Final Work

Design and Construction of a Micromanipulator based Probe Station

Andreas Ernst
Matr.Nr. 2178906
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Savonia Polytechnic Engineering Kuopio
Information Technology R&D Unit
P.O. Box 1188 (Microkatu 1C) FIN-70211 Kuopio
Email: it@savonia-amk.fi

Supervised by
Prof. Gareth Monkman
Ph.D. Mikko Laasanen
M.Sc. (Eng) Anssi Suhonen
Abstract:

For research and development it is necessary to check at the early manufacturing process weather a circuit on a wafer is working appropriately. Only if there are no errors it is clever to go on with the process. In this way you can save time and money.

This final work describes the construction and building up of a customized manual probe station. Probing is done by direct contact with micro manipulated needles up to 4 pads.

It is possible to measure for example resistance of simple electrical circuits with the probe station. The system has also to be build up in an economic way. The work was carried out in Savonia Polytechnic, Engineering Kuopio, Finland.
ERKLÄRUNG

1. Mir ist bekannt, dass dieses Exemplar der Diplomarbeit als Prüfungsleistung in das Eigentum des Freistaates Bayern übergeht.

2. Ich erkläre hiermit, dass ich diese Diplomarbeit selbstständig verfasst, noch nicht anderweitig für andere Prüfungszwecke vorgelegt, keine anderen als die angegebenen Quellen und Hilfsmittel benützt und sinngemäße Zitate als solche gekennzeichnet habe.

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1. Introduction

In microelectronics and particularly in prototyping use it is useful to check if the samples are working appropriately after fabrication. This usually includes measurement of resistance from the contact pads of the sample. However, these pads are usually very small (50-100 µm or less).

Normally, the samples are checked manually under a microscope by using for example sharpened indium probes. This works but is not comfortable.

In addition, improvements are needed since:

- Samples can be destroyed accidentally when a probe touches a wrong place on chip
- If the researcher would like for example to test quickly the RF-properties of the sample, the probes should be kept in the same place a long time
- The probes should be designed for high frequency signal

With a probe station this kind of measurements are more convenient to do. There are some commercial systems available, but they look like home-made devices with fairly simple design (cp 1.a). Therefore, it should be relatively straightforward to design and assemble the system in-house. At the same time the system can be modified so that the dimensions, specifications etc. match better the requirements of the user.

Image of a typical commercially available probe station system:

![Probe Station Image](image_url)

**Picture 1.a** Cascade Microtech (Beaverton, OR, USA), Alessi REL-4500
In this work a custom made probe station was designed and constructed for the Microsensor laboratory of Savonia Polytechnic, Engineering Kuopio, Finland. The probe station design work included settling of the following challenges:

- Manual or piezo movement of the two probes and the z-movement for the electrical contacts (with certain force)
- Integration of the microscope and the system for holding the chip (vacuum for example)
- Possibility to perform radio-frequency measurements (RF-probes)

Different design possibilities and components were considered in order to ensure good price versus quality situation. The parts that cannot be manufactured in-house were ordered.
2. Available Systems

Because a probe station is a special equipment, the amount of suppliers is limited. It was found that the controlled systems are expensive. Typically the computer controlled systems cost more than 10.000€. There are some systems including computer or micro controlled manipulators with integrated frequency generator and oscilloscope (cp 2.a – 2.c).

**Picture 2.a** Cascade Microtech 11008, 8 inch wafer prober² (Cascade Microtech, Beaverton, OR, USA)

**Picture 2.b** Summit 9101³ (Cascade Microtech, Beaverton, OR, USA)

**Picture 2.c** MDC / Materials Development Corporation (Chatsworth, CA, USA), 8 inch CV Plotter System⁴

For example, the Cascade Microtech Summit 9101 costs about 50.000€. That is a 6 inch manual probe station for high frequency up to 110GHz. There is no limit for the price. The more automation and integration you want the more you have to pay.
Only few probe stations were found which cost less than 5,000€. One is the Rucker & Kolls 240 manual prober (cp 2.d). The other one is the Wentworth 0-022-0002 (cp 2.e). However, both of these were second hand systems.

![Picture 2.d Rucker & Kolls (Millpitas, CA, USA) 240 manual prober](image)

**Picture 2.d** Rucker & Kolls (Millpitas, CA, USA) 240 manual prober

![Picture 2.e Wentworth (Brookfield, CT, USA) 0-022-0002](image)

**Picture 2.e** Wentworth (Brookfield, CT, USA) 0-022-0002

In this work, the requirements for the probe station were:

- Manual movement of the probe in all three dimensions
- Sufficient accurate movement to hit 50x50μm pads
- Magnetic base for the micromanipulators
- Possibility to measure high frequency up to more than 10GHz
- Vacuum chuck with a diameter of 100mm
- Stereo microscope with at least a maximal magnification of 60X
- Variable illumination
- Low total price of the system
3. Guarded Measurements


3.1. Voltage Measurements from High Resistance Sources

Measurements from voltage sources with high internal resistance are subject to a number of errors, such as loading errors from the voltmeter’s input resistance and input bias current, as well as from external shunt resistance and capacitance.

Input Resistance loading

![Diagram of input resistance loading](image)

The meter input resistance and also the leakage resistance of the connecting cable can cause errors to measurements from high resistance sources. The voltmeter may be described with an infinite input-resistance voltmeter \( V_M \) in parallel with the specified
input resistance $R_{IN}$ and the voltage source has $V_S$ in series with $R_S$. The displayed voltage is calculated as follows:

$$V_M = V_S \left( \frac{R_{IN}}{R_{IN} + R_S} \right) \tag{3.1.1}$$

Calculated an example with following parameters:

$R_S = 100k\Omega$ and $R_{IN} = 10M\Omega$. If $V_S = 5V$

The actual voltage measured by the voltmeter is:

$$V_M = 5 \left( \frac{10^7}{10^7 + 10^7} \right)$$

$$V_M = 4.95V$$

In this example the input resistance loading causes an error of 1%. If a higher accuracy is needed, the input resistance has to be higher. For a better result than 1% it has to be more than 100 times higher.

*Input Bias Current Loading*

![Diagram of voltage measurement and input bias current loading](image)

**Figure 3.1.b** Effects of input bias current on voltage measurement accuracy
Because the voltage source has a high inner resistance, a small bias current \( I_{\text{BIAS}} \) causes a noticeable error voltage across this \( R_S \) as follows:

\[
V_M = V_S \pm I_{\text{OFFSET}} R_S
\]  

\{3.1.2\}

Calculated an example with following parameters:
\[
I_{\text{OFFSET}} = 1\text{pA} \quad R_S = 10\text{G}\Omega \quad V_S = 10\text{V}
\]
\[
V_M = 10\text{V} \pm 10^{-12} \text{A} \cdot 10^{12} \Omega
\]
\[
V_M = 10\text{V} \pm 0.01\text{V}
\]
\[
V_M = 9.99\text{V} \text{ or } 10.01\text{V} \text{ depending on the polarity of } I_{\text{OFFSET}}
\]

DMMs (digital multi meters) and nanovoltmeters have an \( I_{\text{OFFSET}} \) about 1pA to 1nA. A better alternative to reduce this error is to use electrometers, which have only a few femtoamps. Picoammeters and SMUs (source measure unit) have also a lower bias current, but are not as good as the electrometer.

It could also be that external circuits or insulators and cables can cause voltage drops across \( R_S \).

**Shunt Resistance Loading and Guarding**

Leaky cables or dirty insulators can act as a shunt resistance \( R_{\text{SHUNT}} \). Because this \( R_{\text{SHUNT}} \) is in parallel with \( R_S \) less voltage is measured as follows:

\[
V_M = V_S \left( \frac{R_{\text{SHUNT}}}{R_{\text{SHUNT}} + R_S} \right)
\]  

\{3.1.3\}

Calculated an example with following parameters:
\[
R_S = 10\text{G}\Omega \quad R_{\text{SHUNT}} = 100\text{G}\Omega \quad V_S = 10\text{V}
\]
\[
V_M = 10\text{V} \left( \frac{10^{11}\Omega}{10^{11}\Omega + 10^{10}\Omega} \right)
\]
\[
V_M = 9.09\text{V}
\]

In this case the error is approximately 9%. 
3.1. Voltage Measurements from High Resistance Sources

A common source for this $R_{\text{SHUNT}}$ is cable leakage. To reduce this leakage current, use cables and connectors with the highest available insulation resistance.

\[ V_M = V_S \left( \frac{R_{\text{SHUNT}}}{R_{\text{SHUNT}} + R_S} \right) \]

**Figure 3.1.c** Effects of shunt resistance on voltage measurement accuracy

\[ V_M = V_S \left( \frac{R_L}{R_S + R_L} \right) \]

**Figure 3.1.d** Effects of cable leakage on voltage measurement accuracy
A guarded system can eliminate nearly any residual error of cable leakage.

```
R_S  R_L
|     |
V_S

Connecting Cable

Cable Shield

R_G  I_G
|     |
GUARD

Volts is

Voltmeter with Guard Buffer

Figure 3.1.e Guarded configuration
```

“By definition, a guard is a low impedance point in the circuit that’s at nearly the same potential as the high impedance input terminal.”

The guard buffer, an operational amplifier, drives the shield at the same potential as the input HI terminal. In this way the voltage across \( R_L \) is now many decades lower. \( I_G \) is the current which is supplied by the guard buffer and not by the voltage source to reduce the error.

The circuit of the electrometer when used as a voltmeter is actually as shown 3.1.e. The open-loop gain of the guard amplifier ranges from \( 10^4 \) to \( 10^6 \). The measured voltage becomes:

\[
V_M = V_S \left( \frac{A_{GUARD} \cdot R_L}{R_S + A_{GUARD} \cdot R_L} \right) \tag{3.1.4}
\]

Calculated an example with following parameters:

\[
R_S = 10\, \Omega \quad R_L = 100\, \Omega \quad V_S = 10\, \text{V} \quad A_{GUARD} = 10^5 \quad \text{assumed mid-range}
\]

\[
V_M = 10\, \text{V} \left( \frac{10^5 \cdot 10^{11} \Omega}{10^{10} \Omega + 10^5 \cdot 10^{11} \Omega} \right) = 9.99999\, \text{V}
\]

In this way the loading error is reduced to less than 0.001%. It is 10000 times better than the unguarded system.
3.1. Voltage Measurements from High Resistance Sources

Voltage Measurements from High Resistance Sources

14

Figure 3.1.6 Guarded leakage resistance

Shunt Capacitance Loading and Guarding

The meter input capacitance in parallel with the input cable capacitance is called the shunt capacitance. This shunt capacitance causes a settling time. Because this settling time depends on the RC time constant, a small shunt capacitance multiplicated with a high source resistance can result in RC time constants within seconds. It needs 5 times RC to get an adequate measurement with an error less than 1%.

3.1.f demonstrates the effects of the shunt capacitance. At first the switch is open and \( C_{\text{Shunt}} \) holds zero charge. Then the switch is closed. But the voltage across \( C_{\text{SHUNT}} \) does not rise immediately to the value of \( V_S \), it raises exponentially as follows:

\[
V_M = V_S \left( 1 - e^{-\frac{t}{R_S C_{\text{SHUNT}}}} \right)
\]

\{3.1.5\}

The charge transferred to the capacitor is:

\[
Q_{\text{IN}} = V_S C_{\text{SHUNT}}
\]

\{3.1.6\}
3.1. Voltage Measurements from High Resistance Sources

Figure 3.1.g Shunt capacitance loading

3.1.f shows the percent rise of the measured $V_S$ over the time.

![Graph showing exponential response of voltage across shunt capacitance](image)

**Figure 3.1.h** Exponential response of voltage across shunt capacitance

Settling Times to Percent of Final Value:

<table>
<thead>
<tr>
<th>Time Constant $\tau = RC$</th>
<th>Percent of Final Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>63 %</td>
</tr>
<tr>
<td>2</td>
<td>86 %</td>
</tr>
<tr>
<td>3</td>
<td>95 %</td>
</tr>
<tr>
<td>4</td>
<td>98 %</td>
</tr>
<tr>
<td>5</td>
<td>99.3 %</td>
</tr>
</tbody>
</table>
3.1. Voltage Measurements from High Resistance Sources

Calculated an example with following parameters:

\[ R_S = 10\, \text{G}\Omega \quad C_{\text{SHUNT}} = 100\, \text{pF} \quad V_S = 10\, \text{V} \]

\[ \tau = R_S C_{\text{SHUNT}} = 10\, \text{G}\Omega \cdot 100\, \text{pF} = 1\, \text{s} \]

\[ Q_{\text{IN}} = V_S C_{\text{SHUNT}} = 10\, \text{V} \cdot 100\, \text{pF} = 1\, \text{nC} \]

If a guarded system is used the settling time is extremely reduced because of the high open-loop gain \( A_{\text{GUARD}} \). With guarding it becomes:

\[ V_M = V_S \left(1 - e^{-\frac{1}{R_S C_{\text{SHUNT}}}}\right) \quad \{3.1.7\} \]

The charge transferred to \( C_{\text{shunt}} \) is:

\[ Q_{\text{IN}} = \frac{V_S C_{\text{SHUNT}}}{A_{\text{GUARD}}} \quad \{3.1.8\} \]

Calculated an example with the new parameters:

\[ R_S = 10\, \text{G}\Omega \quad C_{\text{SHUNT}} = 100\, \text{pF} \quad V_S = 10\, \text{V} \quad A_{\text{GUARD}} = 10^5 \]

\[ \tau = \frac{R_S C_{\text{SHUNT}}}{10^5} = \frac{10\, \text{G}\Omega \cdot 100\, \text{pF}}{10^5} = 10^3 \approx 10\, \text{\mu}s \]

\[ Q_{\text{IN}} = \frac{V_S C_{\text{SHUNT}}}{A_{\text{GUARD}}} = \frac{10\, \text{V} \cdot 100\, \text{pF}}{10^5} = 10\, \text{fC} \]

The settling time now becomes \( 50\, \text{\mu}s \approx 5\tau \). This is a reduction of \( 10^5 : 1 \)!

\[ V_M = V_S \left(1 - e^{-\frac{1}{R_S C_{\text{SHUNT}}}}\right) \]

\[ Q_{\text{IN}} = \frac{V_S C_{\text{SHUNT}}}{A_{\text{GUARD}}} \]

**Figure 3.1.i** Guarded shunt capacitance
3.2. Low Current Measurements

There are some error sources, which have an effect on low current measurement accuracy:

- Improper connections
- Ammeter’s voltage burden and input offset current
- Noise of the source resistance
- Leakage current of cables and fixtures
- Triboelectric and piezoelectric effect

**Leakage Currents and Guarding**

Leakage currents can increase the error of low current measurement. This effect can be reduced by using good quality insulators. Also the humidity in the test environment should be low. A very effective way is guarding. The use of guarding is best explained through the next examples:

The next two figures show a high mega-ohm resistor $R_{DUT}$ supported on two insulators mounted on a metal test fixing.

**Figure 3.2.a** Unguarded Circuit
3.2.a: The measured current is the leakage current $I_L$ in addition to the current from the DUT (device under test).

![Diagram of Metal Shielded Test Fixture]

**Figure 3.2.b** Guarded Circuit

3.2.b: With guarding, point A is at almost the same potential as HI of the picoammeter. In this way no significant current will flow through the right insulator.

The next two figures show how to reduce the error of leakage current of a cable.

![Diagram of Unguarded Circuit with Coax Cable]

**Figure 3.2.c** Unguarded Circuit with Coax Cable
3.2.c illustrates a non guarded system where the measured current consists of \( I_{DUT} \) in addition to \( I_L \). \( I_L \) is the undesired leakage current. Figure 3.2.d shows the guarded system. Now the shield is driven by a unity-gain, low impedance amplifier (Guard). Consequently it is at the same potential as the HI terminal and the leakage current is eliminated.

**Figure 3.2.d** Guarded Circuit with Triax Cable

Figures 3.2.e and 3.2.f show almost the same as 3.2.a and 3.2.b. But now a SMU ammeter (source measure unit) is used.

**Figure 3.2.e** Unguarded Circuit with SMU
3.2. Low Current Measurements

It is possible that noise can seriously affect low current measurements. To reduce this effect of some things have to be taken notice. Figure 3.2.g shows a simplified model of a feedback ammeter.

The following equation gives the noise gain of the circuit:

\[
\text{Output } V_{\text{NOISE}} = \text{Input } V_{\text{NOISE}} \left(1 + \frac{R_F}{R_S}\right) \tag{3.2.1}
\]

It is to see that a reduction of \( R_S \) causes a bigger output noise. Consequently there are minimum recommended source resistance values based on the measurement range as shown in the next table.

**Minimum Recommended Source Resistance Values for a Typical Feedback Ammeter:**

<table>
<thead>
<tr>
<th>Range</th>
<th>Minimum Recommended Source Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>pA</td>
<td>1 ( \text{G}\Omega )</td>
</tr>
<tr>
<td>nA</td>
<td>1 ( \text{M}\Omega )</td>
</tr>
<tr>
<td>( \mu )A</td>
<td>1 ( \text{k}\Omega )</td>
</tr>
<tr>
<td>mA</td>
<td>1 ( \text{\Omega} )</td>
</tr>
</tbody>
</table>
3.2. Low Current Measurements

If the source capacitance increases the noise gain also gets bigger. To visualize the correlation, formula 3.2.1 is modified as follows:

\[
\text{Output } V_{\text{NOISE}} = \text{Input } V_{\text{NOISE}} \left( \frac{Z_F}{Z_S} \right) \quad \{3.2.2\}
\]

With

\[
Z_F = \frac{R_F}{\sqrt{2\pi f R_F C_F} + 1} \quad \{3.2.3\}
\]

and

\[
Z_S = \frac{R_S}{\sqrt{2\pi f R_S C_S} + 1} \quad \{3.2.4\}
\]

It is to remark that in both cases, if \( R_S = R_F \) or \( Z_S = Z_F \), the input noise is amplified by a factor of two.

**Figure 3.2.g** Simplified Model of a Feedback Ammeter
3.2. Low Current Measurements

**Voltage Burden**

There is no ideal ammeter with $R_M = 0$. This $R_M$ (internal resistance of an ammeter) causes a voltage drop and the measured current is lower, because the total resistance now is $R_S + R_M$. This voltage drop is called the voltage burden $V_B$.

![Diagram of Voltage Burden](image)

**Figure 3.2.h** Effects of Voltage Burden on Current Measurement Accuracy

The voltage burden is determined at the maximum current input of the ammeter for the used scale. The actual voltage burden is calculated as follows:

$$V_{B1} = V_B \left( I_S \frac{1}{I_{FS}} \right)$$

where $I_{FS}$ is the full-scale current and $I_S$ the actual measured current.

The displayed current is:

$$I_M = \frac{V_S - V_B \left( I_S \frac{1}{I_{FS}} \right)}{R_S}$$

The percent error is:

$$\% \text{ error} = \frac{V_B \left( I_S \frac{1}{I_{FS}} \right)}{V_S} \times 100\%$$
3.2. Low Current Measurements

Calculated an example with the following parameters:

\[ V_S = 0.7V \quad I_S = 100\mu A \quad I_{FS} = 200\mu A \quad R_S = 10k\Omega \]

Voltage burden at full scale is 200mV

\[ I_M = \frac{0.7V - 0.2V \left( \frac{100\mu A}{200\mu A} \right)}{10k\Omega} = 60\mu A \]

If \( R_M \) would be zero like an ideal ammeter, the real current is:

\[ I_M = \frac{0.7V}{10k\Omega} = 70\mu A \]

With this burden voltage the ammeter displays a value with an error of 14%.

If a picoammeter is used with a voltage burden of 200µV, it displays a value of 69.99µA. That is an error of only 0.01%!

_Triboelectric and piezoelectric effect_

If for example a coaxial cable is bended, the insulators and conductors are rubbing together. This causes a separation of charge (Coulomb Friction). This charge generates an unwelcome current. The best is to use “Low noise” cable. Stabilization of the test system (no vibration), sturdy shields and constant temperature also reduces the triboelectric effect.

The piezoelectric effect appears when “mechanical stress is applied to certain crystalline materials when used for insulated materials and interconnecting hardware.”9 For minimizing it is the best to remove mechanical stress and use materials with minimal piezoelectric effect.
3.3. High Resistance Measurements

When measuring resistance greater than 1GΩ, a picoammeter/voltage source, SMU or electrometer is to use. There are two possibilities to measure high resistance.

- Constant-voltage with ammeter and a voltage source
- Constant-current with electrometer and a current source

**Constant-Voltage Method**

With this method a constant voltage source and an electrometer or picoammeter with negligible voltage drop is used (cp 3.3a). Consequently the whole voltage appears across R. The resistance is calculated by using Ohm’s Law \( R = \frac{V}{I} \). The constant voltage source can also be built into the measuring instrument (cp 3.3b).

**Figure 3.3.a** Constant-Voltage Method with Electrometer or Picoammeter and a Voltage Source

**Figure 3.3.b** Constant-Voltage Method with SMU and an intern Voltage Source

**Constant-Current Method**

This method uses a constant current source and a voltmeter (cp 3.3.c). Both, the source and the measuring equipment, must have much higher intern resistances than the measured resistance. Otherwise the loading error is too bad. The resistance is also calculated by using Ohm’s Law.
3.3. High Resistance Measurements

**Figure 3.3.c** Constant-Current Method with separate Voltage Source and Voltmeter

*Guarding*

Without guarding and without leakage the measured resistance is:

\[ R_M = \frac{V_M}{I_R} \]  \hspace{1cm} \text{(Ohm's Law)} \hspace{1cm} \{3.3.1\}

With taking notice of cable leakage the measured resistance becomes:

\[ R_M = R_S \left( \frac{R_L}{R_S + R_L} \right) \]  \hspace{1cm} \{3.3.2\}

*Figure 3.3.d* Guarding Cable Shield to Eliminate Leakage Resistance

By driving the cable shield to the same potential as the HI terminal the current through \( R_L \) is greatly reduced. \( I_G \) is most supplied by the low impedance output of the amplifier and negligible by the current source.

Refer also to chapter 3.2 page 13.
3.4. Charge Measurements

Charge is the time integral of current:

\[ q = \int i \, dt \tag{3.4.1} \]

If the input resistance of the measurement is too low, a noticeable current flows and destroys the stored charge. To minimize this behaviour it is the best to use an electrometer and disable the zero check of the measuring device. The zero check significantly reduces the charge!

The electrometer has a coulombmeter function, in which the charge is measured by integrating the input current. Integrating is realized by using a capacitor in the feedback loop of the input stage.

Some error sources have to be discussed:

*Input Offset Current*

Even an offset current of 4fA causes a significant change of the charge. This current also gets integrated and is to see as a long-term drift with 4fC per second. If the offset current is known, although it is difficult to determine, the charge drift can simply be subtracted from the actual reading to reduce measurements error.

*Voltage Burden*

Normally the voltage burden of a feedback coulombmeter is quite low (<100µV). But when connecting to a charge this voltage burden can reach a lot of volts momentarily. The source voltage has to be at least 10mV. If it is much lower, the voltage burden may become a problem because the amplified input stage noise dominates. Consequently accurate measurements are no longer possible.

*Generated Currents*

Especially when measuring charge less than 100pC it is very important to use low noise cables. Also all connections and the DUT have to be shielded. Otherwise generated or induced current may cause a significant error.
Source Impedance

Figure 3.4.a illustrates a generalized feedback circuit. The feedback impedance of a coulombmeter is a capacitor. The noise gain is calculated as follows:

\[
\text{Output Noise} = \text{Input Noise} \times \left(1 + \frac{Z_F}{Z_S}\right) \tag{3.4.2}
\]

As it is to see, if \( Z_F \) gets larger, the output noise also gets larger.

\[ Z_F \]
\[ Z_S \]
\[ \text{Input Noise} \]
\[ \text{Output Noise} \]

**Figure 3.4.a Generalized Feedback Circuit**

It is also possible to use an external feedback circuit (cp 3.4.b). The feedback capacitor is placed in a shielded test fixture to prevent electrostatic interference. When measuring in this way, the electrometer displays the voltage across the feedback element. The unknown charge is calculated as follows:

\[ Q = CV \tag{3.4.3} \]

Where:  
\( Q = \text{charge (coulombs)} \)  
\( C = \text{capacitance of the external feedback capacitor (farad)} \)  
\( V = \text{displayed voltage (volts)} \)

E.g.: \( C = 10\mu F, V = 5V \)
\[ Q = 10\mu F \times 5V = 50\mu C \]
To avoid errors due stray capacitance and noise gain the feedback capacitance has to be greater than 10 pF.

**Figure 3.4.b** Connections for using External Feedback Capacitor
4. Construction

4.1. Selection of Components

4.1.1. Micromanipulator

The micromanipulator is the most important component of the probe station. The probe’s movement has to be accurate enough to hit for example 50 x 50µm pads. Furthermore the resistance of the measurement cable including the tip of the needle touching the pad has to be very low. For high frequency measurements a special shielded cable and test probe is required.

First it was thought to design and build the micromanipulators in-house. After some calculations about the accuracy and discussing about manufacturing possibilities of the parts, the conclusion was to buy complete micromanipulators. It would have been possible to buy an XYZ stage and fit an own test arm, but it was concluded that it is too expensive. Because of this the research was concentrated on complete available manipulators. The decision was to buy four micromanipulators, two right handed and two left handed, whereby two are able to be retooled with high frequency probe tips.

There are very expensive manipulators such as the Kleindiek (Kleindiek Nanotechnik GmbH Reutlingen, Germany) MM3A, which is driven by control electronics. This is just an example to show what is possible.

Picture 4.1.1.a Example: Six Waver Prober System from Kleindiek\textsuperscript{10}
One nice system would have been a micromanipulator of Wentworth Laboratories (Brookfield, CT, USA).

This PVX 400 has a travel range of 5mm in all three directions. It is available with magnetic or vacuum base and has an SSMA to coaxial needle holder. Only the accuracy of 3µm is much more than it is needed. The price of this system would have been 1.400€ each.

Signatone (Gilroy, CA, USA), offers also micromanipulators, which fulfill all requirements. Indeed, they are cheaper than the PVX 400, but are still very expensive. Especially for the high frequency probe tips they want much money. The total amount would be at 5.000€.

Another possibility to find cheap manipulators is to look for used ones at second-hand shops. There you can get them for about 350€. Often you get only one, or a pair of manipulators (left and right hand). Additionally you have to look for the high frequency probe tips and test needles separately, what is unsatisfactory.
The second cheapest offer from a company was from Süss Microtech (Sack, Germany). They sell a highly modular system with changeable arms and probe tips. But with 3.500€ it all together is still too expensive.

**Picture 4.1.1.d** Süss Microtech, PH100 with HF z Probe

Finally the decision fell on the XYZ-300 TR & TL from Quater Research & Development (Bend, OR, USA). This manipulator provides 0.5” (12.7mm) movement on all three axes and a resolution of 0.025” (63.5µm) per turn. One manipulator comes also with the arm and one needle for DC measurements and costs only 325$ (277€). For HF measurements they offer a separate arm with HF probe tip, which has a frequency range of 0-18GHz. All together it costs 1644$ (1398€).

**Picture 4.1.1.e** Quater Research & Development, XYZ-300 TL

**Picture 4.1.1.f** A-20340 TEST PROBE
4.1.2. Microscope with Illumination

The requirements for the microscope were:

- Stereo objective
- At least a maximal magnification of 60X
- Variable Illumination
- Eyepiece inclination of 45° or max 60°
- Easy to integrate
- Low priced

The angle of inclination of the probe tip (needle) is about 15°. A stereo objective is more comfortable to see when and where the needle hits the pad (three dimensional views). Also the magnification has to be big enough to recognize the pads and tips in a good way. A variable illumination avoids dazzling and highlights the structures. The system stands on a table and normally the laboratory assistant sits in front of it. Therefore the eyepiece inclination should be 45° or 60°. It would be advantageous to mount the microscope in an easy way without needing separate adapters.

All microscopes, which are presented, have a working distance of at least 30mm, because the needle has a length of 1” (25.4mm).

A very modular system is the NIKON (Tokyo, Japan) SMZ645/660. It has a twin zoom objective, a maximal magnification of 300X (depending on eyepiece and objective you choose), continuous zoom (6.3 : 1), different possibilities of stands and illuminations.

Picture 4.1.2.a NIKON SMZ645 with Fiberlux 1500 light source, model LPOD-150\textsuperscript{16}
The benefit is that you can choose all individual parts by yourself. But this modularity has its price. It costs about 1.200€ additionally the light source.
A cheap system was found at Microscopes USA (Norcross, GA, USA).

![Picture 4.1.2.b FD 100 with and without illumination](image)

It comes with a standard eyepiece of 10X. The combination of 2X/4X of the paired fixed objectives offer the biggest magnification. The other available combinations of 1X/2X and 1X/3X do not offer enough magnification. Even with the delivered eyepieces, the total magnification does not fulfill the requirements. Additional eyepieces with 20X magnification are needed. With these the total magnification is 40X/80X. The price with illumination is 329$ (280€), without 279$ (238€) and for the additional eyepieces 79$ (68€).

The power of illumination of all low cost systems is about 5W-15W and is not adjustable and maybe too dark. At this point the decision fell to look for a better solution. One was to buy a separate illumination. There are different systems available like halogen fiber optics, LED or fluorescent ring light or halogen lamp with flexible gooseneck.

![Offered illuminations by Microscopes USA](image)

It was seen that the light sources are relatively expensive. Only the Halogen lamp with flexible gooseneck would be of interest.
The other possibility is to mount a common halogen bulb at the microscope and use a power supply to adjust brightness. An adequate power supply was found for 63€ and the bulb including socket and switch for less than 10€. In this way it is possible now to use different bulbs up to 30W, because the power supply supports maximal 3A. The brightness is controlled by the current because the bulbs are made for 12V and the power supply can handle up to 18V. Therefore it is set to 12V and this knob covered, so you can not change it by accident.

![Power supply, HY1803D](image.png)

**Picture 4.1.2.d** Power supply, HY1803D

Finally, an appropriate microscope was found. It is the Novex AP-8 (Euromex Microscopen BV, The Netherlands). This comes with a 10X eyepiece, a 2X/4X paired fixed objectives and has integrated illumination. They do not offer this microscope without illumination. The body is fixed on a rod with a base. This seems to be easily fixed on the system. With additionally 20X eyepieces it costs 229€.

![Novex AP-8](image.png)

**Picture 4.1.2.f** Novex AP-8
4.1.3. Chuck

It is necessary to keep the sample on one place during measurements. There are several possibilities to fix it. One is to use clamps. The Novex AP-8 has two clamps which are cushioned. But therefore the sample has to have special areas, where you can put the clamps without damaging the structures. Because it should work with all possible shapes of samples this method is useless.

Another one is to use an electrostatic chuck. There are two methods for using this effect.

A special chuck is needed with a dielectric film, also a high voltage source. These are more expensive parts than the next solution.

The easiest way is to use a vacuum chuck, especially if a vacuum pump already exists. Because the metal parts for the system’s body were given to a company to manufacture them anyway, it was the best way to draw sketches and give them also to the company for manufacturing. In this way the chuck has the correct dimensions and drill holes. No additional adapters are needed. 33 holes with a diameter of 1mm give the sample a good hold. To get a proper vacuum the fitting and tubes have an inner diameter of 8mm. When putting a sample on it, unused holes should be covered anyway to reduce leakage. The company was that precise that no extra seal in between the two halves is needed.
4.2. Construction with ProEngineer

The design of the metal parts was implemented with ProE (ProEngineer). On the one hand the parts should be manufactured easily, on the other hand the whole system should be stable and easy to handle. The main stand is called backbone, which includes the feet and arms.

![Picture 4.2.a Backbone]

First the blue part (cp. 4.2.a) was designed much higher, because it was thought to fix the microscope’s body directly on it. As the Novex AP-8 comes with a rod to adjust the height, the backbone was redesigned. This rod is now fixed on the main stand. In this way it was able to spare parts and weight.

The slide is mounted to the backbone by three screws, whereby the holes in the backbone are longish. Consequently the whole slide is adjustable in height for 20mm. This makes possible to use probes, which are already mounted on small devices.

![Picture 4.2.b Slide]
The two rails of the XY-slide have to have a very smooth surface. As the company (Savon ammatti- ja aikuisopisto, Siilinjärvi, Finland) uses CNC machines for the machining this is no problem. Because the used material is iron, which is not stainless, the surface has to be covered in some way, so that the slides are still working. Normally there are only some microns in between slide and rail. For example, a powder coating can not be used. The sliding carriages have a complex shape. For the company it was easier to use aluminium. At this time it was necessary to decide, how to cover the parts. The iron parts were powder coated for 20€ in a local company (J-Metallikaluste, Kuopio, Finland). The rails and slide carriages were given to another company (Suomen Elektropinta OY, Kuopio, Finland) which anodized the aluminium parts and chromed the two iron rails for 30€. Anodizing and chroming ads less than 1µm to the surface, which does not prejudice the function. With these methods to cover the parts it was easier to draw them in ProE, because there was no need to include the thickness of the protective layer.

The valve holder is also made out of aluminium because it has a complex shape, too. For visualising the whole system, crews, hand knobs, valve, fitting, feet and microscope were also drawn in ProE (cp 4.2.d). Only the manipulators are too complicated. In this way it is simpler to look for right distances. For example: Is there enough space to turn the hand knob for the Y-slide (cp 4.2.b)? Indeed the height of the adapter in between the Y-slide carriage and X-rail had to be increased to provide a good handling.

All technical specifications and norms were referred to the book Technisches Zeichnen. Look at the appendix for detailed drawings.
**4.3 Building up the System**

To design the parts in ProE was very helpful. There were no major problems when screwing them together. The slides work perfect. Only the arms were twisted so that the manipulator’s needle on the left arm couldn’t touch the chuck. The right arm was twisted in the opposite way, but this was acceptable. The reason was that the company cuts the long parts off plates. After telling them they corrected the left arm.

![Picture 4.3.a Valve Holder, without foot](Image)

![Picture 4.3.b Valve Holder, with foot](Image)

In addition, one of the stands had to be bended. But the system was still shaky. The solution was to use feet, which are screwed into the stands. In this way the height can be adjusted individually at every one of the four feet. For this the valve holder had to be displaced, because the right drill-hole is used for a foot now (cp 4.3.a & 4.3.b). It is turned 47° counter clock around the left drill-hole and another one was drilled to replace the right one.
On the left side a box is mounted in which the switch for the illumination and resistors for grounding is put in. The switch was built in before the power supply was bought, because it was thought to use an existing, non-adjustable 12V power supply. But it is really better to be able to dim the light. It is also necessary to ground the whole system. An electrical discharge can destroy the sample. The probe station is grounded by 1MΩ, whereby the foot and chuck are connected simultaneous (cp 4.3.c). If there is any problem with the electrical circuit in between stand and chuck, it does not matter. For example, it was necessary to remove the powder coating under the screw heads to get an electrical connection again. There is also a possibility to use a wrist band to ground the laboratory assistant (cp 4.3.d). A blue wire was used for grounding (normally a yellow/green should be used).
The illumination, which came with the Novex AP-8, was removed and replaced by a 20W halogen bulb. As the bulb becomes hot when in use a heating shield is put in between the bulb and the objective. This heating shield is also used for mounting the halogen socket (G 5.3) on it. All together is fixed to the microscope by using the existing drill-holes for the removed illumination. The used halogen bulb has a spotlight. This provides a good view.
5. Summary

In this work, a customized probe station was designed and constructed for the Microsensor laboratory of Savonia Polytechnic, Engineering Kuopio, Finland. Costs of the system were:

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micromanipulators</td>
<td>2345.35 €</td>
</tr>
<tr>
<td>Microscope with separate eyepieces</td>
<td>228.90 €</td>
</tr>
<tr>
<td>Metal works &amp; parts</td>
<td>no bill yet</td>
</tr>
<tr>
<td>Powder coating</td>
<td>20.00 €</td>
</tr>
<tr>
<td>Chroming and anodizing</td>
<td>30.00 €</td>
</tr>
<tr>
<td>Power supply</td>
<td>63.00 €</td>
</tr>
<tr>
<td>Electrical stuff</td>
<td>8.00 €</td>
</tr>
<tr>
<td>Feet &amp; screws</td>
<td>&lt; 20.00 €</td>
</tr>
<tr>
<td>Pressure connection</td>
<td>20.00 €</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2735.25 €</strong></td>
</tr>
</tbody>
</table>

Initially, it was thought that the system would cost about 1000€. However, the amount of 2735.25 € for the whole system is almost three times more. But to get a good system, which fulfills the given requirements, you have to spend that much money. The manipulators are the most expensive single items. However, it was impossible to build up these parts self in time and with low cost. To buy them was the only way to get an appropriate system in short time.

One benefit of the system is that it is easy to change the test arm and probes. If there is any need for using four high frequency coaxial probes, only two additional HF test probes have to be bought. It is also possible to mount own test arms with probes. Consequently this system offers many possibilities for variations in the future.

The system is now in use. To measure the resistance of a commercial neurological sensor was its first task. Afterwards a self made sensor was measured. These sensors are used in rats’ brain for some animal testing.
Here some pictures of the system:

**Picture 5.a** Left: First time screwing together  
**Picture 5.b** Up: View on chuck with probes  
**Picture 5.c** Down: System ready for use
**Picture 5.d** Sample with probes (2x HF, 1x DC)

View through microscope:

**Picture 5.e** Sample used in 5.d  
**Picture 5.f** Another sample with smaller pads

**Picture 5.g** Probe Station at the micro lab, where it was used in the meantime
References

16. Link no longer available, November 2005