeedback' by Steffen Maude Fagerland et al. The second is 'Sensitivity study of a locally developed six electrode focused impedance method' by Trilochan Khanal and K Siddique-e Rabbani. The third is 'Concordance between dual indirect methods for assessing fat percentage' by Hurtado B., Colina E. and Gonzalez-Correa C. H. An 'Accessibility Menu' button is in the bottom right corner.