8. Electrostatics

Propose and make a device for measuring the charge density on a plastic ruler after it has been rubbed with a cloth.

Apparatus general

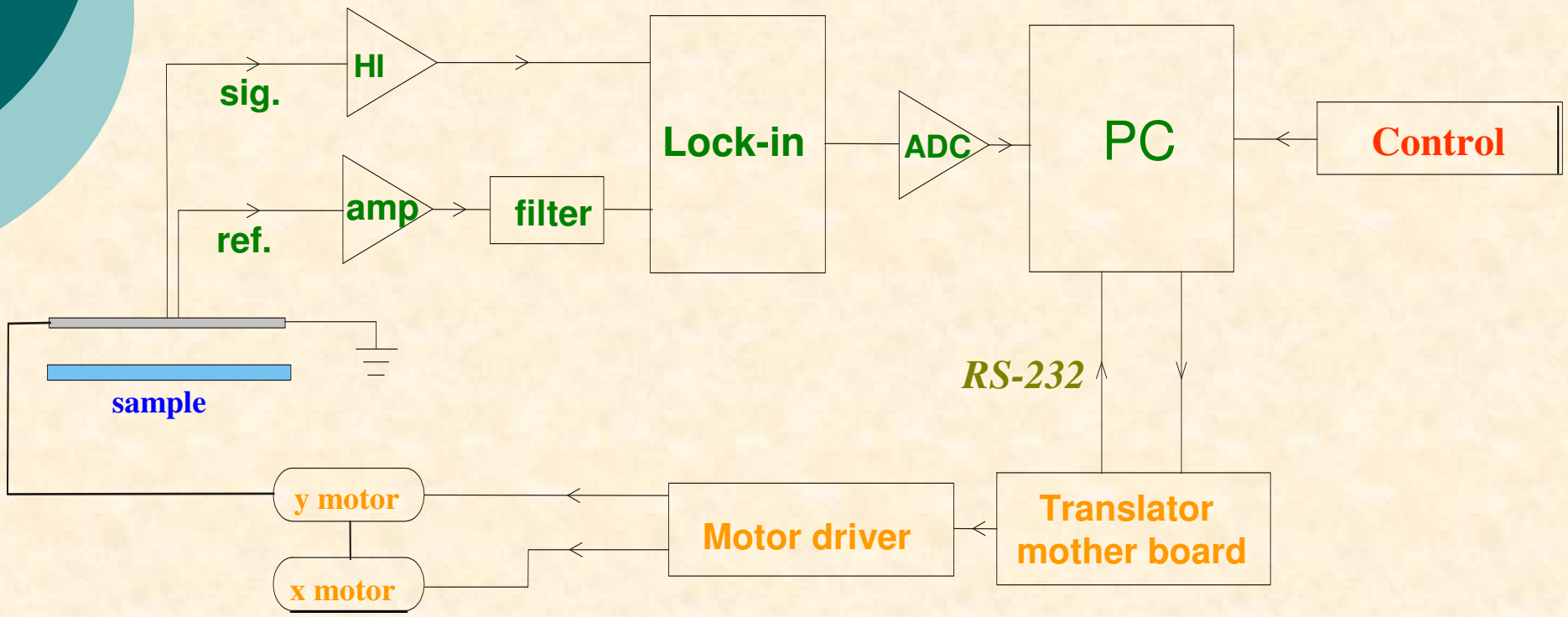
Main parts of our device:

1. **The probe**
2. **High impedance unit**
3. **Reference signal electronics**
4. **Lock-in amplifier**
5. **X-Y translator**
6. **Data acquisition**

Apparatus general



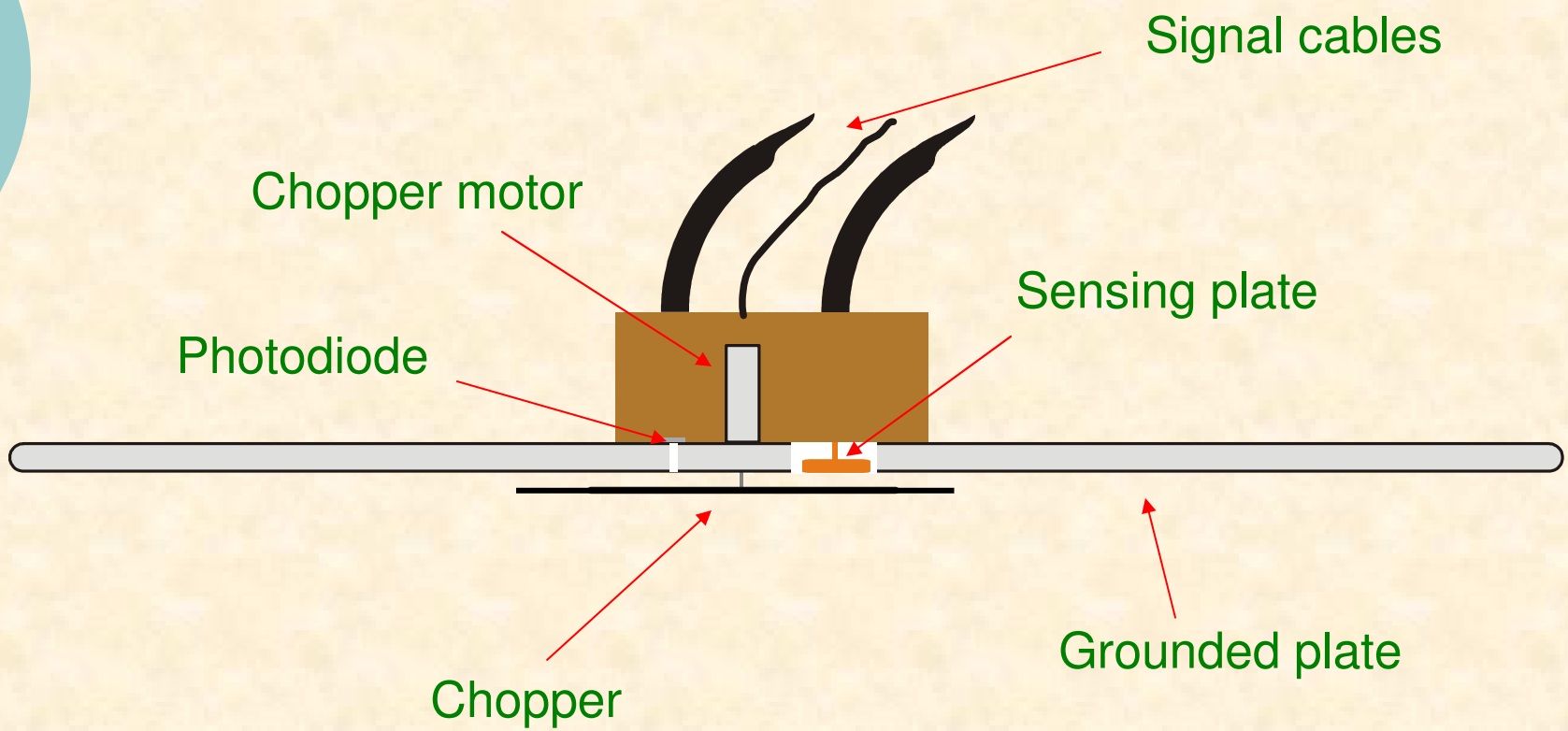
Block diagram



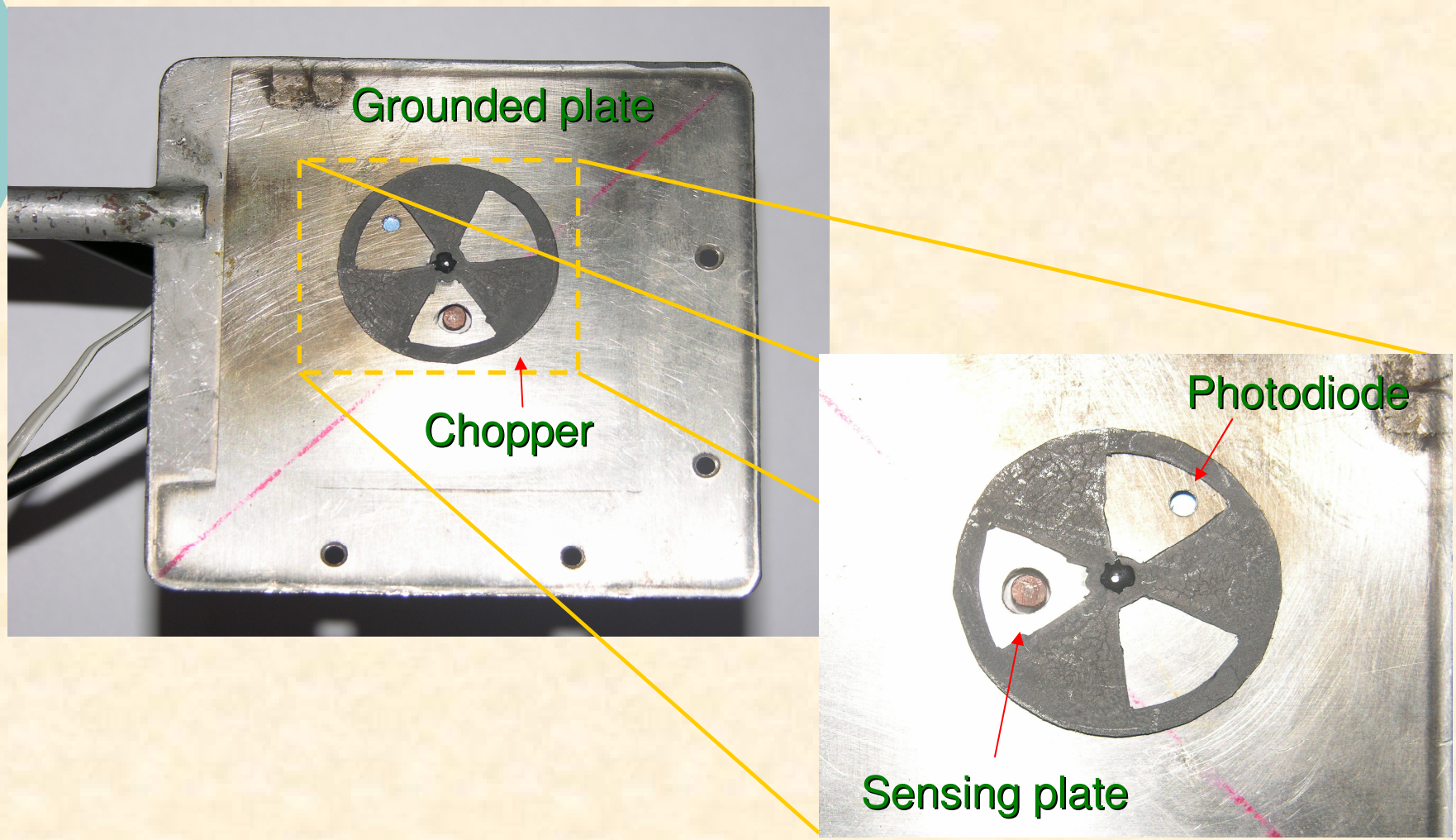
1. The probe

- Probe – detects the potential above charged ruler
- Parts:
  - Copper sensor plate – acts as potential detector
  - Grounded plate – ″doubles″ charge, eliminates upward field gradient
  - Chopper – grounded rotating disc with holes – induces AC signal on sensor
  - Photodiode/optointerrupter – phase reference

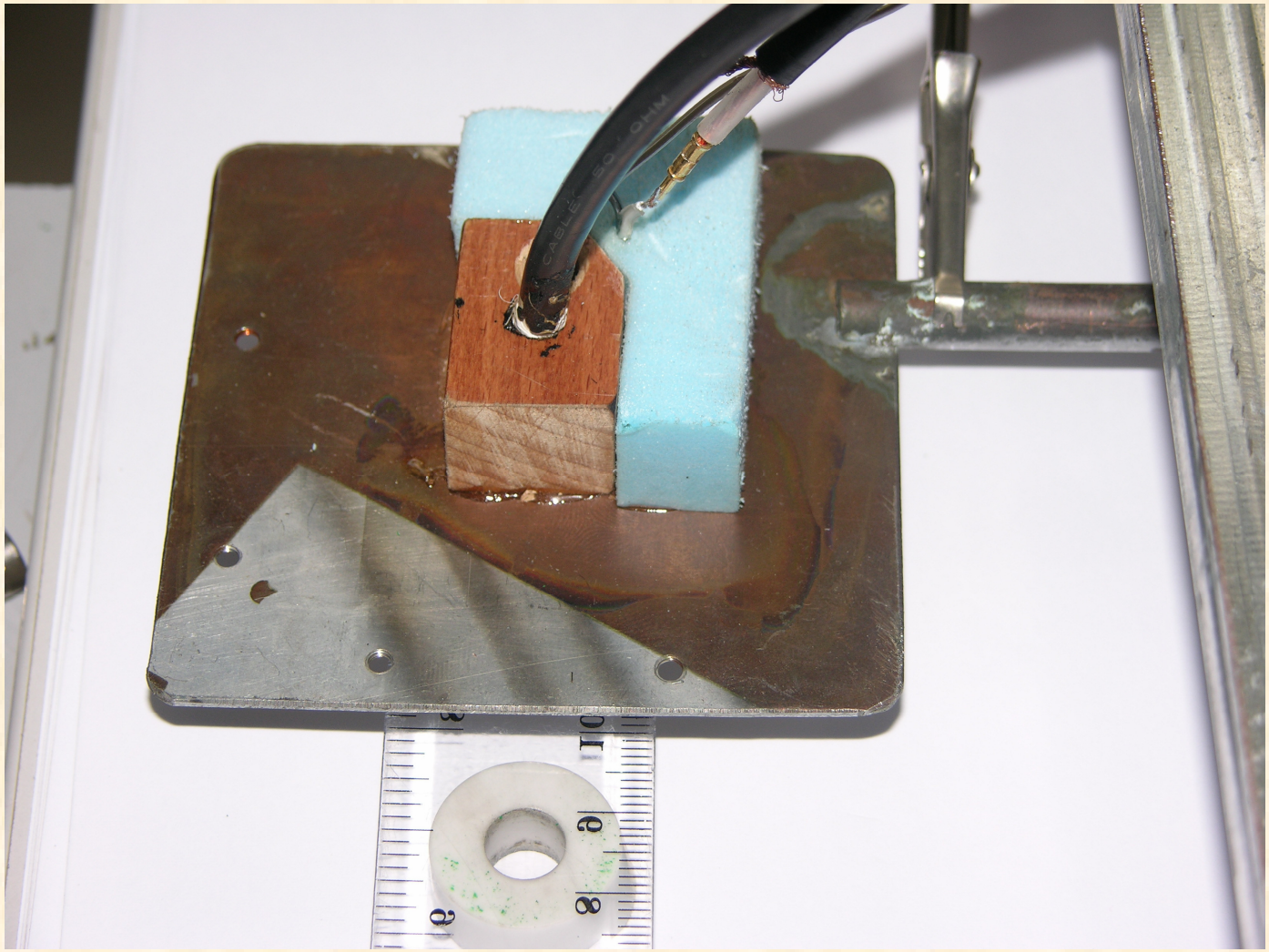
The probe cont.



The probe cont.

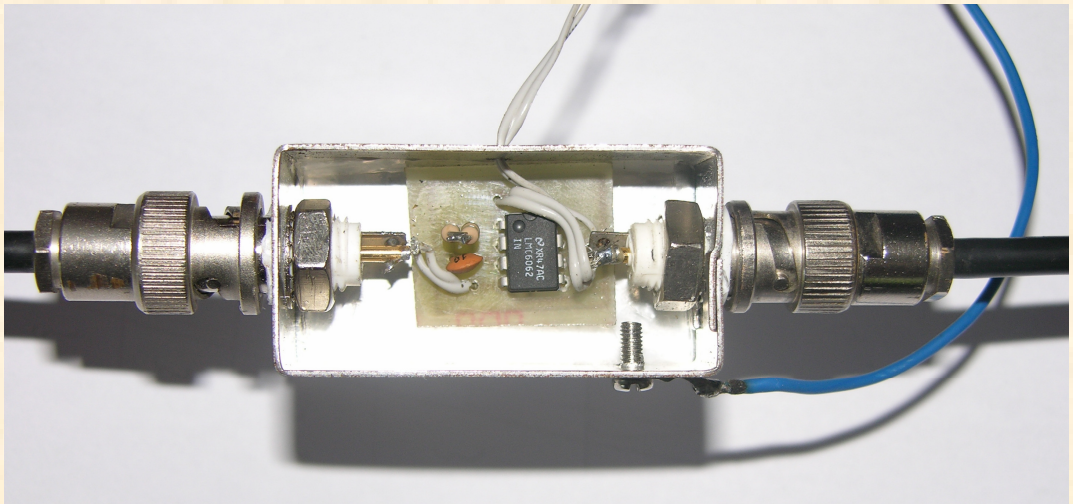


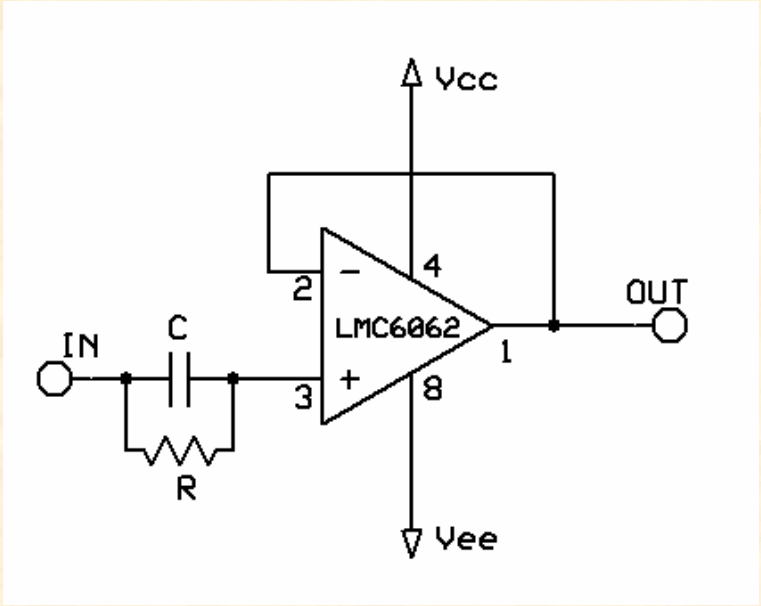
The probe cont.



2. High impedance unit

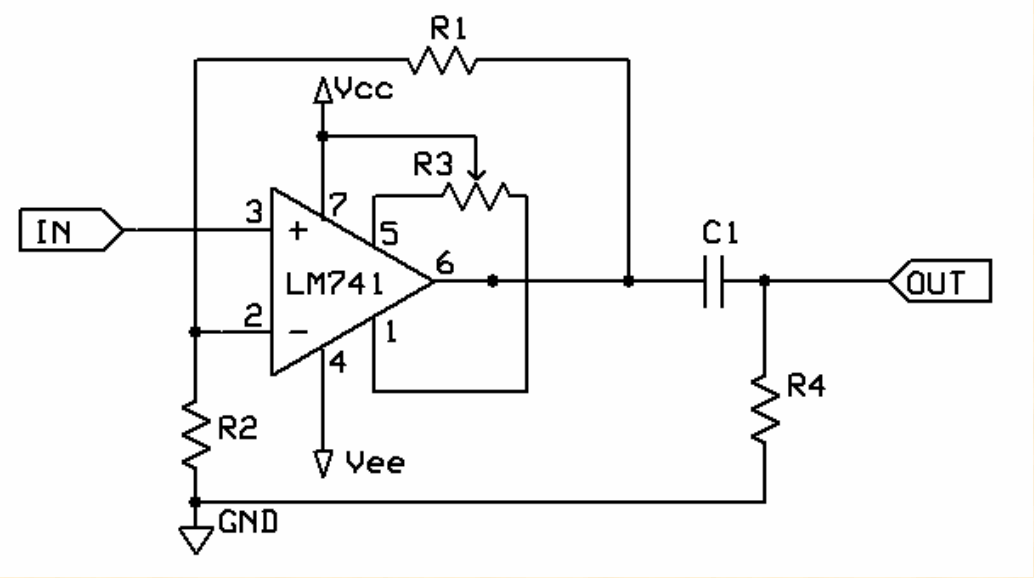
- Picks up signal from sensor plate
- Impedance about 12 Tohm
- Signal opamp follower
- Main part : LMC6026
- Grounded metal cover

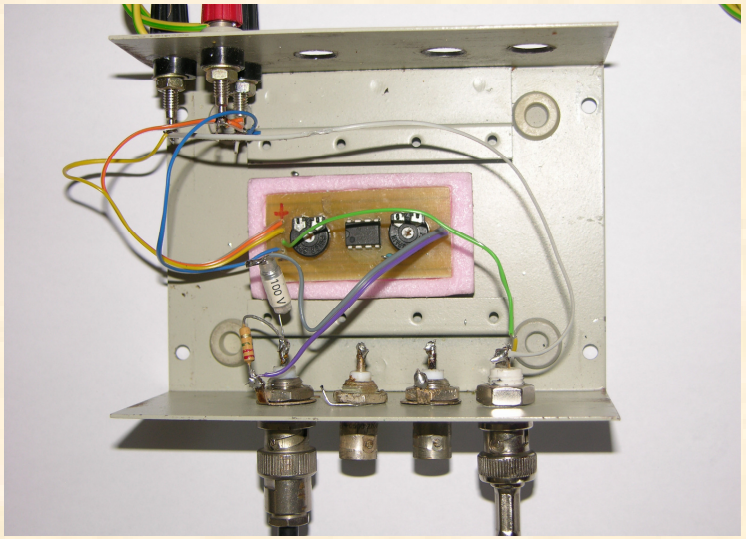




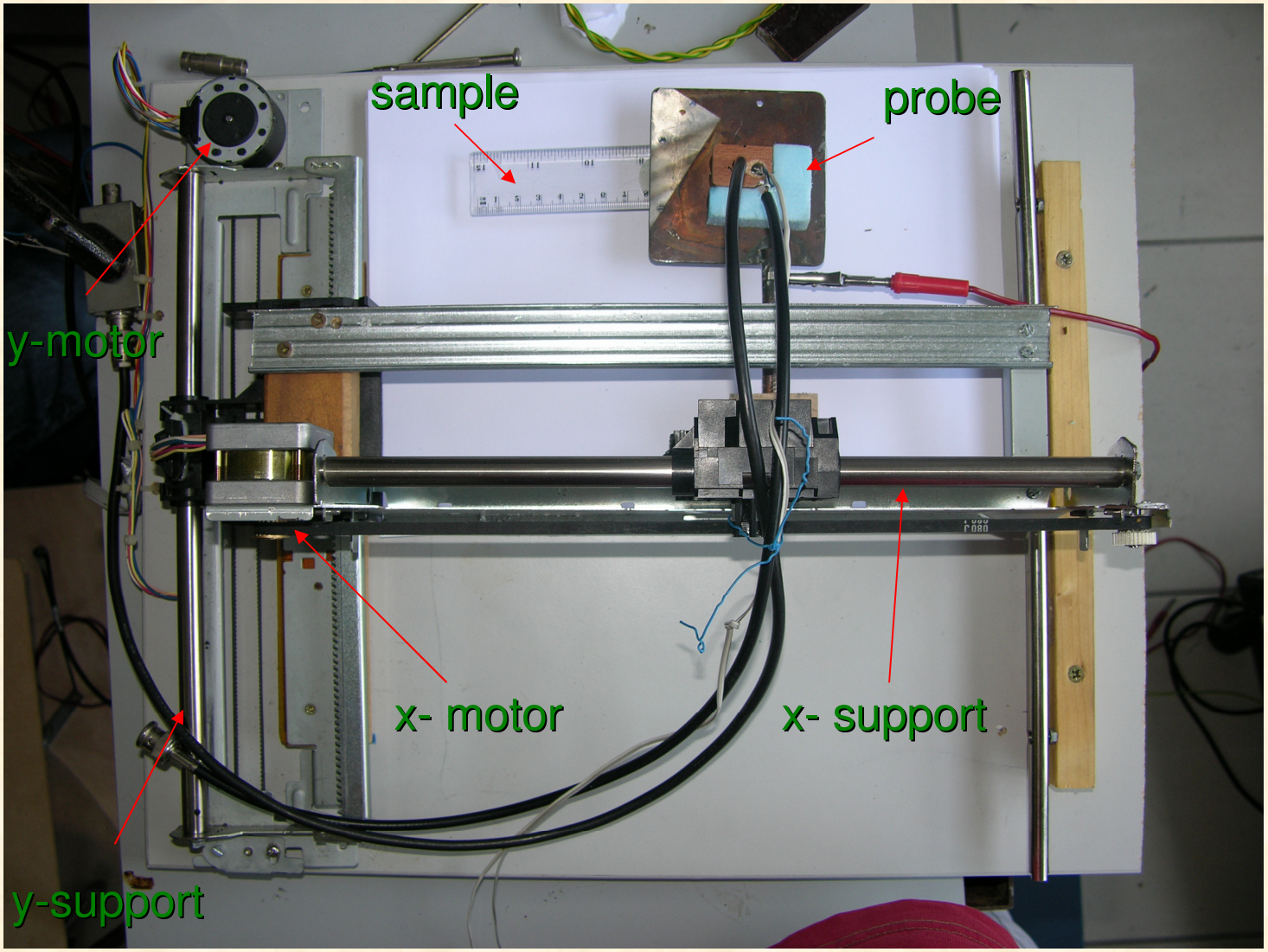
3. Reference signal processing

- Signal form optointerrupter – phase&frequency reference for sensor
- Signal is amplified
- Passive RC filter – DC offset removal





4. xy – translator

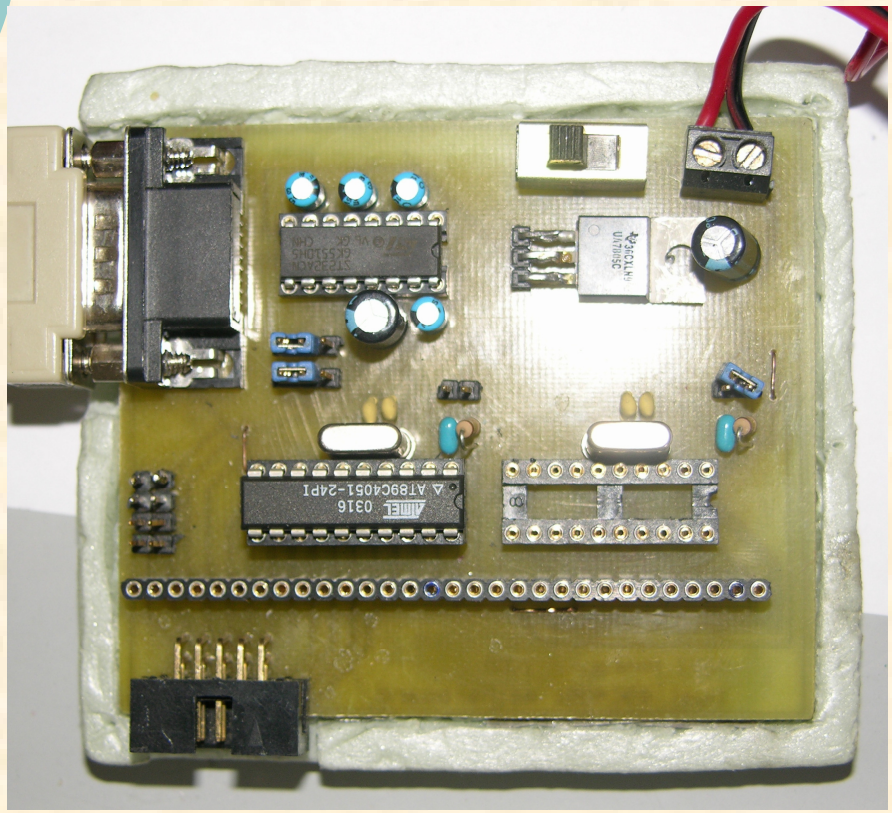


xy – translator cont.

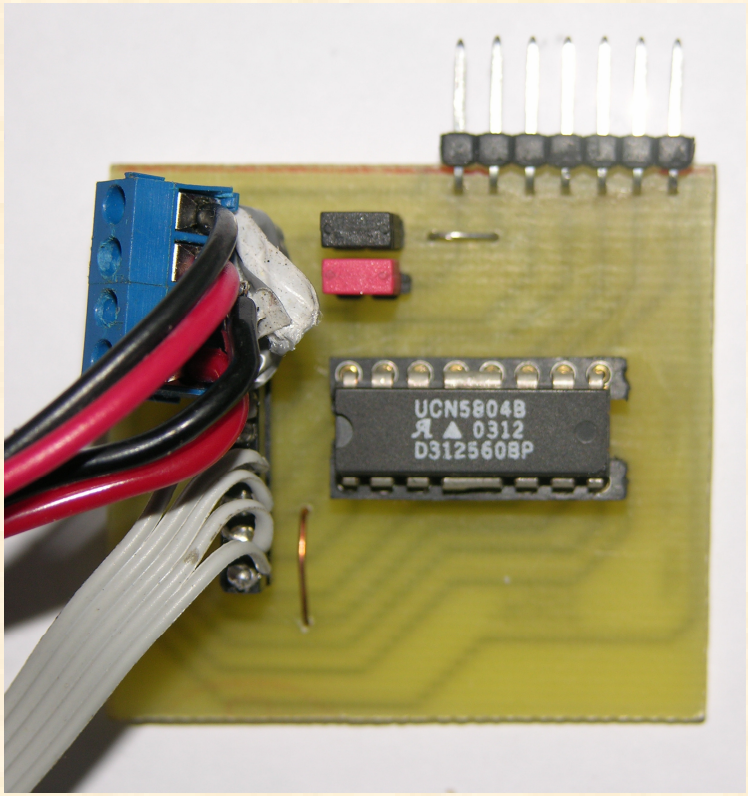
- Translator motherboard
  - RS-232 communication
  - 8051 family processor
  - Parallel motor driver control
- Stepper driver
  - Allegro UCN5804
  - Low power (1A current)
  - Parallel communication
- PC software
  - Pascal written
  - Control and data acquisition

xy – translator cont.

Motherboard



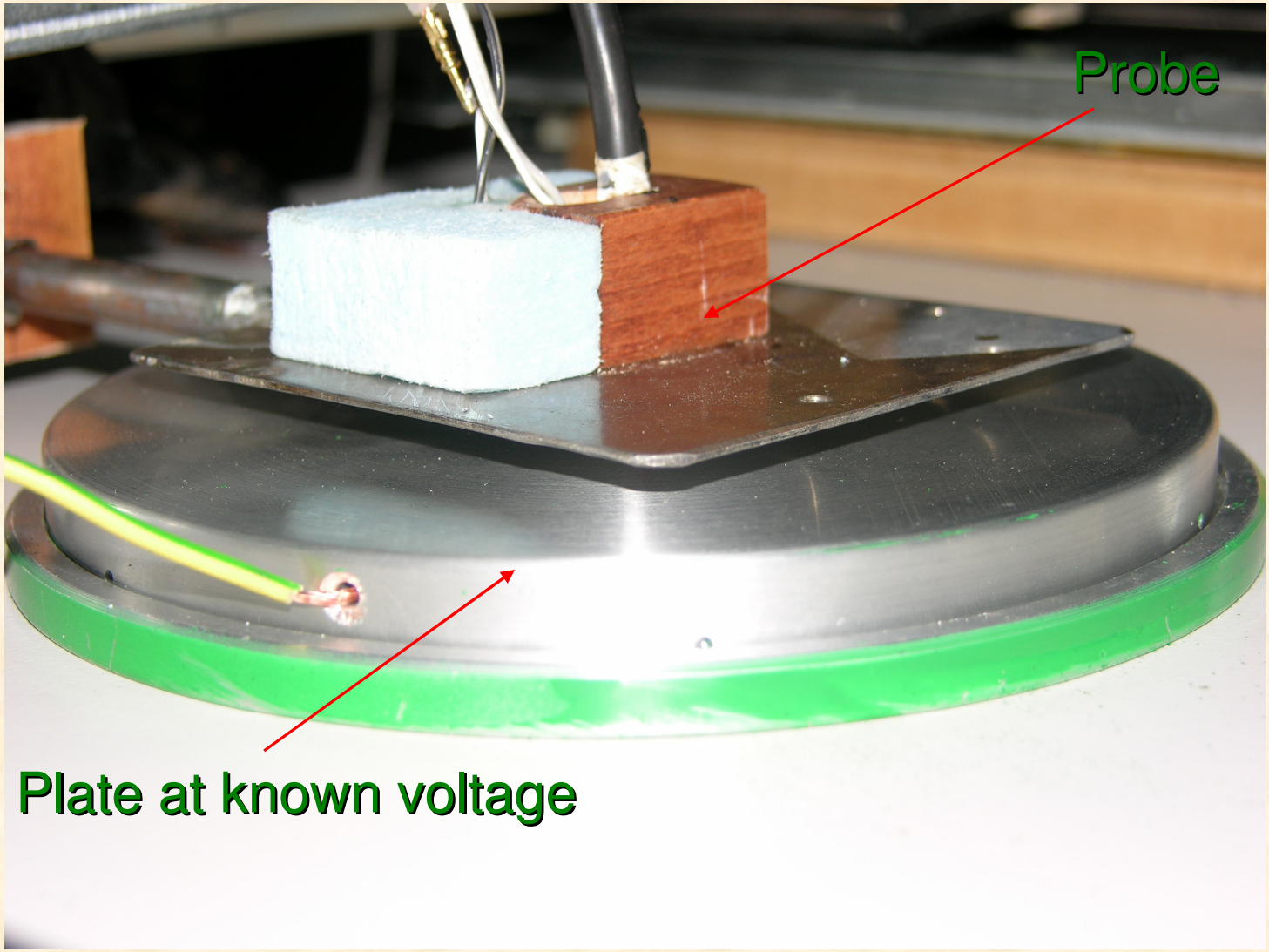
Stepper driver



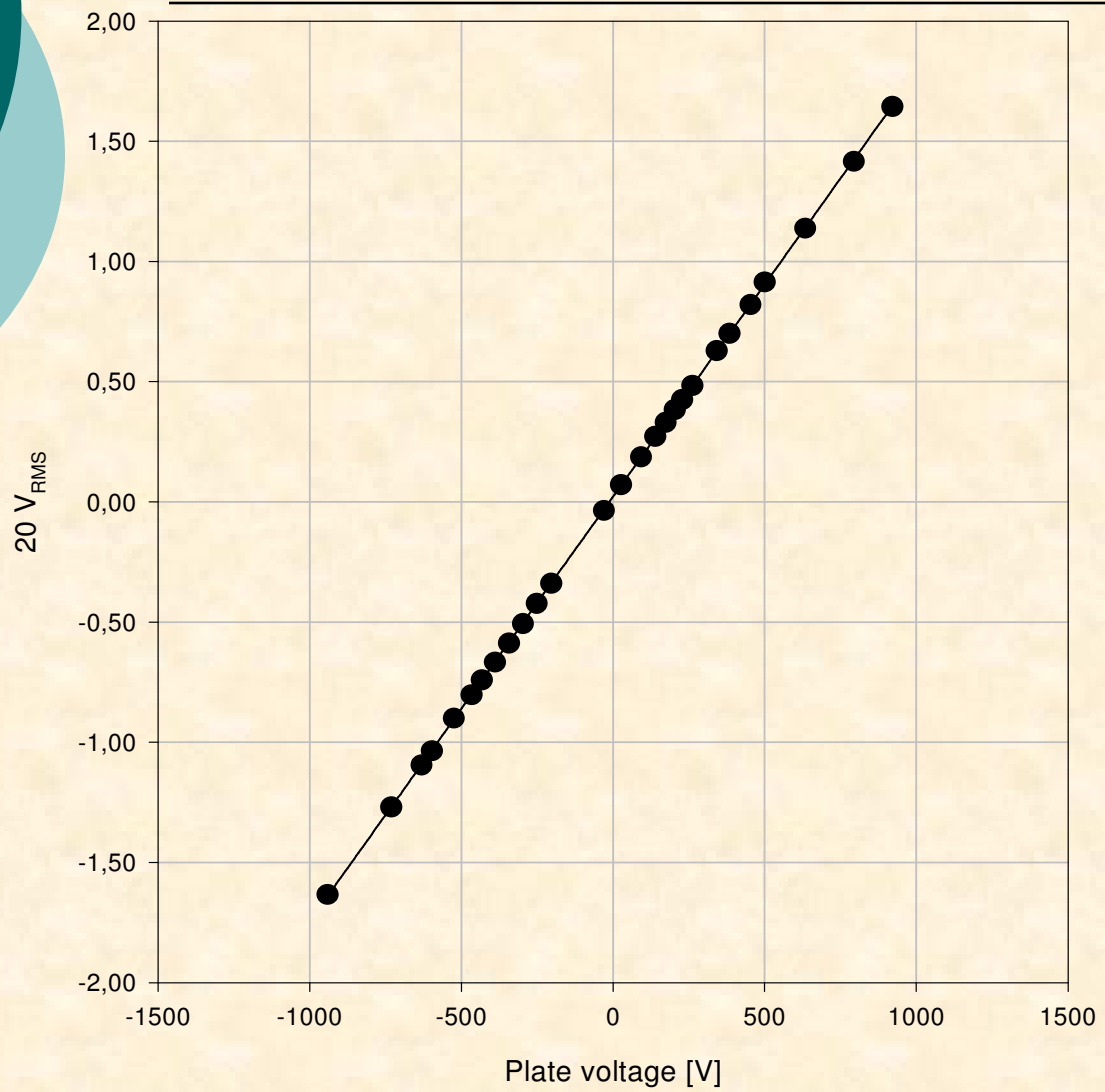
Measurement

- Device calibration
  - Static voltage measurement
  - Sample - known charge
  - Metal plate
  - Charge source - HV supply
- Real measurement
  - Scanning over sample
  - Sample - rubbed ruler
  - Result - potential map

1. Calibration



Calibration cont.

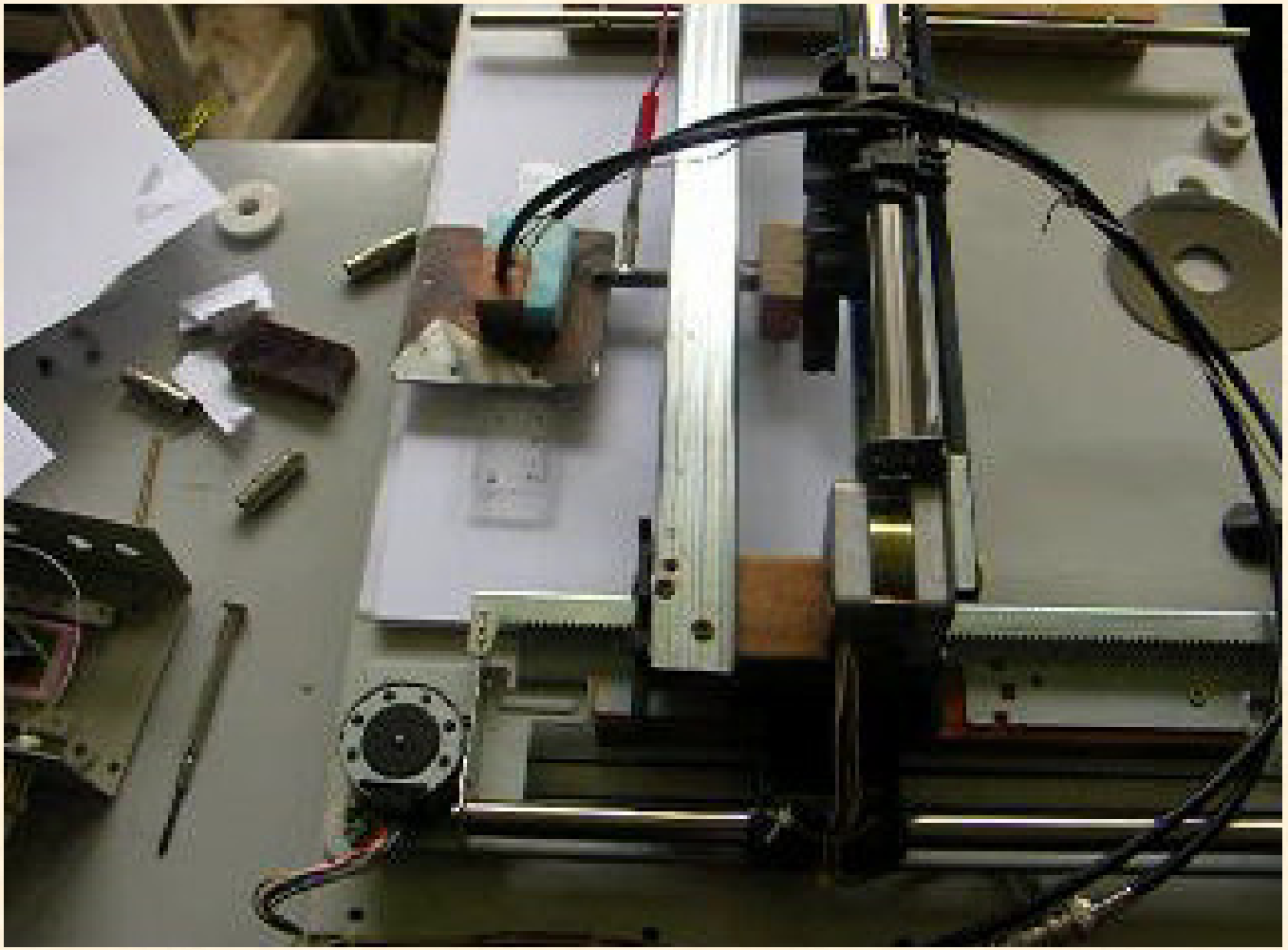


$$\varphi = 11300 V_{RMS}$$

Φ – potential

V_{RMS} – root mean square voltage from sensor

2. Real sample measurement



2. Real sample measurement

- **Measured: potential maps**
- **Sensor distance from ruler 5 mm**
- **Step size 1 mm**
- **Number of steps**

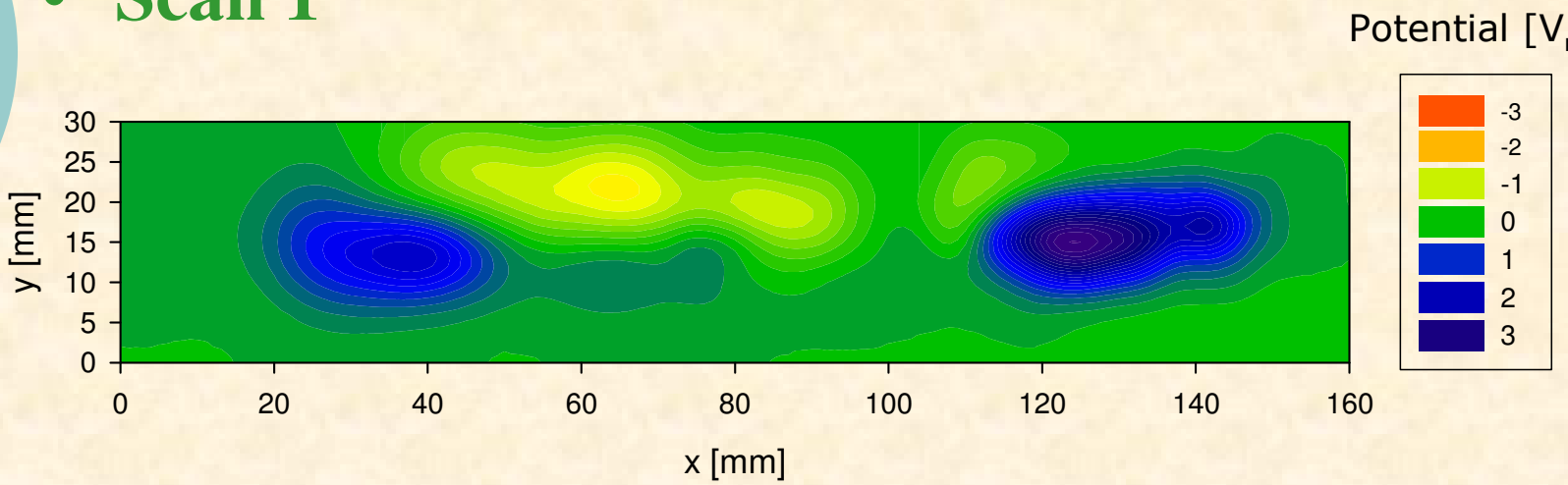
  first map 5796

  second map 4991

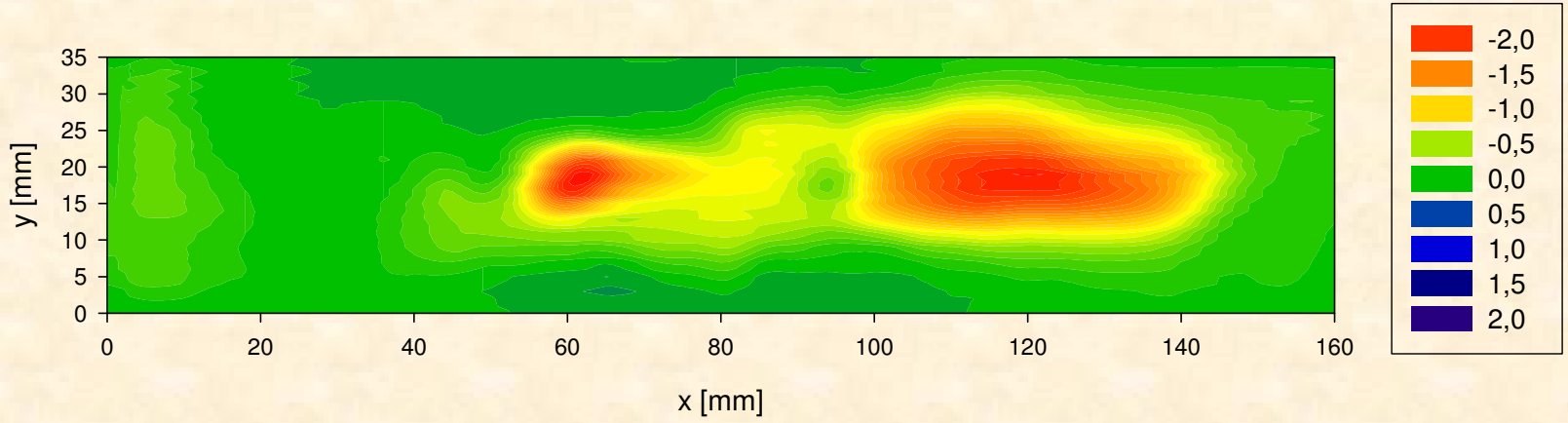
Ruler length [mm]	Ruler width [mm]
150	30

Real sample measurement cont.

- **Scan 1**



- **Scan 2**



Charge calculation

- **Potential at sensor due to all charged parts of ruler:**

$$V_n(x_s, y_s) = \frac{1}{4\pi\varepsilon_0} \sum_{i=0}^{NM} \frac{\sigma_{ij}\Delta x \Delta y}{\left[(x_s - x_i)^2 + (y_s - y_i)^2 + h^2\right]^{\frac{1}{2}}}$$

x_s, y_s – sensor coordinates
ε_0 – vacuum permittivity
N – number of x – steps
M – number of y – steps

σ_i – charge density on place i
x_i, y_i – place i coordinates
Δx, Δy – coordinate steps
h – sensor elevation

Charge calculation cont.

- **In matrix form:**

$$\begin{pmatrix} V_1 \\ V_2 \\ \mathrm{M} \\ V_n \end{pmatrix} = \frac{\Delta x \Delta y}{4\pi\varepsilon_0} \begin{pmatrix} a_{11} & a_{12} & \Lambda & a_{1n} \\ a_{21} & a_{22} & \Lambda & a_{2n} \\ \mathrm{M} & & & \mathrm{M} \\ a_{n1} & a_{n2} & \Lambda & a_{nn} \end{pmatrix} \begin{pmatrix} \sigma_1 \\ \sigma_2 \\ \mathrm{M} \\ \sigma_n \end{pmatrix}$$

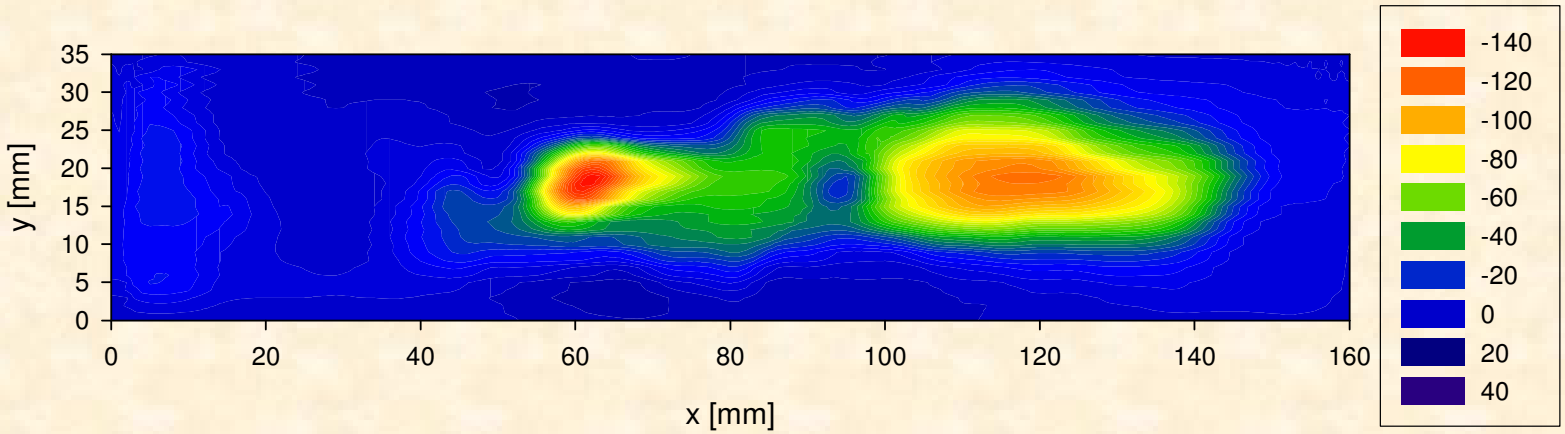
$$a_{ij} = \left[\left(x_i - x_j \right)^2 + \left(y_i - y_j \right)^2 + h^2 \right]^{-\frac{1}{2}}$$

- **Solved with Gauss algorithm**

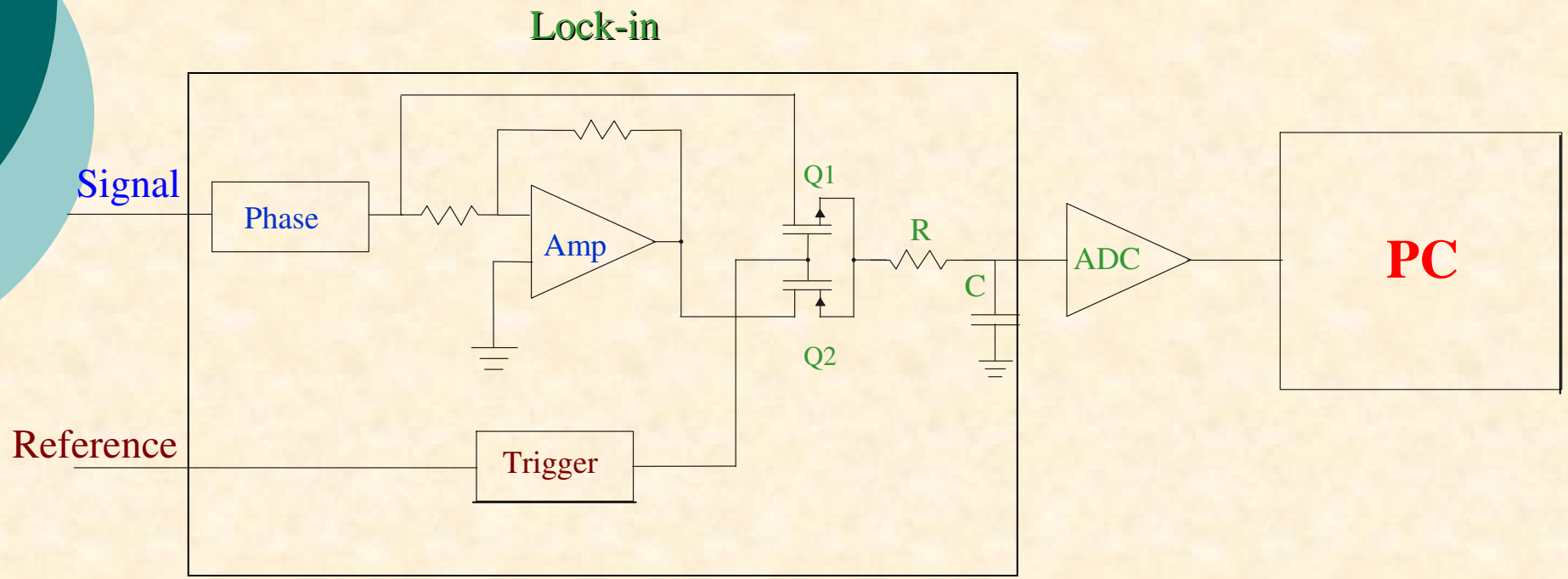
Charge calculation cont.

⇒ **Scan 1:**

Scan 2:



Lock-in and Data Acquisition



Lock-in amplifier :

- Unity gain
- Inverting amplifier
- Trigger - TTL signal
- FET circuit
- RC lowpass filter

Data acquisition :

- MAX 1240
- Parallel communication
- 12-bit A/D conversion
- Arbitrary sampling
- Our logging software