SAPIENZA
UNIVERSITÀ DI ROMA

Environmental Geophysics

Giorgio De Donno

5. DC electrical methods

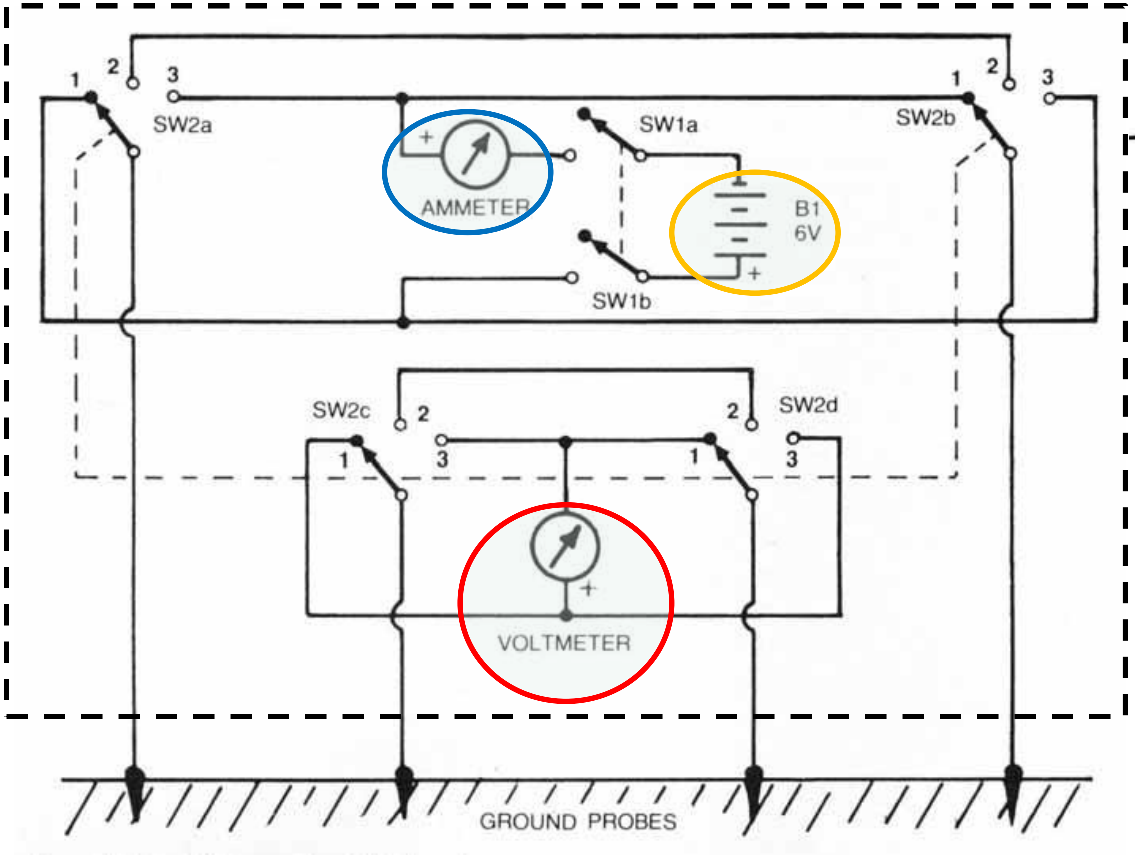
Equipment and data acquisition

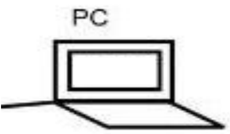
"Sapienza" University of Rome* - *DICEA Area Geofisica

phone: +39 06 44 585 078
email: giorgio.dedonno@uniroma1.it

Multi-electrode acquisition – Resistivimeter

Resistivity-meter: device able to measure both potential and current, to compute the geometric factor for the particular measurement and therefore to calculate the apparent resistivity

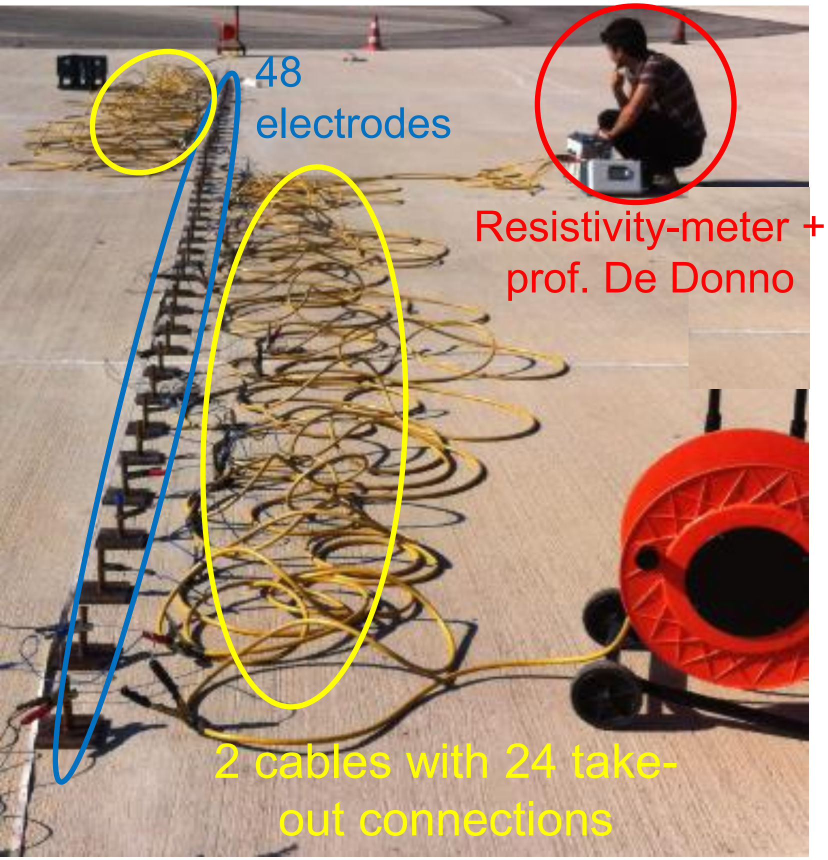




Acquistion software is able to calculate K and to compute the apparent resistivity for each quadrupole

Multi-electrode acquisition – Resistivity-meter+ cables+ electrodes

Data acquisition

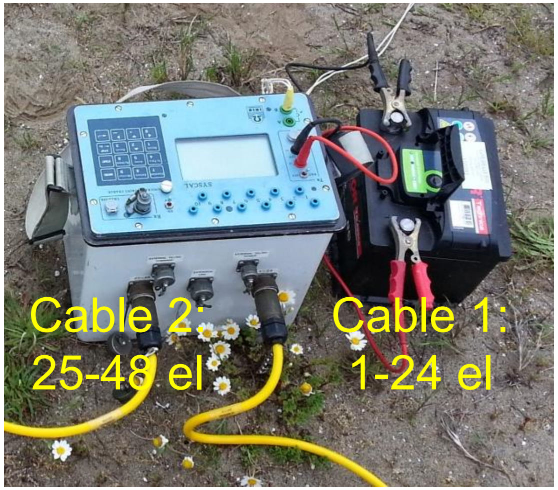


Electrodes (rods)

length = 20 cm – 1 m

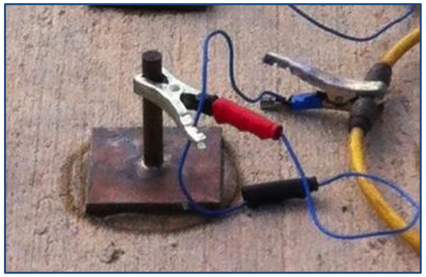
diameter = 1-3 cm

Cables+resistivity-meter connection + 12V battery



Electrode (plates)

size = 10x10 cm



Multi-electrode acquisition - Electrodes

Steel rods for surface investigation

length = 0.2 – 1.5 m
diameter = 1-4 cm

Benefit: good contact resistances also for resistive soils (sand, gravel, rocks…)
Drawback: invasive, weight

Steel rings for borehole investigation

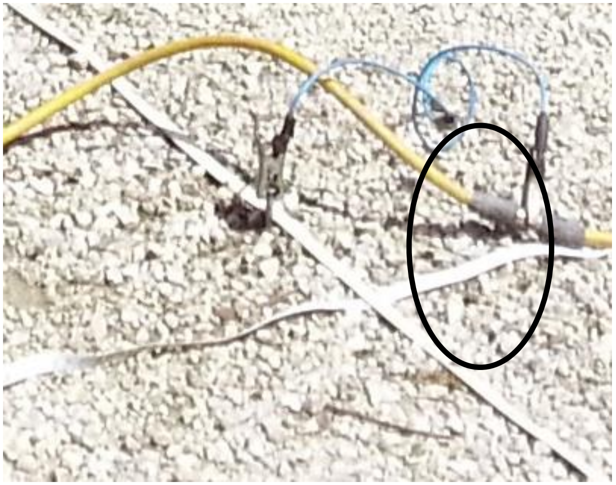
length = 5-15 cm
diameter = 7-15 cm

Benefit: borehole measurements allowed with good contact resistances
Drawback: complexity

Clay

Borehole

Gravel



Multi-electrode acquisition – Acquisition parameters

- ✓ **Contact resistances:** should be low enough to ensure a good current level and of the same order of magnitude among the electrodes
- ✓ **Signal-to-noise ratio (SNR)**: measurements are affected by the noise and therefore SNR should be maximized (SNR >> 1)
- ✓ **Current level:** we can improve the SNR by injecting more current where needed, having in mind that batteries will discharge in a shorter time
- ✓ **Stacking and pulse duration:** performing more stacks we can have an assessment of the experimental errors and we can suppress coherent noise; pulse duration can be set as short as possible in absence of polarizable materials (see lecture 5.4 on IP)
- ✓ **Array choice:**
  - **Signal strength (SS):** inversely proportional to the geometric factor
  - **Depth Of Investigation (DOI):** directly proportional to the line length
  - **Resolution (Sensitivity):** proportional to the electrode spacing and to the capability to «feel» the resistivity changes in the horizontal or vertical direction
  - **Cost-effectiveness:** number of measurement performed in a fixed time

Multi-electrode acquisition – Acquisition parameters

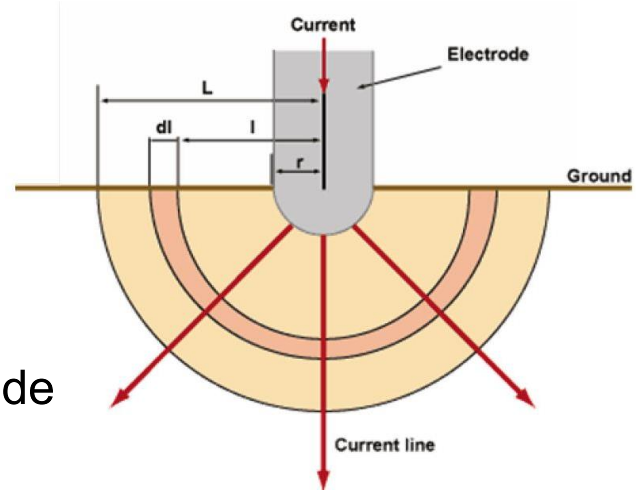
Contact resistances

geometrical term

$$\boxed{R_c = R_g + R_i}$$

interfacial term

$$R_g = \frac{\rho}{2\pi r}$$ for a spherical electrode



R_i interfacial resistance between electrode and soil: it may represent the change in grounding resistance e.g. from electrodes watering or freezing/drying conditions around the electrode

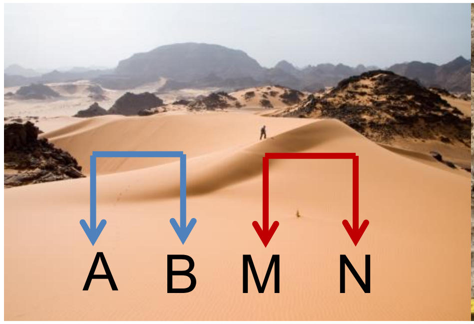
To decrease contact resistances:

- Inject more current (reducing the whole resistance - see the Ohm's law)
- Increase the diameter of electrodes (↓ R_g)
- Ground longer electrodes (↓ R_i)
- Decrease the resistivity of the area surrounding the electrode e.g. adding fresh water or salt water or conductive gel (↓ R_i)

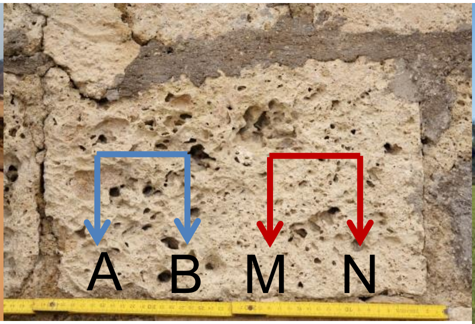
Multi-electrode acquisition – Acquisition parameters

Contact resistances

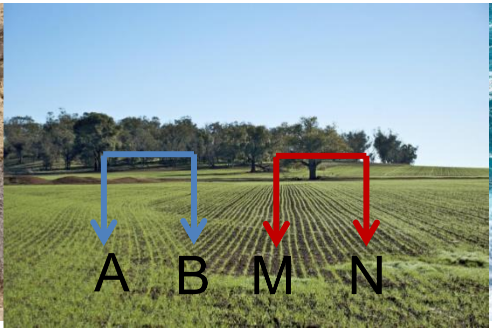
Ensure that contact resistances are relatively low and of the same order of magnitude for all the electrodes: otherwise, we may measure a spurious resistivity due to the unbalanced contact resistances



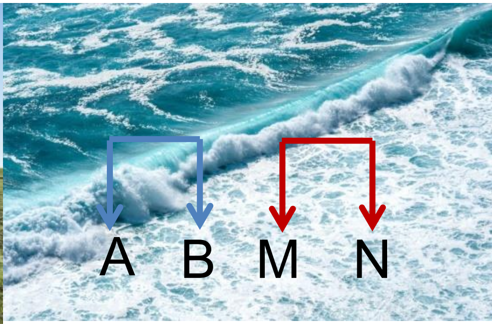
Extremely dry quartz sand
$R_c > 1000\ \text{k}\Omega$



Dry rock
$100\ \text{k}\Omega < R_c < 10\ \text{k}\Omega$



Clayey-silty soil
$10\ \text{k}\Omega < R_c < 0.1\ \text{k}\Omega$



Salt water
$R_c < 10\ \Omega$

ELECTRODES NEED WATERING, A LOT OF CURRENT, A LOT OF POWER

ELECTRODES NEED FEW CURRENT, FEW POWER AND NOT WATER!

Multi-electrode acquisition – Acquisition parameters

Signal-to-noise ratio (SNR)

SNR should be >> 1

$$SNR = \frac{P_S}{P_N} = \left(\frac{A_S}{A_N}\right)^2$$

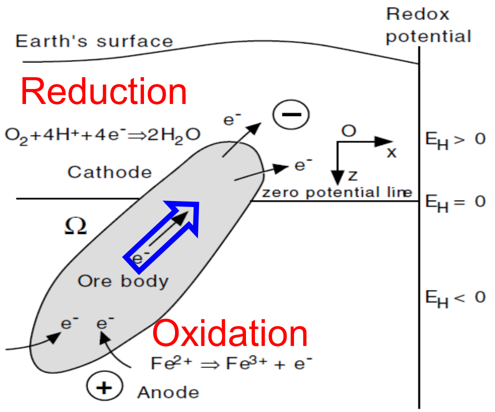
P_S: power of signal; A_S: signal amplitude
P_N: power of noise; A_N: noise amplitude

Sources of noise

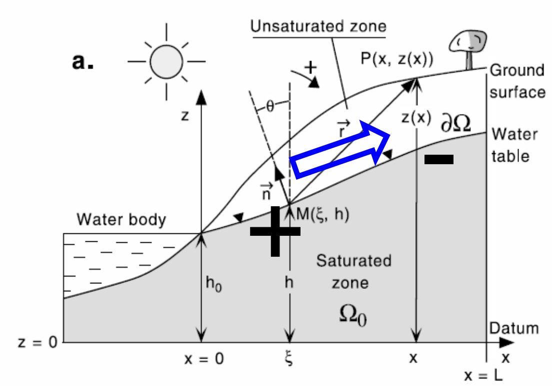
- **Self-potential (SP)**

Natural potential differences in the subsoil due to ore bodies (electro-chemical) or hydraulic flux (electro-kinetic)

Electro-chemical SP



Electro-kinetic SP



- **Man-made currents**

Power lines, pipes, wires, grounded metal

We can maximise SNR by:

- decreasing contact resistance (↑ A_S)
- injecting more current (↑ A_S)
- performing more cycles of the same measurement with reverse polarity (↓ A_N)
- performing survey far from zones with pipes, wires or strong SP (↓ A_N)

Multi-electrode acquisition – Acquisition parameters

Current level

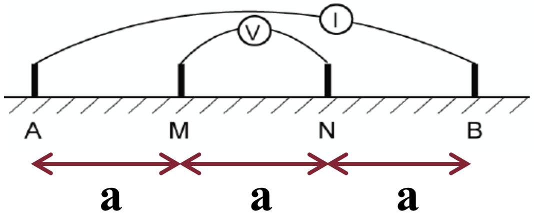
Ex. 1 homogeneous ground

$\rho_a = \rho = 12\ \Omega\mathrm{m}$

constant noise level = 30 mV

4 electrodes - Wenner array a=1

K=2π



$$\boxed{K = 2\pi a}$$

$$\boxed{\rho_a{}^{OBS} = K\frac{\Delta V^{OBS}}{I}} \Rightarrow \boxed{\Delta V^{OBS} = \Delta V^{signal} + \Delta V^{noise} = \frac{\rho}{K} I}$$

constant

constant

constant

I=20mA $\Delta V^{meas} = \Delta V^{signal} + 30\mathrm{mV} = \frac{12}{2\pi}0.02 \cong 38\mathrm{mV}$ $\Delta V^{noise} \cong 79\%\Delta V^{meas}$ $SNR \cong \frac{8}{30} \cong 0.26$

I=50mA $\Delta V^{meas} = \Delta V^{signal} + 30\mathrm{mV} = \frac{12}{2\pi}0.05 \cong 96\mathrm{mV}$ $\Delta V^{noise} \cong 31\%\Delta V^{meas}$ $SNR \cong \frac{66}{30} \cong 2.2$

I=100mA $\Delta V^{meas} = \Delta V^{signal} + 30\mathrm{mV} = \frac{12}{2\pi}0.1 \cong 191\mathrm{mV}$ $\Delta V^{noise} \cong 15.7\%\Delta V^{meas}$ $SNR \cong \frac{161}{30} \cong 5.4$

I=500mA $\Delta V^{meas} = \Delta V^{signal} + 30\mathrm{mV} = \frac{12}{2\pi}0.5 \cong 955\mathrm{mV}$ $\Delta V^{noise} \cong 3.1\%\Delta V^{meas}$ $SNR \cong \frac{925}{30} \cong 30.8$

Multi-electrode acquisition – Acquisition parameters

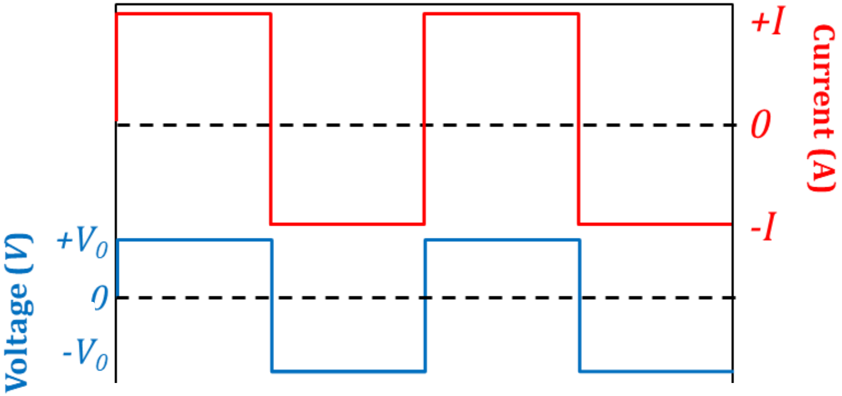
Stacking and pulse duration

It is convenient to perform different pulses of the same measurement (**stacks)** with reverse polarity of current electrodes (AB,BA or +-, -+) to have more than one measurement for each quadrupole and **cancel out coherent noise**. Consequently, we can **estimate also the measurement error**.

In absence of IP effects (see chap. 5.4) the pulse duration can be set as short as possible.

$$\Delta V^{OBS} = \frac{\Delta V_1 + \Delta V^{noise} - (-\Delta V_2 + \Delta V^{noise})}{2}$$

$$\Delta V^{OBS} = \frac{\Delta V_1 + \Delta V_2}{2}$$



Good compromise between acquisition time and data reliability: **from 2 to 4 stacks with a pulse duration between 250 and 500 ms**

Multi-electrode acquisition – Array choice

Signal strength (SS) — Inversely proportional to the geometric factor *K*

Depth of Investigation (DOI) — Directly proportional to the line length *L*

Array	a/L	*n*	*s*	*K*	*SS*	*NSS (Wenner)*	*DOI/L*	*NDOI (Pole-Dipole)*
Wenner	0.3333	-	-	2.094	0.477	100%	0.173	50%
Dipole-Dipole	0.3333	1	-	6.283	0.159	33.3%	0.139	39.8%
	0.2500	2	-	18.850	0.053	11.1%	0.174	49.9%
	0.2000	3	-	37.699	0.027	5.6%	0.192	55.0%
	0.1667	4	-	62.832	0.016	3.3%	0.203	58.2%
	0.1429	5	-	94.248	0.011	2.2%	0.211	60.5%
Wenner-Schlumberger	0.3333	1		2.094	0.477	100.0%	0.173	49.6%
	0.2000	2		3.770	0.265	55.6%	0.186	53.3%
	0.1429	3		5.386	0.186	38.9%	0.189	54.2%
	0.1111	4		6.981	0.143	30.0%	0.19	54.5%
	0.0909	5		8.568	0.117	24.4%	0.191	54.8%
Multiple Gradient	0.0909	1	9	1.120	0.893	187.0%	0.0481	13.8%
	0.0909	2	9	3.160	0.316	66.3%	0.0897	25.7%
	0.0909	3	9	5.640	0.177	37.1%	0.1347	38.6%
	0.0909	4	9	7.740	0.129	27.1%	0.1743	50.0%
	0.0909	5	9	8.570	0.117	24.4%	0.1902	54.5%
Pole-Dipole	0.5000	1	-	6.283	0.159	33.3%	0.2595	74.4%
	0.3333	2	-	12.566	0.080	16.7%	0.30833	88.4%
	0.2500	3	-	18.850	0.053	11.1%	0.327	93.7%
	0.2000	4	-	25.133	0.040	8.3%	0.3412	97.8%
	0.1667	5	-	31.416	0.032	6.7%	0.34883	100%

SS standings

1. Wenner
2. Gradient
3. Wenner-Schlumberger
4. Pole-dipole
5. Dipole-dipole

DOI standings

1. Pole-dipole
2. Dipole-dipole
3. Wenner-Schlumberger
4. Gradient
5. Wenner

Rule of thumb:
DOI~20-25% *L*

Multi-electrode acquisition – Array choice

Signal strength

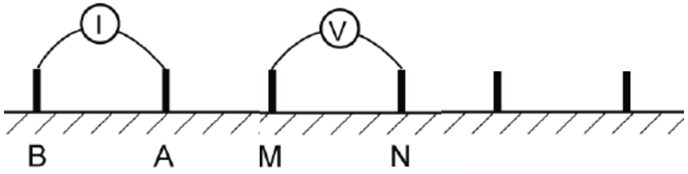
Ex. 2

$\rho_a = \rho = 12\ \Omega\text{m}$ homogeneous ground

$I = 1\ \text{A}$

constant noise level = 30 mV

11 electrodes - dipole-dipole array



$$K = \pi n(n+1)(n+2)a$$

$$\boxed{{\rho_a}^{OBS} = K\frac{\Delta V^{OBS}}{I}}$$

constant

constant

$$\boxed{\Delta V^{OBS} = \Delta V^{signal} + \Delta V^{noise} = \frac{\rho}{K}}$$

a=1; n=1 - K=6π m $\Delta V^{meas} = \Delta V^{signal} + 30\text{mV} = \frac{12}{6\pi} = \frac{2}{\pi} \cong 636\text{mV}$ $\Delta V^{noise} \cong 4.7\%\Delta V^{meas}$

a=1; n=2 - K=24π m $\Delta V^{meas} = \Delta V^{signal} + 30\text{mV} = \frac{12}{24\pi} = \frac{1}{2\pi} \cong 160\text{mV}$ $\Delta V^{noise} \cong 18.7\%\Delta V^{meas}$

a=1; n=3 - K=60π m $\Delta V^{meas} = \Delta V^{signal} + 30\text{mV} = \frac{12}{60\pi} = \frac{1}{5\pi} \cong 63\text{mV}$ $\Delta V^{noise} \cong 47.6\%\Delta V^{meas}$

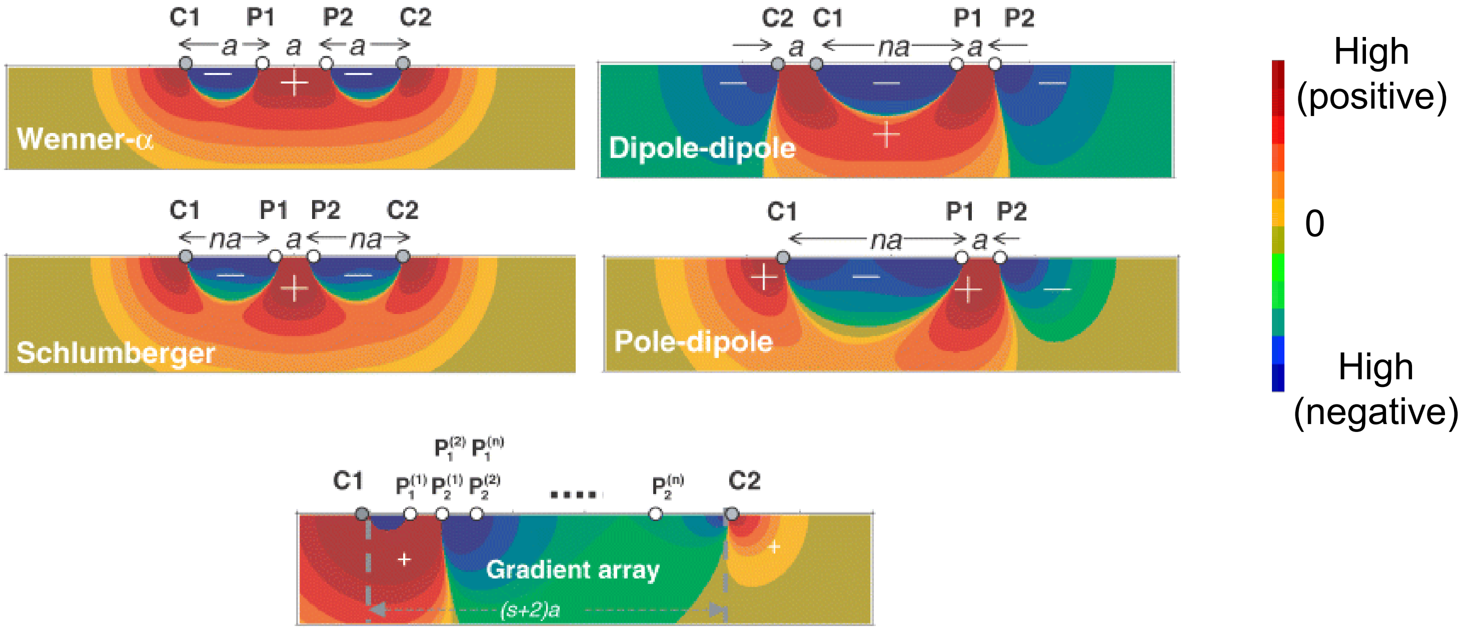
a=2; n=3 - K=120π m $\Delta V^{meas} = \Delta V^{signal} + 30\text{mV} = \frac{12}{120\pi} = \frac{1}{10\pi} \cong 31.5\text{mV}$ $\Delta V^{noise} \cong 95.2\%\Delta V^{meas}$

Multi-electrode acquisition – Array choice

<u>Sensitivity</u>
<u>(Resolution)</u>

Some arrays are more sensitive to changes in vertical direction, other to changes in the horizontal direction

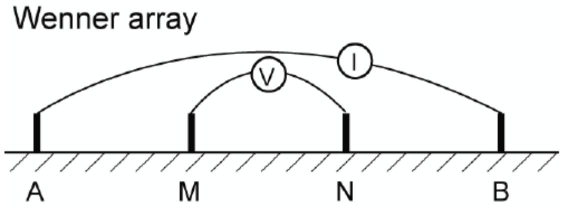
Good vertical sensitivity **Good lateral sensitivity**



Multi-electrode acquisition – Array choice

Cost-effectiveness

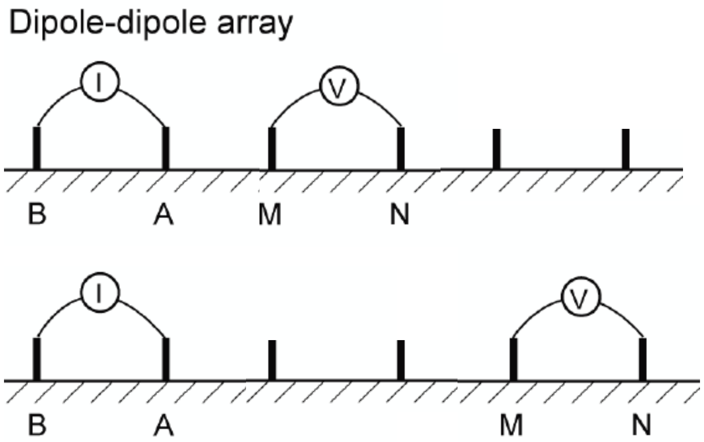
Wenner and Wenner-Schlumberger



fixed array: I need to move the current electrodes to perform other measurements

I cannot execute more than one voltage measurement for each current injection → **SLOW**

Dipole-dipole, pole-dipole and gradient



flexible array

I can execute more voltage measurements for each current injection, because **MN can be shifted** along the line, being fixed AB → **RAPID**

Array choice

Signal strength

1. Wenner
2. Gradient
3. Wenner-Schlumberger
4. Pole-dipole
5. Dipole-dipole

DOI

1. Pole-dipole
2. Dipole-dipole
3. Wenner-Schlumberger
4. Gradient
5. Wenner

Sensitivity (Resolution)

1. Gradient
1. Wenner-Schlumberger
3. Pole-dipole
3. Dipole-dipole
3. Wenner

Cost-effectiveness

1. Dipole-dipole
1. Pole-dipole
1. Gradient
4. Wenner
4. Wenner-Schlumberger

Final standings
(if the weight of all parameters is the same)

1. Gradient (8 points)
2. Pole-dipole (9 points)
3. Dipole-dipole (11 points)
4. Wenner-Schlumberger (11 points)
5. Wenner (13 points)

However, for a specific application, one parameter could be more important than the others!!!