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Institute of Bioelectromagnetism

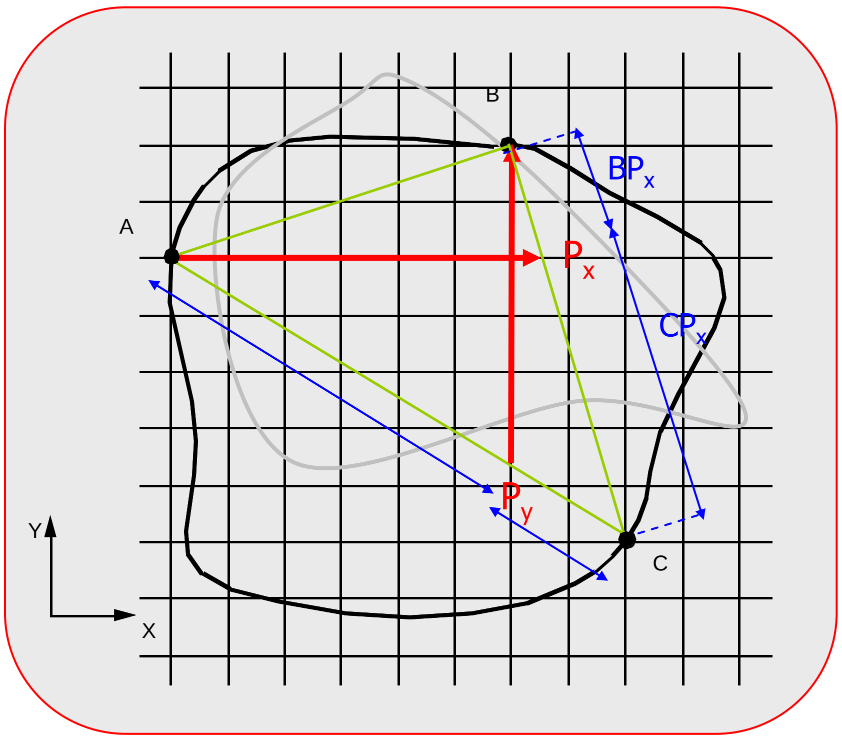
Bioelectromagnetism

Exercise #4 – Answers

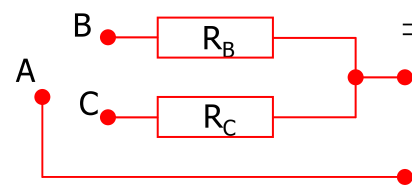
Q1: Vector Leads X & Y

- Figure 1 represents an *image surface* of a volume conductor. Construct new X and Y-leads that would measure dipole sources parallel to X and Y-axis, respective. Use the electrode locations A, B, and C.

  dipole in a fixed location!



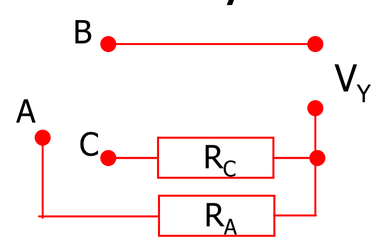
X-Lead: A-P_x



$R_B/R_C = BP_x/CP_x \sim 1/3$

$\Rightarrow \quad R_C \sim 3*R_B$

Y-Lead: P_y-B



$R_A/R_C = AP_y/CP_y \sim 4/1$

$\Rightarrow \quad R_A \sim 4*R_C$

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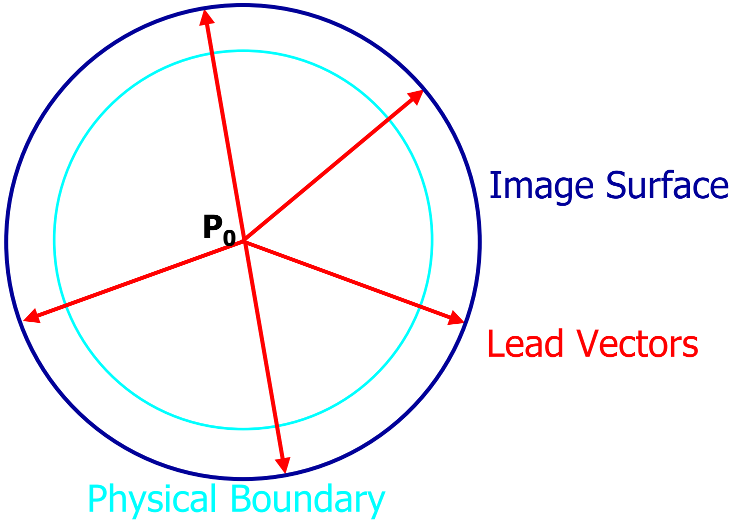
Q2: Torso/Image Surface

- In the centric dipole model for a spherical homogeneous torso, why is the image surface corresponding to the surface of the torso also a sphere? How about when the dipole is not located in the center?

- ”Transversal” plane:



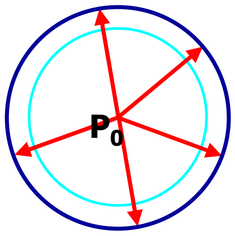
- Frontal plane:
  - same thing!
- Answer:
  - homogeneous, spherical, source in the middle, distance from surface points to the center equal
    => lead vector magnitudes equal

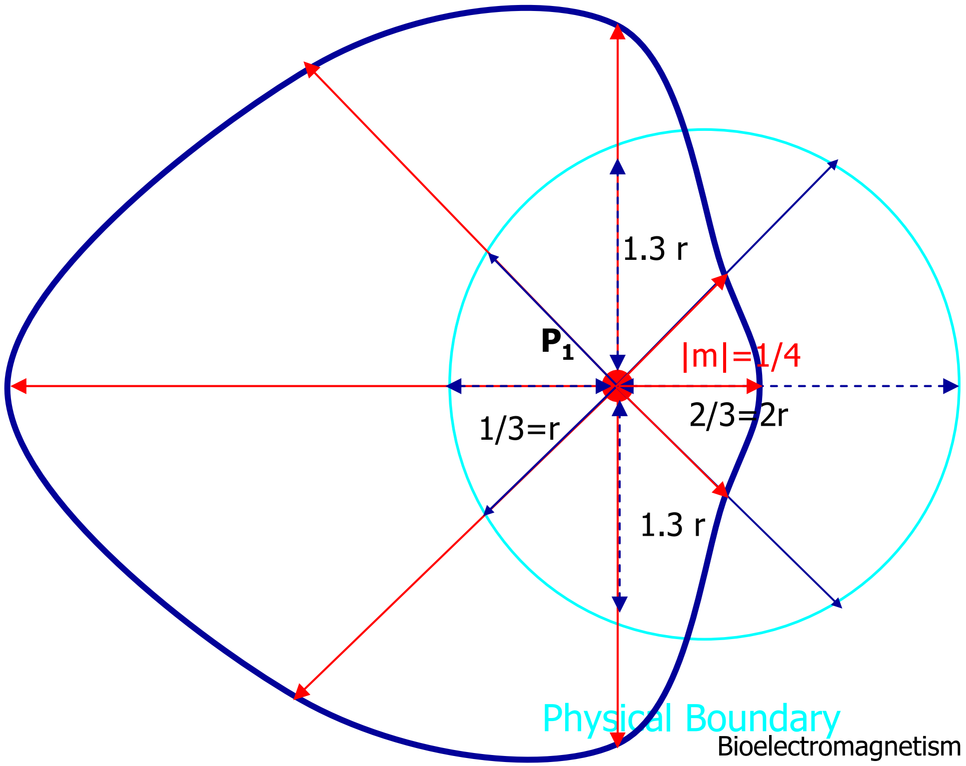
Q2: Torso/Image Surface

- How about when the dipole is not located in the center?
- In this example an infinite homogenous volume conductor is assumed, and the image surface is derived for and imaginary surface, which would correspond to the torso surface.
- If a dipolar source is located at the center of a spherical model, the field at the surface has the same form as in the infinite homogeneous volume conductor at the same radius except that its magnitude is three times greater.

Q2: Torso/Image Surface

- Theory: dipole field magnitude varies as $1/r^2$ (eq. 8.15)
- Example for dipole location P_1
  - $1/(2r)^2$ => relative lead vector magnitude ¼
  - $1/(r)^2$ => relative lead vector magnitude 1
  - $1/(1.3r)^2$ => relative lead vector magnitude 0.6



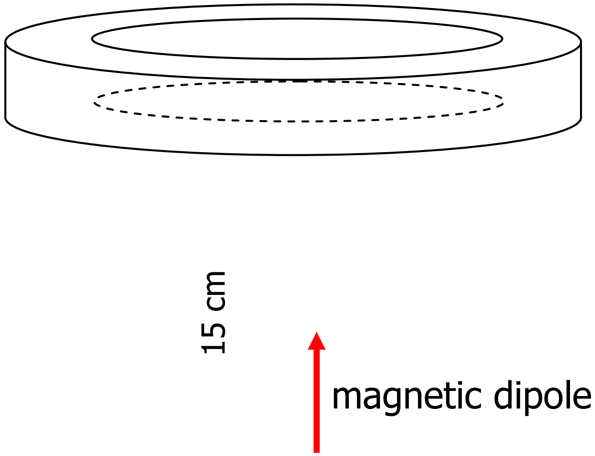


Q3: Magnetometer/Gradiometer

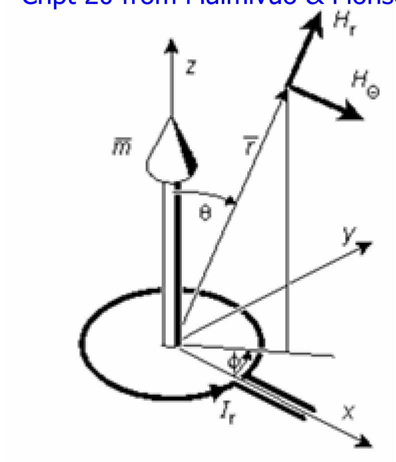
- Calculate the field strength in the center of a coil measuring magnetic field if the source ***m*** (magnetic dipole, normal parallel to the normal of the coil) situates on a plane 15 cm from the coil? Another coil is introduced to the system (10 cm from the original coil) and these two identical coils are used as a gradiometer. What is the level of the signal in this new system compared to the single coil arrangement if the source is 15 cm apart under the measuring coil and the normal of the source is parallel to the normal of the coils?

Q3: Magnetometer/Gradiometer

- First: magnetometer
  - magnetic field vector in the center of the coil



Chpt 20 from Malmivuo & Plonsey



$$H_r = \frac{2m}{4\pi r^3}\cos\theta$$

$$H_\theta = \frac{2m}{4\pi r^3}\sin\theta$$

$$H_\phi = 0$$

  - only z-component (**m** directly below the coil):

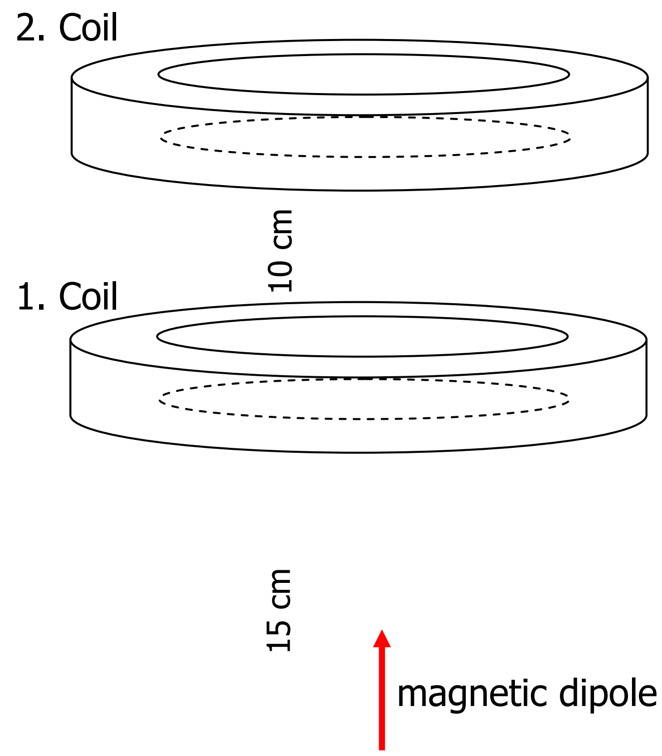
$$H_r = \frac{m}{2\pi r^3}$$

$$H_r \propto \frac{1}{r^3}$$

Q3: Magnetometer/Gradiometer

- Second: gradiometer
  - Two-coil arrangement
  - differential measurement
  - > background (noise) fields decreased

$$H_r \propto \frac{1}{r^3}$$
$$V(t) = -N\frac{d\Phi}{dt} = -N\frac{d\mathbf{B}}{dt}A$$
$$B_r = \mu H_r$$
$$\Rightarrow V(t) \propto \frac{1}{r^3}$$



- Signals
  - $v_1(t) \propto 1/0.15^3$
  - $v_2(t) \propto 1/0.25^3$
  - $v_{gradiometer}(t) \propto v_1 - v_2$
  - Change: $A = v_{gradiometer}/v_1 = 1 - v_2/v_1 \approx$ **0.78 ≈ -4.7 dB**

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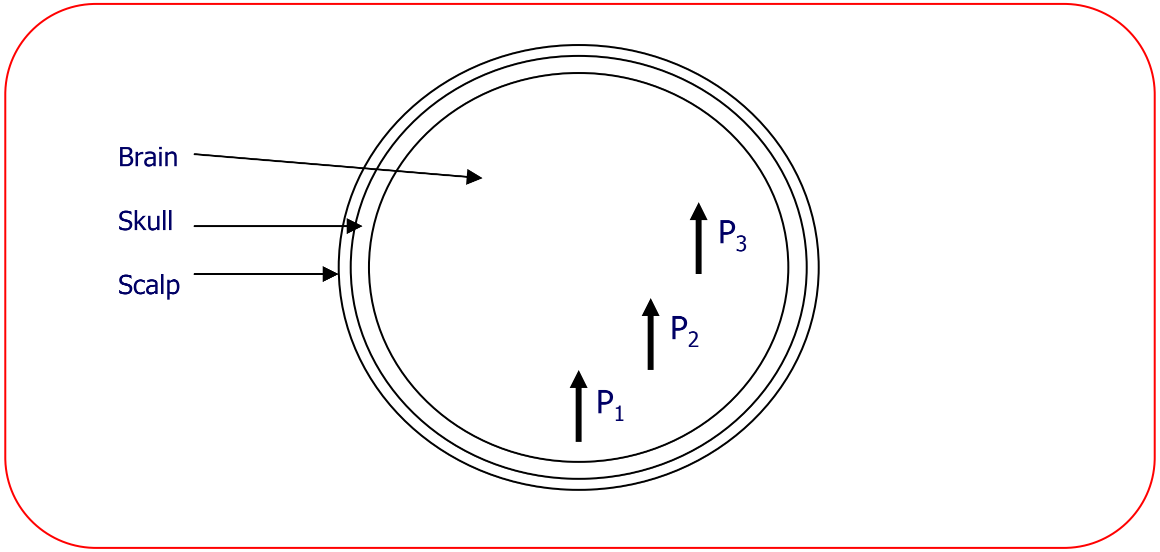
Q4: MEG Sensitivity

- Figure 2 represents a transversal view of a three-concentric-spheres model of the head. A measurement coil is located directly above the center of the model and its normal is directed parallel to the normal of the viewing plane. Current dipoles P1, P2 and P3 have the same magnitude. Which dipole gives the largest signal?



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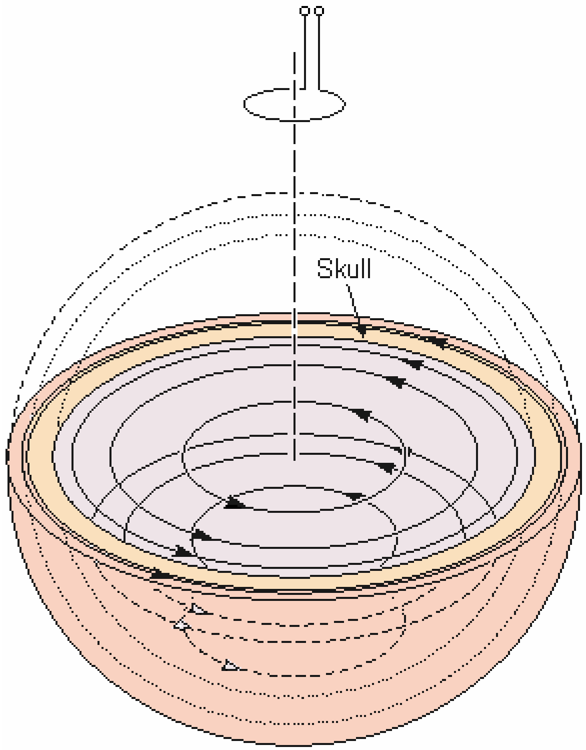
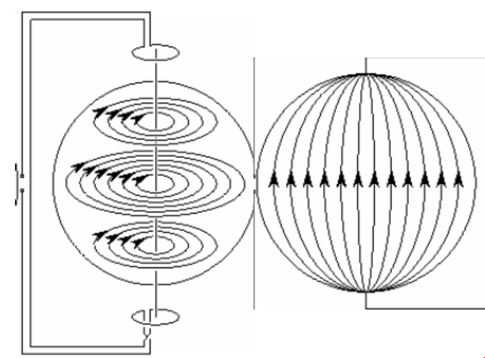
Q4: MEG Sensitivity

- MEG measurement sensitivity in simplified case



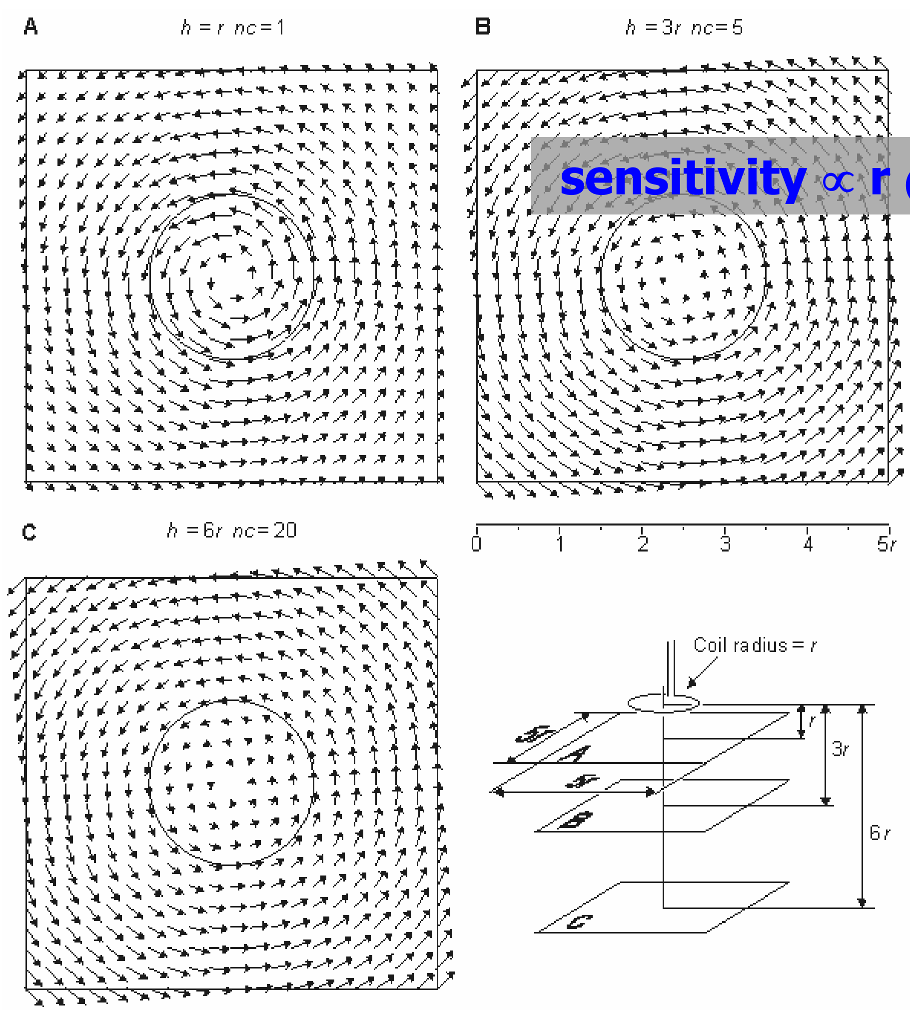
From eq. 12.6: second term has no effect ->

sensitivity ∝ r



Q4: MEG Sensitivity

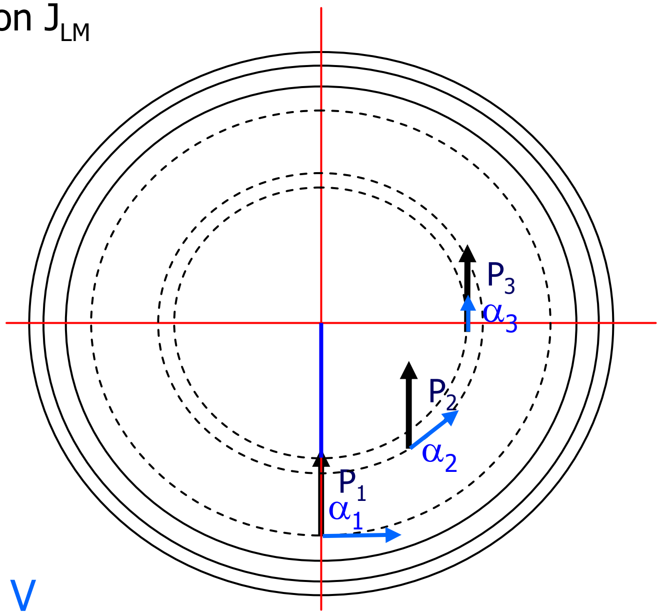
- MEG measurement sensitivity in simplified case



sensitivity ∝ r (Fig 14.2)

Q4: MEG Sensitivity

- MEG measurement sensitivity proportional to r, in our case
  - V = **c** • **p** (no matter what…) $V_{LM} = \int_v \frac{1}{\sigma} \bar{J}_{LM} \bullet \bar{J}^i \, dv$
    - Signal proportional to the projection of source on J_{LM}
  - |m1| = 1 (r1= 2.79)
    - r2 = 2.0
  - |m2| = 2/2.79 = 0.72
    - r3 = 1.8
  - |m3| = 1.8/2.79 = 0.65



- V1 = **m**1 • **p**1 = 1 * p*cosα_1 = p*cos 90° = 0 V
- V2 = **m**2 • **p**2 = 0.72 * p*cosα_2 = 0.72*p*cos 45° = p*0.51 V
- V3 = **m**3 • **p**3 = 0.65 * p*cosα_3 = 0.65*p*cos 0° = p*0.65 V

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Q5: ICG Lead Fields and Measurement Sensitivity

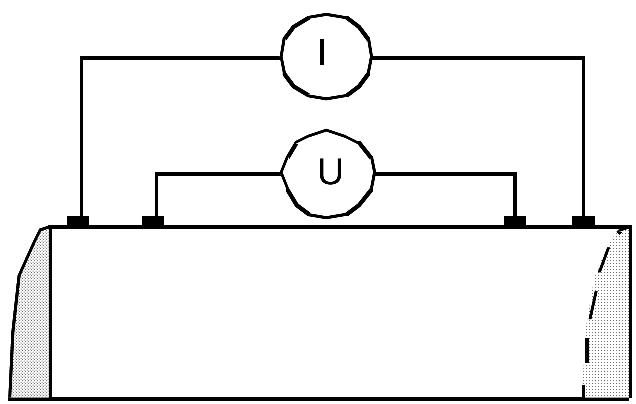
- In impedance cardiography (ICG) an electric current is injected to the body and the corresponding voltage is measured. The ratio of the voltage and current gives the impedance, Z. Z can be obtained using the concept of lead field as follows

$$Z = \int_V \frac{1}{\sigma} \bar{J}_{LE} \bullet \bar{J}_{LI} \, dv$$

where

	σ	= conductivity
	$\mathbf{J}_{LE}$	= lead field of the voltage measurement
	$\mathbf{J}_{LI}$	= lead field of the current feeding electrodes
	v	= volume.

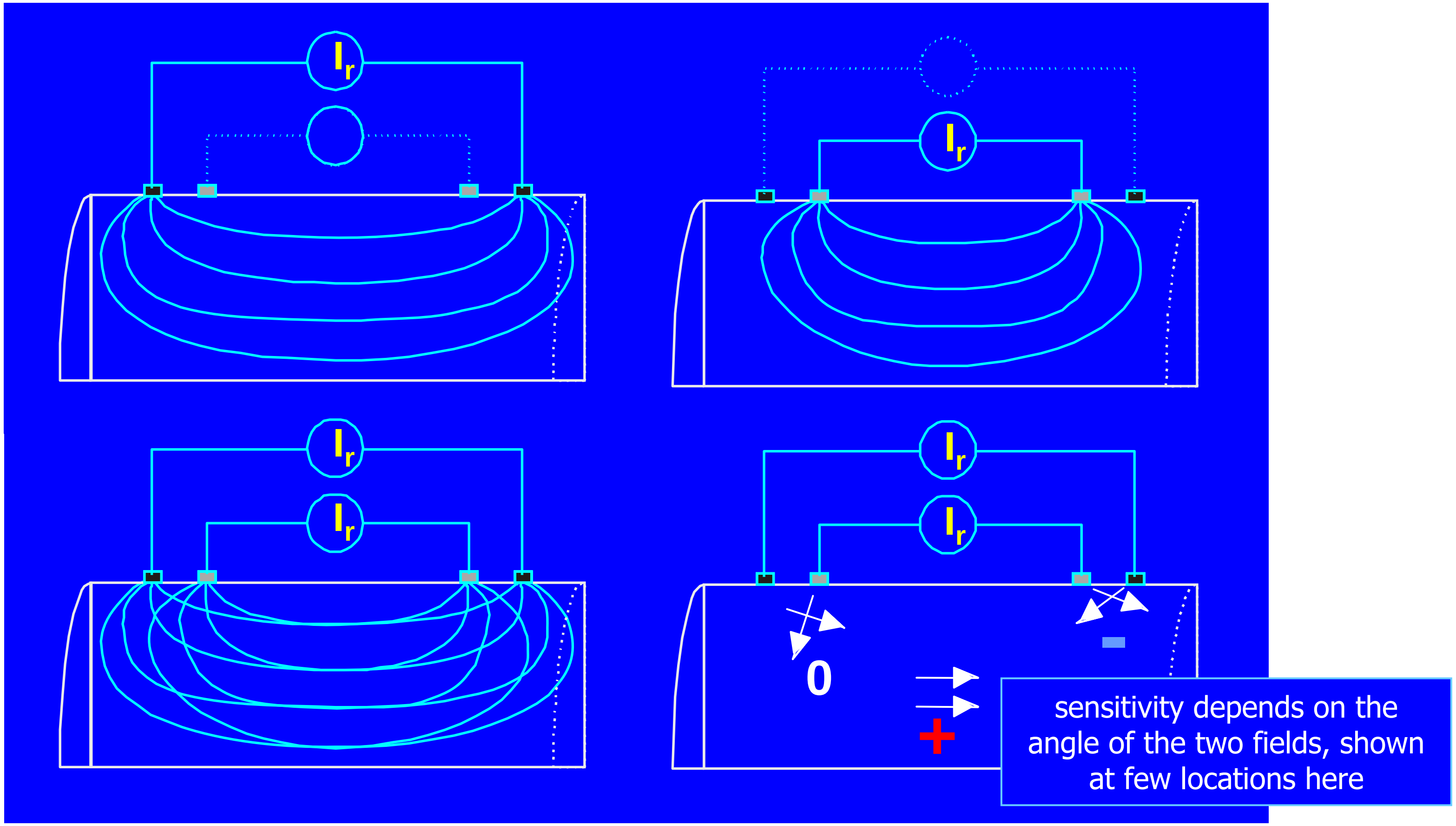
Sketch the lead fields for a system shown in Fig 3. What kind of sensitivity is obtained for impedance changes in different regions?”



Q5: ICG Lead Fields and Measurement Sensitivity

- Current injected using one electrode pair
- Voltage measured by another
- Both leads are associated with a lead field
- Measurement sensitivity by $Z = \int_V \frac{1}{\sigma} \bar{J}_{LE} \bullet \bar{J}_{LI} \, dv$

again, just about the same formula – see Fig 1.3!



Q5: ICG Lead Fields and Measurement Sensitivity

- Simulated example: Homogeneous 2D rectangle