Precision Tiltmeter for the EDM Experiment

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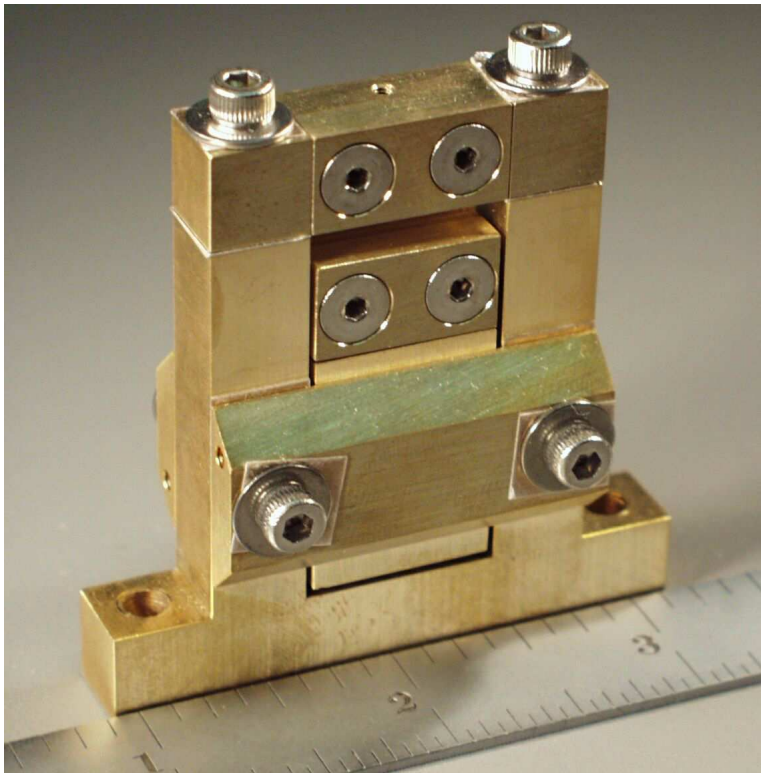
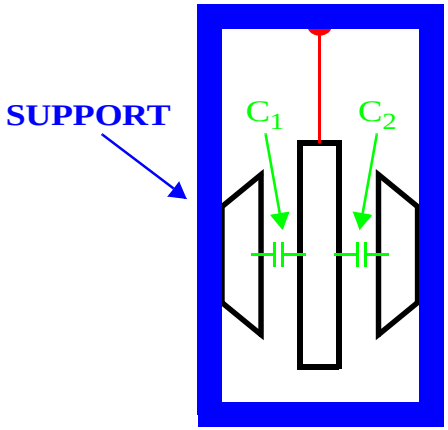
- **Tiltmeter Principle**
- **Revised Specifications**
- **Tiltmeter Characterization:short term (~100 s) stability**

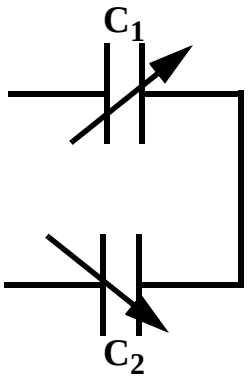
Acknowledgment:

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

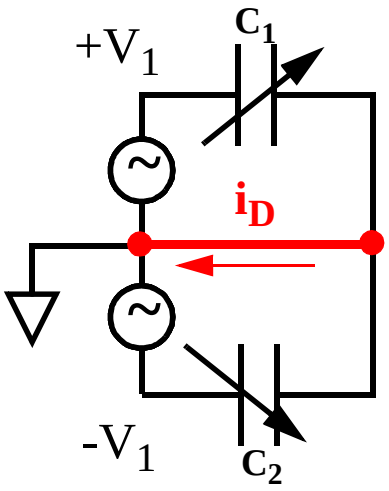
Tiltmeter







Readout: AC Bridge

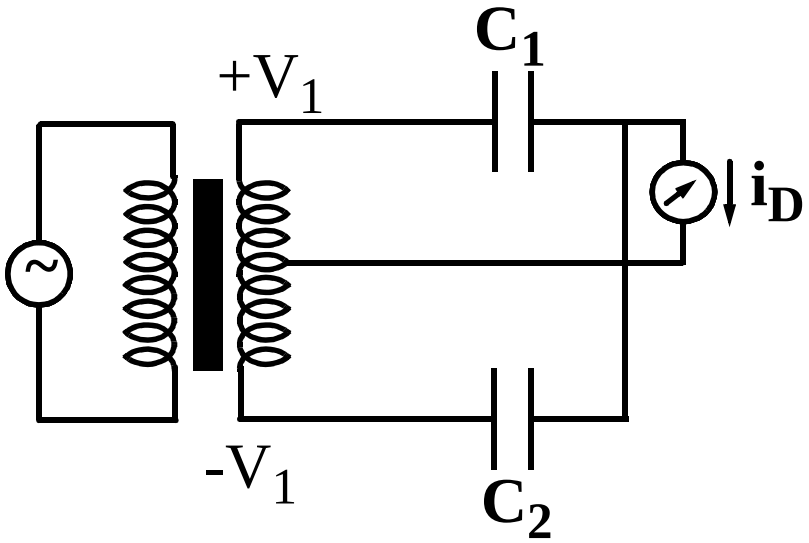


$C_1 - C_2 = \varepsilon\, A/(\delta x - x_0) - \varepsilon\, A/(\delta x + x_0) = 2\, C_0\, \delta x/x_0$

$A = 400\ mm^2$ $x_0 = 75\ \mu m$ $C_0 = C_1 = C_2 = 50\ pF$

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

$\delta C = 40\ aF$ for $\delta\theta = 1\ nrad$



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

for V1 = 1V, f = 16 kHz

$i_D = 4\ pA$

Revised specifications

Is it possible to have 1 prad (10^{-12} radians) sensitivity?

Given a transducer gain of 40 aF per nrad, this requires having a noise in capacitance of less than ~ few zF (zeptofarad = 1 x 10^{-21} F)

ELECTRICAL NOISE

$$\overline{C_n^2} = \frac{1}{V_1^2}\left(\overline{e_n^2}C_T^2 + \frac{\overline{i_n^2}}{\omega_0^{\,2}}\right)BW$$

C_T = 1 nF
e_n = 1 nV/Hz$^{1/2}$
V_1= 3 V
BW = 10^{-4} Hz
(TC = 2500 s)

} **$C_n = 3\ 10^{-21}$ F = 3 zF**

Best noise results by Jones: ~ 40 zF for BW = 1 Hz by extreme methods ($V_{exit.}$=100V, Q = 100 resonant circuit)
Best published results: 1 zF for small capacitance

In practice: limited by vibrational noise, not electrical noise

Other 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 and offset variation

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

  $700\ 10^{-6}$/°C for moist air)

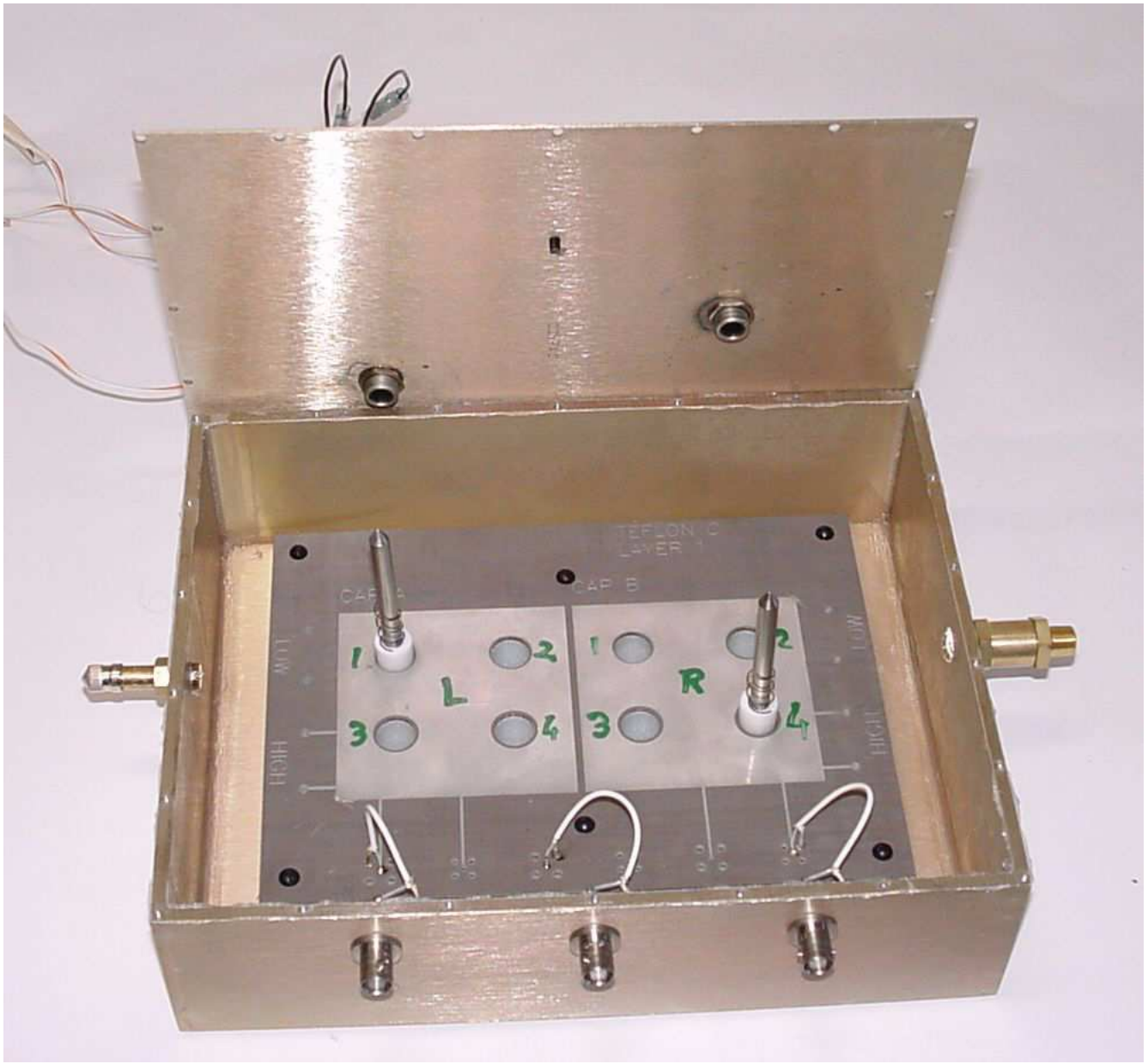
- **Pressure changes**

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

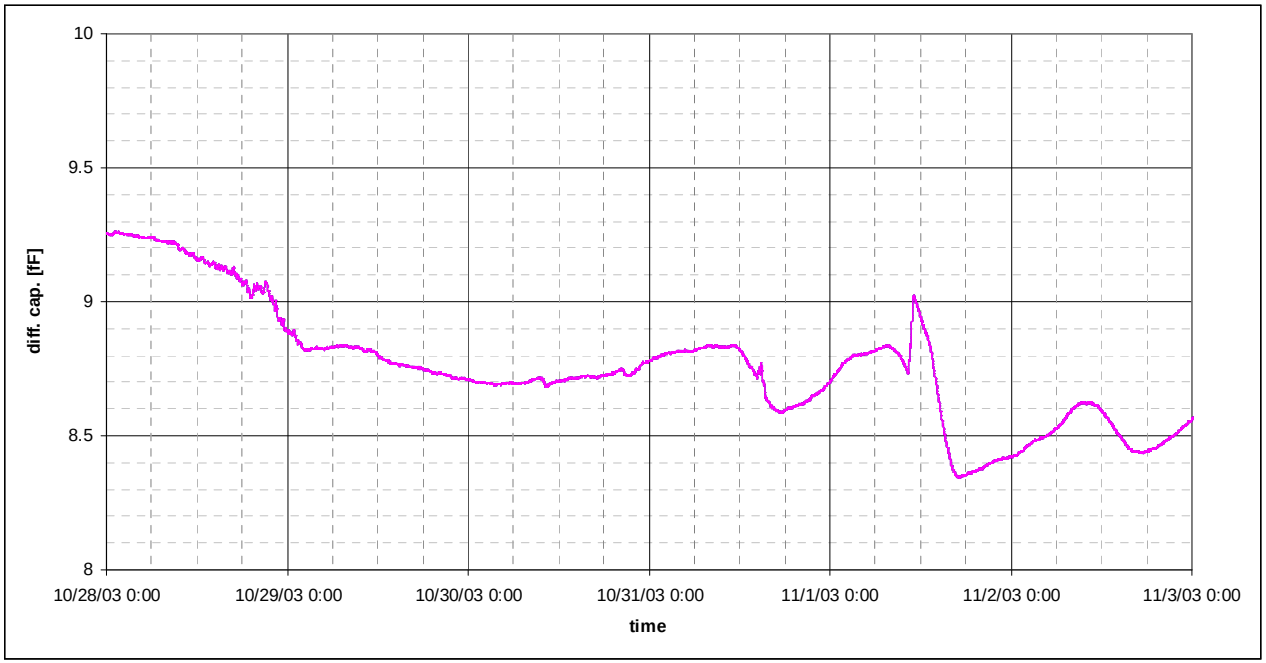
  causes dimensional changes (a brass cube of 1 cm contracts by 3 μm for a 1 atm change)

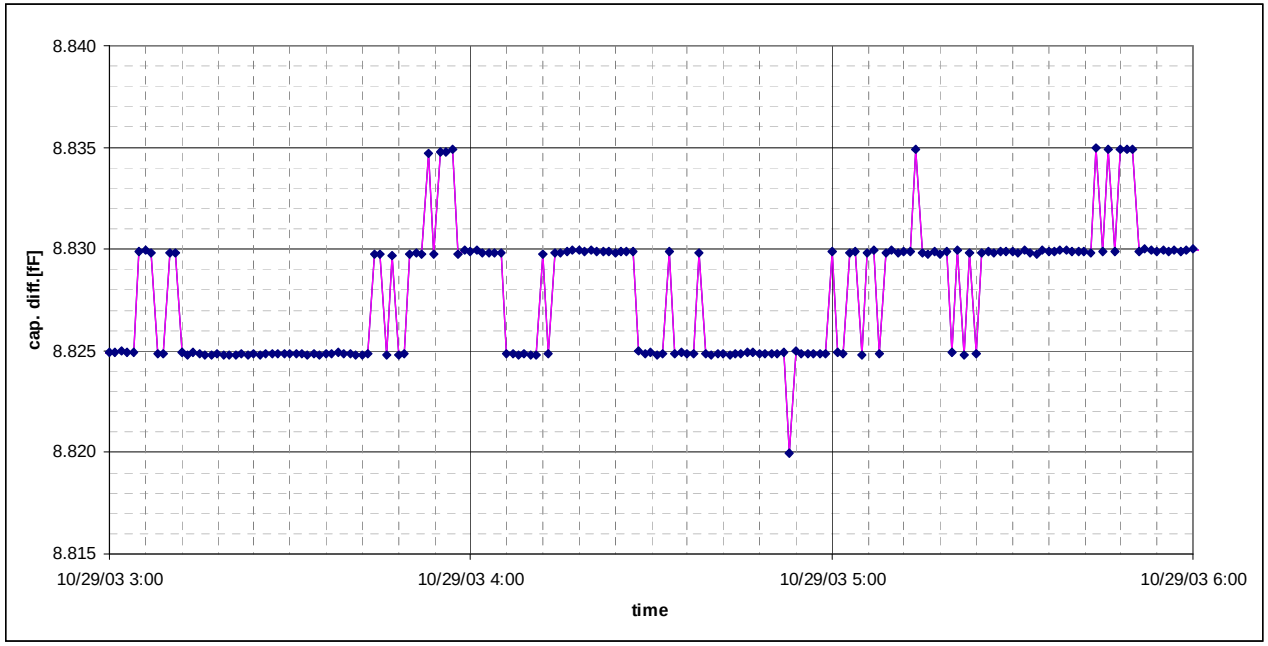
- **Oxidation of surfaces (rodium plating recommended)**
- **Stability of materials (70-30 brass gives good results)**
- **Creep of materials**
- **Relaxation of screw tension**
- **Microseismicity (about 2 μm peak to peak displacement, period 3-8 s)**

Readout: tiltmeter electrical equivalent



TILTMETER ELECTRICAL EQUIVALENT: TC = 100 s





Issues:

- **Testing: How to generate << 1 nrad tilt for testing?**
- **Dynamic range:**

  min. signal ~ 1 zF

  max signal ~ 1 μrad => 50 bits!!

It will require frequent “zeroing” to be able to limit the dynamic range