Noise is a powerful tool …. From CM … medicine…to financial markets

Direct Observation of a Fractional Charge

R. de-Picciotto, M. Reznikov, M. Heiblum, V. Umansky, G. Bunin and D. Mahalu

Braun Center for Submicron Research, Department of Condensed Matter Physics, Weizmann Institute of Science Rehovot 76100, Israel

Ever since Milliken's[1] famous experiment it is well known that the electrical charge is quantized in units of the electronic charge - *e*. For that reason, Laughlin's[2] theoretical prediction of the existence of fractionally charged *quasi particles*, put forward in order to explain the *Fractional Quantum Hall* (FQH) effect, is very counter intuitive. The FQH effect is a phenomenon that occurs in *a Two Dimensional Electron Gas* (2DEG) subjected to a strong perpendicular magnetic field. This effect results from the strong interaction among the electrons and consequently current is carried by the above mentioned *quasi particles*. We directly observed this elusive fractional charge by utilizing a measurement of *quantum shot noise*. *Quantum shot noise* results from the discreteness of the current carrying charges and thus is proportional to their charge, *Q*, and to the average current *I*, namely, $S_i=2QI$. Our *quantum shot noise* measurements unambiguously show that current in a 2DEG in the FQH regime, at a *fractional filling factor* $\nu=1/3$, is carried by fractional charge portions *e/3*; in agreement with Laughlin's prediction.

VOLUME 70, NUMBER 9 PHYSICAL REVIEW LETTERS 1 MARCH 1993

Long-Range Anticorrelations and Non-Gaussian Behavior of the Heartbeat

C.-K. Peng,[1] J. Mietus,[2] J. M. Hausdorff,[2] S. Havlin,[1],[3] H. E. Stanley,[1] and A. L. Goldberger[2]
[1] *Center for Polymer Studies and Department of Physics, Boston University, Boston, Massachusetts 02215*
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(Received 15 October 1992)

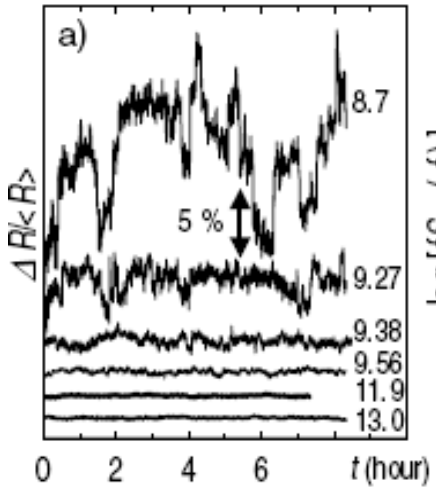
We find that the successive increments in the cardiac beat-to-beat intervals of healthy subjects display scale-invariant, long-range anticorrelations (up to 10^4 heart beats). Furthermore, we find that the histogram for the heartbeat intervals increments is well described by a Lévy stable distribution. For a group of subjects with severe heart disease, we find that the distribution is unchanged, but the long-range correlations vanish. Therefore, the different scaling behavior in health and disease must relate to the underlying dynamics of the heartbeat.

PACS numbers: 87.10.+e

VOLUME 89, NUMBER 27 PHYSICAL REVIEW LETTERS 30 DECEMBER 2002

Universal Behavior of the Resistance Noise across the Metal-Insulator Transition in Silicon Inversion Layers

J. Jaroszyński,[1,*] Dragana Popović,[1] and T. M. Klapwijk[2]



DETRENDED FLUCTUATION ANALYSIS OF THE FOREIGN EXCHANGE MARKET

N. VANDEWALLE AND M. AUSLOOS
SUPRAS, Institut de Physique B5, Université de Liège, B-4000 Liège, Belgium

Noise and grounding issues

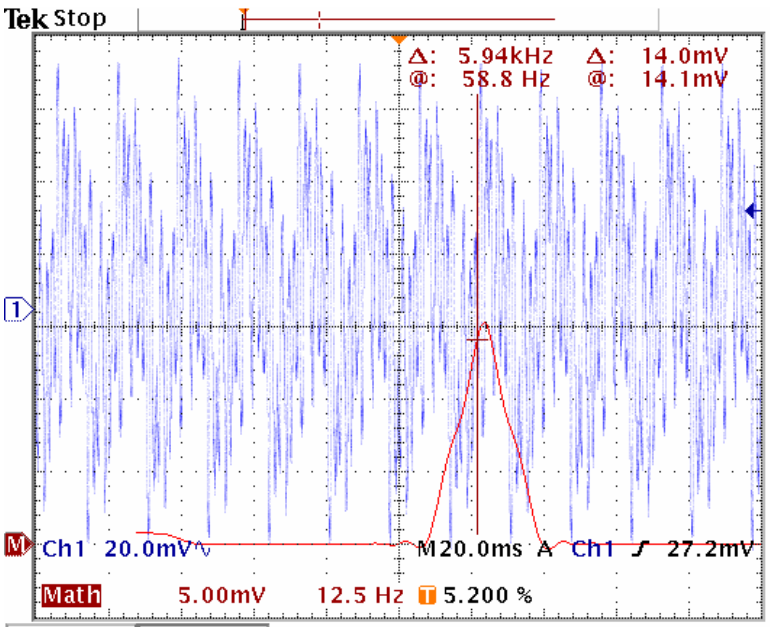
Noise team:

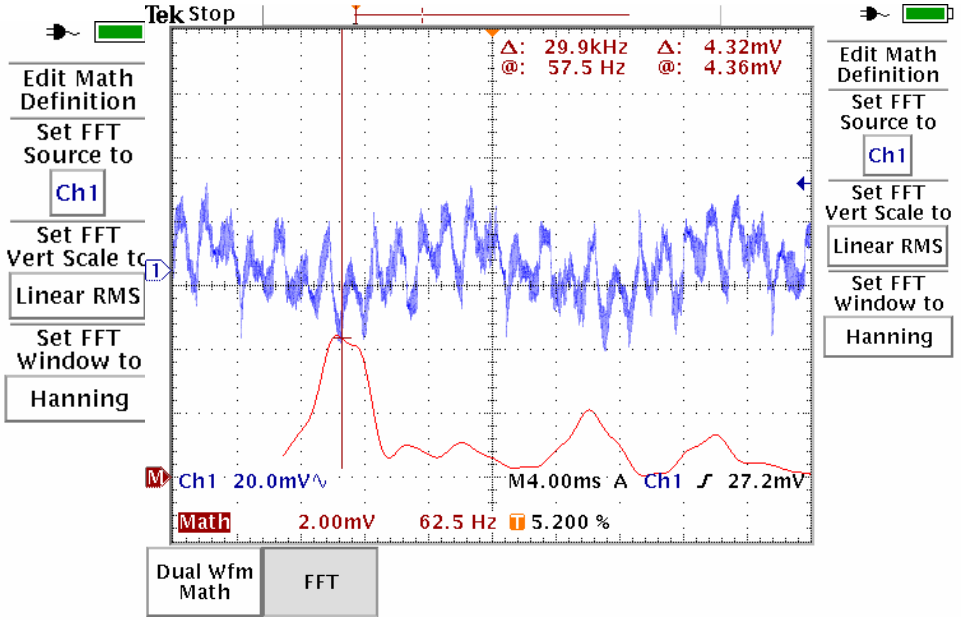
B.L. Brandt, L.W. Engel, S.T. Hannahs, J.J. Jaroszynski, A. Migliori, T.P. Murphy, E.C. Palm, D. Popovic, A. P. Reyes, A. Souslov

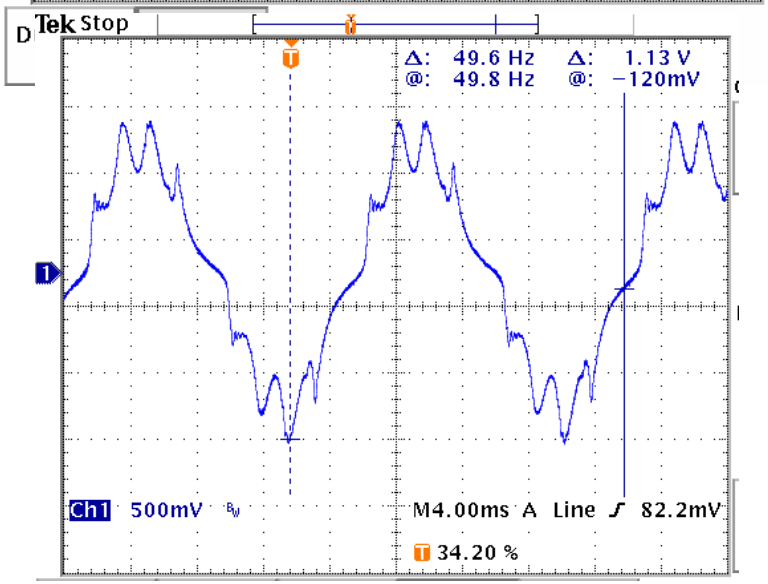
Outline

- Sources of low frequency noise
- Existing grounding system
- New grounding system
- High frequency problems
- Diagnostic methods
- How to increase signal/noise ratio
- Examples of improvement
- Plans for further improvements

At lower frequencies, here is what we are up against







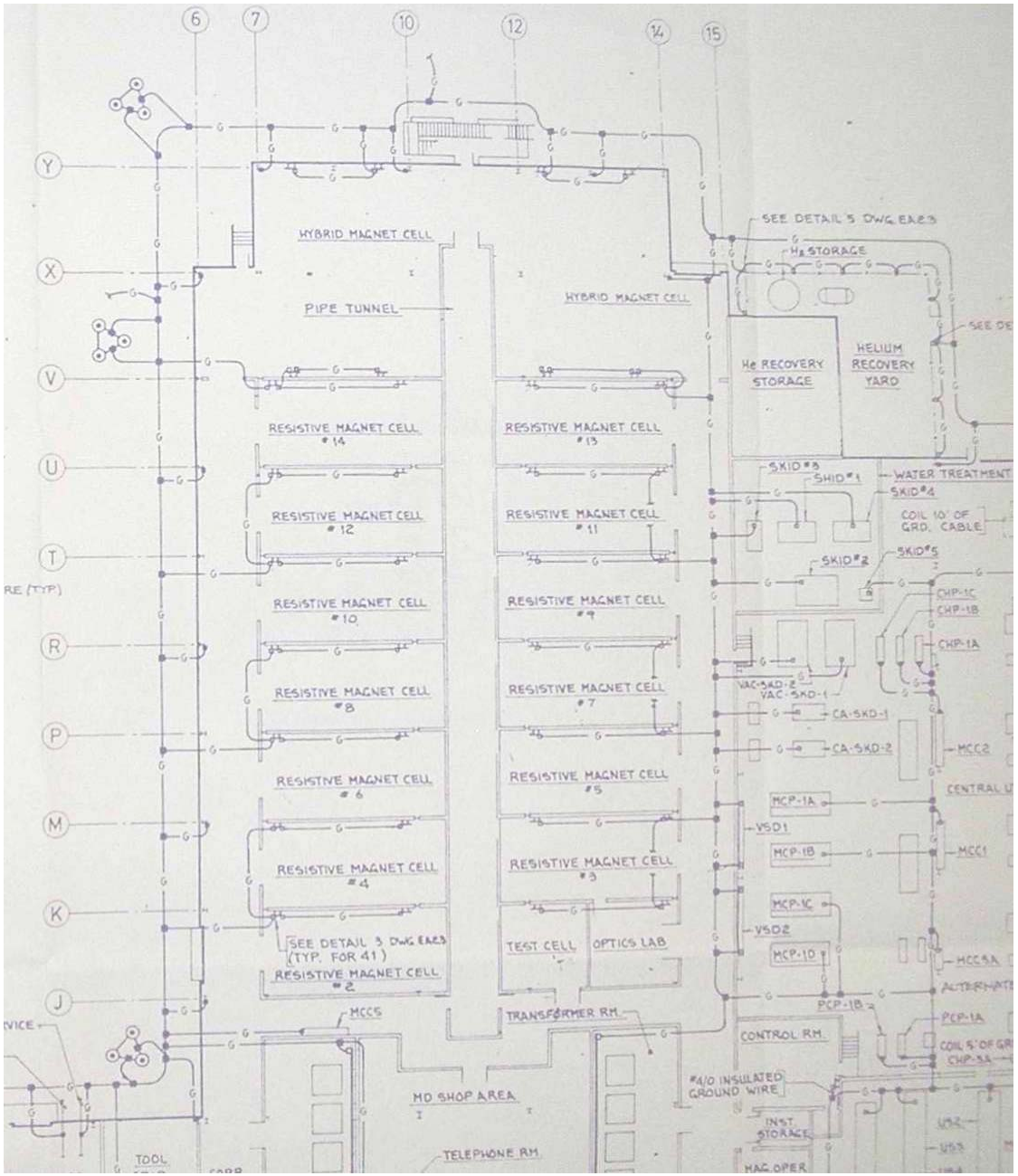
In the air-radiated

On the ground

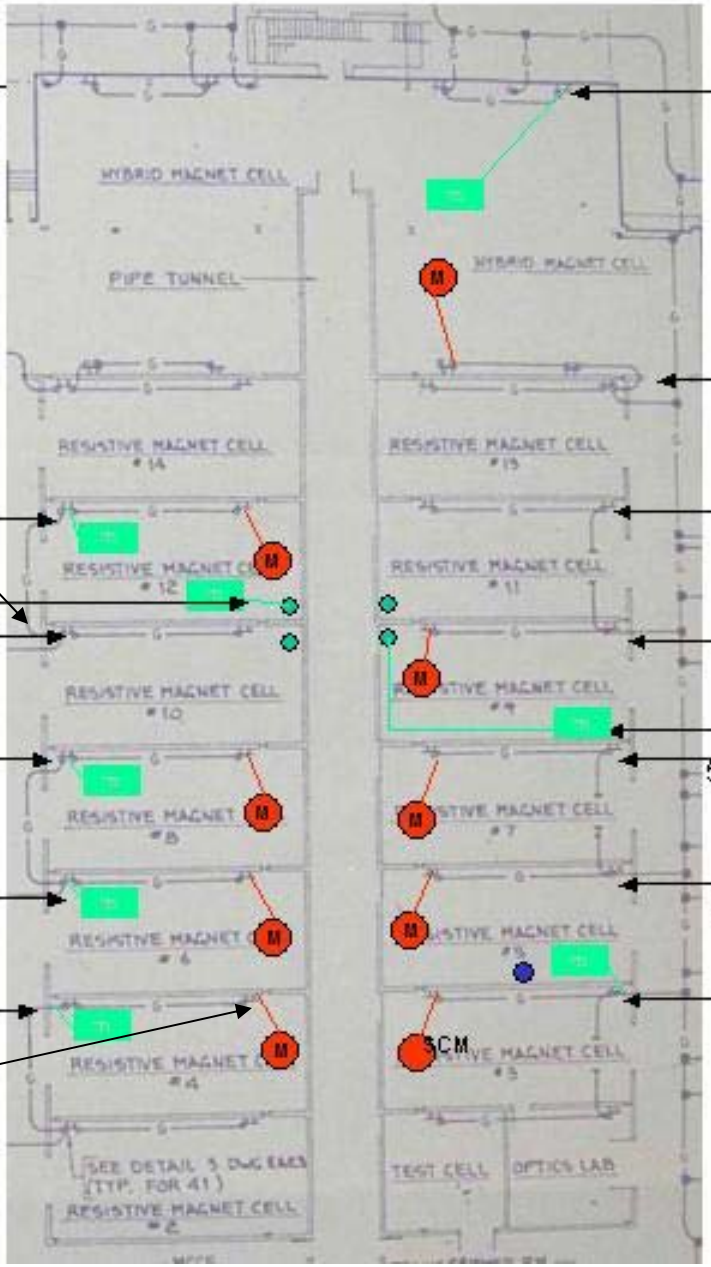
higher voltages than excitation on the samples, thermometers

Existing grounding system:

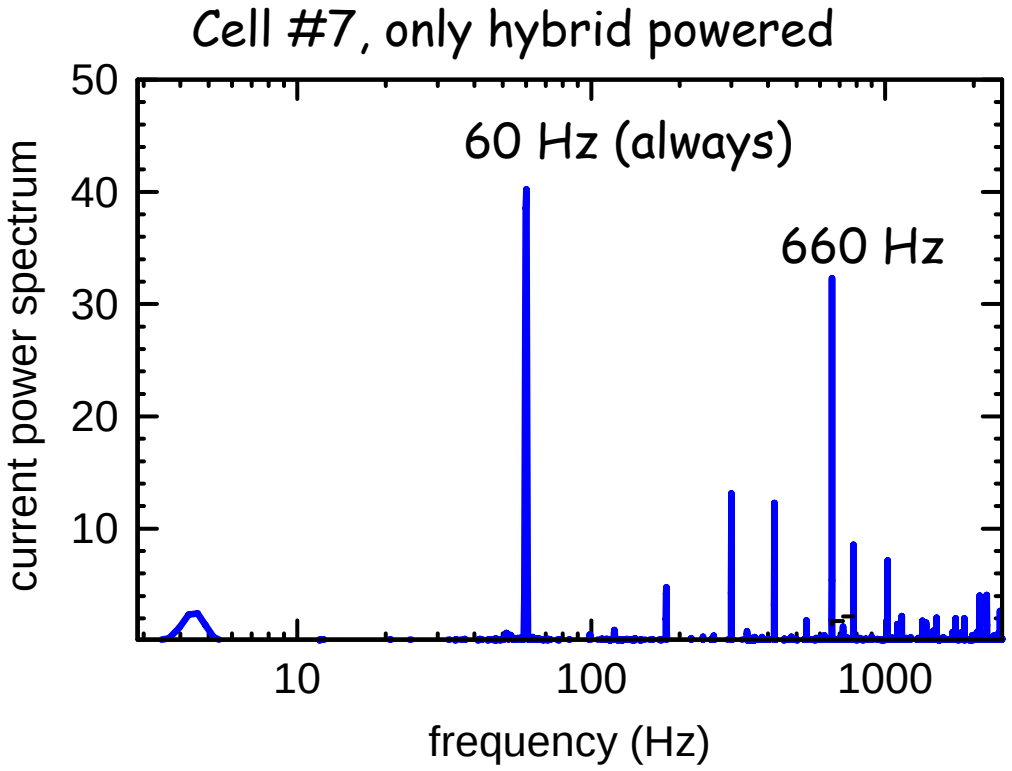
- existing grounding system is interconnected between magnets, cells, power outlets water mains, building construction
- this makes it a huge net which picks-up a lot of noise: currents up to 1 A, voltages up to 1 V



Existing grounding system:



Typical spectrum of the noise in grounding cables in cells #2-14
when switching DC power supply is on



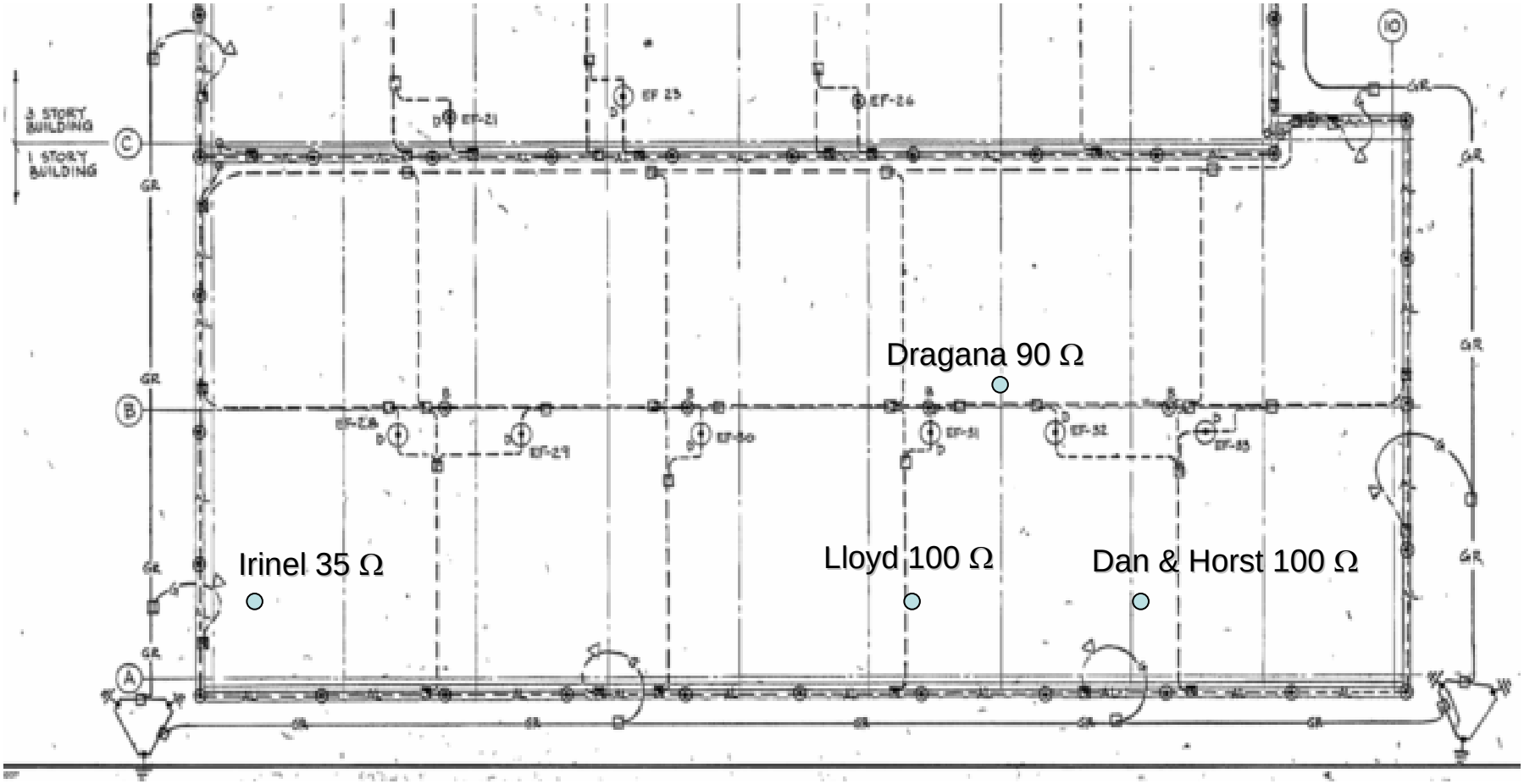
(only when DC PS on)

set your frequency f<60 Hz or f>3 kHz:
Johnson noise (nV) from 1 kOhm resistor could be measured here
avoid especially 200Hz - 2 kHz
users from Europe: be aware of 60Hz, not 50 Hz
new power supply will be installed soon

It is not easy to make a good ground in Florida soil:

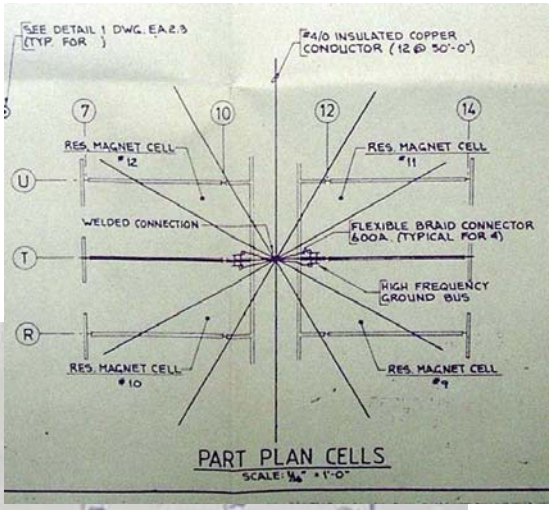
Grounding rods in C120 measured with 3 probe method vs. the racetrack
@575 Hz, 2 days after 1 in of rain and 2 months of drought in April
Now: 50% more

Safety: maximum 25 Ω !!!

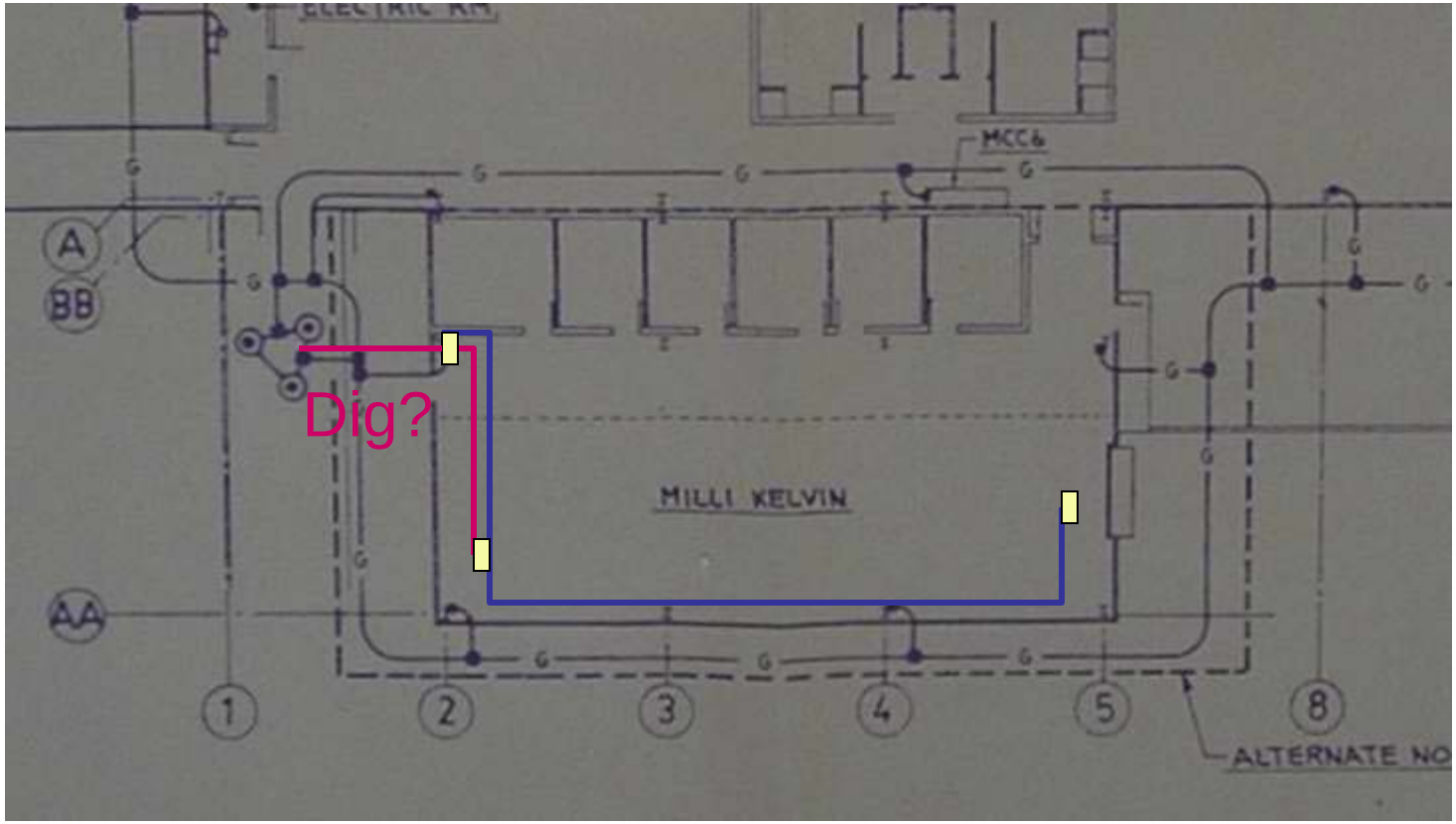


New grounding system (almost done)
flat festoon cables extended from star ground in cells #9-12
these cables have reduced inductance

any cable has approx. 1 μH per meter!!!



Millikelvin building:

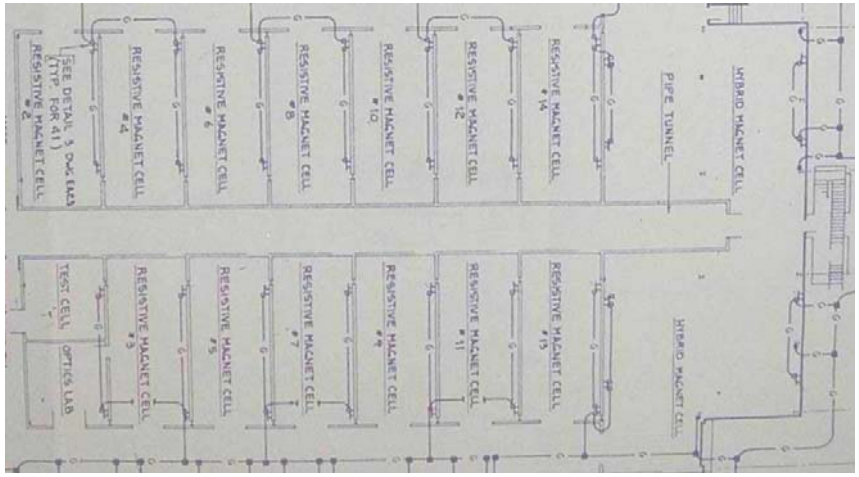


New grounding bars:

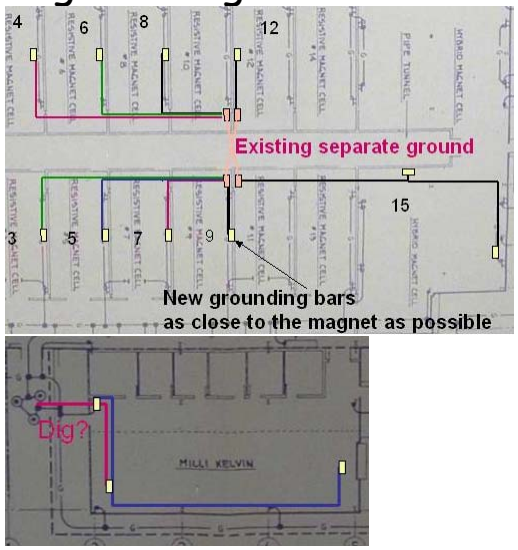
It is absolutely critical not to connect it to any other grounding
It could spoil your experiment as well as experiment in other cells !!!

Grounding issues

- existing grounding system is interconnected between magnets, cells, power outlets water mains, building construction
- this makes it a huge net which pick-up a lot of noise: currents up to 1 A, voltages up to 1 V

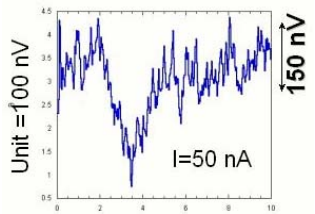


- alternate solution: to extend "forgotten" star ground from cells #9,10,11,12 to other cells (work almost done)
- using flat festoon cable 4x4 AWG
- it has resistance as 3/0 welding cable but lower inductance,
- in millikelvin building: connect ground directly to grounding rods



- solution: to separate ground in each cell
- however, measurements show that existing home made grounding rods have high resistance: 15-140 Ohm after 2 month of drought, while the most liberal US safety norm is 25 Ohm.
- it is also not easy to drill trough 2' concrete platform

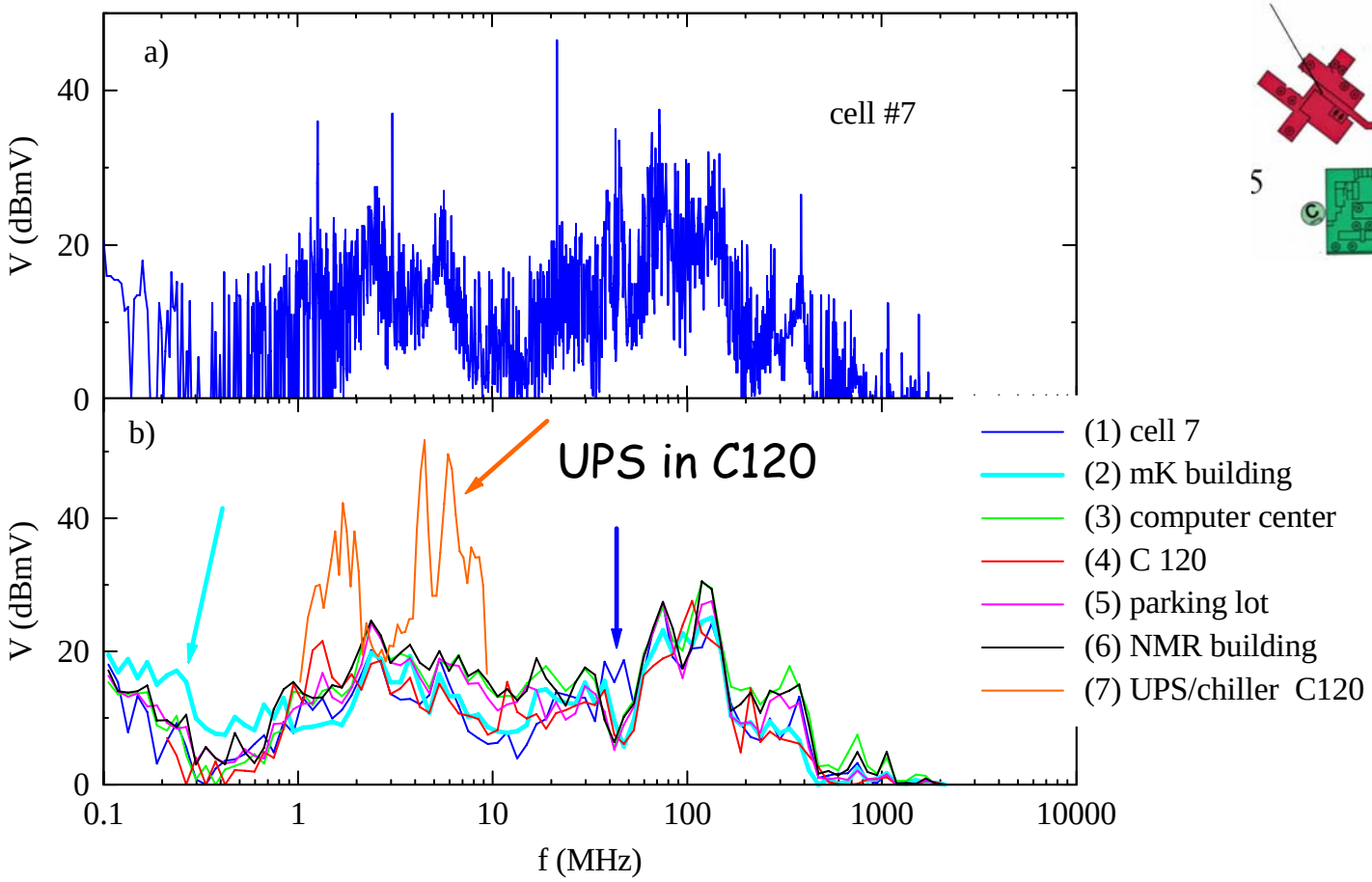
- importance of good grounding: after "cleaner" grounding point found, resistive detection of NMR in FQHE regime is possible in the hybrid (Jiang&Stormer)

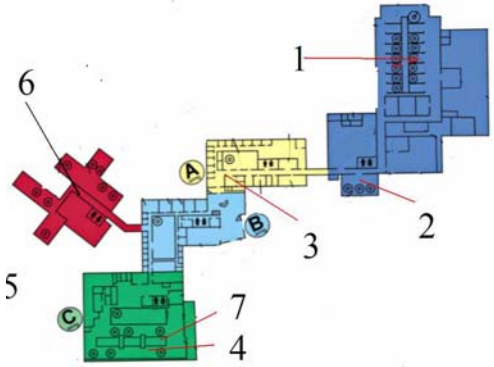


High frequency problems:

HF not only interfere with HF measurements as NMR
but also sneaks to cryostats heating samples in the mK range,
and dephasing electrons

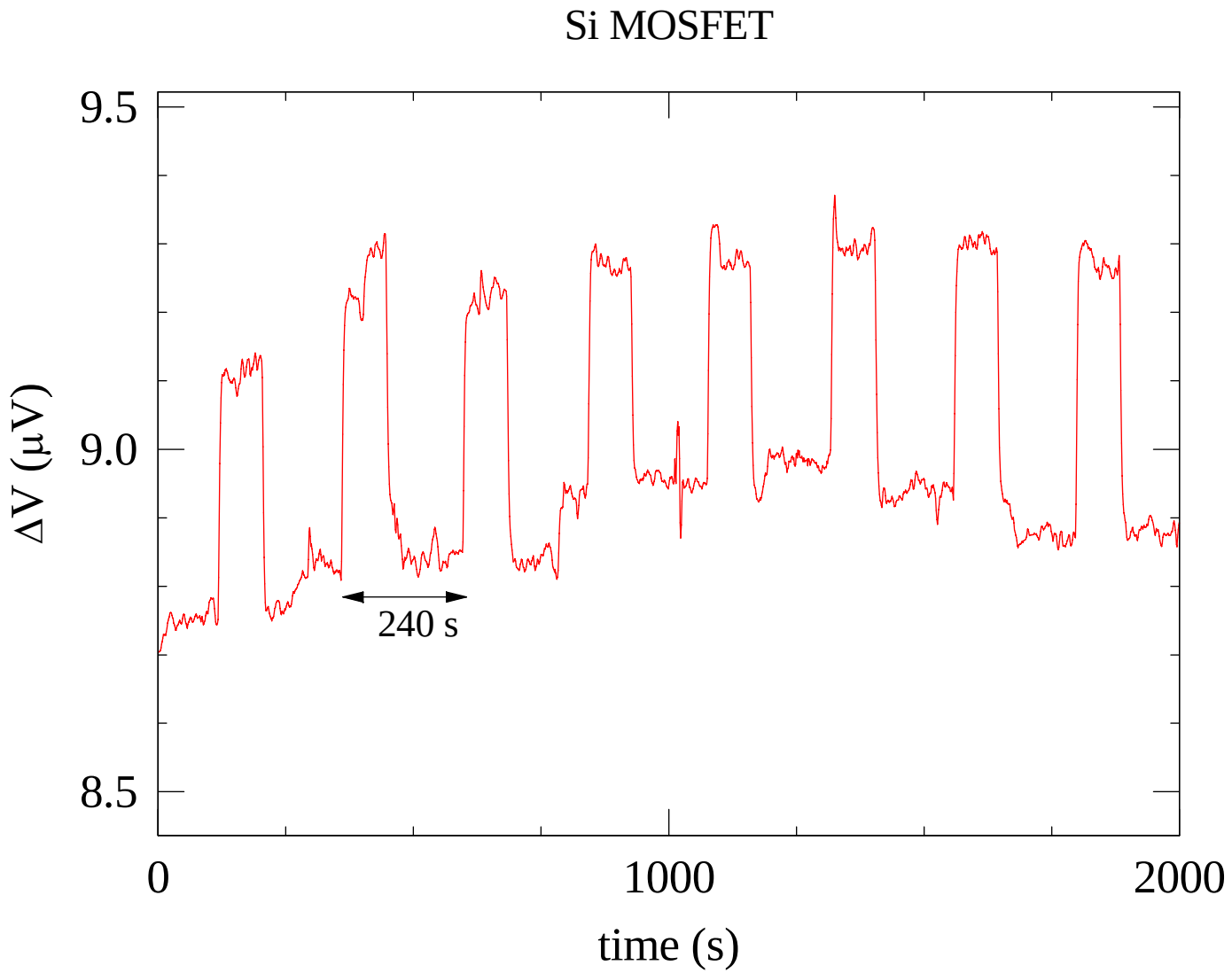
Figure 3





almost the same spectrum everywhere
+ computers, monitors etc

“4 min” switching due to e-microscope chiller
(local C-120 problem solved)



Diagnostic: Noise crash cart

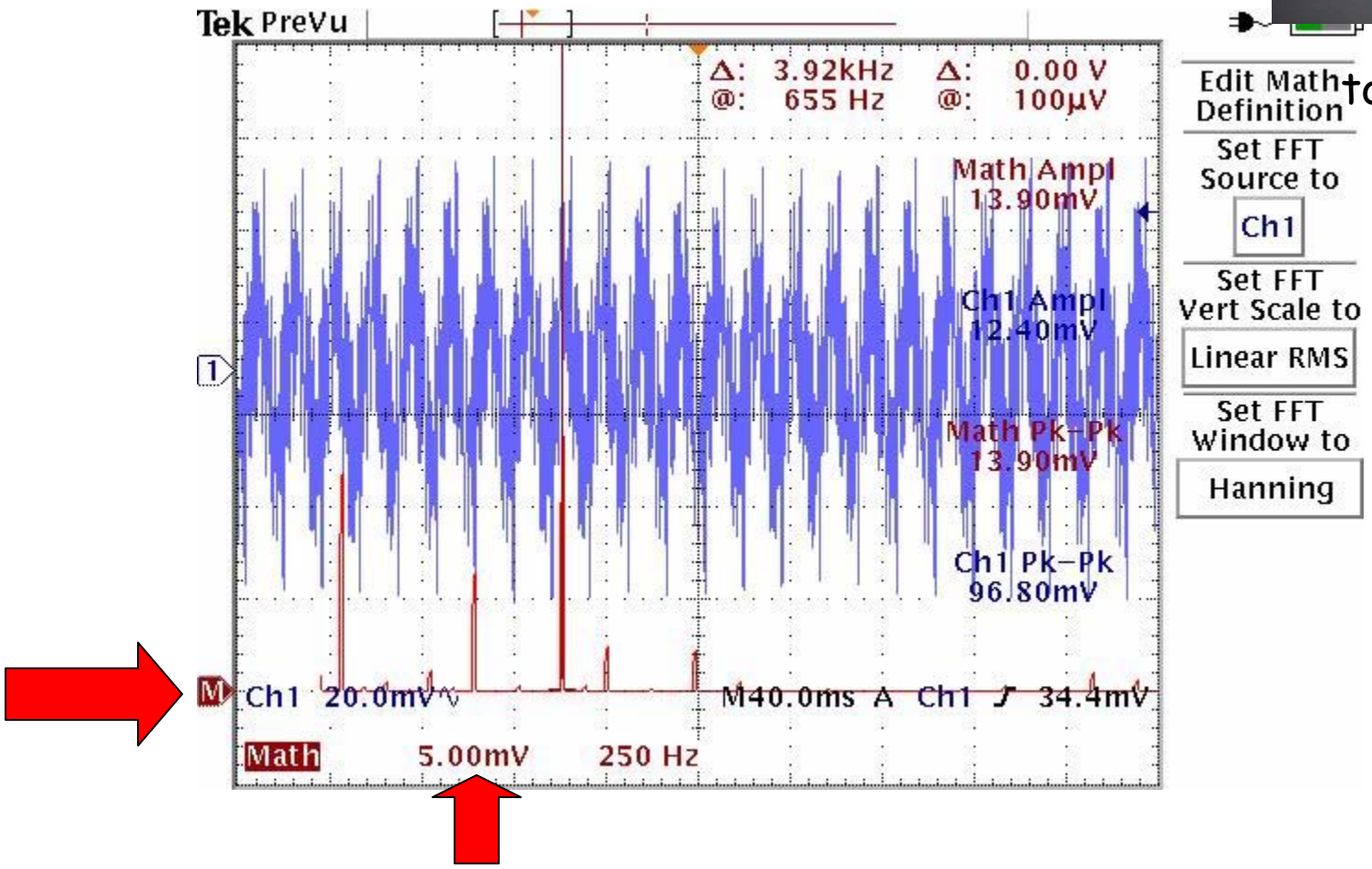
The ability to measure and log noise problems whenever they arise

- **Megger ground meter for ground loop detection and ground resistance meas.)**
- **Tektronix oscilloscope with FFT**
- **AC current clamp (ground loop current detection and spectroscopy**
- **DC current clamp**
- **Differential preamp, voltage probe**
- **Protek 3290 RF Spectrum Analyzer 0.1-2900MHz**
- **Laptop all can run on batteries**
- **isolation transformer**

Quick detection of ground loops:
current should be zero!

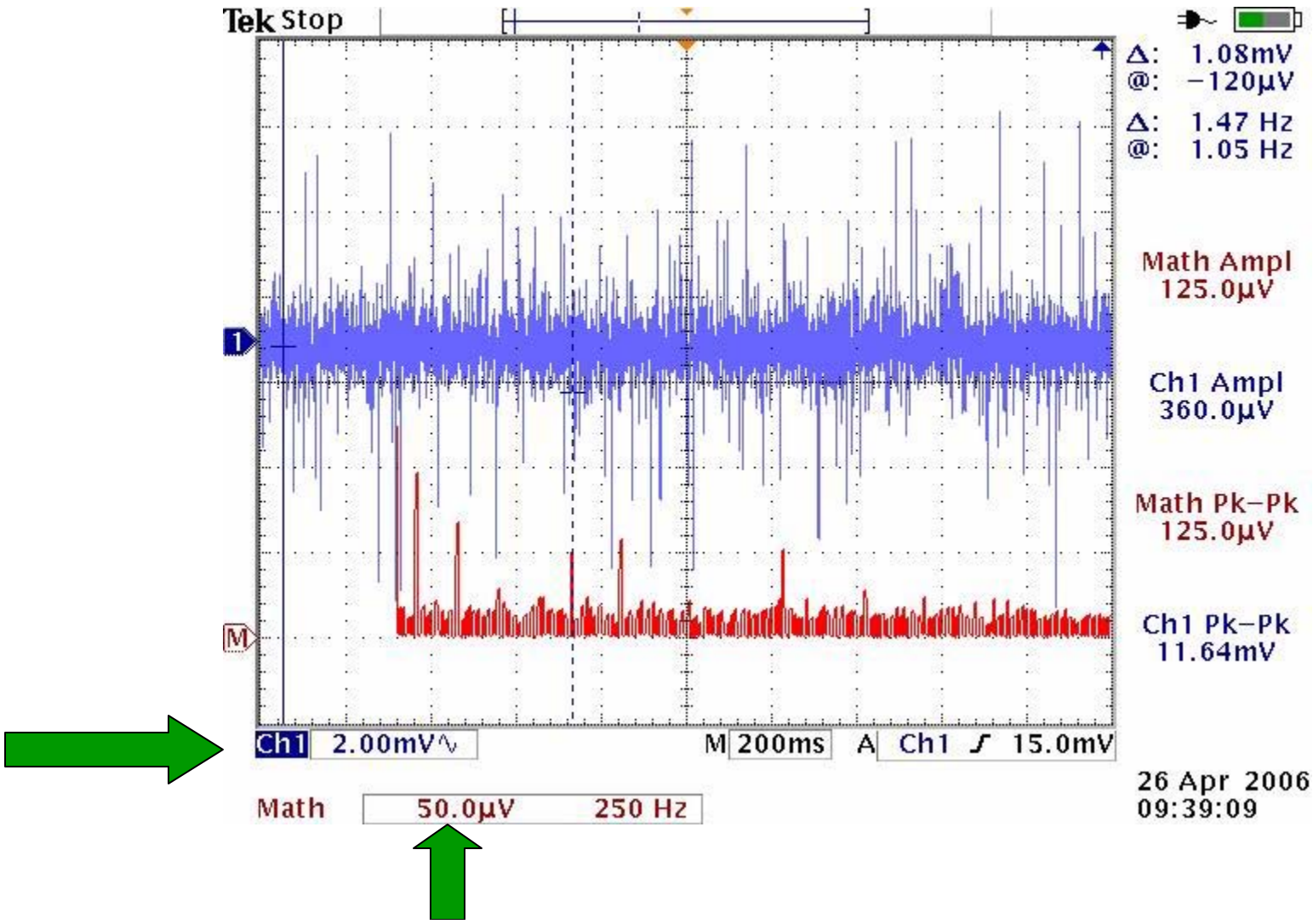
Ground current measurements and spectra in grounding cables, pumping lines

Very bad, strong 60 and 660 Hz



to isolation transf.

Good,
residual 60 Hz and harmonics



Noise Crash Cart (NCC)

S. Hannahs, J. Jaroszynski, A. Migliori, T. Murphy, E. Palm

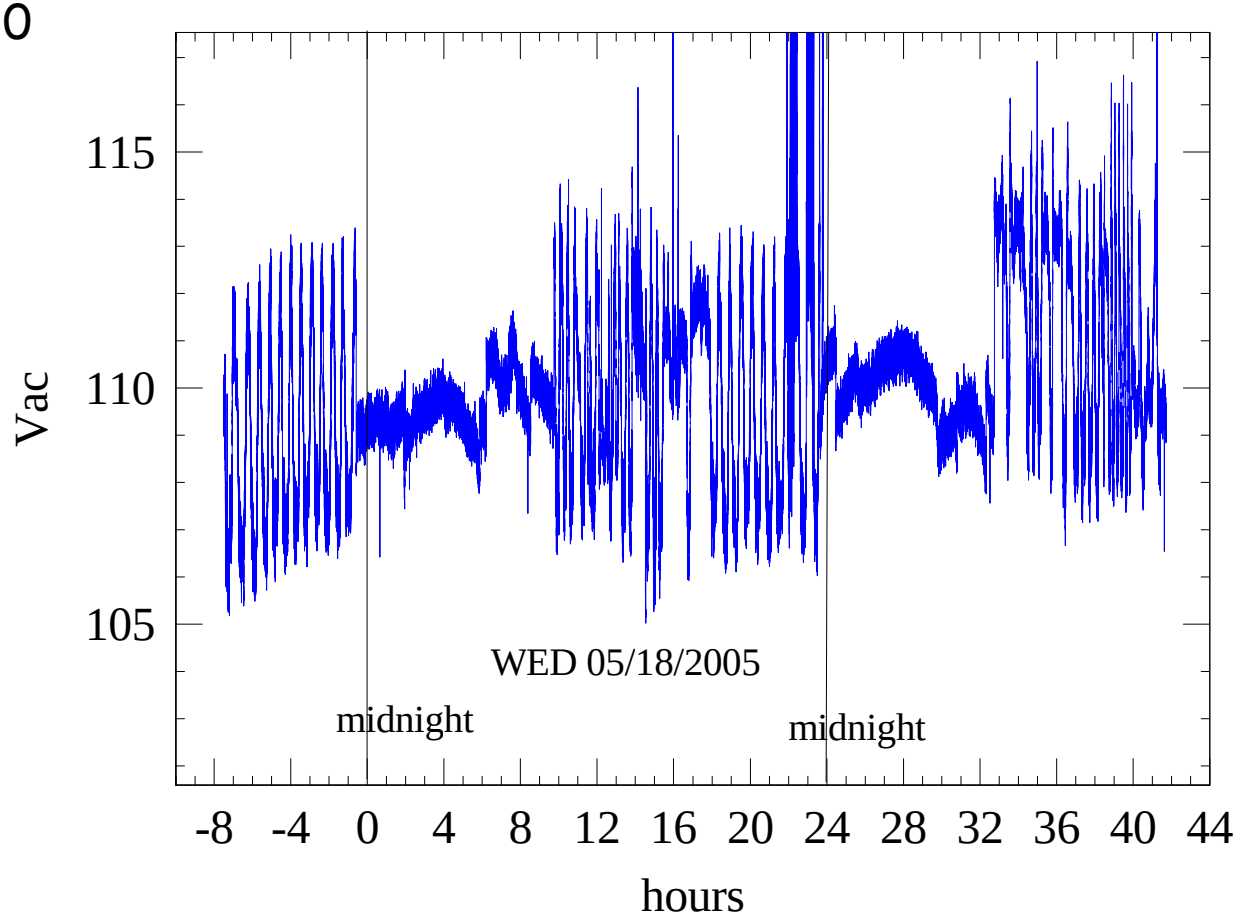
We describe here a “noise crash cart” (NCC, photo below). The NCC will provide a portable system able to respond to an obvious need to quantify noise in magnet measurement systems. Without the ability to quantify, the expected incremental response of systems to noise-abatement strategies cannot be detected reliably—and we expect that almost all improvements to be made will be individually small—so it is important not to miss any opportunities for lack of testability. The NCC is comprised of a portable isolation transformer, digital phosphor oscilloscope with Ethernet porting of data and a spectrum analyzer function built in (FFT) for making quantitative measurements, clamp-on current probes for measuring ground currents, and especially important to the mK facility, a RF signal strength analyzer. With this system we can measure and log ground noise and ground-loop currents, magnet power supply noise and frequency components, transmissions from the ELF (Navy) through cellular phone (893MHz to 1990MHz) and correlate these with noise in a measurement.

Item	Cost for each NCC
Tektronix TDS 3012B DPO scope with FFT and TDS3BATB battery pack, differential preamp	4.5K
Sola MCR 63-13-210-6 Isolation transformer	0.9K
AEMC MN 312 AC Current Clamp DC current gun	0.54K
Protek 3290 RF Signal Strength Analyzer 0.1-2900MHz	2.2K
Cables, cart and connectors	0.4K
Laptop and USB-RS-232 adapter	1.7K
Megger ground meter	1.4K

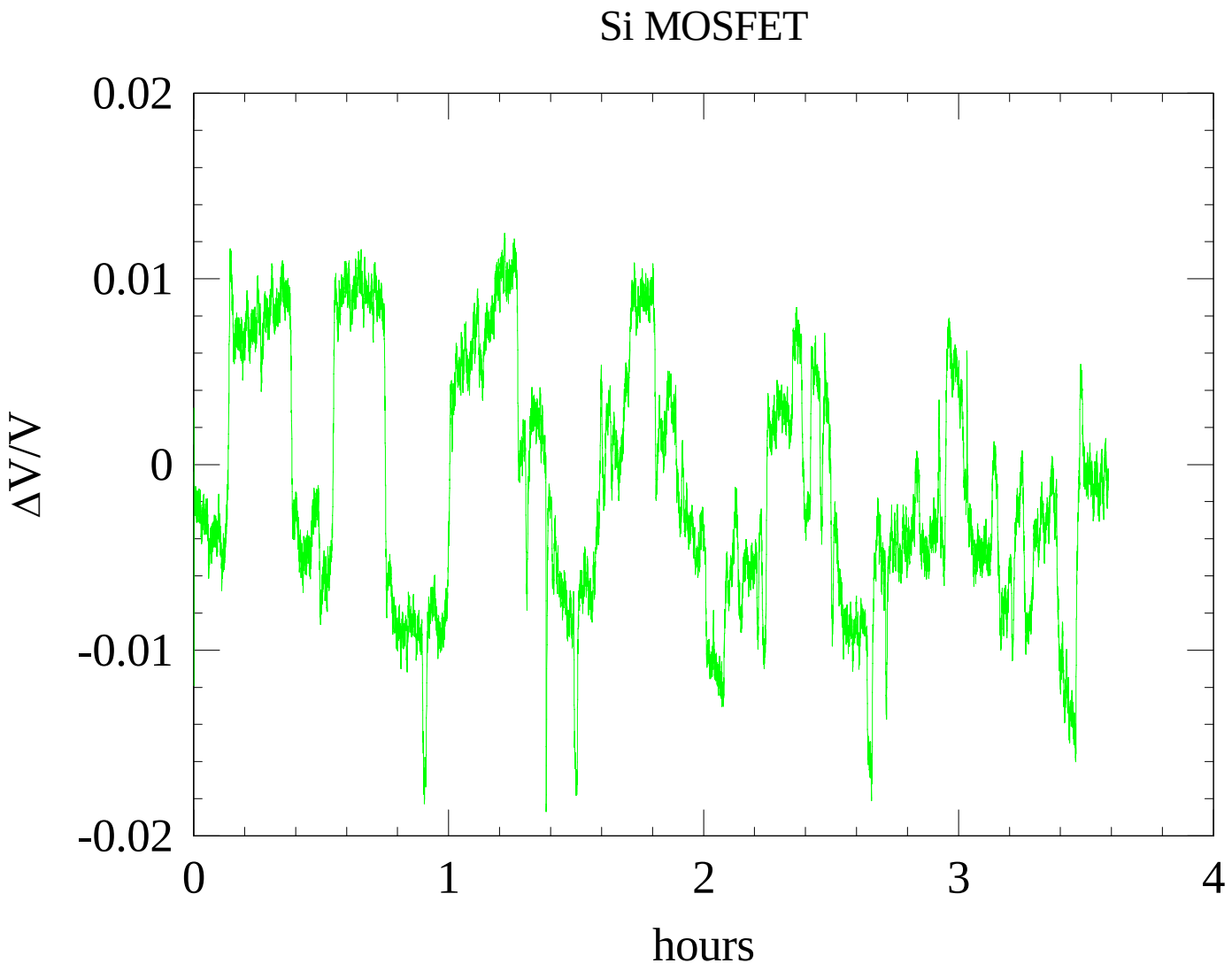
Fighting the noise

Yet another problem:
Changes of Vac from power line due to sweeps in resistive magnets

as seen in C-120



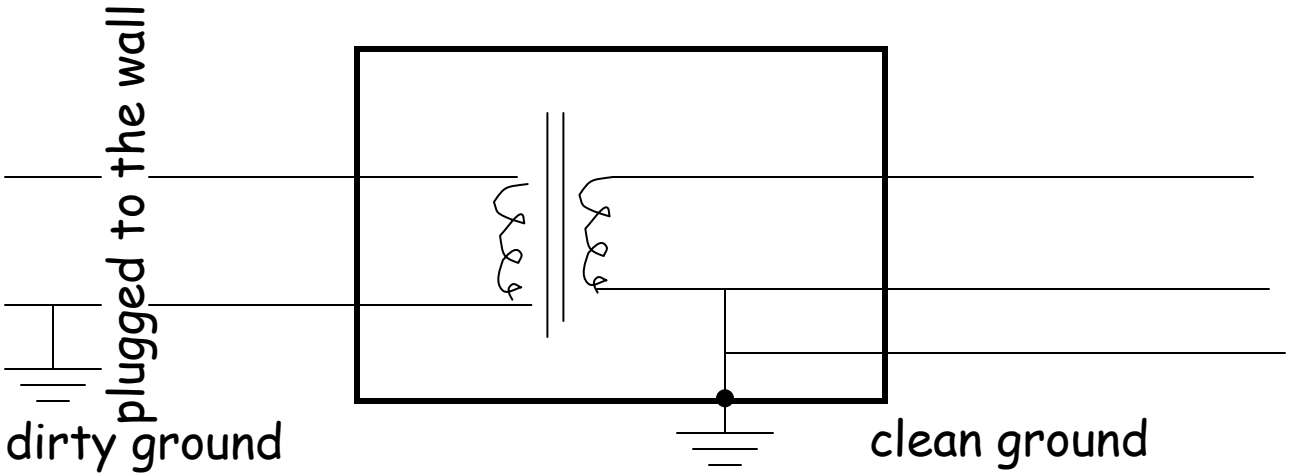
Sometimes these Vac fluctuations influence measurements
(here V was is measured by lockin @ 10μV range)



To stabilize V:
ferro-resonant line-voltage regulators

they serve also as isolation transformers
providing clean power and clean ground
for experiment

to exp. set up



to exp. set up

GPIB opto-isolators:

to cut ground loop between the computer
and the experimental setup
to reduce HF in mK experiment

B: clean side

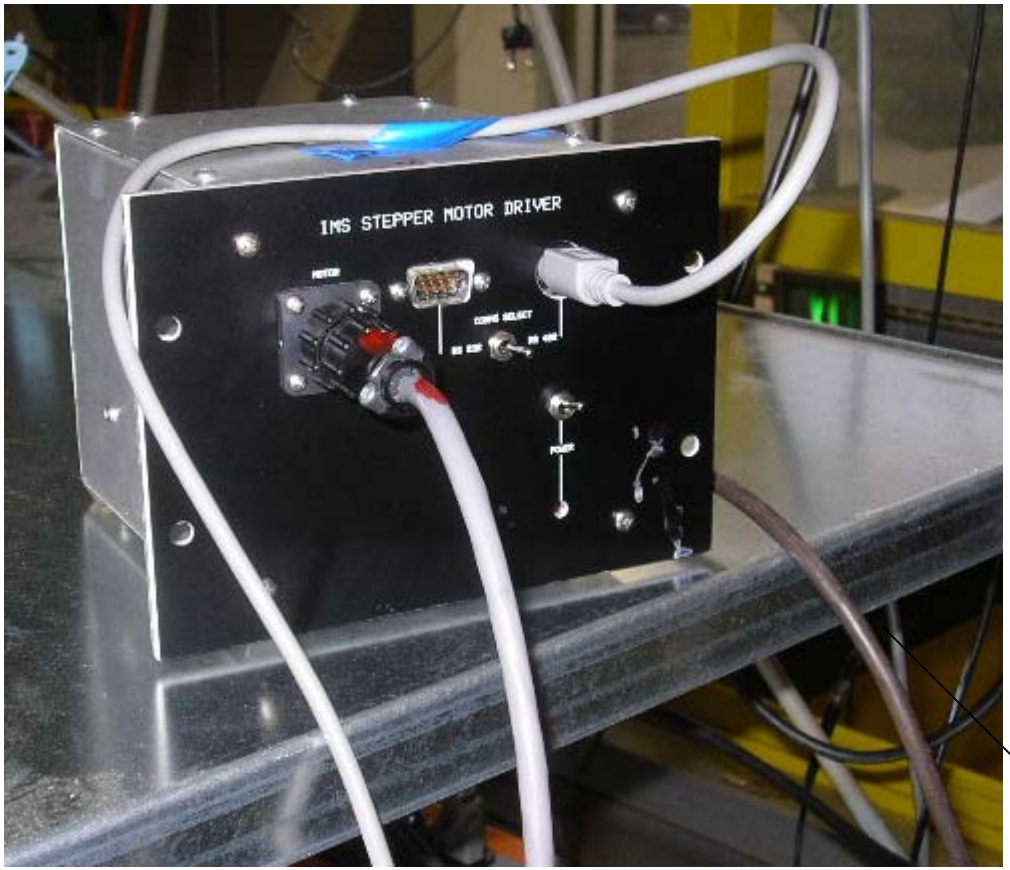
A: dirty side

plugged into
the wall outlet

experiment

computer

Important: plug into dirty ground other instruments which are connected to the computer via USB, RS etc. or isolate their ground



stepper motor driver

to the wall

Suggested good practices:

Things to be done well before magnet time starts:

1) Mount samples maximizing use of twisted pairs in the probe and cables

2) Isolate you probe or cryostat from the magnet, double-check if cables/shields connect ground between instruments and the probe
(usually they don't)
Secure cables against vibrations

3) Isolate the probe from pumping lines using plastic clamps/orings

4) Check these connection using ohmmeter with sharp terminals (stainless steel, oxided aluminum are difficult to contact)

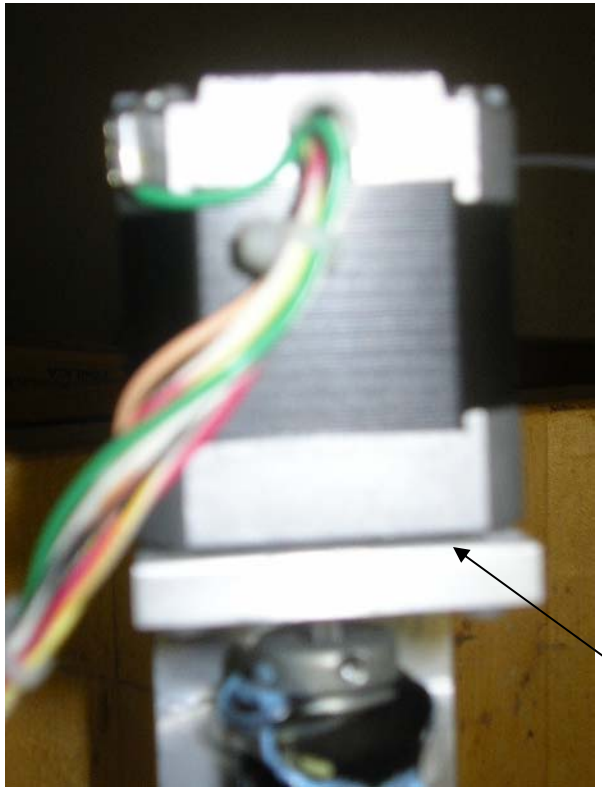
5) Then check your setup for ground loops using Megger ground meter and/or the scope and current clamps

Important exception:
in SC magnets do not isolate sliding probes
Just opposite: ground them

Keep control on if possible noisy ground loops
on the new SS instrumentation carts
bad example:

Sometimes ground loop arises very unexpectedly:

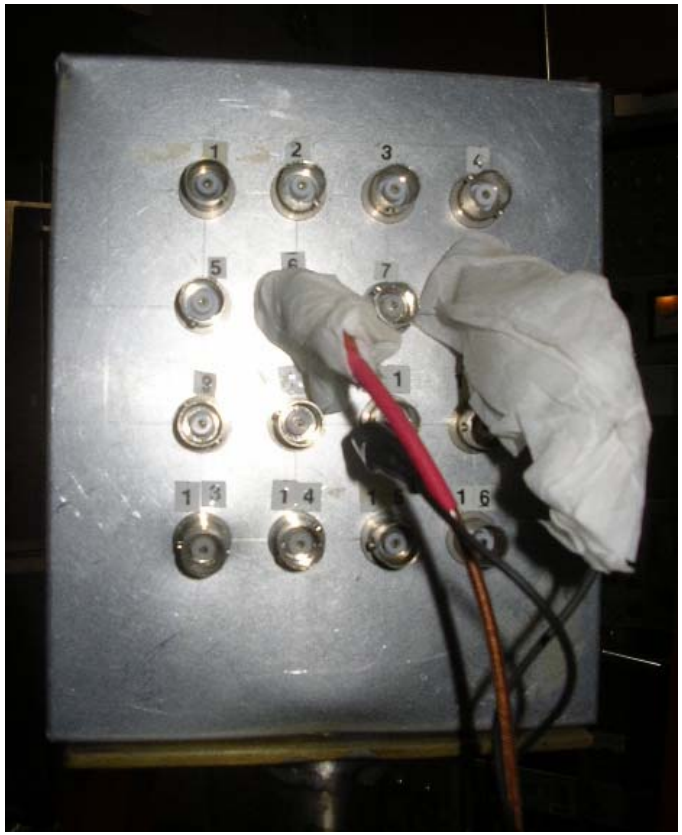
manufacturer fault:
random connection between SR830
chassis and transformer cover



dirt between stepper motor
and the probe connects
dirt computer to the clean experiment

Thermoelectric effects (DC measurements only)

Cu/CuO could give as much as 1 mV/deg
Thermally isolate terminals esp. when LN2 vapors from the cryostat
Noise reduction down to nV possible



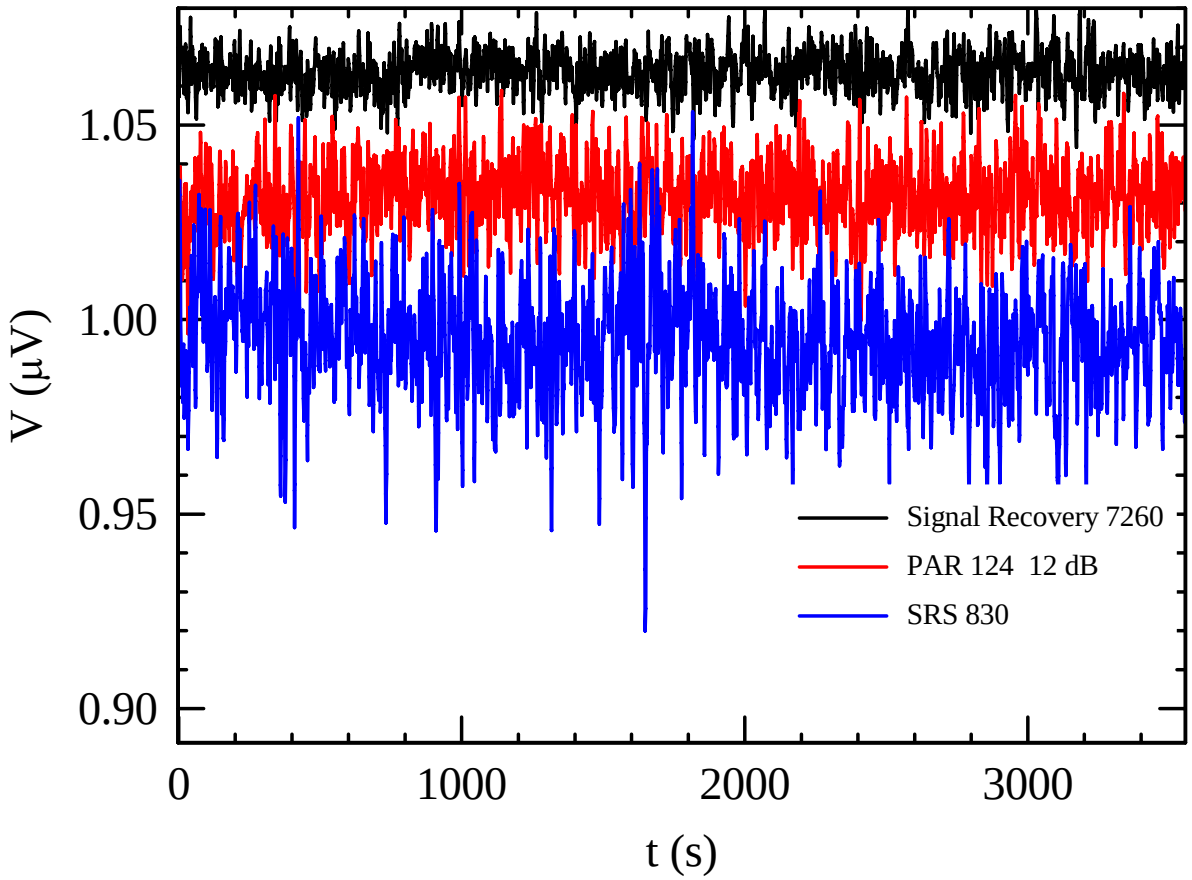
electrometer

To reduce vibrations from pumping lines

Yet another source of noise and heating/cooling in the mK range:
II type superconductors as a soldering alloy SnPb
Excess heat when sweeping field up from B=0

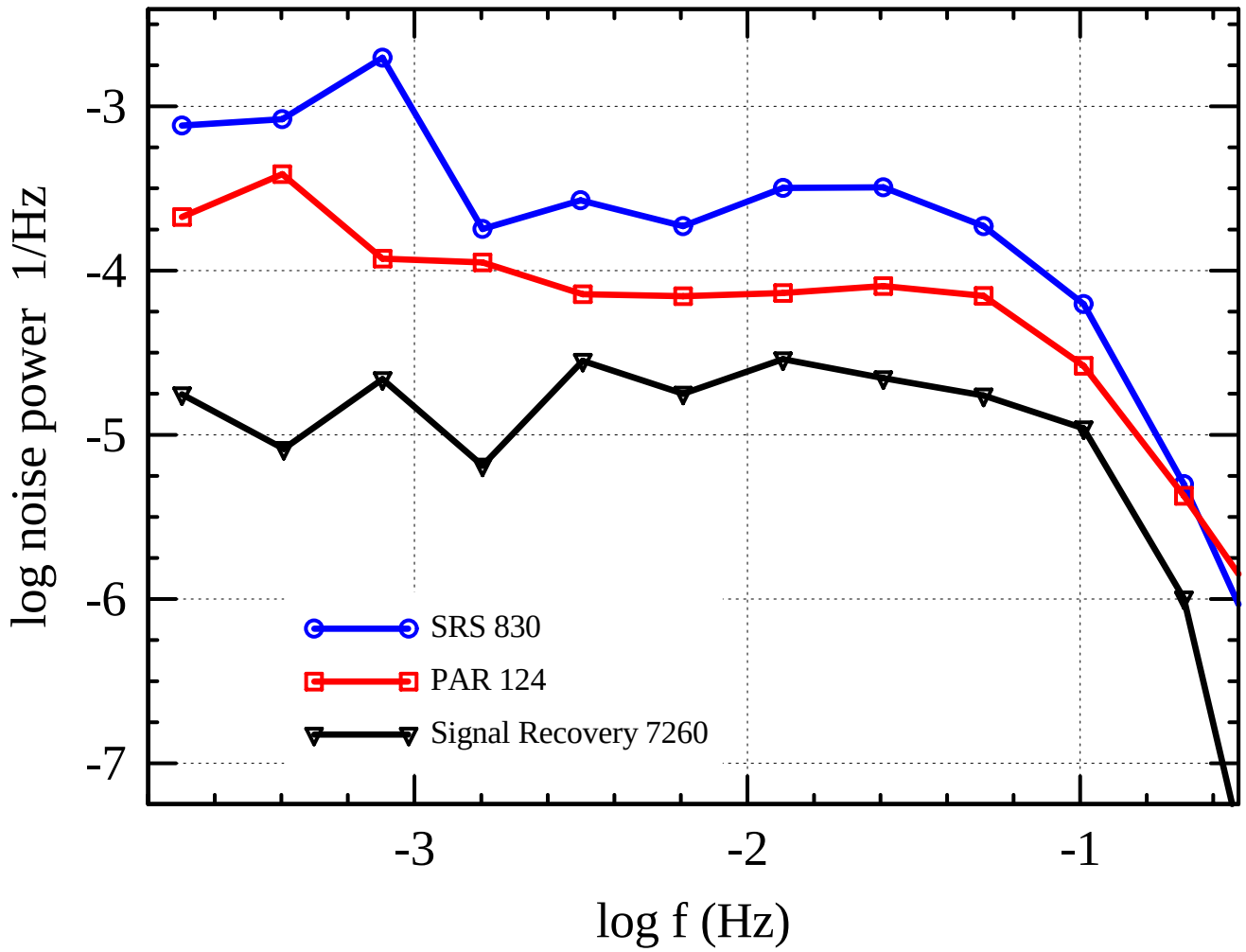
Solution: In, silver paste where possible

Search for better lockins: Signal Recovery 7280 tested



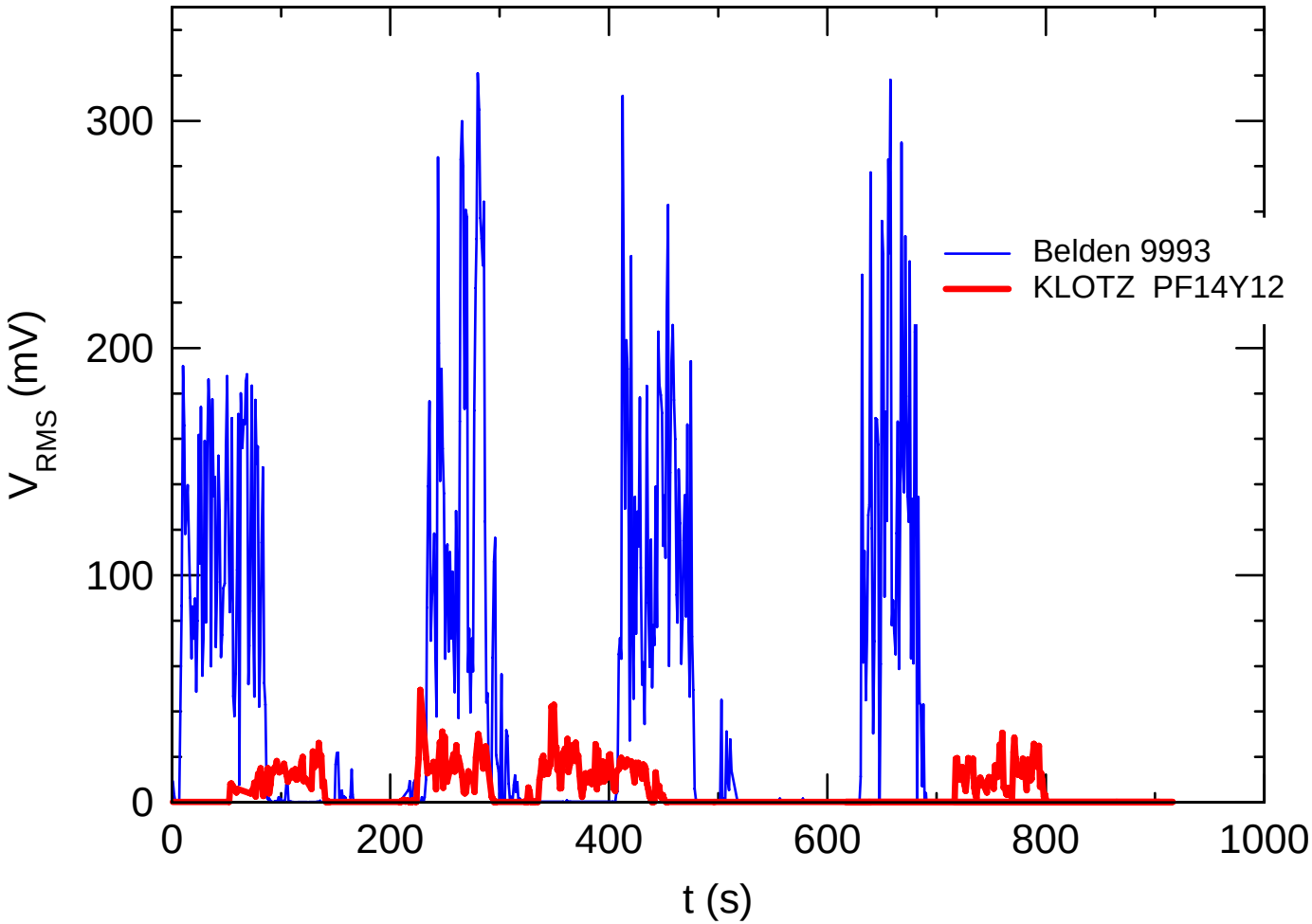
V vs. time, 1 nA on 1 kOhm metal film resistor
time constant 1 s f=7 Hz, V_{RMS}=5, 9, and 15 nV for
Signal Recovery 7280, PAR 124 and SRS 830, respectively

Power spectra, averaged over octaves
almost 2 orders of magnitude difference between SRS 830
and Signal Recovery 7280 in a longtime (1h) stability



Search for better cables: triboelectricity vs. electromagnetic pick-up

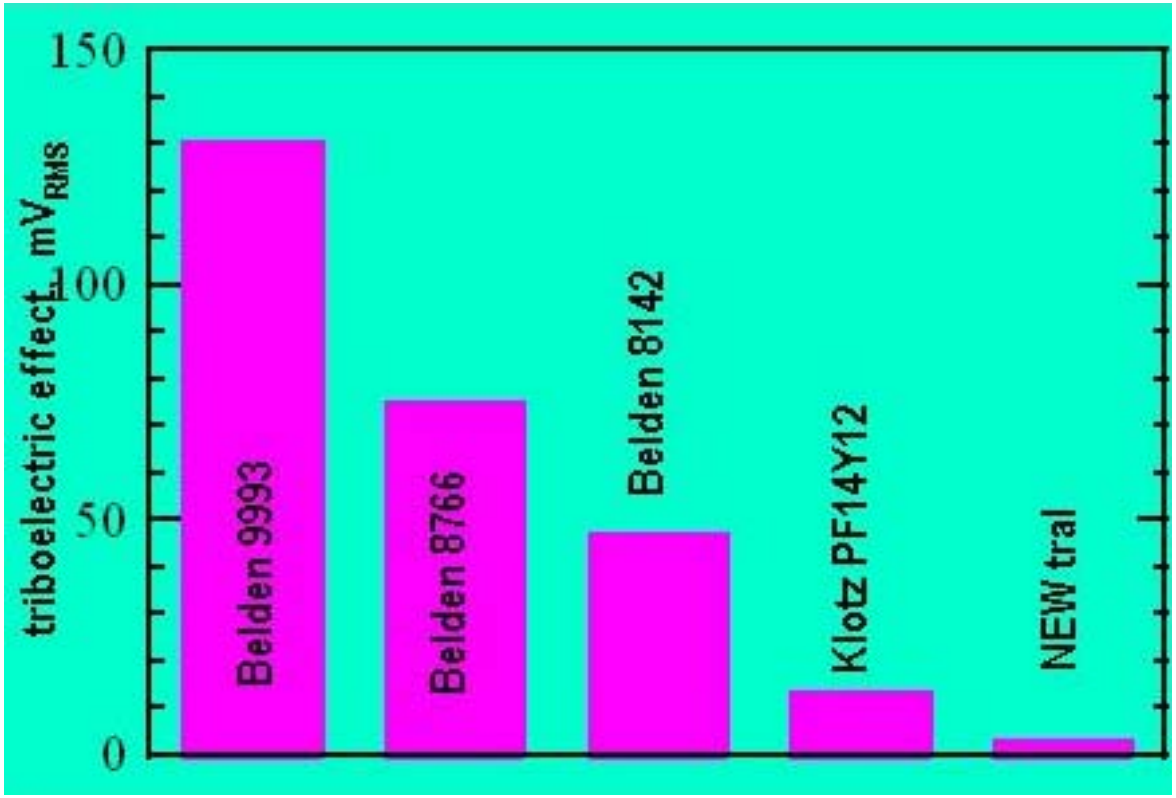
different cables: triboelectric effect : voltage when cable bent



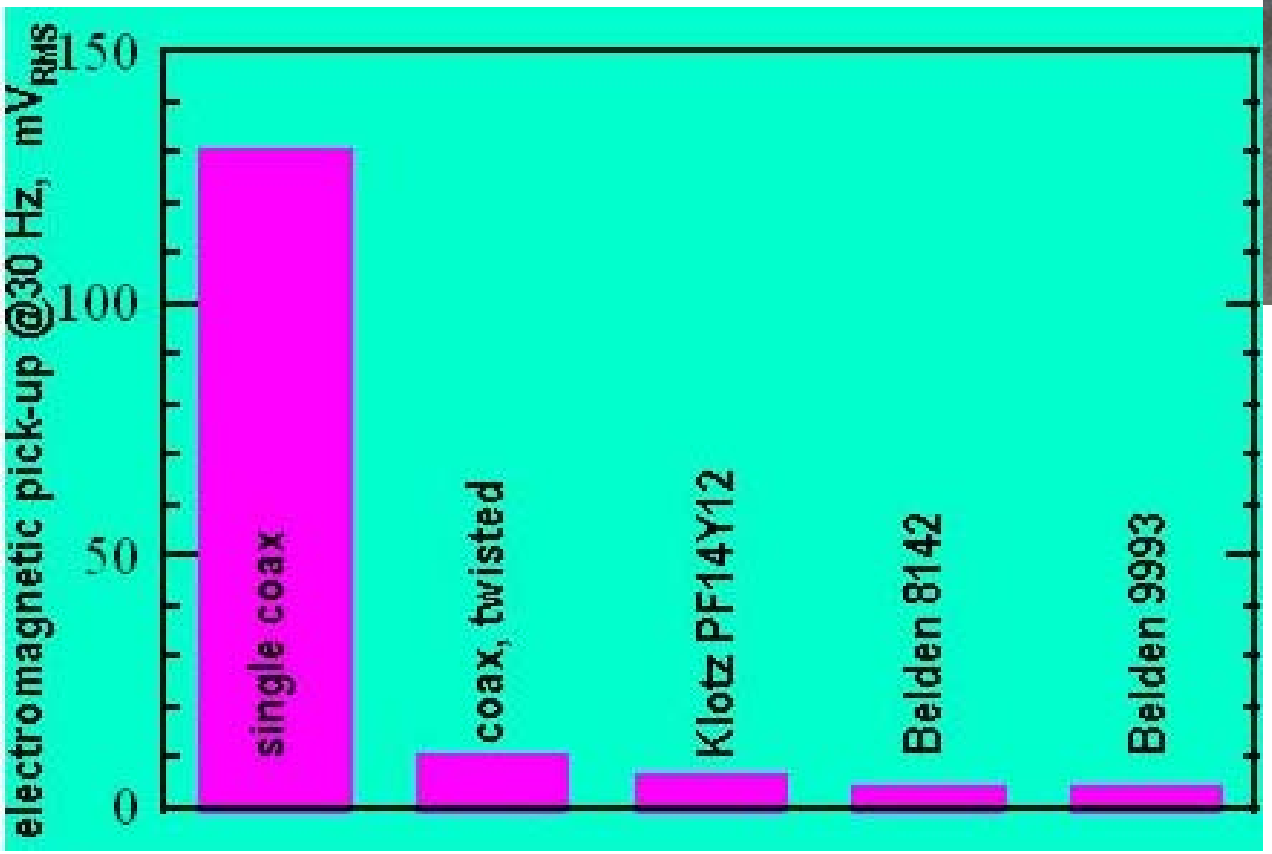
8142

Paired- Parallel Digital Video **Number of Pairs:** 12 **Total Number of Conductors:** 25 **AWG:** 28 **Stranding:** 7x36 **Conductor Material:** TC - Tinned Copper **Insulation Material Trade Name:** Datalene® **Insulation Material:** FPE - Foam Polyethylene **Outer Shield Material Trade Name:** Beldfoil® **Outer Shield Material:** Aluminum Foil-Polyester Tape w/Shorting Fold,TC - Tinned Copper **Outer Jacket Material:** PVC - Polyvinyl Chloride **Plenum (Y/N):** N **Applications:** Precision Video Cable for Analog and Digital, Parallel Digital Video, Low-Capacitance Computer Cables for EIA RS-232 and EIA RS-485 Applications

Triboelectricity: results



Electromagnetic pick up @ 33 Hz

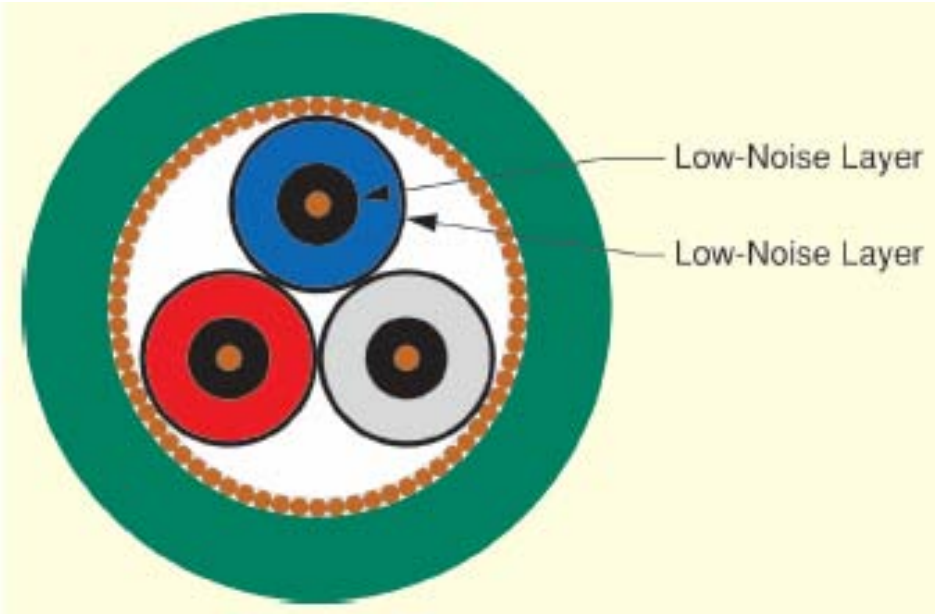


results for twisted pairs

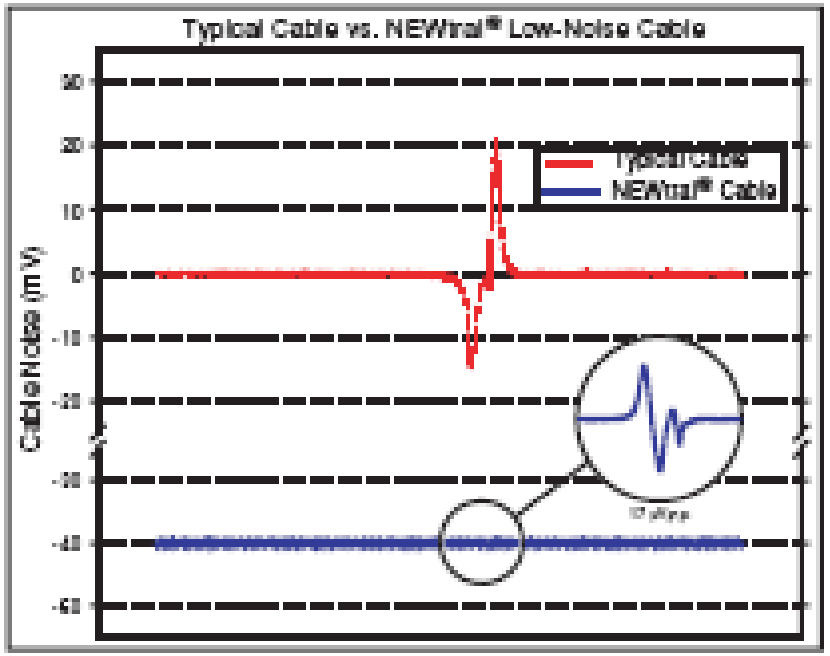
however an order of magnitude stronger between wires from different pairs!

try to avoid them mounting the sample!!!

Solution: new, very quiet cables from NEW
(we already have their coaxes)

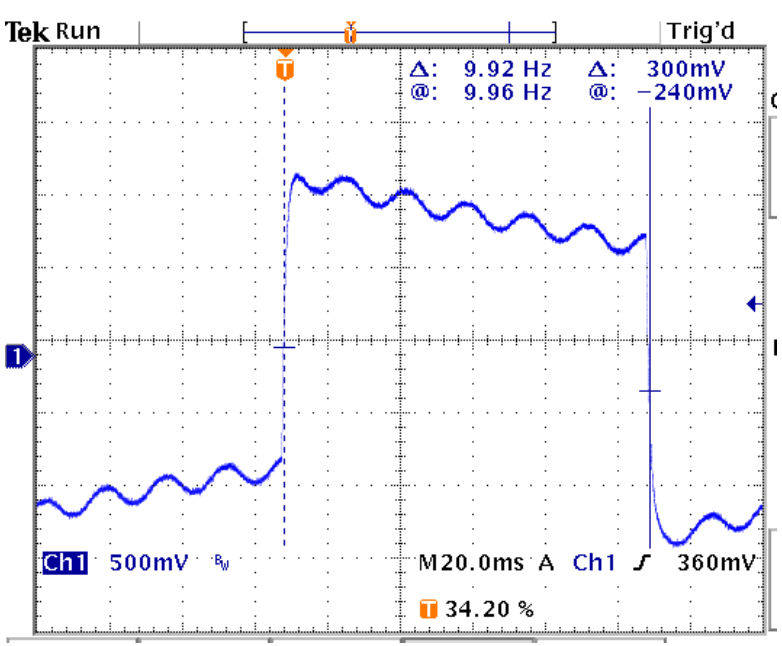


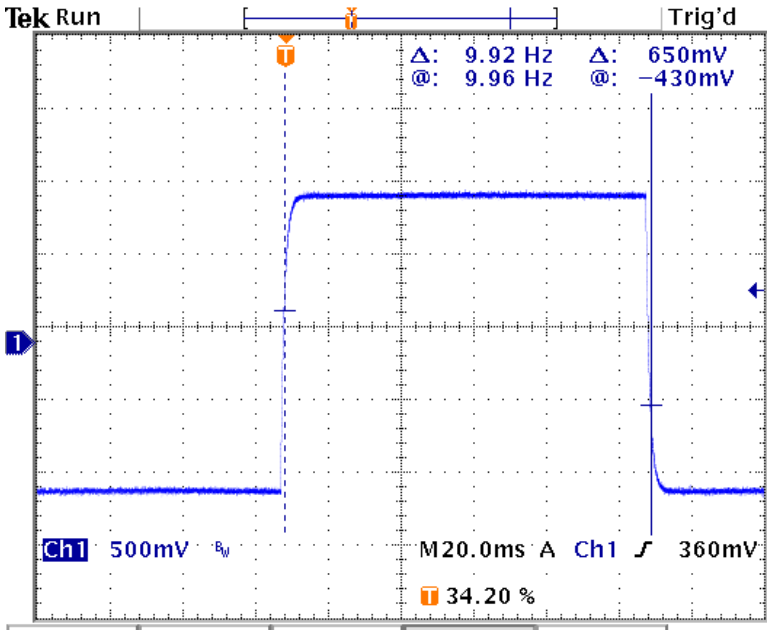
NEWtral



Examples: better T stabilization

Lakeshore control heater/thermometer noise before and after proper grounding





Control thermometer waveform before connecting current-source shield on Lakeshore temperature controller and platform thermometer current source shields to racetrack ground, and replacing coax with twisted pair.

After-from 500mK fluctuations to sub mK temperature stability

S. Riggs, A. Migliori et al.

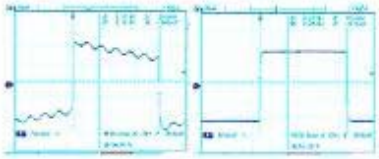
Avoiding grounding/noise problems*

The following items are critical to obtaining an optimum grounding system, otherwise ground loops would pick-up substantial interference from transformers and magnet power supplies (60 Hz, 720 Hz and harmonics)

Vibration isolate cryostat from magnet with rigid support & cryostat XYZ tilt.
Isolate the cryostat or the probe from the magnet and from pumping lines.
Use plastic clamps/o-rings.
Check with multimeter that resistance between cryostat and magnet is high (before grounding cryostat)

Ensure that isolation transformer is grounded, otherwise high floating voltage will be present on its chassis and the instruments.
Power all the instrumentation (but computer and GPIB isolator) from isolation transformer
Ground the cryostat and breaking box at the same ground bar.
Use twisted pair with shield, avoid coax cables.
Ensure that shields of all the cables are grounded only on one side, usually on the breaking box.

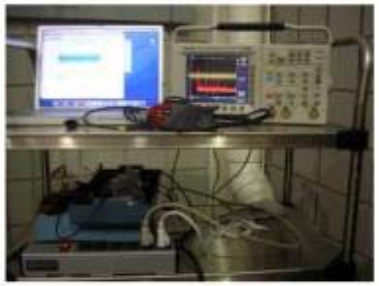
Isolate GPIB bus ground using National Instruments GPIB-120A isolator. Use "noise crash cart" to check if you have proper grounding without loops.



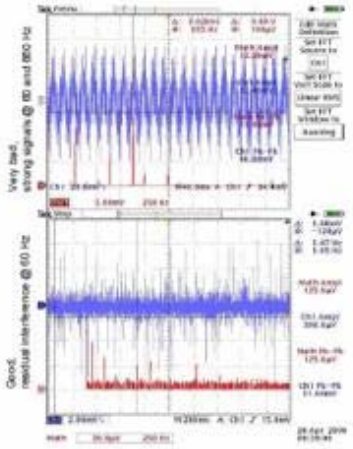
Proper grounding reduces unwanted noise dramatically and improves temperature stability. Example: temperature controller waveforms before and after proper grounding correspond to improvement from 500 mK to sub mK temperature stability.

* in case off grounding/noise issues contact Jan Jaroszyński 644 1175 jaroszy@magnet.fsu.edu

Noise crash cart



To quick check your setup you may use one of the noise crash carts, usually located in cell #7 or instrumentation storage room



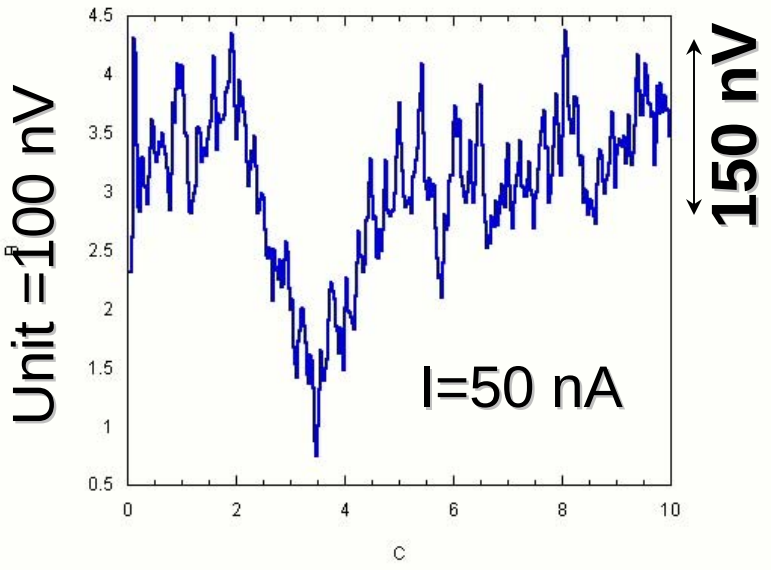
Put clamp on the grounding cable of isolation transformer (or cryostat) and connect it to the oscilloscope. Set the scope to, say, 200 ms/div, 1 mV/div. If signal looks as a white noise with amplitude < few milivolts, your set-up is properly grounded. For spectral analysis switch on FFT option: MATH, FFT. If ground loops are absent, almost flat FFT would be seen. Otherwise several characteristic frequencies show up: 60 Hz (power lines, transformers), 720±60 Hz (magnet DC power supply if on) and their harmonics. Still, if their amplitude is less than a few hundreds microvolts (1μV corresponds to 10μA ground current) it is probably a result of capacitive pick-up, not bad ground. Additionally you could see $f \simeq 8$ Hz, 20 kHz, 500 kHz, 1.27 MHz, ~ 20 MHz, broad band from FM radio and TV. These frequencies should be avoided in measurements.

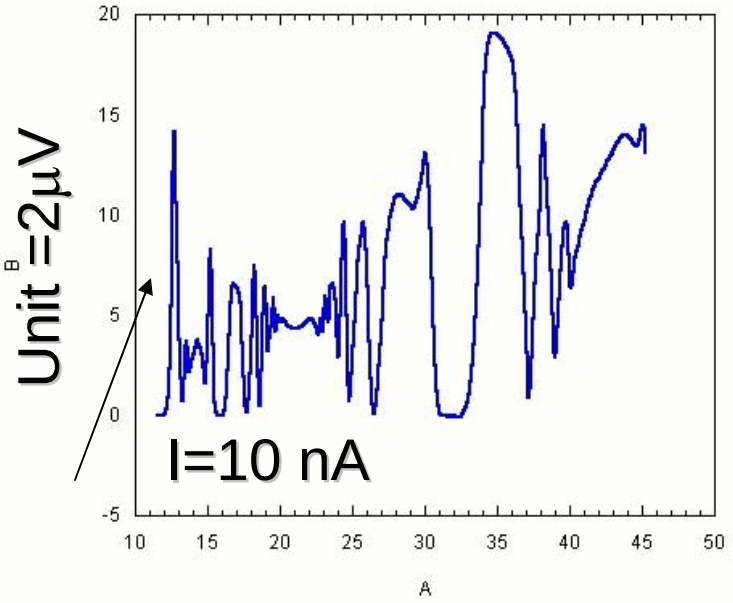
To spot sources of high frequency in the range 100 kHz – 2.9 GHz other then listed (for instance some UPSs, computers) above you may use Protek 100kHz–2.9Ghz RF Signal Strength Analyzer. Set the center frequency (e.g. set 100 CTR/. ENTER). Then select the step. Measured spectra consist of 160 steps: e.g. F2, set 1 MHz, ENTER, and F1 for run. Protek will scan from 20 to 180 MHz.

On noise crash carts you could also find clamp-on Hall probe to measure DC current in ground cables, voltage probes and preamplifiers to analyze signals in your circuit, and laptops for data taking. Importantly, all these instruments could be powered from batteries which makes it possible to avoid interference from their power lines.

Examples

Noise @ 50 nA 150 nV p-p/10μV = 1.5%

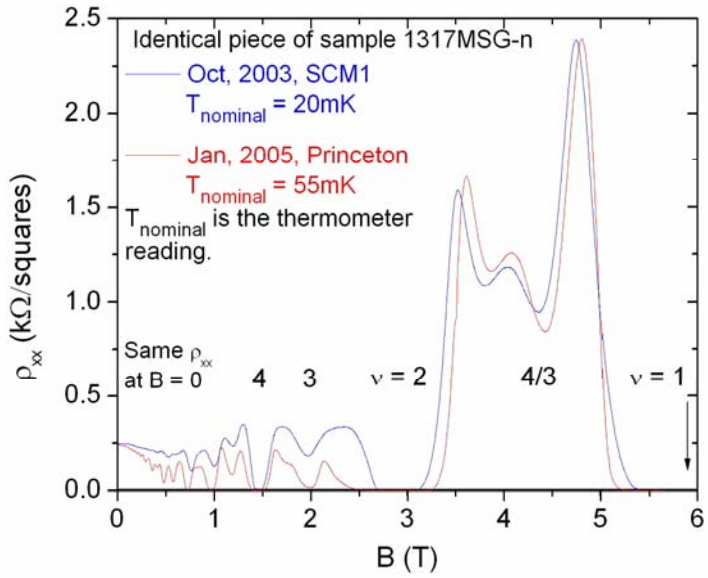




FQHE and RDNMR measurement in the hybrid (Jiang et al)
after better grounding

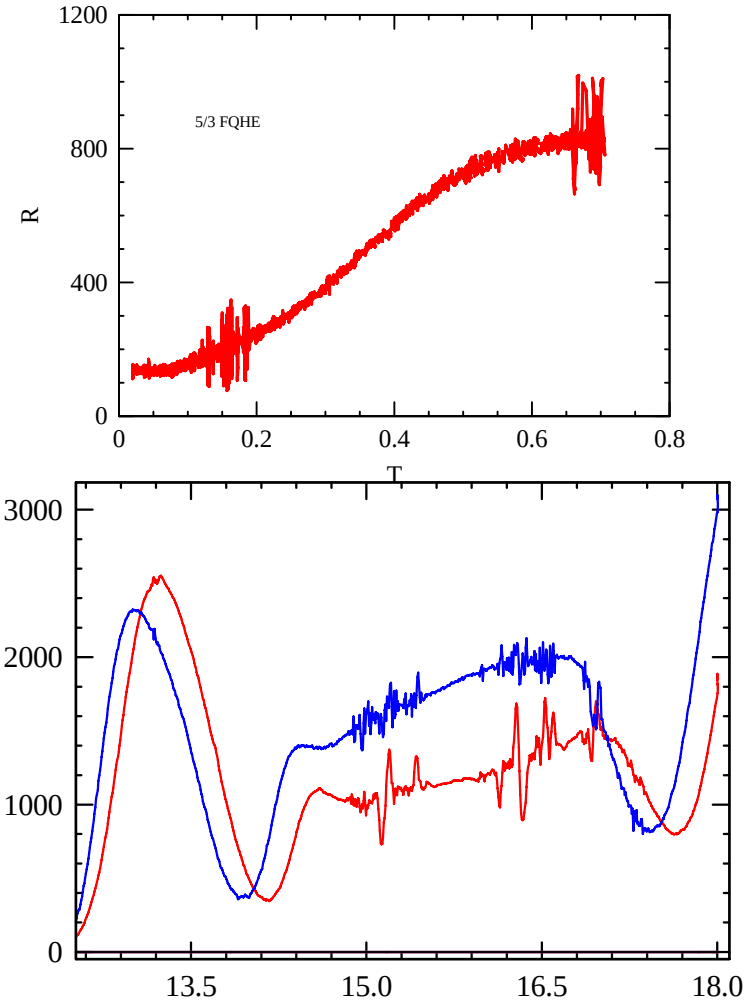
Examples: SCM1 problems

cooling problems?



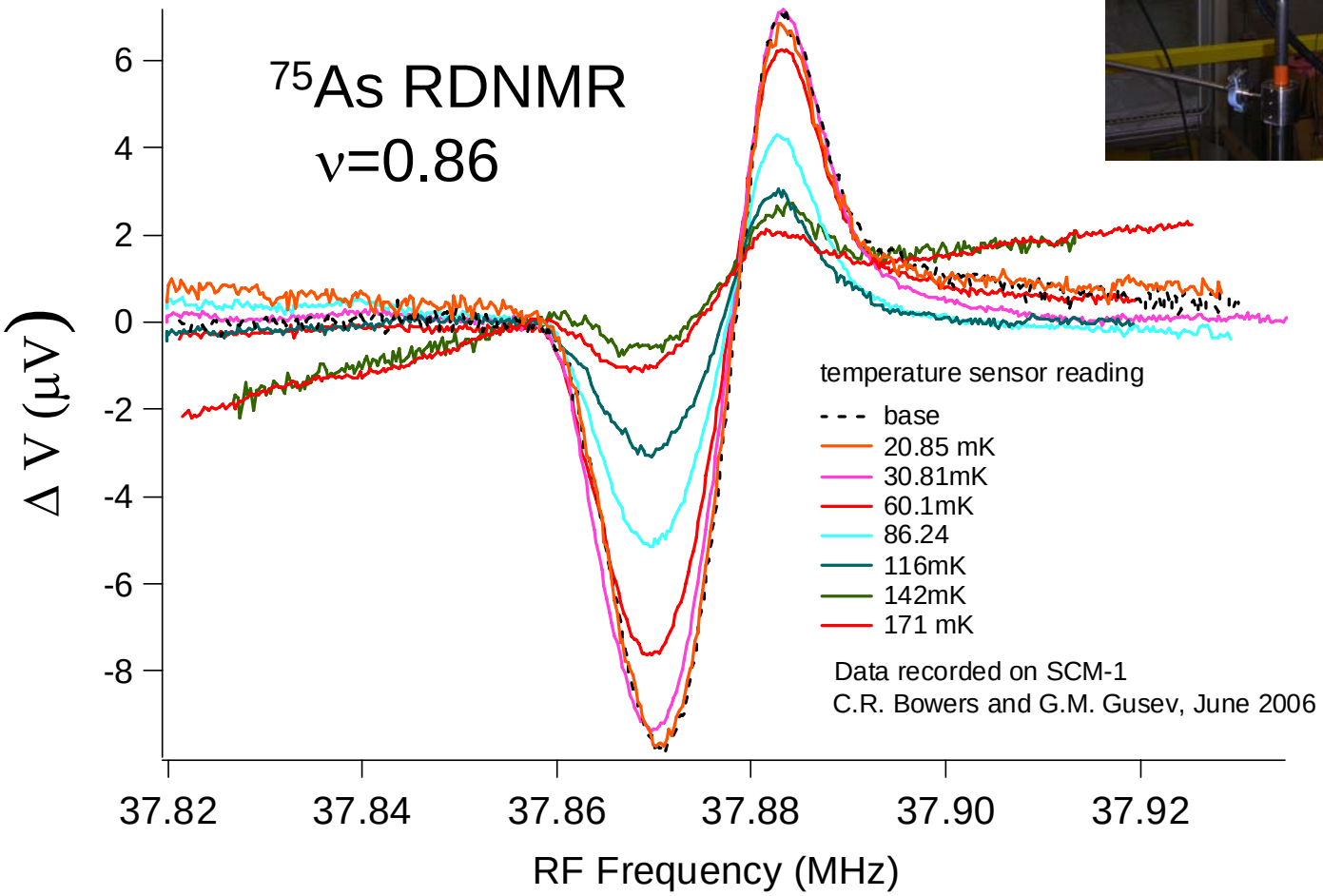
Keji Lai et al.

cooling and noise problems



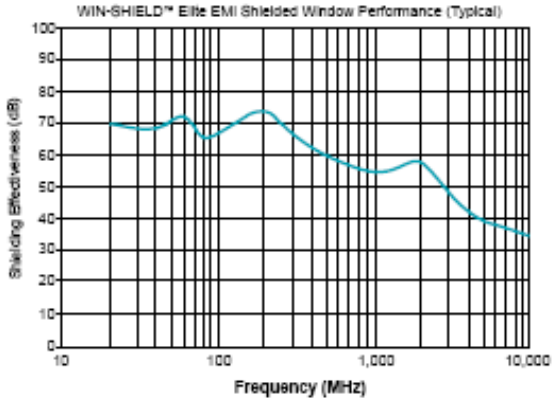
Nathaniel Bishop et al.

Recent improvement in SCM1: proper grounding, quiet cables, HF filters, better lockin
10 days/nights long hard work of our guests:
R. Bowers and G. Gusev



Other issues, ideas

- high frequency interference in millikelvin bldg., hybrid which are elevated and probably constitute good resonance cavities for FM frequency which spoils NMR and other HF experiments
  solution: to shield windows with foil or mesh



- better lockins: Signal Recovery (former PAR, E&G etc) model 7280 tested, 7265 will be tested soon. Tests show 7280 is much better for sensitive measurements as RDNMR, noise measurements, etc

- purchase small accessories as DC ground breakers for coaxes ferrite clamp on, clamp on ground resistance meter for quick tests, zippered cable shielding to reduce HF, electrostatic, vibration

- preamps closer to experiment (cryogenic?)

- "universal" breaking boxes