5TH CLABIO
LATIN AMERICAN BIOIMPEDANCE
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Impedance measurements on a layered object – some surprising phenomena

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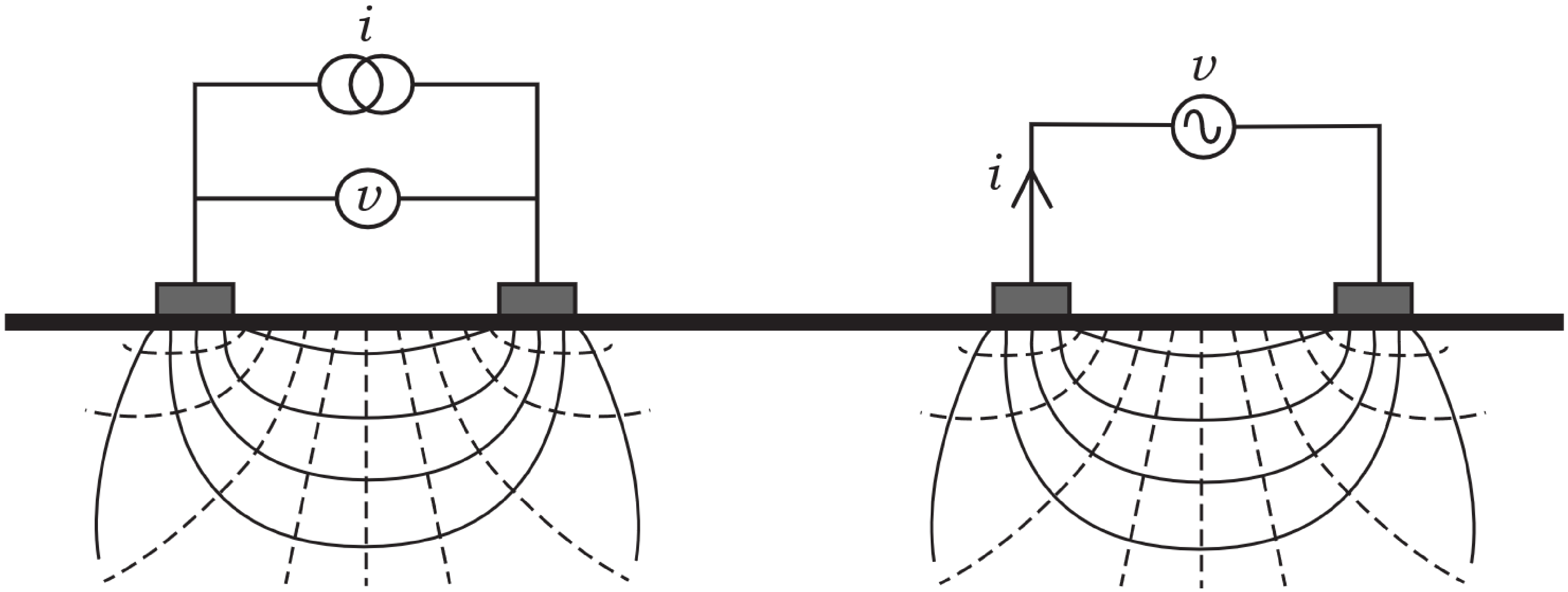
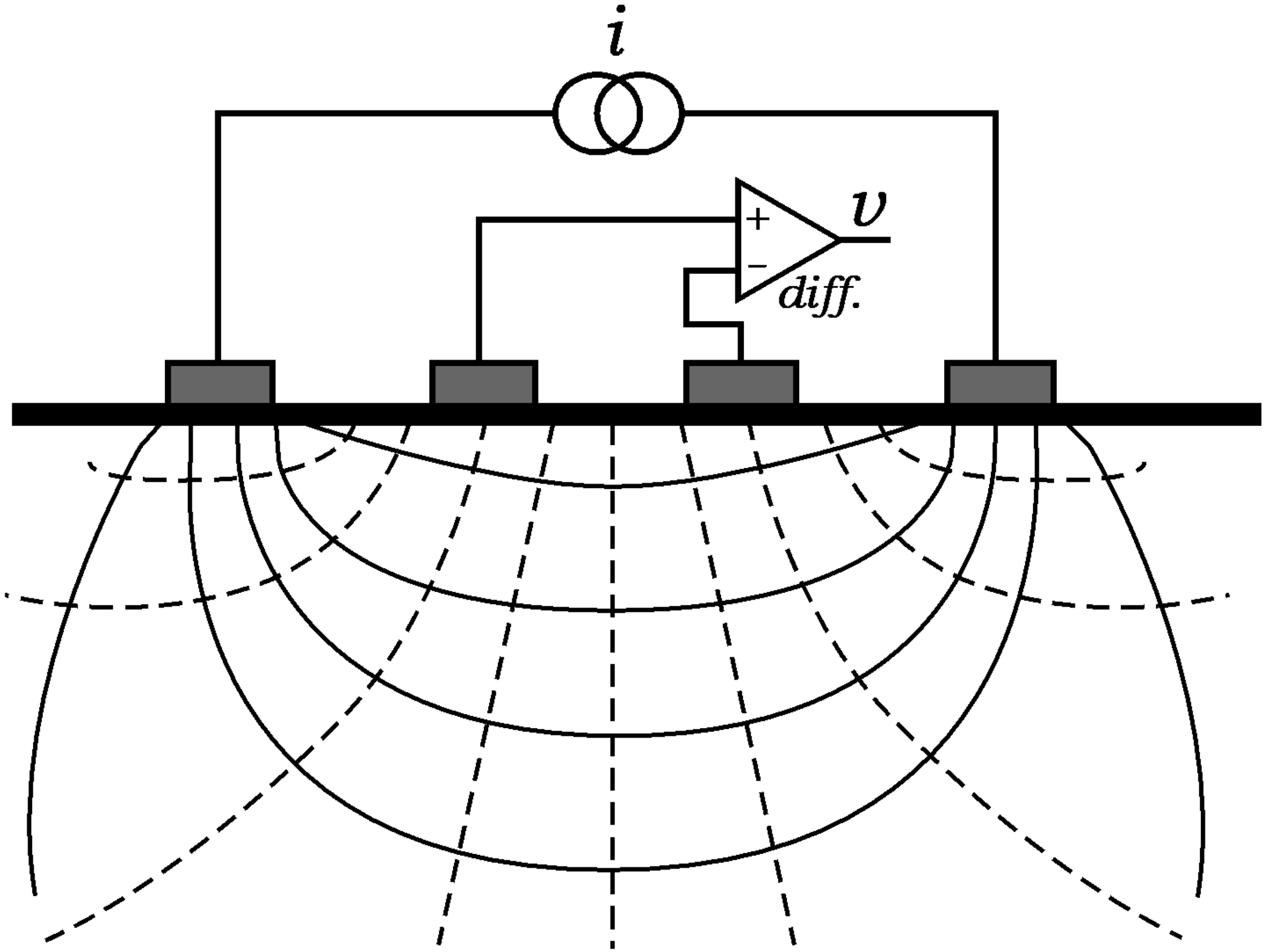
Impedance measurements: Two-electrode system



Impedance measurements: Four-electrode system

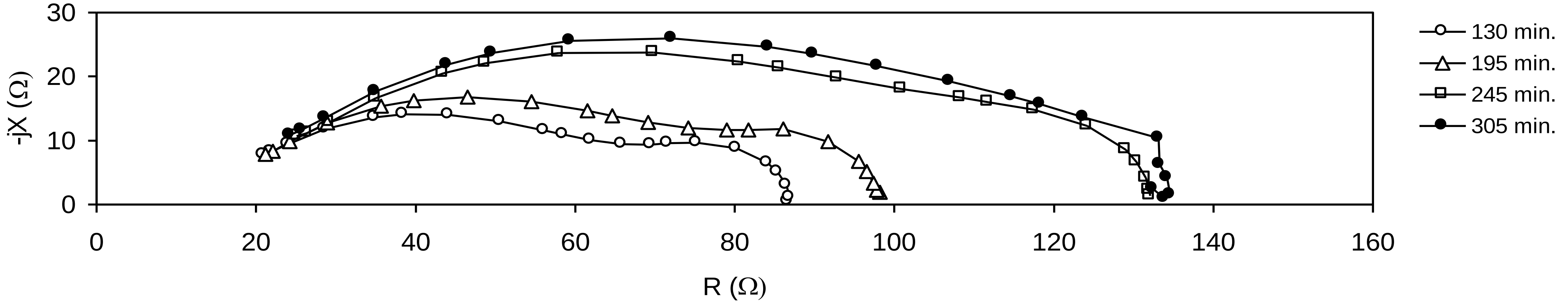
- Originates from the invention of the Kelvin bridge in 1861 by William Thomson (Lord Kelvin)
- Two-port network
- Transfer function is per definition an impedance
- Hence, transfer impedance

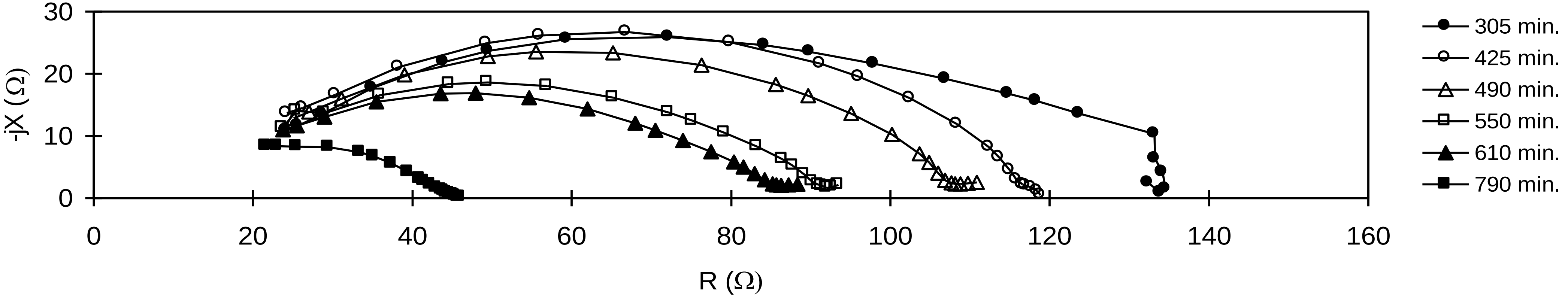


Martinsen *et al*. J. Food. Eng. 43, 1

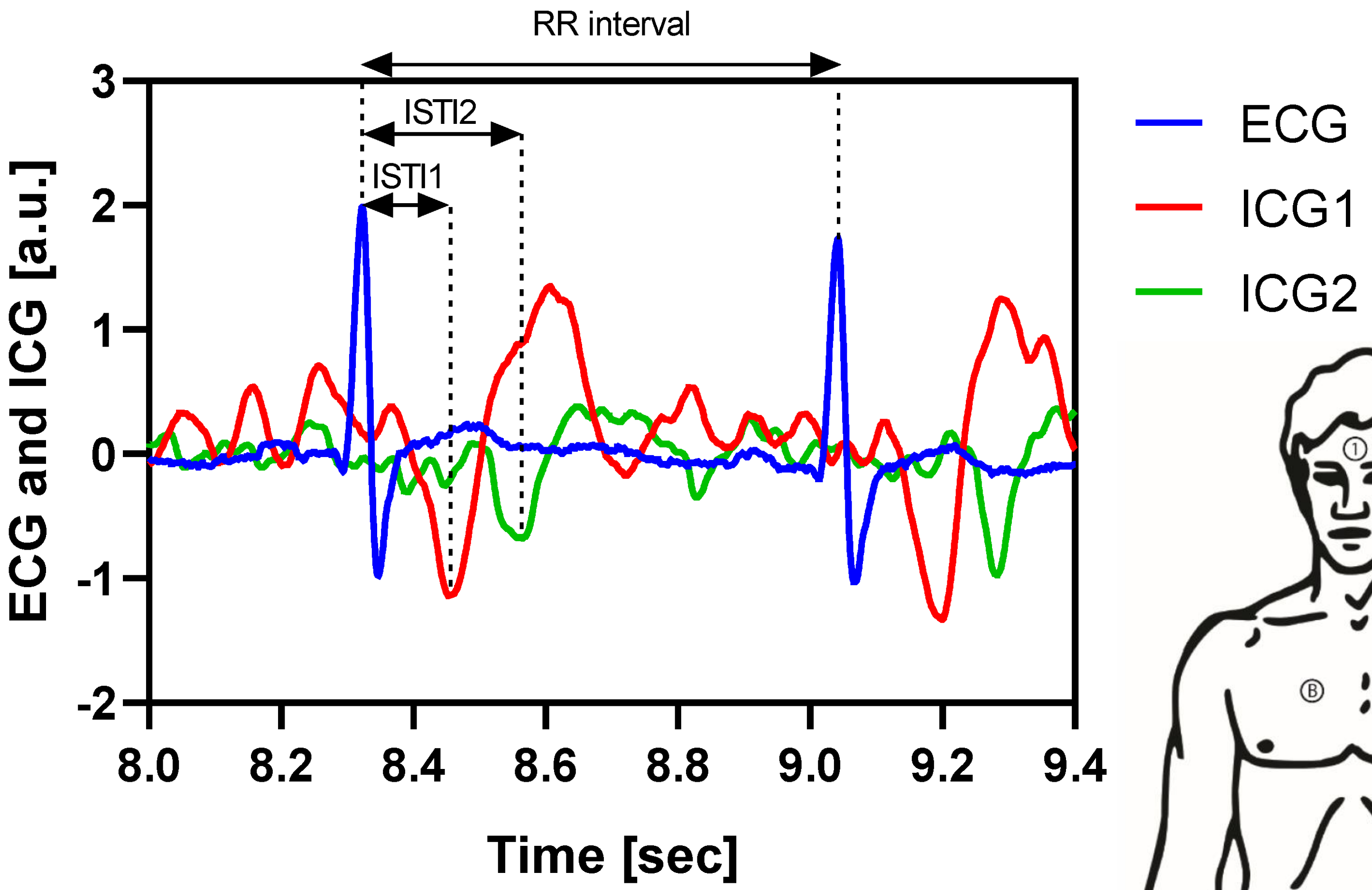
Example: Fish

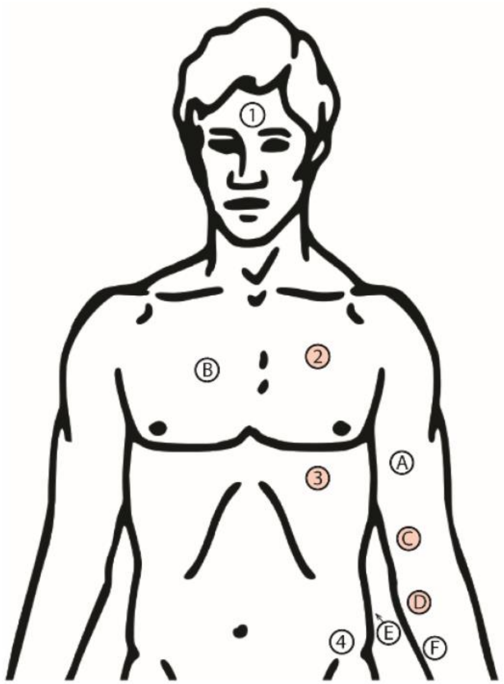
Measured on haddock muscle with surface electrodes





Example: Pulse wave velocity

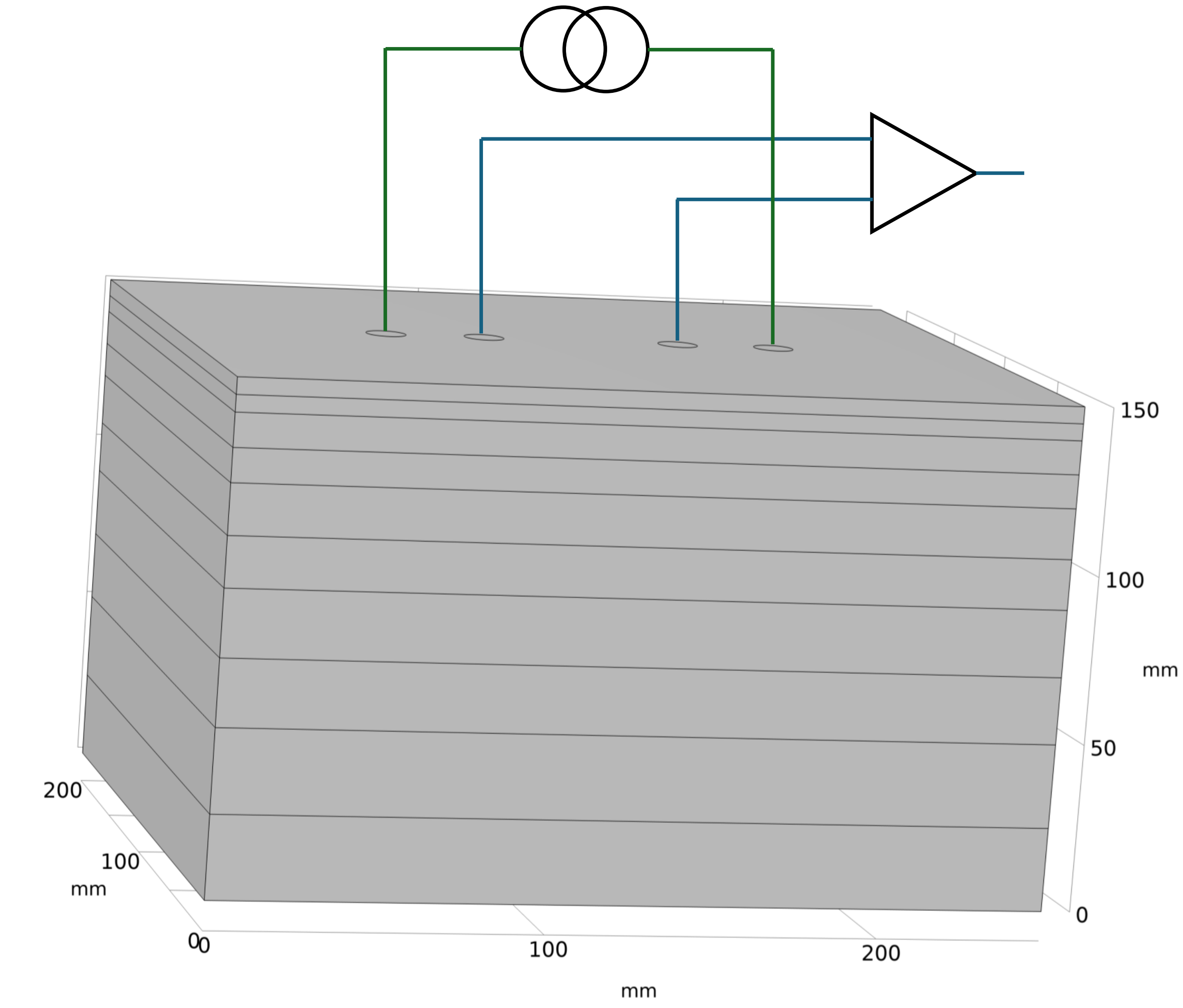




- ISTI = Initial Systolic Time Interval
- From R-peak in ECG to C-wave in ICG
- Injected 300 µA @ 64 kHz
- ECG and ICG
- 10 subjects 20-30 years old
- 10 subjects > 60 years old
- Velocity significantly higher in older subjects
- Method for measuring degree of

Theory

Lead field theory: Geselowitz. IEEE Trans Biomed Eng



- Sensitivity is a negative or positive scalar

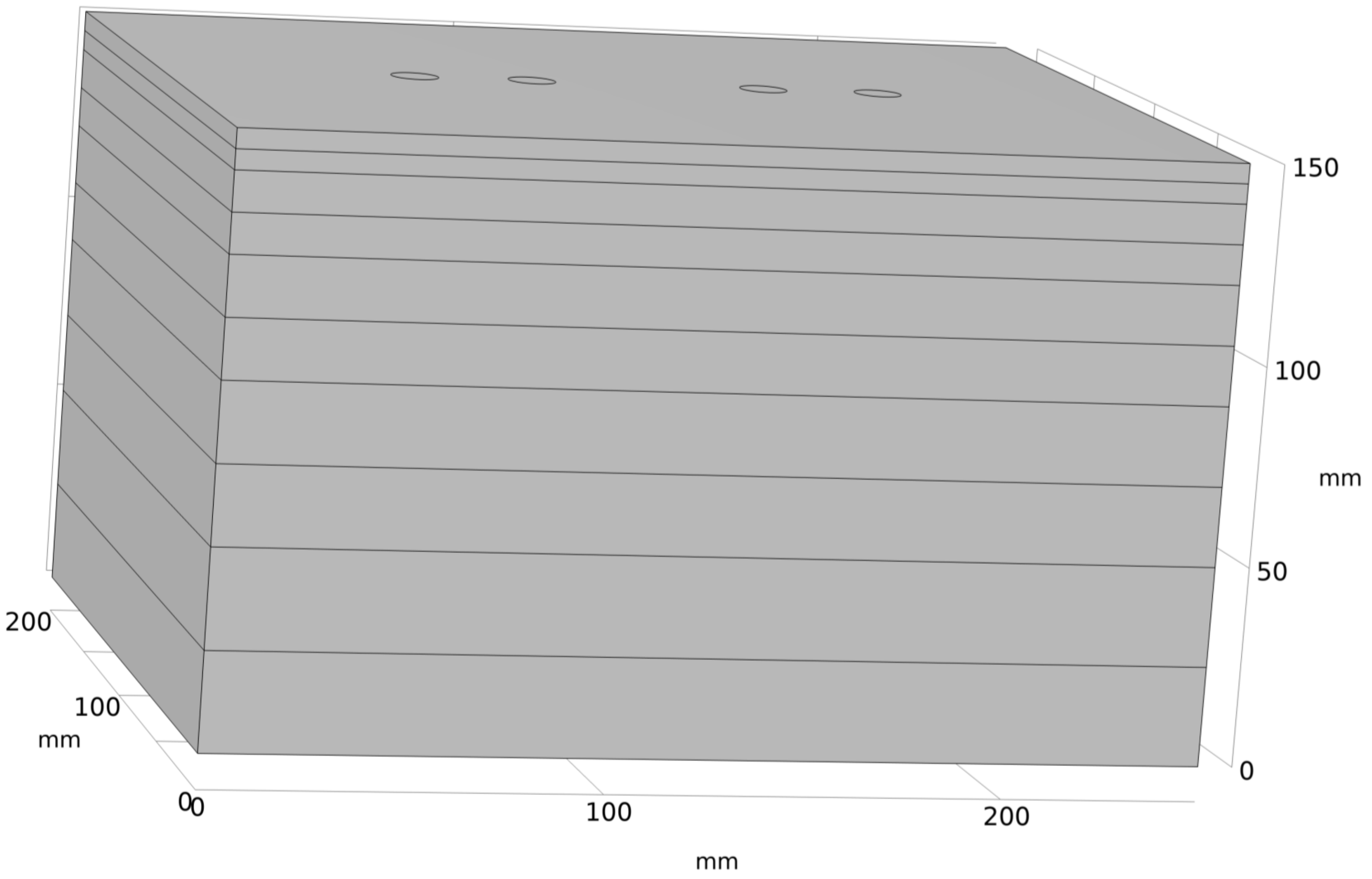
$$S = \int_V \frac{\vec{J}_1 \cdot \vec{J}_2}{I^2} \quad [m^{-4}]$$

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

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

- 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 as if

Measurements on a layered object



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

VID for each voxel:

$$\vec{z} = \frac{(ec.Jx \cdot ec2.Jx + ec.Jy \cdot ec2.Jy + ec.Jz \cdot ec2.Jz)}{(1[A])^2} \cdot \frac{\left(\frac{ec.Ex}{ec.Jx} + \frac{ec.Ey}{ec.Jy} + \frac{ec.Ez}{ec.Jz}\right)}{3}$$

Sensitivity

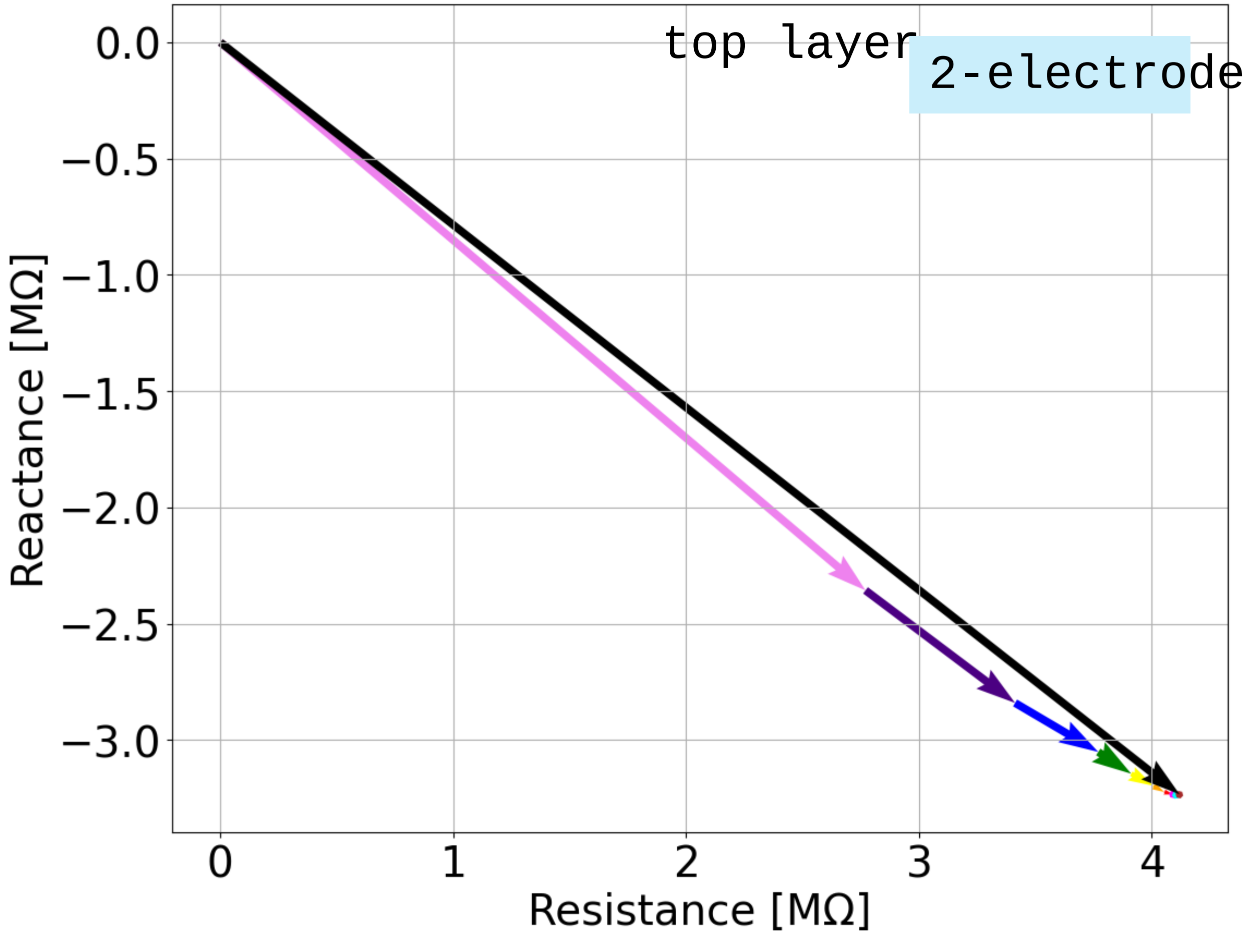
Complex resistivity

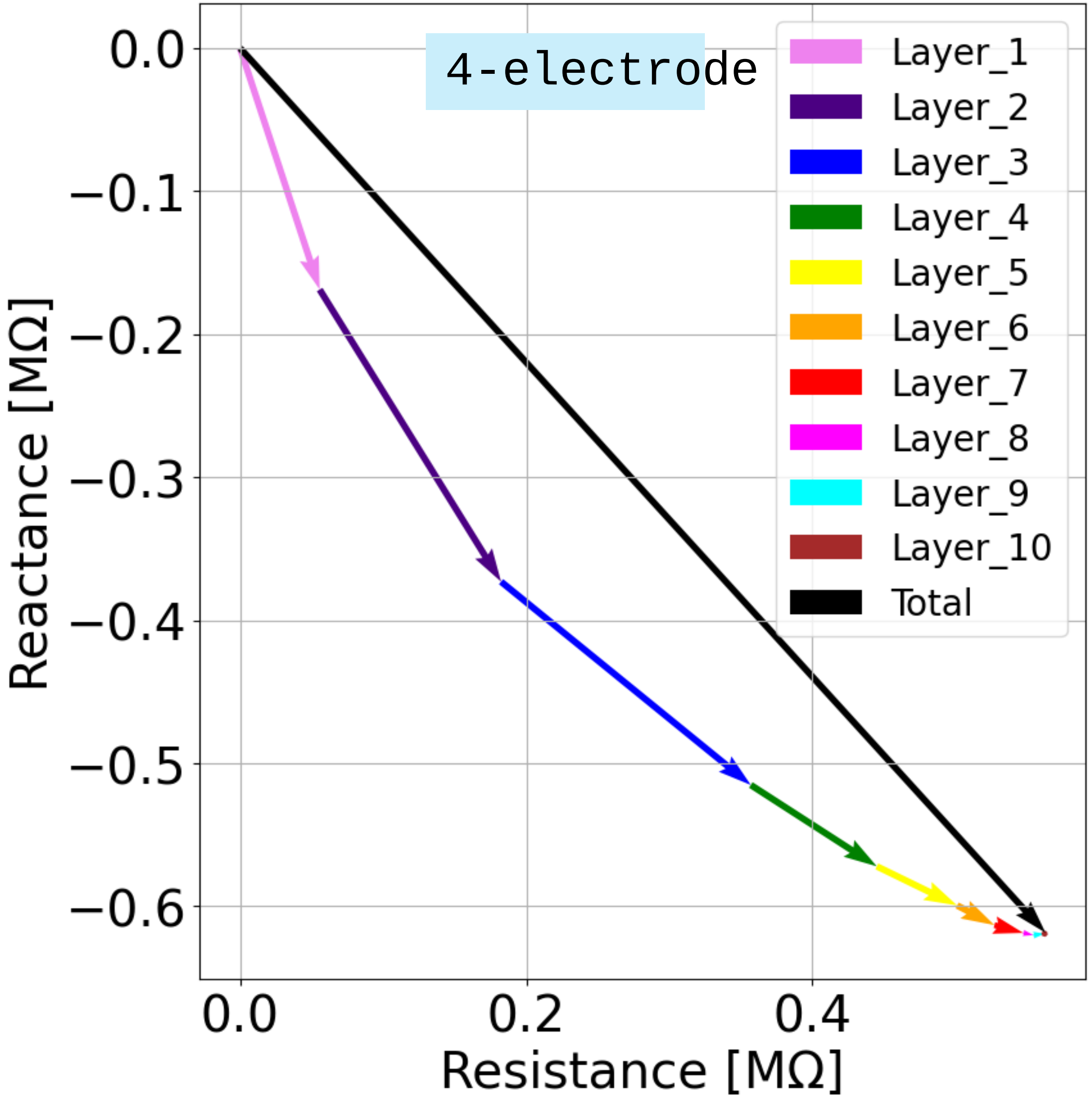
Four test cases

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

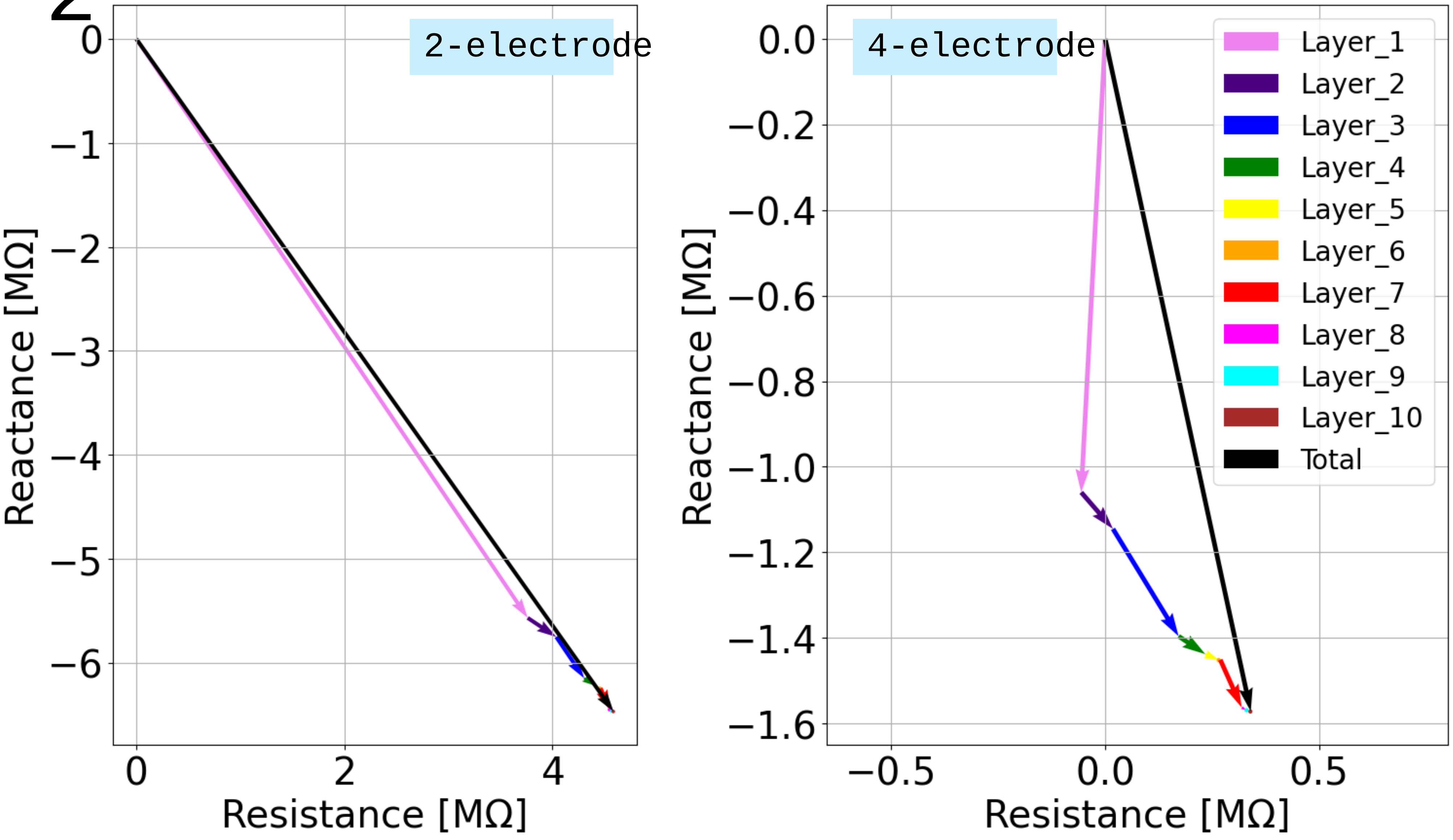
- Increasing thickness
- Alternating properties
- Better conducting top layer





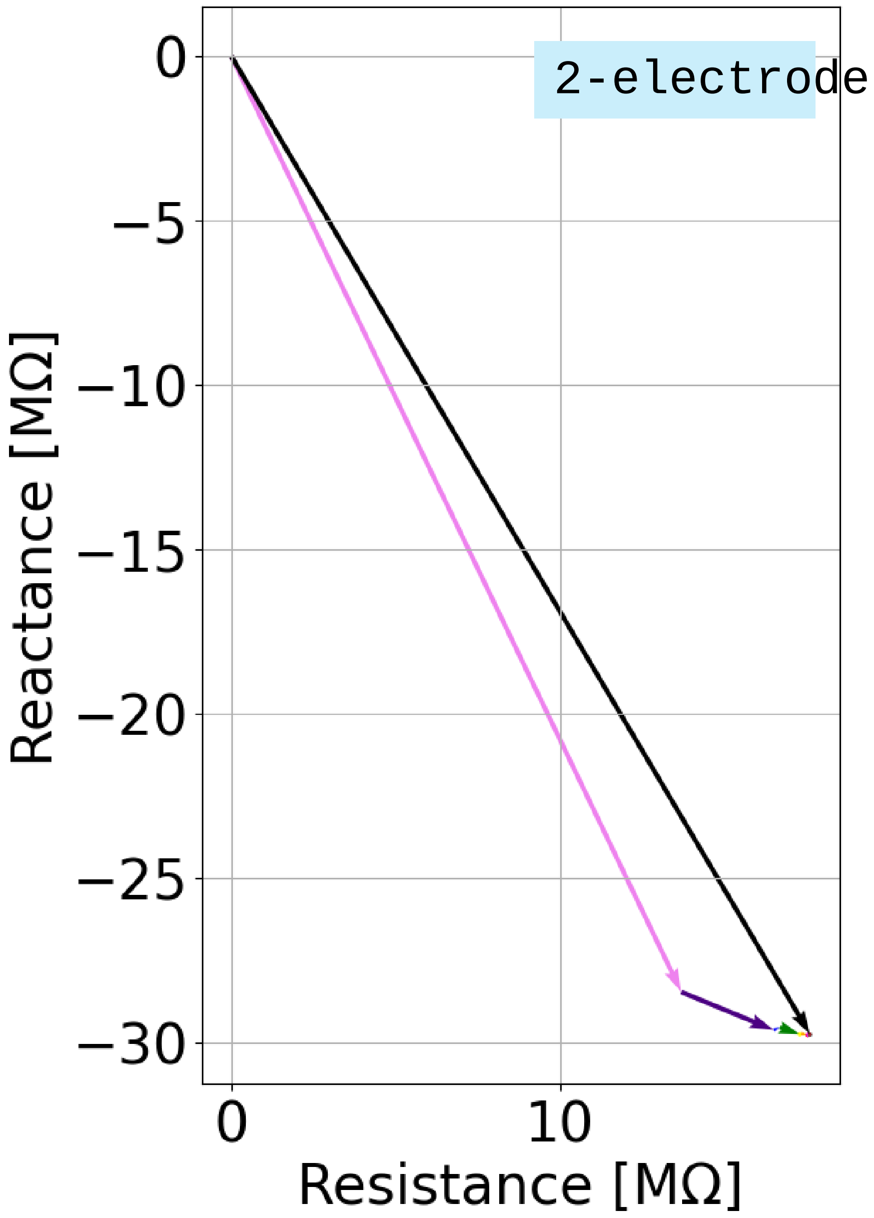
Test 2

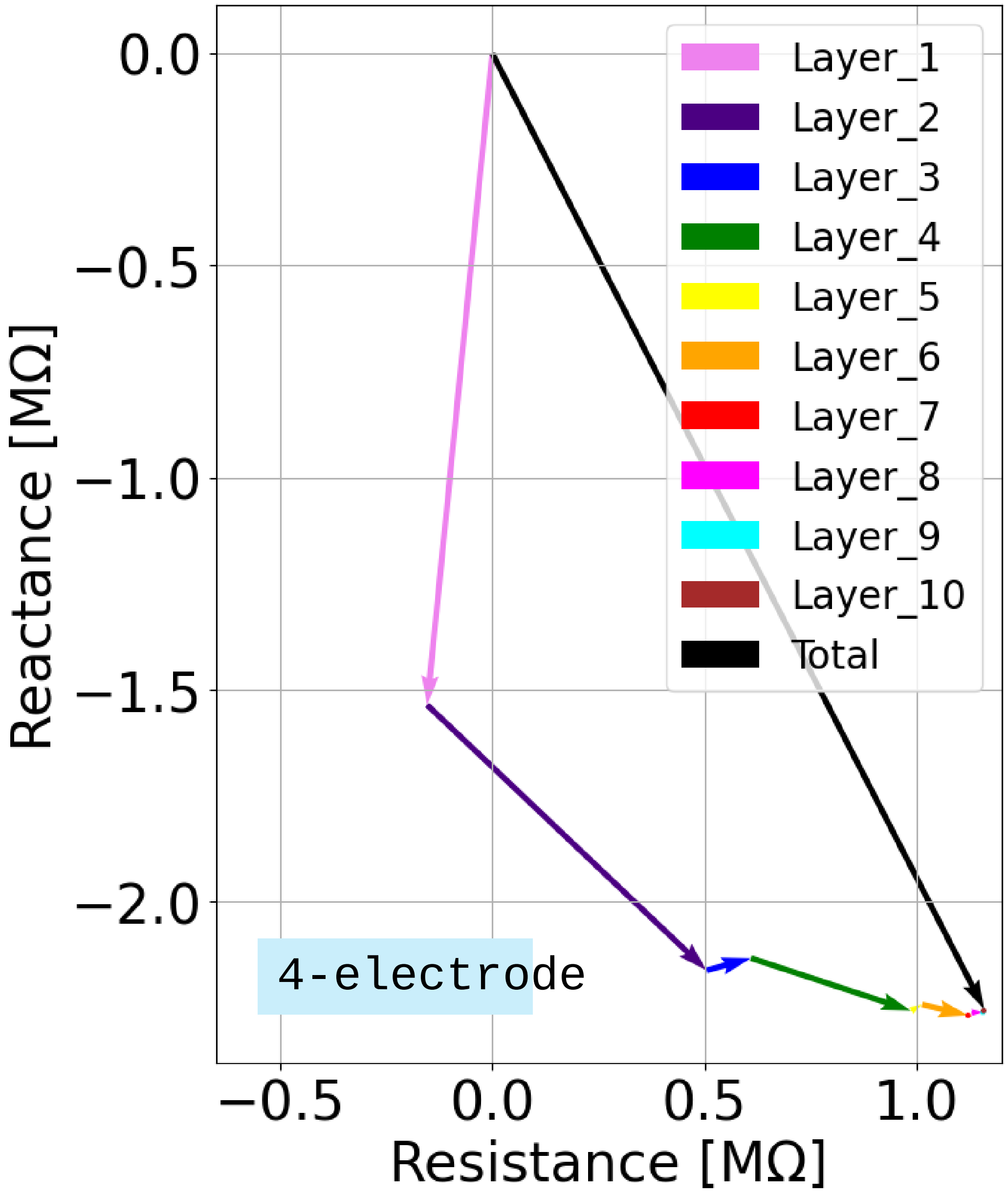
- Equal thickness
- Alternating properties
- Better conducting top layer



Test

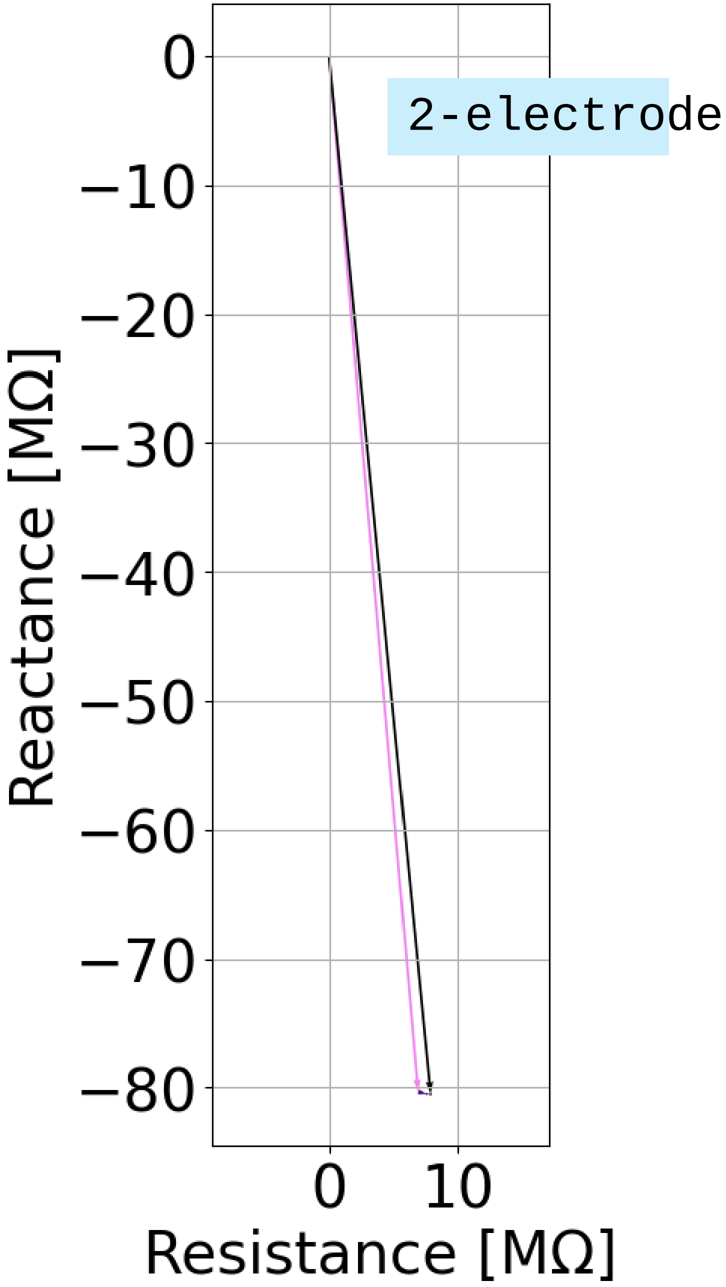
- Increasing thickness
- Equal properties
- But better conducting top layer

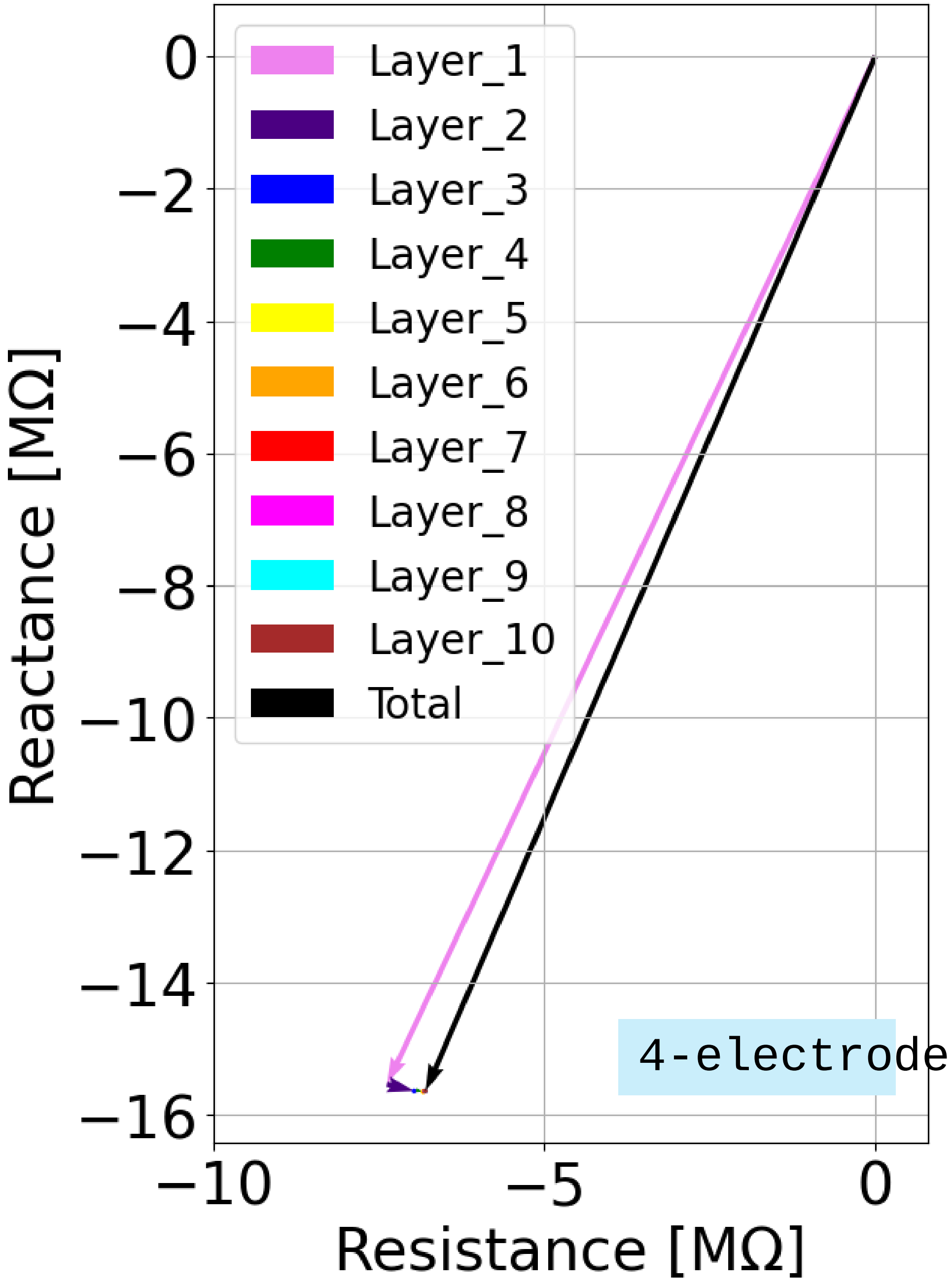




Test 4

- Equal thickness
- Equal propertie s
- But better conductin g 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)

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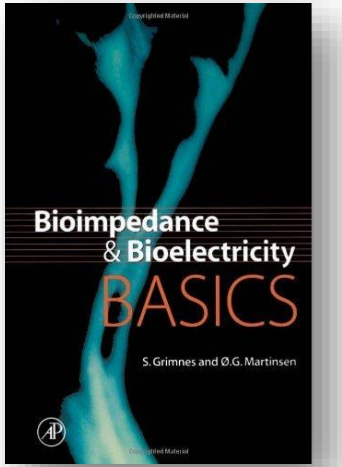

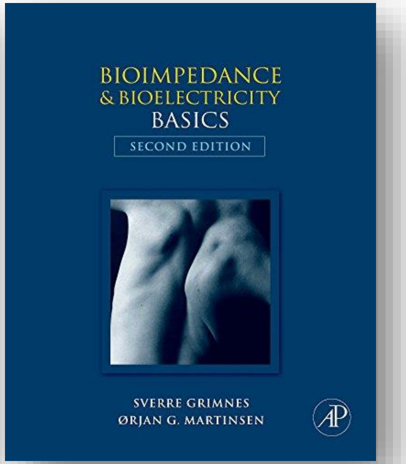

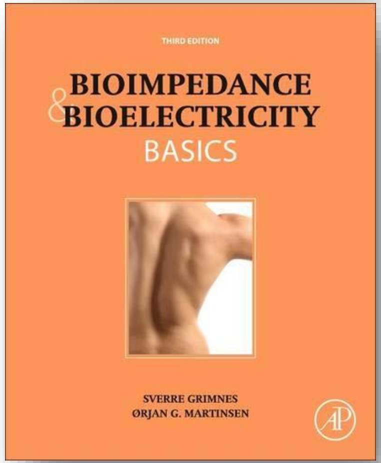

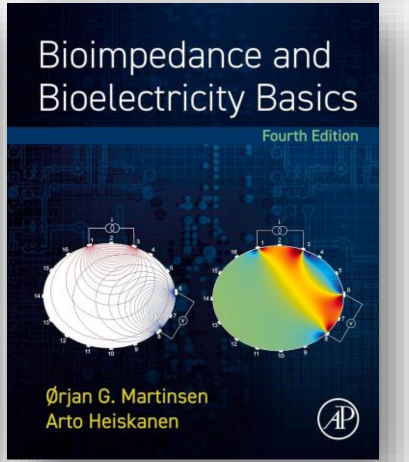

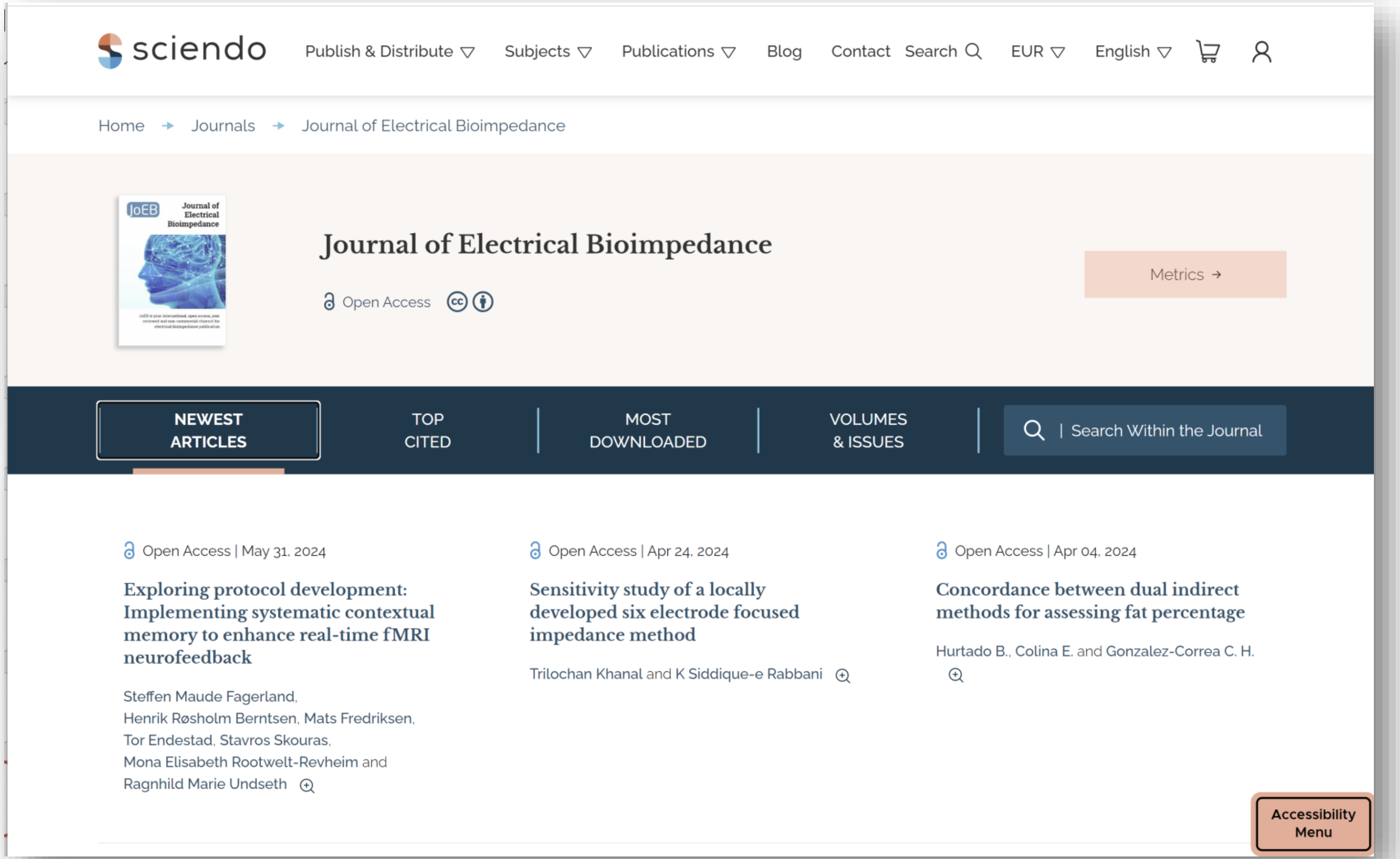

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