Measurements of electrical charge variations on fused silica samples

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Variation of charge as a source of noise

- Electrical charges located on the test mass interact with surrounding objects (e.g. by image force with metal support structure of the test mass suspension)

- Variation of charge produce variation of force and additional noise if the spectrum of variations is in the detector frequency band.

Results of our previous measurement

In measurements of charging of monolithic high Q fused silica pendulum it was found:

- Electrical charge with the equivalent surface density of order of $10^6 – 10^7$ e/cm^2 is usually located on the fused silica pendulum mass.

- In the long lasting measurements we observed monotonic change at the average of the charge with the rate of order of 10^5 e/cm^2 per month corresponding to the negative charging of the test mass near the plate with electrodes.

Seismic noise did not allowed to determine variation of charge at small time intervals with good resolution.

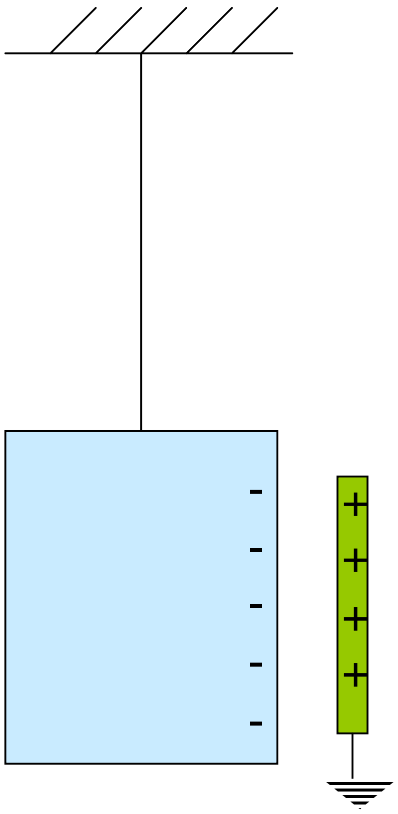
V.P.Mitrofanov, L.G.Prokhorov, K.V.Tokmakov, Phys.Lett.A300 (2002) 370

Possible sources of variations of charge on the test mass

- Relaxation of the initially created charge distribution
- Cosmic rays
- Background radioactivity
- Adsorption and desorption of molecules on the surface
- Other ?

The charging effect of high energy cosmic ray particles is discussed in: *V.B.Braginsky, O.G.Ryazhskaya, S.P.Vyatchanin, Phys.Lett.A 350 (2006) 1*

Estimation of fluctuating force acting on the test mass



- *Variation of electrical charge Δq produces variation of force ΔF :*

$$\Delta F \approx 4\pi\sigma \, \Delta q$$

If charge density on test mass $\sigma = 10^7$ e/cm^2 $\Delta q = 10^4$e, then:

$$\Delta F = 3\times10^{-7} \text{ dyn}$$

(may mimic GW signal at the level of sensitivity LIGO)

Goal: to study spatial and time variations of charge located on fused silica sample

The special electrometer for measurement of charge variation

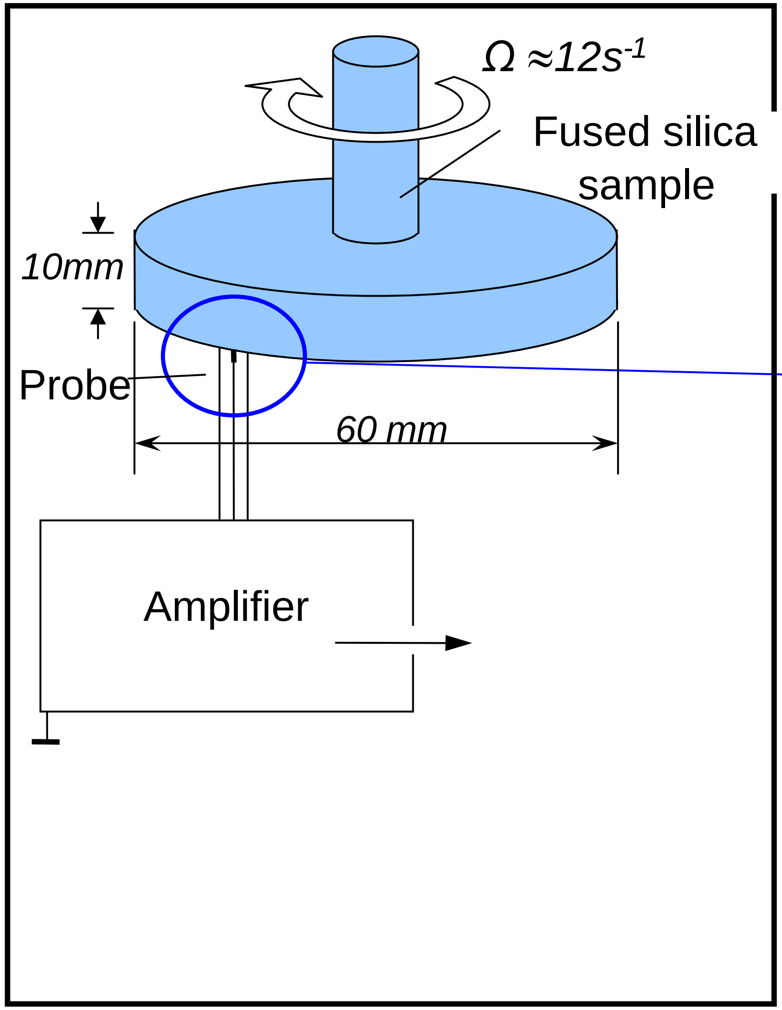
- There is a number of methods for measurement of electrical charge located inside and on the surface of dielectric.

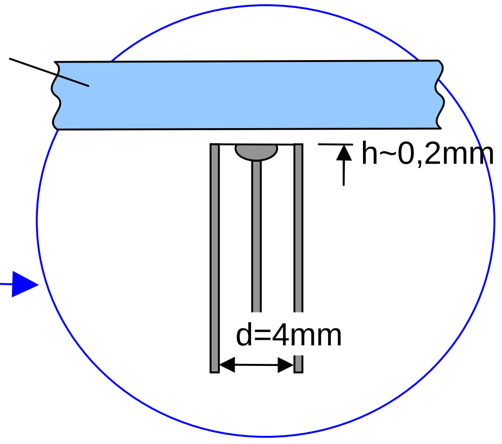
  The main requirements: high sensitivity and minimal action on the charge on the sample.

  Measurements of charge on dielectrics with resolution of less than one electron are well known for thin films by means of AFM or for tiny particles.

  For thick samples we have developed the capacitive probe electrometer with rotating sample. The samples were fabricated from fused silica.

Schematic construction of electrometer

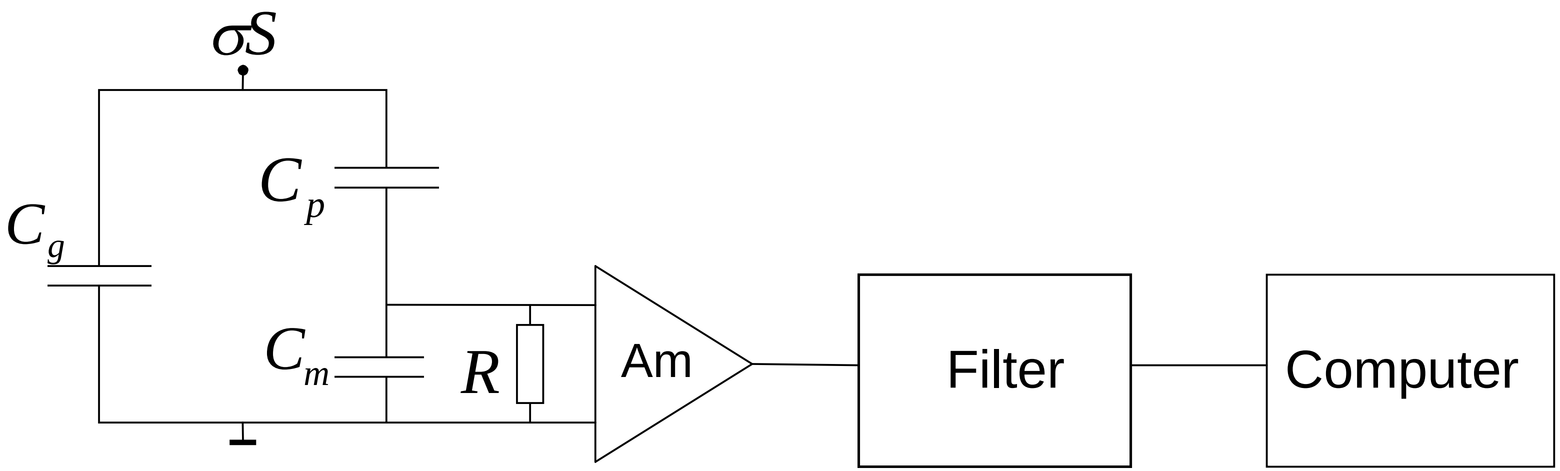




Probe scans along a strip on rotating sample and transforms the charge distribution ***q*** (φ,*t*) to the probe voltage ***U***(*t*)

Probe area A ≈ 0.1 cm^2

Equivalent circuit and block diagram of the electrometer



Am – high impedance amplifier, R = 300 GOhm

C_P – capacitance between sensor plate of the probe and area of sample induced the charge σS,

C_g – capacitance between that area and the ground,

C_m – total input capacitance of the probe and the amplifier

Features of the electrometer

- There is no a direct calibration of the electrometer.
- Uncertainties in measurement of charge are associated with its distribution in the bulk and on the other side of the sample as well as with uncertainty of capacitance C_g and other parameters of the probe and the sample.
- Electrometer does not detect DC component of charge distribution.

To estimate the charge variation the approximate formula was used:

$$\Delta q(\varphi,t) \approx 2\, C_m \Delta U_m (t)|_{\varphi}$$

Nevertheless this technique allowed searching of effect of various factors on the charge distribution on dielectric samples.

Also the role of rotating sample will be shown.

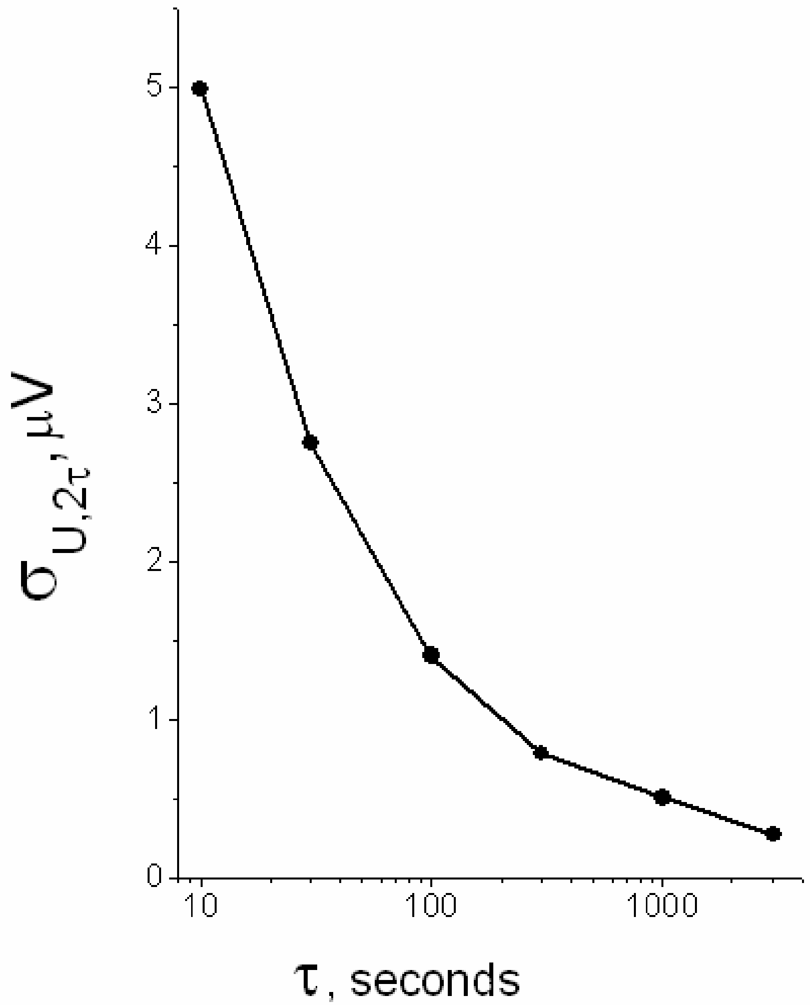
Sensitivity of the electrometer

- Sensitivity of the electrometer is limited by thermal noise of input resistor and noise of the amplifier

$$S_U^2(\omega) = \frac{4kTR}{1+\omega^2 R^2 C^2} + S_{U_{Amp}}^2(\omega) + \frac{S_{I_{Amp}}^2(\omega) R^2}{1+\omega^2 R^2 C^2}$$

Standard deviation $\sigma_{U,2\tau}$ of the probe voltage variation $\Delta U_{i,2\tau} = U_{i+1,\tau} - U_{i,\tau} = 5\mu V$ corresponds to standard deviation of variation of the charge 350 ***e*** over time interval $\tau = 10$ s and the probe area of 0.1cm^2.

This measurement was carried out with shielded or moved aside probe.



Results of measurements (in air)

We present results of measurements which were carried out by means of the developed electrometer in air.

- It is the first preliminary step of the search used to test the setup before measurements in vacuum.
- It is interesting for LIGO because the initial charge distribution on the test mass is formed in air before evacuation of the chamber.

Relaxation of deposited charge

Relaxation time of peak of charge distribution in air depends on state of the surface:

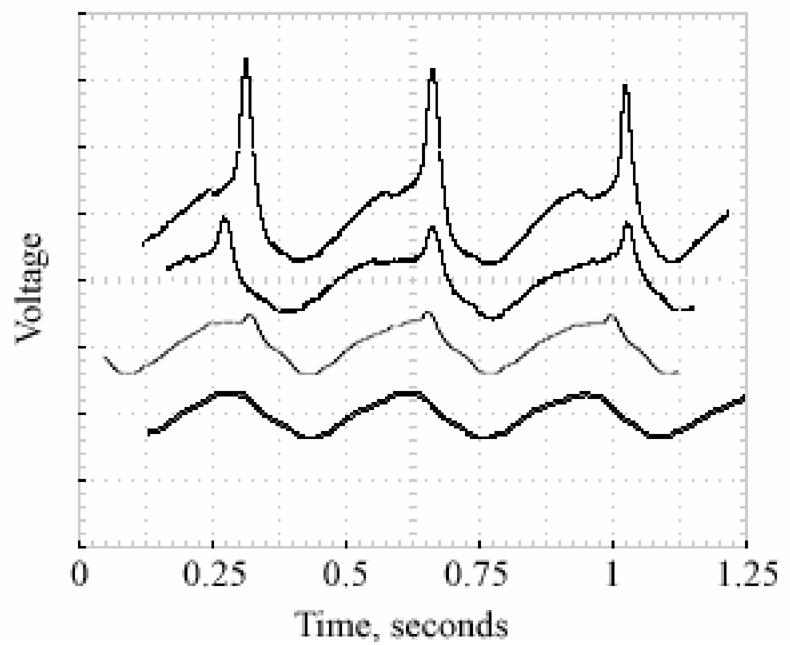
$\tau^* \approx$ 1min (after treatment in flame of gas torch)

$\tau^* \approx$ 1 hour (in usual state in air)

$\tau^* \approx$ 5 hours (after baking in oven)

$\tau^* \approx$ 1000 hours in vacuum

Likely, it is effect of water on the conductivity of fused silica sample



Relaxation of distribution of charge deposited by local contact electrification on fused silica sample: pictures from oscilloscope at different time

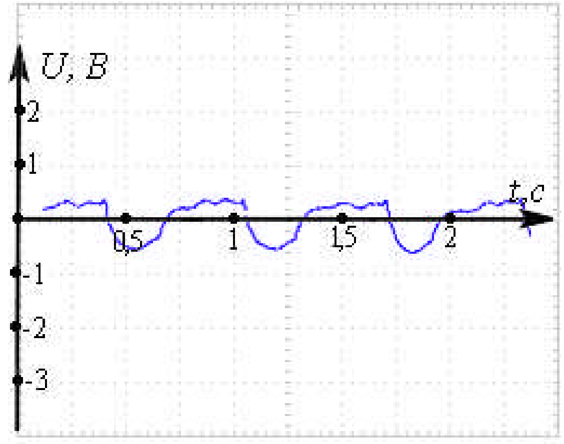
Effect of the probe on charge distribution

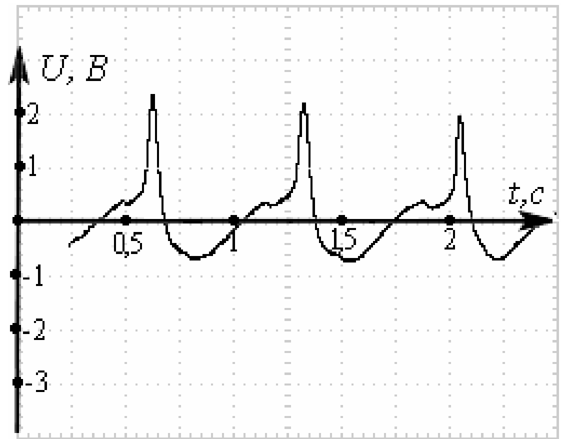
- If the probe was under the immovable sample during some time a peak in the charge distribution was formed on the sample over the probe.

  Time of the peak formation is approximately the same as the relaxation time.

  A value of the concentrated charge depends on the total charge on the sample and distribution of capacitances: sample-probe, sample-environment.

  It is the result of action of image forces on mobile charges





Effect of environment on charge distribution

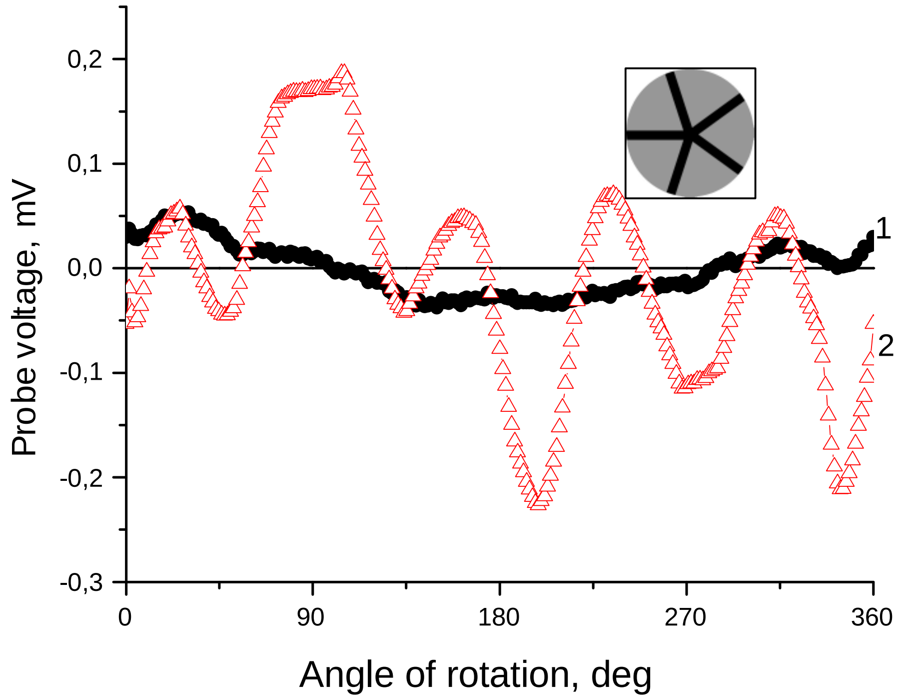
Fig. Distribution of probe voltage (electrical charge on the sample)

1- sample rotated during 8 hours before the measurements

2- copper plate with 5 aluminum strips (see insertion) was 11 mm under the immovable sample during 18 hours before the measurement.

Stray electric fields ≈ 1V/m (due to contact potential difference) form the charge distribution on the sample with variation of charge density of about 3×10^5 e/cm^2.

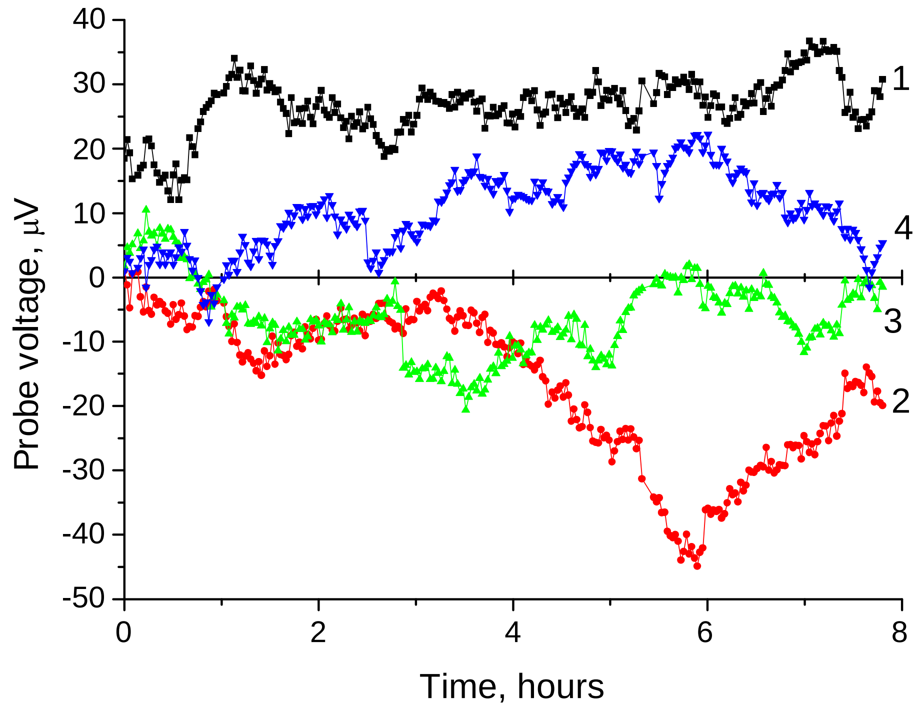
A reason to use rotating sample is to exclude effects of environment and probe on the charge distribution.



Time variations of charge on the sample (measurement in air)

Fig. Time dependence of the voltage from the probe (averaged over 100 s) obtained for 4 points of the sample: when the probe is under the points with coordinates:
1 - φ = 0°, 2 - φ = 90°,
3 - φ = 180°, 4 - φ = 270°,

There are variations of the probe voltage exceeded 5σ correspon-ding to about 10^4 e/cm^2.

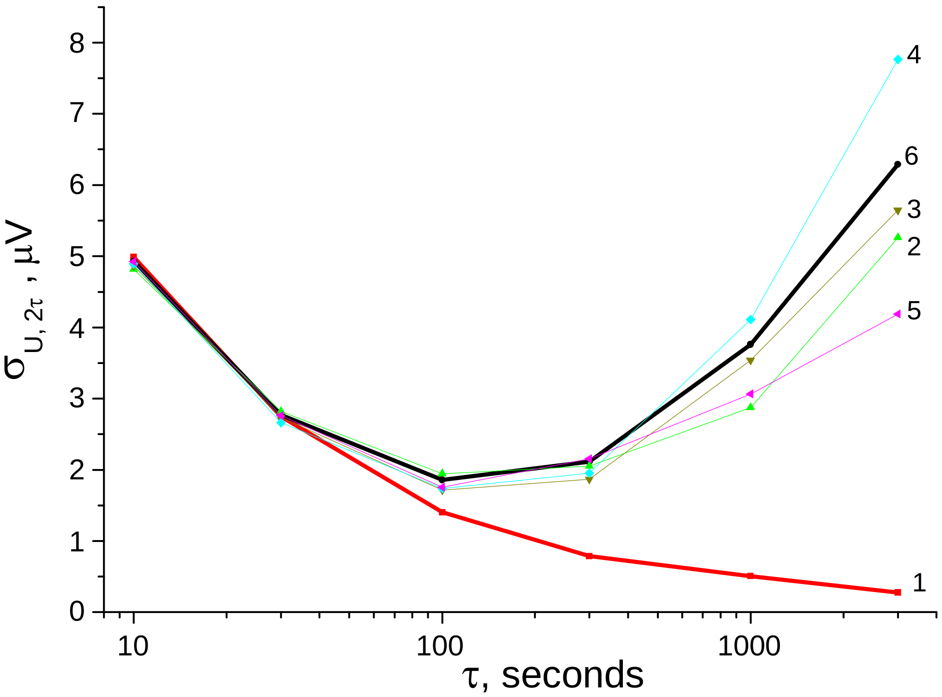


Standard deviation of charge variations

Fig. Random variations of voltage from the probe in different places of the sample (curves #2-6).
The variations were larger than those associated with the amplifier noise (for averaging time more than 30 sec) which were measured with the shielded probe (curve #1).

It is likely a result of electrification of fused silica by dust particles.

We have no clean room but hope to exclude this effect making measurements in vacuum



Conclusion

- So we have found some factors which determine distribution of electrical charge on fused silica. This distribution may be formed when fused silica is in air before evacuation of the vacuum chamber. Water on the surface likely provide mobility of electrical charges to form their distribution due to stray electric fields inside the chamber.

- When charges are concentrated in some places where their density is larger than the average density, smaller variations of charge may mimic the action of gravitational waves. It is possible to discharge (neutralize the charge) the test mass, although we have no good physical model of process of charging and discharging of fused silica.

- We plan to carry out measurements of spatial and time variations of electrical charges on fused silica sample in vacuum over short time intervals by means of the designed electrometer.