Some examples of electrode systems and their sensitivity fields

Taken from the tutorial at
ICEBI 2010 in Gainesville, Florida

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About this presentation

- ✓ You can use this presentation for whatever you like, as long as you always clearly refer to:

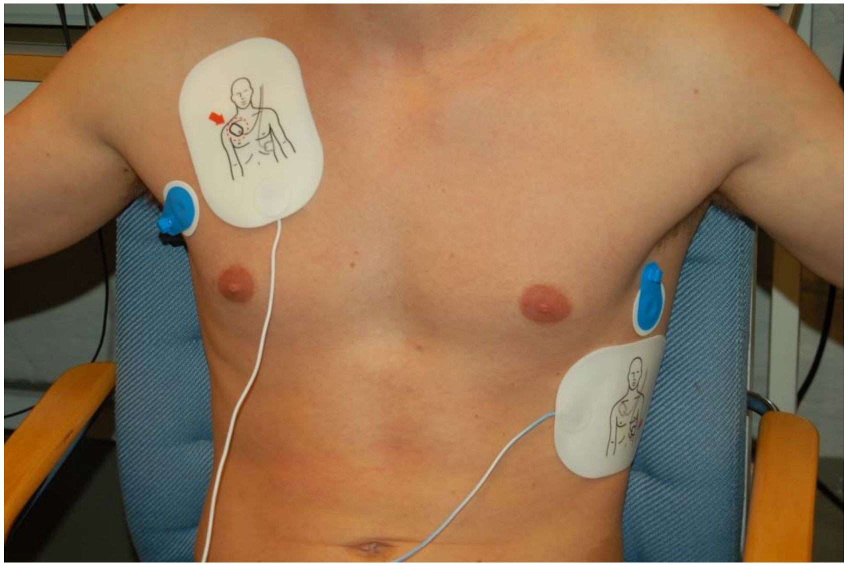
The Oslo Bioimpedance Group

www.bioimpedance.org

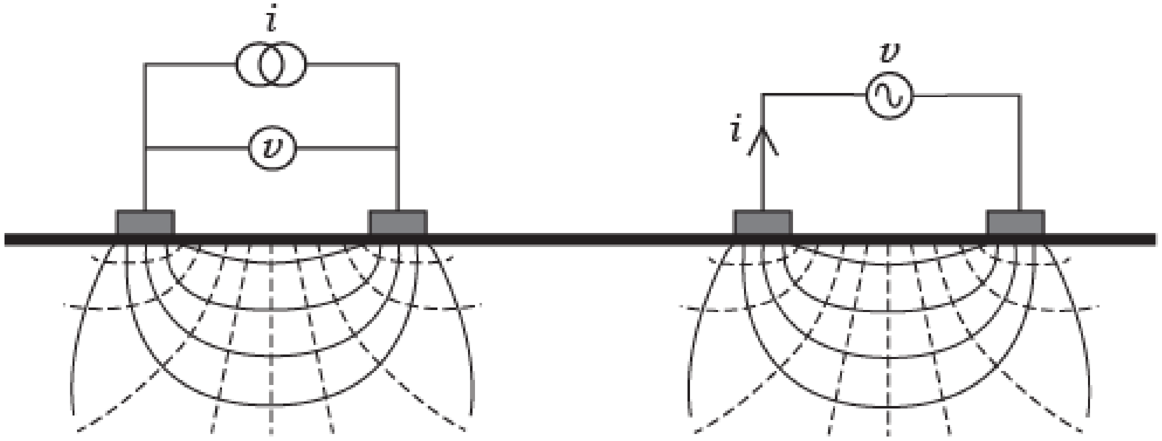
- ✓ Please note that some of the slides have comments in the “Notes” pages.
- ✓ The basic theory can be found in Grimnes & Martinsen: Bioimpedance and Bioelectricity Basics. 2nd ed. Academic Press, 2008.

Electrode systems

- ✓ Two electrodes: Measures everything between the electrodes, e.g. polarization impedance, skin layers, etc.
- ✓ Three electrodes: Enables monopolar measurements
- ✓ Four electrodes: For segmental measurements (e.g. to avoid influence from electrode polarization or skin layers). Transfer impedance.



Two-electrode system



$$\text{Impedance } Z = \frac{v}{i}$$

$$\text{Resistance } R = \frac{\mathrm{Re}(v)}{i} = \frac{v}{i}\cos\varphi$$

$$\text{Reactance } X = \frac{\mathrm{Im}(v)}{i} = \frac{v}{i}\sin\varphi$$

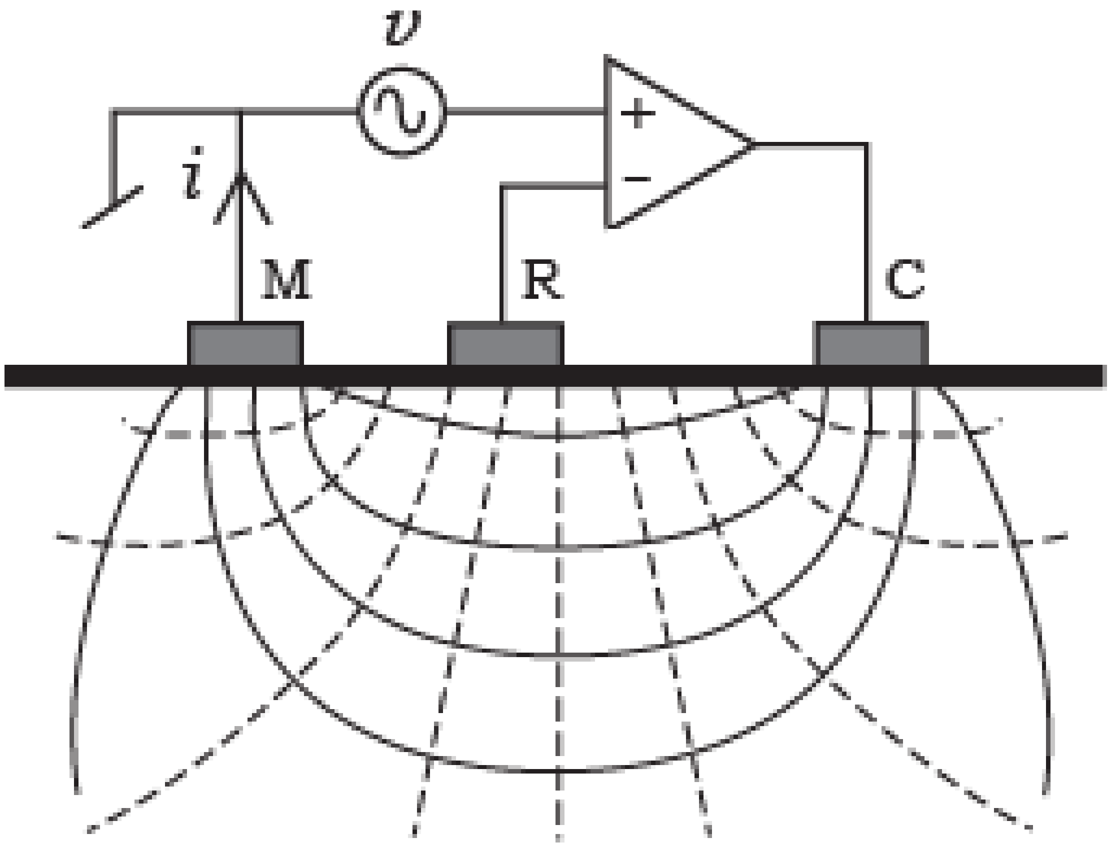
$$\text{Admittance } Y = \frac{i}{v} \left(= \frac{1}{Z} \right)$$

$$\text{Conductance } G = \frac{\mathrm{Re}(i)}{v} = \frac{i}{v}\cos\varphi$$

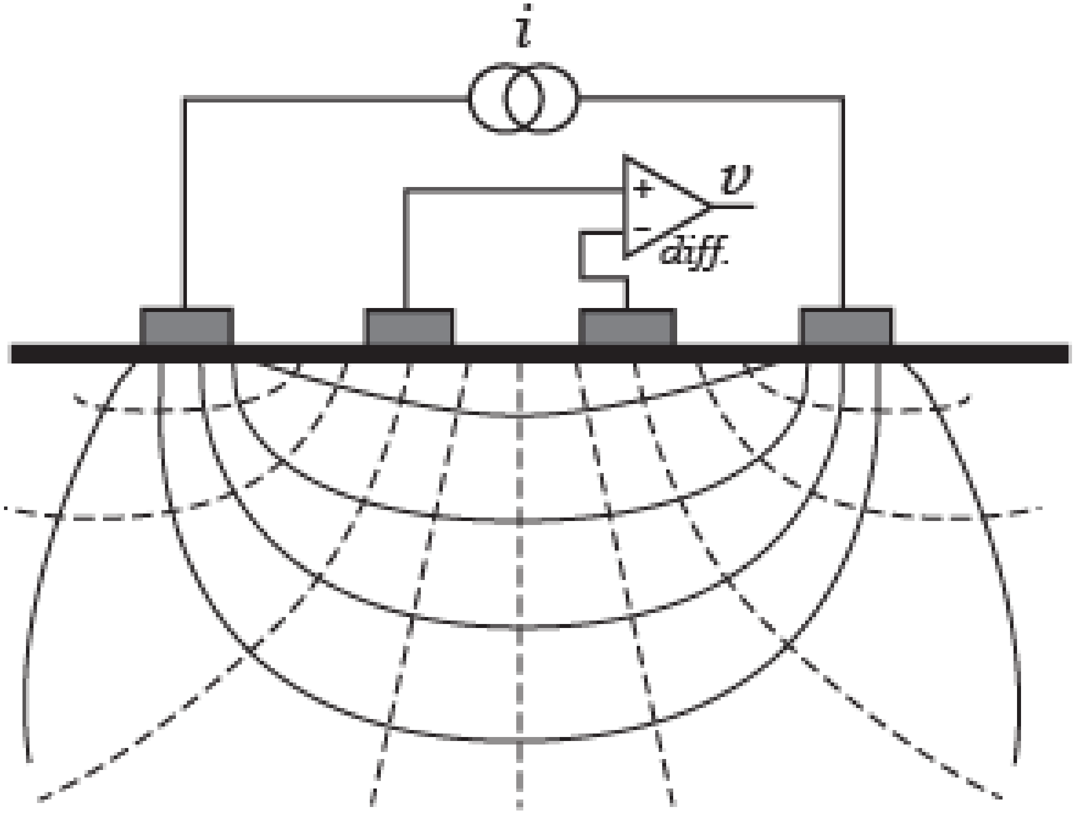
$$\text{Susceptance } B = \frac{\mathrm{Im}(i)}{v} = \frac{i}{v}\sin\varphi$$

$$R = \frac{1}{G} \text{ only if } \varphi = 0^\circ \left(\cos\varphi = \frac{1}{\cos\varphi} \right) \quad \text{and} \quad X = \frac{-1}{B} \text{ only if } \varphi = 90^\circ \left(\sin\varphi = \frac{1}{\sin\varphi} \right)$$

Three-electrode system

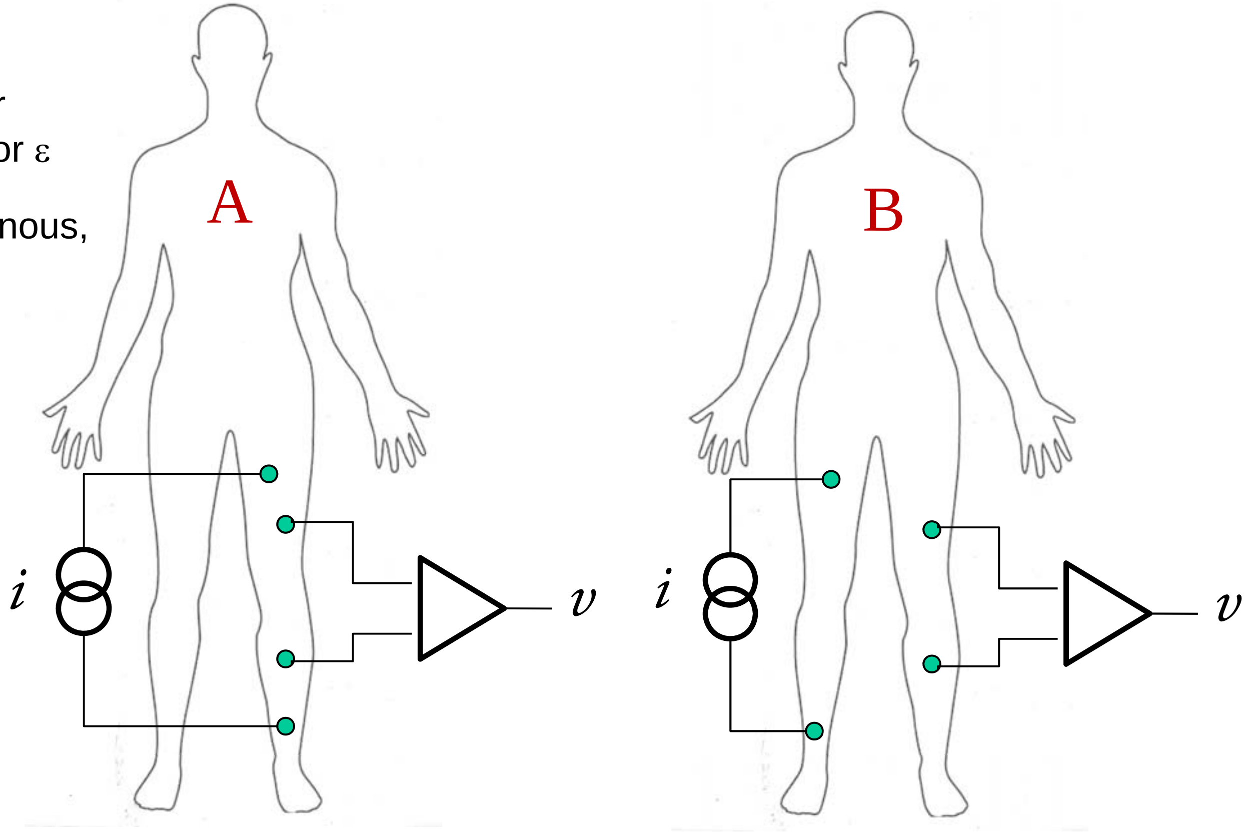


Four-electrode system



Transfer impedance

- ✓ Input: i , output: v , transfer function: $\frac{v}{i} \equiv Z$
- ✓ This is transfer impedance, not impedance
- ✓ Cannot be used for calculation of σ, ρ or ε
- ✓ except for homogenous, uniform material

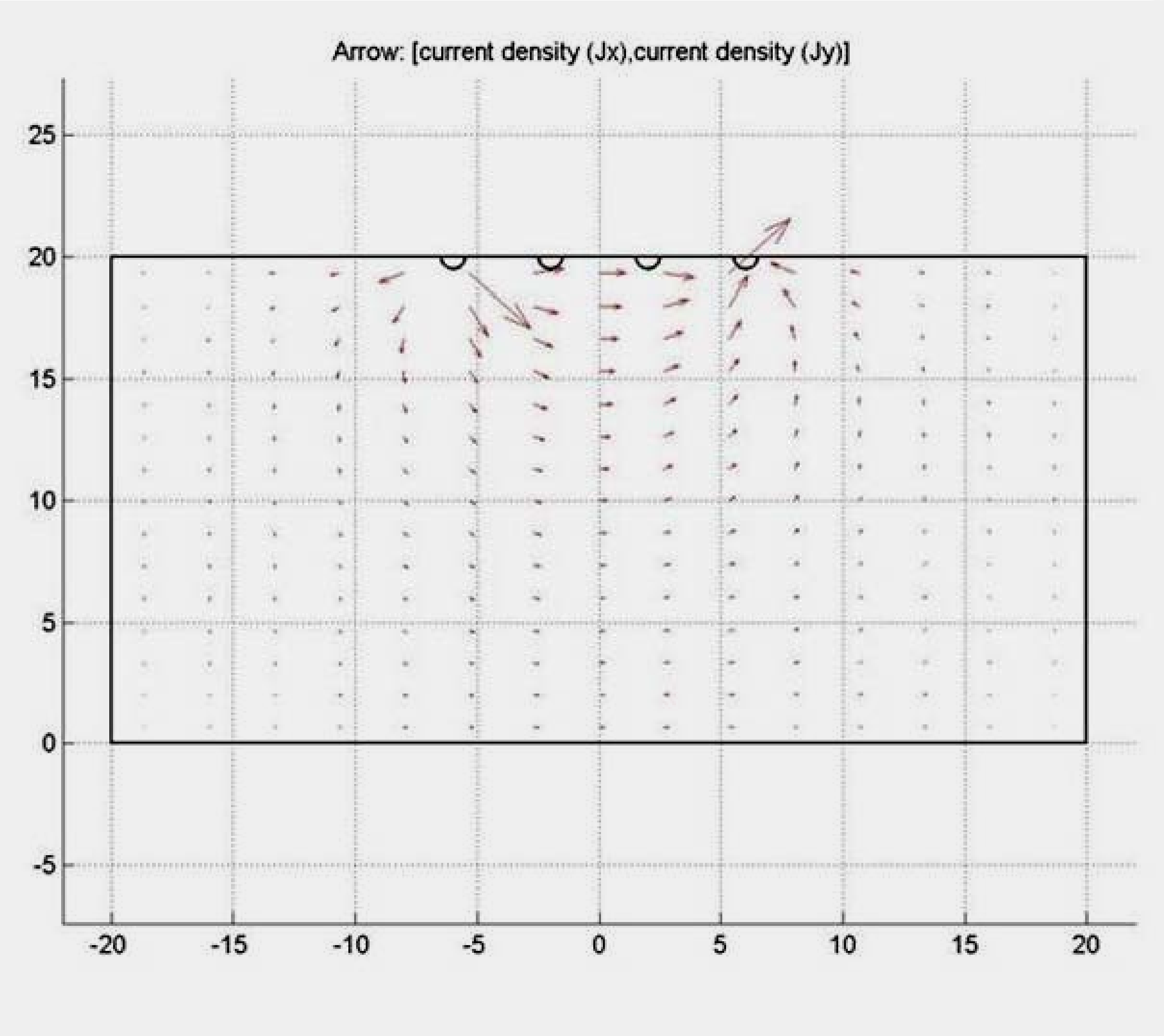


Sensitivity field calculations

- ✓ Simple and very powerful tool, but not used very much
- ✓ Example: Direct current resistance measurement with a four-electrode system on a homogeneous medium

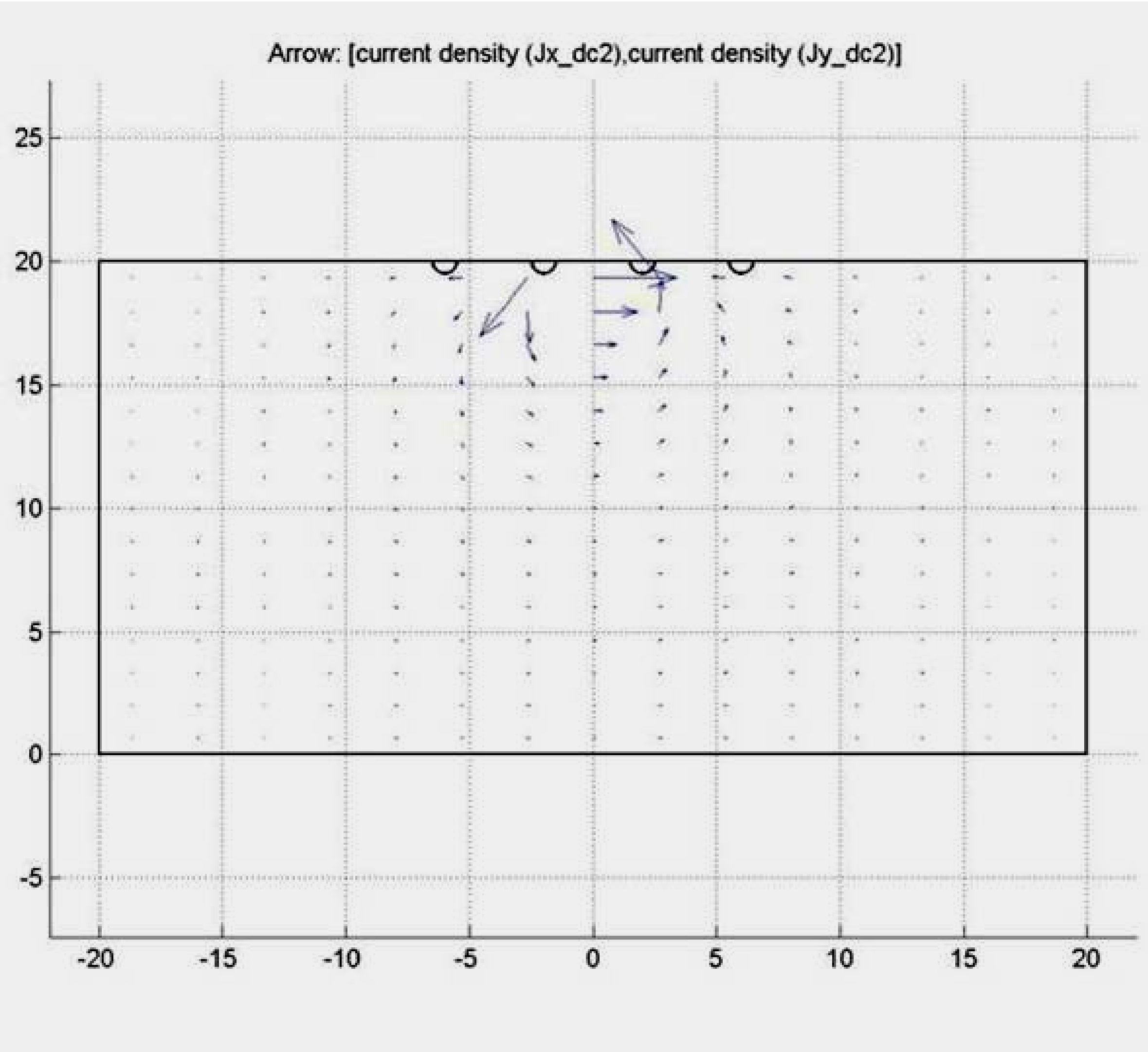
Sensitivity field calculations $^{\#1}$

Imagine that you inject a current I between the two current electrodes, and compute the current density $\mathbf{J}_1$ in each small volume element in the material as a result of this current



Sensitivity field calculations $^{\#2}$

Imagine that you instead inject the same current between the voltage pick-up electrodes, and again compute the resulting current density $\mathbf{J}_2$ in each small volume element.



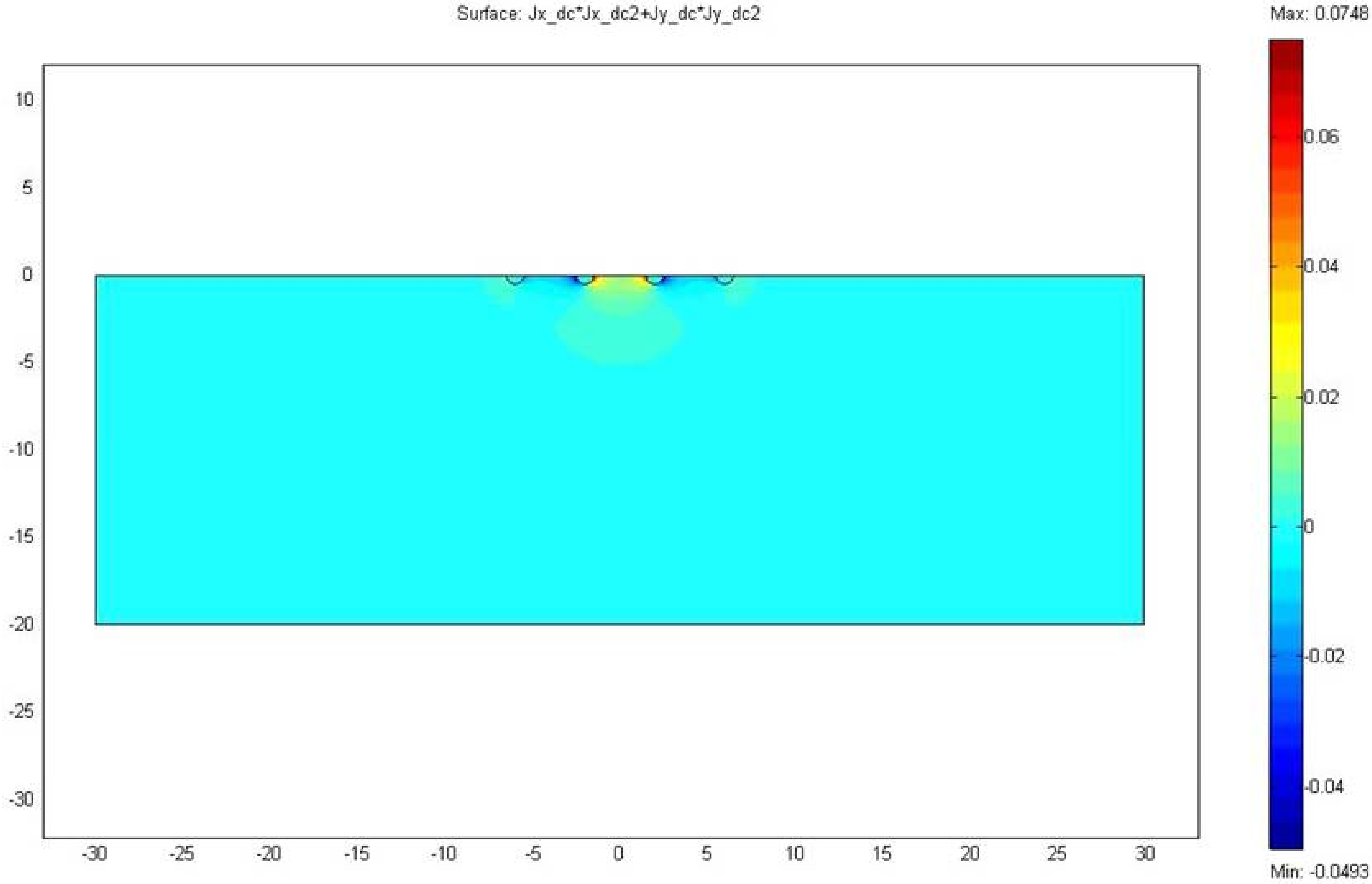
Sensitivity field calculations #3

- ✓ The sensitivity S and total measured resistance R are then (reciprocal system):

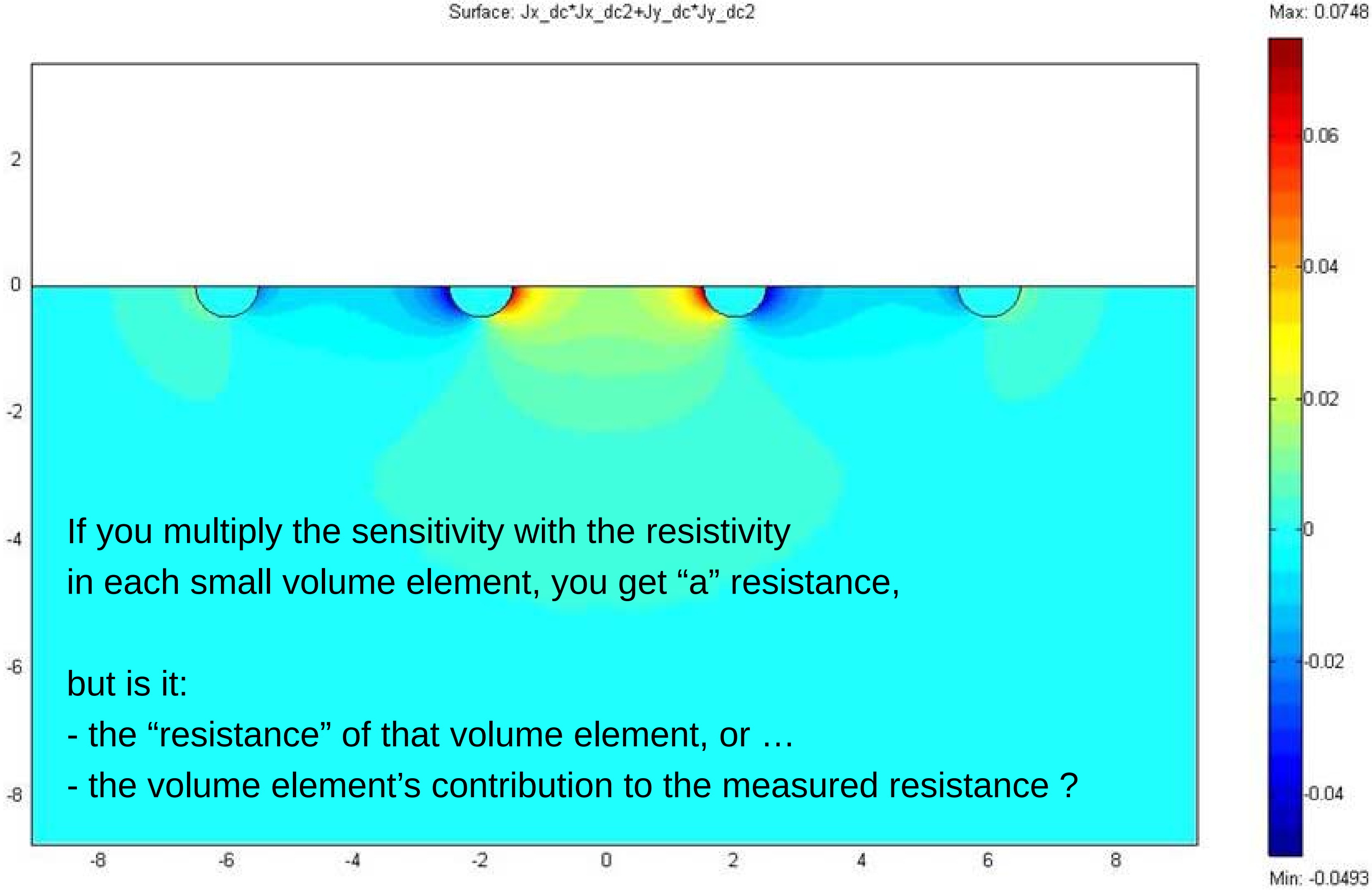
$$S = \frac{\mathbf{J}_1 \cdot \mathbf{J}_2}{I^2} \quad \text{and} \quad R = \int_V \frac{\rho \mathbf{J}_1 \cdot \mathbf{J}_2}{I^2} dv$$

- ✓ **Positive S:** Increased resistivity in this area → higher total measured resistance
- ✓ **Negative S:** Increased resistivity in this area → lower total measured resistance
- ✓ High absolute value of S: Very sensitive to changes in resistivity

Four-electrode system



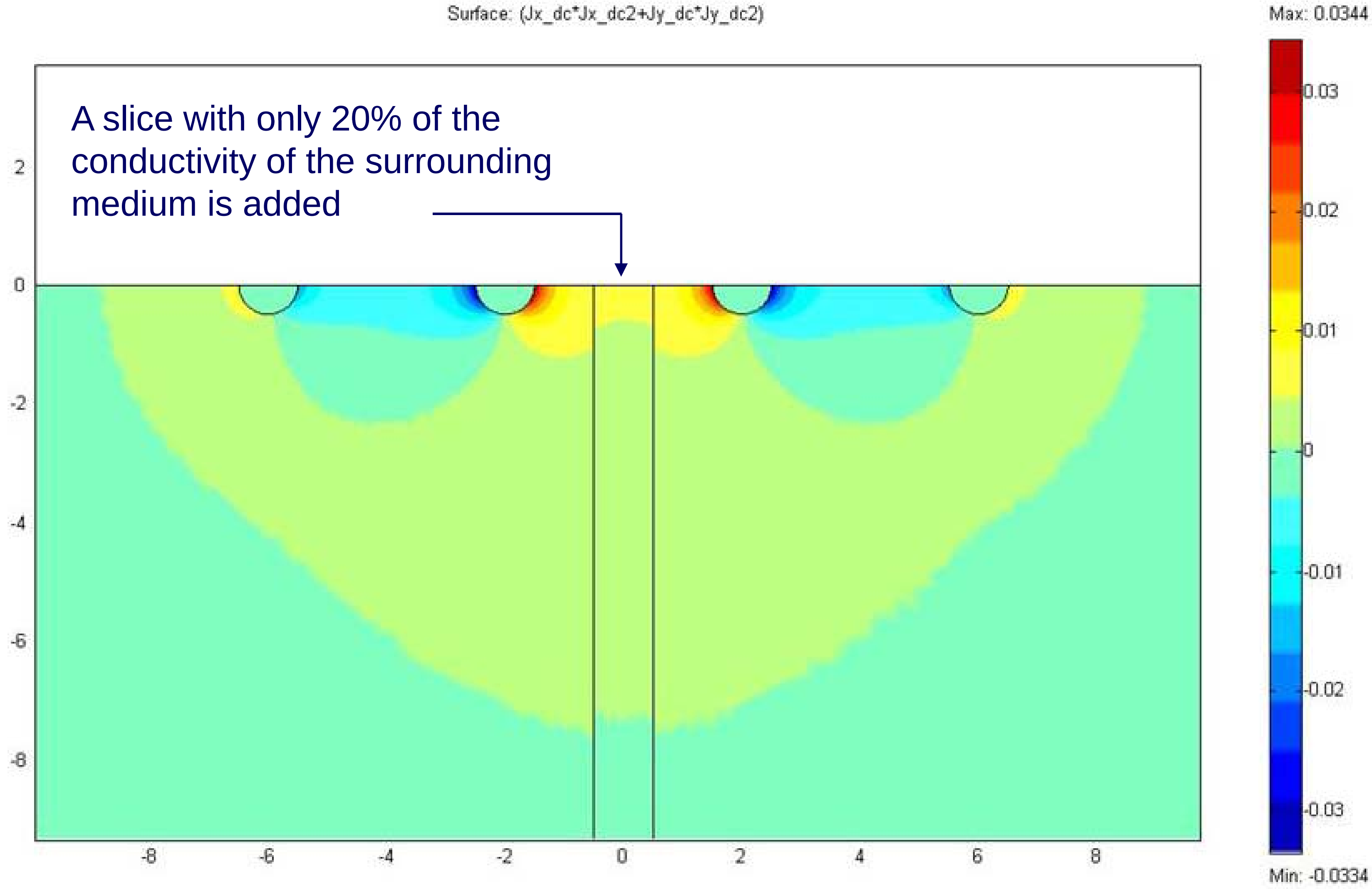
Closer look …



If you multiply the sensitivity with the resistivity
in each small volume element, you get “a” resistance,

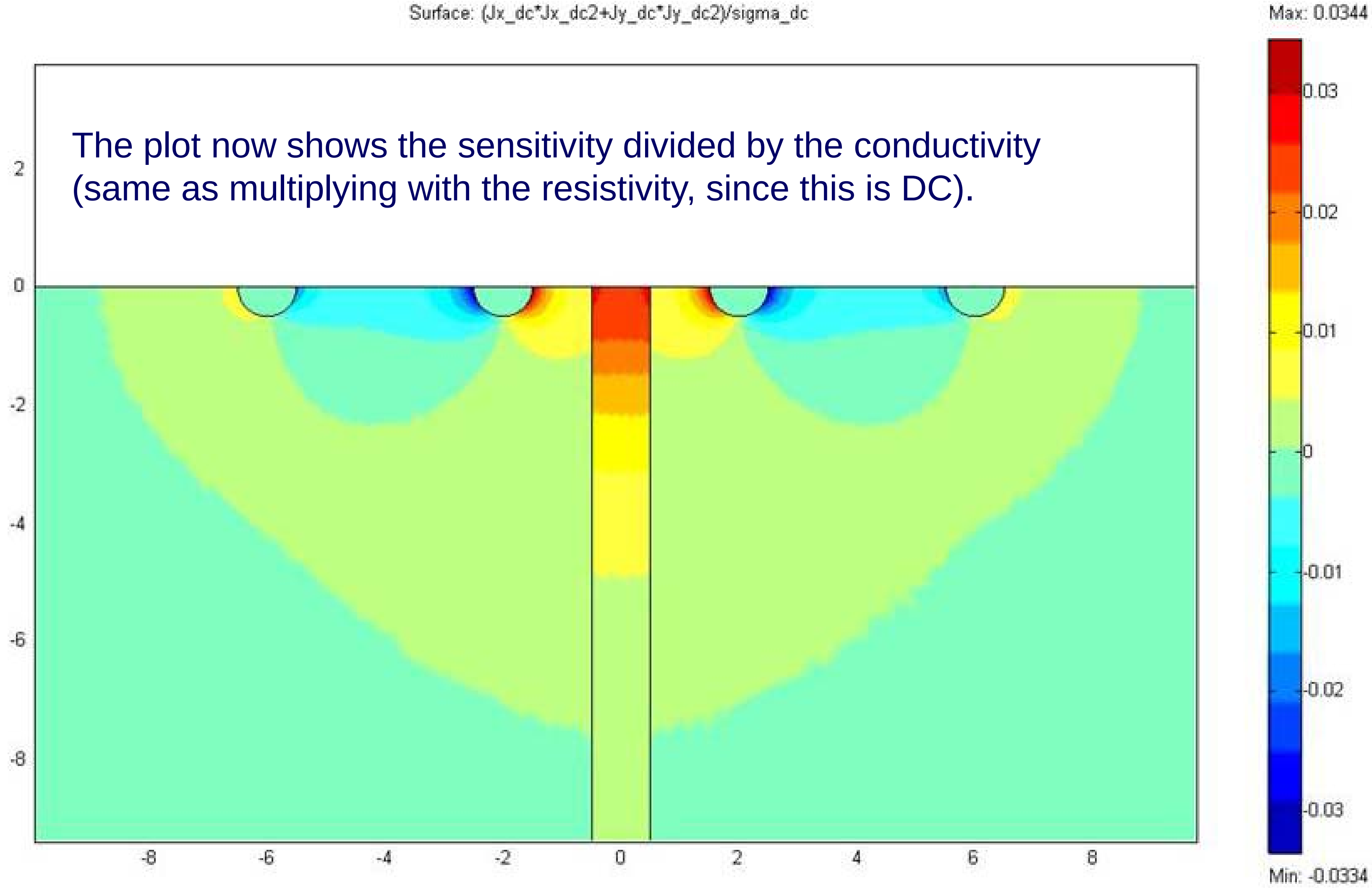
but is it:
- the “resistance” of that volume element, or …
- the volume element’s contribution to the measured resistance ?

Adding a low-conducting slice



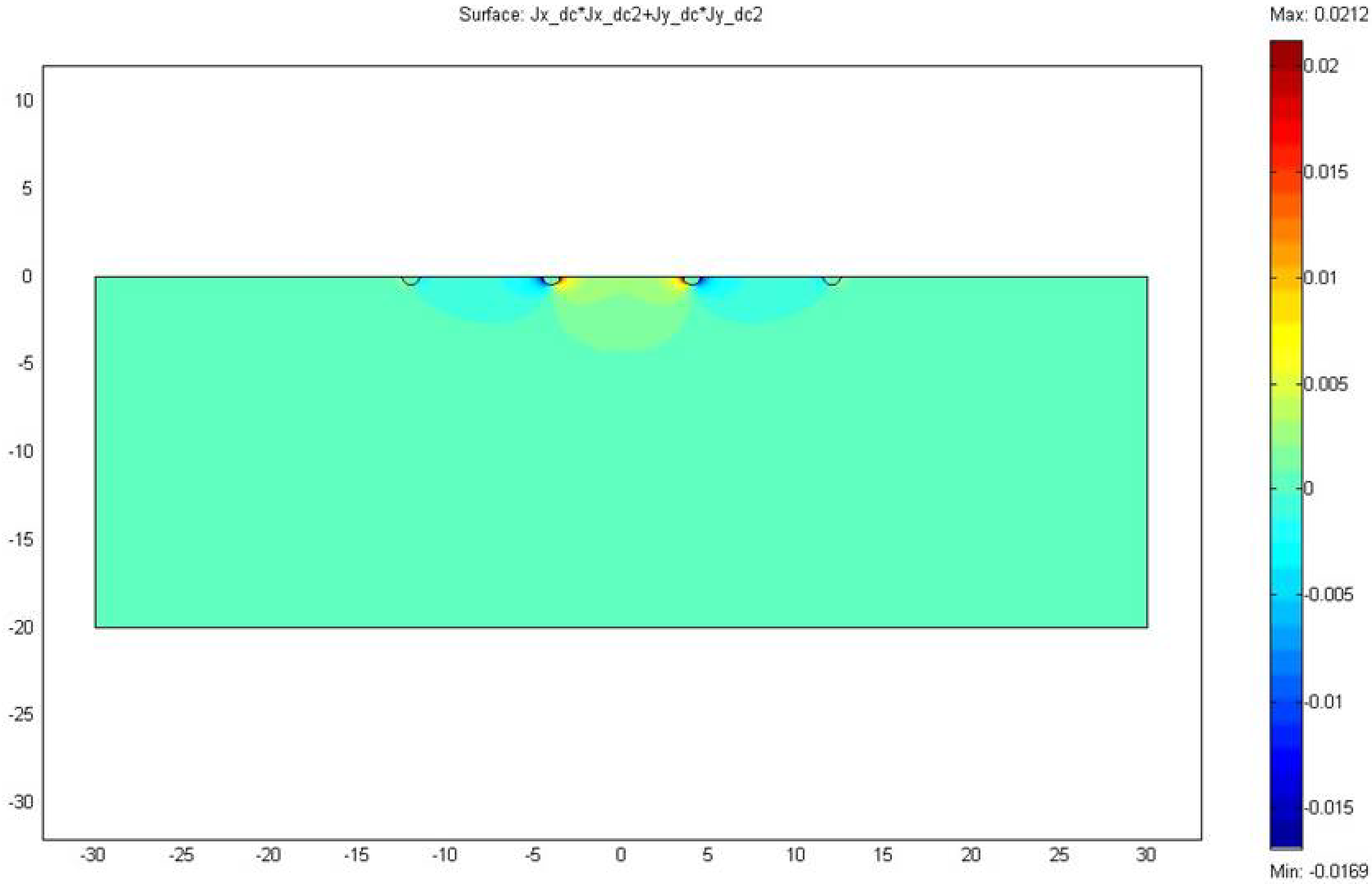
A slice with only 20% of the conductivity of the surrounding medium is added

Volume impedance density

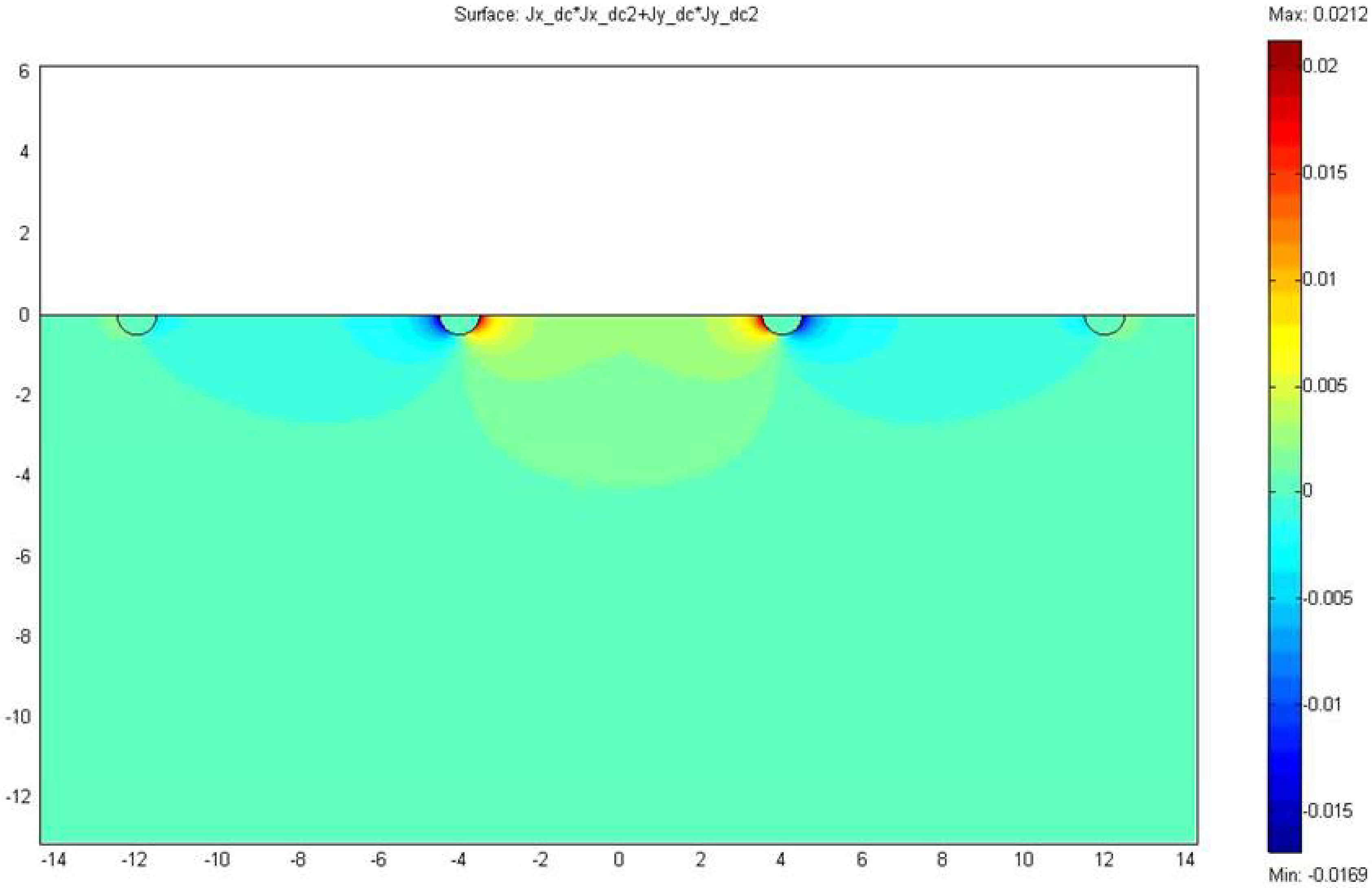


The plot now shows the sensitivity divided by the conductivity (same as multiplying with the resistivity, since this is DC).

Increased electrode separation



Closer look …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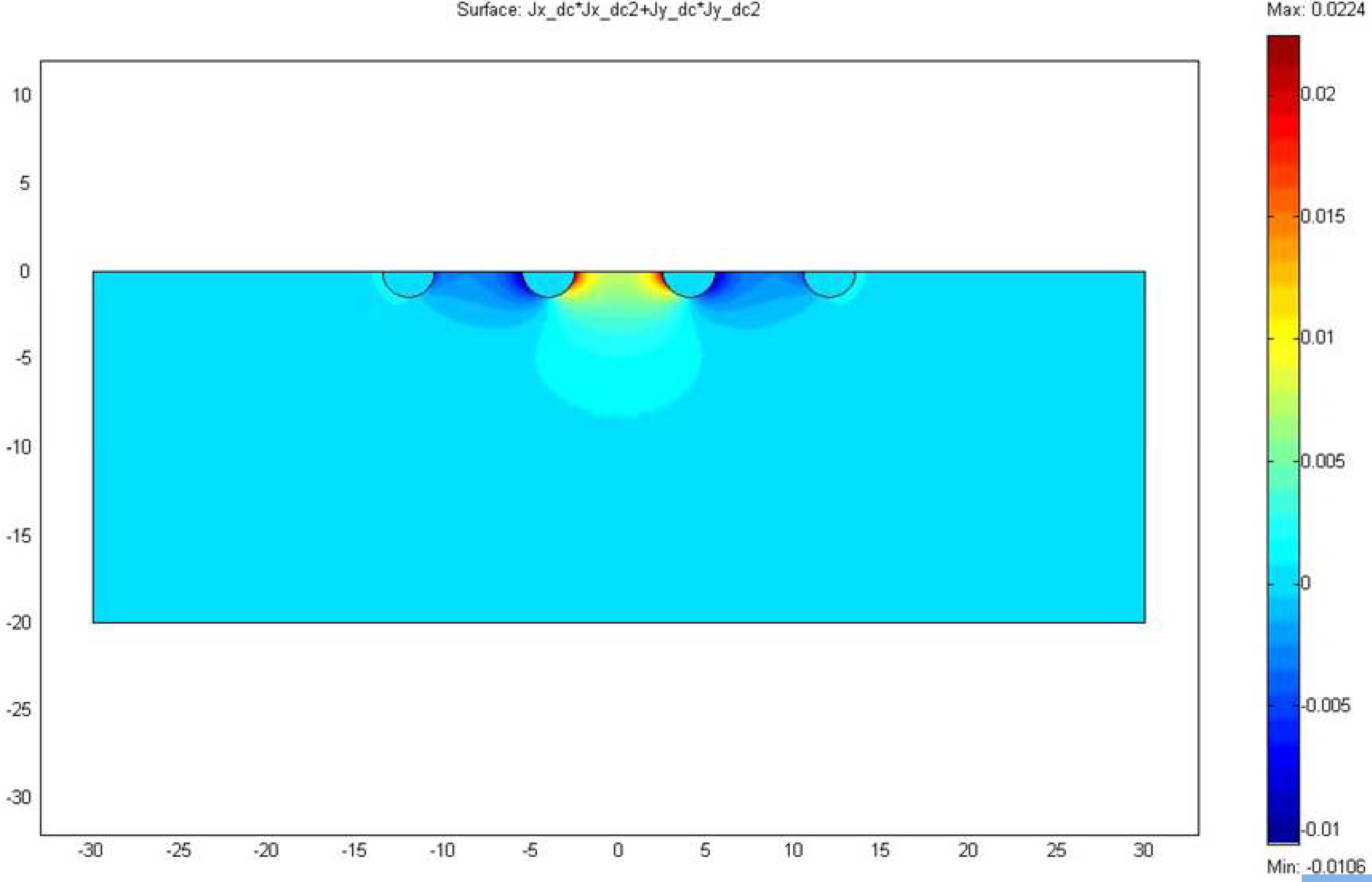
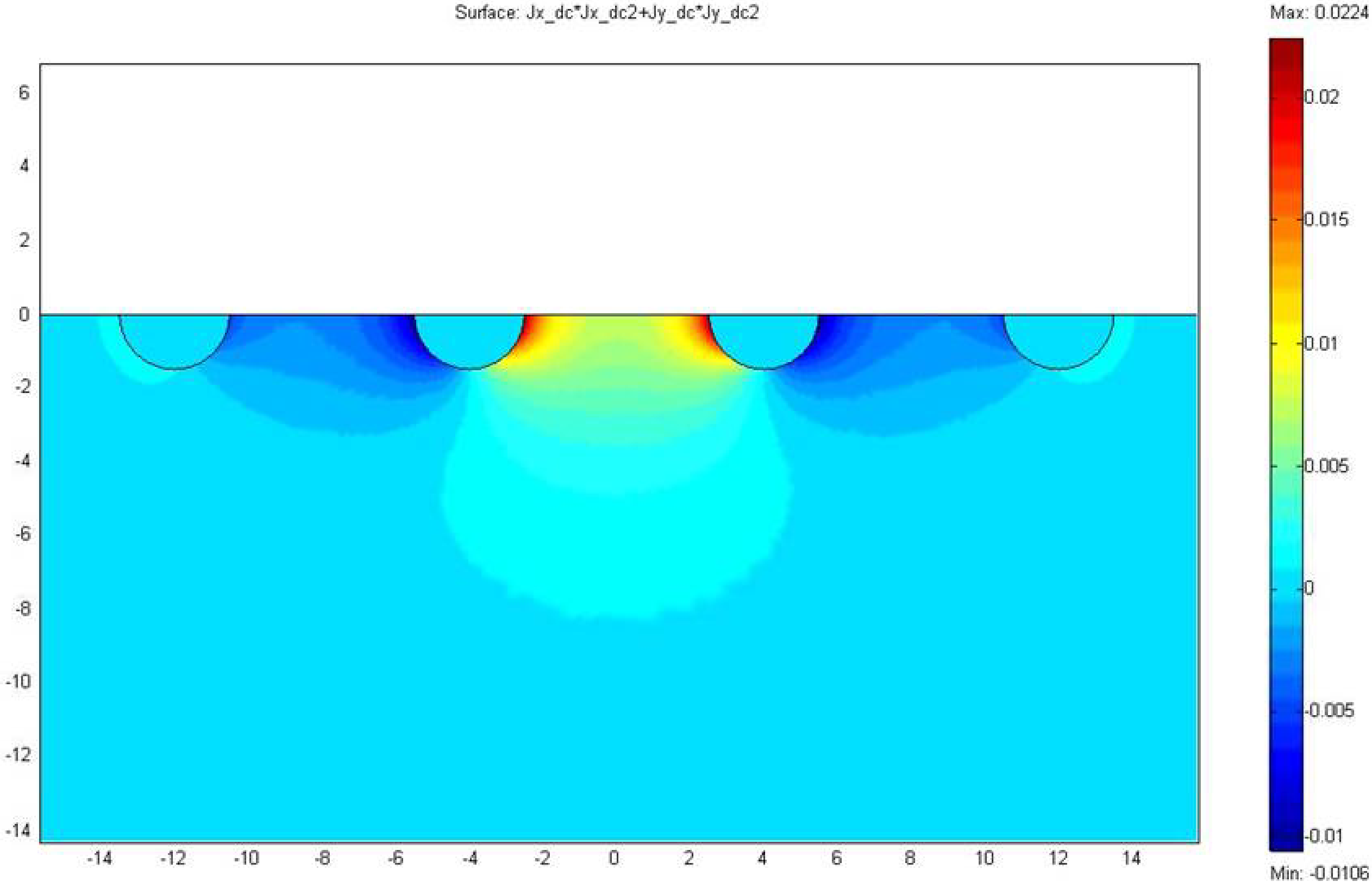
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
Min: -0.0169
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-12
-10
-8
-6
-4
-2
0
2
4
6
8
10
12
14

Larger electrodes



Closer look …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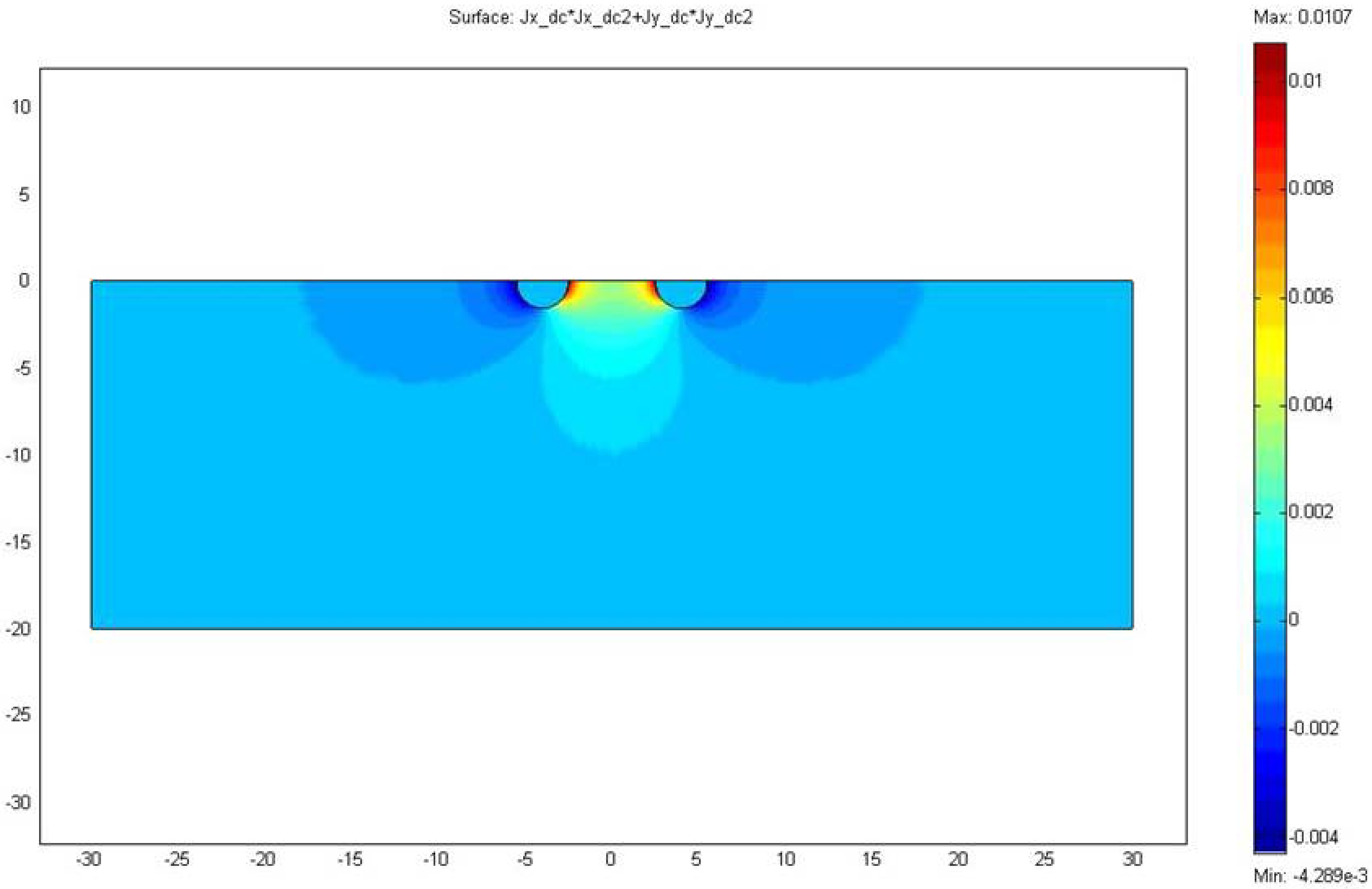
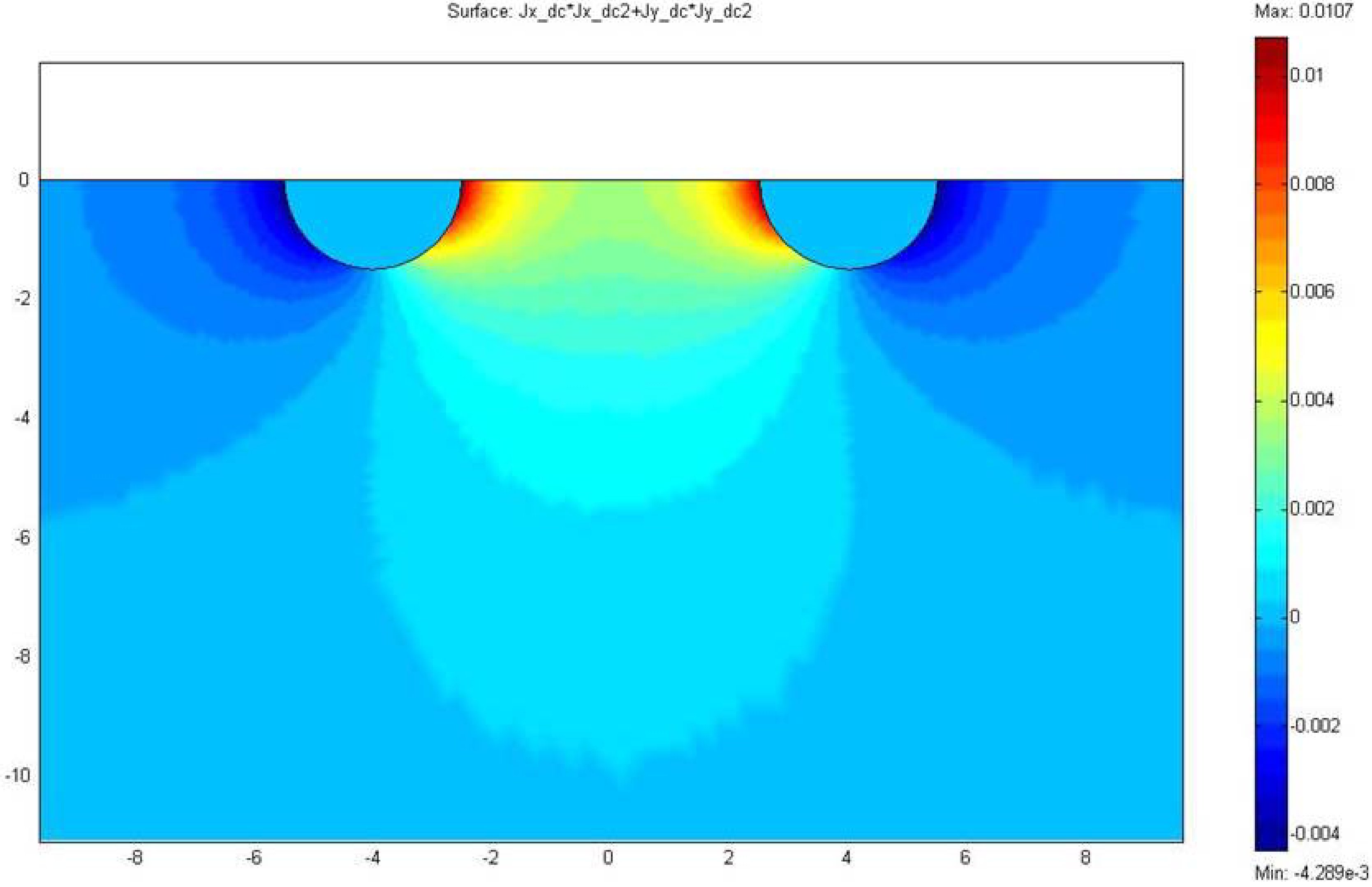
0.02
0.015
0.01
0.005
0
-0.005
-0.01
Min: -0.0106
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-14
-12
-10
-8
-6
-4
-2
0
2
4
6
8
10
12
14

Current carrying electrode plates on the sides



Closer look ...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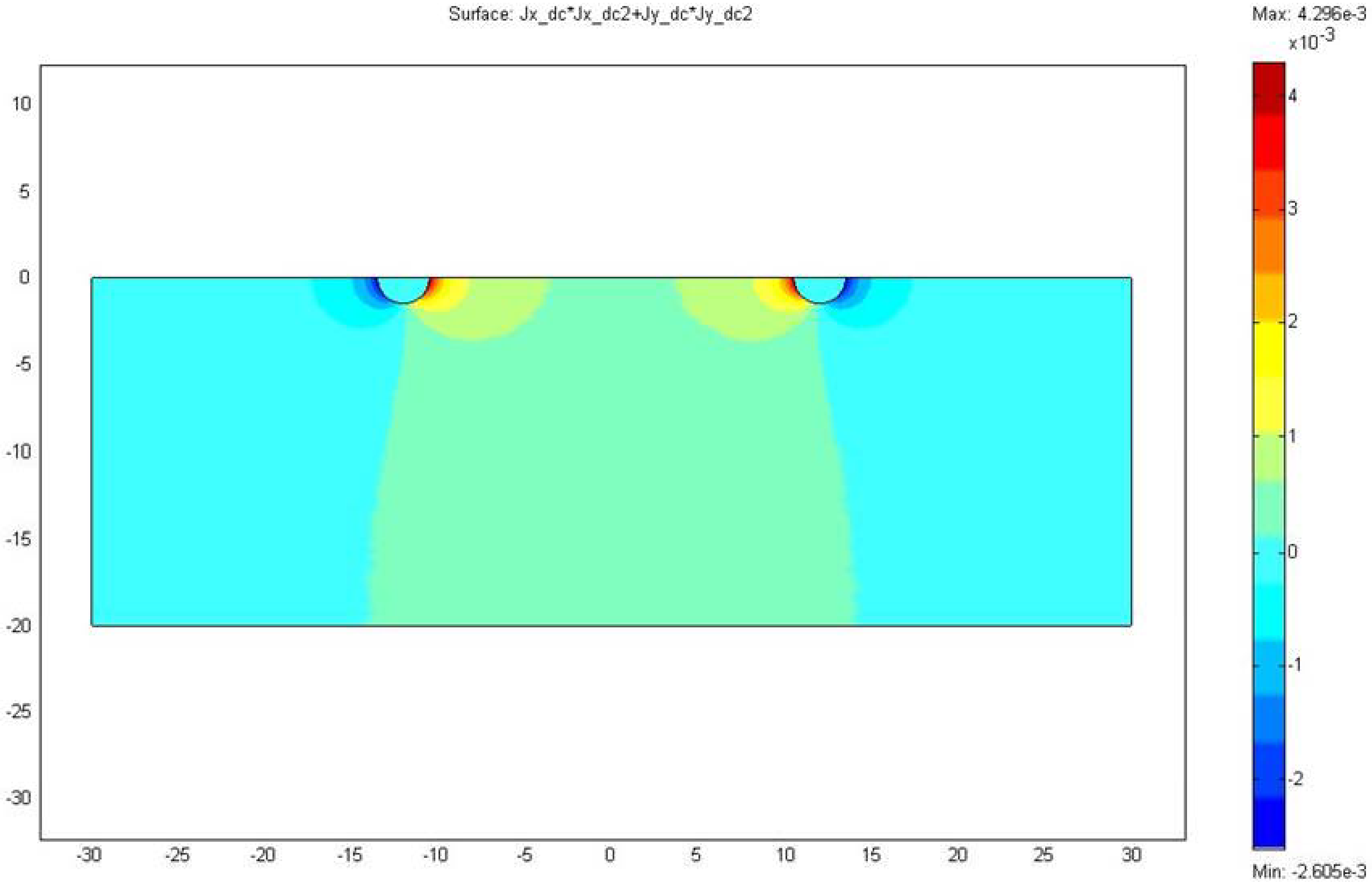
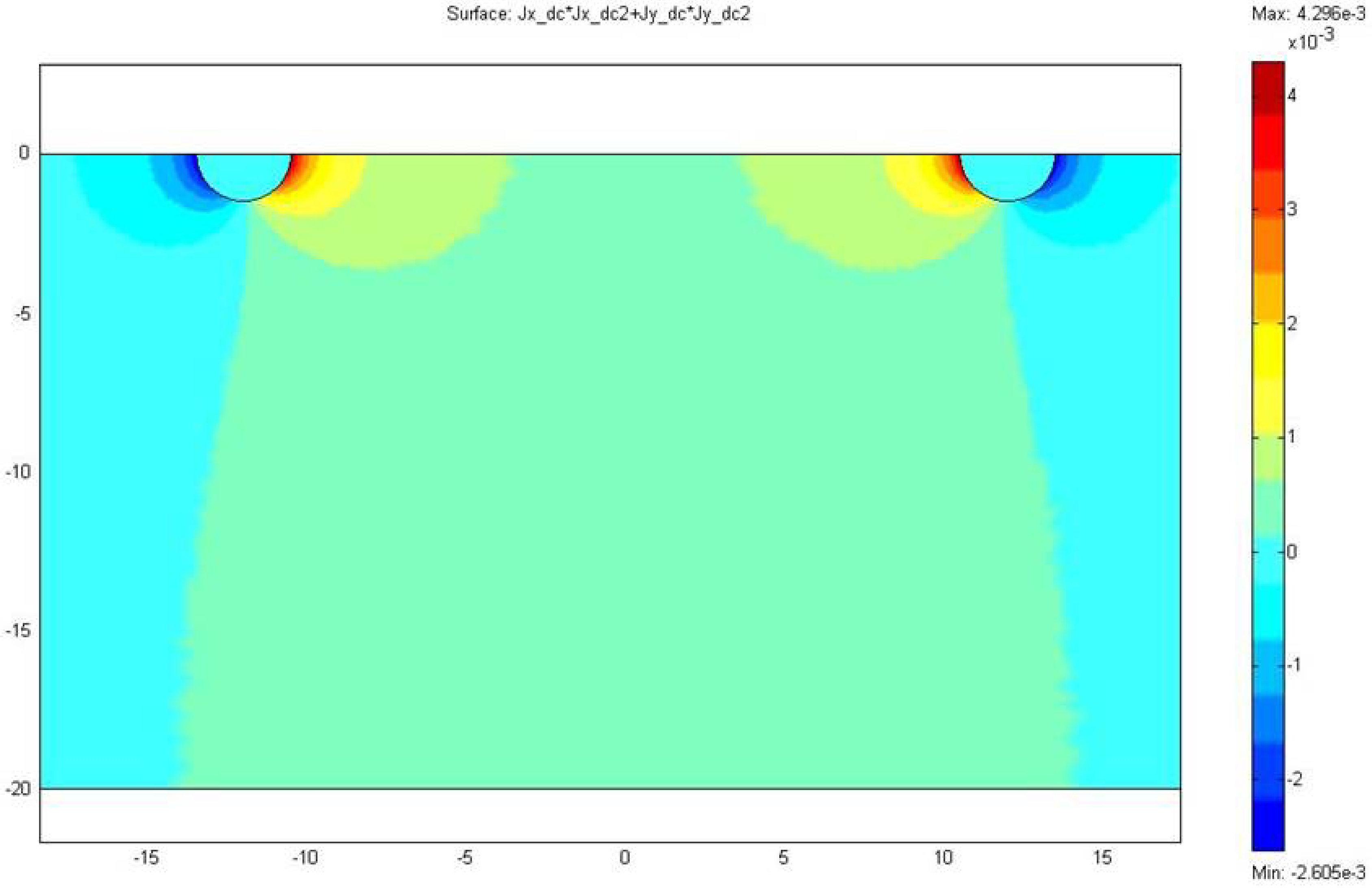
0.008
0.006
0.004
0.002
0
-0.002
-0.004
Min: -4.289e-3
0
-2
-4
-6
-8
-10
-8
-6
-4
-2
0
2
4
6
8

Increased electrode separation



Closer look …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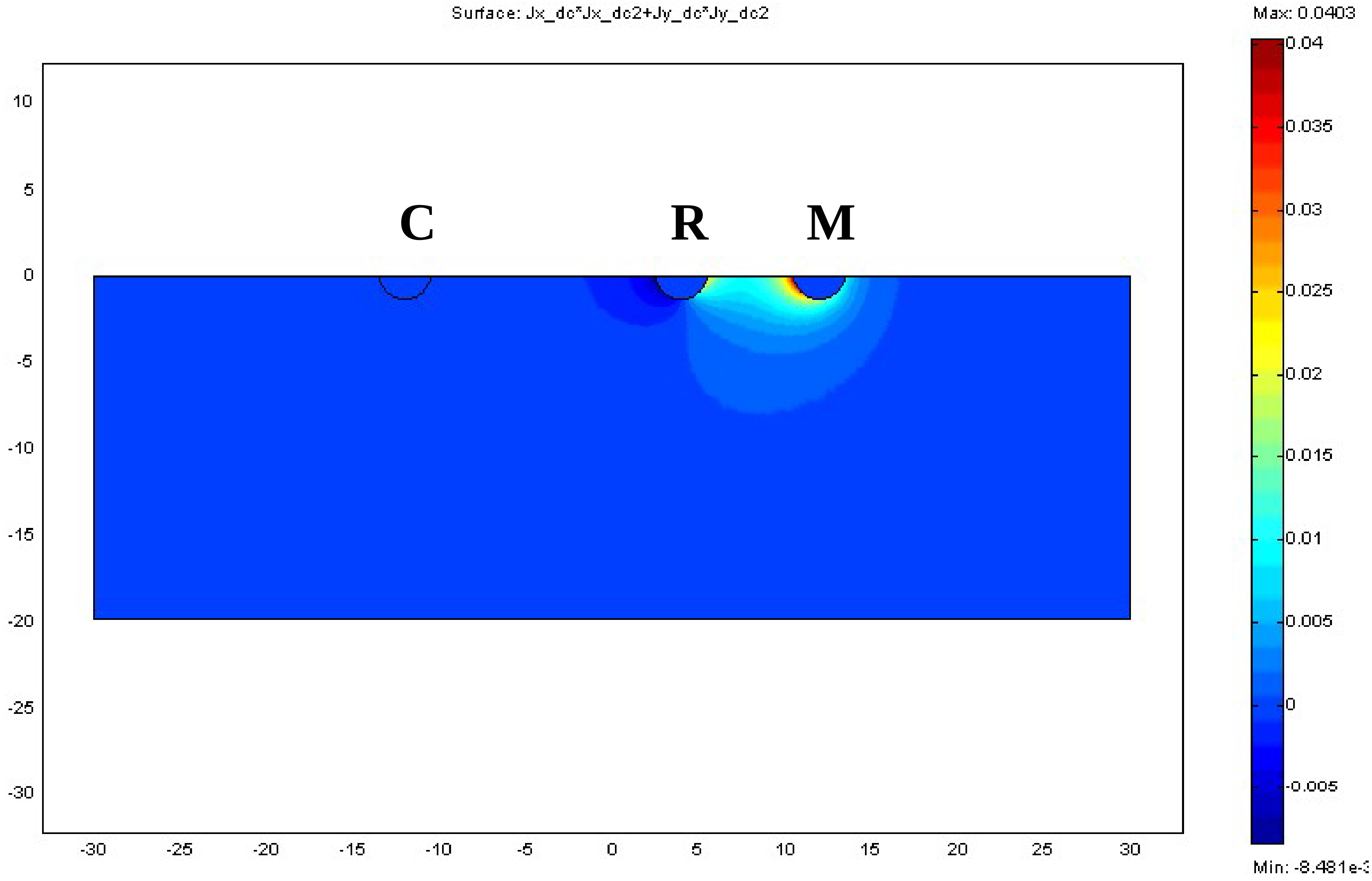
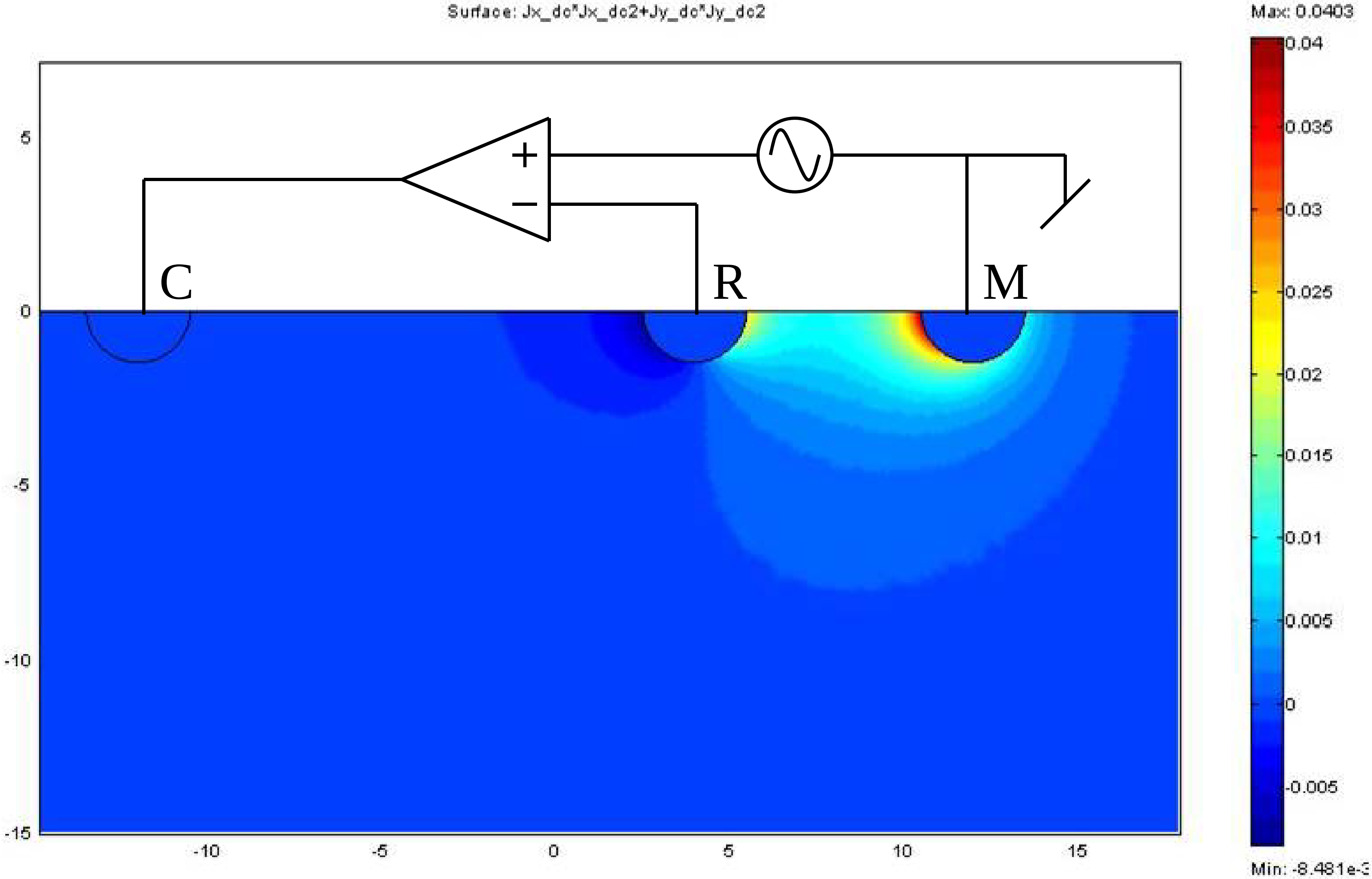
Max: 4.296e-3
x10^-3
4
3
2
1
0
-1
-2
Min: -2.605e-3
0
-5
-10
-15
-20
-15
-10
-5
0
5
10
15

Three-electrode system



Closer look …


Surface: Jx_dc*Jx_dc2+Jy_dc*Jy_dc2
Max: 0.0403
+
−
C
R
M
5
0
-5
-10
-15
-10
-5
0
5
10
15
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
-0.005
Min: -8.481e-3

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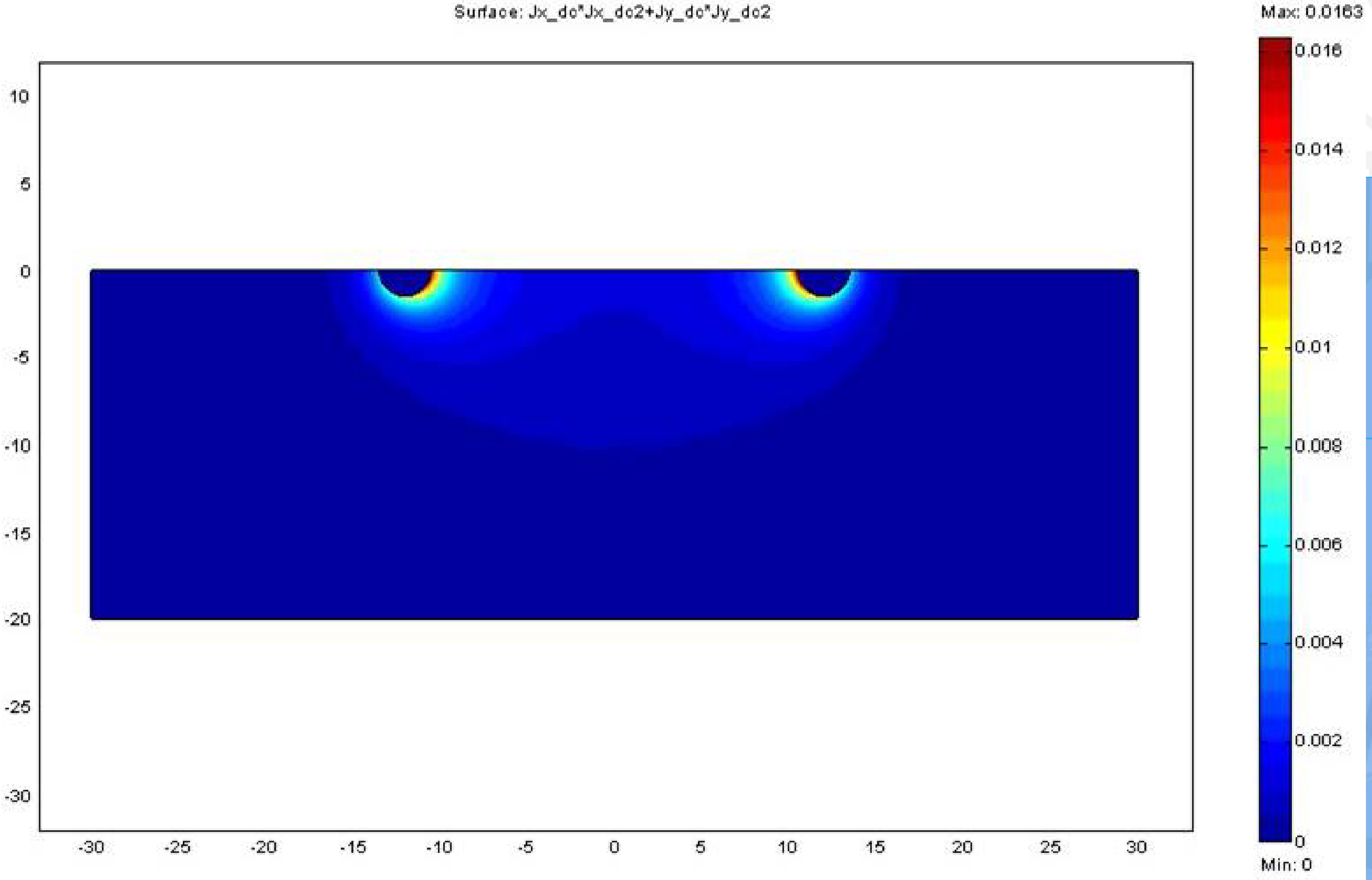
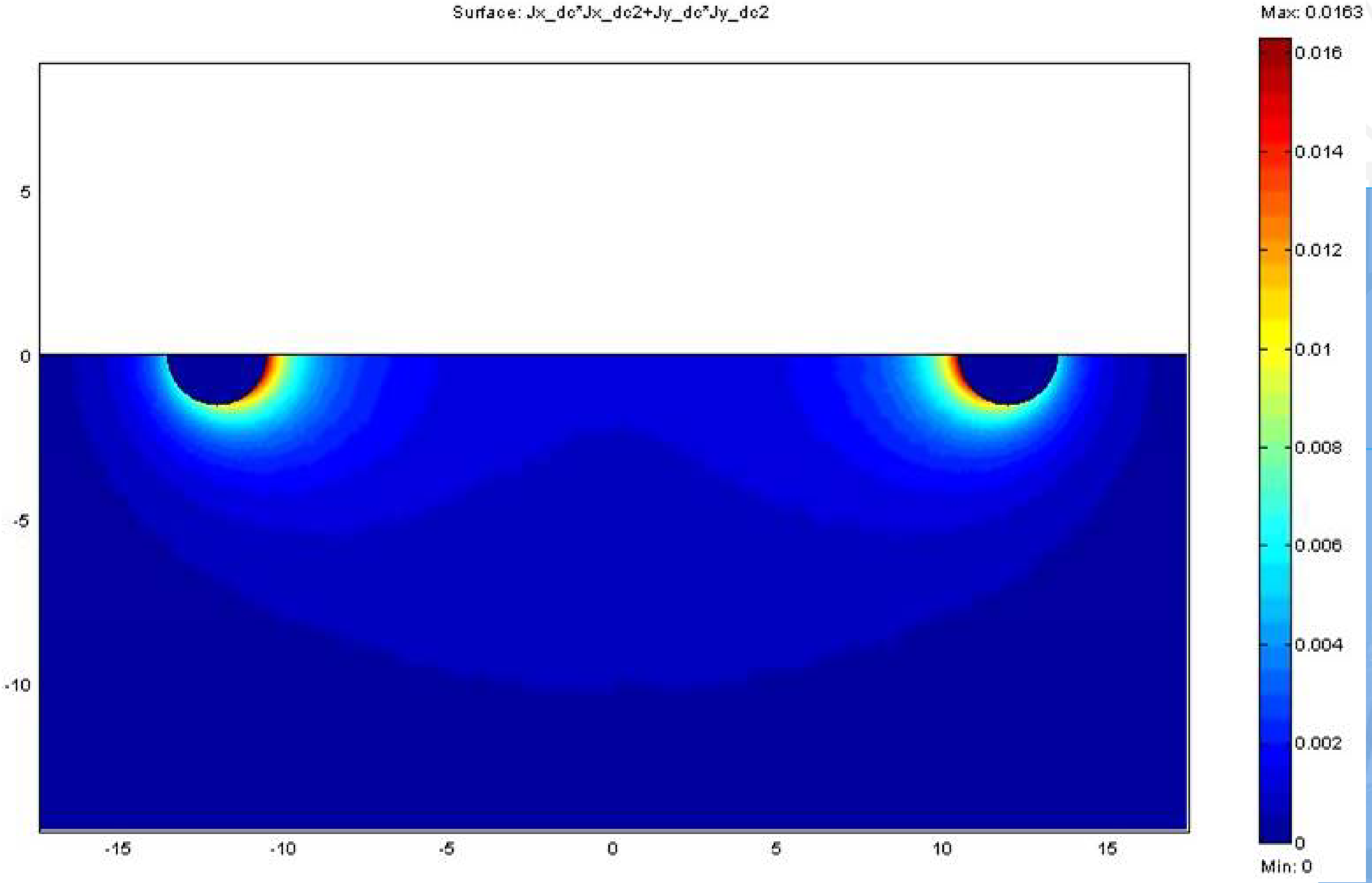
Two-electrode system



Closer look ...


Surface: Jx_dc*Jx_dc2+Jy_dc*Jy_dc2
Max: 0.0163
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
Min: 0
5
0
-5
-10
-15
-10
-5
0
5
10
15