Do It Yourself –

Scanning Tunneling Microscope

Journal

Kantonsschule Wettingen
Maturaarbeit 2008/2009

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STM DIY: Journal

Week 26

- Request for sponsorship sent to several companies:

  ABB Rejection

  Alstom No answer

  Atel No answer

  ETH No answer

  Leica Geosystems Rejection but forwarded to Leica Microsystems

  Metrohm AG No answer

  National Instruments No answer

  Roche No answer

  Siemens Rejection

  Uni Basel/Bern/Zürich Rejection

  Carl Zeiss AG Up to 500.- CHF of the material costs

  Empa All the material costs

  IBM All the material costs and contact to the technical manager

  Paul Scherrer Institut All the material costs and possibility to take parts out of the repository – However the offer was relativized afterwards and we need to present our project at the PSI first.

Week 27

- **School** Meetings with Siegfried Ebers (PSI) and Paul Studerus (ETH) in week 28 planned.
- **Home** Burr-Brown OPA 129 sample ordered. It will arrive at the end of the week.

Week 28

- **Monday, ETH:** Meeting with Paul Studerus

  Discussion of operational amplifiers: OPA128, OPA129 and OPA111 recommended

  Earthed metal case around amplifier necessary

  Analog controller easiest to establish

  Propositions for basic stamp, DAC/ADC as interface

  Possibility to etch tips at the ETH

  Posstibilty to have parts manufactured at the ETH

  External People: Paul Studerus (ETH)

  (1 h)

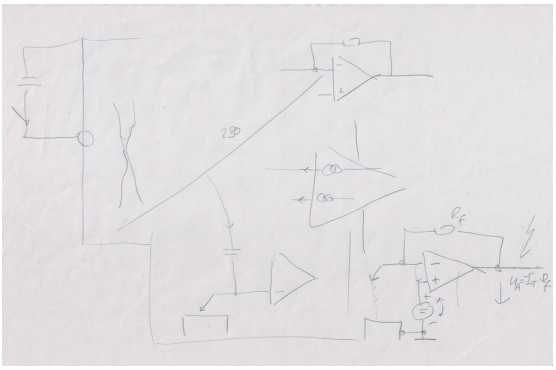

Figure 1: Notes from the meeting with Paul Studerus.

- **Tuesday, PSI:** Meeting with Siegfried Ebers

  Gives us an amplifier (with OPA111 on it) and a power supply

  Mentions proper insulation of all wiring to be important

  External People: Mr Ebers (PSI)

  (1 h)

- **Tuesday, PSI:** Meeting with Mr Ovinnikov

  Discussion and subsequent decision to use USB Microcontroller interface with Mr Ovinnikovs help

  External People: Valeri Ovinnikov

  (1 h)

- PIC32USB evaluation board delivered.

Week 29

- **Monday, School:** We succesfully tested Mr Ebers' amplifier.

  Notes: Wiring was unclear at first, but after successful wiring and attaching a battery coupled with a resistor as the input source, the amplification could be seen using a multimeter.

  Resources: Amplifier, school-provided power supplies, battery, cables

  External People: Hansulrich Schmutz

  (1 h)

- **Wednesday, PSI:** Presentation and subsequent confirmation of sponsorship. Confirmation that parts can be produced at PSI and know-how will be gladly provided whenever asked for.

  Notes: Short outline of what we had done so far and answering of questions. We outlined that our work was separated in three parts (mechanical, physical, electronical) and structured our plans in steps. Afterwards, we received confirmation that our endeavor was feasible and hence, support from the PSI was granted.

Resources: Merkli's Car

External People: Dr. Peter Allenspach - chief of logistics, Dagmar Baroke - chief of personnel

(2h)

Week 30

- **Friday, School:** Gather sources for research during summer vacation and distribute topics of research.

  Dominik Physical backgrounds, electronics

  Ivan Electronics, programming

  Sandro Mechanics, programming

Week 31-33

- Summer vacation – individual research.

Week 34

- **Thursday, School:** Some work on the mechanical parts, including drilling holes into the top plate of the STM and starting to cut it down to its designed size

  Notes: Using the machines to work on the plates was a time-consuming process, as we had to learn their usage first before actually doing any work on the raw aluminium plates provided for our work. Mr Schmutz was a big help to us, as he provided both the material and the know-how to work with the machines. We decided that it would be best if one of us (Ivan) knew the machines best and the others focused on other work, so we would not all have to learn everything.

  Resources: School's mechanical facility, aluminium plates provided by school

  External People: Hansulrich Schmutz

  (2 h)

- **Friday, School:** Further work, completion of several parts and purchase of a heavy metal plate for oscillation damping

  Notes: Work on the parts went well, and in the meantime, the others could go to the Debrunner mechanical parts store and purchase a heavy metal plate previously located and ordered by Martin Merkli. Due to the 30 kg weight of the plate, a car was needed for transport. The actual use of such plates is to close pipes that will be under pressure, so it was neither cleaned nor galvanized, so both had to be done by us.

  Resources: Car, aluminium parts

  Externalactual People: Hansulrich Schmutz (School)

  (4 h)

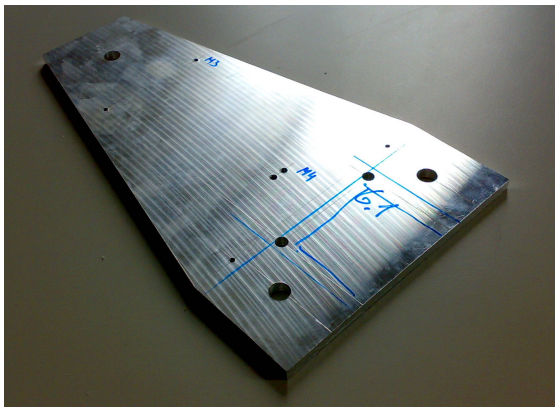

Figure 2: The top plate of the STM after week 34.

Week 35

- **Thursday, Home:** Sending metal plate in for galvanization

  External People: Martin Merkli (Family)

- **Friday, PSI:** Meeting with Jan Hovind, planning of production of scanning head parts at PSI

  Notes: Jan proved very helpful and discussed the parts with us in detail, asking for important factors in production. After the discussion, we decided to have him manufacture the scanning head in different materials so we could later choose which would be best. He produced two aluminium heads and one out of plastic, which arrived a few days later.

  Resources: Car

  External People: Jan Hovind (PSI)

  (1 h)

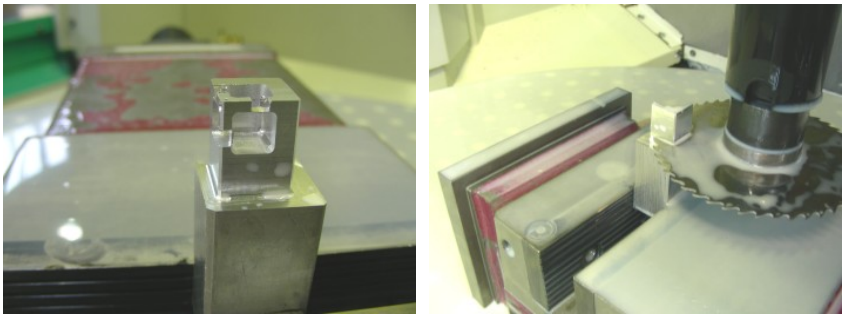

Figure 3: The scanning head in the CNC.

- Whole week: Purchase of a case for the preamplifier card, processing of the metal plate

  Notes: As the plate had about the same size as a computer hard drive, we decided to purchase an external HDD case so we would not have to resize it and so it would not look all too do-it-yourself in the end. We found one on ricardo.ch and it was shipped quickly.

  Resources: Home computers

  External People: Martin Merkli

  (1/2 h)

Week 36

- **Monday, PSI:** Meeting with Thomas Jung, providing know-how and further information concerning the Platin-Iridium tips

  Notes: Mr Jung made us aware of our mechanic build being too large and that our microscope would rather become a microphone if we would not apply some kind of noise cancellation. He explained that a cardboard box and foam, and that the best way to figure out what would be problematic would be to just try it. He showed us a few other, a lot smaller STM designs, but we decided not to change our buildup due to time constraints.

  Resources: Car

  External People: Thomas Jung (PSI)

  (2 h)

- **Friday, School:** Work on last mechanical parts, planning and partial execution of the preamplifier card case production from stock HDD enclosure

  Notes: Finishing of the two plates was done by Ivan, Dominik and Sandro thought about how to fit the card into the case. vertical screws and plastic buffers for horizontal fixation were chosen, and we started looking at what outlets and inlets the front and back plates needed.

  Resources: School's mechanical facility, purchased HDD enclosure

  External People: Hansulrich Schmutz

  (4 h)

- **Weekend, Home:** Fabrication of a box to protect the microscope from acoustic interferences using a cardboard box and cone foam mounted inside using duct tape

  Notes: This box was a quick-and-dirty production, and hence also looked accordingly. A simple cardboard box found at Sandro's home was cut down to fit horizontally and then reinforced with broad duct tape, the foam we found at school cut down to size. Afterwards, the foam was fit into the box, not using any tape so we could switch foams if the used one would be insufficient.

  Resources: Cardboard box, duct tape, cone foam provided by school

  (1 h)

Week 37

- **Tuesday, School:** Finishing of the box for the preamplifier card design and its front and back plates, calibration of the amplifier

  Notes: The design of the front and back plates was finished with final touches - the question whether to put outlets and inlets on the same side of the case or not was a holdup, but further testing of the preamplifier card showed that only one of the two available output ports was reliable, and hence we decided to use this one and put outlets and inlets on discrete plates. Furthermore, we measured the characteristic line of the amplifier (Figure 4). The fixation of the plates to the case was a mechanical problem, as it would be convenient to be able to remove and reinsert the card into the case so adjustments to the amplification factor could be done, but as we decided to use both plates for I/O, this was impossible without any soldering.

  Resources: School's mechanical facility, front and back plates supplied by Martin Merkli

  External People: Hansulrich Schmutz

  (2 h)

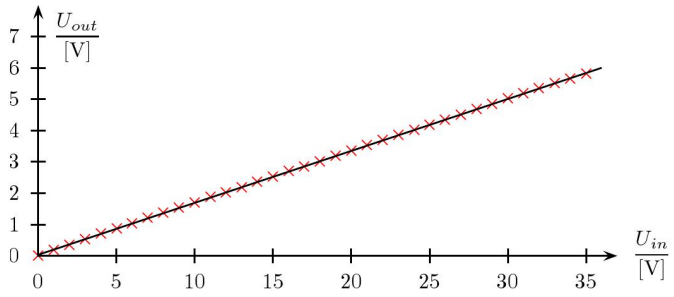

Figure 4: Characteristic line of the amplifier.

- **Friday, School:** Planning of cabling, eloxation attempts of scanner head parts, drilling holes for cabling into the preamp box, planning of work to be done in the autumn vacation

  Notes: Eloxation of the scanner head was surprisingly difficult, as the parts were too small to be properly attached to a wire to hang them into the eloxation solution. After subsequent unsuccessful tries to eloxate the parts, we gave up and decided that it was not worth the time effort, and decided to use the second aluminium scanning head in the final product. Eloxation always had to be cancelled early due to the construction falling appart and the parts not being connected to the electrodes, stopping the actual eloxation process.

  Resources: School's chemical and mechanical facilities

  External People: Hansulrich Schmutz, chemical laboratory assistance

  (4 h)

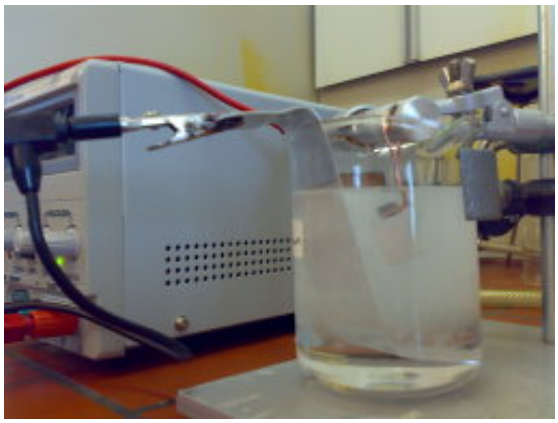

Figure 5: The eloxation did not work as intended.

Week 38

- **School** Course of the week: Fixing of piezo elements on scanner head and mounting of the tripod holding the needle using araldit quick-dry glue

  Notes: The quick-dry glue did not dry as quickly as we expected, and it needed pressure to actually hold afterwords, so we had to try several times, always pressing the piezo element against the tripod. This circumstance proved to be a big difficulty when we tried to attach the tripod to the scanning head, having to glue three piezos simultaneously. With patience and multiple tries, we were successful in the end though.

  Resources: Purchased glue, aluminium scanning head produced by PSI

  (1 h)

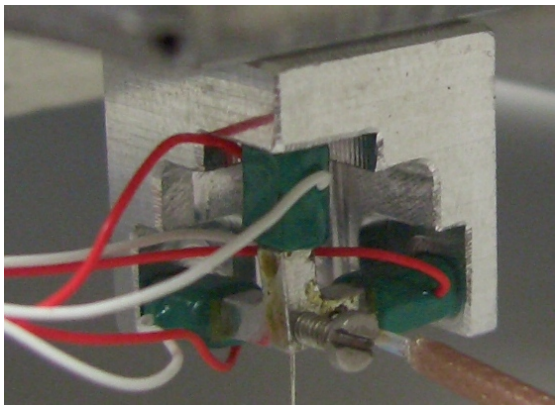

Figure 6: Glueing the piezos required a lot of patience.

- **Friday, School:** Final works on mounting the scanner head on microscope body, planning of work that is to do during the holidays: start of written theoretical treatment and documentation of the process

Notes: The scanner head was attached to the microscope body using two small plates and screws, which was convenient and a straightforward process. We started to lay out the contents of our paper and decided to start writing the theoretical treatment in the holidays, in addition to enriching the journal.

Resources: screws and tools provided by school, own computers

External People: Hansulrich Schmutz

(4 h)

Week 39

- Matura trip to Amsterdam

Week 40, Week 41

- Vacation
- Reception of Platin-Iridium wiring for tip production and highly-oriented pyrolytic graphite samples from Dr. Jung from PSI via post package

Week 42

- **Wednesday, School:** Wiring the preamplifier card with the case, initial work on learning PIC32 architecture programming, some tests on preamplifier card, concerns about its speed, experimentation with grounding several parts of the mechanical build to minimize electrical interferences

Notes: The soldering of the ports was of no big difficulty as they were reasonably sized, but as there were cables on both exits of the box, the process still was a bit unadvantageous. Those not being busy with soldering looked at the documentation of the PIC32 chip and tried to understand a few tutorials, with relatively little success. Further tests of the card showed that it was a bit too slow but we decided to use it nevertheless. We had a strong 50 hz interference though, which we tried to locate and eliminate by grounding all metal parts that were close to it, including the table everything was put on. This attempt was successful in limiting and lowering the interference, but we were not able to eliminate it altogether.

Resources: School's soldering facilities, own laptops, cables, power supplies and oscilloscope provided by school

(3 h)

Figure 7: The amplifier is being wired.

Week 43

- **Ongoing, School:** Improval and extension of physical treatment and documentation, first attempts to produce tips from wire

  Notes: Further planning in terms of documentation was done, especially in terms of size of the physical treatment. We decided to keep it short but as understandable as possible, which we knew would not be easy, and hence we made sure to start early doing it. As the wire for the tips had arrived, we could start and produce tips, using the method we learned from the internet using two pairs of pliers to rip a piece off the main wire in an acute angle to achieve, hopefully, a tip on the part that was ripped off.

  Resources: own laptop computers

  (2 h)

Week 44

- **Home:** Ongoing work: PCB design for scanning electronics using P-CAD 2006 software

  Notes: Usage of the program had to be learned first, and due to it being discontinued, some components were not available and parts had to be hand-drawn, which was a very time-consuming process and came with its own share of difficulties and necessities for research.

  Resources: home computers, P-CAD software provided by PSI's Valeri Ovinnikov

  External People: Valeri Ovinnikov (Family)

  (5 h)

- **Tuesday, School:** Readjusting the amplification factor, re-fitting preamplifier card into case, soldering the card to the outputs, fitting front and back plates onto the case

  Notes: The before only provisionally closed box had to be re-openend for new adjustments, and we fit it in more definately afterwords, using screws and parts provided and manufactured by Martin Merkli at his mechanical facility. No appropriate screws were available right away, so we had to cut a few long ones down to size and use them afterwords.

  Resources: School's soldering facility and tools

  External People: Hansulrich Schmutz

  (1 h)

Figure 8: The amplifier in its finished case.

- **Friday, School:** Testing of preamplifier card, choosing of power supplies for testing, further experimentation in terms of producing tips

  Notes: Further experimentation was done using the card, and location of the source of the interferences proved to be a bigger problem than we expected, making us spend almost all afternoon on figuring out how to

minimize it further. We found no results immediately, and first thoughts to build a secondary amplifier for testing emerged, but were dropped again quickly as we were pretty sure that the source of the interference would be from the outside and that corrections to the current amplifier plate would be more time-efficient. New attepmts to produce tips were more successful, but still we did not really manage to produce any really good tips.

Resources: Testing setup utilities (power supplies, oscilloscope and cables) from school

External People: Hansulrich Schmutz

(4 h)

Week 45

- **Friday, School:** Finding a location to do testing in cellar, thoughts about vibration damping and different approaches, further experimentation with grounding

  Notes: Since the vibrations on the fourth floor could negatively influence our measurements, we looked for a new location, ideally in the basement of the building. We did not get permission to use basement so we moved everything to the ground floor and conducted further tests with insulation and interference limitation.

  Resources: Cabling, oscilloscope and power supplies provided by school, microscope setup so far

  External People: Hansulrich Schmutz

  (3 h)

Week 46

- **Friday, School:** PCB design update, almost finalized, power supplies ordered via PSI

  Notes: The PCB design neared completion, and further work and planning concerning it and the all-in-one solution that was to be used for scanning later on was done. Linear power supplies for the control electronics were ordered via the PSI.

  Resources: own computers

  (3 h)

Week 47

- **Friday, School:** Glueing of the samples to wiring with conductive glue, buildup of testing configuration, extension of the box for acoustic isolation by electrical isolation using aluminium foil and duct tape, tunneling measured for the first time

  Notes: Achieval of conductive glue was unexpectedly difficult, and after visiting an electronics parts store in Baden and not having found any, Mr Ebers could order some for us. It quickly arrived then so we could start

work on Friday. The glue did not really seem to glue or at least to dry very slowly, hence we spent a lot of time glueing a wire to the sample and had to re-attach the wire several times due to the glue not being strong at all. We used duct tape to fix it a bit more, and this solution held pretty well. While Dominik and Ivan were glueing the cables to the samples, Sandro put aluminium foil around the cardboard box that was to be used for noise cancellation. For the first time, tests were conducted using sample and tip and not the resistor anymore. The test was partly successful and we could measure the tunneling current. However, we did not achieve any stable tunneling current yet, as the sample always crushed into the sample at the smallest noise or vibration. We did conduct tests both on the fourth and on the first floor, seeing that indeed on the first floor it was a lot better, but nowhere near good yet.

Resources: Purchased conducvite glue, microscope setup so far, testing setup utilities from school

External People: Hansulrich Schmutz, Siegfried Ebers (PSI) (4 h)

Figure 9: Glueing the wire onto the sample.

Week 48

- **Friday, School:** Further glueing, insulation tests, improvement of amplifier card by modifying capacitors on it, further planning, looking for possible amplifier replacement concepts

  Notes: The cable had again fallen off the sample even though the tape was above it, so we had to re-glue it to the sample. We tried to increase the ampliefier's speed by removing and downsizing capacitors at the input. This caused 50 Hz to rise to an unacceptable level so we decided to build our own amplifier to at least compare it to the previous one.

  Resources: Purchased glue, testing setup utilities

  External People: Hansulrich Schmutz

  (4 h)

Week 49

- **Tuesday, PSI:** Etched PCB board arrived, soldering

  Notes: The PCB board had arrived and hence soldering of the componence could be started, a difficult process involving a big amount of time and Valeri Ovinnikovs assistance over the whole process. As a few errors made it into the final PCB design, some rewiring and rerouting had to be done, again consuming a lot of time. The very small size of the components to be soldered and none experience in soldering SMD components beforehand made this work especially difficult. Valeri Ovinnikov provided a lot of help and Ivan did the soldering. The others continued to work on the documentation, treatment and journal as only one person can work on one PCB board at a time.

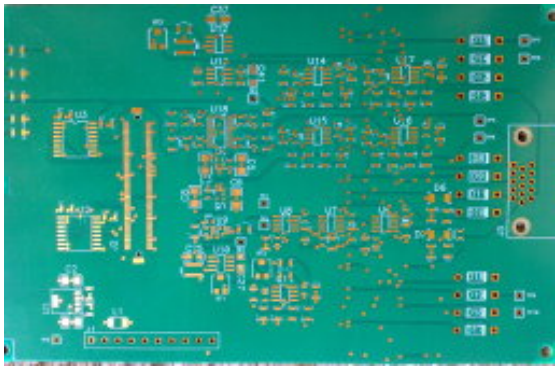

Figure 10: The empty board has arrived.

- **Wednesday-Friday PSI:** Further soldering of control electronics, voltage converters and calibration of the board

  Notes: Due to the fact that the linear power supply acquired did not present a possibility to adjust the output voltage, a voltage converter board was necessary to provide the board with power. Once this was complete, the PCB needed to be calibrated, using an old Schlumberger microprocessor voltagemeter.

  External People: Valeri Ovinnikov (10 h)

Week 50

- **Friday, School:** Production of a second amplifier for testing purposes using a test board and individual parts, further testing, plans for new oscillation damping using elastic ropes

  Notes: A new amplifier was built. We produced a provisional case out of a thin plate of bent aluminium and some duct tape. We had to reopen it though, as we wired things wrongly in the beginning, spending another half an hour doing that. The new amplifier was much faster and noise had almost completely disappeard. As a consequence, the measurements of

the tunneling became better but vibrations still posed a problem. Plans to use a new vibration damping system using elastic ropes emerged, but were not considered important yet.

Resources: Individual electronic parts (mostly samples), soldering facility

External People: Hansulrich Schmutz

(4 h)

Figure 11: The provisional amplifier mounted onto the STM for testing purpose.

- **Saturday, PSI:** Assembly and completion of the control electronics box, incorporating our PCB board, the voltage regulators and the power supply

  Notes: We assembled a box for the control electronics. Some minor parts had to be made at the stock box, kindly manufactured by Jan Hovind. Putting in the electronics was quickly done.

  Resources: Box, PCB board, voltage regulators, power supply, mechanic facilities at PSI

  External People: Jan Hovind

  (3 h)

Figure 12: The control electronics box.

Week 51

- **Tuesday, PSI:** LabVIEW software tutorial by Martin Reizek at PSI, initial planning of software structure and LabVIEW virtual instrument, LabVIEW considered suited for our purpose, decision to use it

  Notes: Martin Reizek showed us what could be done using Labview, and during the tutorial and subsequent discussion, we deemed it a good solution to our problem and decided to use a so-called virtual instrument in labview to conduct our measurements. We started doing our own first steps in Labview, and saw that it was going to be very time consuming to produce such a working virtual instrument, especially because we had to also write an interface in C for communication with the microprocessor. This task would not be feasible for us lacking in the required knowledge. Hence, Valeri Ovinnikov needed to write the interface. We started to think about limiting our Matura work to the tunneling current and its function to the distance.

  Resources: Car

  External People: Valeri Ovinnikov, Martin Reizek (PSI)

  (1 h)

- **Ongoing, Home:** Planning of better box for noise cancellation using new materials

  Notes: Testing with the cardboard box showed that it had no effect on the tunneling current whatsoever, and hence we decided that a better box had to be produced. Sandro started looking for materials to be used and found glass wool, which is used in building insulation, to be a probable solution. Due to its fuzzy nature, it had to be packed, which we decided to do with aluminium to achieve a certain insulation from electrical interference in addition to noise cancellation.

  Resources: home computers for research

  External People: Martin Merkli

  (1 h)

- **Friday, School and PSI:** Second amplifier improvements, new case with proper ports for wiring, moving of microscope to PSI

  Notes: We had asked at PSI to move our microscope there so we could continue work over the holidays, and received confirmation that we had a place there. We spent the first half of the afternoon producing a box for the new amplifier with ports and cabling (Ivan had became good at the machines since the beginning of the matura work). Afterwords we moved everything attached to the microscope into Merkli's car and went to PSI, moving all parts to the location assigned to us. All was now ready for continued work over the holidays.

  Resources: Car, capacitors provided by school, small metal box provided by PSI

  External People: Hansulrich Schmutz

  (4 h)

Week 52

- **Monday, PSI:** Further work on the amplifier, organisation of a new box for noise cancellation, planning of documentation

  Notes: The amplifier had to be retrofitted with capacitors we had forgotten earlier, and after that was done, we went to the local do-it-yourself store and purchased a plastic box to be used as the base for the new noise cancellation box. We updated the journal and started thinking about the setup we were going to realise at the PSI, and the documentation of our working process. All tools necessary to do testing were present at the PSI, as our new location was a place intended to do such testing and hence provided everything imaginable for testing purposes.

  Resources: location provided by PSI, tools provided by PSI (including oscilloscopes, multimeters, cables, power supplies, soldering facilities and more)

  External People: Valeri Ovinnikov

  (5 h)

Figure 13: Constructing the new box.

- **Friday, PSI:** Attaching of the amplifier to microscope body, tests of new box, assembly of control electronics box, testing setup at new location, experimentation

  Notes: The now complete new amplifier box was quickly attached to the microscope body, and tests showed it to be working as intended. We set up the microscope at the new location using our tire and metal plate for vibration isolation, and tested the new noise cancellation box, which seemed to be a lot more efficient than the old one, yet not as efficient as we wished it to be. the tunneling current was already a lot more stable, which we figured had to do not only with the change of location, but also with the new amplifier which was a lot better than the old ones.

  Resources: PSI location and tools

  External People: Valeri Ovinnikov

  (5 h)

Figure 14: The third amplifier in a more elegant case.

- **Home** Purchase of elastic ropes from BodyMarkt in Baden-Dättwil

  Notes: We wanted to try out the vibration damping approach using elastic ropes so Sandro went and bought elastic strings at the local BodyMarkt store in Dietikon. The use of those strings would be to do exercise in fitness nevertheless they were apparently fine to be used for our purpose too.

  Resources: Car

  (1 h)

- **Saturday, PSI:** Testing of new oscillation damping method using elastic ropes, successful attempts at stabilizing the current further using the new amplifier and newly designed noise cancellation box

  Notes: The new vibration damping setup was a lot more efficient than the one using the tire, although we initially set it up using a ladder and a board we found somewhere in the office nearby, so this setup was very experimental. Still one could walk around next to the microscope and not affect the tunneling current. We had to take the ropes in multiples for every corner of the board due to their very big elongation. This was, after we figured it out, no big problem anymore, and we could start doing more tests. We found another source of interference in a very exact multimeter we had attached to the setup, which led us to remove it when not absolutely needed.

  Resources: PSI location and tools, purchased elastic ropes

  External People: Valeri Ovinnikov

  (5 h)

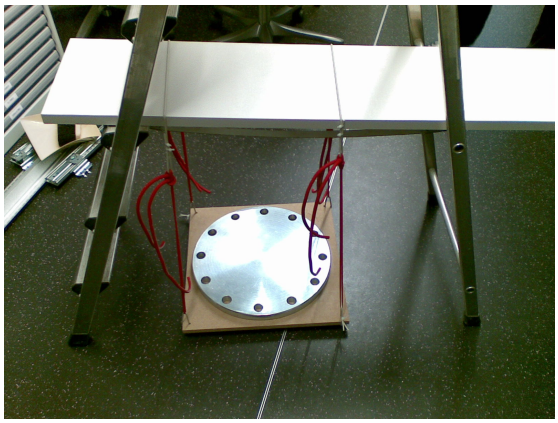

Figure 15: The new damping system using a ladder as stand.

- **Sunday, PSI:** New stands for elastic ropes, further experimentation, first usable results

  Notes: As the ladder had been too unstable for a stand, Sandro brought wooden stands that were more fit for the purpose to the PSI, and as expected, the vibration damping became even better and the current more stable.

  Resources: PSI location and tools, purchased elastic ropes, setup so far

  External People: Valeri Ovinnikov

  (4 h)

Week 53

- **Monday, PSI:** Recording of test results using a macbook and Logger Pro, further experiments, planning and extending of documentation

  Notes: Before going to the PSI we went to school to get a laptop with Logger Pro on it so we could record our results with greater accuracy and achieve a bigger sample space. The laptop was provided by the school including some sensors to measure voltages. We had to use a potentiometer to measure our voltages as they went from 0 to 30 Volts and the sensors only went to 10 Volts. Logger pro allowed for up to 200 measurements per second, so measuring became very convenient and also a lot more exact. The documentation content became clearer after further discussion and was ready to be worked on.

  Resources: PSI location and tools, school's Macbook and Logger Pro software, wooden stands provided by Martin Merkli, setup so far

  External People: Valeri Ovinnikov

  (5 h)

- **Ongoing, Home:** Improvements and extension of paper, working towards finalization, interpretation of the results from the experimentation

Figure 16: The voltage probes used in our experiments.

Notes: Our paper consisted mainly of the physical treatment so far, so we extended the documentation a lot and properly structured it, adding much information about how we solved our problems to it as that part was one of our main goals and also deemed important by Schweizer Jugend forscht. The interpretation of the results posed some difficulties however, as they were not entirely consistent yet. Further measurements should give a clearer picture.

Resources: home computers

(3 h)

- **Friday, PSI:** Extended tests and logging, planning of final structural changes to written paper, removal of microscope from PSI

  Notes: The idea to get further test results was a success - quite a few consistent measurements could be achieved. We had enough results so we could remove the microscope from there again and continue working at home. However, we had problems interpreting the results accordingly to the theory. The values are far off so we sent an email to Dr. Thomas Jung (PSI) and to a member of the SXM project and hope they can help.

  Resources: PSI location and tools, school's Macbook and Logger Pro software, setup so far

  External People: Valeri Ovinnikov

  (4 h)

- **Ongoing, Home:** Finalization of paper, enriching of the journal, roundup

  Notes: A lot of formatting and error correction had to be done and the consistency of the paper had to be ensured. Therefore we had to read it through over and over and keep a strong communication who commited what changes to the work, which was simplified a lot by our communication means over the internet.

  Resources: Home computers