Precision Tiltmeter for the EDM Experiment

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- Tiltmeter Principle
- Readout
- Tiltmeter Characterization: Temperature
- Future Plans
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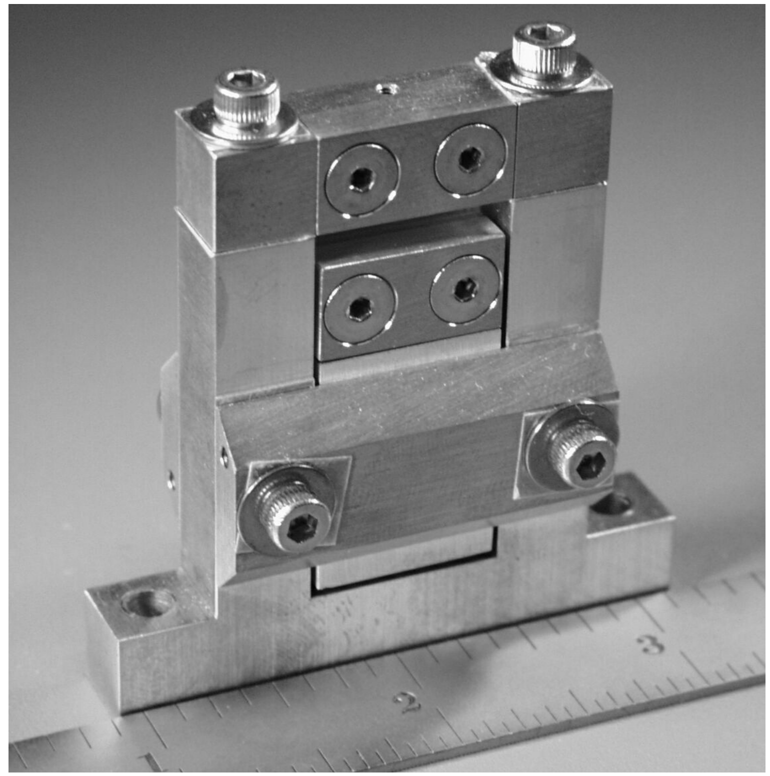
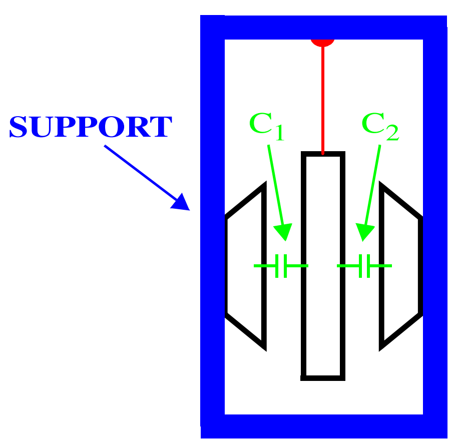
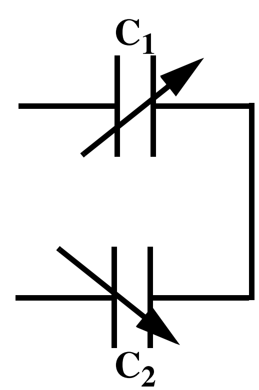
Acknowledgment:

The EDM Collaboration, especially G. Bennet, R. Burns, W. Morse, Y. Semertzidis, L. Snydstrup

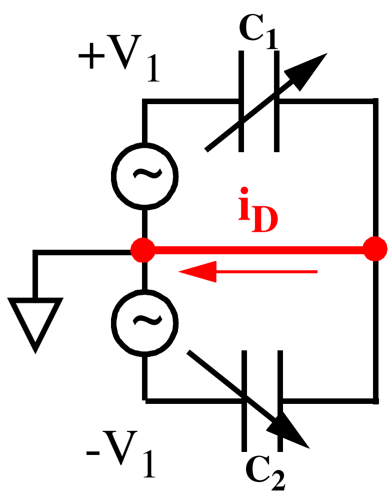
Tiltmeter







Readout: AC Bridge



$C_1 - C_2 = \varepsilon A/(\delta x - x_0) - \varepsilon A/(\delta x + x_0) = 2 C_0 \delta x/x_0$

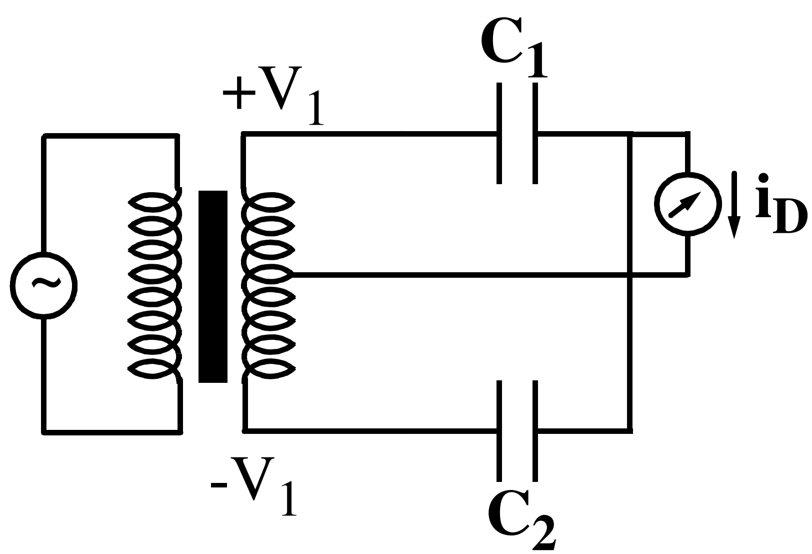
$A=400\ mm^2$ $x_0 = 75\ \mu m$ $C_1 = C2 = 50\ pF$

$l = 30\ mm$ $\delta\theta = 1\ nrad$ $\delta x = \delta\theta\, l = 30\ 10^{-12}\ m$

$\delta C = C_1 - C_2 = 40\ aF$

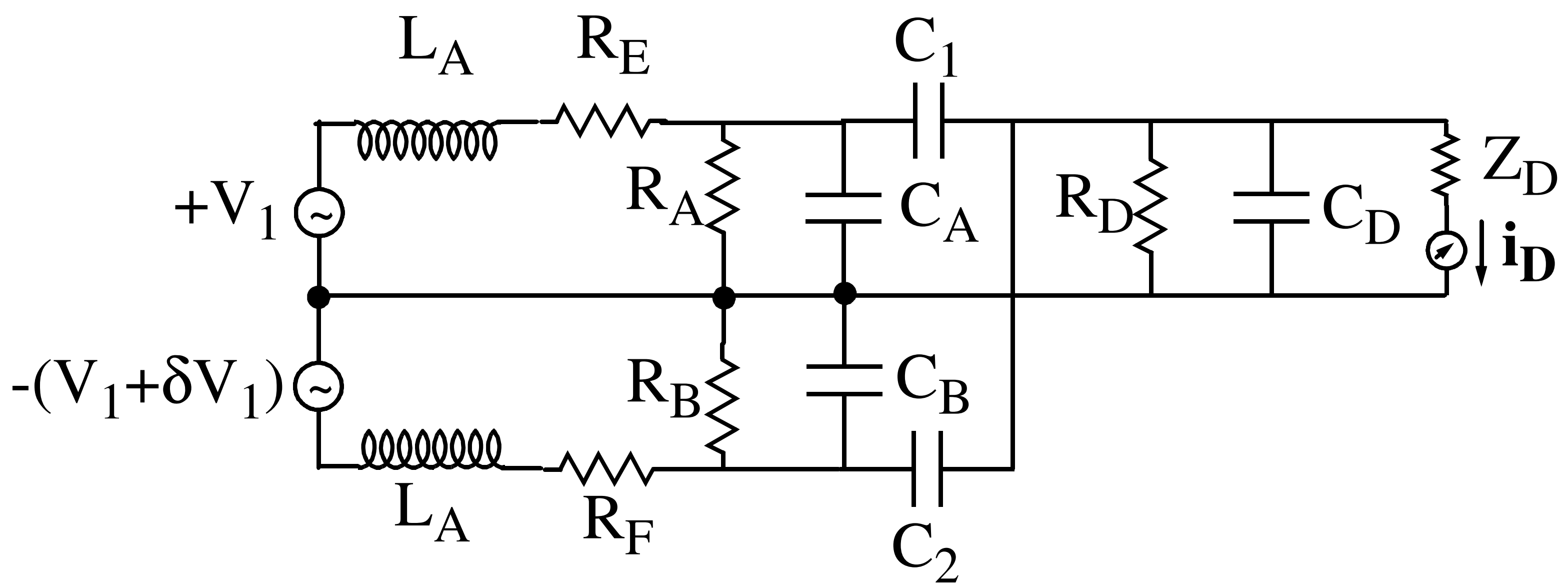
$$Force = \frac{1}{2} \cdot \frac{C_1}{x_0} \cdot V_1^2$$

Force=F = 0 for a symmetrical system



$i_D = V1\ \omega\ (C_1 - C_2)$

AC Bridge: Readout Equivalent Circuit

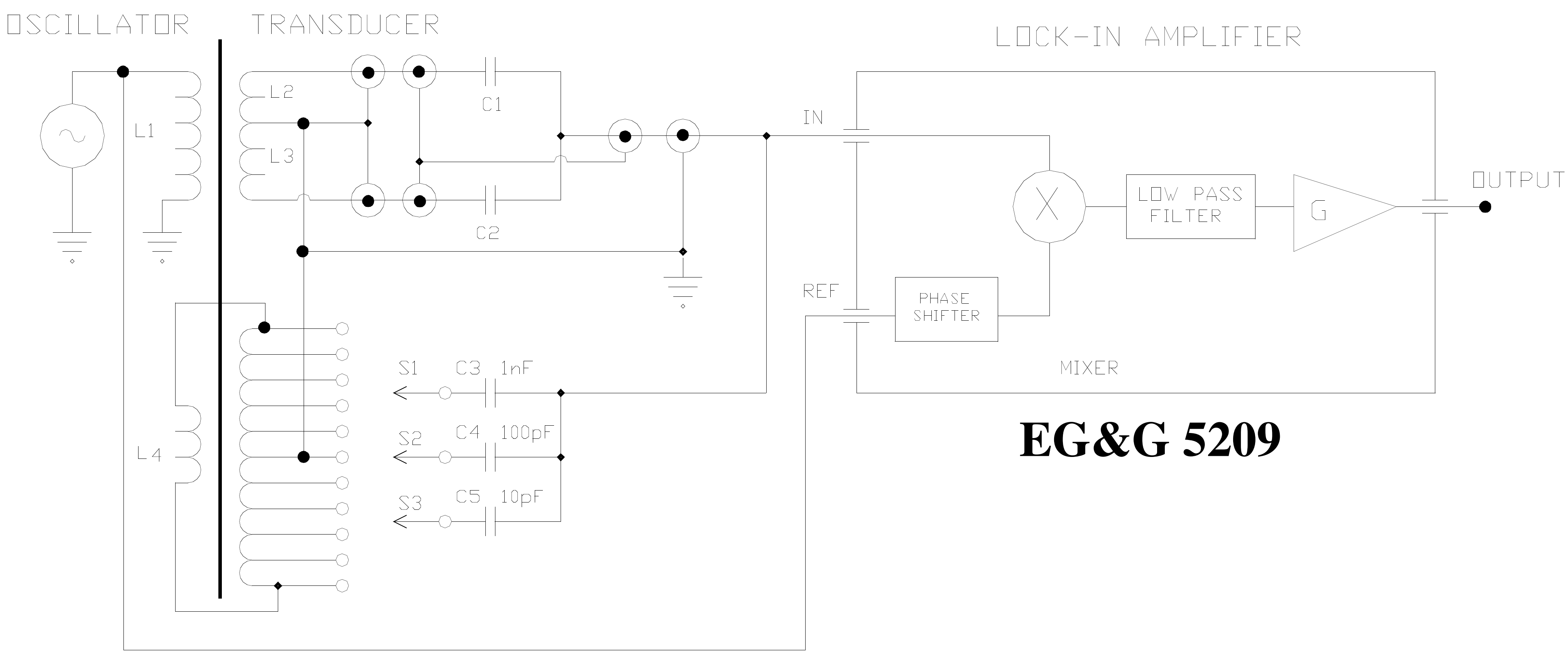


For zero output from the capacitance balance detector must be:

$$\frac{C_1}{C_2} = 1 + L_B(C_2 + C_B)\omega^2 - L_A(C_1 + C_A)\omega^2 + \frac{R_E}{R_A} - \frac{R_F}{R_B} + \frac{\delta V_1}{V_1}$$

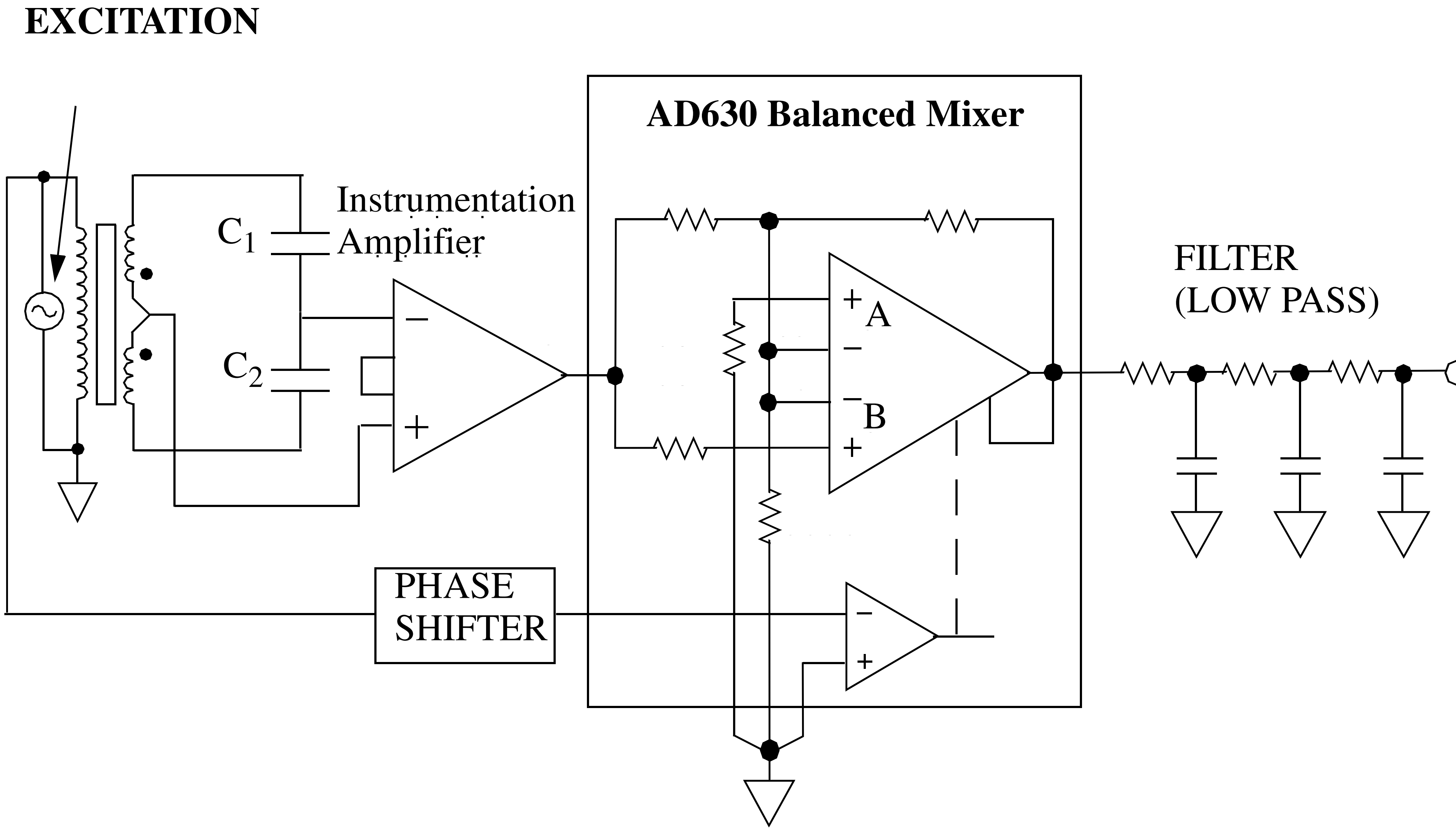
L_A, L_B	0.4 mH	ratio transformer Leakage inductance
R_E, R_F	<1 Ω	transformer secondary DC resistance
R_A, R_B	>10 MΩ	Dielectric losses
C_A, C_B	~ 1000 pF	Stray capacitance to "ground" (cables, interwinding C)
R_D, C_D		Impedance shunting the preamplifier. Does not affect balance
Z_D	low	Current preamplifier input impedance

Readout: Synchronous Detection Method (Lock-in Aplifier)
Electronic Zeroing



EG&G 5209

Readout Circuit



Sources of Errors

- **Humidity variations**

  at 20°C a change in humidity from 40 to 90% changes the dielectric constant by 200 ppm

- **Temperature variations**

  Thermal expansion => cancelled in a symmetrical design

  Effects on the readout electronics: Gain Variation

  temperature dependence of dielectric constant (2 10^{-6}/°C for dry air at STP;

  700 10^{-6} for moist air

- **Pressure changes**

  a pressure change of 1 atm at 20°C changes the dielectric constant by 200 ppm

  causes dimensional changes (a brass cube of 1 cm contracts by 3 μm for a 1 atm change)

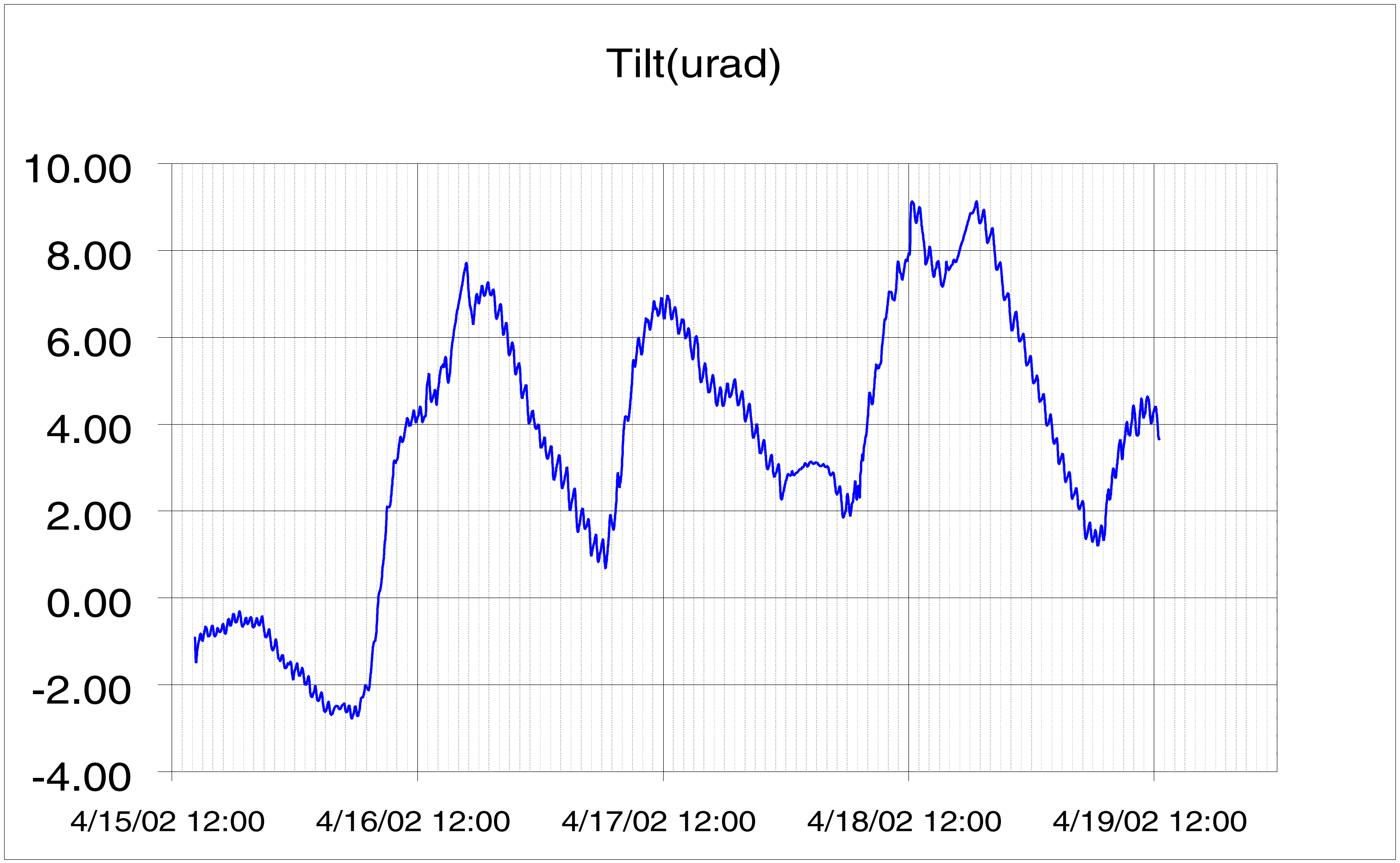
- **Oxidation of surfaces (rodium plating recommended)**
- **Stability of materials (70-30 brass gives good results)**
- **Creep of materials**
- **Relaxation of screw tension**
- **Microseismicity (about 2 μm peak to peak displacement, period 3-8 s)**

Temperature Dependence Studies:

$$V_{OUT}(\theta, T) = K_1(T) \times \theta + K_2(T)]$$

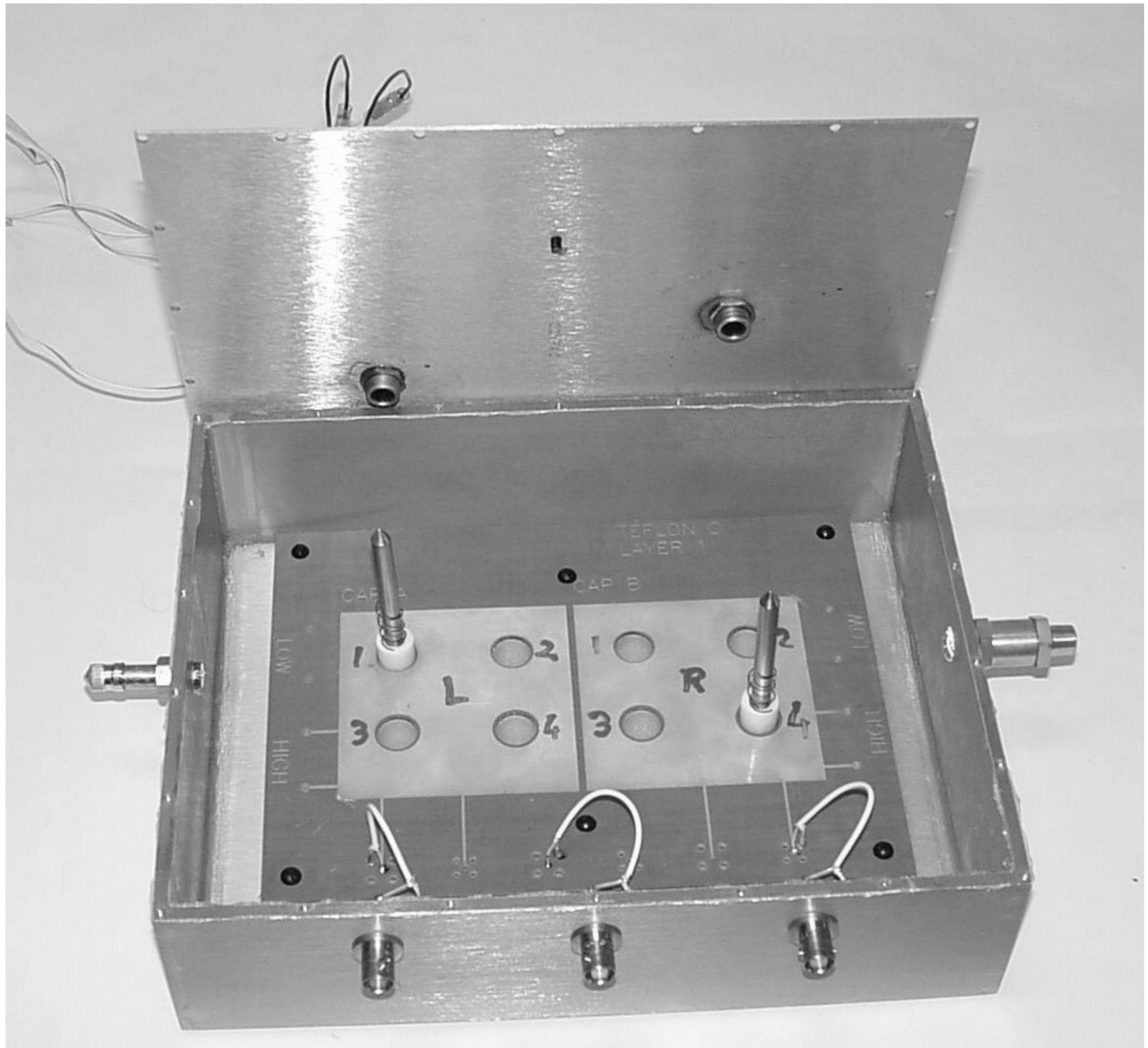
- **K_1 (gain): weakly dependent on T**
- **K_2 (offset): there is evidence of some dependence on T, but it is difficult to study (ground shifts constantly)**

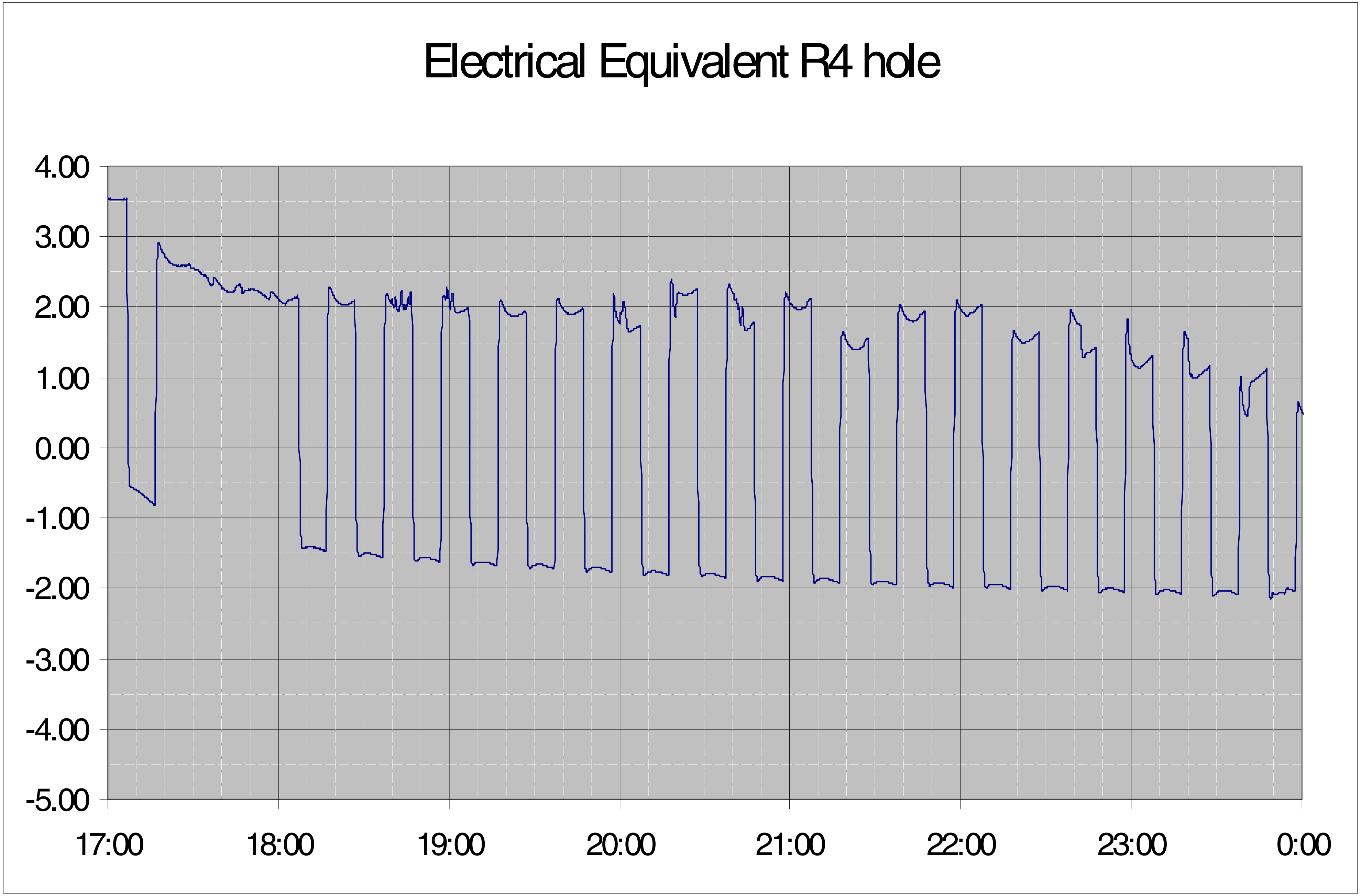
Instrumentation Division Basement



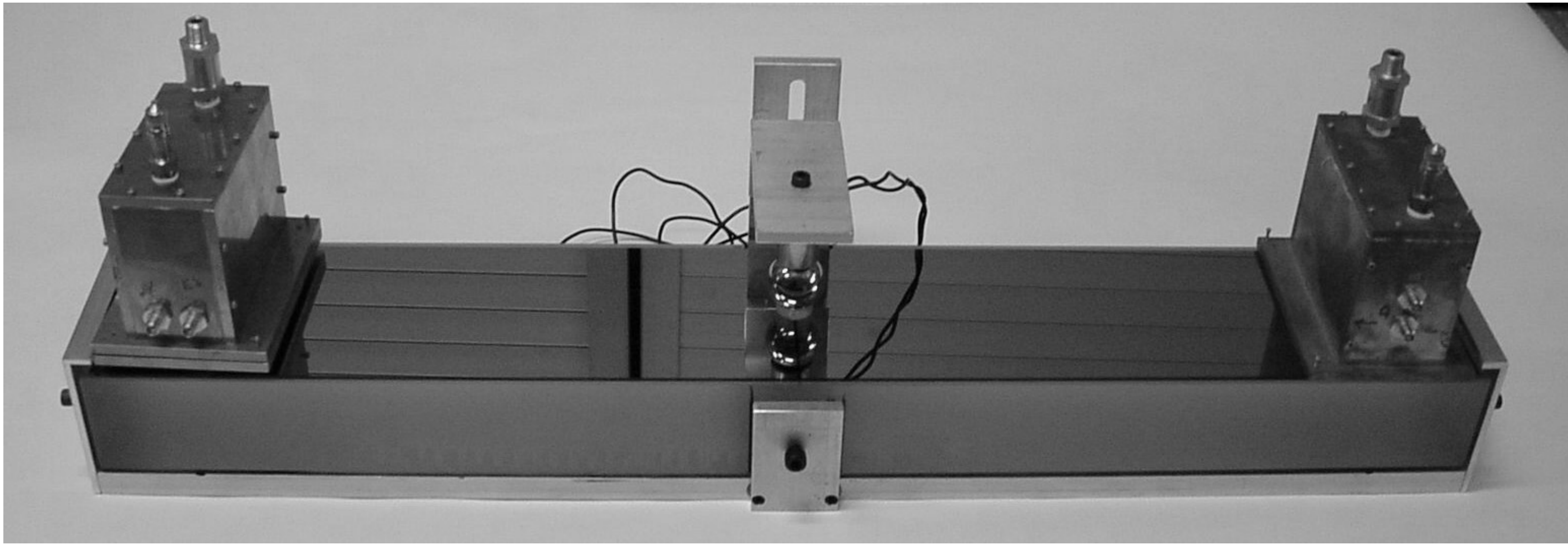
Temperature Dependence Studies: Readout

- Use reference capacitors (tiltmeter electrical equivalent

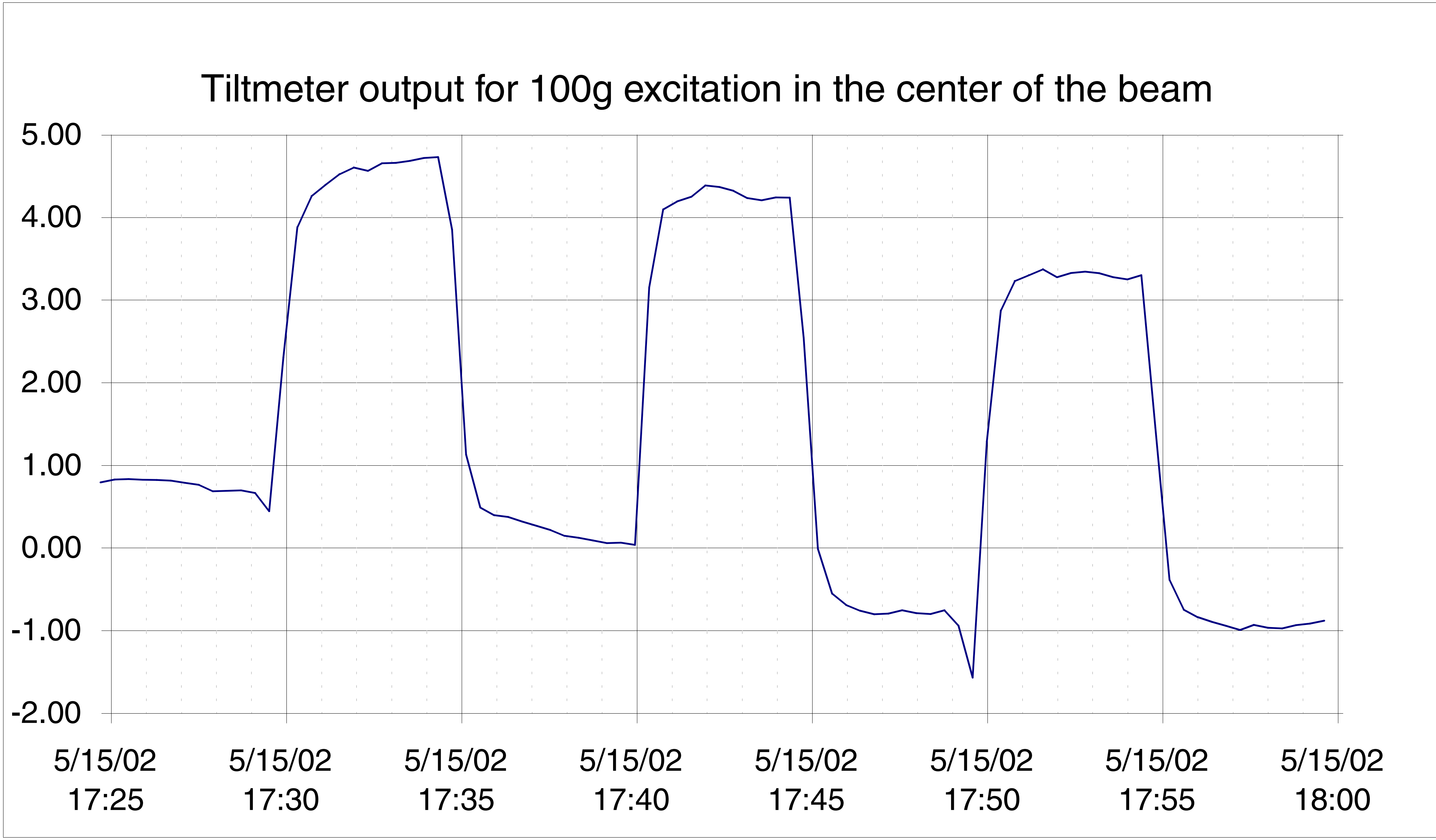



Electrical Equivalent R4 hole
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
0:00

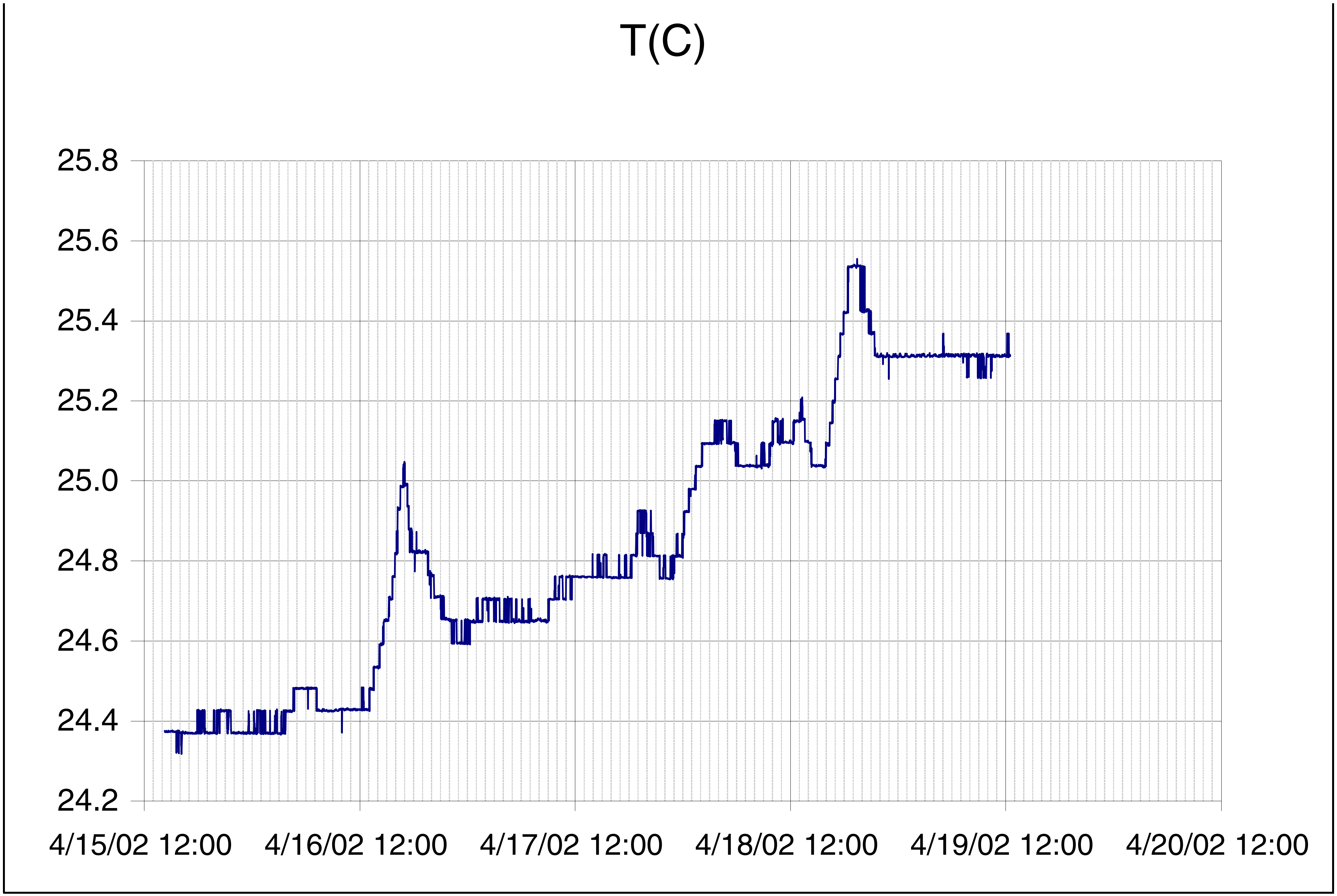
Tiltmeter Calibration with Glass Beam



Tiltmeter Calibration with Zerodur Beam



Instrumentation Div. Basement



To Be Done:

- **Quantify Temperature Dependence of Readout**
- **Quantify Temperature Dependence of Tiltmeter (use 2 tiltmeters in differential configuration)**
- **Build custom-designed lock-in amplifier to be able to read multiple tiltmeters (at least 2 at a time)**
- **Improve temperature/humidity recording (integrate multiple sensors in the data acquisition system)**