Warranty

Supracon warrants this product to be free from defects in the materials and workmanship for a period of one year from the date of shipment. If any such product proves defective during this warranty period, Supracon, at its discretion, will either repair the defective product without charge for parts and labor, or will provide a replacement in exchange for the defective product.

In order to obtain service under this warranty, the customer must notify Supracon of the defect before the expiration of the warranty period and make suitable arrangements for the undertaking of service. The customer shall be responsible for the packaging and shipping of the defective product to Supracon, with shipping charges prepaid. The customer shall be responsible for paying all shipping charges, duties, taxes, and other charges for the returned products.

This warranty shall not apply to any defect, failure or damage caused by improper use or improper or inadequate maintenance and care. Supracon shall not be obliged to furnish a service under this warranty: a) to repair damage resulting from attempts by personnel other than Supracon representatives to repair or service the product, b) to repair damage resulting from improper use or connection to incompatible equipment, or c) to service a product that has been modified or integrated with other products when the effect of such a modification or integration increases the time or difficulty of servicing the product.

Supracon reserves the right to make changes in design and specification at any time without incurring any obligation to install the same on the units previously purchased.

April 2013

Preface

Thank you for purchasing the **supra*VOLT*control** system. In this manual you will find a detailed description of the Josephson voltage standard (JVS) system`s features. Furthermore, the manual gives guidelines on the installation and operation of the system.

While installing and operating the system please take into account, that the **supra*VOLT*control** is a very sensitive measuring system and, thereby, vulnerable to outside disturbances. Therefore, Supracon recommends the installation of the system in your laboratory by a specialist of its company. You are kindly asked not to hesitate to contact our experienced staff in case of any problems with the system.

We hope that you will find the system easy to handle for your voltage calibration requirements.

The **supra*VOLT*control** system will be provided in two versions: The liquid helium (LHe) version cooled with LHe and the LHe-free version cooled with a cryocooler. This manual describes both systems. In the chapters is clearly written whether they are applicable to the one or to the other system or to both.

Table of Contents

Table of Figures

Symbols and Abbreviations

b	offset voltage of a DVM
e	elementary charge
f	microwave frequency
h	Planck`s constant
I_{RF}	microwave current
K_{J90}	Josephson constant K_{J90} = 483 597.9 GHz/V
m	gain of a DVM
n	integer (Josephson voltage step order)
N	number of measurements
V_{cal}	voltage of the calibrated secondary standard
V_{diff}	difference voltage $Vj - V_{dvm}$
V_{diff+}	difference voltage $Vj_+ - V_{dvm}$ at positive Josephson voltage setting
V_{diff-}	difference voltage $Vj_- - V_{dvm}$ at negative Josephson voltage setting
V_{dvm}	measured and displayed voltage of the voltmeter
V_{fit}	voltage of the linear fit, $V_{fit} = m \cdot V_{in} + b$
V_{fluke}	voltage of the Fluke secondary standard
V_{in}	input voltage of a DVM
Vj	Josephson voltage
Vj_+	Josephson voltage at positive setting
Vj-	Josephson voltage at negative setting
S_+	standard deviation of the difference voltage at positive Josephson voltage setting
S-	standard deviation of the difference voltage at negative Josephson voltage setting
σ	standard deviation
t	time
T_C	critical temperature (transition from the normal to the superconducting state)
SIS	Superconductor-Insulator- Superconductor
JJ	Josephson junction

DVM	digital voltmeter
DUT	device under test
JVS	Josephson voltage standard
JVSC	Josephson voltage standard circuit
RMSE	root mean squared error
WR12	rectangular waveguide for the E-band, 60 to 90 GHz

1 Safety Precautions

In order to operate this sensitive measuring system it is advisable to comply with the following safety instructions.

1. Before opening product covers or panels disconnect the power cable.

2. Do not remove product covers or panels except for modifications as specified in this manual. Do not operate without all covers and panels in place.

3. Do not attempt to repair, adjust, or modify the system, except for modifications as specified in this manual. This could cause nullification of any warranty. For servicing, return the system to Supracon or any authorized representative.

4. Do not operate the system in a volatile environment, such as in the presence of any flammable gases or fumes.

5. Read the manual carefully before operating the system,
especially the safety instructions.

2 Specifications

Specifications for the **supra*VOLT*control** system are listed in Table 1.

Table 1: **supra*VOLT*control** specifications

SPECIFICATIONS

Typical calibration accuracy (direct comparison to a second Josephson voltage standard)
± 4 nV @ 10 V $\Delta V/V_{10V} = 4\times10^{-10}$

Typical calibration accuracy of secondary voltage standards (type A) for all three channels (limited by the noise of the secondary voltage standard):
± 20 nV @ 1 V $\Delta V/V_{1V} = 2\times10^{-8}$
± 100 nV @ 10 V $\Delta V/V_{10V} = 1\times10^{-8}$

Typical calibration accuracy of the gain factor of external voltmeters
(depends on the type of voltmeter)
$\Delta g/g < 2\times10^{-6}$

Step flatness
= 0 mΩ
*test measurements are limited by the noise of the secondary voltage standard:
< 25 mΩ @ 10 V
< 10 mΩ @ 1 V

Isolation resistance for all channels
> 100 GΩ @ Low – High
> 50 GΩ @ Low – Ground
> 50 GΩ @ High – Ground

Leakage current at 10 V for all channels
< 100 pA @ Low – High
< 200 pA @ Low – Ground
< 200 pA @ High – Ground

* **Thermal voltage** of the reversal switch including the connecting cables
< 25 nV, typically below 5 nV for each channel

Accuracy of the 10 MHz reference frequency
$\Delta f/f < 1\times10^{-10}$ (option external 10 MHz reference frequency)

Stability of the 75 GHz Gunn oscillator (locked by the EIP source locking microwave counter):
± 10 Hz @ 75 GHz $\Delta f/f < 1.4\times10^{-10}$

***Gain error of the null detector** (see also the specification of the Keithley 2182 voltmeter)
1.00003 @ 10 mV range
1.00001 @ 10 V range

Accuracy of the Sensors:
± 0.5 K for a temperature of 0°C to 30°C
± 2 % for a relative humidity of 10 % to 100 %
± 1 mbar for an air pressure of 800 mbar to 1100 mbar

*… can be measured with the system performance tests, see chapter 9.

3 An Overview

3.1 The basic principle of a Josephson voltage standard

The **supraVOLTcontrol** is a primary voltage standard which uses arrays of Josephson junctions (JJ). These junctions consist of a thin insulating barrier between two superconductors, see Figure 1. When exposed to electromagnetic radiation of frequency f, the dc voltage V_J across the junction can only assume discrete values given by

$$V_J = n \times \frac{1}{K_{J90}} \times f \,, \qquad \text{eq. (1)}$$

n = integer (… -1, 0, 1, 2 …), K_{J90} = 483 597.9 GHz/V, f = frequency

where n is an integer which identifies a constant voltage step in the current voltage characteristic and the value of K_{J90} has been defined since 1990 to be **K_{J90} = 483 597.9 GHz/V** without any uncertainty. The constant K_{J90} is equal to 2e/h, the combination of the fundamental physical constants h and e (the Planck`s constant and the elementary charge). Because the reproducibility of 2e/h given by the Josephson effect was much better than the uncertainties of the constants e and h, the value of 2e/h = K_J was internationally accepted to be **K_{J90} = 483 597.9 GHz/V** in order to ensure world wide uniformity of dc voltage measurements.
With the equation 1 the voltage will be traced back to a frequency which can be controlled to a very high precision. The accuracy of the generated voltage depends only on the stability and accuracy of the frequency of the incident electromagnetic radiation. For a frequency of 75 GHz, the voltage difference between adjacent steps is about 155 µV.

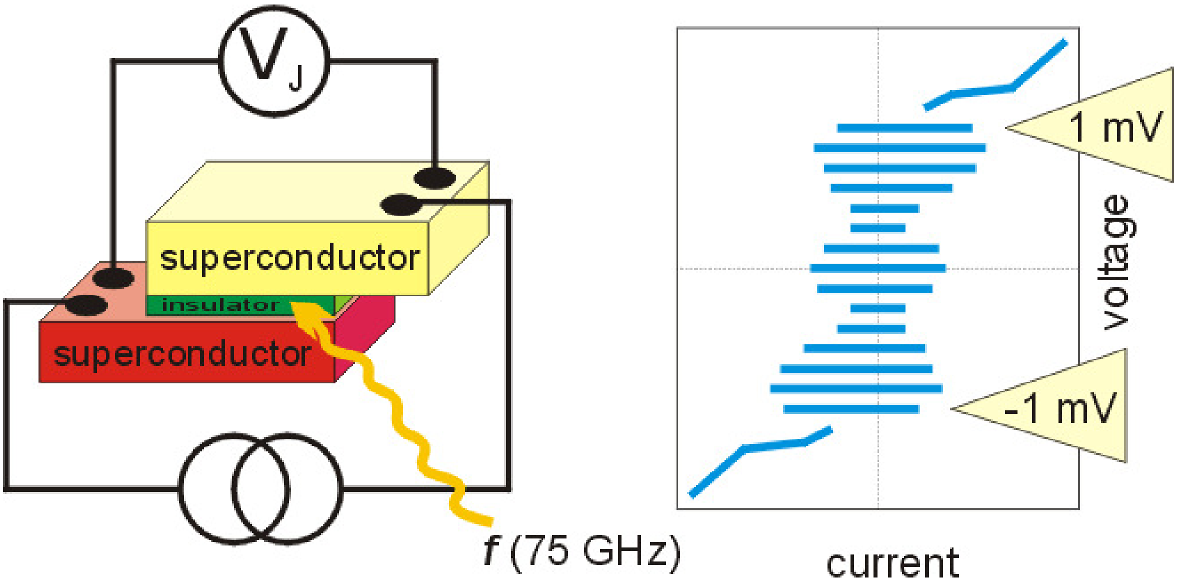


Figure 1: Schematic Superconductor-Insulator-Superconductor (SIS) Josephson junction (JJ) with current voltage characteristic

On the right of Figure 1 the principle current voltage characteristic of a single Josephson junction (JJ) is shown under microwave irradiation at a frequency of 75 GHz. Clearly seen are the steps of constant voltages, the so called Shapiro steps. Their voltage is given by eq. 1, in which the integer n represents the step order of the Shapiro step. For a single JJ the quantised Josephson voltage is limited to a maximum of about 1 mV, therefore a large number of JJs connected in series is required to obtain practical voltage levels up to 10 Volt.

3.2 The basic system by operation with liquid helium (LHe)

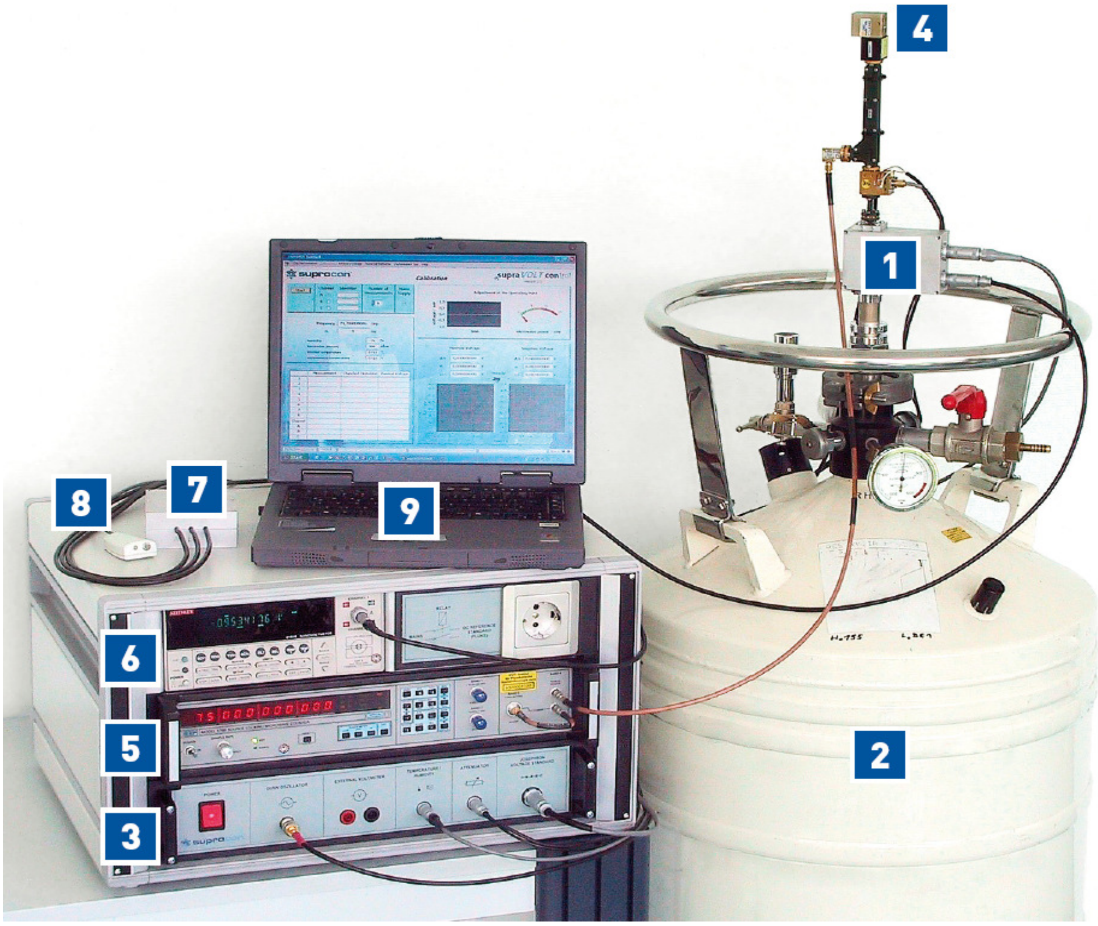


Figure 2: The complete **supra*VOLT*control** system (liquid helium version).

The complete **supra*VOLT*control** system consists of the following components:

1. **Cryoprobe with the 10 V SIS JJ Array Chip**,
2. **Liquid Helium Dewar** (optional) with 50 mm flange (ND50),
3. **JVS Electronics Unit**,
4. **Microwave Electronics** including
   75 GHz Gunn oscillator, isolator, directional coupler, remote sensor (mixer),
   voltage controlled attenuator,
   and a special power supply (assembled in the 19" rack),
5. **EIP Source Locking Microwave Counter**,
6. Keithley nanovoltmeter as **Null Detector**,
7. **3-channel Polarity Reversal Switch** with special low thermal voltage cables,
8. **Sensors** for temperature, humidity and barometric pressure with cables,
9. **Host Computer** with IEEE interface,
10. GPS disciplined oscillator for the **10 MHz Reference Frequency** (optional),
11. USB cable to connect the **JVS Electronics** unit to the **Host Computer**,
12. IEEE cable to connect the **JVS Electronics** unit to the **Host Computer**,
13. SMA microwave cable to connect the 75 GHz **Microwave Electronics** to the **EIP Source Locking Microwave Counter**,
14. LEMO connector counterpart cable to connect the **JVS Electronics Unit** to the **Cryoprobe with the 10 V JJ Array Chip**,
15. CD-ROM with **supra*VOLT*control** software,
16. User Manual.

The **supraVOLTcontrol** is a complete 3-channel microprocessor-controlled Josephson voltage standard (JVS) with a highly integrated low-Tc JJ array microwave circuit. It allows a very easy calibration of secondary voltage standards and external voltmeters, and a direct comparison to another Josephson voltage standard.
The **supraVOLTcontrol** operates in the following way: The JJ array is connected in series to a high resolution null detector and the secondary voltage standard which has to be calibrated. The null detector measures the difference voltage between the secondary voltage standard and the quantized voltage level of the JJ array chip for both polarities. With these two readings the software calculates the calibration voltage of the secondary voltage standard by eliminating the thermal voltage (thermal EMF), see chapter 8.2.2.1. During the calibration the JJ array chip is completely disconnected from ground and the JVS electronics.
The absolute accuracy of the **supraVOLTcontrol** itself is better than $4x10^{-10}$, measured to another Jpsephson voltage standard system. For calibration purposes the noise of the secondary voltage standard limits the accuracy to about 10^{-8}.
Additionally, the **supraVOLTcontrol** can measure the linearity and the gain factor of external voltmeters. The complete **supraVOLTcontrol** system is shown in Figure 2.

3.3 The Josephson voltage standard circuit

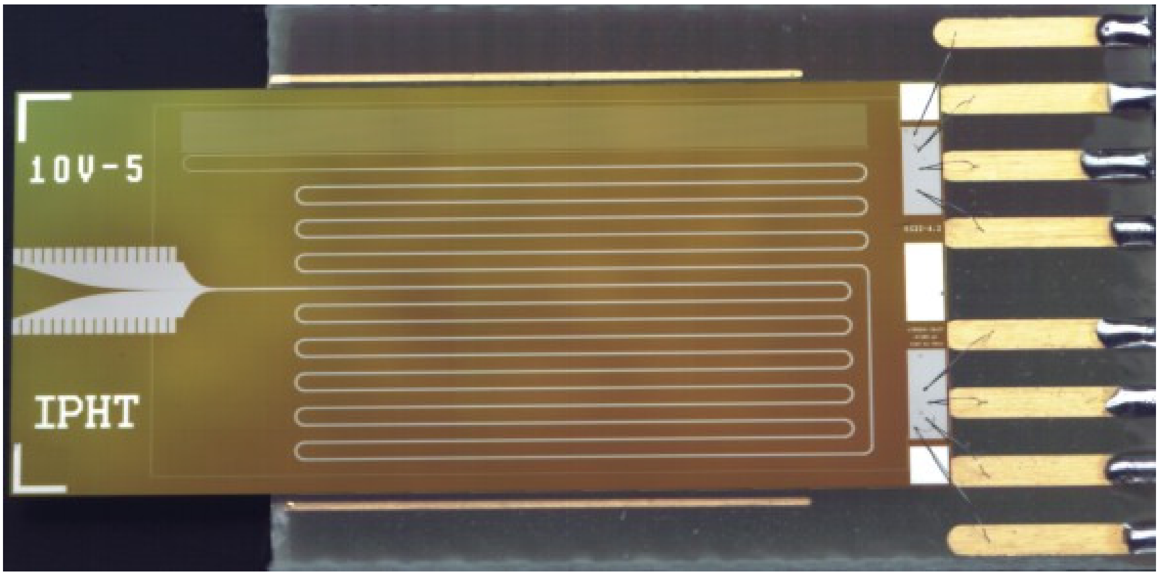


Figure 3: 10 Volt Josephson voltage standard circuit with 19,700 SIS Josephson junctions.

The maximum Josephson voltage which can be generated with one JJ is about 1 mV. In order to generate a voltage of 10 V with quantum accuracy an array with a minimum number of 10,000 JJs connected in series is necessary. In the 10 Volt **supraVOLTcontrol** system an array with 19,700 SIS (Superconductor-Isolator-Superconductor) JJs is used. The JJs are integrated in a microwave transmission line, see Figure 3. The dc pads are connected to both fins of the finline antenna in order to supply the bias current and pick up the Josephson voltage. The JJ array chip is glued on a small printed board and its dc pads are bonded to the copper contacts of the printed board, which are soldered to the dc contacts of the chip carrier, see Figure 12.
The JJ array chip is based on standard Nb/Al trilayer technology. Its operating frequency is about 75 GHz, and its operating temperature is 4.2 K, the boiling temperature of liquid helium.

A typical current voltage characteristic of an array with 19 700 SIS JJs is shown in Figure 4, upper curve without microwave and below the characteristic with 75 GHz microwave irradiation. The main important parameter of the JJ array is the critical current I_C indicated in the figure. It represents the maximum current at zero voltage (a current flow without a voltage drop). The characteristic shows the typical hysteretic behaviour for SIS JJs. Under microwave irradiation the characteristic changes to the graph seen in Figure 4 below. The curve represents the envelope of nearly 130 000 quantized voltage steps. The voltage of each of these steps is given by eq. 1 and its current width is limited to about 20 µA, see the small inset of Figure 4 and Figure 5. The Josephson junction array can generate each voltage between -10 Volt till +10 Volt, with a grid of 155 µV, the distance between neighbouring steps. Important to mention, the stability of the voltage strongly depends on environment noise.

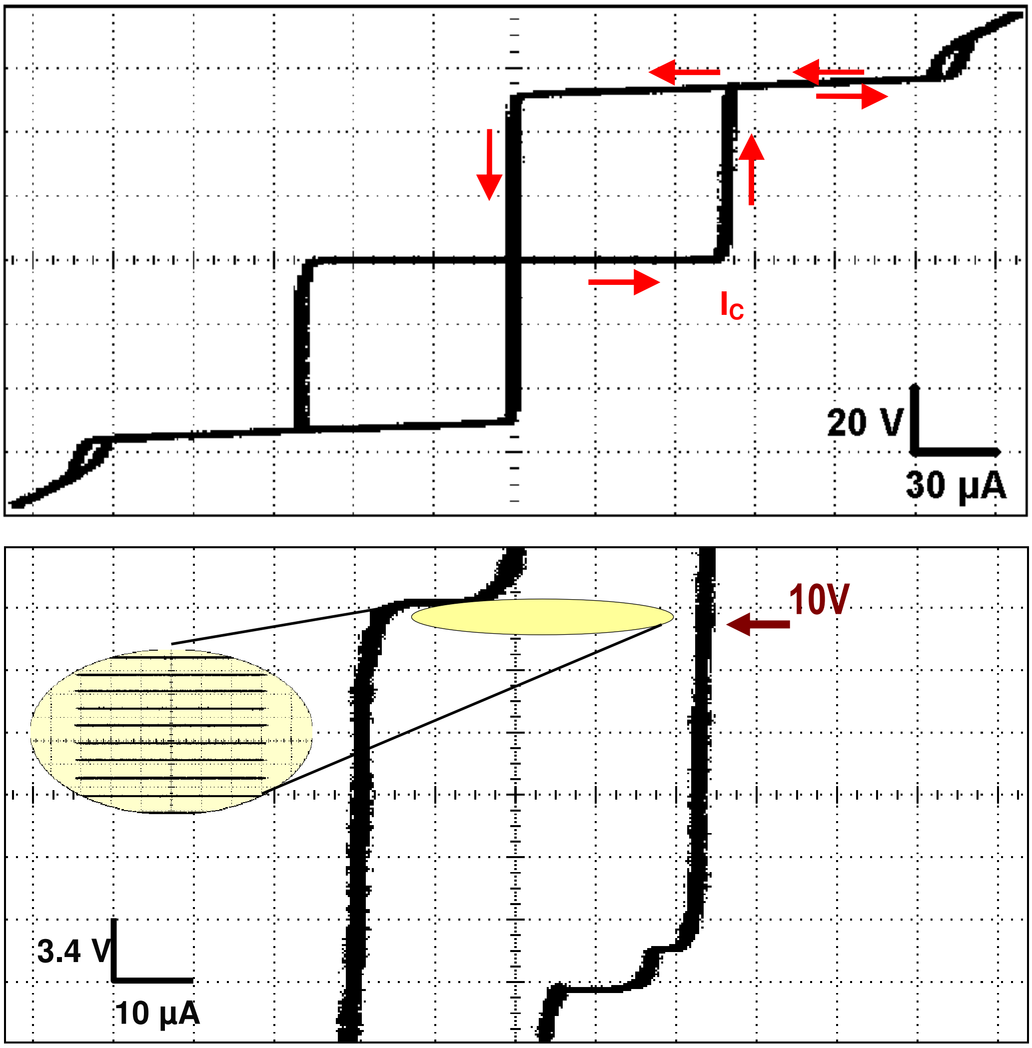


Figure 4: Current voltage characteristic of an array with altogether 19700 JJ. Upper figure is without microwave and figure below by applying a 75 GHz microwave irradiation.

As an example different quantised voltage steps at 10 Volt at a driving frequency of 75 GHz are shown Figure 5. Because of noise the voltage can jump between these neighbouring steps. Under good environment conditions the Josephson voltage is stable for several minutes. For calculation the Josephson voltage the step number n of equation 1 is determined by a course voltage measurement using the internal nanovoltmeter. The accuracy of this voltage measurement must be better than 50 µV to be definable the right step order n. The three marked Shapiro steps of the figure have Josephson voltages of V_{64479} = 9.999 888 337 Volt, V_{64480} = 10.000 043 424 Volt and V_{64481} = 10.000 198 512 Volt, corresponding to the step orders n=64479, 64480 and 64481. Because the current widths of the Shapiro steps are limited to about 20 µA, the JJA cannot be used as a voltage source; the load current would exceed the step widths.

A test report with the parameters of the installed JJ array chip is included in the documents of your 10 Volt **supra*VOLT*control** system.

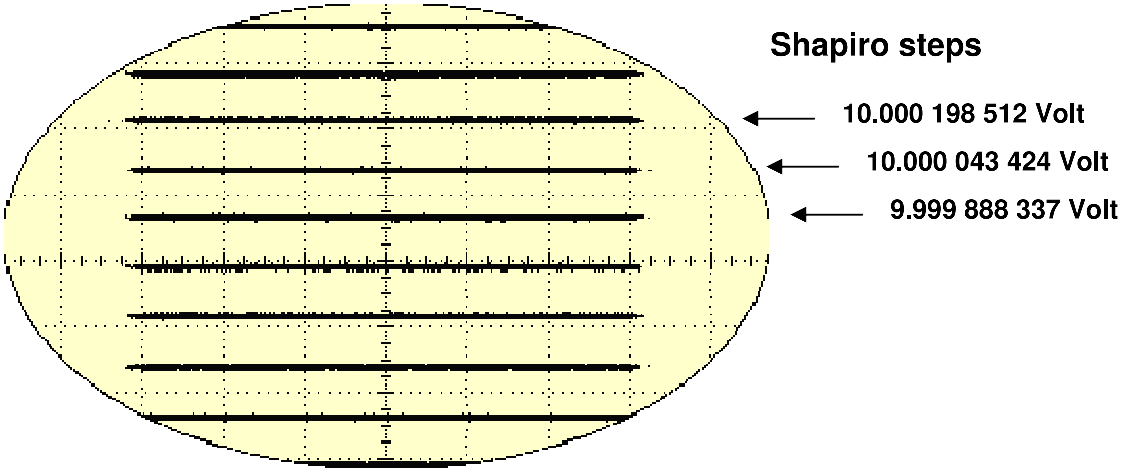


Figure 5: Typical current voltage characteristics (X: 3 µA/div; Y: 200 µV/div) of Shapiro steps at 10 Volt under microwave irradiation of 75 GHz. The marked step orders are n=64479, 64480 and 64481.

3.4 The functional principle of the supraVOLTcontrol electronics

At an operating frequency of 75 GHz the Josephon voltage standard circuit (JVSC) can generate about 130,000 discrete voltage levels in the range of −10 V to +10 V at intervals of about 155 µV according to equation 1. These discrete voltage levels are referred to Shapiro steps. The task of the microprocessor-aided control electronics is to select a Shapiro step with a well-defined voltage and to verify its stable operation during the calibration or measurement process. The block diagram of the control electronics is shown in Figure 6, and the left part of Figure 7 represents the graph of the ADC data during the operation point adjustment.

A voltage source delivers an adjustable voltage in the range of ±11 V with a resolution of 50 µV for a coarse preselection of the desired high precision Josephson voltage. The current source provides a 30 Hz triangle AC current with a typical amplitude of 50 μA_{pp}.
Without a microwave irradiation or at a too low microwave power the JVSC is highly resistive. Therefore the AC current flows mainly through the 100 Ω resistance R_A, resulting in a corresponding AC voltage drop which is shown in the left part of the graph of Figure 7. This is in contrast when a Josephson voltage is applied, then all the current flow through the Josephson array chip, because its internal resistance is zero. In this case the voltage drop of R_A does not change; you will see a straight line as is indicated in the right part of the graph of Figure 7.
The search for an applicable operating point starts with at low microwave power and the actual power level is shown in the right part of Figure 7. Afterwards the microwave power will be increased automatically up to a level where the JVSC forms Shapiro steps, and the AC voltage drop at the ADC input is constant. Then the amplitude of the AC current will be reduced automatically to typically 5 μA_{pp}, the AC current flows through the JVSC, the voltage drop at the input of the ADC is constant, and the graph in Figure 7 shows a straight line. This procedure starts at the beginning of every measurement process or if the Josephson voltage becomes instable due to external noise.

For the sake of simplicity the polarity reversal switch which is used for elimination of offset voltages and thermal EMFs (see chapter 8.2.2.1) is not shown in the block diagram of Figure 6.

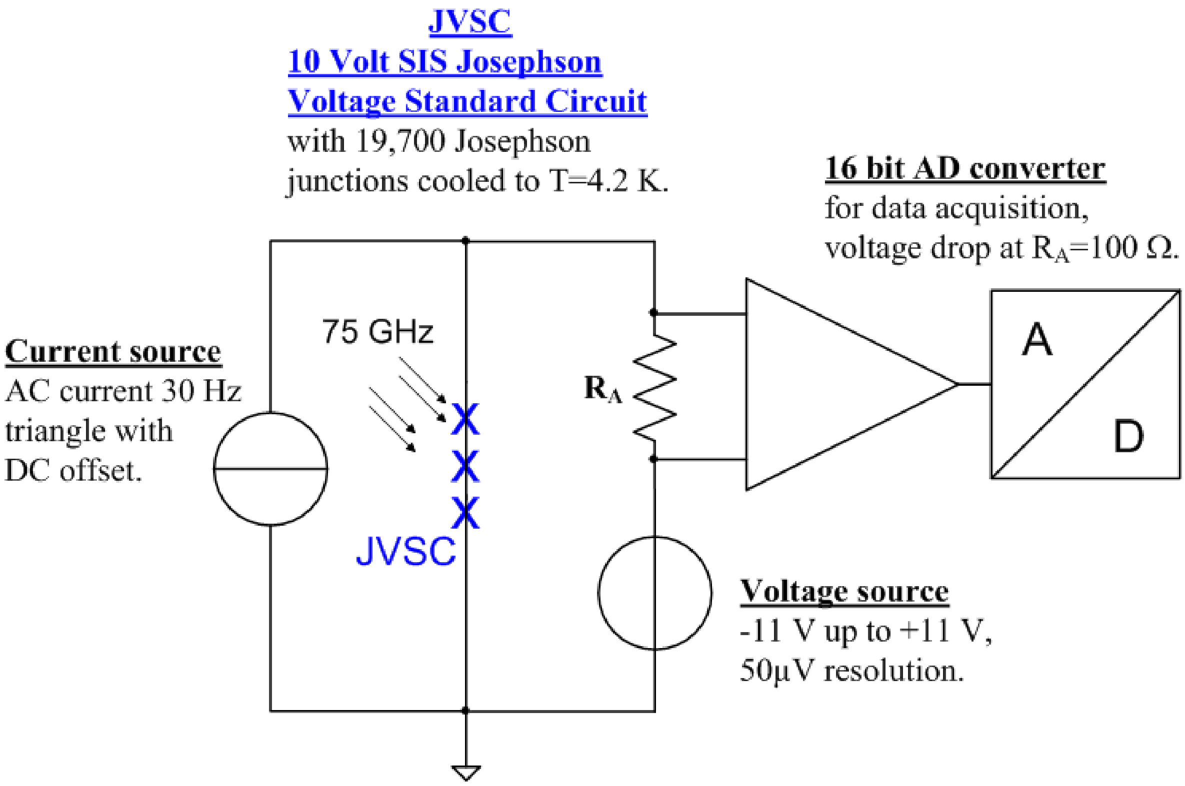


Figure 6: Block diagram of the supraVOLTcontrol electronics.

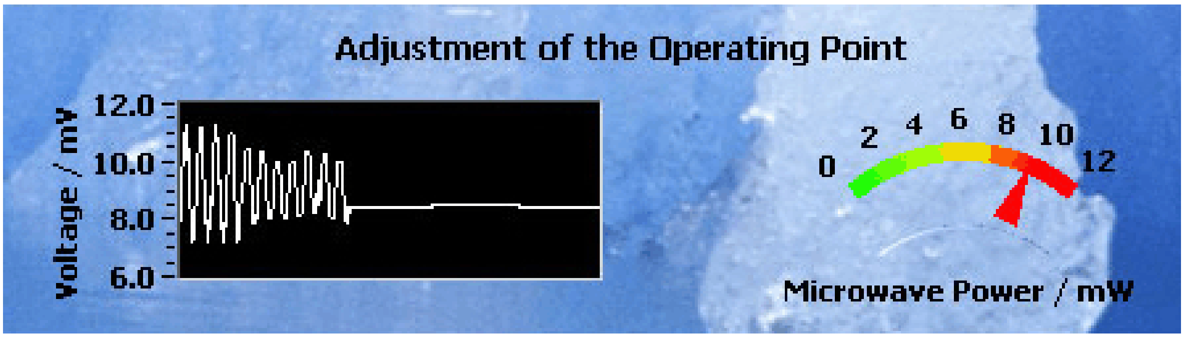


Figure 7: View of the operation point adjustment of the user interface.

4 Hardware Installation

This section provides information about the **supraVOLTcontrol** system components. The control devices are installed in a 19” rack as shown in Figure 8: The JVS electronics unit at the bottom, the EIP source locking microwave counter in the middle, a Keithley nanovoltmeter as the null detector, top left, and a switchable power socket, top right.

4.1 The JVS electronics unit embedded in the 19” rack

Figure 8: Front panel of the JVS electronics unit installed at the bottom of the 19” rack (liquid helium version).

The **JVS electronics unit**, together with the host computer, controls the **supraVOLTcontrol** system. The following elements are placed on the front panel of the **JVS electronics unit** installed at the bottom of the 19” rack:

- **POWER** - mains switch,
- **GUNN OSCILLATOR** - BNC connector for connection to the 75 GHz Gunn oscillator,
- **EXTERNAL VOLTMETER** - jacks for the connection to an external voltmeter,
- **TEMPERATURE/ HUMIDITY** - 6-pole Lemo-connector for temperature/humidity sensors,
- **ATTENUATOR** - 4-pole Lemo-connector for the connection to the voltage controlled attenuator,
- **JOSEPHSON VOLTAGE STANDARD** - 6-pole Lemo-connector for connection to the JJ array chip assembled in the cryoprobe.

Figure 9: Rear panel of the JVS electronics unit installed at the bottom of the 19” rack (liquid helium version).

On the rear panel of the **JVS electronics unit** are placed:

- **USB (TYP B)** - USB cable connector (TYP A → TYP B) for connection to the host computer,
- **POWER SOCKET** - 2-pole Lemo-connector for the activation of the on/off switch for the power socket on the front panel,
- **POLARITY REVERSAL SWITCH** - 15-pole SubD socket for the connection to the polarity reversal switch,
- **Ø LOCK OUT** - BNC socket for the connection to the EIP source locking microwave counter (BNC socket J6, Ø LOCK OUT),
- **COARSE TUNE OUT** - BNC socket for the connection to the EIP source locking microwave counter (BNC socket J7, COARSE TUNE OUT),
- **POWER** - power socket for mains power 110 – 230 VAC, 50/60 Hz, connected to the multiple socket outlet, top left.

4.2 EIP source locking microwave counter

Please look at the manual of the EIP source locking microwave counter in order to get detailed information about its operation.
The EIP source locking microwave counter is required for the stabilisation of the microwave frequency of the 75 GHz Gunn oscillator. The frequency down converted output signal of the remote sensor (mixer) of the microwave electronics, see chapter 4.6, is fed to the input of the EIP counter (BAND 4, REMOTE SENSOR). This signal, and with it the 75 GHz signal of the Gunn oscillator, is phase locked to a 10 MHz external reference frequency. Thus, the accuracy and stability of the 75 GHz microwave oscillator is the same as that of the 10 MHz reference frequency. The locking frequency of about 75 GHz can be adjusted in 10 kHz steps. A GPS disciplined oscillator for the 10 MHz reference frequency is an optional component. **The 10 MHz reference frequency has to be connected to the J5 BNC socket, 10 MHz TIME BASE, on the rear panel of the EIP counter, and the corresponding switch has to be set to the EXT. position**. The outputs of the EIP counter, the BNC sockets J6 and J7 on the rear panel, are connected to the inputs of the special power supply of the Gunn oscillator which is integrated in the JVS electronics

unit, Ø LOCK OUT and COARSE TUNE OUT, respectively. These signals tune the operating voltage of the bias tuned Gunn oscillator permanently so that its frequency is permanently phase locked on the 10 MHz reference frequency.

4.3 Keithley nanovoltmeter as null detector

The Keithley nanovoltmeter as null detector measures the difference voltage between the Josephson voltage standard and the secondary standard, the device under test DUT, in both polarities, see Figure 26 and Figure 27 in chapter 8.2.2.1. With these measurements the influence of thermal voltages can be eliminated arithmetically. Twenty measurements in both polarities will be made in order to determine the difference voltage with a high accuracy. The polarity of the Josephson voltage is reversed by the polarity change of the bias current through the JJ array chip and the polarity of the DUT is reversed by the polarity reversal switch, see chapter 4.7. It is recommended to make a selfcalibration of the nanovoltmeter, as described in chapter 9.2, in order to increase its accuracy of measurement. In this way the accuracy of the measured difference of the Josephson voltage and the DUT voltage will be improved and an unambiguous determination of the step index n, for the exact calculation of the Josephson voltage, becomes possible.

4.4 Switchable power socket

Sometimes it is not possible to calibrate a mains operated secondary voltage standard, the DUT, due to the nature of the secondary voltage standard and/or electromagnetic interferences on the mains. In these cases the DUT should be powered by the switchable power socket installed in the 19” rack. Consequently, the DUT can be detached from the mains during the short time of the calibration measurements, provided that the DUT possesses a battery supply like the Fluke secondary standards. Furthermore, the noise level will be reduced in the battery-powered case. For instance the noise level of a Fluke standard 732A at 1 V will be reduced from about 150 nV to 40 nV.

4.5 Cryoprobe with Josephson junction array (LHe version)

The cryoprobe is the interface between the JJ array chip at 4.2 K and the electronics at room temperature. A drawing of it is shown in Figure 10. A filter box for the dc wires and a galvanic isolation of the microwave system from the cryoprobe reduce the electromagnetic interference. In order to prevent trapped flux the JJ array chip is magnetically shielded by a cup of cryoperm which is a magnetically soft material even at the low temperature of 4.2 K.

Four twisted pairs of copper wires with low thermoelectric voltages contact the JJ array chip with the 6-pin and the 2-pin connector of the filterbox. One pair is for the Josephson voltage connected to the 2-pin connector, two pairs are for the bias current and for the measurement of the Josephson voltage, and one pair is a reserve. The twisted wire pairs are guided in a 3 mm shielding tube. The wiring of the chip and the filter box is shown in Figure 11.

For the microwave transmission a waveguide is used with a microwave attenuation of about 1.5 dB at 75 GHz.

A thin foil between the two WR 12 flanges in the filter box seals the waveguide and prevents helium air exchange.

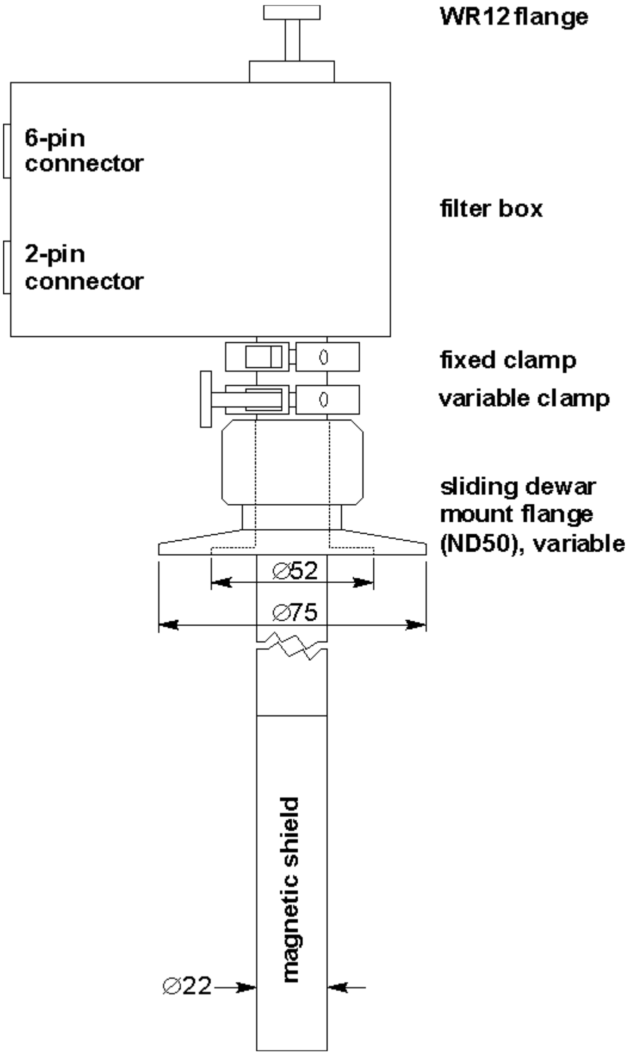


Figure 10: A drawing of the cryoprobe.

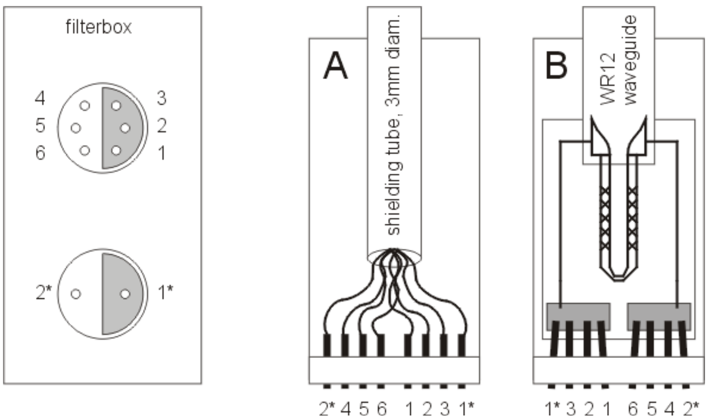


Figure 11: Wiring of the JJ array chip with the filter box.
A: Bottom of the chip carrier, B: Top of the chip carrier

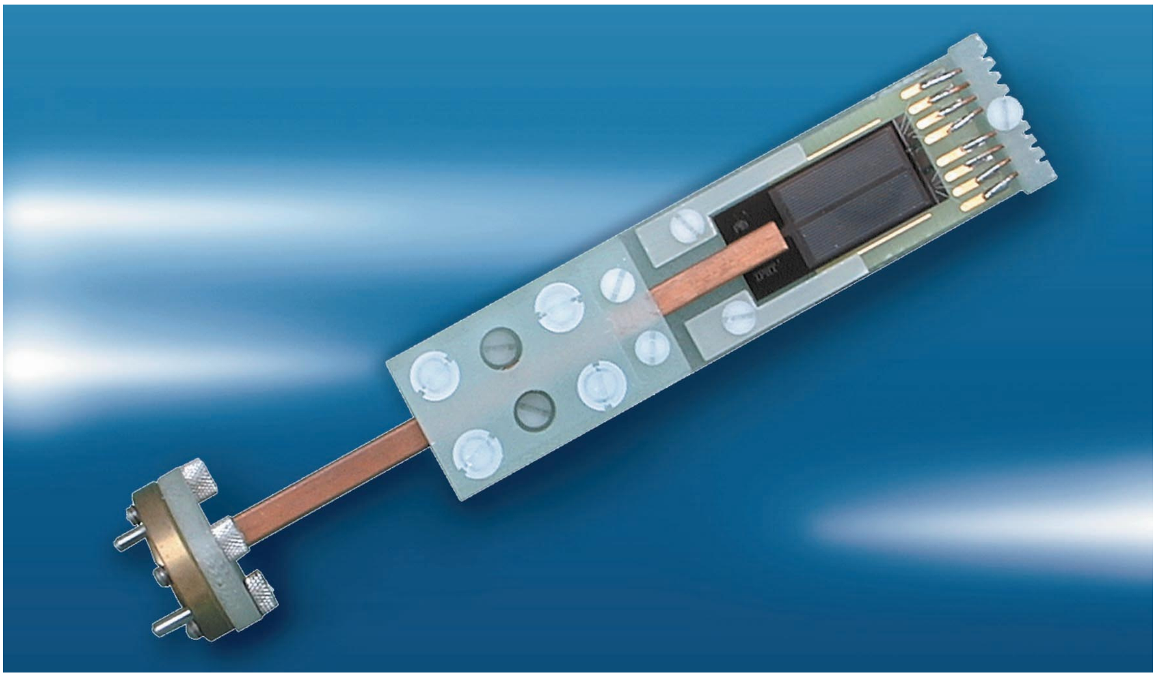


Figure 12: The 10 Volt JJ array chip mounted on a chip carrier.

The 10 Volt JJ array chip is mounted on a chip carrier as shown in Figure 12. The chip, mounted on a carrier, is magnetically and electrically shielded by a cryoperm cup. The chip carrier is arranged only one millimetre from the bottom of the cryoperm cup. The fixed clamp on the stick of the cryoprobe is adjusted so that the cryoperm cup is at its lowest position very near to the bottom of the liquid helium Dewar, in order to fully utilise the liquid helium. For instance, in a 65 Litre liquid helium Dewar from Air Liquide a level of 60 mm, which corresponds to about 5 litre liquid helium, is the minimum necessary for the calibration measurements.
The contribution of the cryoprobe to the liquid helium boil off rate of a 65 Litre Dewar from Air Liquide is about 2.4 Litre per day, at which the intrinsic boil off rate of this Dewar without any cryoprobe is about 1.6 Litre per day. If the cryoprobe is immersed permanently in this liquid helium Dewar, starting with a full Dewar, measurements can be done over a period of about 15 days. If the cryoprobe is positioned overnight in the topmost position, where the cryoprobe cannot be moved any higher, then the measuring period can be extended up to about 20 days. The cryoprobe can be stationed at the topmost, the lowest or any other position by means of the variable clamp.
In the case the Dewar is just filled with liquid Helium (the Dewar was at room temperature); the losses are about 20 liter to cool the Dewar firstly to 4.2K. The thermal equilibrium in the Dewar is reached after about 12 hours and the losses of liquid Helium in that time are increased to about 15 liter. Without a refill after the first day you have about 50 liter Liquid Helium available. This must be taken into account in the estimation of the measuring period.

4.6 The microwave electronics

The microwave electronics consists of a bias tuned Gunn oscillator with an integrated isolator, a 20 dB directional coupler, a remote sensor which acts as a mixer, a voltage controlled attenuator, and a special power supply which is assembled in the 19” rack. This power supply stabilise the 75 GHz Gunn oscillator frequency by phase locking on a 10 MHz reference frequency by means of an EIP source locking microwave counter. As an option the output signal of a GPS disciplined 10 MHz oscillator can be used as the reference frequency.
The aforementioned components are mounted on the input microwave flange of the cryoprobe as shown in Figure 13.
The output power of the 75 GHz Gunn oscillator at the output of the integrated isolator is about 50 mW. The isolator protects the Gunn oscillator from damage due to reflected power, also in the case of an extreme mismatch. The directional coupler couples 1 % of the microwave power to the remote sensor, which acts as a down converter and which converts the frequency at its input down by a factor of ten. The frequency down converted signal is fed to the source locking microwave counter by a special coaxial cable.

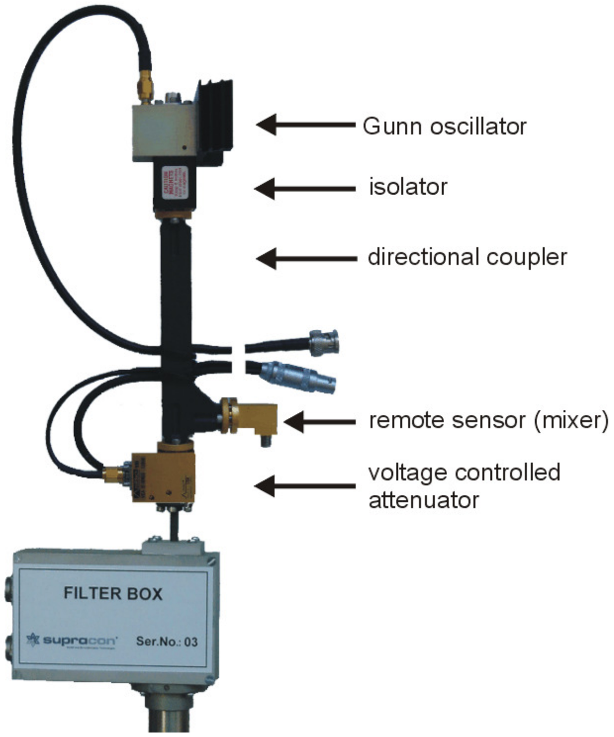


Figure 13: Components of the microwave electronics mounted on the input microwave flange of the filter box of the cryoprobe.

Due to the voltage controlled attenuator the microwave power is adjusted to an optimum for the operation of the JJ array chip.

4.7 Polarity reversal switch

The **supra*VOLT*control** system uses a three channel computer-controlled polarity reversal switch, with very low thermal voltages, in order to reverse the polarity of the DUT. This reversal switch allows a simultaneous calibration of three voltages, for example 10 V, 1 V, and 1.018 V of a Fluke secondary standard. The interconnection of the reversal switch to the Fluke standard is shown in Figure 24 in chapter 8.2.1.
Each of the three scanner channels and the wires that connect the switch to the DUT should be tested regularly in order to check their low value of the thermal voltage. This test is done by replacing the DUT with a short *circuit* and making the low thermal voltage test, see performance tests chapter 9.4.
The thermal voltage of the scanner is typically below 10 nV, as can be measured by the performance test described in chapter 9.4.

4.8 Sensors

The **supra*VOLT*control** system includes sensors for the barometric pressure and internal temperature, which are integrated in the JVS electronics unit, and for humidity and environmental temperature, which are installed in a separate small box. This box can be put on or nearby the secondary standard which should be calibrated. The data from the sensors are permanently displayed and are listed in the calibration reports. The interconnection of the external sensors to the JVS electronics unit is shown in Figure 21.

5 Software Installation

The **supraVOLTcontrol** software is already installed on the host computer of the **supraVOLTcontrol** system.

The software runs on the following operating systems: **Microsoft Windows 9x/NT/2000/XP/Vista/7**.

Reinstallation

A CD-ROM with the **supraVOLTcontrol** software is included to the system for the case that a software reinstallation is necessary.

In order to reinstall the software insert the **supraVOLTcontrol** CD-ROM into the CD-ROM drive of the host computer and follow the steps given below:

1. Select **run program** in your Windows start menu.
2. Change to CD-ROM drive and run **setup.exe**.
3. Now an installation wizard appears and prompts you to enter the destination path for the software **supraVOLTcontrol** and LabVIEW Runtime Engine
4. After the complete installation you can use the **supraVOLTcontrol** software by running it from the Windows start menu.

   Before you can use the **supraVOLTcontrol** software it is necessary to reinstall drivers for the USB-UART communication between host computer and JVS electronics unit. For that purpose connect the JVS electronics unit to a spare USB port on the host computer. The file path of the correct driver is “D:\Virtuell COM\CDM 2.00.00” on the **supraVOLTcontrol** CD-ROM.
   Additionally you must reinstall drivers and software for the GPIB-USB-HS communication which is used for data acquisition of the source locking counter and the voltmeters. For their reinstallation see the GPIB Installation Guide of National Instruments delivered with the **supraVOLTcontrol** system.

For information on Microsoft Windows (WIN95/98/2000/XP/Vista/7), see the Microsoft Windows documentation.

For information on LabView, see the National Instruments LabView documentation.

6 Instructions for handling liquid helium (only LHe version)

It is necessary to cool down the JJ array chip to its operation temperature of 4.2 K, the boiling temperature of liquid helium at normal barometric pressure, in order to operate the **supra*VOLT*control** system. For these reasons the chip is mounted on a chip carrier which is installed in a cryoprobe (see chapter 4.5). This part of the cryoprobe has to be immersed into a liquid helium Dewar. This chapter describes the safe handling of liquid helium and the cooling down and warming up cycles of the cryoprobe.

Follow the operating instructions of the manufacturer of the liquid helium Dewar, for instance Air Liquide, which you will find in the accompanying documentation.

6.1 Safety precautions

Before handling liquid helium:

1. Read the following guidelines.
2. Know and understand the properties and hazards associated with liquid helium.
3. Understand your liquid helium Dewar and its correct operation.

Liquid helium boils at a temperature of 4.2 K (-269°C). It is inert, colourless, odourless, non-corrosive, extremely cold, and non-flammable. Helium will not react with other elements or compounds under ordinary conditions. Since helium is non-corrosive, special construction materials are not required. However, the materials must be suitable for use at the extremely low temperatures.
Heating of the liquid helium leads to pressure increase and danger of the Dewar bursting. Spilled fluid is extremely cold and evaporates very quickly. Fluid contact to the skin leads to cold burns and fluid contact to the eyes leads to eye injuries. Helium gas can cause suffocation without preceding symptoms by displacing the oxygen of the air. Helium gas has a lower density than air, consequently it rises to the ceiling and spreads along the ceiling. There is also a **danger of skin adhesion to super cooled metal parts**. It is recommended to wear safety glasses, protective gloves and closed clothing when you have to carry out a refilling procedure.
To know what precautions to take is to recognize that at 4.2 K all other gases are solidified (the melting points of nitrogen, oxygen, and argon are 63.1 K, 54.4 K, and 83.8 K, respectively). Therefore, helium systems and Dewars must prevent the backflow of air as this constitutes a major safety hazard. **Dewars open to the atmosphere for prolonged periods can form "ice plugs" which help to contain the boil off which in turn can lead to overpressure and potential catastrophic failure (explosion)**. If you discover a Dewar which has been left open to the atmosphere for a period of time (e.g. via syphon entry port, helium recovery valve or bladder pressurisation valve):

1. Probe the inside of the Dewar with a helium dipstick in order to establish if it is clear and able to vent.
2. Report the event to your supervisor, senior technical staff or Departmental Safety Officer.
3. If the Dewar is blocked or partially blocked: Clear the area near the Dewar of all personnel and inform your supervisor immediately.

The extremely low temperatures associated with liquid helium can lead to condensation of the air's oxygen on the cold pipes. The condensed oxygen has the potential to drip down and combust spontaneously if it comes into contact with oil or fat. Also contact with flames (e.g. lighters or lit matches) can result in explosive combustion.
Overpressure in the Dewar due to faulty operation is an explosion hazard. The pressure must be reduced slowly by a slight opening of the discharge valve. High pressures within the Dewar can lead to a large increase of the boiling temperature of the liquid helium. Consequently, an abrupt tension release of the overheated liquid helium can result in a very high boil off and strong oscillations until the liquid gas has cooled down to its boiling temperature at atmospheric pressure again.

Cryogenic liquids kept in insulated Dewars remain at a constant temperature at their respective boiling points and will gradually evaporate. The very large increase in volume accompanying the vaporization of the liquid into gas and the subsequent process of warming up is approximately 1:700 for helium.

It is very important to consider the following safety precaution summary.

Liquid Helium Handling Golden Rules:

a. Always use and store in a well-ventilated area.
b. Always wear your eye protection.
c. Always wear your safety gloves.
d. Keep the liquid containers vertical at all times, avoid tilting the liquid helium Dewar.
e. Avoid mechanical or thermal shock.
f. Open valves slowly and be aware of gas noises.
g. Avoid splashing and use the minimum quantity required.
h. Never touch un-insulated pipes, parts or vessels.
i. Always transfer slowly.
j. Never leave a Dewar open to the atmosphere.
k. Never drop objects into the liquid helium.
l. Never accompany cryogenic liquid vessels in lifts.
m. Use protective goggles and protective gloves when handling cryogenic fluids, like liquid helium.
n. Avoid humidity intrusion into the liquid helium Dewar. Otherwise ice-formation inside the neck of the liquid helium Dewar is possible.

Finally imagine cryogenic liquids to be like "hot boiling water – only worse!"

Take extreme care at all times!

6.2 Instructions for cooling down and warming up the cryoprobe with the JJ array

Read the following instruction for cooling down and warming up the cryoprobe with the JJ array chip carefully.

The cryoprobe can be kept continuously immersed in the 65 Liter Dewar for as long as about 15 days between refills, see last paragraph of chapter 4.5.
The contribution of the cryoprobe to the liquid helium boil off rate of a 65 Litre Dewar from Air Liquide is about 2.4 Litre per day. The intrinsic boil off rate of this Dewar without the cryoprobe is about 1.6 Litre per day. If the cryoprobe is immersed permanently in this liquid helium Dewar, starting with a full Dewar, measurements can be done over a period of about 15 days. If the cryoprobe is positioned overnight in the topmost position, where the cryoprobe cannot be moved any higher, then the measuring period can be extended up to about 20 days. The cryoprobe can be stationed at the topmost, the lowest or any other position by means of the variable clamp.

6.2.1 Preconditions

Release the BHK head (see Dewar manual of AIR LIQUIDE) of the liquid helium Dewar and insert the cryoprobe into the liquid helium Dewar only if:

- **No overpressure exists, see in Figure 14 the differential pressure manometer (5) on the Dewar!**
- **Secondly the gas discharge valve (4) of the Dewar is in the open position!**

6.2.2 Cooling down cycle of the cryoprobe

Cool down the cryoprobe without the microwave electronics attached.
Avoid an overpressure of more than 50 mbar in the liquid helium Dewar during the cooling down cycle.
Slightly tip on the differential pressure barometer (**5** in Figure 14) with a finger in order to overcome the friction in it and to improve the measurement. Cool down slowly: Insert the cryoprobe in small steps into the liquid helium Dewar over a time of at least 40 minutes.
We advise the cooling down of the JJ array chip by inserting the cryoprobe in several 10 cm steps, with a pause at each position of about 5 minutes.

1. **Satisfy yourself that no overpressure exists in the Dewar.**
2. **Open the gas discharge valve (4) and open the road transport relief valve (1) of the Dewar**, see Figure 14.
3. Slide the ND50 sliding Dewar mount flange (**3** in Figure 14) of the cryoprobe down to the cryoperm shield and fix this position by means of the variable clamp.
4. Open the flange clamp and take out the BHK head of the liquid helium Dewar. Insert the cryoprobe in the Dewar at its highest position, fix the ND50 sliding Dewar mount flange with the flange clamp.
5. Close the gas discharge valve (4), the road transport relief valve (1) must be still open.
6. Move the cryoprobe about 10 cm down, fix it at this position with the variable clamp, and wait for about 5 min. Repeat this procedure until the cryoprobe is fully inserted in the liquid helium Dewar marked by the fixed clamp.
Caution: If the overpressure is higher than 40 mbar keep the cryoprobe at this position, for at least 10 minutes and then continue.

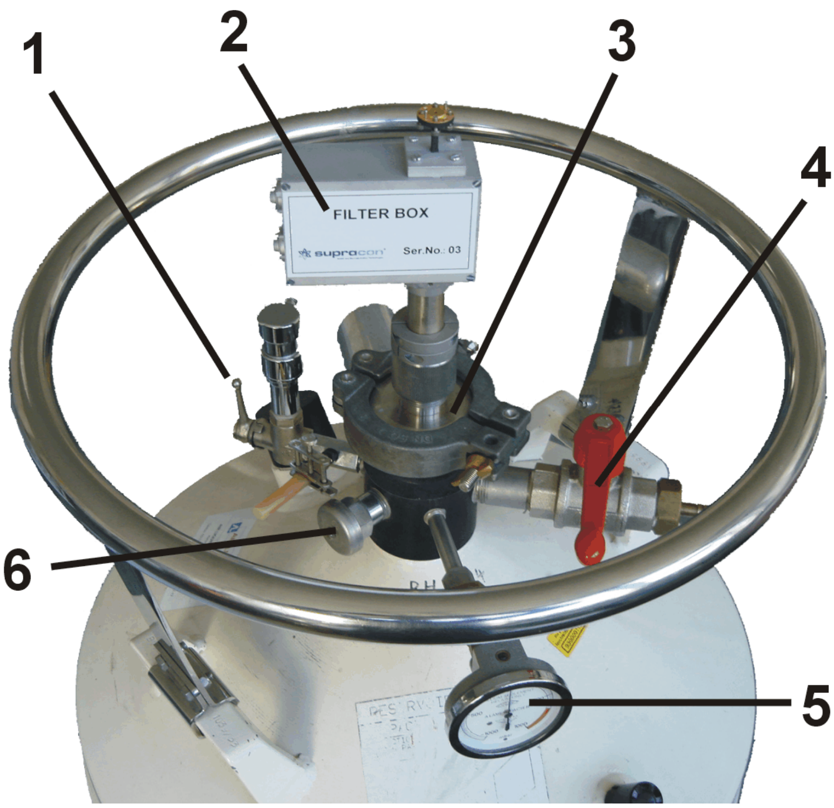


Figure 14: Top view of the liquid helium Dewar with the inserted cryoprobe.
1: Road transport relief valve (here in the open position), 2: filterbox of the cryoprobe, 3: ND50 sliding Dewar mount flange, 4: gas discharge valve (here in the closed position), 5: differential pressure barometer, avoid an overpressure of more than 50 mbar in the liquid helium Dewar, 6: safety valve set at 0.5 bar.

6.2.3 Warming up cycle of the cryoprobe

Follow the instructions of chapter 6.2.2 in the reverse sequence.

1. Disconnect the microwave electronics from the cryoprobe.
2. Pull out the cryoprobe in 10 cm steps and wait at these positions for at least 5 minutes.
3. Leave the cryoprobe at its highest position if measurements are to undertaken with the same liquid helium Dewar.

If the liquid helium Dewar must be exchanged by a refilled Dewar then leave the cryoprobe at its highest position for about 30 minutes.

Open the discharge valve (**4** in Figure 14), open the flange clamp, pull out the cryoprobe, insert the BHK head, fix it with the flange clamp, and close the gas discharge valve (**4** in Figure 14) of the Dewar.

Do not heat the cryoprobe during the warm up procedure! Warm up the cryoprobe slowly in order to reduce the formation of frost and water caused by melting frost. Heating of the cryoprobe causes worse problems than condensed water.

7 Instructions for operation the system with a cryocooler (LHe free version)

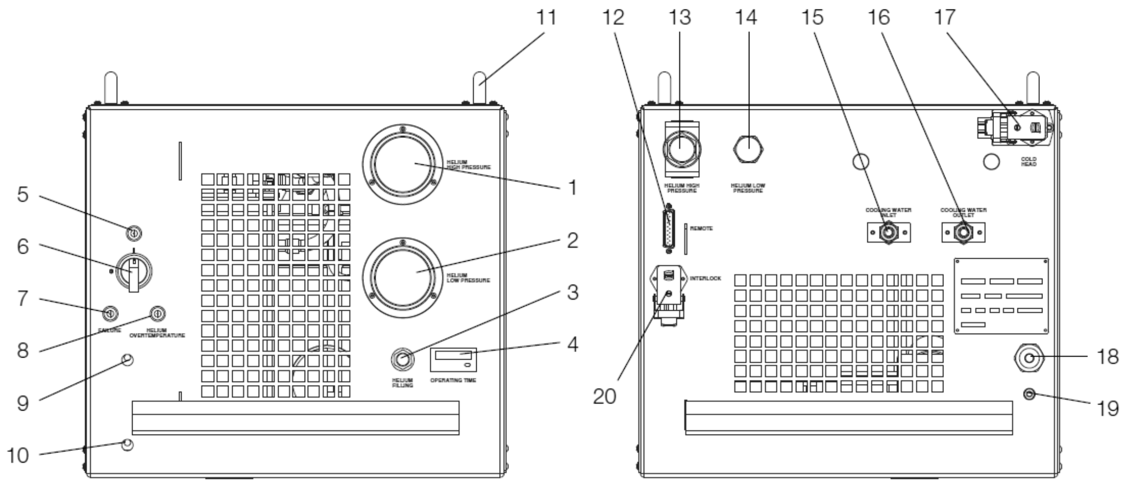
7.1 The basic system by operation with a cryocooler

1. 19“ rack with **cryocooler** and integrated **Josephson voltage standard circuit**
2. **JVS Electronics Unit**
3. **Microwave source locking counter**
4. **Nanovoltmeter**
5. **Polarity reversal switch**
6. **Sensors** for humidity, pressure and temperature
7. **Computer**
8. **Compressor**

Figure 15: Cryocooler-based Josephson voltage standard system ”SupraVOLTcontrol”.

The cryocooler system, see Figure 15, consists of some additional components compared to the liquid helium based system. These components are:

- The cryocooler itself for cooling down the Josephson voltage standard array to its operation temperature below 4.2 K. For explanations, see the attached cryocooler manual.
- A compressor unit, see schematic of Figure 16. For explanations please refer also the attached compressor manual.
- A rotary valve to establish a cycling change in the helium gas pressure, see Figure 17.
- The Toshiba frequency converter to run the rotary valve of the cryocooler, see Figure 17.
- A vacuum pump with valve and pressure sensor to evacuate the cryocooler chamber, see Figure 17. The manual of the pump is attached.



Pos.	name	Comment
1	Pressure gauge 1	Pressure in the helium high-pressure side of the compressor
2	Pressure gauge 2	Pressure in the helium low-pressure side of the compressor
3	Helium top-up fitting	For draining and topping up helium
4	Elapsed hours meter	
5	Mains control	
6	Mains switch	Connects / disconnects the compressor to the mains voltage
7	Error display	
8	Overtemperature	
9	Reset low pressure	
10	Reset high pressure	
11	Eyebolt	
12	Remote interface	
13	Helium high-pressure fitting	Marked with a red dot
14	Helium low-pressure fitting	Marked with a green dot
15	Cooling water inlet	Do not restrict the cooling water flow at the inlet (Water cooled version only)
16	Cooling water outlet	Restrict here to set the cooling water flow (Water cooled version only)
17	Electrical connection for the cold head	
18	Cable duct	for the mains cable
19	Ground connection	
20	Interlock interface	

Figure 16: Compressor CP2000, connections and operator controls with explanations

7.2 Instructions for cooling down the cryocooler

Before you can start the cool down process, connect the cryocooler components as shown in Figure 17 and follow the instructions below.

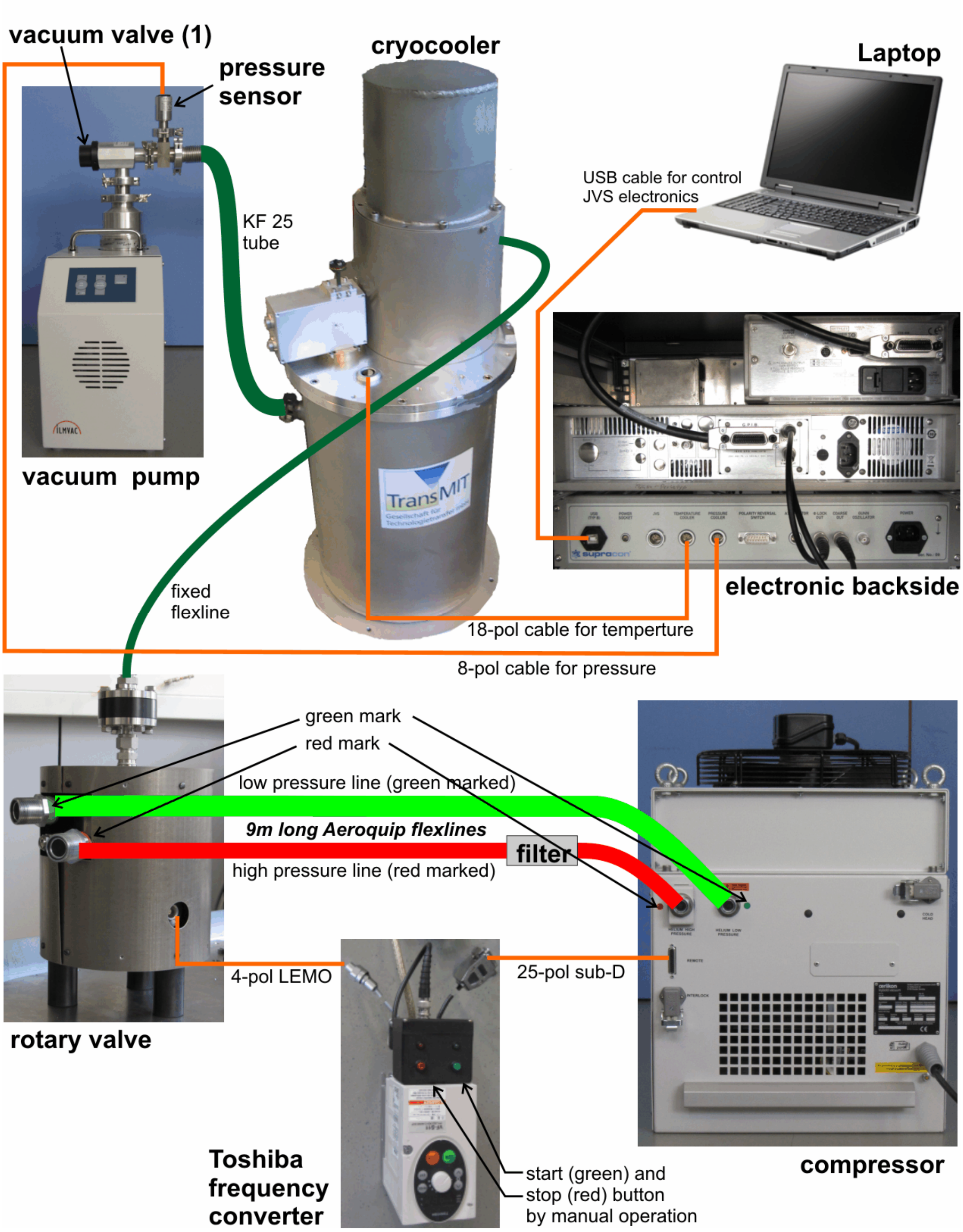


Figure 17: The interconnections of the cryocooler components.

Note: Before starting the cool down process, the cryocooler chamber must be evacuated! (see description below)

1. Monitoring temperature and pressure of the cryocooler

1.1 Switch on Laptop and control electronics unit and connect the temperature and pressure cables, as well as the USB cable to the computer, see Figure 17.

1.2 Start the software tool "**supra*VOLT*control**" (The program is located in the folder C:\program\supravoltcontrol). Choose on the menu bar "Performance tests" and select the item "Temperature/Pressure_Cooler".

1.3 A window appears which monitors the actual temperature and pressure of the sensors.

2. Evacuate the vacuum chamber of the cryocooler

2.1 **Precondition:** The vacuum pump must be already connected to the cryocooler chamber by means of the flexible KF25 metal tube and the vacuum valve (1) must be closed.

2.2 Starting the vacuum pump.

2.3 After 10 minutes open the vacuum valve (1) carefully, see Figure 17
Note: Open the vacuum valve only if the cryocooler is at room temperature (>280K)!

2.4 Pump the cooler chamber for several hours.

2.5 If the pressure is below 2×10^{-4} mbar **close the vacuum valve (1).**

2.6 Switch off vacuum pump.

3. Start cool down process of the cryocooler

3.1 Connect the compressor CP2000 to the rotary valve by means of the Aeroquip flexlines as shown in Figure 17. The filter cartridge with Aeroquip connectors should be connected to the high-pressure outlet at the compressor.

The connectors at the rotary valve are labelled with "**high pressure" (red marker)** and **"low pressure" (green marker)**. The same markers are also shown at the compressor. The Aeroquip flexlines must be attached in the order red to "high pressure" and green to "low pressure". **Pay attention to a proper connection of the Aeroquip flexlines!**

After the installation of the flexlines the pressure gauge at the compressor front panel should indicate about **16 bar**.

3.2 The Toshiba frequency converter must be connected to the rotary valve motor via the delivered power cable with the 4-pole-Lemo connector, see Figure 17. Connect the Toshiba frequency converter to the remote connection of the compressor unit via the 25-pin Sub-D cable. Connect the frequency converter to the mains supply.

Note: The display of the Toshiba frequency converter must illuminate and indicate 0.00. (The user manual of the Toshiba frequency converter is provided)

3.3 Start the compressor unit by turning on the mains switch (6), see Figure 16.

Note: The compressor unit starts only, if the 25-pin sub-d connector of the Toshiba frequency converter is connected to the compressor.

At the same time the rotary valve starts running and a periodic sound of compression and expansion is present.

Attention:
In the case the rotary valve does not start running automatically switch off the compressor immediately.
You can start the rotary valve manually by pressing the green button of the Toshiba frequency converter, see Figure 17.

Do not run the rotary valve for an extended period of time without the compressor being turned on. Otherwise the rotary valve heats up, which can lead to a contamination of the working gas and to a degradation of the cooling performance.

The rotary valve can be operated for a short period of time without the compressor being turned on. For this, the frequency converter is equipped with a timer circuit. After starting the timer by pressing the green button, the rotary valve runs for approximately two minutes with the preassigned frequency. Pressing the red button stops the rotary valve immediately.

3.4 Wait about 6 hours to reach the operating temperature below 4.2K. Then the system is ready for operation.

You can save the temperature and pressure data displayed in the diagram of the **supra*VOLT*control** software by selecting the “save” button, please refer to chapter 9.6.

7.3 Instructions for warming up the cryocooler

The shutdown (warming up) of the cryocooler system should be carried out in the following way:

1. **Exit the SupraVOLTcontrol software**

2. **Disconnect the detachable interconnections of the system** (see Figure 23), which are the cables to the microwave components and to the filterbox.

3. **Turn off the compressor unit.**
   The rotary valve stops automatically when the compressor stops.

   Ensure that the rotary valve is no longer running. **The display of the Toshiba frequency converter should indicate “0.00”.** (If not, stop the rotary valve manually by pressing the red button of the Toshiba frequency converter).
   (The frequency converter stops automatically when the frequency converter is connected to the remote connection of the CP2000A compressor.)

   Do not disconnect the Aeroquip flexlines between the compressor and the rotary valve when the cooler is cold! **Otherwise a dangerous overpressure will build up in the cryocooler upon warming!** - There is a pressure safety valve at the rotary valve that opens at a pressure of 30-32 bar.

4. **Switch off the control electronic unit**

5. **Let the system warm up to room temperature (290 K) for at least 40 hours.**

7.4 Temperature of the different stages of the cryocooler

For diagnostics, it can be helpful to determine the temperature of the different stages of the cryocooler. Three temperature sensors are installed in the cryocooler, one is located at the chip stage, one at the first stage and the third at the pulse tube. Their typical temperatures are:

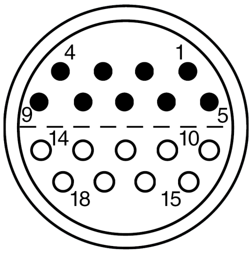
	Location	Type of sensor	Temperature	Calibrated T-R-curve
A)	Chip stage	TVO	≈ 4 K	see cooler manual
B)	First stage	PT100	≈ 55 K	see cooler manual
C)	Pulse tube	PT100	≈ 85 K	see cooler manual

By means of measure the resistance of the sensors their temperature can be determined by using the calibrated temperature-resistance dependence (T-R-curve), which can be found in the cooler manual from the TRANSMIT GmbH (Two-stage 4 K pulse tube cooler PTD-4200, User manual), which is enclosed to the system.

<u>Note:</u> The measurement of the resistance of the temperature sensors require a 4-wire method (V+, V-, I+, I-) with a bias current of less than 10µA. By using a standard multimeter typically the highest range (>100kΩ) should be used. If the bias current is too high, the temperature is increasing due to the self-heating effect.

Connect the provided 18 pin LEMO – banana plug – cable from the cryocooler connector to the multimeter according the pin assignment of Figure 18 and measure the resistance of the temperature sensors.

18-pole LEMO Connector Pins at the cryocooler



● Male connector ○ Female connector

Pin	Location	Banana plug	Label	Wiring
1		Red	1 I +	Manganin 0.10 mm
2	Cold platform	Red	1 V +	Manganin 0.10 mm
3	1st stage	Blue	1 V –	Manganin 0.10 mm
4	(Pt100)	Blue	1 I –	Manganin 0.10 mm
5		Red	2 I +	Manganin 0.10 mm
6	Middle of PT 2	Red	2 V +	Manganin 0.10 mm
7	(PT100)	Blue	2 V –	Manganin 0.10 mm
8		Blue	2 I –	Manganin 0.10 mm
9		Red	3 I +	Manganin 0.10 mm
10	Chip stage	Red	3 V +	Manganin 0.10 mm
11	(TVO SN 7595)	Blue	3 V –	Manganin 0.10 mm
12		Blue	3 I –	Manganin 0.10 mm
13	Heater	Red	4 I +	Copper 0.13 mm
14	Chip stage	Red	4 V +	Manganin 0.10 mm
15	(100 Ω)	Blue	4 V –	Manganin 0.10 mm
16		Blue	4 I –	Copper 0.13 mm
17	Heater 1st stage	Black		Copper 0.20 mm
18	(100 Ω)	Black		Copper 0.20 mm

Figure 18: Pin assignment of the 18-pin LEMO connector of the cryocooler for temperature readout.

7.5 Maintenance the cryocooler

In general after **18000 hours** of operation the system should be maintenance by Supracon.
In the case the temperature of the cryocooler increases during time a refilling of the helium gas or a cleaning of the helium gas becomes necessary. For this please refer the paragraphs 7.5.4 and 7.5.5 of this chapter.

7.5.1 Compressor

An adsorber in the compressor removes oil vapour, hydrocarbons, water vapour, and other residual gases from the helium working gas. Contamination of the helium gas can lead to a severe degradation of the cooling performance, because of the freezing of contaminant gases in the cold head. For maintenance or replacement of the adsorber please refer to the manual of the compressor. For a CP 2000A compressor the maintenance interval is about **18000 hours** of operation.

7.5.2 Cold head of the cryocooler

There are no parts inside the cold head that need regular maintenance. After about **18000 hours** of operation the rotor of the rotary valve should be replaced. Please contact Supracon.

7.5.3 Molecular sieve filter

Upon maintenance of the compressor it is recommended to re-activate the filter cartridge that is attached to the high-pressure line of the CP 2000A compressor. We advise to reactivate the filters in an interval of about **18000 hours**. Please contact Supracon.

7.5.4 Refilling the helium gas

In the case the helium pressure gauges at the compressor show lower pressure than 15.5 bar we advise to refill some amount of pure helium gas (Helium 5.0 = 99.999% purity). A typical time interval of refilling is about **two years**. Please use the attached accessories (pressure reducer, 6mm copper tube, 19 mm Aeroquip connector (wrench size 19mm) and Aeroquip discharge plug) and follow the instructions below.

1. Connect the pressure reducer to a Helium gas bottle with **He 5.0 or higher purity**. The main valve of the helium gas bottle and the pressure reducer valve must be closed.
2. Connect the 6mm cooper tube to the pressure reducer and the other side to the small Aeroquip connector (wrench size 14mm and 19mm) as seen in Figure 19.
3. Open the main valve of the Helium gas bottle, and tune the adjusting valve of the pressure reducer to a pressure of about 5 bar.
4. Carefully screw the Aeroquip discharge plug into the Aeroquip connector **for purging** the copper tube with pure helium. Then disconnect the discharge plug.
5. Connect the Aeroquip connector with the copper tube to the “Helium top-up fitting” of the compressor; see Figure 16 by using a 19mm wrench.
6. Fill the compressor and the connected cryocooler with 16 bar of pure helium by using the adjusting valve of the pressure reducer. Then close the valve of the pressure reducer.
7. Unscrew the Aeroquip connector with the copper tube (wrench size 19mm) from the compressor. Close all valves.

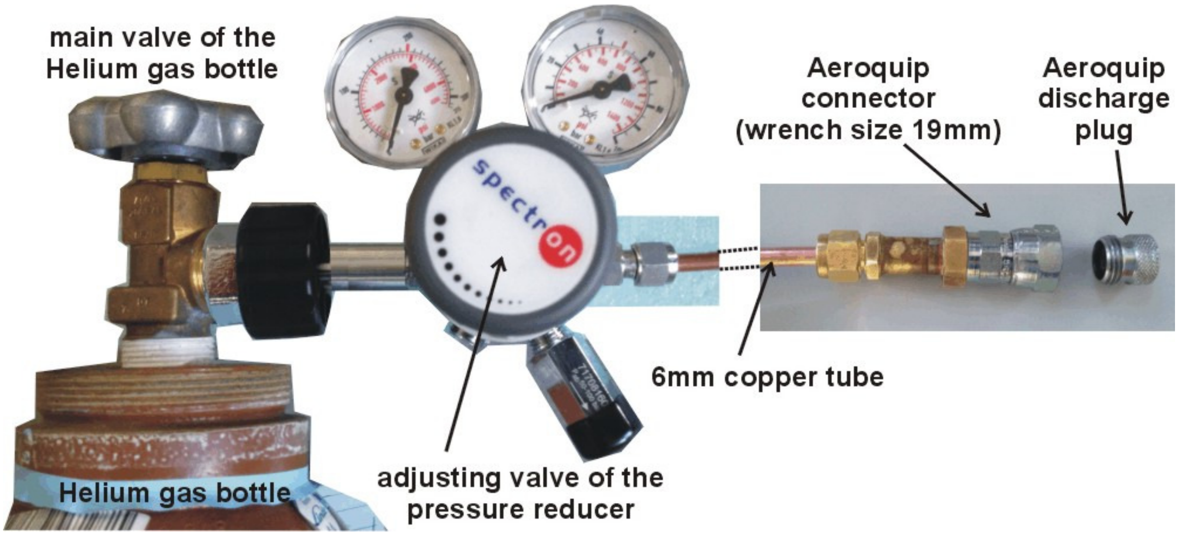


Figure 19: Accessories for refilling helium gas to the compressor

7.5.5 Cleaning the helium gas

In the case the operating temperature of the cryocooler does not reach a temperature below 4.2 K, a purification of the working helium gas is necessary. Please check the helium pressure gauges at the compressor before (see chapter 7.5.4). A typical time interval for purification the helium gas is about **5000 hours** of operation (about **15 cool down cycles** of the cryocooler).

Attention: Please use for the exchange of the working gas only pure helium with a purity of better than 99.999% (5.0er helium) which is delivered in a compressed gas cylinder. (By using a 10 litre gas cylinder the helium pressure must be higher than 50 bar).

Please follow the instruction below.

User instructions

A) Complete cleaning the working gas (5.0 helium) in the cryocooler and the compressor

1. Make sure that all three valves of the pump- and purge-unit are closed.
2. Warm up the cryocooler to room temperature; then disconnect the two flexlines from the rotary valve of the cryocooler.
3. Connect the two Aeroquip connectors labelled “rotary valve” (see Figure 20) of the pump- and purge-unit to the rotary valve of **the cryocooler**.
4. Connect the two Aeroquip connectors labelled “flexlines” (see Figure 20) of the pump- and purge-unit to the **two flexlines (including the compressor)**.
5. Connect a vacuum pump to valve no. 3 (labelled “KF25 vacuum connector”, see Figure 20) by using the accessory 1m long KF25-metal-tube.
6. Open the vacuum valve and start the vacuum pump.
   Monitor the pressure of the pressure sensor by using the supraVOLTcontrol software user interface “Performance tests” -> ”Temperature/Pressure_Cooler”.
7. Connect valve no. 2 (labelled “He 5.0 feed-in”, see Figure 20) to the pressure reducer of a Helium gas bottle (He 5.0 or higher purity) by means of the enclosed 6 mm copper tube. **The valve of the Helium gas cylinder must be closed,** and **the adjusting valve of the pressure reducer must be closed (This valve must be unscrewed)!**
8. Open valve no. 2. (labelled “He 5.0 feed-in”)

9. Use valve no. 1 (labelled “emptying”, see Figure 20) to discharge the component connected to the pump-and purge-unit to about 3 bar.
   During discharge **start the rotary valve** by the Toshiba frequency converter (manual operation) **for a short period** (several seconds). (The green button of the Toshiba frequency converter starts the rotary valve and the red button stops it, compare Figure 17). Stop the rotary valve by using the red button of the Toshiba frequency converter.
   Further discharge the pump-and purge-unit to a pressure of about **1 bar (2 bar absolute pressure,** the pressure gauge of the pump- and purge-unit shows relative pressure**)**. Then close the valve no. 1.

   Note: The frequency converter and / or the motor can take damage, if the rotary valve runs at lower pressure than 0.2 bar (1.2 bar absolute pressure)! The display of the frequency converter should indicate “0.00” (rotary valve stopped).

10. Further discharge the pump-and purge-unit to a pressure of 0.1 bar (1.1 bar absolute pressure) by using valve no. 1 (labelled “emptying”). Then close valve no. 1.

11. Evacuate the pump-and purge-unit and the connected components by opening valve no. 3 carefully.
    Avoid an overload of the vacuum pump (the turbo pump speed down, which is acoustic audible) by means of a step by step opening of the valve no. 3. Just open the valve no. 3 to such a point, when the pressure (displayed on the computer) starts to increase. If the pressure starts decreasing again, continue opening valve no. 3 by a certain amount. These steps have to be repeated several times till valve no. 3 is completely open.

    Sometimes it can happen that the pressure sensor displays “**out of range**”. In such a case wait till the pressure sensor gives a number again, than continue with the stepwise opening of valve no. 3.

12. Open valve no. 3 completely and evacuate the pump-and purge unit to a pressure **below 5×10^{-4} mbar. (This takes several hours).** Then continue with pumping for an additional half hour. Check the pressure with the connected sensor by using the software tool “Performance test” -> “Temperature/Pressure_Cooler”, see chapter 9.6.

13. Close valve no. 3.

14. Close valve no. 2, then open the adjusting valve of the pressure reducer at the helium gas cylinder to pressurise the 6 mm copper tube.
    Note: Check the two pressure gauges of the pressure reducer. One gauge shows the pressure of the compressed gas cylinder, the other the pressure at the outlet of the pressure reducer. (The main valve of the compressed gas cylinder must be opened before). By using the adjusting valve of the pressure reducer the pressure in the copper tube can be tuned; adjust about 3 or 4 bar at the gauge output of the pressure reducer.

15. Open valve no. 2 carefully and fill the pump-and purge unit **slowly** (in several minutes) with 3-4 bar of helium 5.0. Then turn on the rotary valve for about 1 minute, then turn off the rotary valve.
    Close valve no. 2.

16. **Repeat sub steps 9. - 15. four times.**

17. Switch off vacuum pump.

18. **Slowly fill the cooler and the compressor with 16 bar of He 5.0** by carefully opening of valve no. 2 and adjust a pressure of 16 bar by means of the adjusting valve of the pressure reducer. **The time for filling should be longer than 5 minutes.**

19. **Close** valve no. 2, **close** the adjusting valve of the pressure reducer, and **close** the main valve of the compressed gas cylinder.

20. **Detach the pump- and purge-unit and connect both flexlines to the rotary valve** (they must be attached in the order red to “high pressure” and green to “low pressure”, see Figure 17.

21. **Reset the compressor** by pressing the button “Reset low pressure” and “Reset high pressure”, refer Figure 16.

    Now the cryocooler and the compressor are cleaned completely.

B) More effective cleaning the working gas (Helium 5.0) by a separate cleaning of cryocooler, compressor with Aeroquip-flexlines and filter in 4 steps (B1-B4).

(B1) Effective cleaning the working gas (Helium 5.0) only in the cryocooler by using the "cryopump effect" (without cleaning the compressor)

1. Cool down the pulse tube cooler to minimum temperature.
   Make sure that all three valves of the pump- and purge-unit are closed.

2. Turn off the compressor. Ensure that the rotary valve is no longer running. (Otherwise turn off the Toshiba frequency converter manually) The display of the frequency converter should indicate "0.00". (The frequency converter will stop automatically when the frequency converter is connected to the remote 25-pole sub-D connection of the compressor.)

3. **Directly after sub step 2!,** detach both flexlines and connect **immediately** the pump- and purge-unit by connecting the two Aeroquip connectors labelled "rotary valve" (see Figure 20) of the pump- and purge-unit to the rotary valve of the cryocooler. (**All three valves of the pump- and purge-unit must be closed**)

   Because of the "cryopump effect" most of the "contaminations" in the working gas are trapped in the cold stage of the cryocooler and not in the detached compressor.

4. Use valve no. 1 (labelled "emptying", see Figure 20) to discharge the cryocooler to a pressure of about 3 bar (4 bar absolute pressure). The pressure gauge of the pump- and purge-unit shows relative pressure.

   Note: A dangerous overpressure will build up in the cold head upon warming with the compressor detached! Therefore sub steps 3 and 4 have to be completed within a few minutes! After discharging the cooler to a pressure of about 3 bar no dangerous overpressure can build up upon warming to room temperature.

5. Let warm up the cryocooler to room temperature. (It takes about 40 hours).

6. Connect a vacuum pump to valve no. 3 (labelled "KF25 vacuum connector", see Figure 20) by using the accessory 1m long KF25-metal-tube.

   Open the vacuum valve and start the vacuum pump.

   Monitor the pressure of the pressure sensor by using the supraVOLTcontrol software user interface "Performance tests" > "Temperature/Pressure_Cooler".

7. Connect valve no. 2 (labelled "He 5.0 feed-in", see Figure 20) to the pressure reducer of a Helium gas bottle (He 5.0 or higher purity) by means of the enclosed 6 mm copper tube. **The valve of the helium gas cylinder and the adjusting valve of the pressure reducer must be closed! (The pressure reducer valve must be unscrewed)!**

8. Open valve no. 2 (labelled "He 5.0 feed in").

9. Use valve no. 1 (labelled "emptying", see Figure 20) to discharge the cryocooler to about 3 bar.
   During discharge **start the rotary valve** by the Toshiba frequency converter (manual operation) **for several seconds**. (The green button on the Toshiba frequency converter starts the rotary valve and the red button stops it, compare Figure 17). Stop the rotary valve by using the red button at the Toshiba frequency converter.

   Further discharge the cryocooler to a pressure of about 1 bar (2 bar absolute pressure, the pressure gauge of the pump- and purge-unit shows relative pressure). Then close the valve no. 1.

   Note: The frequency converter and / or the motor can take damage, if the rotary valve runs at lower pressure than 0.2 bar (1.2 bar absolute pressure)! The display of the frequency converter should indicate "0.00" (rotary valve stopped).

10. Use valve no. 1 (labelled "emptying", see Figure 20) to discharge the cryocooler to a pressure of 0.1 bar (1.1 bar absolute pressure). The pressure gauge of the pump- and purge-unit shows relative pressure. Then close valve no. 1.

11. Evacuate the cryocooler by opening valve no. 3 carefully.

    Avoid an overload of the vacuum pump (the turbo pump speed down, which is acoustic audible) by means of a step by step opening of the valve no. 3. Just open the valve no. 3 to such a point, when the pressure (displayed on the computer) starts to increase. If the pressure begins to decrease again continue opening valve no. 3 by a certain amount. These steps have to be repeated several times till valve no. 3 is completely open.

    Sometimes it can happen that the pressure sensor displays "**out of range**". In such a case wait till the pressure sensor gives a number again, than continue with the stepwise opening of valve no. 3.

12. Open valve no. 3 completely and evacuate the cooler to a pressure **below 5×10^{-4} mbar**, this takes several hours. Then continue pumping for an additional half hour. Check the pressure with the connected sensor by using the Software "Performance test" -> "Temperature/Pressure_Cooler", see chapter 9.6.

13. Close valve no. 3.

14. Close valve no. 2, then open the adjusting valve of the pressure reducer at the compressed helium gas cylinder to pressurise the copper tube.

    Note: Check the two pressure gauges of the pressure reducer. One gauge shows the pressure of the compressed gas cylinder, the other the pressure at the outlet of the pressure reducer. (The main valve of the compressed gas cylinder must be opened before). By using the adjusting valve of the pressure reducer the pressure at the connected copper tube can be tuned; adjust about 3 or 4 bar at the gauge output of the pressure reducer.

15. Open valve no. 2 carefully and fill the cooler **slowly** (several minutes) with 3-4 bar of He 5.0. Then turn on the rotary valve for about 1 minute and then turn off the rotary valve (manual operation of the Toshiba frequency converter).
    Close valve no. 2.

16. **Repeat sub steps 9. - 15. four times.**

17. Switch off vacuum pump.

18. **Slowly fill the cryocooler with 16 bar of He 5.0** by opening valve no. 2 carefully and adjust a pressure of 16 bar by means of the adjusting valve of the pressure reducer.
    The time for filling should be longer than 5 minutes.

19. **Close** valve no. 2, **close** the adjusting valve of the pressure reducer, and **close** the main valve of the compressed gas cylinder.

20. Detach the pump- and purge-unit.

    The cleaning of the cryocooler is completed.

(B2) Cleaning the working gas (Helium 5.0) only in the compressor

1. Make sure that all three valves of the pump- and purge-unit are closed.
2. Be sure the cryocooler is at room temperature; disconnect the two flexlines from the rotary valve of the cooler.
3. Disconnect the filter cartridge (both Aeroquip connectors) from the high-pressure-flexline and connect the high pressure-flexline directly to the compressor
4. Connect only the two Aeroquip connectors labelled "flexlines" (see Figure 20) of the pump- and purge-unit to the two flexlines.
5. Continue with **steps 5. till 15.** as described in **part (A)** of this chapter . But **do not run the rotary valve**!
6. **Switch off** vacuum pump,
   Close valve no. 2, **close** the adjusting valve of the pressure reducer, and **close** the main valve of the compressed gas cylinder.
   Detach the pump- and purge-unit.

After performing these steps the **compressor and the flexlines** are cleaned completely and filled with pure Helium at a pressure of about 3-4 bar.

(B3) Cleaning the working gas (Helium 5.0) only in the filter

1. Make sure that all three valves of the pump- and purge-unit are closed.
2. Be sure the cryocooler is at room temperature; disconnect the two flexlines from the rotary valve of the cryocooler.
3. Disconnect the filter cartridge from the high-pressure-flexline (both Aeroquip connectors)
4. Connect only one Aeroquip connector labelled "flexlines" (see Figure 20) of the pump- and purge-unit to one Aeroquip connector of the filter cartridge.
5. Continue with **steps 5. till 15.** as described in **part (A)** of this chapter. But **do not run the rotary valve**!
6. **Switch off** vacuum pump,
Close valve no. 2, **close** the adjusting valve of the pressure reducer, and **close** the main valve of the compressed gas cylinder.
Detach the pump- and purge-unit.

After performing these steps the **filter cartridge** is cleaned completely and filled with pure Helium at a pressure of about 3-4 bar.
The cleaning of the filter is even more effective, if you heat up the filter cartridge (max. 80℃).

(B4) Final cleaning of all components

1. Connect the filter cartridge again between the high pressure flexline and the compressor. Connect the low pressure flexline to the compressor.
2. Follow the instructions as described in part (A) of this chapter, but skip point no. 16. (one time cleaning will be enough in this case)

Now the cooler and the compressor and the filter are cleaned more efficiently!

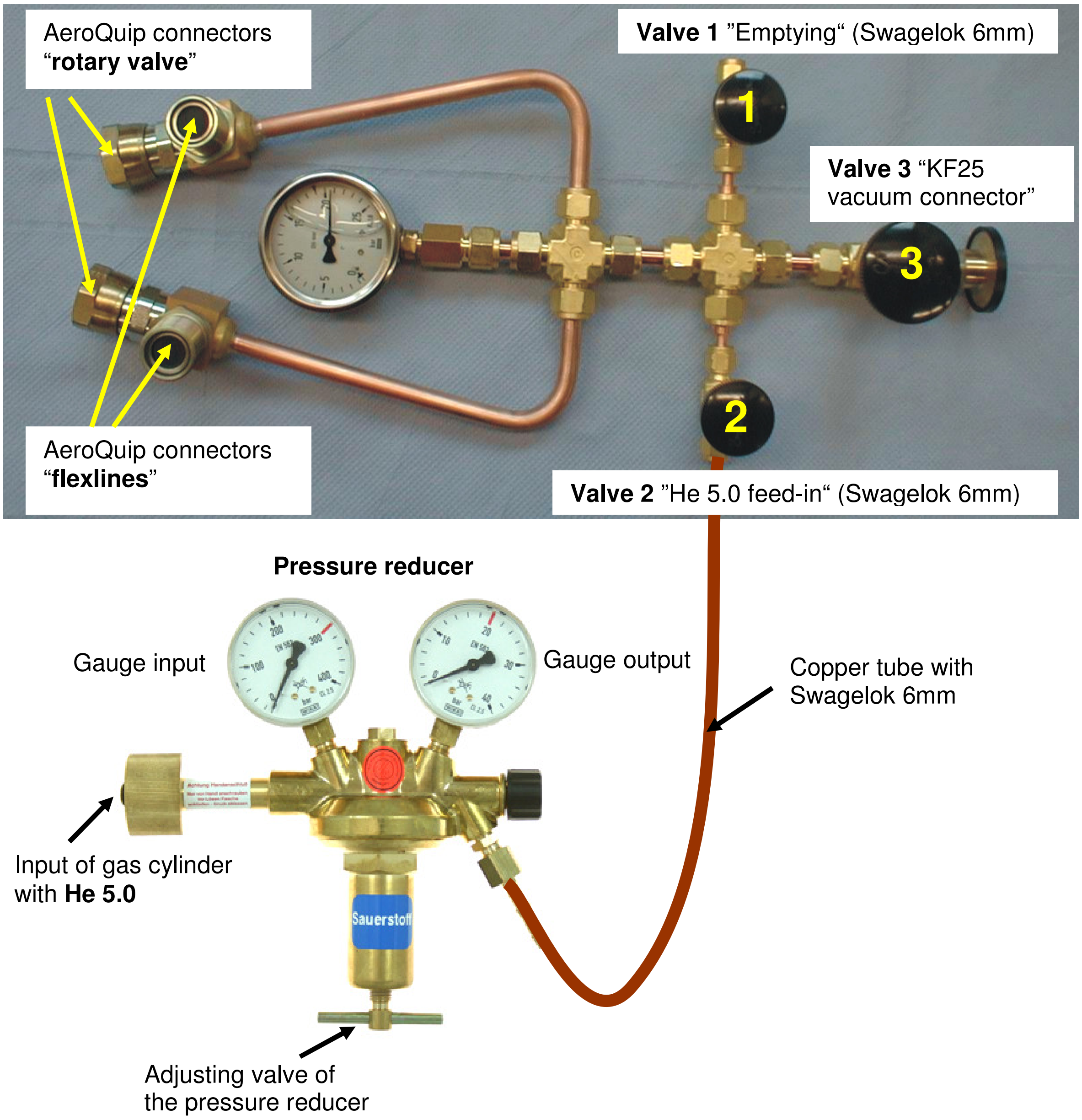


Figure 20: Pump- and Purge-Unit for Cryocooler and Helium-Compressor

8 System Operation

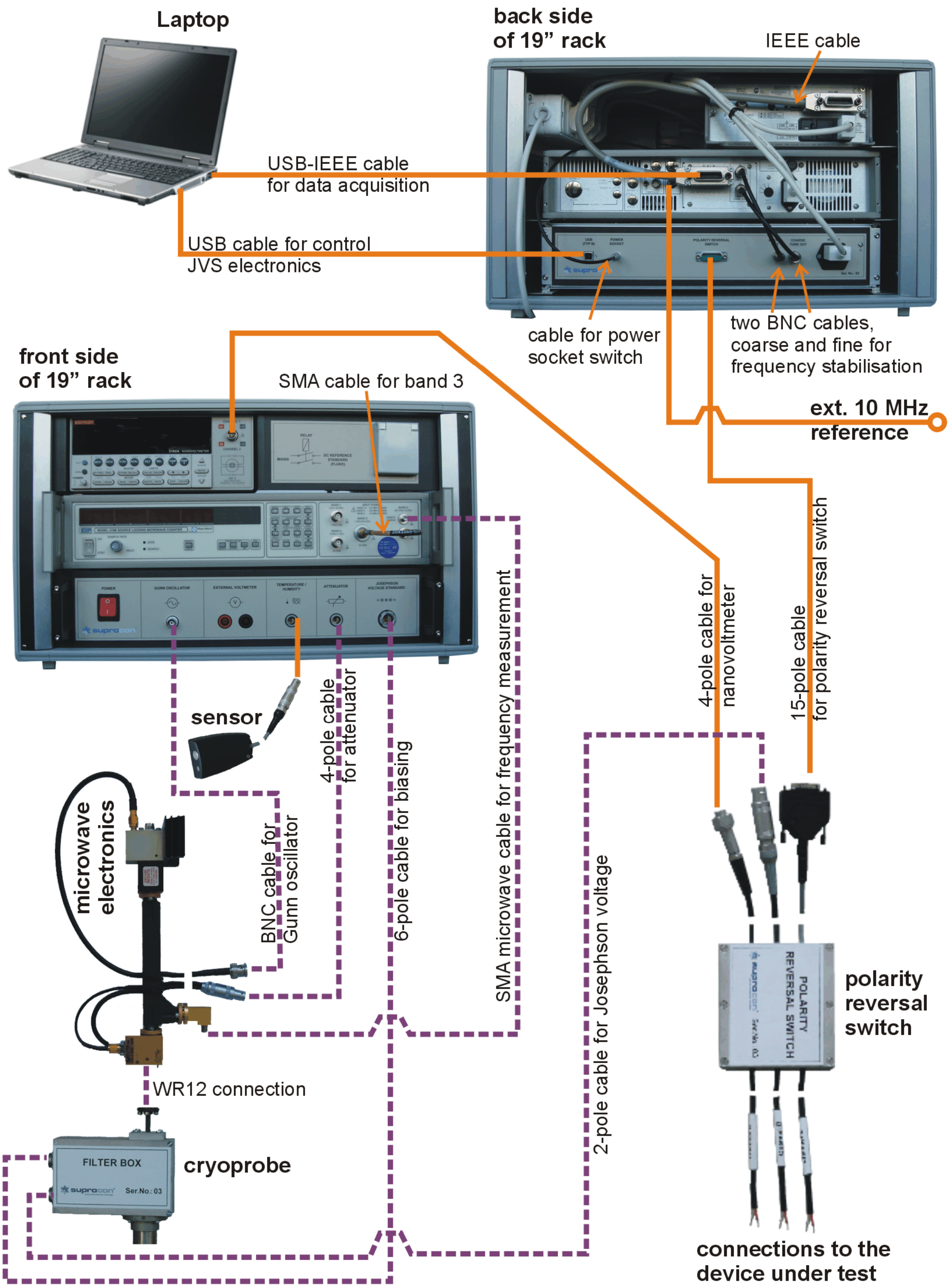
8.1 System installation

8.1.1 Installation step by step – liquid helium version (LHe)

1. Connect only the fixed interconnections of the **supra*VOLT*control** system as shown in Figure 21.
2. Switch on the laptop, JVS electronics unit, EIP source locking microwave counter, and the Keithley nanovoltmeter.
3. Cool down the cryoprobe as described in chapter 6.2.2, taking at least 40 minutes.
4. Be sure that you have connected the 10 MHz reference frequency to the J5 BNC socket, 10 MHz TIME BASE, on the rear panel of the EIP source locking microwave counter and the corresponding switch is set to the EXT. position.
5. Fix the 75 GHz microwave electronics at the microwave flange of the cryoprobe by using the 4 socket screws. Tighten them with the hex-wrench delivered with the system, be careful not to over tighten. The maximum torque used should be no more than about 0.1 Nm.
6. Connect the detachable interconnections of the filterbox of the cryoprobe and the microwave electronics to the JVS electronics unit, the EIP source locking microwave counter, and the polarity reversal switch as shown in Figure 21.
7. Start the program **supra*VOLT*control** and the user interface seen in Figure 22 appears.
8. Let the system electronics warm up for at least 2 hours.
9. The system is now ready for operation and you can start to perform calibration.

After starting the **supra*VOLT*control** program the user interface shown in Figure 22 appears on the display of the host computer. With a mouse click on the menu bar at the top, or on a soft key top left, you can choose the desired function. The functions will be explained in the following chapters. On the status bar at the bottom are shown the date and time, the number of the installed JJ array chip, and several messages concerning the operation status. One of the soft LED`s on the status bar at the bottom right shines green if all is okay or it shines red if a failure exists, for instance during a calibration procedure.
The serial interface, the chip number, and the loaded files are shown in the “Setup” window. The crucial circuit parameters are shown in the window “Circuit Parameter”. Changes should be done only by expert users. In this case the expert user clicks on the “Expert” button and inserts the correct password.

With a click on the Exit soft key, or the cross soft key on the menu bar, you can close the **supra*VOLT*control** program.



Fixed interconnections made by installation of the supraVOLTcontrol system.

Detachable interconnections which must be disconnected when cooling down and warming up the cryoprobe with the 10 V JJ array chip.

Figure 21: The interconnections of the **supra*VOLT*control** system by using liquid helium (LHe).

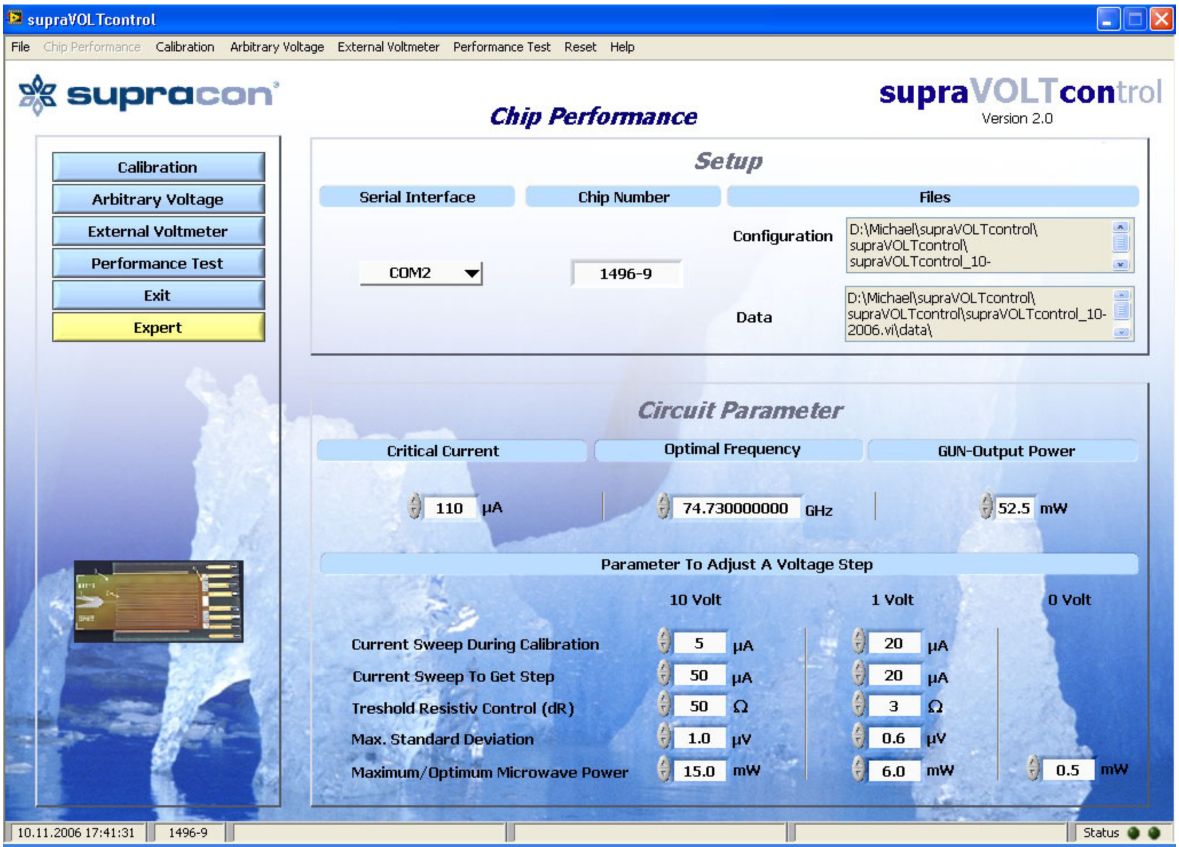


Figure 22: User interface → Chip Performance.

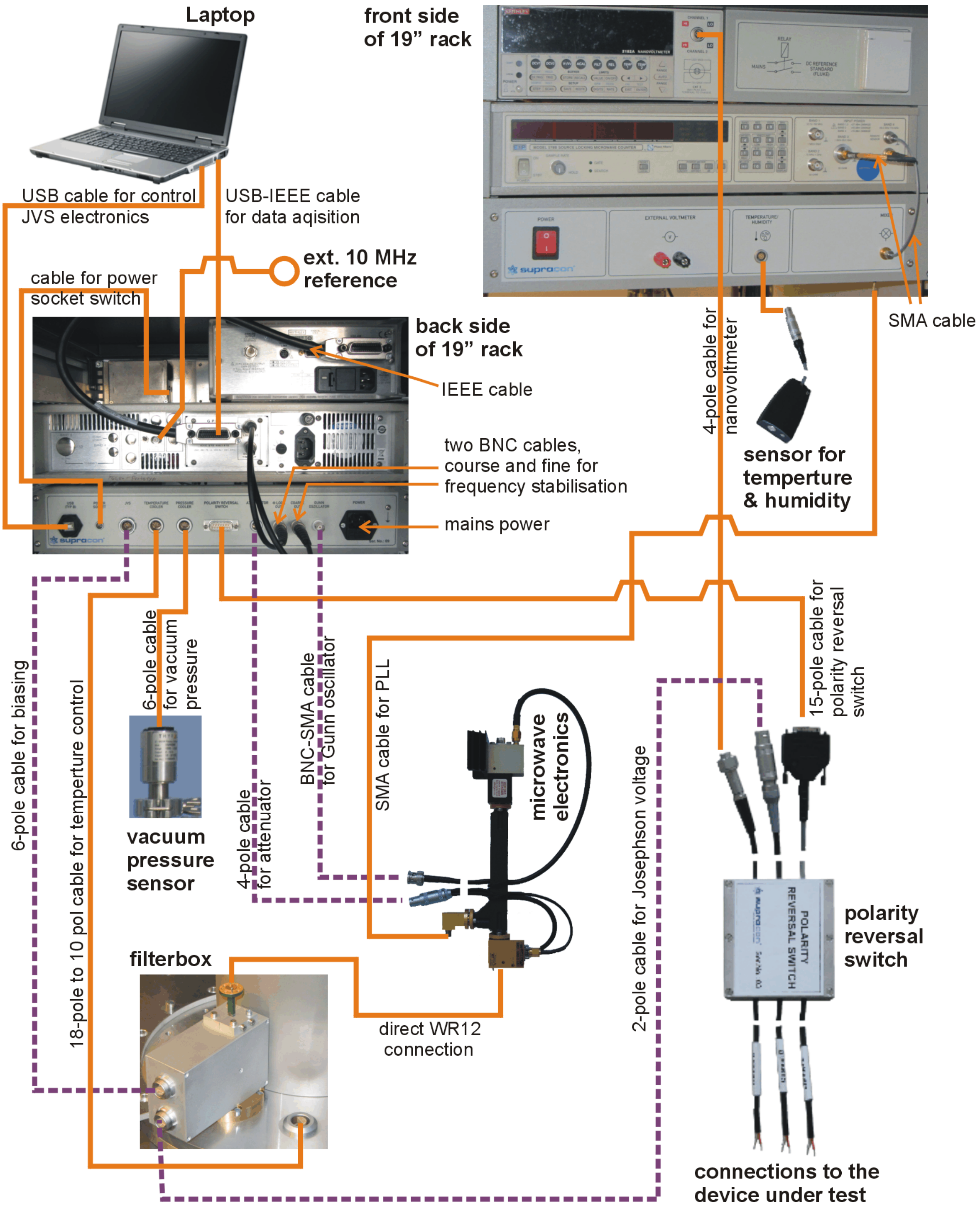
In order to shut down the **supraVOLTcontrol** system close the program with the “exit” button, disconnect the detachable connections and warm up the cryoprobe as described in chapter 6.2.3. **Do not heat the cryoprobe during warming up!** Warm up the cryoprobe slowly in order to avoid or reduce the formation of frost and water caused by melting frost. Heating of the cryoprobe causes worse problems than condensed water.
Switch off the Laptop, JVS electronics unit, EIP source locking microwave counter, and Keithley nanovoltmeter.

8.1.2 Installation step by step – cryocooler version

Before the Josephson voltage standard setup can be installed the cryocooler must have a temperature below 4.2K. This is the essential precondition.

1. The fixed interconnections of the **supraVOLTcontrol** system must be already connected, see Figure 23.
2. Switch on the Laptop, JVS electronics unit, EIP source locking microwave counter, and the Keithley nanovoltmeter.
3. Be sure that you have connected the 10 MHz reference frequency to the J5 BNC socket, 10 MHz TIME BASE, on the rear panel of the EIP source locking microwave counter and the corresponding switch is set to the EXT position.
4. Connect the detachable interconnections, see Figure 23. That means the Josephson voltage standard array is connected to the polarity reversal switch and the JVS electronics via the filterbox and the microwave electronics unit is connected to the EIP source locking microwave counter and the JVS electronics.

5. Start the program **supraVOLTcontrol** and the user interface seen in Figure 22 appears.
6. Let the system electronics warm up for at least 2 hours. Then the system is ready for operation. For calibration purposes please refer the next chapter 8.2 of this manual.



Fixed interconnections made by installation of the supraVOLTcontrol system.

Detachable interconnections which must be disconnected when cooling down and warming up the cryocooler

Figure 23: The interconnections of the supraVOLTcontrol system by operation with a cryocooler.

8.2 Calibration of secondary voltage standards

The **supra*VOLT*control** system was developed for the calibration of DC voltage standards and external voltmeters in the range from -10 V up to +10 V.

Note: Before starting calibration procedure, check the critical current, see chapter 9.1.

8.2.1 Connection of the device under test (DUT), for example a Fluke 732A

Please note, the connected secondary voltage standard must be floating from ground!

Connect the mains power cable of the secondary voltage standard to the switchable power socket installed in the 19” rack, see Figure 24.
Connect the output voltage of the secondary voltage standard to the cables of the polarity reversal switch, **red insulated wires to HIGH** (positive polarity) **and white insulated wires to LOW**, as shown in Figure 24. Only the connection of channel A to the secondary standard is shown for the sake of clarity. You can connect the channels A, B, and C to the 10 V, 1 V, and 1.018 V output of the 732 A if you would like to calibrate all three voltages, or you can connect the channels A, B, and C to three different secondary voltage standards for calibration.

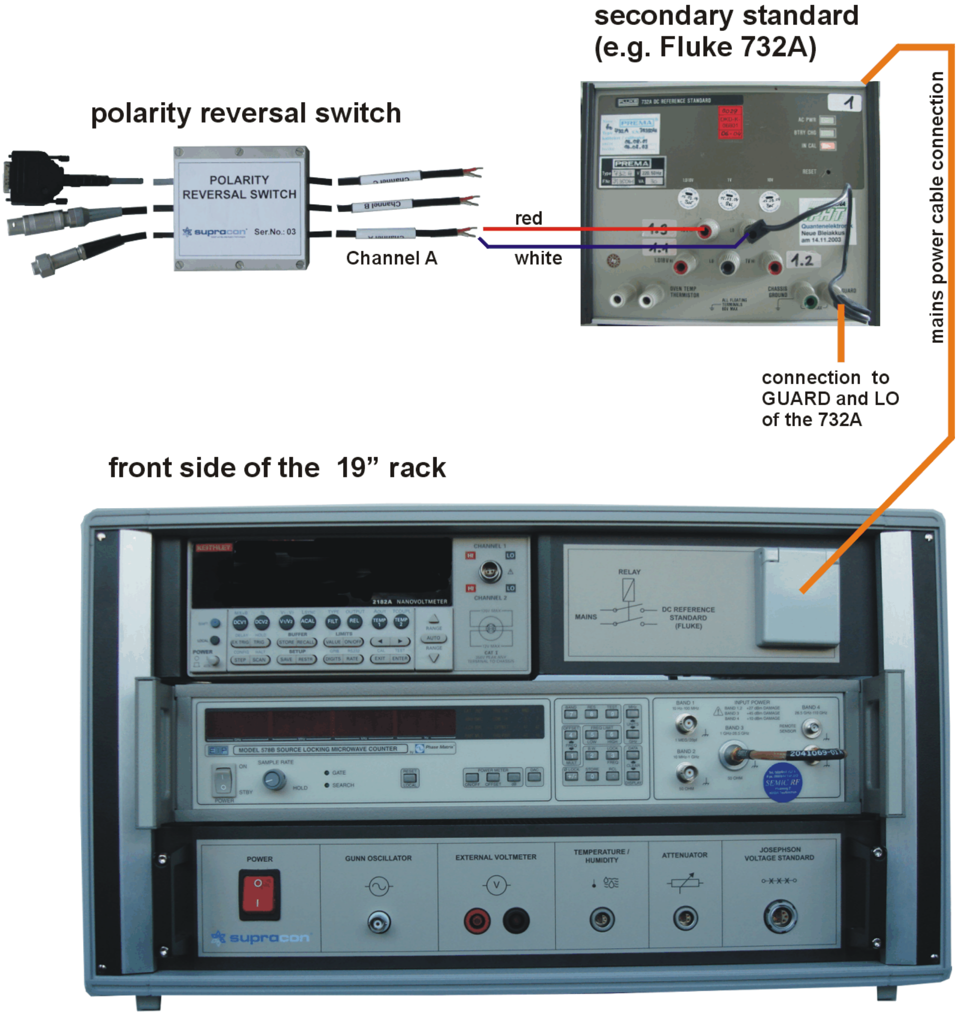


Figure 24: Connection of the secondary voltage standard to be calibrated, for example a Fluke 732A, to the polarity reversal switch. Only the connection of channel A is shown for the sake of clarity.

The insulation resistance of each channel (between the red and white cable and to ground) is dominated by the input resistance of the Keithley nanovoltmeter which is used as the nulldetector. It exceeds 10 GΩ, please see the manual of the Keithley nanovoltmeter 2182A for more information.

For an effective suppression of the noise at the output voltages of the Fluke standard (10 Volt, 1 Volt and 1.018 V) due to interferences in the mains, it is recommend to connect LO to GUARD, as seen in Figure 24.
In some cases it can be that a calibration of a mains operated secondary voltage standard (the DUT) is not possible, because of strong electromagnetic interferences on the mains. Therefore, there is the possibility to disconnect the mains power supply of the DUT during the short time of the calibration measurement, provided that the DUT possesses a battery supply like the Fluke secondary standards. In such a case click the “off” button in the “Mains Voltage” window seen in the user interface of Figure 25.
If you choose the mains power to be off, be aware that the secondary voltage standard is reconnected to the mains power after the calibration measurement. In the case of a computer crash, it can happen that the DUT will be not reconnected to the mains power and its battery can be discharged. If the battery is discharged and if the DUT is a Fluke secondary standard then the red “IN CAL” illumination will go out, and the DUT is out of calibration. This status should be avoided.

8.2.2 Calibration procedure

Connect the secondary voltage standard, for example a Fluke 732A, to the polarity reversal switch as shown in Figure 24 and click on the Calibration soft key, see Figure 22. The picture shown in Figure 25 appears on the display.
The data in the plain blue-coloured window (here top left) must be entered and can be changed by the operator. This applies to all of the following figures.

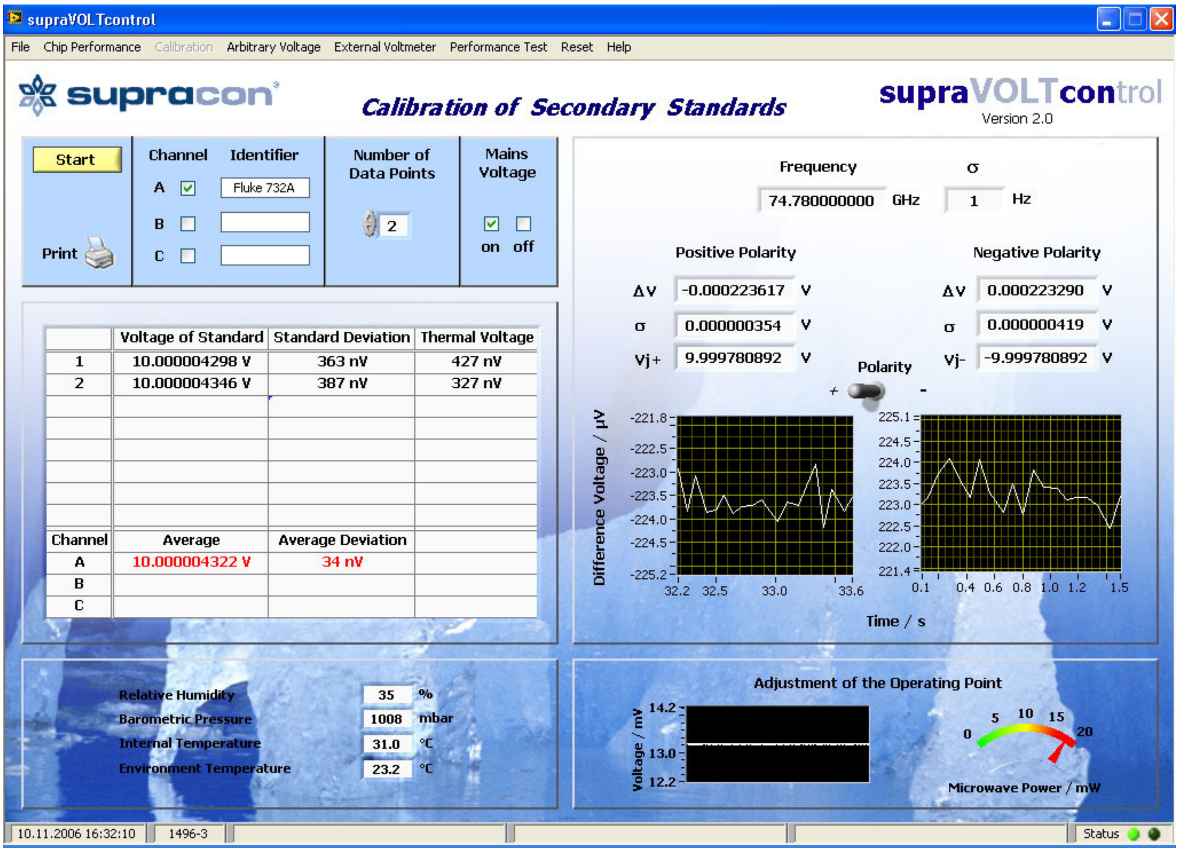


Figure 25: User interface → Calibration of secondary standards.

The operator has to decide if he would like to calibrate one, two or all of the three channels, and he has to enter an identifier for each selected channel. Furthermore, he has to enter the desired number of data points, from a minimum 1 to a maximum 8, and if the mains voltage should be switched on or off during the short time of the calibration measurements.

At top right the mean value of the Gunn oscillator frequency calculated from five measurements is displayed. The frequency of the microwave Gunn oscillator and its standard deviation σ will be measured during each calibration measurement.
In the case when the standard deviation of the Gunn oscillator frequency is higher than 50 Hz the calibration procedure will be aborted automatically and a message is displayed on the status bar. The software automatically searches for a frequency nearby the original one, but with a lower standard deviation, and restarts the calibration procedure.

The readings of the sensors, see chapter 4.8, are shown bottom left.

The adjusted microwave power is indicated bottom right. The graph, at the bottom right, shows the operating point of the JJ array. A stable Shapiro step is generated if the graph shows a straight line like in the indicated graph. If there is no stable Shapiro step the graph shows a signal which is proportional to the 30 Hz triangular bias current.

The two diagrams, middle right, show the readings of the Keithley null detector, one for the positive polarity and the other for the negative one. The null detector measures the difference voltage between the Josephson voltage and the voltage of the secondary standard. If the measured difference voltage is higher than 235 µV the electronics adjust to an adjacent step index n (see eq. 1), where the Josephson voltage will be changed closer to the voltage of the secondary standard, and the difference voltage will be minimised in order to increase the accuracy.

During the measurement of the difference voltage the JVS electronics is completely disconnected from the JJ array chip in order to avoid grounding problems.

In the table, middle left, the calculated data points of the voltage of the secondary standard, their standard deviations, and the thermal voltages are displayed. Each measured data point and its standard deviation is calculated from forty measurements, twenty in the positive and twenty in the negative polarity.
At the bottom of the table (below "Channel") the average value of the data points of the voltage of the secondary standard is given. The corresponding standard deviation is calculated from the data points.

8.2.2.1 Functional principle of the elimination of the thermal voltage V_{th}

Thermal voltages exist in the wires and contacts between the 10 Volt JJ array chip at 4.2 K and the electronics at room temperature. These voltages falsify the calibration measurements and, therefore, must be eliminated. This is done by reversal of the polarity and measuring the voltage of the secondary standard in both, the positive and negative polarity by help of the polarity switch. One measurement point of the voltage of the secondary standard (in the print reports only denoted as measurement), its standard deviation, and the thermal voltage are calculated from twenty single measurements in both polarities.
Figure 26 shows the principle of the measurement of the difference voltage V_{diff+} for a positive adjusted Josephson voltage V_{j+}, and Figure 27 shows the principle of the measurement of the difference voltage V_{diff-} for a negative adjusted Josephson voltage V_{j-}. The pole reversal of the Josephson voltage is made by reversing the bias current polarity and the pole reversal of the second standard is made by the polarity reversal switch. In both cases it is made automatically by the **supra*VOLT*control** system.
The voltage of the secondary standard, e.g. V_{fluke}, and the thermal voltage V_{th} are calculated from the adjusted Josephson voltages V_{j+} and V_{j-}, and the measured difference voltages V_{diff+} and V_{diff-} according to equation 2 and equation 3.

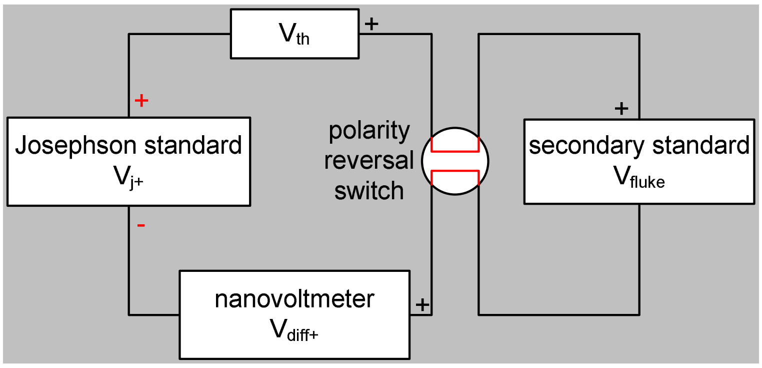


Figure 26: Principle of the measurement of the difference voltage V_{diff+} for a positive Josephson voltage V_{j+} setting.

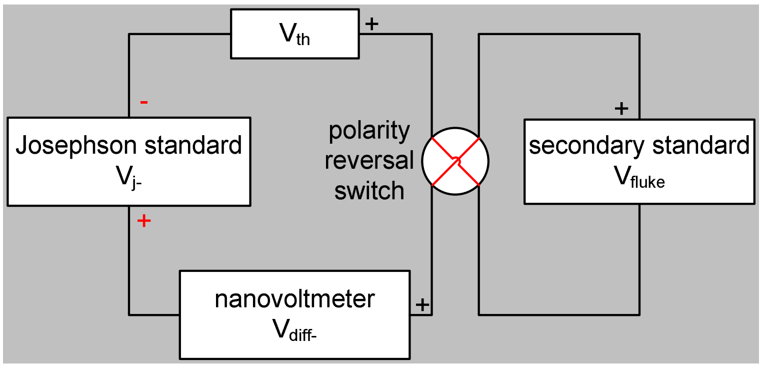


Figure 27: Principle of the measurement of the difference voltage V_{diff-} for a negative Josephson voltage V_{j-} setting.

$$I: \quad V_{j+} = V_{fluke} + V_{diff+} - V_{th}$$
$$II: \quad V_{j-} = V_{fluke} - V_{diff-} + V_{th}$$

$$I + II: \quad V_{j+} + V_{j-} = 2V_{fluke} + V_{diff+} - V_{diff-}$$

$$V_{fluke} = \frac{V_{j+} - V_{diff+} + V_{j-} + V_{diff-}}{2} \qquad \text{eq. (2)}$$

$$I - II: \quad V_{j+} - V_{j-} = V_{diff+} + V_{diff-} - 2V_{th}$$

$$V_{th} = \frac{-V_{j+} + V_{diff+} + V_{j-} + V_{diff-}}{2} \qquad \text{eq. (3)}$$

Analysing equation 2 and 3, the question arises how we determine the Josephson voltage V_{j-} and V_{j+}. These values can be calculated according eq. 1. Of course the step order n must be determined and this is done at the beginning of the calibration procedure by a coarse voltage measurement of the connected secondary voltage standard using the integrated nanovoltmeter. If we know this voltage with a better accuracy than 50 µV, we can calculate the right step order n and with it the Josephson voltage.

To assure an accuracy of the nanovoltmeter better than 50µV at 10 V ($5x10^{-6}$), the nanovoltmeter must be calibrated itself. This must be done with the internal performance test "Calibration nanovoltmeter", see chapter 9.2. Once performed and saved into the software with "*Save to Configuration*", this correction is taken into account. After about a quarter year we advise to repeat this performance test and save it again.

8.2.3 Storage of the results of the secondary voltage standard calibrations

If the calibration procedure is successfully completed the datasets are stored in two different files. One is a Short Test Report file, see Figure 28, and the second one is an Extensive Test Report file in which you can find all measured data, see Figure 29.

The Short Test Report file (html-file), an example of which is shown in Figure 28, is saved in the folder C:\Program\supraVOLTcontrol\data. The name of the file is generated automatically and given by:
Identifier_calibration voltage_channel_date_time. The time is defined by hour-minutes-seconds.

An example is: Fluke732A_10V_ChannelA_ 10November2006_16-30-37.html.

If you press the print button in the user interface shown in Figure 25 top left, the Short Test Report (html-file) as shown in Figure 28 appears on the display, and it can be printed if a printer is connected.

The Extensive Test Report file (text-file), an example of which is shown in Figure 29, is saved in the folder C:\Program\supraVOLTcontrol\data. The name of the file is generated automatically and is given by:
Identifier_calibration voltage_channel_date_time. The time is defined by hour-minutes-seconds.

An example is: Fluke732A_10V_ChannelA_10November2006_16-30-37.txt.
This file can be opened with a standard text editor.

supracon®

10.11.2006
16:30:37

Test Report

Object	**DC-Reference Standard**
Identifier	**Fluke 732A**
Mains Voltage	ON
Frequency (standard deviation)	74.780000000 GHz (+/- 1 Hz)
Environmental Temperature	23.2 °C
Relative Humidity	36 %
Barometric Pressure	1007 mbar

	Voltage of Standard	**Standard Deviation**	**Thermal Voltage**
1	10.000004298 V	363 nV	427 nV
2	10.000004346 V	387 nV	327 nV
Channel	Average	Average Deviation	
A	10.000004322 V	34 nV	

Figure 28: Short Test Report file (html-file).
Only two data points were used instead of the maximum eight for the sake of simplicity.

In the table the calculated data points of the voltage of the secondary standard, their standard deviations, and the thermal voltages are displayed. Each measured data point and its standard deviation is calculated from forty measurements, twenty in the positive and twenty in the negative polarity.
At the bottom of the table (below “Channel”) the average value of the data points of the voltage of the secondary standard is given. The corresponding standard deviation is calculated from the data points (in the example of Figure 28 the standard deviation is calculated from two data points).

Extensive Test Report

10.11.2006 16:30:37
Identifier: Fluke 732A

Data Point	Voltage of Standard	Standard Deviation	Thermal Voltage
1	10.000004298 V	363 nV	427 nV
2	10.000004346 V	387 nV	327 nV

Channel	Average	Average Deviation
A	10.000004322 V	34 nV
B		
C		

Environmental Temperature:	23.2 °C
Temperature Electronic:	31.0 °C
Barometric Pressure:	1007 mbar
Relative Humidity:	36 %
Mains Supply:	ON

==

Data Point:	1	Data Point:	2
Frequency (GHz):	74.780000000	Frequency (GHz):	74.780000000
	74.780000001		74.780000001
	74.779999999		74.779999999
	74.780000000		74.780000000
	74.780000000		74.780000000
P / mW:	17.2	P / mW:	18.0
Vcal / V:	10.000004298	Vcal / V:	10.000004346
Vth / nV:	427	Vth / nV:	327
S+ / nV:	340	S+ / nV:	354
S- / nV:	386	S- / nV:	419

positive polarity
Vj+ = 9.999780892

positive polarity
Vj+ = 9.999780892

t / s	Vdiff+ / µV	t / s	Vdiff+ / µV
0.01	-222.895	70.69	-222.947
0.09	-223.652	70.76	-223.832
0.18	-224.043	70.84	-223.085
0.25	-223.136	70.93	-223.875
0.33	-223.301	71.00	-223.823
0.40	-223.585	71.08	-223.499
0.47	-223.820	71.15	-223.881
0.57	-223.333	71.22	-223.747
0.64	-223.554	71.31	-223.718
0.71	-224.113	71.39	-223.593
0.79	-223.264	71.46	-223.828
0.86	-223.319	71.53	-224.055
0.95	-223.815	71.60	-223.638
1.03	-223.655	71.70	-223.728
1.10	-223.991	71.77	-223.306
1.17	-223.450	71.84	-222.838
1.24	-223.942	71.91	-224.182
1.34	-224.096	71.98	-223.378
1.41	-223.798	72.08	-223.839
1.48	-223.610	72.15	-223.541

negative polarity
Vj- = -9.999780892

negative polarity
Vj- = -9.999780892

t / s	Vdiff- / µV	t / s	Vdiff- / µV
36.63	222.749	38.59	223.041
36.70	223.001	38.63	223.156
36.77	222.796	38.70	223.734
36.84	222.725	38.79	224.092
36.92	223.350	38.86	223.571
37.01	222.985	38.93	223.166
37.09	222.708	39.00	224.050
37.16	222.915	39.07	223.280
37.23	223.403	39.17	222.817
37.30	222.823	39.24	223.496
37.40	223.466	39.31	222.756
37.47	222.865	39.38	223.822
37.54	223.343	39.46	223.400
37.61	223.730	39.55	223.373
37.69	223.325	39.62	223.117
37.78	223.597	39.70	223.169
37.85	223.790	39.77	223.155
37.93	223.326	39.84	222.986
38.00	223.949	39.94	222.435
38.07	222.992	40.01	223.186

Vcal .....Voltage of the calibrated secondary standard
Vj+ ....positive Josephson voltage
Vj- ....negative Josephson voltage
Vth ....Calculated thermal voltage
S+ …….Standard deviation of the difference voltage in positive polarity
S- ....Standard deviation of the difference voltage in negative polarity
Vdiff+ ...Difference voltage in positive polarity
Vdiff- ....Difference voltage in negative polarity
t ....Time

Figure 29: Extensive Test Report file (text-file).
Only two data points were used for the sake of simplicity. Each data point is calculated from 40 measurements, 20 in the positive and 20 in the negative polarity.

8.3 Calibration of the gain factor and linearity of external voltmeters

This chapter describes the calibration procedure for the gain factor and linearity of external voltmeters.

Regardless of the type of digital voltmeter, calibration adjustments can be performed in order to reduce measurement error due to offset, gain, and linearity of the transfer functions of the signal processing circuits.
In general, all DVMs (digital voltmeters) have a transfer function of:

$$V_{dvm} = mV_{in} + b \qquad \text{eq. (4).}$$

Here:

V_{dvm}	:	measured and displayed voltage of the DVM,
m	:	gain,
V_{in}	:	input voltage of the DVM,
b	:	offset voltage.

The DVMs are designed in such a way that the gain m has an exact nominal value of 1 and b should be zero. However, usually this is not the case.
If the gain m is not equal to 1 all values of V_{dvm} will deviate from the nominal value by the same percentage. If b is not equal to zero, all values of V_{dvm} will be offset from their correct value by a constant amount. The slope of V_{dvm} as a function of $mV_{in}+b$ should be a straight line. Deviations from a straight line are referred to as nonlinearity.

The operation of a DVM can be approximately fitted by the relationship of eq. 4. It takes an unknown input voltage V_{in} and converts it to V_{dvm}. This is what is displayed by the DVM. Variations in gain, offset, and linearity of a DVM cause an error in the measurement. Traditionally, these deviations are referred to gain, offset, and linearity errors.

For the following voltmeters the gain m can be measured automatically:

→ **Keithley 2182A**

→ **Keithley 2001**

→ **Keithley 2000**

→ **Keithley 182**

→ **HP 3457A**

→ **HP 3458A**

→ **HP 34401A**

→ **HP 34420A**

→ **Fluke 8508A**

8.3.1 Connection of an external voltmeter, for example a Keithley 2001

Connect the voltmeter to the red and black banana jacks “EXTERNAL VOLTMETER” of the JVS electronics unit as shown in Figure 30.

For automatically operation the data acquisition of the connected DVM is realised via GPIB bus. Please be sure that your connected DVM has a different GPIB address than 07 or 19, because these addresses are already used in the system for the microwave source locking counter and the Keithley nanovoltmeter.

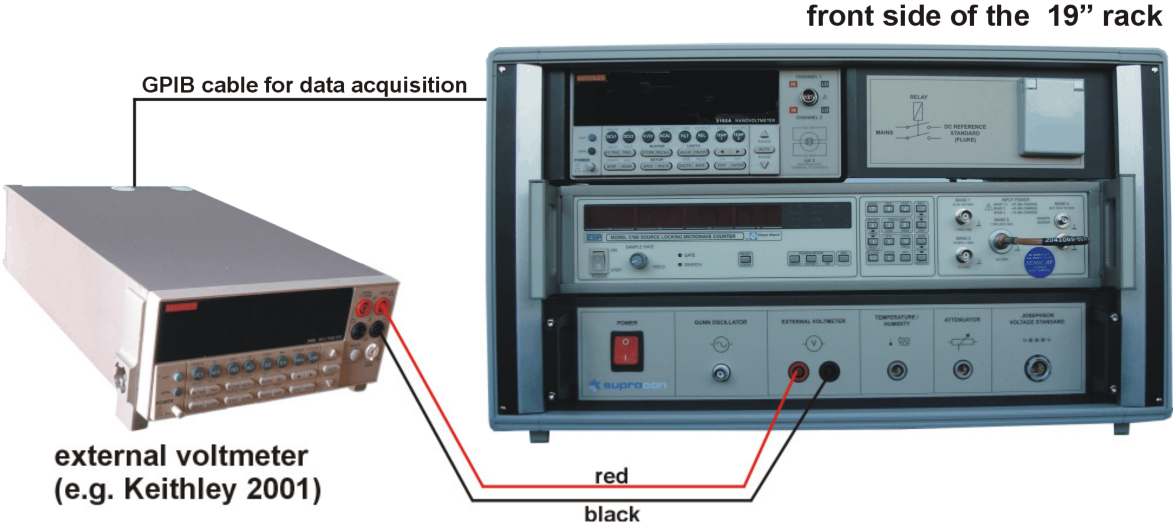


Figure 30: Connection of an external voltmeter for calibration, for example a Keithley 2001.

8.3.2 Operation

Click on the External Voltmeter soft key, see Figure 22, and the picture shown in Figure 31 appears on the display.
In the plain blue-coloured window, top left, the operator has to enter the identifier of the DUT, the voltmeter model, in this case an Agilent HP 34420A, the measurement range, and the number of data points from a minimum 3 to a maximum 100. A number of 21 data points is recommended as a compromise between the accuracy of measurement and measurement period.

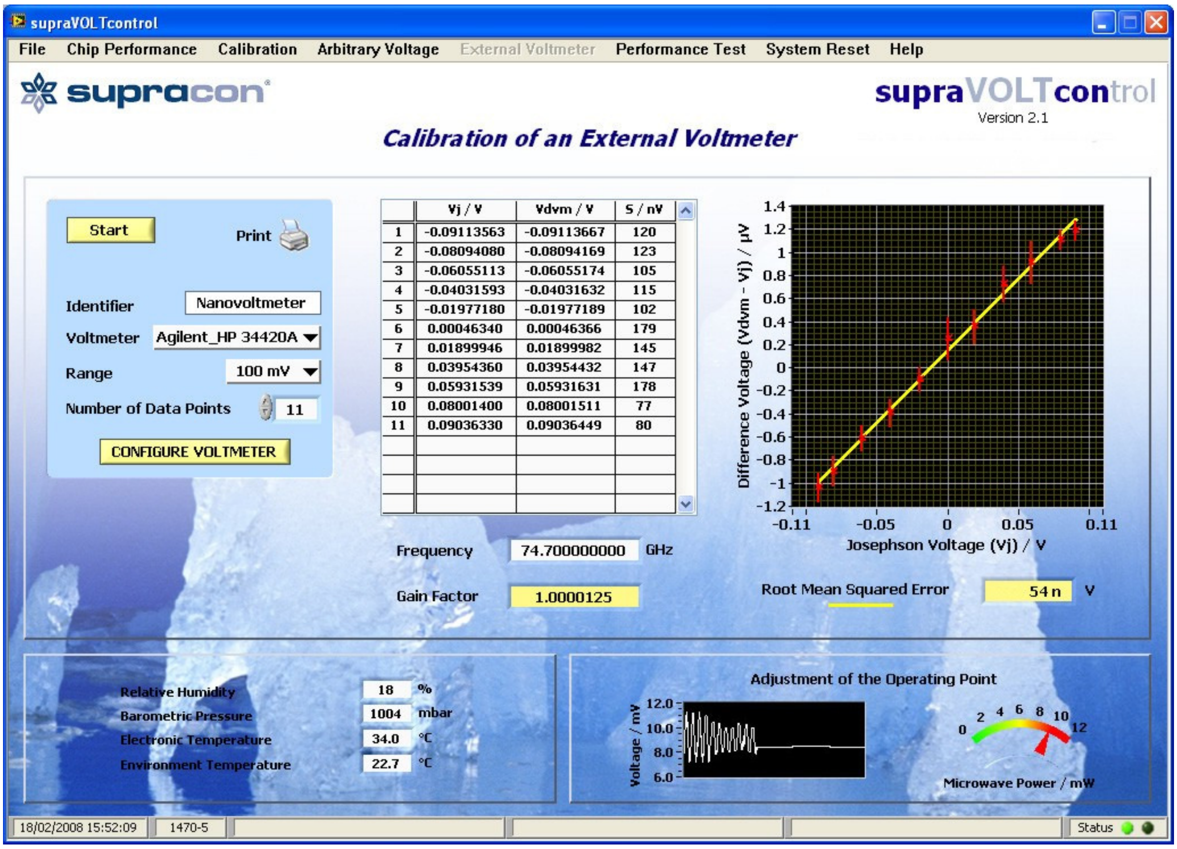


Figure 31: User interface → Calibration of an External Voltmeter.

Expert users can configure the external voltmeter via IEEE programming with a click on the CONFIGURE VOLTMETER button. Here different parameters like integration time, number of power line cycles etc., can be changed.

The readings of the sensors, see chapter 4.8, are shown bottom left. The adjusted microwave power is indicated bottom right. The simple graph shows that the operating point is adjusted optimally and stable Shapiro steps are generated. A stable Shapiro step is generated if the graph shows a straight line like in the graph to the right. If there is no stable Shapiro step the graph shows a signal which is proportional to the 30 Hz triangular bias current.

The table in Figure 31, middle top, shows the Josephson voltage, the voltage measured by the external voltmeter, and their standard deviation. Each measured value and its standard deviation are calculated from ten measurements. In the case of the Fluke 8508A only three measurements are made because of its large integration time.

The diagram, top right, shows the difference voltage between the voltage measured by the external voltmeter and the Josephson voltage. It demonstrates the linearity of the external voltmeter.

Finally the gain factor and the root mean squared error (RMSE) will be calculated and indicated. It is recommended to transfer the gain factor to the external voltmeter in accordance with the instructions in the manual of the voltmeter.

The RMSE is defined as

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{i=N}\left(V_{dvm} - V_{fit}\right)_i^2}\ , \quad V_{fit} = m \cdot Vj + b \qquad \text{eq. (5)}$$

N: number of measurements,
V_{dvm}: measured and displayed voltage of the voltmeter,
Vj: Josephson voltage,
V_{fit}: voltage of the linear fit,
m, b: gain and offset voltage of the DVM.

8.3.3 Storage of the results of the external voltmeter calibrations

If the calibration procedure is successfully completed the datasets are stored in two different files. One is a Short Test Report file of the external voltmeter, see Figure 32, and the second one is an Extensive Test Report file, in which you can find all measured data, see Figure 33.

The Short Test Report file (html-file), an example of which is shown in Figure 32, is saved in the folder C:\Program\supraVOLTcontrol\data. The name of the file is generated automatically and given by:
Identifier_DCrange_date_time. The time is defined by hour-minutes-seconds.

An example is: Nanovoltmeter_AgilentHP34420A_100mV_ 18February2008_15-51-55.html.

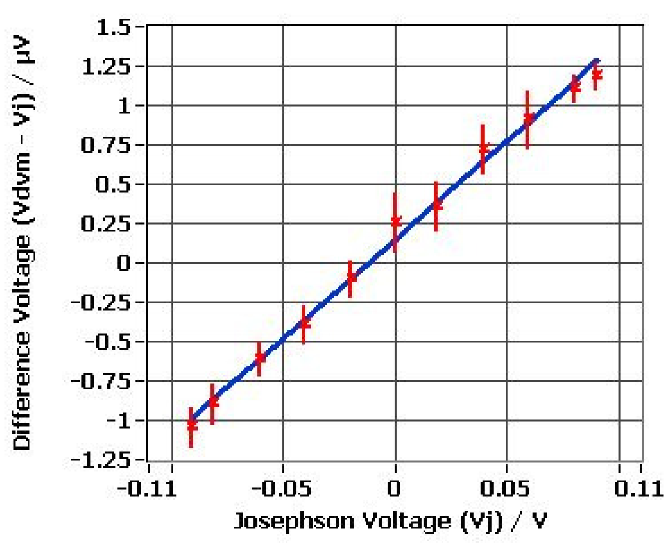
If you press the print button in the user interface shown in Figure 25 top left, the Short Test Report (html-file) as shown in Figure 32 appears on the display, and it can be printed if a printer is connected.

	18/02/2008 15:51:55

Test Report

Object	**External Voltmeter**
Model/Identifier	**Agilent_HP 34420A/Nanovoltmeter**
DC Range	**100 mV**
Frequency (standard deviation)	74.700000000 GHz (+/- 1 Hz)
Environmental Temperature	22.7 °C
Relative Humidity	18 %
Barometric Pressure	1004mbar
Root Mean Squared Error	54 E-9 V

Gain: **1.0000125**



	Josephson Voltage [V]	**Measured Voltage [V]**	**Standard Deviation [nV]**	**Difference Voltage (Vdvm-Vj) / [µV]**	**Vdvm-Vfit / [µV]**
1	-0.09113563	-0.09113667	120	-1.035	-0.039
2	-0.08094080	-0.08094169	123	-0.891	-0.023
3	-0.06055113	-0.06055174	105	-0.604	0.008
4	-0.04031593	-0.04031632	115	-0.386	-0.028
5	-0.01977180	-0.01977189	102	-0.097	0.005
6	0.00046340	0.00046366	179	0.260	0.108
7	0.01899946	0.01899982	145	0.362	-0.023
8	0.03954360	0.03954432	147	0.729	0.086
9	0.05931539	0.05931631	178	0.919	0.029
10	0.08001400	0.08001511	77	1.114	-0.035
11	0.09036330	0.09036449	80	1.192	-0.087

Figure 32: Short Test Report file (html-format) of an external voltmeter, gain and linearity. Only 11 data points were used instead of the recommended 21 for the sake of simplicity.

Extensive Test Report

18/02/2008 15:50:11

Voltmeter: Agilent_HP 34420A
Identifier: Nanovoltmeter
DC-Range: 100 mV

Frequency:	74.700000000 GHz (+/- 1 Hz)
Environmental Temperature:	22.7 °C
Barometric Pressure :	1004 mbar
Relative Humidity:	18 %
Gain:	1.0000125
Root Mean Squared Error:	54 E-9 V

==

	Vj / V	Vdvm / V	S / nV	Vdiff / µV	Vdvm-Vfit / µV
1	-0.09113563	-0.09113667	120	-1.035	-0.039
2	-0.08094080	-0.08094169	123	-0.891	-0.023
3	-0.06055113	-0.06055174	105	-0.604	0.008
4	-0.04031593	-0.04031632	115	-0.386	-0.028
5	-0.01977180	-0.01977189	102	-0.097	0.005
6	0.00046340	0.00046366	179	0.260	0.108
7	0.01899946	0.01899982	145	0.362	-0.023
8	0.03954360	0.03954432	147	0.729	0.086
9	0.05931539	0.05931631	178	0.919	0.029
10	0.08001400	0.08001511	77	1.114	-0.035
11	0.09036330	0.09036449	80	1.192	-0.087

==

1.V_{dvm} / V	2.V_{dvm} / V	3.V_{dvm} / V	4.V_{dvm} / V	5.V_{dvm} / V	…	11. V_{dvm} / V
-0.091136655	-0.080941884	-0.060551779	-0.040316209	-0.019772003	…	0.090364369
-0.091136655	-0.080941450	-0.060551779	-0.040316427	-0.019771786	…	0.090364477
-0.091136547	-0.080941667	-0.060551779	-0.040316209	-0.019772003	…	0.090364477
-0.091136655	-0.080941667	-0.060551562	-0.040316209	-0.019771786	…	0.090364477
-0.091136655	-0.080941667	-0.060551779	-0.040316427	-0.019772003	…	0.090364477
-0.091136547	-0.080941667	-0.060551779	-0.040316427	-0.019771786	…	0.090364477
-0.091136547	-0.080941667	-0.060551888	-0.040316427	-0.019771786	…	0.090364694
-0.091136873	-0.080941884	-0.060551779	-0.040316427	-0.019772003	…	0.090364477
-0.091136655	-0.080941667	-0.060551670	-0.040316209	-0.019771895	…	0.090364477
-0.091136873	-0.080941667	-0.060551562	-0.040316209	-0.019771895	…	0.090364477

Vj	...	Josephson voltage
Vdvm	...	measured voltage of voltmeter
S	...	standard deviation of measured voltage
Vdiff	...	difference voltage (Vj – Vdvm)
Vfit	...	voltage of the linear fit

Figure 33: Extensive Test Report file (text-format) of an external voltmeter, gain and linearity. Only five data points were used for the sake of simplicity. Each data point is averaged from the ten displayed measurements.

The Extensive Test Report (text-file), an example of which is shown in Figure 33, is saved in the folder C:\Program\supraVOLTcontrol\data. The name of the file is generated automatically and is given by:
Identifier_DCrange_date_time. The time is defined by hour-minutes-seconds.

An example is: Nanovoltmeter_AgilentHP34420A_100mV_ 18February2008_15-50-11.txt.

8.4 Arbitrary voltages

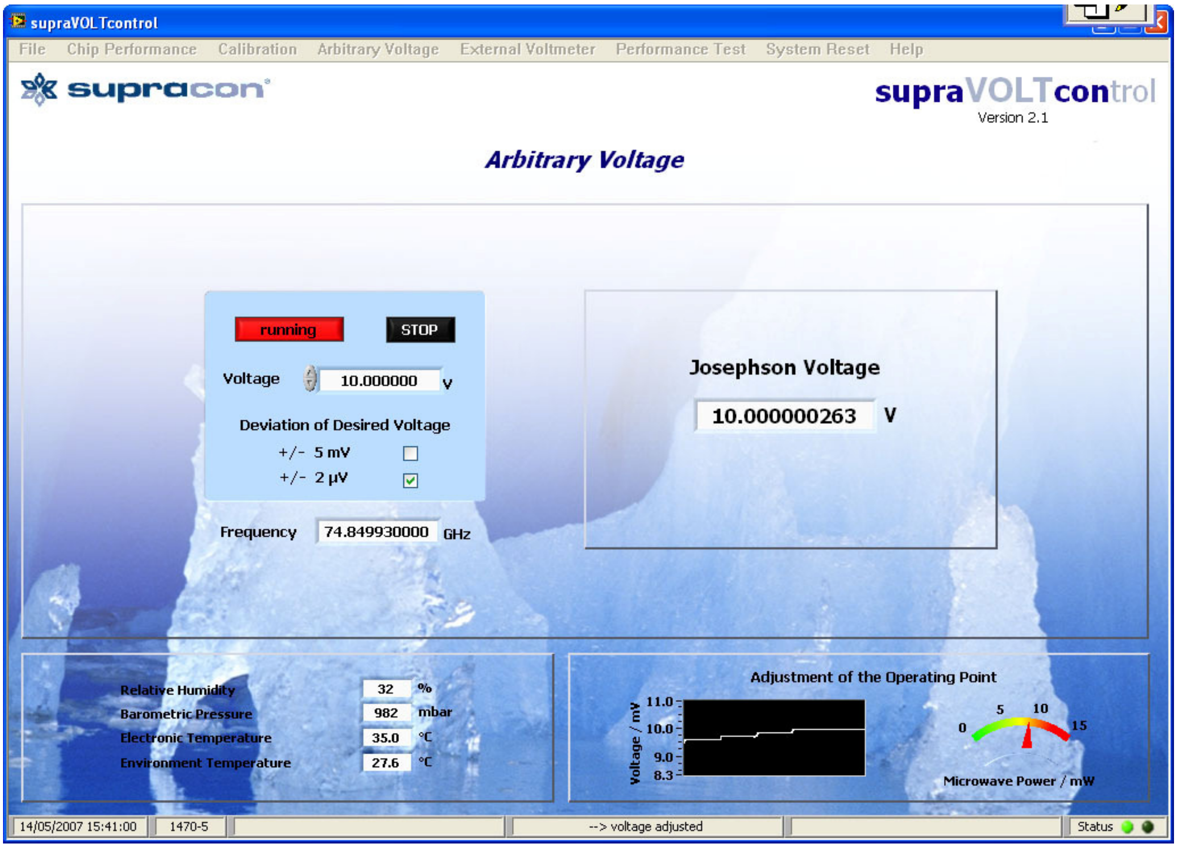


Figure 34: User interface → Arbitrary Voltage

The **supraVOLTcontrol** system can generate exact arbitrary Josephson voltages in the range of – 10 V up to + 10 V which is applied to the banana jacks "EXTERNAL VOLTMETER" of the JVS electronics unit, see Figure 35. During adjusting the Josephson voltage the "low" output is connected to ground. When the adjustment of the Josephson voltage is finished, the "low" and "high" output are floating from ground with help of internal switching relays.

Arbitrary voltages can be used only for measurements with a **low noise** DUT. The stability of the Josephson voltage depends strongly on the environmental conditions, like the noise of the DUT, electromagnetic interferences, and disturbances in the mains power. It can happen that no stable operation is obtained if the noise is too large.
For example, when a digital voltmeter is connected to the arbitrary voltage and this instrument is in overflow modus, no stable operation of the system can be obtained. The overflow modus of a DVM generates pulses on the input, resulting in huge disturbances.

Arbitrary voltages are **not suitable as a voltage source**, because the load current is less than few microamperes. The connected DUT must have **a higher input resistance then 10 MΩ.**

Arbitrary Josephson voltages can be useful for an auto-calibration of some voltmeters, or if you want to calibrate a voltmeter manually. But keep in mind, there can be thermal EMFs and offset voltages on the wires. You can estimate and eliminate these error voltages by adjusting first zero voltage, than you have the value of the thermal EMFs and offsets.

In order to use arbitrary voltages connect the DUT to the banana jacks "EXTERNAL VOLTMETER" of the JVS electronics unit, see Figure 35. Click the soft key Arbitrary Voltage from the main menu, and the user interface shown in Figure 34 appears on the display.
In the plain blue-coloured window the operator has to enter the desired arbitrary voltage and the tolerable deviation of the desired arbitrary voltage from the generated Josehson voltage, +/- 5 mV or +/- 2 µV.

In the case you have chosen a tolerable deviation of +/- 5 mV the Josephson voltage is more stable, resulting in a longer measurement period. On the other hand, if the voltage step is disturbed and jumps to another level, the Josephson voltage will normally not return to the same value. It can differ by +/- 5 mV from the desired voltage.
In the case of an entered tolerable deviation of +/- 2 µV it takes much more time to adjust the Josephson voltage and it can be less stable, resulting in a shorter measurement period. However, if the Josephson voltage step is disturbed it returns each time to the same value. The +/-2 µV option is only available for voltages higher than 60 mV.
We advise to use the 5mV option if possible, there are better operation conditions.

The Josephson voltage is adjusted correctly if a number appears in the field “*Josephson voltage*” of the user interface, see Figure 34. **Important to mention, the Josephson voltage is only applied to the output jacks, if a number is displayed in the field “*Josephson voltage*”.** Otherwise “*Searching Voltage*” is indicating that the Josephson voltage is adjusted currently.

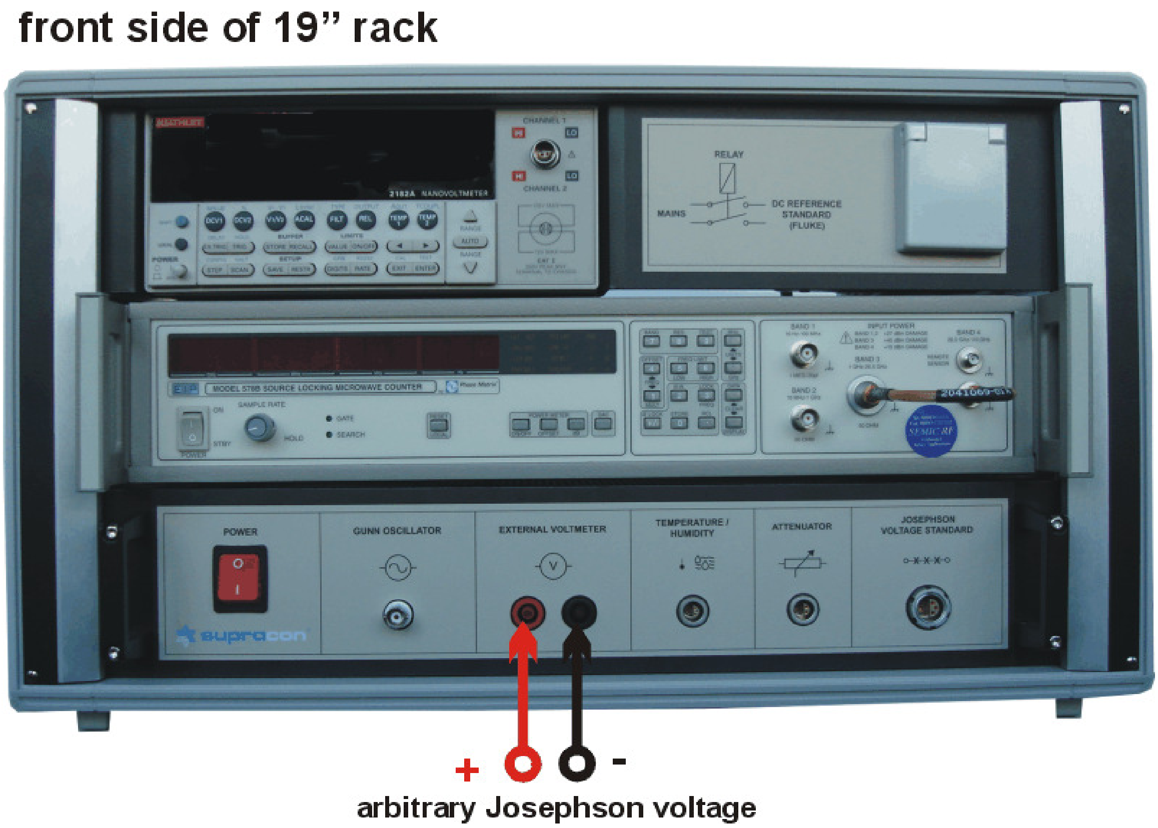


Figure 35: Output of the arbitrary Josephson voltage.

9 Performance Tests

This chapter gives instructions how to examine the performance of the **supra*VOLT*control** system. The performance test measurements must be made under the real operating conditions of the system. The Josephson chip should be at the operating temperature of about 4 K and the system should be connected as shown in Figure 21 or in the case of a cryocooler system as in Figure 23, respectively.
It is recommended to carry out the performance tests before you make a new calibration cycle and in a case of an anomalous function of the system in order to ensure a correct operation of the system. The tests verify the system specifications listed in the Table 1 marked with "*".

Click on the "Performance Test" soft key, see Figure 22, in order to list the below-mentioned performance tests. From the list you can select the desired performance test.

9.1 Critical current

The critical current performance test should be made with one (or two, or three) connected secondary voltage standard(s), the DUT(s), see chapter 8.2.1.
Select "Critical Current" and the picture of Figure 36 appears on the display. The performance test "Critical Current" measures the most sensitive parameter of the JJ array. The nominal value of the critical current of the installed JJ array chip is written in the **supra*VOLT*control** software. By pressing the Start button the current fed into the JJ array is increased step by step until the voltage drop across the JJ array jumps from zero to a certain value, see the graph in Figure 36. The current at which this voltage jump occurs is the critical current of the JJ array. It is indicated and compared with the nominal value. The result is displayed in the status bar fields at the bottom of the user interface (channel A,B,C from left to right).
The measurement of the critical current will be made in both polarities of the DUT.
If the message "Critical Current OK" is displayed you can continue with measurements.

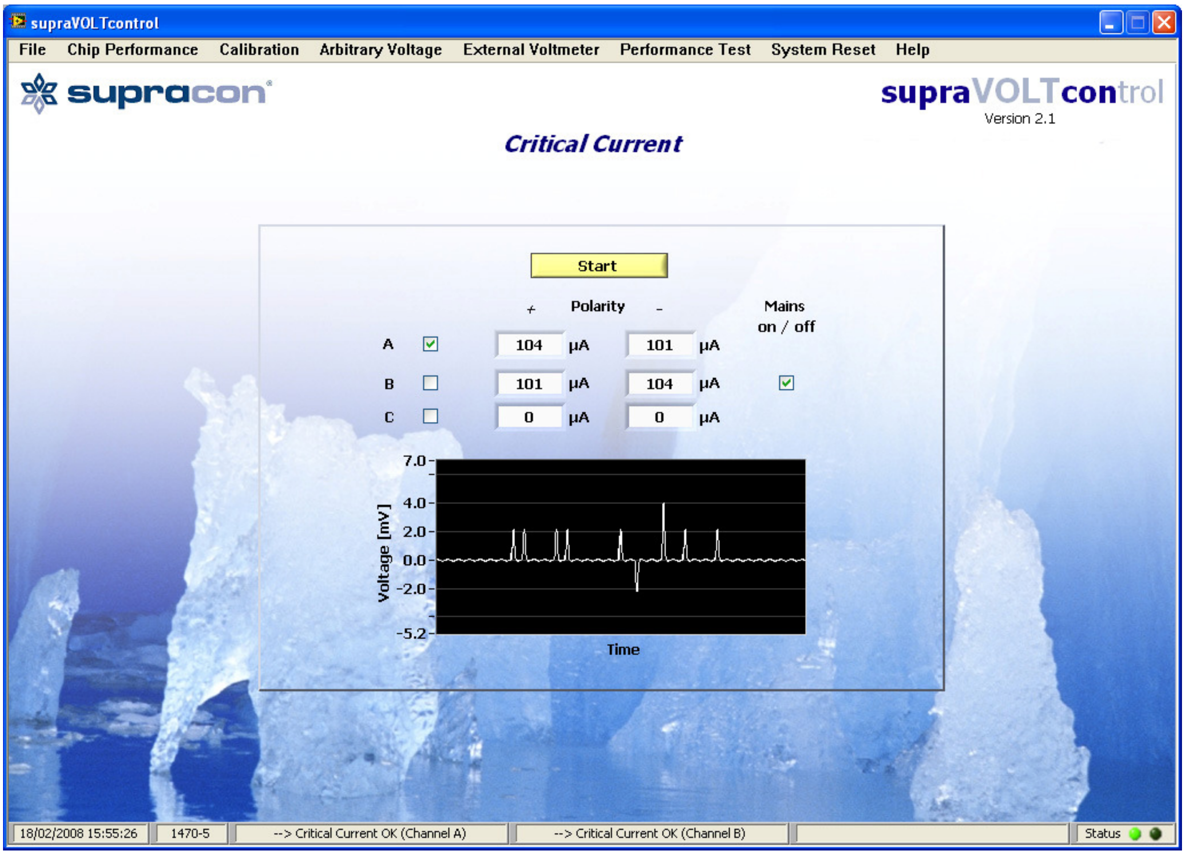


Figure 36: User interface → Critical Current

If the message “Critical Current too Low” is displayed the cause of it must be analysed. Because the critical current is a sensitive detector of unwanted interferences and noise sources, it can be reduced or suppressed by such disturbances.

In the case of to low critical current you should **disconnect the DUT from the mains** power and operate the DUT with a battery if possible (usually the mains power produces additional noise), and repeat the critical current performance test. If the DUT is connected to the mains via the switchable power socket it can be disconnected automatically if you choose “mains off”, see Figure 36.
If, after the test, the message “Critical Current OK” is displayed you can continue the measurements with the battery powered DUT.
If the message is again “Critical Current too Low” **disconnect the DUT completely** from the **supra*VOLT*control** system and measure the critical current again. Now the critical current should be OK, however, it is not possible to calibrate this DUT, it is too noisy.

If the critical current is still too low a possible reason can be a parameter change of the control electronics. In this case please choose the user interface -> Performance Test -> Reset DA converters, see chapter 10.2 of this manual. Start this test, save the new parameters, and repeat the critical current performance test.

If the critical current is too low also in this case, probably some junctions have trapped flux and you have to warm up the cryoprobe.
Go to the user interface -> Chip Performance and warm up and cool down the cryoprobe as described in chapters 6.2.2 and 6.2.3.

If the critical current is OK after this cool down cycle you can continue the measurements. If not please contact Supracon, see last page of the manual.

9.2 Calibration Nanovoltmeter

Before starting the nanovoltmeter calibration please wait at least 2 hours after switching on in order to warm up the complete system.

You can calibrate the integrated Keithley nanovoltmeter in the same way as an external voltmeter, as described in chapter 8.3. Select “Calibration Nanovoltmeter” and the picture of Figure 37 appears on the display.

Please specify the desired voltage ranges of the nanovoltmeter which should be calibrated and press the start button on the user interface. If you have chosen more than one voltage range they will be calibrated successively. By default the 10 mV and the 10 V range is activated, because only these ranges are used in the system.

The gain factor of the selected voltage range is calculated from 21 data points. Each data point is calculated from 20 single measurements.

The graphs in Figure 37 show the measured data points with their standard deviation indicated as bars. The readings of the sensors are shown bottom left, and the adjusted microwave power and the generation of a stable Shapiro are shown bottom right.

Most important is the 10 Volt range of the nanovoltmeter, because in this range the step order n from equation 1 is calculated and with it the exact Josephson voltage. The nanovoltmeter has to measure each voltage in the 10 V range with an accuracy of better than 50 µV in order to ensure a correct calculation of the Josephson voltage and with it the voltage of the secondary standard.
If the 10 V range is successfully calibrated, please press the “SAVE to Configuration” button in order to save the current gain factor to the system configuration. Select the correct configuration file (default is configuration.txt) in the folder C:\Program\supraVOLTcontrol\configuration and press ok.
With the newly measured current gain factor the accuracy of the nanovoltmeter is better than 10 µV in the 10 V range.

The gain factor of the 10 mV range is used and taken into account only for the measurement “Direct comparison to another Josephson voltage standard”, see chapter 9.5. Usually the type B measurement uncertainty of the nanovoltmeter is negligible, because the difference voltage is with 250 µV very low, but for the direct comparison measurement even this resulting error of few nV plays a role.

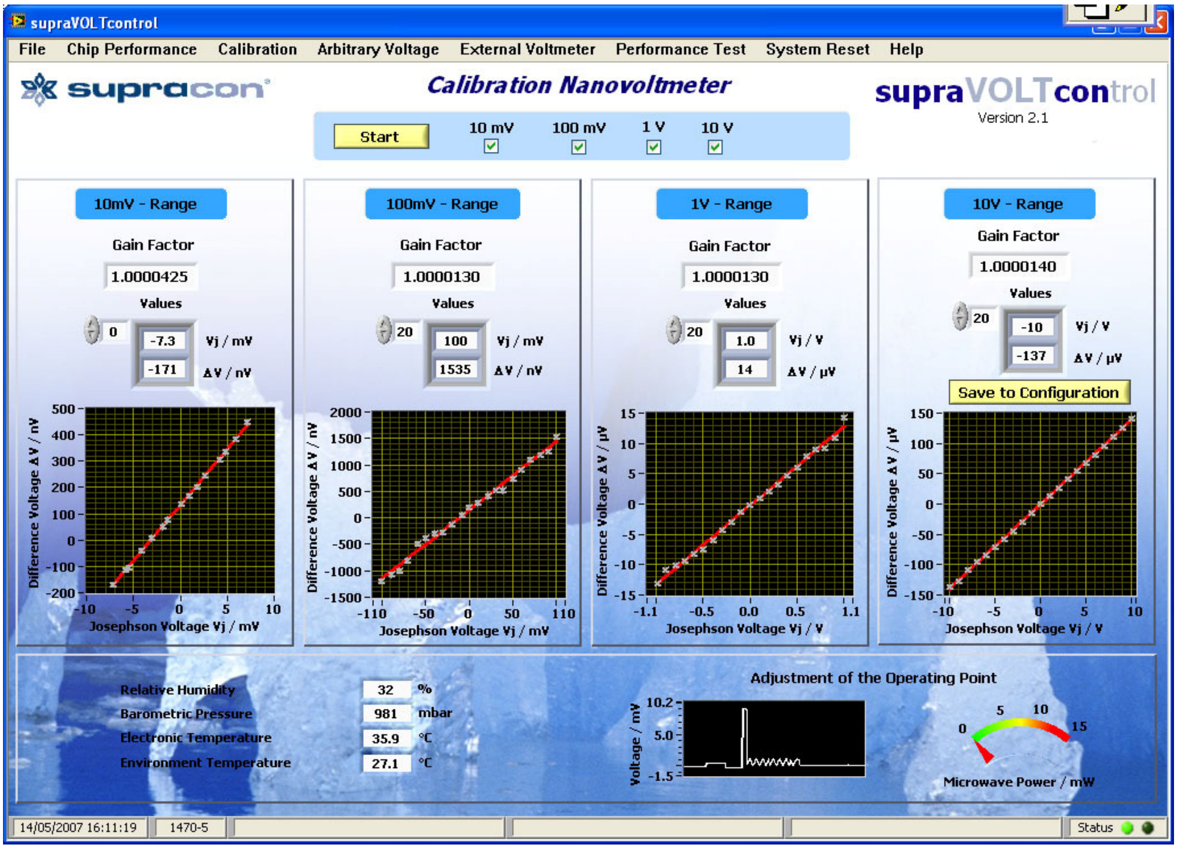


Figure 37: User interface → Calibration Nanovoltmeter

9.3 Step flatness

This test checks the flatness of the Josephson voltage step. Please wait at least 2 hours, in order to warm up the complete system, before performing the step flatness test.

Verify the performance of the Josephson junction array by using the performance test “Step Flatness”. It measures the step flatness of the Josephson voltage of the array which is applied to the selected channel. The step is flat when the Josephson voltage does not depend on the offset current through the JJ array. This means, that the Josephson voltage is constant for different offset currents, the incremental resistance of the JJ array is zero.

The step flatness performance test can be made only with a secondary voltage standard connected to the polarity reversal switch. For example, connect the 10 V reference voltage of a Fluke 732A to channel A and/or the 1 V to channel B, as shown in Figure 24.

Select the desired channel in the plain blue-coloured window of Figure 38 and press the start button. The connected voltage is displayed. An appropriate Josephson voltage is generated by the JVS electronics unit. The Keithley null detector measures the difference voltage between the voltage applied on the selected channel and the Josephson voltage for different operating currents. In the diagram of Figure 38 the difference voltage in dependence on the offset current is shown. Each data point is the average of 20 single measurements. The bars indicate the standard deviation of the 20 measurements.

If the Josphson voltage of the JJ array is changed by any interference it is re-adjusted. If the new Josephson voltage differs from the first one the difference is taken into account in the displayed data points.

If the JJ array works properly the measured and displayed data points should have a flat region, indicated by a flat yellow line.

The smallest detectable incremental resistance is limited by the noise of the connected secondary voltage standard, clearly seen by the length of the displayed bars of the data points.
For the 10 V range an incremental resistance of larger than 25 mΩ can be detected and for the 1 Volt range the limit is about 10 mΩ.

The results of the test are displayed in the status fields at the bottom of the user interface in Figure 38. If there is a slope in the step see chapter 11, troubleshooting, last item.

Please keep in mind that the JJ array is not disconnected from ground during this test because of applying an additional offset current to the JJ array by the JVS electronics unit.

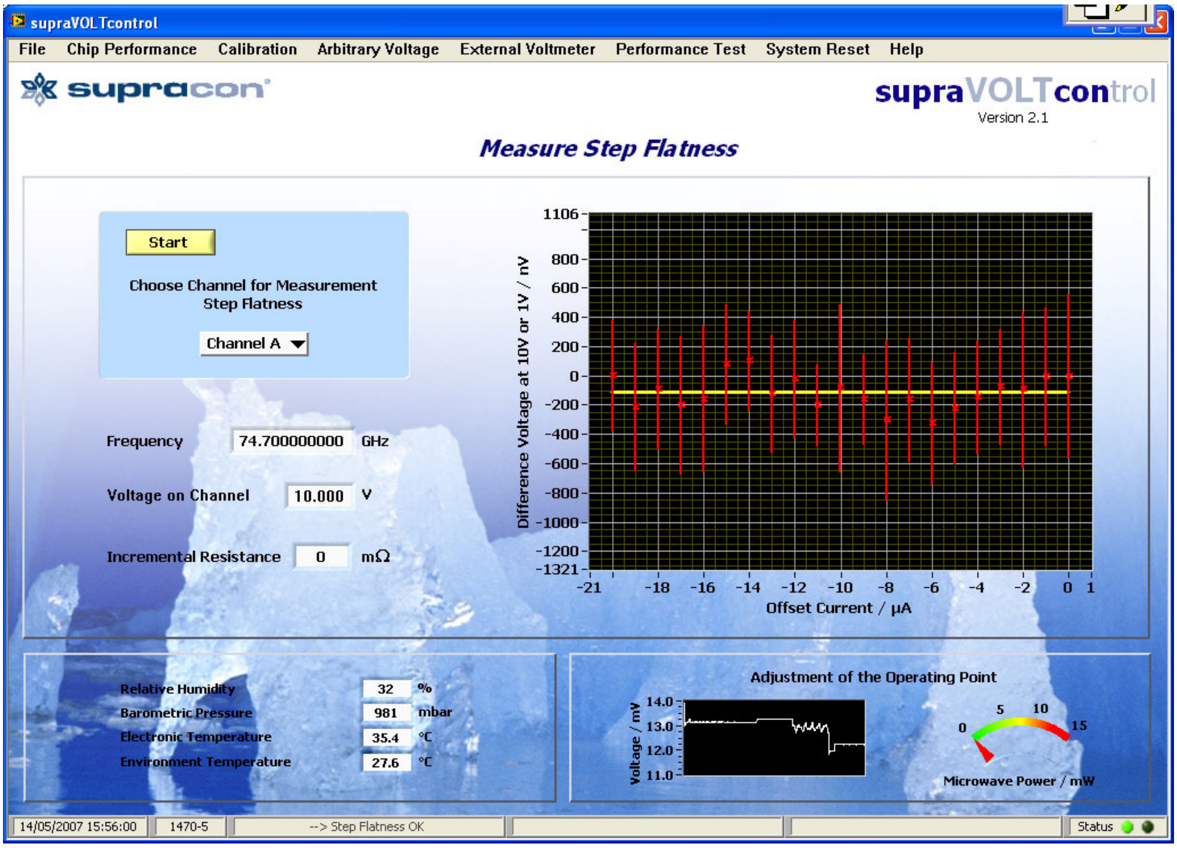


Figure 38: User interface → Measure Step Flatness

9.4 Thermal voltage

This test verifies the performance of the polarity reversal switch, of the connecting cables of each channel at room temperature, and of the wires in the cryoprobe.

Short the red and white wires of the channel which you would like to check, for example the red and white wires of channel A as shown in Figure 39.
It is recommended to press the two bare copper wires, red and white insulation, to each other by using a clamp. **Do not solder the wires!** Prevent airflow at the short. This can cause a temperature gradient and with it an increased thermal voltage.

Please wait for at least 30 minutes in order to get temperature equilibrium at the short before performing the thermal voltage test.
Select the shorted channel and press the "Start" button, see Figure 40.

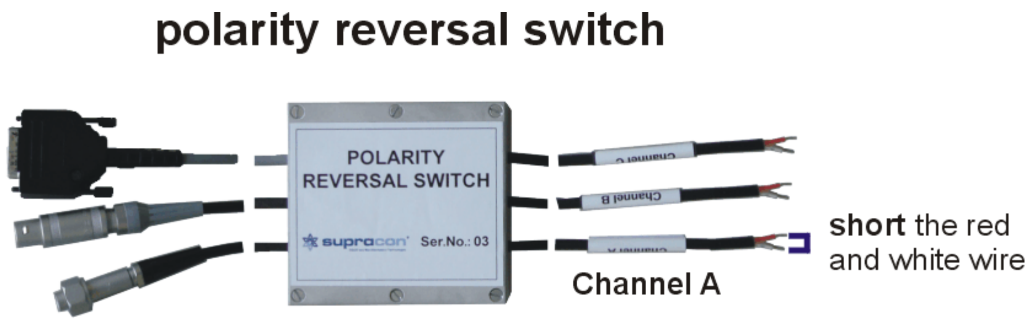


Figure 39: Short the wires of the channels by clamping the bare wires. **Do not solder the wires!** Only the short of channel A is shown for the sake of simplicity.

First the Keithley nanovoltmeter measures the shorted channel in the positive polarity and after 30 seconds the relays of the polarity reversal switch change to the negative polarity. After additional 30 seconds the polarity is switched again to the positive polarity. In the diagram, for channel B in this case, in Figure 40 you can see a voltage jump due to the thermal voltage. The thermal voltage should be lower than 20 nV, usually it is about 5 nV, if the wires, the short, and the relays are working properly.
The indicated thermal voltage is calculated from the voltage difference between the two polarities. In the calculation the readings of a period of 5 seconds before and after the switching of the polarity reversal switch are taken into account.
If the displayed thermal voltage is larger than 20 nV, please check at first the short and repeat the test.

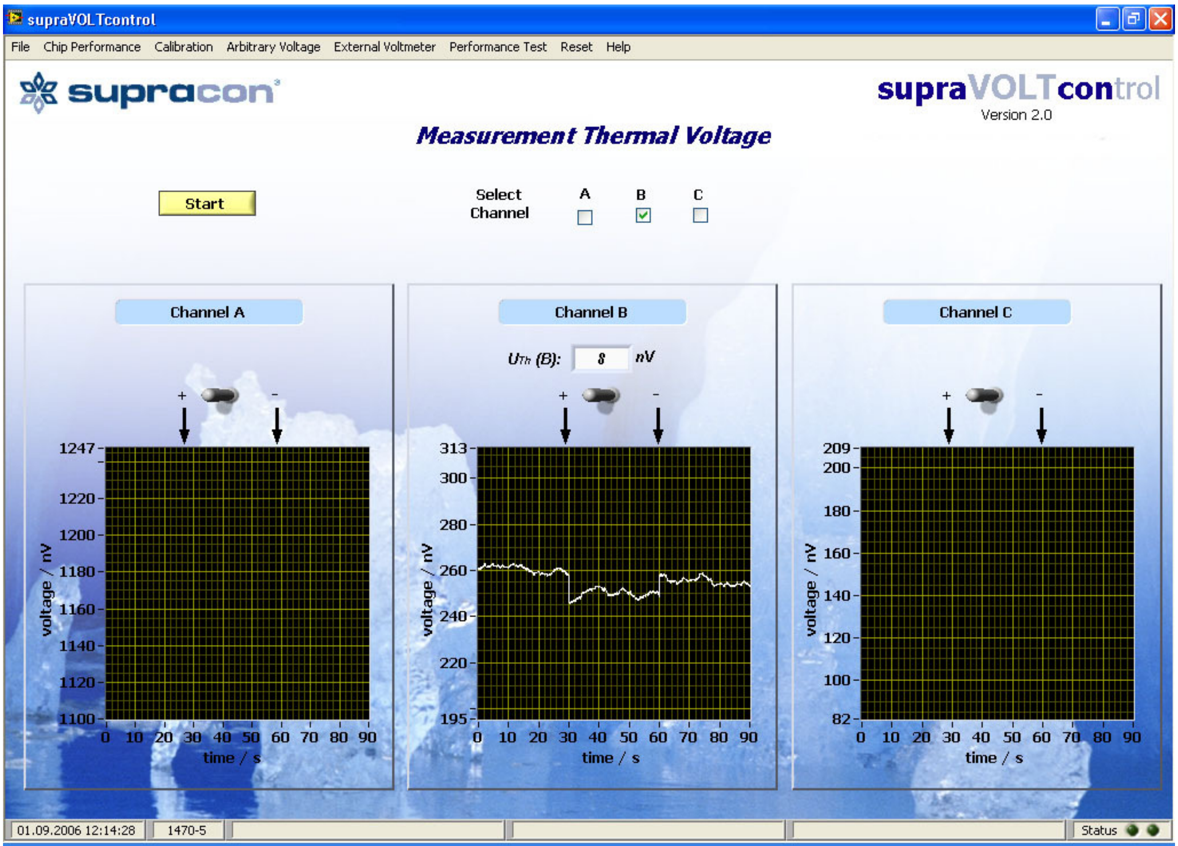


Figure 40: User interface → Measurement Thermal Voltage

If the thermal voltage for different shorts is still larger than 20 nV, please look at the troubleshooting chapter or contact Supracon.

9.5 Direct comparison to another Josephson voltage standard

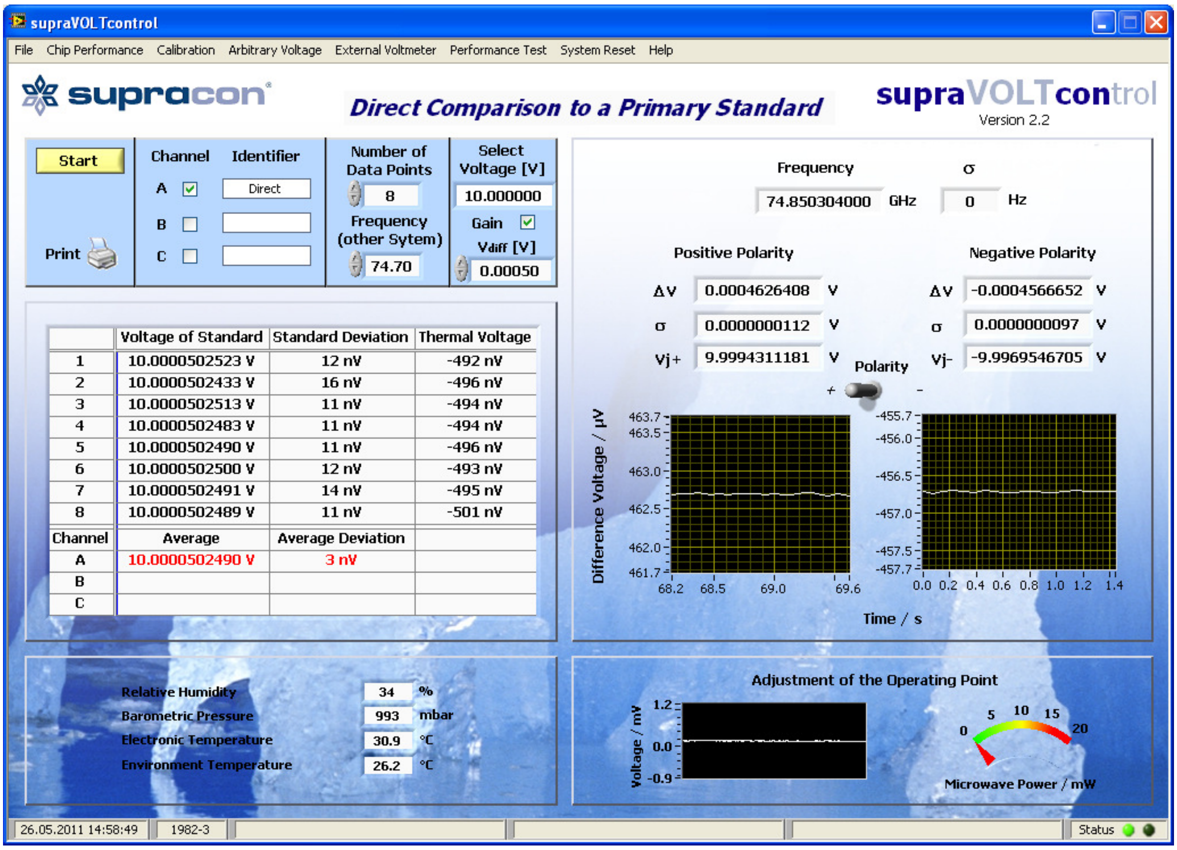


Figure 41: User interface → Performance Test -> Direct Comparison

The system has the performance of a direct comparison to another primary Josephson voltage standard. Such direct comparison is possible if the other primary standard can be operated in a floating ground status.

The measurements are similar to the calibration measurements of a secondary voltage standard as described in chapter 8.2.2.
Connect the other primary standard to the polarity reversal switch just like a secondary standard as shown in Figure 24. It is important to point out that during the measurement only the relay which short and connect the nanovoltmeter to the system is switched in order to minimize thermal voltages of the relays.

Important: ***It is necessary to calibrate the nanovoltmeter in the 10 mV range first to reduce the measurement uncertainty.*** You can do this from the menu bar -> performance test -> calibration nanovoltmeter and choose the 10 mV range. After finishing this performance test the software takes the measured gain factor into account.
We advise to calibrate the nanovoltmerer after the direct comparison again, to get a number of the uncertainty (drift etc.) of the gain factor of the nanovoltmeter.

By selecting the soft key from the menu bar -> performance test -> direct comparison, the user interface shown in Figure 41 appears on the display.
In the plain blue-coloured window (top left) the operator has to select the channel to which the other primary standard is connected and an identifier for the storage of the test reports. Furthermore, enter the desired number of data points from a minimum 1 to a maximum 8.

In the field “Select Voltage” the applied positive Josephson voltage of the other primary standard has to enter with a resolution of 10 µV, for instance 10.00001 V. The frequency of the other primary standard must be inserted in the field “Frequency (other system)”. With it the **supra*VOLT*control** software chooses a matched frequency to minimize the difference voltage read out by the nanovoltmeter.

In the field “Vdiff [V]” the operator has to enter an acceptable voltage difference between the voltages of the two primary standards. Usually 500µV is a good compromise between measuring speed and uncertainty.

It is important to point out, that the gain factor of the nanovoltmeter is taken into account, only if the check mark in the “Gain” box is selected.
Perform the test “*Calibration Nanovoltmeter*”, see chapter 9.2 shortly before you make the direct comparison measurements.

For calculation the uncertainty of the gain factor of the nanovoltmeter in the 10 mV range we advise to perform this test several times.

From the value entered in “Select Voltage” and “other frequency” the system calculates an optimum frequency and generates a Josephson voltage step very close to the voltage of the other primary standard. From the optimum microwave frequency and the value entered in “Select Voltage” the exact Josephson voltage of the system will be calculated.

By pressing the start bottom, a small window appears: “Josephson voltage adjusted?” If you have adjusted this voltage press “ok”. Now the other primary standard will be connected via relay to the **supra*VOLT*control** system and the first measurements in positive polarity will be started.
At top right the mean value of the Gunn oscillator frequency calculated from the selected Josephson voltage is displayed. The frequency of the microwave Gunn oscillator and its standard deviation will be measured during each measurement in order to check the proper operation of the Gunn oscillator.
After the first 20 measurements in positive polarity the measurement will be stopped, the other primary standard will be disconnected via relay and the Nanovoltmeter is shorted.
Then the window appears: “Josephson voltage adjusted and polarity changed?”. Change the polarity of the Josephson voltage of the other primary standard to its negative polarity and press “ok”. The other primary standard will be connected again to the **supra*VOLT*control** system and the measurement with negative polarity will be started.
After the 20 measurements in negative polarity the measurement will be stopped, the first data point will be calculated and the result will be indicated in the table of the picture in Figure 41.
Afterwards 20 measurements in negative polarity will be made a second time; they will be used for the calculation of the second data point. After these 20 single measurements the other primary standard will be disconnected and the window “Josephson voltage adjusted and polarity changed?” appears again. Change the polarity of the Josephson voltage of the other primary standard (now again to positive polarity) and press “ok”. The other primary standard will be connected again to the **supra*VOLT*control** system and the measurement will be continued until the window “Josephson voltage adjusted and polarity changed” appears again. The second data point will be calculated and indicated in the table.
Continue this procedure until all measurements are made and the desired number of data points are calculated and indicated in the table.

If the measurements of the direct comparison to another Josephson primary standard are successfully completed the datasets are stored in two different files, similar like in the case of the calibration of a secondary voltage standard as described in chapter 8.2.3. One is a Short Test Report file and the second one is an Extensive Test Report file in which you can find all measured data.
The Short Test Report file (html-file) is saved in the folder C:\Program\supraVOLTcontrol\data. The name of the file is generated automatically and is given by:
Identifier_direct comparison_channel_date_time. The time is defined by hour-minutes-seconds.
By pressing the print button in the user interface shown in Figure 41 top left, the Short Test Report (html-file) appears on the display, and it can be printed if a printer is connected.

The Extensive Test Report file (text-file) is saved in the folder C:\Program\supraVOLTcontrol\data. The name of the file is generated automatically and is given by:

Identifier_direct comparison_channel_date_time. The time is defined by hour-minutes-seconds. This file can be opened with a standard test editor.

9.6 Cryocooler performance (only cryocooler version)

By means of this performance test you can monitor the chip stage temperature and the pressure of the vacuum chamber in the case you run the system with a cryocooler.

Additionally you can adjust the optimal operation temperature of the Josephson junction array by activating the integrated cold stage heater. There are two modes; one applies a fixed voltage to the heater and the second one tune the voltage to reach an appropriate chip stage temperature. Default the second mode is active. In the case an optimal temperature is specified in the conficuration.txt file the system automatically stabilised to that temperature before continuing a calibration measurement.

Connect the temperature and pressure cables, as well as the USB Laptop cable as shown in Figure 17 to be able to read out the integrated sensors.

The performance test is located in the menu bar -> performance test -> Temperature/Pressure_Cooler. By selecting the item a new window appears similar to Figure 42. The actual temperature and pressure in the cooler chamber is displayed. You can save the data of the diagram by pressing the save button. The data of temperature and pressure are saved in ASCII-format. A data file with the name “cool_down_mode_date-time.txt” is saved in the folder C:\Progeamme\supraVOLTcontrol\data with actual date and time.

This test is useful to check and optimise the temperature of the chip stage; typically it is in the range of 3.2 K to 5 K.

Furthermore the pressure in the vacuum chamber of the cryocooler is displayed. In the case the cryocooler is at its operation temperature near 4 K the pressure should be below 1×10^{-4} mbar!
<u>Note:</u> The vacuum valve (1) of Figure 17 must be closed all the time. Only if the temperature of the cryocooler reaches 290 K the valve can be opened!

The values of the cryocooler temperature and pressure are required especially before starting the cool down process, compare chapter 7.2 and for cleaning the helium gas, see chapter 7.5.5,

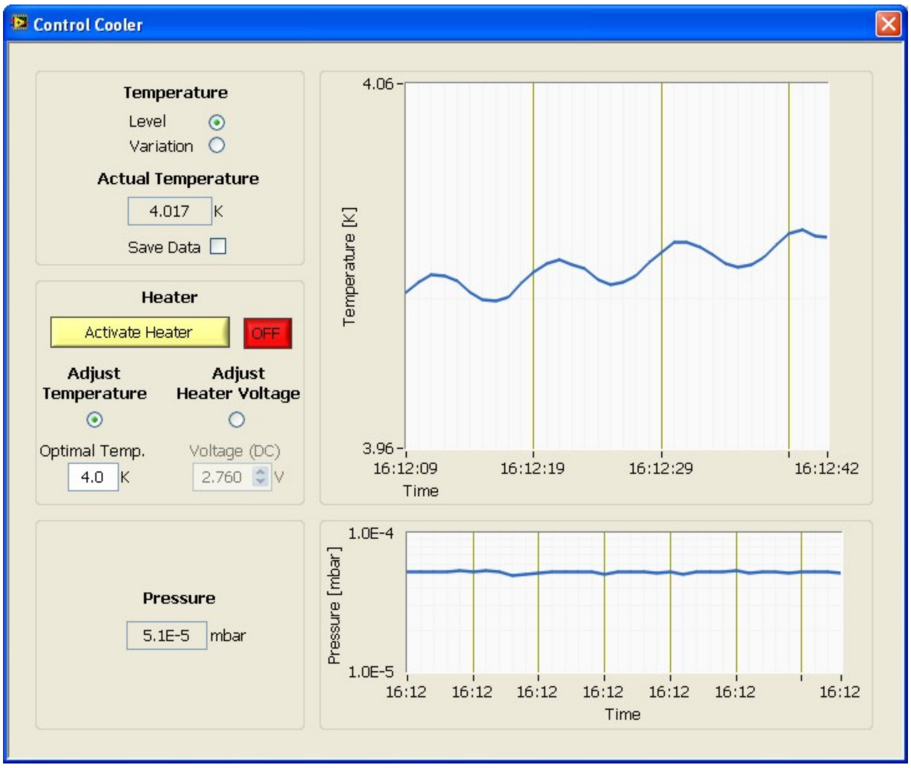


Figure 42: User interface -> Performance test -> Temperature/Pressure Cooler

10 System Reset

Please refer to this chapter if the system does not operate properly or if unusual results occur.

10.1 Reset electronics

If you get unusual or no results it can be a problem with the electronic status. In such a case please simple press the **Reset** soft key from the menu bar: -> System Reset -> Reset Electronic, in order to reset the system. Then repeat the measurement.

10.2 Reset DA converters

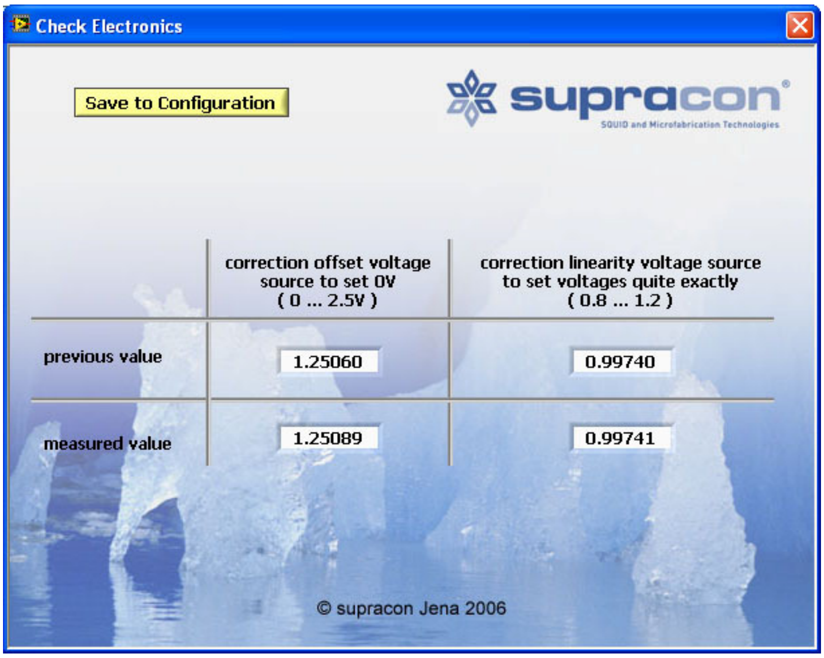


Figure 43: User interface -> System reset -> Reset DA converters

In the case the performance test -> critical current (chapter 9.1) gives to small values (usually below 10 µA); it can be due to a parameter change of the internal DA converters.
In such a case please run the self-calibration procedure -> System reset -> Reset DA converters and save the new values displayed on the user interface, see Figure 43.

The old and new parameters are displayed, and you can see the changes. Usually the difference is very small. That means the internal DA converters are not the reason for the too low critical current.

After performing the -> System reset -> Reset AD converters test run the Performance test -> critical current again, and look what happen. If the critical current is still too low please refer chapter 9.1 of this manual for more information.

10.3 Searching optimal frequency

You should run this procedure in the case the system finds no stable operation or a calibration of a secondary standard is not possible.

For some reasons it can be that the optimal operating frequency of the Josephson junction array chip has changed. This program part finds the optimal operation frequency automatically. The test can take about 2 hours, depending on the selected frequency range.

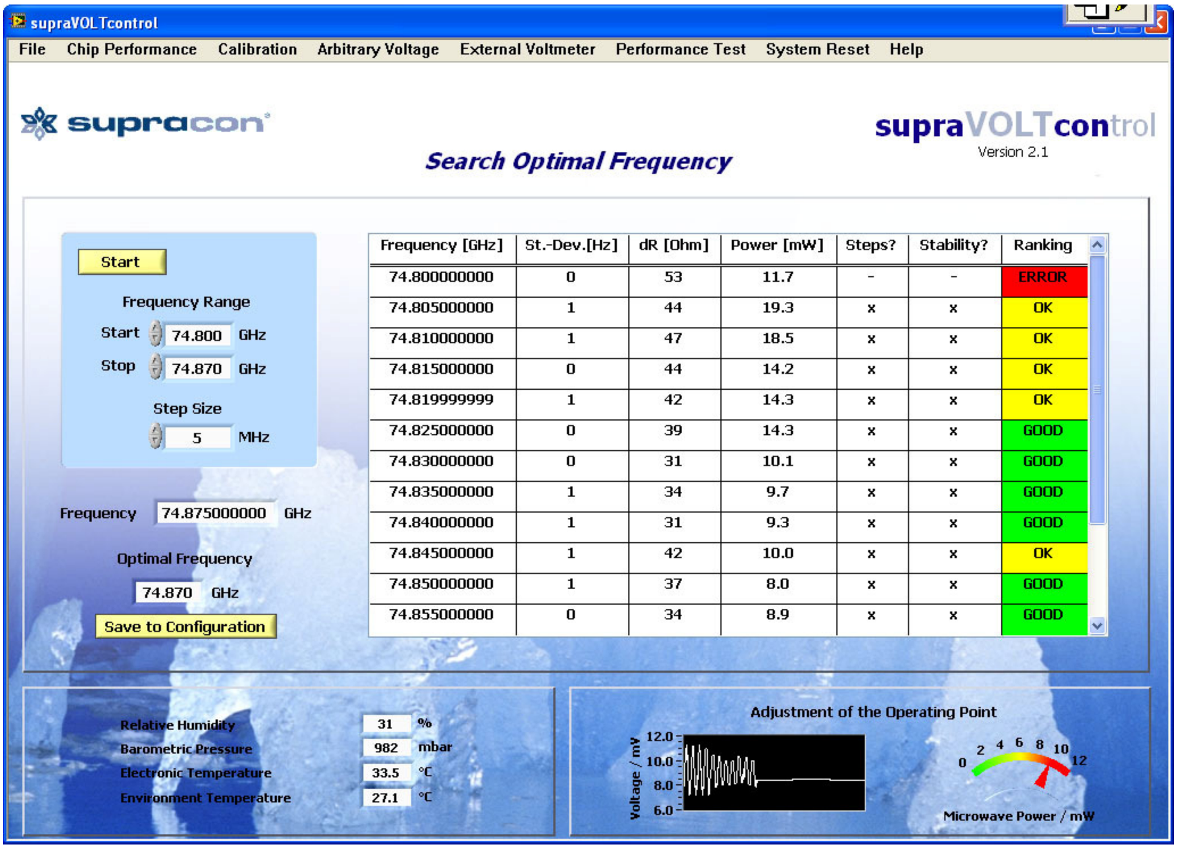


Figure 44: User interface -> System reset -> Searching optimal frequency.

Please connect the standard system setup in order to run the test, see Figure 21: The interconnections of the **supraVOLTcontrol** system by using liquid helium (LHe).

Please select from the main menu -> System Reset -> Searching Optimal Frequency. In the blue box you can choose start and stop frequency, and the step size. We advise to use the standard adjustments: Start 74.5 GHz, Stop 75 GHz, in steps of 10 MHz. By pressing the yellow start bottom the optimal frequency search is running.

In the table the results of the measurements are displayed. In the last column the result for the respective frequency is shown. If it is green or yellow you can use this frequency, if it is red the frequency is not useable.

Please save the new optimal frequency to the configuration file at the end of the procedure, in order to take over the new setting.

If no optimal frequency can be found, please contact Supracon.

For service reasons and fault analysis the results of these measurements are saved automatically to a file in C:\Programme\supravoltcontrol\Configuration.

11 Troubleshooting

On the status bar at the bottom of each user interface are shown the date and time, the serial number of the installed JJ array chip, and several messages concerning the operating status. One of the soft LED`s on the right of the status bar shines green if all is okay or it shines red to announce a failure.

For service reasons and fault analysis each unusual measurement and behavior is saved automatically to the log file in C:\Programme\supravoltcontrol\Configuration. If the file size becomes larger than 1 Mbyte a new log file is generated.

Different reasons may be responsible in the case of unusual or no results. We advise to run first the procedures described in the chapter 10, System Reset. If the system reset will not solve the problem please follow the instructions given below.

Technical failures of the system and how you can clear the faults are listed below.

A) The EIP microwave source locking counter shows no readings:

1. No user interface started -> start user interface.
2. No external 10 MHz reference is connected -> connect the 10 MHz reference.
3. The TIME BASE switch on the rear panel of the EIP microwave counter is set to the INT position -> change it to the EXT position.
4. The COARSE and LOCK BNC cables from the EIP microwave counter to the JVS electronics unit are not connected, see Figure 21 -> connect cables.
5. The Gunn oscillator does not work properly -> select manually a different frequency in steps of 1 MHz according to the instructions of the manual of the EIP microwave counter.
6. The operating voltage of the JVS electronics unit for the Gunn oscillator does not work -> please contact the Supracon service.

B) The standard deviation of the microwave frequency is larger than 50 Hz:

1. Check the cables and connectors of the external 10 MHz reference frequency.
2. Unfavorable microwave frequency -> change manually the frequency in steps of 1 MHz according to the instructions of the manual of the EIP microwave counter.
3. The phase noise of the external 10 MHz reference frequency is too large-> switch TIME BASE switch on the rear panel of the EIP microwave source locking counter to the “INT” position. If, after the switching, the standard deviation is ok, replace the external 10 MHz reference frequency.
4. The signal of the remote sensor is too low -> check the cable to the remote sensor.
5. Problems with the Gunn oscillator -> please contact the Supracon service.

C) Large standard deviation of the null detector:

1. Bad connections of the red and white insulated copper wires of the reversal polarity switch to the secondary standard -> improve the connections.
2. High noise level of the connected secondary standard, which you would like to calibrate -> replace the secondary standard.
3. The connectors of the polarity reversal switch make a poor connection -> check the correct connection of the connectors of the polarity reversal switch -> if necessary, clean the pins of the connectors.
4. Problems only with one channel -> chose another channel.
5. Defect of a relay of the polarity reversal switch -> please contact the Supracon service.
6. Make the performance test “Measurement Thermal Voltage”, see chapter 9.4.

D) The performance test “Critical current” indicates “Critical current too low”:

1. Check the level of the liquid helium in the Dewar -> if necessary transfer liquid helium in the Dewar.
2. The noise of the secondary standard is too high -> remove the mains power to the secondary standard and measure the critical current again, -> remove the secondary standard completely and measure the critical current again. If the critical current is ok, it is

probably impossible to calibrate the removed secondary standard because of its too high noise level.
3. The noise of the external voltmeter is too high -> remove the external voltmeter and measure the critical current again.
4. Internal DA converters have to be readjusted, run the procedure Reset DA converters given in chapter 10.2.
5. Magnetic flux is trapped -> warm up the cryoprobe and cool it down again.

E) Too high thermal voltage during the calibration of a secondary voltage standard:

1. Check the correct connection of the connectors of the polarity reversal switch -> if necessary clean the pins of the connectors of the polarity reversal switch.
2. Choose another channel.

F) Error message in the operation mode “External Voltmeter”

1. No GPIB cable connected -> connect GPIB cable from the external voltmeter to the Keithley nanovoltmeter
2. GPIB address of the external voltmeter is set to 07 or 19 -> Change the GPIB address of your voltmeter. Do not use the GPIB address 07 or 19, because these addresses are already in use for the source locking microwave counter and the nanovoltmeter.

G) No stable Josephon voltage in operation mode “Arbitrary Voltage”:

1. The external voltmeter indicate overflow -> select auto range of the voltmeter.
2. The DUT is too noisy -> filter the DUT or disconnect the DUT for test.

H) The performance test “Thermal Voltage” measures higher thermal voltages than 20 nV:

1. Check the short, clean the bare copper wires, and remove oxide layers using an abrasive paper.
2. Check the connectors of the polarity reversal switch. If necessary, clean the connector pins.

I) No data files are displayed in the folder C:\program files\supraVOLTcontrol\data

1. In the WINOWOWS Vista explorer you must push the compatibility bottom.

J) The performance test “Step flatness” indicates a larger incremental resistance than 25 mΩ:

1. Please contact the Supracon service.

Several messages are displayed in the status bar of the user interface. Please keep an eye on it.

Some failures of the system are indicated by ***Toubleshooting No.X*** in the fields of the status bar on the bottom of each user interface. The following list gives an overview and how you can try to make a fault recovery.

11.1 Troubleshooting No. 1

Reason: out of range of the internal AD converter

1. There is no connection between JVS electronics unit and cryoprobe → connect them.
2. Guard and chassis ground of the secondary voltage standard are connected → disconnect them.
3. The internal temperature of the **JVS Electronics** unit is to high → electronic components do not work correctly -> please contact the Supracon service.

11.2 Troubleshooting No. 2

Reason: no microwave attenuation adjustable

1. The voltage controlled attenuator is not connected -> connect the voltage controlled attenuator.
2. The voltage controlled attenuator is out of order -> please contact the Supracon service.

11.3 Troubleshooting No. 3

Reason: no microwave frequency locking

1. The source locking microwave counter is not connected -> connect the counter.
2. Check the Sample Rate of the Source Locking Counter, there is a tuning knob on the front which must be on the left mechanical stop.
3. Check the connection of the 10 MHz reference frequency.
4. Check the connection of the source locking microwave counter to the JVS electronics unit (COARSE TUNE OUT and ϕ LOCK OUT).
5. Restart the source locking microwave counter -> disconnect the cables to the counter (disconnect the Gunn oscillator) and switch OFF/ON the source locking microwave counter **→ Start your measurement again**.
6. Try to lock manually the microwave frequency with the source locking microwave counter according to the instructions of its manual. Check several frequencies from 74.6 GHz to 75GHz **-> Start your measurement again if the frequency is locked and if it is stable**.
7. The source locking microwave counter is out of order -> please contact the Supracon service.
8. There is a problem with the Gunn oscillator -> please contact the Supracon service.

11.4 Troubleshooting No. 4

Reason: no operation point adjustable

1. No connection of the voltage controlled attenuator -> Check the connection of the VCA.
2. The critical current is too low -> make the “Critical current” performance test.
3. The liquid helium level is too low -> refill the Dewar with liquid helium.
4. The microwave frequency is wrong -> change the microwave frequency.

11.5 Troubleshooting No. 5

Reason: Josephson array chip cannot be set to zero voltage

1. Check the control cable of the polarity reversal switch.
2. Load the correct configuration file.

12 Technical Support

In the case of any technical problems with the system or if you have some questions please do not hesitate to contact us. We will do our best to help you.

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