



Real-Time Controller RC5

User Manual

November 2016 (R6860)

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Conventions

The following signal words and symbols appear in this manual:



Danger: Indicates a hazardous situation which, if not avoided, will result in death or major injury.

Warning: Indicates a hazardous situation which, if not avoided, could result in death or major injury.

Caution: Indicates a hazardous situation which, if not avoided, could result in minor or moderate injury.



High voltage: Risk of electric shock. Lethal voltages present.



Hot surface: Indicates that the surface of the instrument might become hot. Avoid coming into contact with the hot surface.



Static sensitive devices: Observe precautions for handling electrostatic sensitive devices.



Note: Indicates a situation which, if not avoided, could result in damage or a malfunction of the instrument.



Refer to instruction manual: The instruction manual mentioned in the text must be read before operating the instrument.



Disconnect mains plug from electrical outlet: The mains plug must be disconnected from the electrical outlet before proceeding.

Italic

Commands, programs, menu items, functions, field names and product names are shown in italic characters.

Safety information

- Carefully read this manual and all related documents before installing and using the instrument.
- The safety notes and warnings have to be obeyed at all times.
- The RC5 may only be installed and used by authorized and instructed personnel who have read this manual.
- The RC5 is designed for indoors dry laboratory use only.
- The RC5 may only be used as specified in this manual, otherwise it may not fulfill safety requirements.
- Do not install substitute parts or perform modifications to this instrument. No user serviceable parts inside.
- Do not operate the RC5 if it is damaged or not functioning properly. Never use damaged accessories.
- Do not operate the instrument during electrical storms in order to avoid damaging the instrument.
- Never use corrosive or abrasive cleaning agents or polishes. If necessary, clean the instrument with a soft and dry cloth, and make sure that it is completely dry and free from contaminants before returning it to service.



Warning: Lethal voltages are present inside the instrument. Disconnect the mains plug from the electrical outlet before opening the instrument

About this Manual

This manual is intended as a reference tool for users of the Nanonis RC5 Real-time controller. It covers the functionality of the instrument and explains its installation and operation.

This manual is not a service manual for the RC5.

Revision history

November 2016 (R6860) Updated release of the RC5 manual:

- Updated conformity declaration

August 2016 (R6641) Updated release of the RC5 manual:

- Added or updated information and pictures for NI PXIe-8840 embedded controller
- Updated to software V5
- Updated host computer requirements

May 2013 (R3800) Initial release of the RC5 manual

The SPECS order number for this manual is: 2078000363

Introduction

The Nanonis Real-Time Controller RC5 is the central data processing unit of a Nanonis System. The RC5 provides connectivity to other instruments in the Nanonis family, FPGA processing for high-speed calculations, CPU power for slower time-deterministic processes, and a TCP/IP connection to the host computer running the Nanonis software.

The RC5 is equipped with six device ports for connecting the Nanonis SC5 or OC4. Up to three instruments of each type can be connected, with a maximum total of four instruments being supported in the software. The configurations are shown in the table below.

	No SC5	One SC5	Two SC5s	Three SC5s
No OC4		✓	✓	✓
One OC4	✓	✓	✓	✓
Two OC4s	✓	✓	✓	(✓)
Three OC4s	✓	✓	(✓)	(✓)

The RC5 also provides four digital ports (DIO ports) with eight digital lines each, for digital control and readout of other Nanonis or third-party instruments. All four ports are bidirectional and allow data rates of up to 500 kHz. For faster data rates, four additional high speed digital inputs and outputs can be used e.g. for counting purposes (inputs), or fast pulse generation (outputs). These lines allow data rates of up to 200 MHz.

Note: Under Version 4.5 of the Nanonis software, only two digital ports can be used, and the high speed digital outputs are disabled.

The RC5 allows for a flexible clock management, making it possible to change or upgrade the clock source depending on experimental requirements. The clock source can be either the low phase-noise internal clock, an optional oven-controlled crystal oscillator (OCXO) which can be fitted to the RC5, the OCXO of a Nanonis OC4, or an external clock source. The clock source is chosen automatically based on a priority list.

The RC5 is connected to the host computer running the control software using a single Ethernet cable. No other connections are required for operation and installation of software and operating system upgrades.

Instrument overview

Block diagram

The block diagram of the RC5 is shown in the picture below.

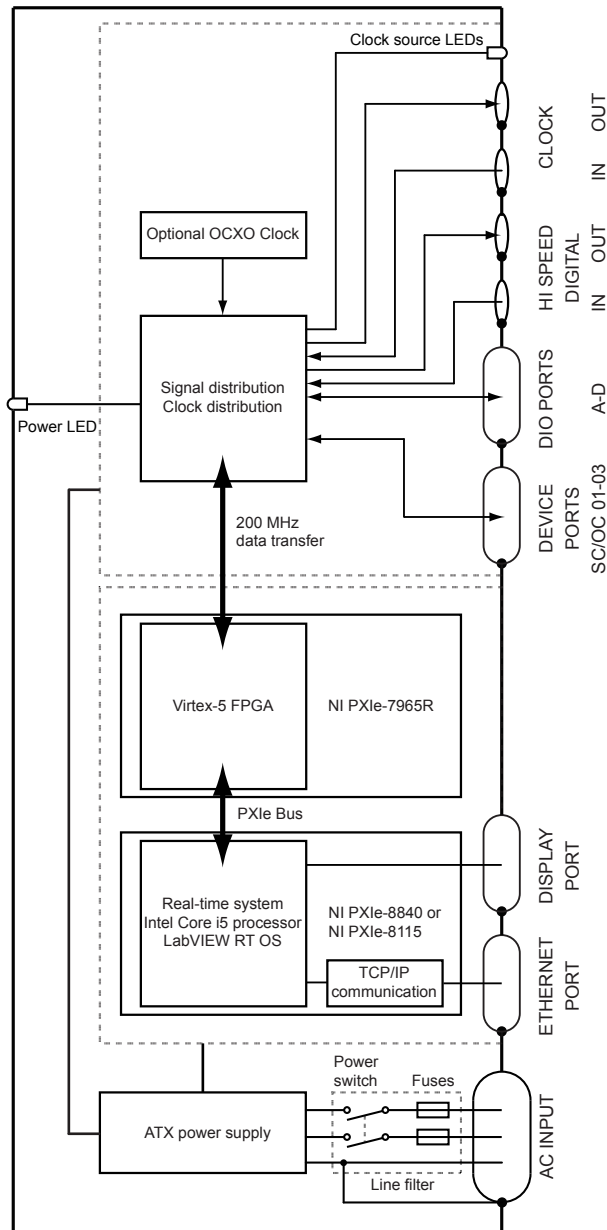


Figure 1: Block diagram of the Nanonis RC5.

The main functional units of the RC5 are the real-time system, the FPGA, and the signal and clock distribution unit. These units are powered by a medical grade ATX power supply and actively cooled by a fan placed at the bottom of the RC5 enclosure.

The real-time system unit is a NI PXIe-8840 (RC5 serial number 17517 and higher) or NI PXIe-8115 embedded controller. It is based around an Intel Core i5-4400E processor running at 2.7 GHz (3.3 GHz in turbo mode) with 4 GB of RAM (NI PXIe-8840) or Intel Core i5-2510E processor running at 2.5 GHz (3.1 GHz in turbo mode) with 2 GB of RAM (NI PXIe-8115). It provides processing power for all time-critical loops, scan and sweep generation, and for data acquisition. It also takes care of the TCP/IP communication with the host computer over its ethernet connection. The complete real-time unit can be easily removed from the RC5, if necessary. For status information, a computer screen can be connected to one of the two DisplayPort connectors.

The FPGA card is a NI PXIe-7965R FlexRIO card, connected to the real-time unit over a PXIe-bus. The Virtex-5 SX95T FPGA offers high processing power and speed for all fast data processing tasks, including PLLs, lock-in amplifiers, digital filters, oversampling, PI controllers, and hrDAC™ modulation. The FPGA is clocked through the signal and clock distribution unit.

The signal and clock distribution unit is connected over a 200 MHz data bus to the FPGA, and provides connectivity to the measurement instruments of the Nanonis range. It also addresses the four digital ports (DIO ports, 500 kHz maximum frequency), the eight high speed digital ports (200 MHz maximum frequency), and manages the clock sources. The optional OCXO clock is also plugged to the electronic board of the signal and clock distribution unit.

Front panel

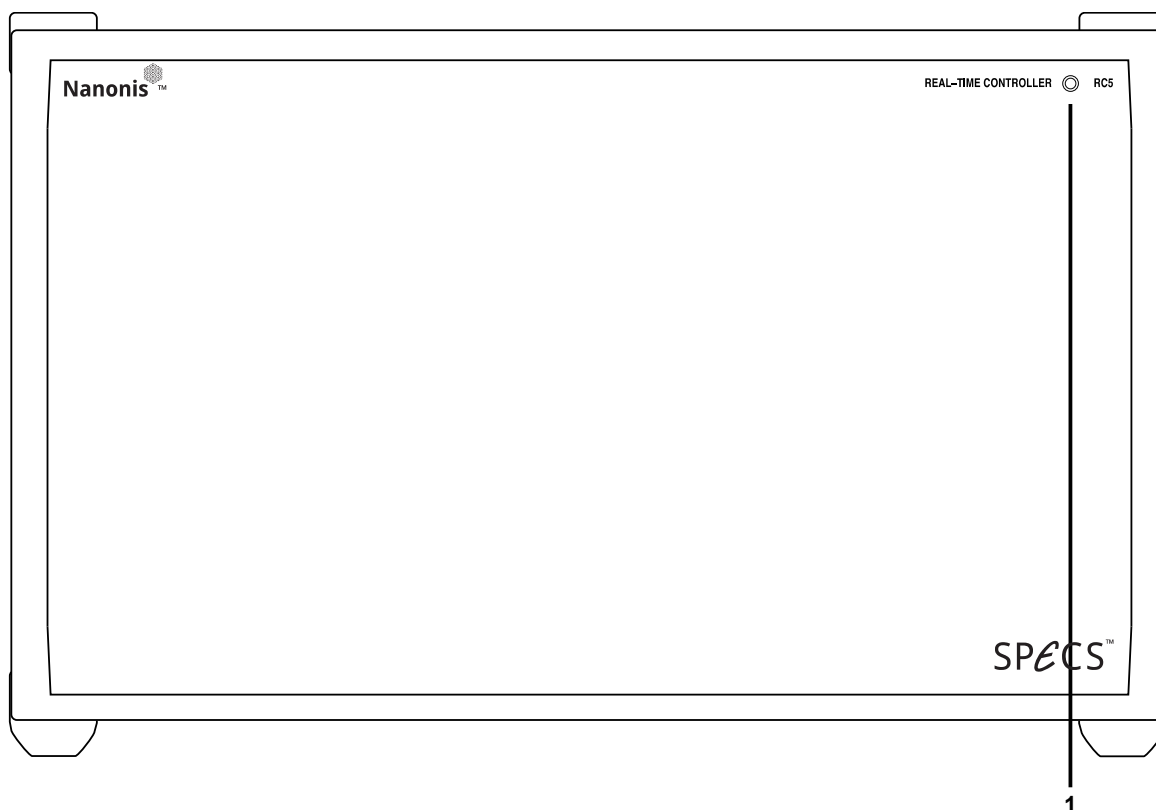


Figure 2: RC5 front panel.

1. **Power LED (blue):** Indicates that the instrument is powered up

Rear panel

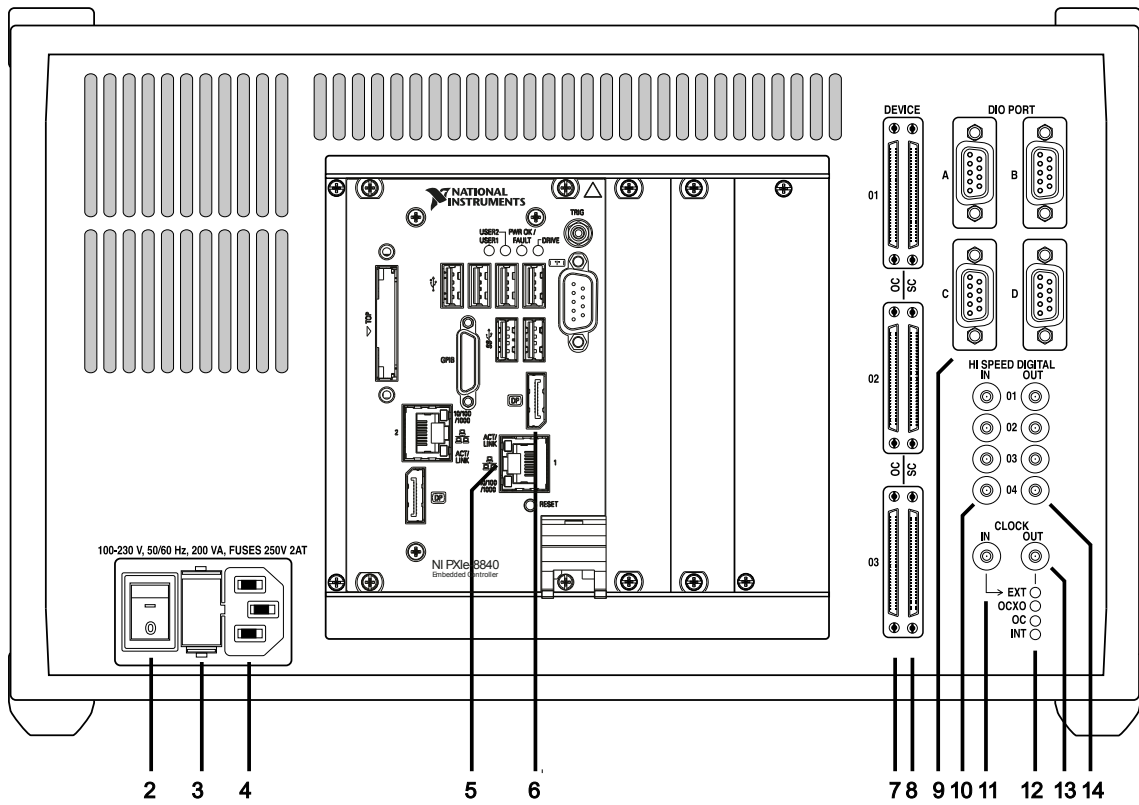


Figure 3: RC5 rear panel (NI PXIe-8840 version).

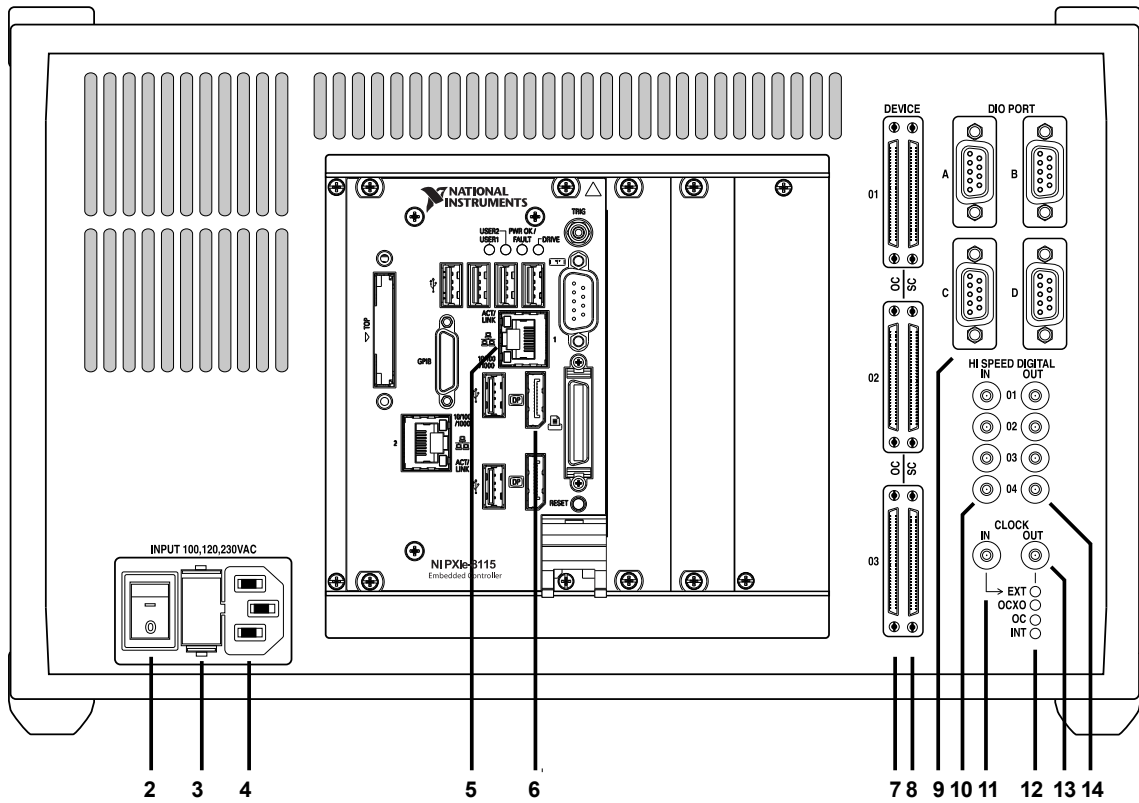


Figure 4: Figure 3: RC5 rear panel (NI PXIe-8115 version).

2. **Power switch:** Turns the RC5 on and off.
3. **Fuse holder:** Contains two identical slow blowing fuses. Slow blowing 2A fuses (2AT, rated 250 VAC, 5×20 mm) should be used independently from the line voltage.
4. **IEC power socket.**
5. **Ethernet connector:** This connector is used for TCP/IP communication with the host computer. The other ethernet port available should not be used. Please refer to the [Connection to host computer](#) section for details.
6. **DisplayPort connector:** This connector is used for connecting a computer display to the RC5. The screen displays the status information of the instrument. Please refer to the [Connection to computer screen](#) section for details.
7. **OC4 device connectors:** The Nanonis OC4 is connected to these connectors using the DEVICE RDIO cable supplied with the OC4. Do not connect a Nanonis SC5 to these connectors. Please refer to the [Connection to OC4](#) section for details.
8. **SC5 device connectors:** The Nanonis SC5 is connected to these connectors using the DEVICE RDIO cable supplied with the SC5. Do not connect a Nanonis OC4 to these connectors. Please refer to the [Connection to SC5](#) section for details.
9. **DIO Ports A-D:** These four D-sub9 female connectors are used for communication and control of other Nanonis instruments, as well as third party equipment. Please refer to the [DIO Ports](#) section for details.
10. **High Speed Digital Input connectors:** These four SMB connectors provide four inputs for high speed digital communication. Please refer to the [High Speed Digital Inputs](#) section for details.
11. **Clock input:** This SMB connector accepts a clock signal from an external 10 MHz clock source. Please refer to the [Clock](#) section for details.
12. **Clock source LEDs (green):** Indicate that the corresponding clock source is selected and that the RC5 digital circuits are locked to that clock signal. Please refer to the [Clock](#) section for details.
13. **Clock output:** This SMB connector outputs the 10 MHz clock signal of the clock source indicated by the Clock source LEDs (12). For details, please refer to the [Clock](#) section.
14. **High Speed Digital Output connectors:** These four SMB connectors provide four outputs for high speed digital communication. Please refer to the [High Speed Digital Outputs](#) section for details.

Symbols:



Earth



Protection Earth

Installation Guide

This installation guide shows how to prepare and power up the RC5. Following these instructions ensures that the instrument is working correctly, and that it can be connected to other instruments. Further steps will be explained in detail in the chapters following this guide.

Please carefully read the manuals of the instruments to be connected to the RC5 before proceeding.

Content of delivery

When first unpacking the RC5, please check for the following items:

1. Nanonis RC5
2. Power cord
3. DisplayPort to VGA adapter
4. Test protocol
5. User manual
6. NI Real-time deployment license

These items are shown in the picture below. Note that the power cord appearance will depend on the country where the RC5 is used (type J power cord shown).

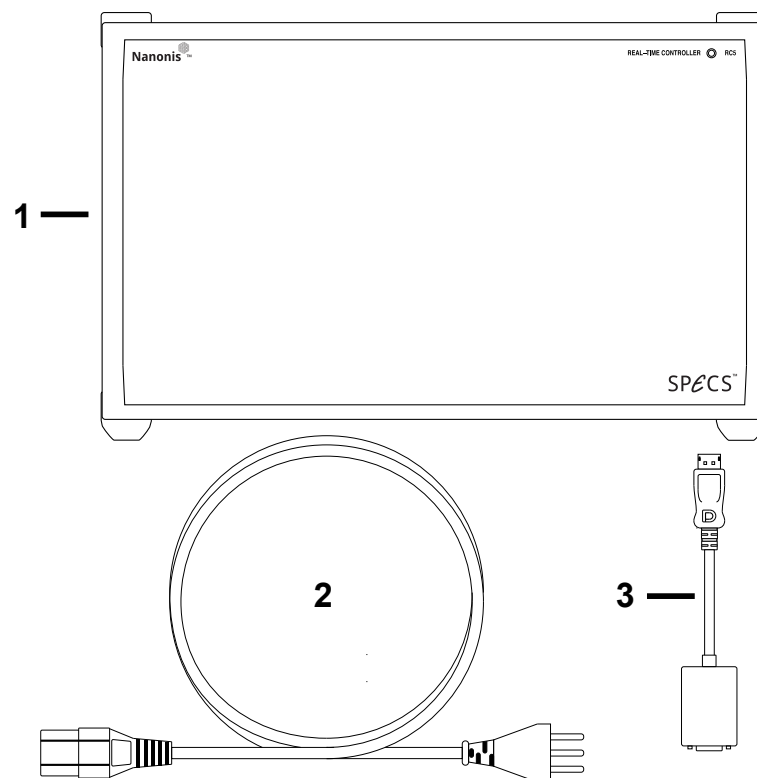


Figure 5: These items are delivered with the RC5.

Setup

To properly set up the instrument, a square space of at least 40 cm × 50 cm × 25 cm (W × D × H) is required. Additional Nanonis instruments require an additional height of 10 cm for each instrument. The RC5 weighs approximately 7.8 kg, and stability of its supporting table must be guaranteed. It must be possible to access the hardware from the front and the rear in order to connect all necessary cables. The space has to be dry and kept within the specified temperature range.



Note: Make sure that the power cord is accessible at all times. It must be possible to disconnect the power cord immediately in case of emergency.

The RC5 is actively cooled, and the air intake is placed at the bottom of the instrument. The four plastic feet supporting the instrument must not be removed, and no items should be placed between the supporting table and the bottom of the instrument.

The RC5 requires one power socket (120 VA typical, 200 VA max at 100-230 V ±10%, 50/60 Hz ±5%) with proper grounding. A complete Nanonis SPM Control System can require up to eight power sockets, with a total power consumption of about 600 VA maximum.



Note: The power cord must be connected to a properly wired and earthed socket.



Note: Use only the provided power cord or power cords conforming to IEC60227 with a connector conforming to IEC60320.



Note: Make sure that the air intake at the bottom of the instrument is not obstructed, otherwise the RC5 might exceed its maximum operating temperature and shut down.

Connection to SC5

Only one single cable, supplied with the SC5, is needed as a connection between the SC5 and the real-time controller RC5. The DEVICE RDIO cable is labelled as *SHC68 – 68 – RDIO*. Place the SC5 and RC5 at the desired location, and make sure that the space requirements listed in the previous section are fulfilled.



Note: Please carefully read the SC5 user manual delivered with the Nanonis SC5 before proceeding!



Note: Do not connect a Nanonis SC4 to the RC5. Doing this might result in damage to the RC5.



Note: Only use the supplied DEVICE RDIO cable for the connection between the SC5 and RC5. Do not use cables labelled as *SHC68 – 68 – RMIO* or the SC5 will not function.

Single SC5

Make sure that both the SC5 and the RC5 are switched off, but connected to the mains. Connect the DEVICE RDIO cable delivered with the SC5 to the *DEVICE SC 01/02/03 port* of the SC5 first, then to the *SC 01 port* (8) at the back of the RC5, as shown in the figure below. Always tighten the screws on either side of the connectors.

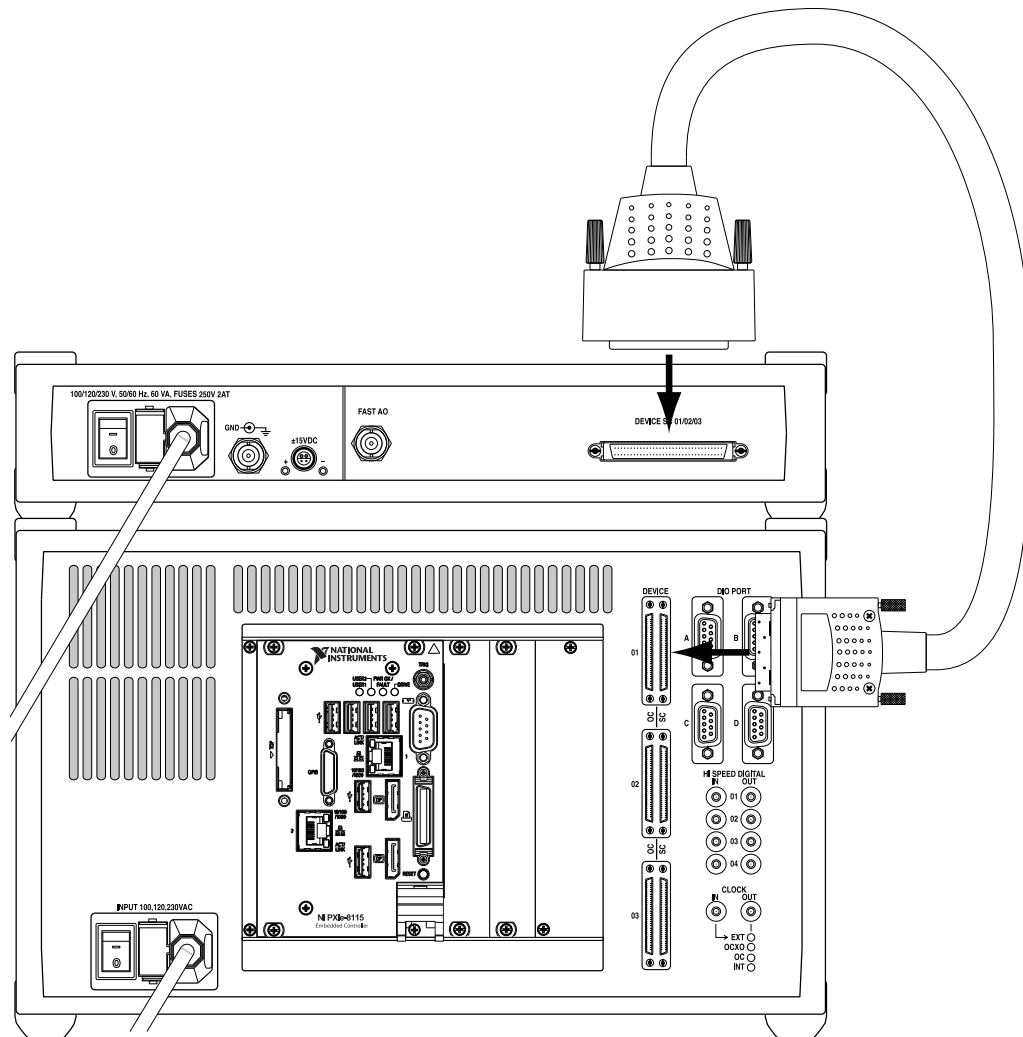


Figure 6: Connection of one SC5 to the RC5. The power cords of both instruments have to be connected to the mains first.



Note: Connect both the SC5 and the RC5 to the mains using the supplied power cords before connecting the instruments together!



Note: Make sure that the screws of the DEVICE RDIO cable connectors are tightened, otherwise the connectors might be damaged. Do not overtighten the screws!



Note: If a single SC5 is connected to the RC5, it must be connected to the SC 01 port at the back of the RC5. Do not connect it to the SC 02 or SC 03 ports.

Multiple SC5s

Up to three Nanonis SC5s can be connected to a single RC5. Follow the instructions given in the previous section for the connection of the additional SC5 units.

Since the different SC5s are addressed by their port number in the Nanonis software, make sure to label the instruments on the front panel in order to recognize which instrument is connected to which port. The figure below shows the maximum configuration with three SC5s connected to the RC5.

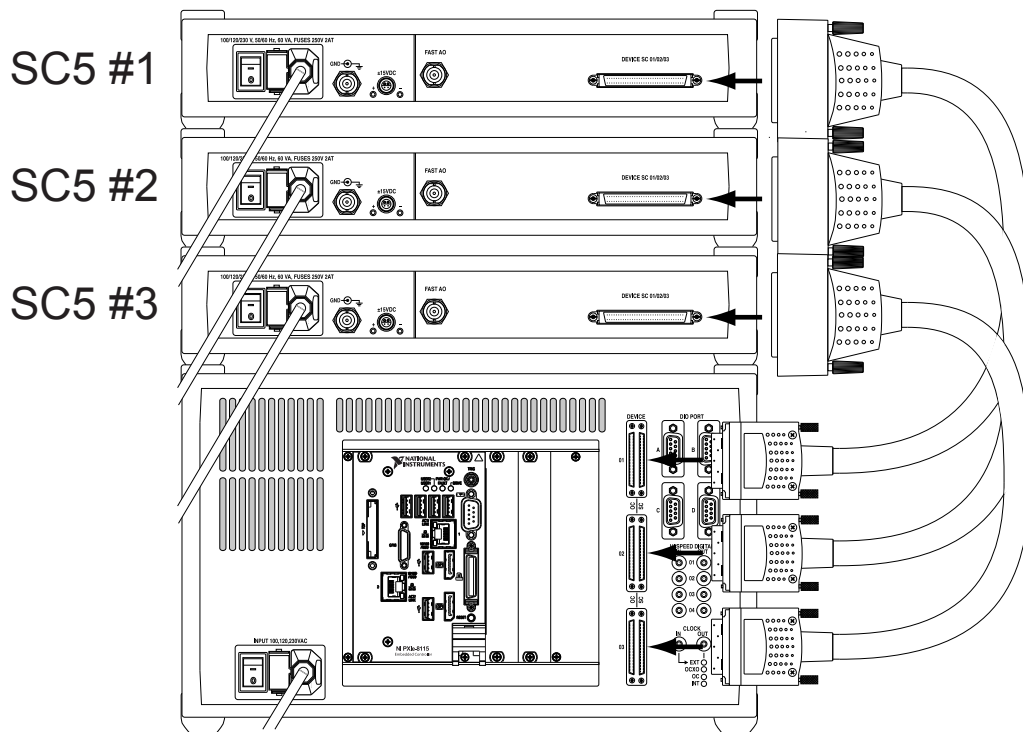


Figure 7: Connection of three SC5s to a RC5. The SC5s are shown placed above the RC5, but they can be also placed below the RC5. Note that this arrangement is recommended only with an external source of forced cooling for the SC5s. Otherwise a mixed arrangement (below and above the RC5) is recommended.



Note: If two SC5s are connected to the RC5, they must be connected to the SC 01 and SC 02 ports at the back of the RC5. Do not connect the second SC5 to the SC 03 port.



Note: The SC5 must be able to dissipate a large amount of heat. It is not recommended to stack three SC5s on top of the RC5 unless an external source of forced cooling provides a stream of air towards the SC5 enclosures. It is recommended to use a mixed arrangement with SC5s placed below and above the RC5.



Caution: Avoid touching the instrument and the BNC connectors if multiple SC5s are stacked on top of each other since the surface of the instruments and the connectors may become very hot. Switch off the instrument and let it cool down before touching it.

Connection to OC4

Only one single cable, supplied with the OC4, is needed as a connection between the OC4 and the real-time controller RC5. The DEVICE RDIO cable is labelled as *SHC68 – 68 – RDIO*, and is identical to the cable used for connecting the SC5. Place the OC4 and RC5 at the desired location, and make sure that the space requirements listed in the previous section are fulfilled.



Note: Please carefully read the OC4 user manual delivered with the Nanonis OC4 before proceeding!



Note: Only use the supplied DEVICE RDIO cable for the connection between the OC4 and RC5. Do not use cables labelled as *SHC68 – 68 – RMIO* or the OC4 will not function.

Single OC4

Make sure that both the OC4 and the RC5 are switched off, but connected to the mains. Connect the DEVICE RDIO cable delivered with the OC4 to the *DIO C1/C2 port* of the OC4 first, then to the *OC 01 port* (8) at the back of the RC5, as shown in the figure below. Always tighten the screws on either side of the connectors.

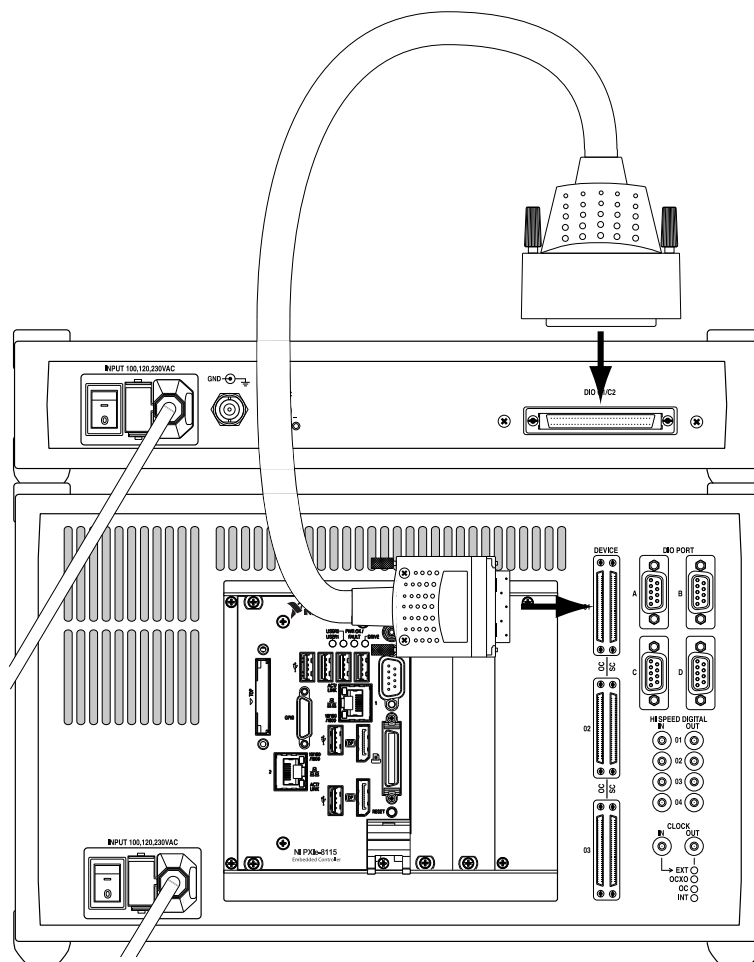


Figure 8: Connection of one OC4 to the RC5. The power cords of both instruments have to be connected to the mains first.



Note: Connect both the OC4 and the RC5 to the mains using the supplied power cords before connecting the instruments together!



Note: Make sure that the screws of the DEVICE RDIO cable connectors are tightened, otherwise the connectors might be damaged. Do not overtighten the screws!



Note: If a single OC4 is connected to the RC5, it must be connected to the OC 01 port at the back of the RC5. Do not connect it to the OC 02 or OC 03 ports.

Multiple OC4s

Up to three Nanonis OC4s can be connected to a single RC5. Follow the instructions given in the previous section for the connection of the additional OC4 units.

Since the different OC4s are addressed by their port number in the Nanonis software, make sure to label the instruments on the front panel in order to recognize which instrument is connected to which port. The figure below shows the maximum configuration with three OC4s connected to the RC5.

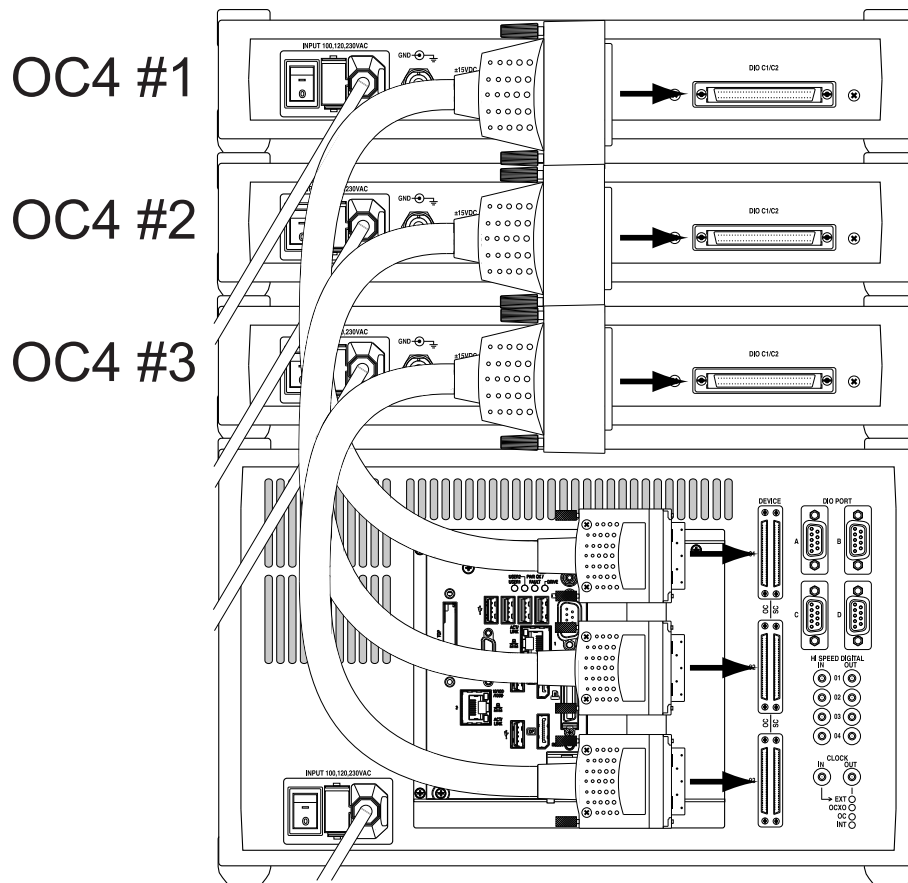


Figure 9: Connection of three OC4s to a RC5. The OC4s are shown placed above the RC5, but they can be also placed below the RC5.



Note: If two OC4s are connected to the RC5, they must be connected to the OC 01 and OC 02 ports at the back of the RC5. Do not connect the second OC4 to the OC 03 port.



Note: The OCXO of the OC4 can be used as a clock reference for the RC5 and all instruments connected to it. Only port OC 01 accepts the clock of the OC4 as a reference, therefore the OC4 providing the clock reference must be connected to this port.

Connection to host computer

The host computer running the control software is connected to the RC5 over a single Gigabit-Ethernet cable. A crossed cable should be used if the RC5 is connected directly to the host computer, while a normal cable should be used if the RC5 is connected over a switch. In both cases Cat-5e or Cat-6 cables should be used.

The cable should be connected to *Ethernet connector 1* (5) at the back of the RC5, as shown in the picture below. Ethernet connector 2 is disabled and should not be used.

For information about how to set-up the network adapter of the host computer, please refer to the *Nanonis SPM Control System* section below.

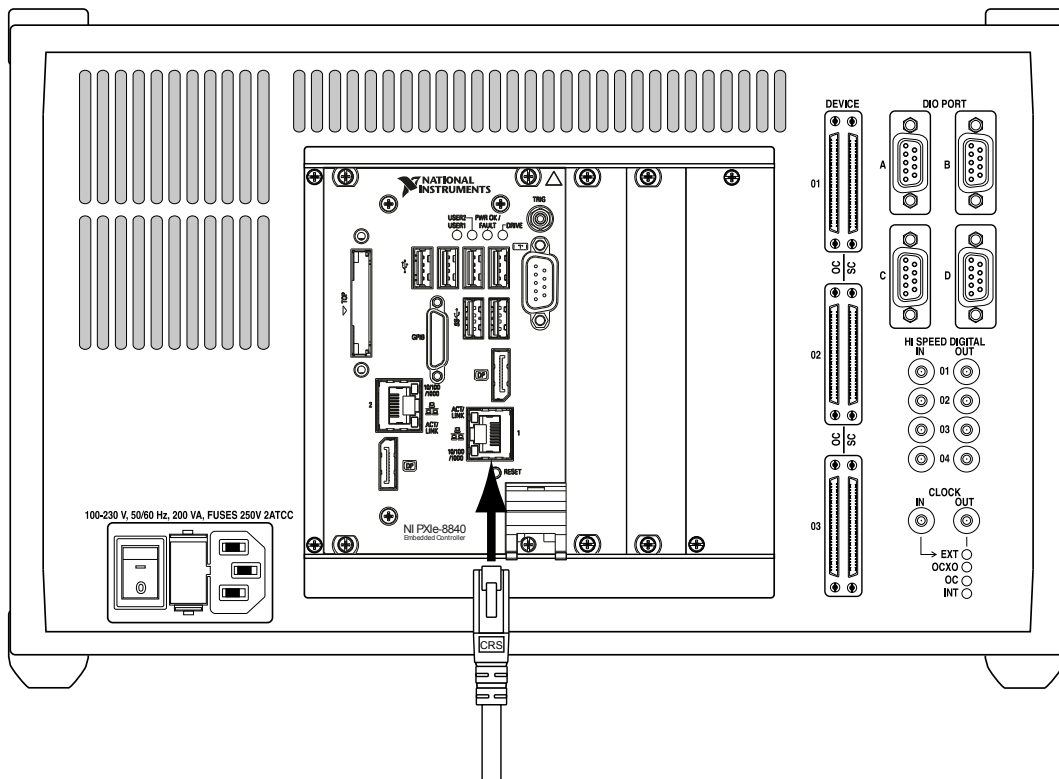


Figure 10: RC5 with NI PXIe-8840 real-time controller: The Ethernet cable for the connection of the RC5 with the host computer should be plugged in Ethernet connector 1 as shown above.

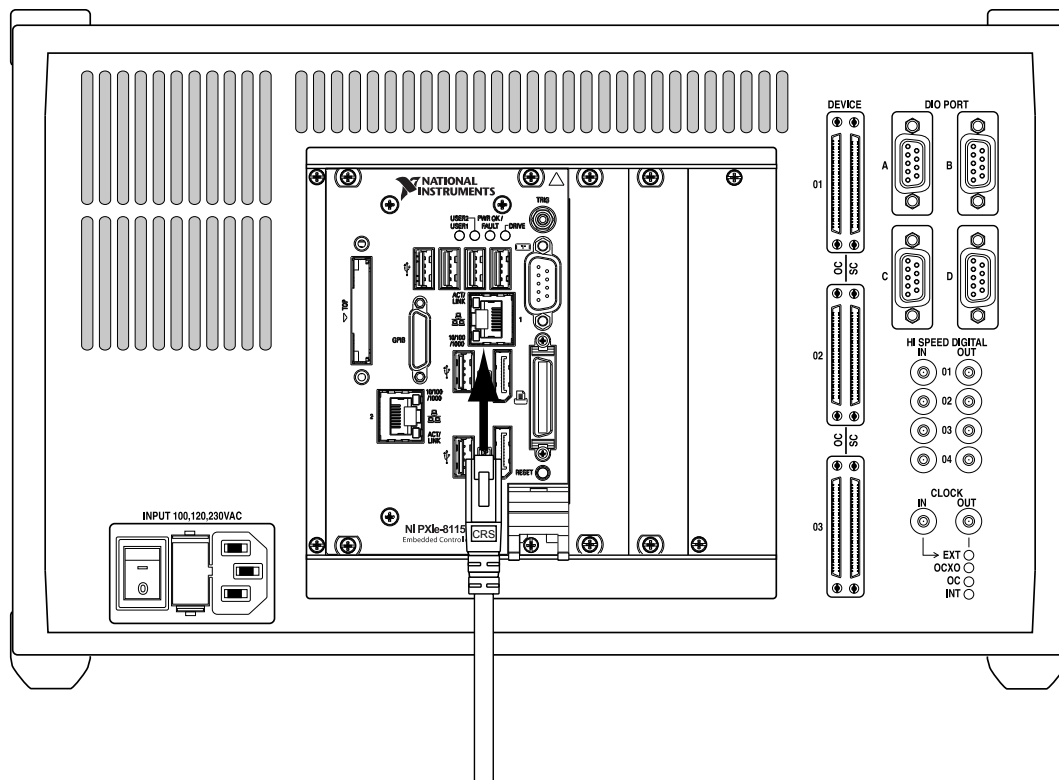


Figure 11: RC5 with NI PXIe-8115 real-time controller: The Ethernet cable for the connection of the RC5 with the host computer should be plugged in Ethernet connector 1 as shown above.

Connection to computer screen

A computer screen connected to the [DisplayPort connector](#) (6) of the RC5 displays status information about the instrument. Connecting a computer screen to the RC5 is not necessary during normal operation, but it can help to trace a fault in case one of the following issues should occur:

- A connection between host computer and RC5 cannot be established and the RC5 does not respond to a “ping” request.
- The software does not detect the RC5
- A Warning indicates a wrong real-time operating system release, and the update fails
- A real-time operating system update fails
- None of the instruments connected to the RC5 seems to be responding

A computer screen is connected using a DisplayPort cable as indicated in the figure below on the left. For computer screens using a VGA input, the supplied DisplayPort to VGA adapter should be used, as shown below on the right. For computer screens using DVI inputs, a DisplayPort to DVI adapter (not supplied) should be used.

Note: Certain computer screens connected over the DisplayPort to VGA adapter might not be recognized if plugged when the RC5 is already running. If nothing appears on the screen connected to the RC5, although the RC5 is running, it is necessary to restart the RC5 by switching it off and then on again.

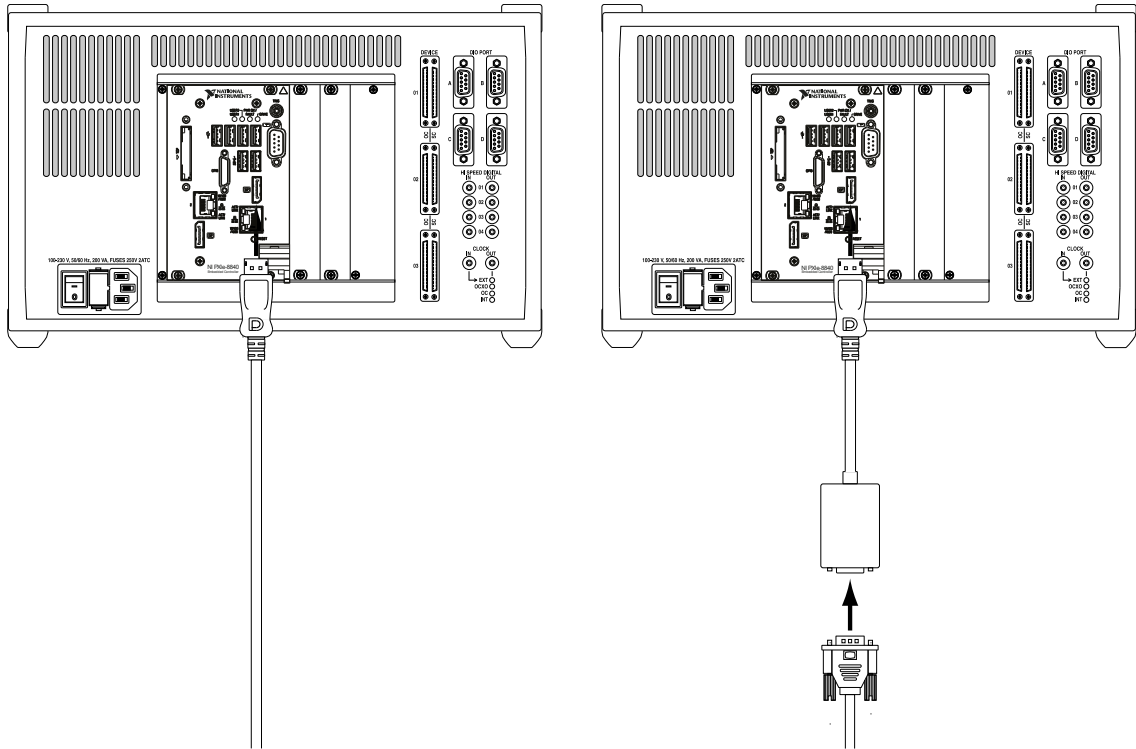


Figure 12: Connection of a computer screen to the DisplayPort connector of the RC5 (with NI PXIe-8840 real-time controller) using a DisplayPort cable (left). Connection to a computer screen using the supplied DisplayPort to VGA adapter (right). An adapter to DVI (not supplied) must be used for computer screens with DVI input only.

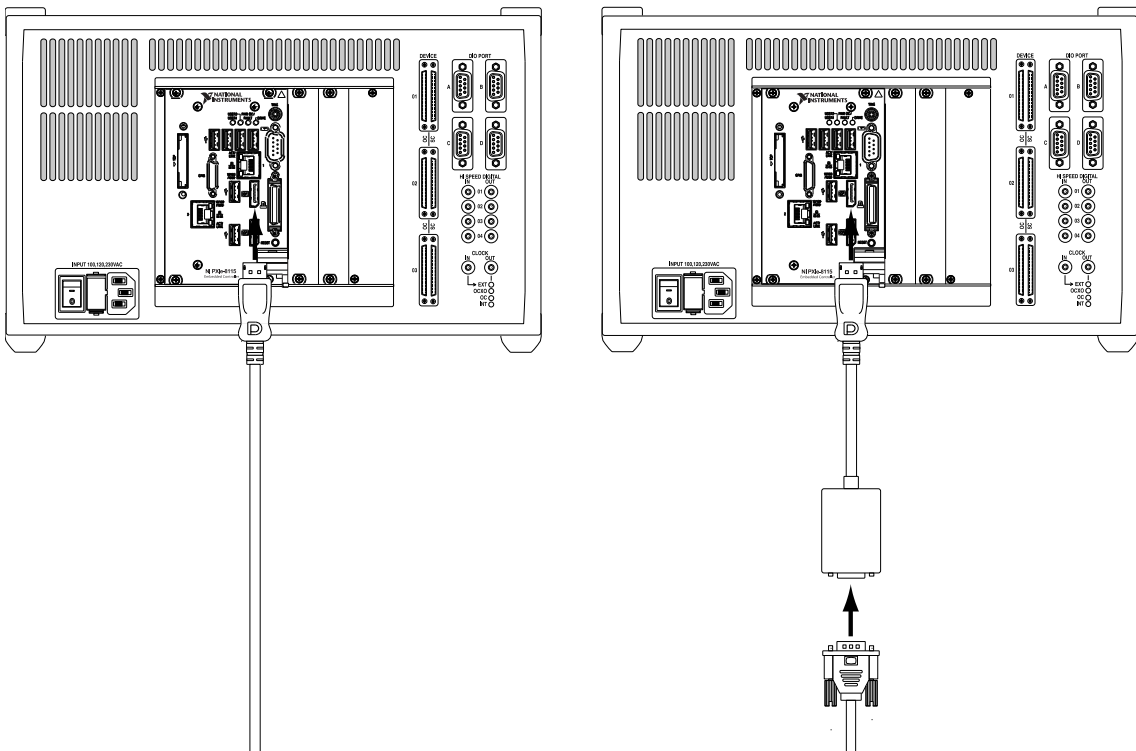


Figure 13: Connection of a computer screen to the DisplayPort connector of the RC5 (with NI PXIe-8115 real-time controller) using a DisplayPort cable (left). Connection to a computer screen using the supplied DisplayPort to VGA adapter (right). An adapter to DVI (not supplied) must be used for computer screens with DVI input only.

Powering

Before powering the RC5, make sure that:

- All SC5s and OC4s are connected to the RC5.
- If an external clock source is used as the clock reference, this source is connected and active.

Then turn on the RC5 with the *power switch* (2) located at the back of the unit (see picture below). The *power LED* (1) will turn on.

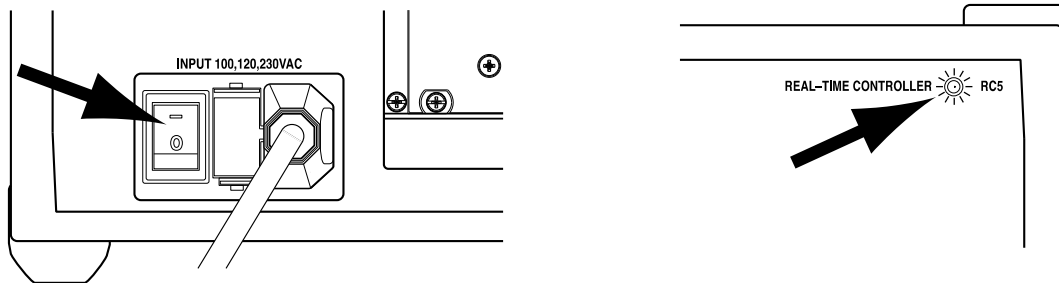


Figure 14: Powering up the RC5. Left side: Location of the power switch at the back of the RC5. Right side: LED which will turn on after powering the unit.

The RC5 is now ready for use. Should the RC5 not turn on as described above, please refer to the *Troubleshooting* section before proceeding. If a solution to the unexpected behavior is not listed there, please contact SPECS before taking any further action.

How to proceed

- Make sure that all SC5s and OC4s which will be operated are connected to the RC5, as explained in the *Connection to SC5* and *Connection to OC4* sections
- Connect an active external clock source to the *Clock input connector* (11) (only if the internal clock sources are not used), as explained in the *Clock* section
- Connect the instruments requiring digital communication to the *DIO ports* (9), as explained in the *DIO ports* section
- Connect the instruments requiring high-speed digital signals to the *High Speed Digital Input* (10) and *Output* (14) connectors as explained in the *High Speed Digital Inputs* and *High Speed Digital Outputs* sections
- Turn on the OC4s
- Turn on the SC5s
- Turn on the RC5

DIO ports

The four DIO ports (DIO: Digital Input Output) of the RC5 are independent bidirectional digital interfaces with eight signal lines each with a TTL signal level of 3.3 V. Each port uses a D-sub9 female connector, with one pin used for digital ground. The maximum current in output mode is 25 mA for each pin, and the maximum bandwidth of the signal lines is 500 kHz. The ports can therefore also be used for controlling external instruments over a Serial Peripheral Interface bus (SPI). The DIO ports should not be used for pulse counting purposes. The *High Speed Digital Inputs* should be used instead.

Nanonis instruments requiring control over a digital interface like the *Nanonis PMD4* and *PD5* have to be connected to these ports.

DIO ports connection

A connection to the DIO ports has to be made using cables fitted with a D-sub9 male connector. A conventional D-sub9 1:1 cable can be used for this purpose. All Nanonis instruments requiring a connection to a DIO port (*Nanonis PMD4*, *PD5*, *HVA4*, as well as all adaptation kits) are delivered with a suitable double-shielded cable. For these instruments, do not replace the double-shielded cable with a conventional cable.

For all Nanonis products requiring a connection to a *DIO port*, as well as for many third-party instruments, the DIO port to be used is specified within the license file of the Nanonis system. Please make sure to connect the instrument to the correct DIO port. The picture below shows the connection to *DIO port A*.

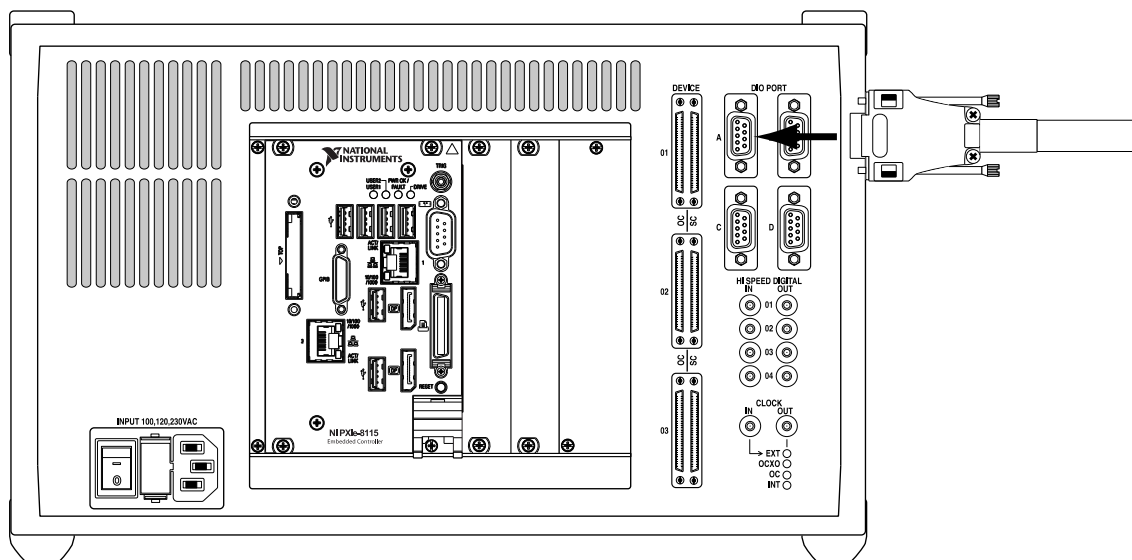


Figure 15: Connection of a digital cable to a DIO port of the RC5 (DIO port A shown).

DIO ports schematic and connector pin layout

The *DIO ports* are connected to the signal distribution unit over a general purpose input output (GPIO) expander, which provides electrical protection and isolation. The ground line of the DIO ports is connected to digital ground of the RC5. All four ports use D-sub9 female connectors. The following picture shows the schematic of one of the ports. All four ports are identical.

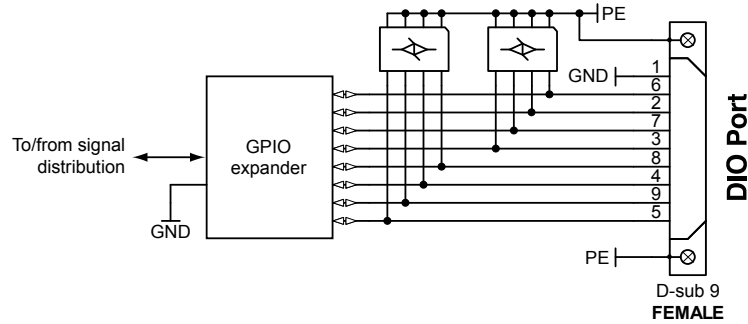


Figure 16: DIO ports schematic. All four DIO ports have the same electrical configuration.

For the pin assignment of the DIO ports, see the figure and table below.

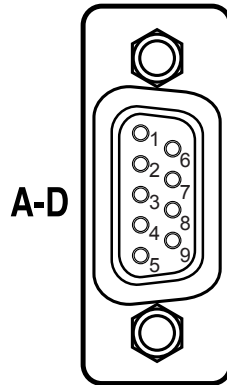


Figure 17: DIO port pin configuration. The pin configuration is valid for all four DIO ports A to D.

PIN	Digital line
1	DGND
2	DIO1
3	DIO3
4	DIO5
5	DIO7
6	DIO0
7	DIO2
8	DIO4
9	DIO6

Table 1: Signal assignment of the DIO port of the RC5.

Specifications (DIO ports)

Lines set to input

Pull-up resistance	100 k Ω \pm 40%
Low input threshold	< 0.8 V
High input threshold	> 2.0 V
Maximum input voltage	5.5 V
Input capacitance	< 10 pF
Input leakage current	\pm 10 μ A

Lines set to output

Nominal output level	3.3 V
High output voltage	> 2.6 V (@ 8 mA load)
Low output voltage	< 0.5 V (@ 8 mA load)
Maximum current per line	25 mA (max. 100 mA per connector)

Timing

Maximum sampling frequency	500 kHz
----------------------------	---------

High Speed Digital Inputs

The four *high speed digital inputs* of the RC5 offer a high-speed input interface typically used for pulse-counting purposes. In contrast to the DIO ports, which are designed for frequencies up to 500 kHz, the high speed digital inputs can accept input signals with frequencies up to 200 MHz. Each input uses a SMB male connector, with the shield connected to digital ground.

High speed digital inputs connection

Connection to the high speed digital inputs has to be made using a cable fitted with female SMB connectors. The connectors can be straight or angled. The connection of SMB cables is shown in the picture below.

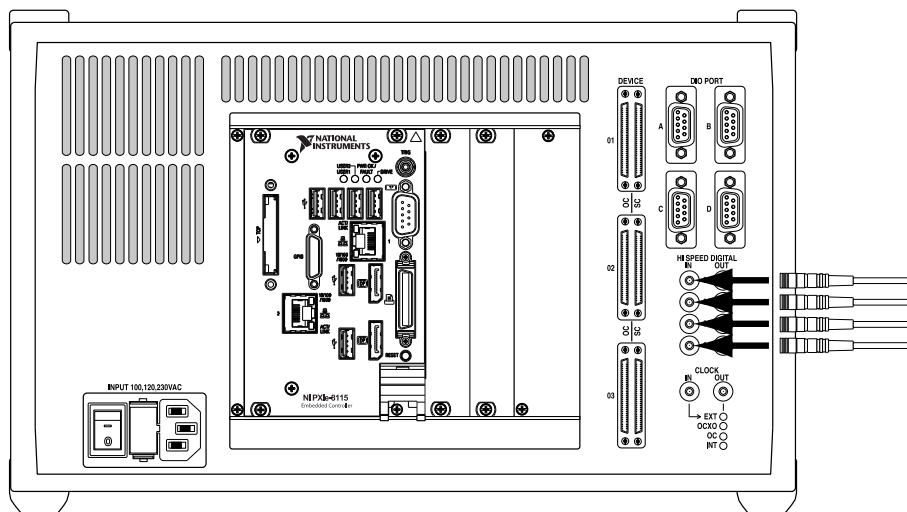


Figure 18: Connection of SMB cables to the high speed digital inputs.

High speed digital inputs schematic

The signal applied to the *High Speed Digital Inputs* is converted to a LVDS signal after passing protection and level matching circuits. The shield of the SMB connector is connected to digital ground of the RC5. All four inputs use SMB male connectors. The following picture shows the schematic of the four high speed digital inputs.

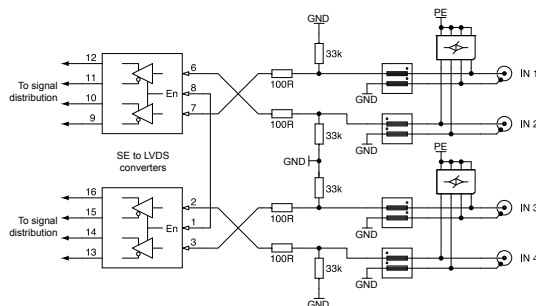


Figure 19: Schematic of the High Speed Digital Inputs.

Specifications (high speed digital inputs)

Electrical parameters

Nominal high input level	3.3 V (5 V TTL tolerant)
Low input threshold	< 0.8 V
High input threshold	> 2 V
Maximum input voltage	6 V
Input capacitance	< 10 pF

Timing

Maximum sampling frequency	200 MHz
----------------------------	---------

High Speed Digital Outputs

The four *High Speed Digital Outputs* of the RC5 offer a high-speed output interface typically used for fast pulse-generation purposes. As for the *High Speed Digital Inputs*, in contrast to the DIO ports, which are designed for frequencies up to 500 kHz, the high speed digital outputs can generate signals with frequencies up to 200 MHz. Each output uses a SMB male connector, with the shield connected to digital ground.

High speed digital outputs connection

Connection to the high speed digital outputs has to be made using a cable fitted with female SMB connectors. The connectors can be straight or angled. The connection of SMB cables is shown in the picture below.

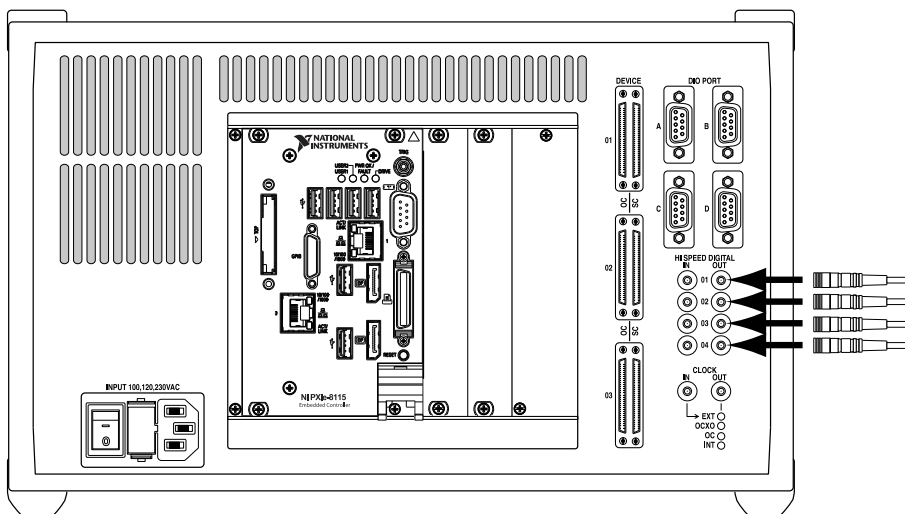


Figure 20: Connection of SMB cables to the high speed digital outputs.

High speed digital outputs schematic

The high speed digital outputs are driven by high speed signal drivers with paralleled outputs, which can drive long cables. The shield of the SMB connector is connected to digital ground of the RC5. All four outputs use SMB male connectors. The following picture shows the schematic of the four high speed digital outputs.

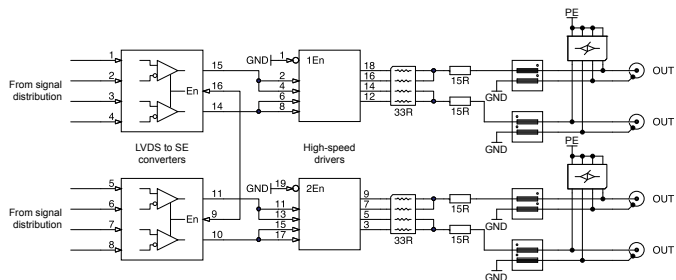


Figure 21: Schematic of the high speed digital outputs.

Specifications (high speed digital outputs)

Electrical parameters

Nominal output level	3.3 V
Output impedance	$\cong 50 \Omega$
High output voltage	$> 2.0 \text{ V @ } 33 \text{ mA load}$
Low output voltage	$< 0.4 \text{ V @ } 33 \text{ mA load}$
Maximum current per line	33 mA

Timing

Maximum sampling frequency	200 MHz
----------------------------	---------

Clock

Clocking options

The RC5 can accept four different clock sources, which are selected automatically when the RC5 is powered on based on a priority list. The clock source can be either the low phase-noise clock of the FPGA, an optional oven-controlled crystal oscillator (OCXO) which can be fitted to the RC5, the OCXO of a Nanonis OC4, or an external clock 10 MHz source. Only one clock source will be used, while clock sources at a lower priority will be ignored. The clock signal is used as a clock reference for all instruments connected to the RC5. The clock signal from the selected clock source is then available at the *CLOCK OUT connector* (13).

The clock source is selected during power-up of the RC5 according to the following priority list:

- **First priority: External 10 MHz clock source, e.g. atomic clock.** As soon as a valid clock signal is applied to the *CLOCK IN connector* (11) it is used as a clock reference for the RC5 and all instruments connected to it. The internal optional OCXO, the OCXO clock signal of the attached OC4, as well as the internal FPGA clock signals are ignored.
- **Second priority: Optional internal OCXO.** If the optional OCXO is installed, and no valid clock signal is applied to the *CLOCK IN connector* (11), its signal is used as a clock reference for the RC5 and all instruments connected to it. The OCXO clock signal of the attached OC4, as well as the internal FPGA clock signals are ignored.
- **Third priority: OCXO of a Nanonis OC4.** If a Nanonis OC4 is connected to the RC5, its clock signal is used as a clock reference for the RC5 and all instruments connected to it, if no valid clock signal is applied to the *CLOCK IN connector* (11), and the optional internal OCXO is not installed. The internal FPGA clock signal is ignored. The OC4 providing the clock source must be connected to the *OC 01 port*.
- **Fourth priority: Internal FPGA clock.** If none of the other clock sources are available, the internal FPGA clock is used as a clock reference for the RC5 and all instruments connected to it.



Note: Before connecting an external clock source, make sure that its frequency is 10 MHz and that the signal level is 3.3 V.

The Clock Source LEDs (12) indicate which clock source is active, and therefore which clock source is available at the *CLOCK OUT connector* (13). Only one source can be active at one time, therefore only one LED can be lit at one time. The picture below shows the situation for an active external clock source.

If an external clock source is connected to the *CLOCK IN connector* but the EXT LED does not light up, then the external clock signal does not comply with the frequency and amplitude requirements. Please check the *Clock ports specifications* section and make sure that the external clock source provides a compatible clock signal.

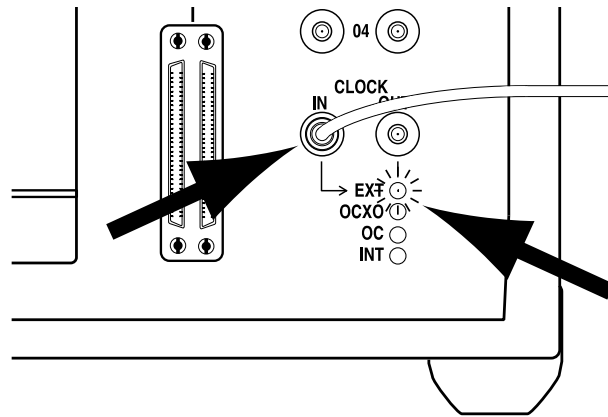


Figure 22: Function of the Clock Source LEDs: In this case, an external clock source is connected to the **CLOCK IN** connector. The **EXT** LED lights up, indicating that the external clock is chosen as reference clock, and that the **CLOCK OUT** connector outputs this clock signal.

Clock ports connection

Connection to the *Clock ports* (11,13) has to be made using a cable fitted with female SMB connectors. The connectors can be straight or angled. An example for the connection of an external clock source is shown in the figure above.

A connection to the clock ports is required only if:

- The clock reference of external instruments has to be synchronized with the clock reference of the RC5. In this case the signal available on the *CLOCK OUT connector* (13) has to be connected to the reference clock input of the external instrument.
- The RC5 and all instruments connected to it have to be synchronized with an external clock reference, e.g. an atomic clock. In this case the external reference should be connected to the *CLOCK IN connector* (11).

Clock ports schematic

The clock input and output circuits are identical to those of the *High Speed Digital Inputs* and *Outputs*. The schematic is shown in the picture below.

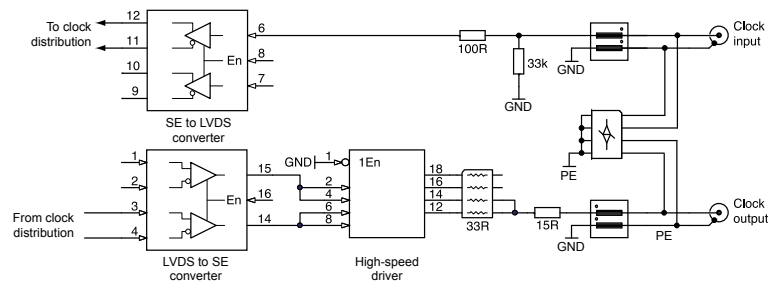


Figure 23: Schematic of the clock input and output.

Optional OCXO clock mounting instructions

The optional OCXO is user-installable and can also be fitted to the RC5 after purchase of the instrument. The oscillator is delivered without other components, and needs to be inserted into a dedicated socket on the signal distribution board inside the RC5.

In order to install the OCXO, the RC5 needs to be opened. The following tools are required:

- 3 mm hex screwdriver



Note: Installation of the optional OCXO requires the RC5 to be opened, and requires the placement of a relatively small object close to electronic components sensitive to electrostatic discharge (ESD). Make sure to follow all directives for handling ESD sensitive components before proceeding. A wrist strap connected to ground must be worn when performing the modification. Please send the RC5 back to SPECS for the modification if there is any doubt about how the modification should be performed.

Before proceeding with the installation of the optional OCXO, please make sure that:

- All instruments (SC5s and OC4s) are disconnected from the RC5
- All DIO, High Speed Digital Input and Output, as well as Clock input and Output cables are disconnected from the RC5
- The RC5 is disconnected from the mains.



Warning: Lethal voltages are present inside the RC5.



Note: Before installing the optional OCXO, make sure that the RC5 is disconnected from the mains.



Caution: The inner frame of the RC5 and the printed circuit boards have sharp edges. Proceed with care in order to avoid injury.

Once the above criteria are fulfilled, put the RC5 on a stable and sufficiently large surface. Remove the four plastic caps covering the screws which hold the top cover of the instrument as shown in the figure below, and remove the screws by turning them CCW using the 3 mm hex screwdriver. Make sure not to lose the lock washers placed below the screws. The top cover can now be carefully lifted, and should be put on the side of the instrument. Note that there is a grounding wire connecting the top cover with the rest of the instrument. This prevents the top cover being completely separated from the unit but allows the top cover to be lifted by approx. 10 cm to facilitate removal.

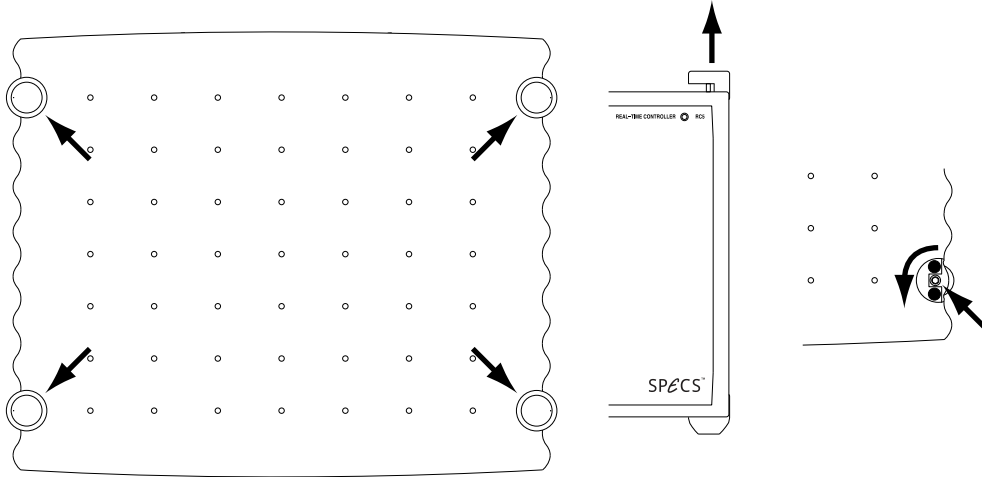


Figure 24: Removing the top cover of the RC5: First remove the four plastic caps covering the screws by lifting them, then remove the four screws by turning CCW with a 3 mm hex screwdriver.

After removal of the top cover, face the rear panel of the instrument. The optional OCXO needs to be installed in a dedicated socket located on the printed circuit board in the right part of the instrument as shown below.

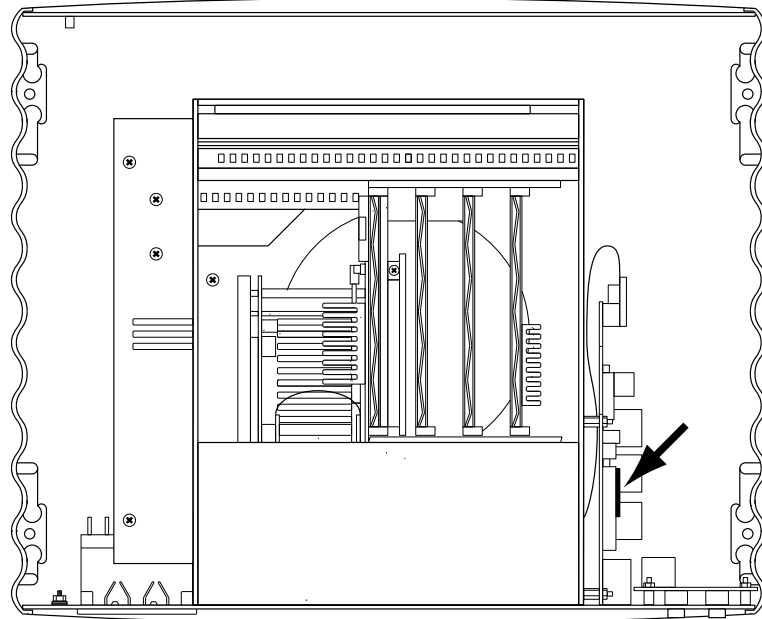


Figure 25: Internal view of the RC5. The location of the optional OCXO socket is indicated by the arrow.

The figure below shows the correct orientation of the optional OCXO.

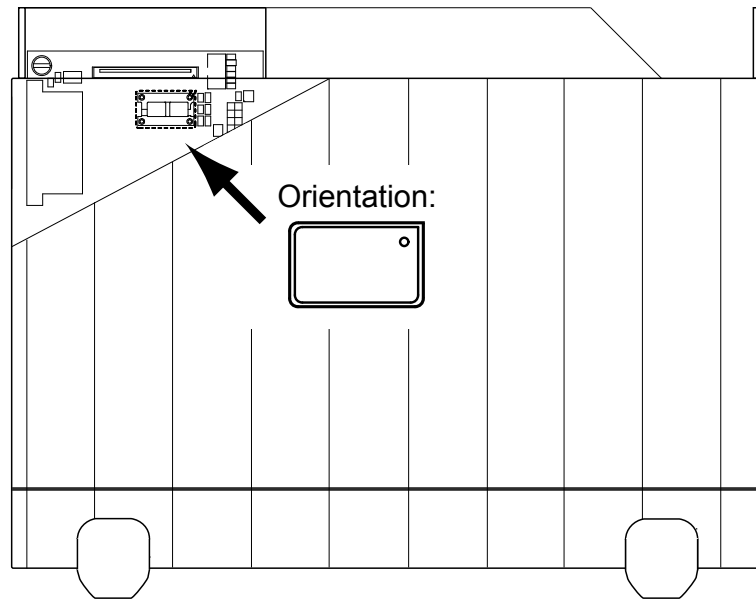


Figure 26: Mounting position and orientation of the optional OCXO (side view, in reality the components are behind the side panel). Pin 1 has to be positioned on the upper right. Note that a ribbon cable covers the OCXO socket, and needs to be lifted. Do not remove the ribbon cable.



Note: Make sure to install the optional OCXO as shown in the picture above. Installing it in the wrong orientation might lead to damage of the OCXO and malfunctioning of the RC5.

Once the optional OCXO is correctly installed, the RC5 will use it as its clock source, as long as no external source is connected to the *CLOCK IN connector* (11).



Warning: Avoid any physical contact with or modification of the areas of the instrument marked by the high voltage warning sign, as this might impair the safety of the instrument.



Note: Make sure that the grounding wire is still firmly connected to the top cover and to rear panel before closing the instrument. A loose grounding wire will impair safety of the instrument. Also make sure that no OCXO, screws, tools, or other objects have been dropped or forgotten inside the instrument. Any object left inside the instrument might impair its safety.

Specifications (clock)

Internal Clock and optional OCXO specifications

Internal Clock

Accuracy	±50 ppm
Maximum jitter	5 ps RMS phase jitter (10 Hz – 1 MHz range)

Optional OCXO

Accuracy	±4 ppm
Maximum jitter	5 ps RMS phase jitter (10 Hz – 1 kHz range)
Phase noise (bandwidth = 1 Hz)	-70 dBc/Hz @ 1 Hz -100 dBc/Hz @ 10 Hz -130 dBc/Hz @ 100 Hz -140 dBc/Hz @ 1 kHz
Short term stability	< 5E-10 (0.1 s to 30 s), 5E-11 typical @ 1 s
Frequency stability over temperature	±0.075 ppm (0.15 ppm p-p) 0 to 60°C
Frequency stability over time	First year: < ±0.7 ppm After 10 Years: < ±4.0 ppm

Clock ports specifications

Electrical parameters (input)

Nominal high input level	3.3 V (5 V TTL tolerant)
Low input threshold	< 0.8 V
High input threshold	> 2 V
Maximum input voltage	6 V
Input capacitance	< 10 pF

Timing requirements (input clock)

Required clock frequency	10 MHz
Signal rise and fall time requirement	< 5 ns
Duty cycle range	40% - 60%

Electrical parameters (output)

Nominal output level	3.3 V
Output impedance	≅ 50 Ω
High output voltage	> 2.0 V @ 33 mA load
Low output voltage	< 0.4 V @ 33 mA load
Maximum current	33 mA

Timing (output)

Clock frequency	10 MHz
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Upgrades and replacements

Firmware update

The RC5 is delivered with a firmware which defines all functionality and enables connection with all instruments described in this manual. Changes to these parameters might require a firmware update.



Note: Perform a firmware update only if instructed to do so by SPECS. An update of the firmware without being advised to do so by SPECS voids the RC5 warranty.

Note: Firmware upgrades should not be confused with real-time software upgrades. The latter is performed automatically from the Nanonis software when required. A firmware upgrade is only necessary when hardware-related changes require new or modified functions of the signal and clock distribution unit.

Updating the firmware is a simple procedure, which only requires replacing a small printed circuit board (PCB) inside the RC5. There is no software operation required, and the RC5 does not need to be connected to the host PC. The board is shipped by postal mail if required. Please ship the old firmware PCB back to SPECS once the new one has been installed.

In order to replace the firmware PCB, the RC5 needs to be opened. The following tools are required:

- 3 mm hex screwdriver



Note: A replacement of the firmware PCB requires the RC5 to be opened, and requires to place a relatively small object close to electronic components sensitive to electrostatic discharge (ESD). Make sure to follow all directives for handling ESD sensitive components before proceeding. A wrist strap connected to ground must be worn when performing the modification. Please send the RC5 back to SPECS for the replacement if there is any doubt about how the modification should be done.

Before proceeding with the replacement of the firmware PCB, please make sure that:

- All instruments (SC5s and OC4s) are disconnected from the RC5
- All DIO, High Speed Digital Input and Output, as well as Clock input and Output cables are disconnected from the RC5
- The RC5 is disconnected from the mains.



Warning: Lethal voltages are present inside the RC5.



Note: Before replacing the firmware PCB, make sure that the RC5 is disconnected from the mains.



Caution: The inner frame of the RC5 and the printed circuit boards have sharp edges. Proceed with care in order to avoid injury.

Once the above criteria are fulfilled, put the RC5 on a stable and sufficiently large surface. Remove the four plastic caps covering the screws which hold the top cover of the instrument as shown in the figure below, and remove the screws by turning them CCW using the 3 mm hex screwdriver. Make sure not to lose the lock washers placed below the screws. The top cover can now be carefully lifted, and should be put on the side of the instrument. Note that there is a grounding wire connecting the top cover with the rest of the instrument. This prevents the top cover being completely separated from the unit but allows the top cover to be lifted by approx. 10 cm to facilitate removal.

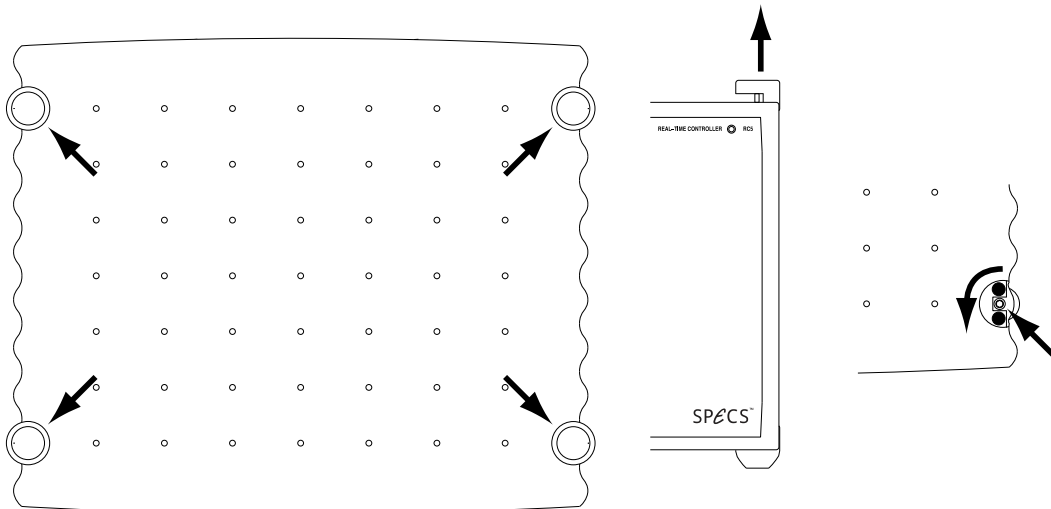


Figure 27: Removing the top cover of the RC5: First remove the four plastic caps covering the screws by lifting them, then remove the four screws by turning CCW with a 3 mm hex screwdriver.

The figure below shows the location of the firmware PCB.

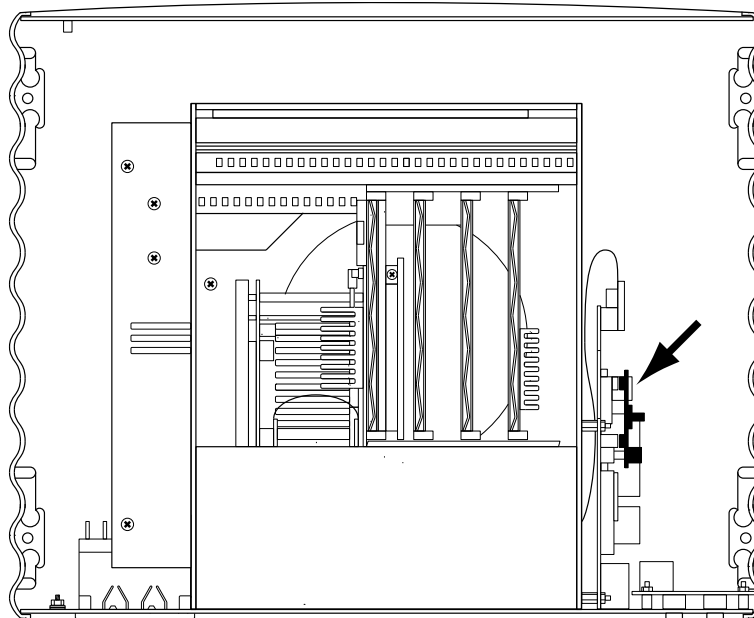


Figure 28: Internal view of the RC5. The location of the firmware PCB is indicated by the arrow.

In order to remove the firmware PCB, the board needs to be removed from its sockets by pulling to the right when the RC5 is oriented as shown in the picture above. The new firmware PCB is inserted by pushing it into the socket left empty after removing the old one. Removing the firmware PCB might require some force to be applied. Make sure to keep the main printed circuit board (onto which the firmware PCB is plugged) in place when removing the firmware PCB by holding it tightly. Do not use pliers for this purpose, as the board could be damaged.



Warning: Avoid any physical contact with or modification of the areas of the instrument marked by the high voltage warning sign, as this might impair the safety of the instrument.



Note: Make sure that the grounding wire is still firmly connected to the top cover and to rear panel before closing the instrument. A loose grounding wire will impair safety of the instrument. Also make sure that no firmware board, screws, tools, or other objects have been dropped or forgotten inside the instrument. Any object left inside the instrument might impair its safety.

Real-time unit replacement

A replacement of the real-time unit is necessary only in the following cases:

- Malfunction of the unit (see the [troubleshooting](#) section for details).
- Increased CPU-load from future revisions of the software requires more CPU processing power, which might be available with future models of the real-time unit.
- Any other reason for which more CPU processing power than available with the originally delivered real-time unit might be necessary.



Note: Please contact SPECS before replacing the real-time unit, if not instructed to do so by SPECS. Not all PXIe real-time units might be compatible with the Nanonis software. Any unsolicited replacement of the real-time unit is done at own risk and voids the RC5 warranty.



Note: By replacing the real-time unit, the MAC address of the network adapter also changes. The software license files are therefore not valid anymore, and the control software will not start with the replacement real-time unit. Please contact SPECS in order to obtain a new license file, and provide the network adapter MAC address of the new real-time unit.

In order to replace the real-time unit, loosen the four screws marked by the arrows in the figure below. Then, push down the the lever at the lower right, and pull-out the complete RT-unit from the RC5 enclosure.

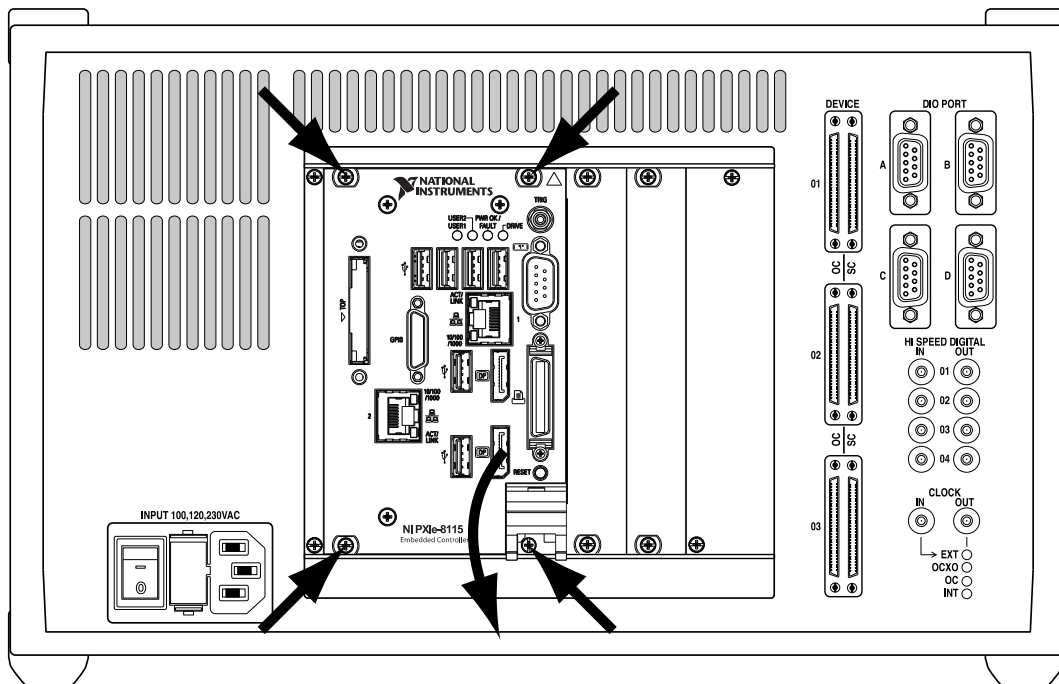


Figure 29: Removal of the real-time-unit: After loosening the four screws marked by the arrows, the lever at the lower right can be pushed down, and the RT-unit pulled out of the RC5 enclosure.

The new real-time unit is inserted by repeating the above procedure in the inverse order. Make sure to carefully align the real-time unit with the guiding rails inside the RC5, or the unit cannot be inserted correctly into its slot.

FPGA card replacement

A replacement of the FPGA card is necessary only in the following cases:

- Malfunction of the FPGA card.
- Future software revisions require the change of the FPGA card. Users who might require a change of the card will be contacted by SPECS.



Warning: Only the FPGA card delivered inside the RC5, or FPGA cards which SPECS explicitly recommends as a replacement are compatible with the Nanonis software. Other PXIe FPGA cards will not work. Any unsolicited replacement of the FPGA card voids the RC5 warranty.



Caution: Replacement of the FPGA card requires disconnecting a connector, which could be easily damaged if not extracted with great care. Please send the RC5 back to SPECS for the replacement if there is any doubt about how the modification should be done.

In order to replace the FPGA card, loosen the two screws marked by the arrows in the leftmost figure below. Then, remove the metallic cover in order to reveal the connector to the FPGA card as shown in the center. Very carefully extract the connector, making sure not to apply any force on the flexible flat-cable, and place it on the right of the FPGA card slot, so that the card can be extracted. In order to extract the FPGA card, loosen the two screws marked by arrows in the rightmost figure below, and pull the FPGA card out of the RC5 enclosure.

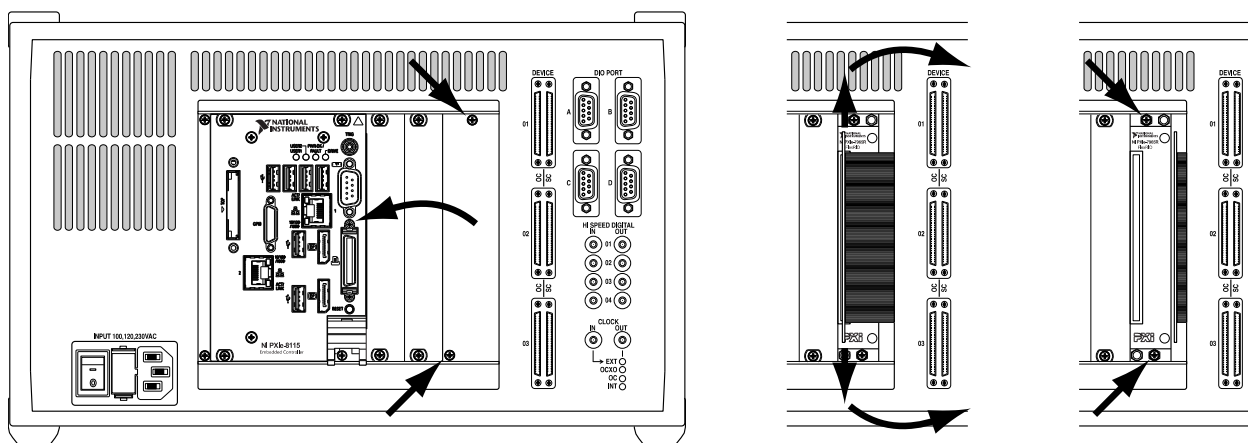


Figure 30: Removal of the FPGA card. Left: after loosening the two screws marked by the arrows, the metallic cover can be removed. Center: The FPGA connector can be extracted by pulling on both the upper and lower edges of the green printed circuit board, as marked by the arrows. Care should be taken not to pull on the flexible flat-cable at the right of the connector. The connector can be placed at the right, in order to allow the FPGA card to be taken out. Right: The two screws marked by the arrow need to be untightened, then the FPGA card can be removed by pulling on the screws, which are anchored to the card.

The new FPGA card is inserted by repeating the above procedure in the inverse order. Make sure to carefully align the FPGA card with the guiding rails inside the RC5, and make sure to insert the connector perpendicularly to the rear panel, without applying any lateral forces.

Example: Nanonis SPM Control System, Tramea and OC4.5-S

This chapter describes how the RC5 is connected to and used with a typical *Nanonis SPM Control System* or *Nanonis Tramea*™ configuration, and how the host computer has to be configured. Please make sure that you have read and understood the sections above before proceeding. All safety warnings are also valid for this section. For more information about the other instruments shown in the following paragraphs, please refer to the corresponding user manuals.

SPM Control System: Connections on the rear side of the instruments

In a typical SPM controller configuration, the following instruments are connected to the RC5:

- **Nanonis SC5 and OC4.** Connected to the *Device Connectors* (7, 8).
- **Nanonis HVA4, PMD4, PD5, all Nanonis adaptation kits, as well as third-party instruments e.g. preamplifiers or piezo motor drivers.** Connected to the *DIO ports* (9).
- **Host PC.** Connected to the *Ethernet port* (5).
- **Additional instruments, clock source.** Connected to the *High Speed Digital Inputs and Outputs* (10, 14), or the *clock ports* (11, 13).

The following picture shows a Nanonis SPM control system with two SC5s, two OC4s, one HVA4, and one PMD4a. Cables other than those connected or related to the RC5 have been omitted. This is a rather complex configuration. The simplest configuration is the *Nanonis SPM Base Package*, which includes the RC5 and one SC5.

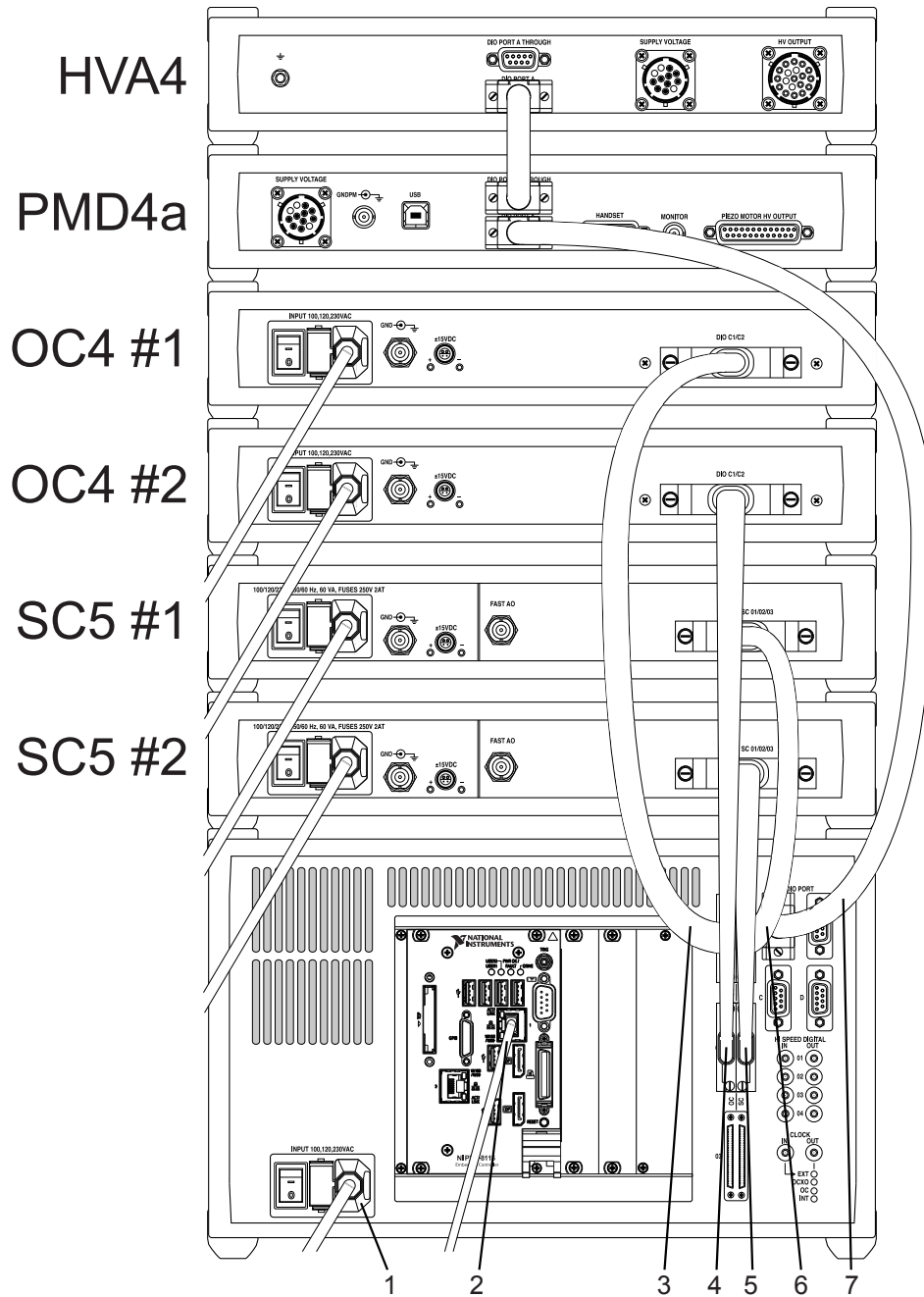


Figure 31: Rear panel of a Nanonis SPM system showing the connections used for the operation of the RC5. 1: Power cord, 2: Ethernet cable, 3: DEVICE RDIO cable to the first OC4, 4: DEVICE RDIO cable to the second OC4, 5: DEVICE RDIO cable to the second SC5, 6: DEVICE RDIO cable to the first SC5, 7: DIO cable to PMD4 and HVA4. Note: The devices can be stacked in a different order, the picture above is an example.



Caution: Nanonis systems including a RC5 and many other instruments can become very tall if all instruments are stacked on top of each other. Make sure that the supporting table is stable enough, or place the instruments in two different stacks (e.g. low voltage and high voltage instruments in different stacks).

Nanonis Tramea: Connections on the rear side of the instruments

The following picture shows the configuration of a *Nanonis Tramea*™ with 8 I/Os, consisting of a RC5 and one SC5. This configuration corresponds to the Nanonis SPM Base Package in terms of hardware.

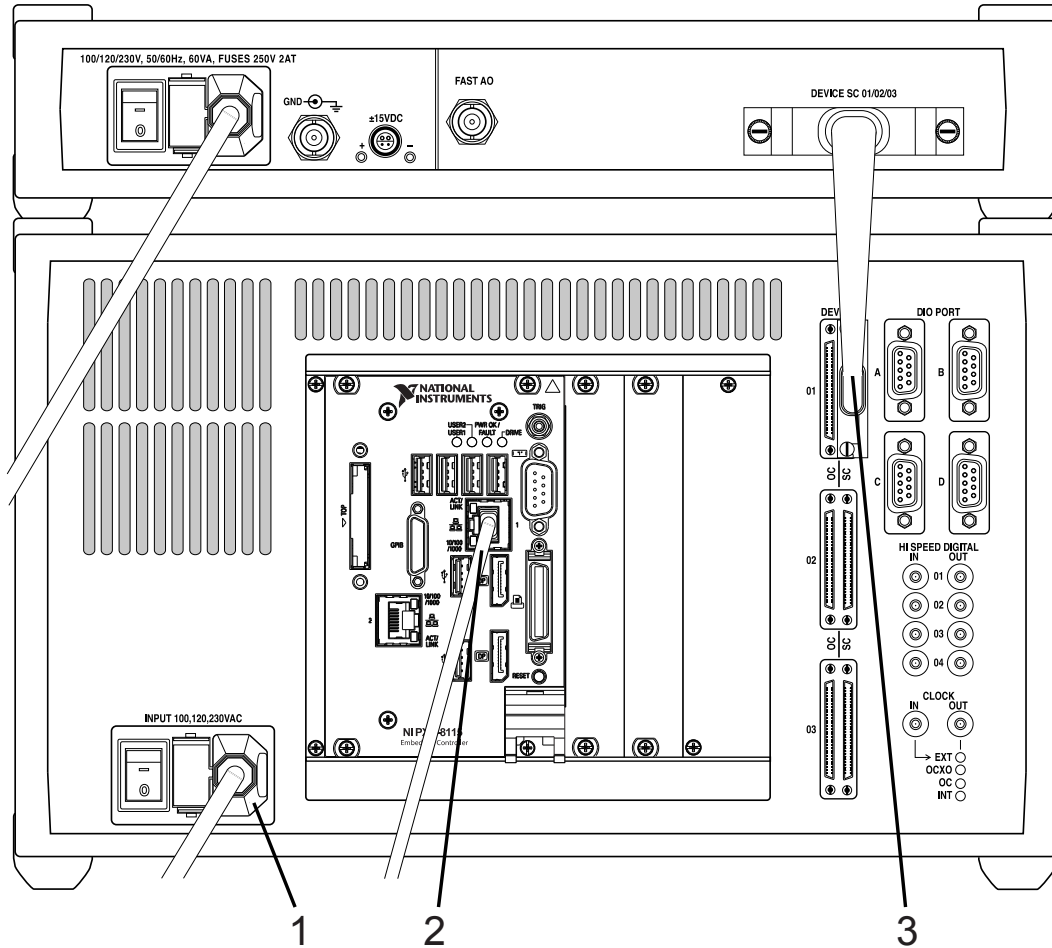


Figure 32: Rear panel of a Nanonis Tramea™ with single SC5. 1: Power cord, 2: Ethernet cable, 3: DEVICE RDIO cable to SC5 connected to SC5 device connector 01.

OC4.5-S: Connections on the rear side of the instruments

The following picture shows the configuration of a *Nanonis OC4.5-S*, consisting of a RC5 and one OC4.

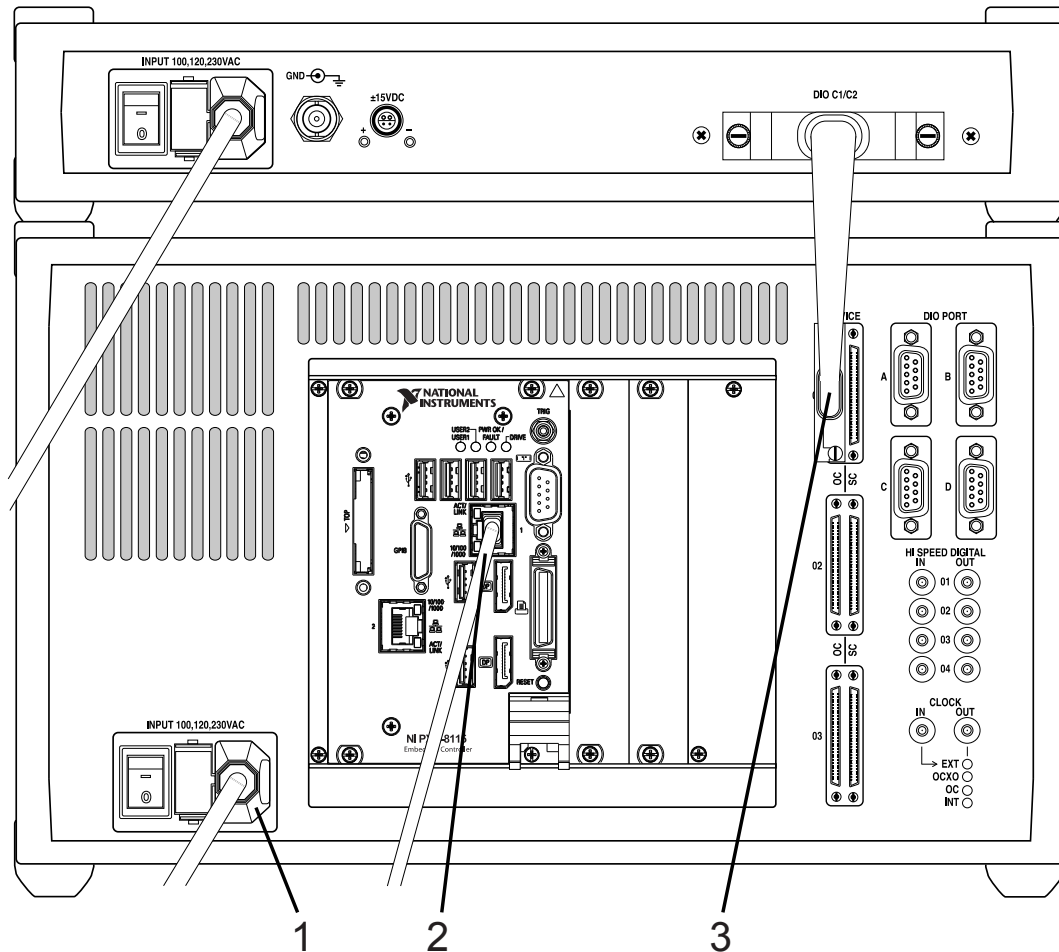


Figure 33: Rear panel of a Nanonis OC4.5-S. 1: Power cord, 2: Ethernet cable, 3: DEVICE RDIO cable to OC4 connected to OC4 device connector 01.

Software Installation Guide

Host computer requirements

The software running on the host computer is the control and visualization interface of a Nanonis system. The host computer must therefore be able to handle and visualize all data transferred to/from the Nanonis system, translating into the following basic requirements:

- There should be sufficient screen space for the software modules and for data visualization. The use of two screens is highly recommended.
- CPU power should be sufficient for handling data transfers, processing data, and allowing a smooth user interface operation.
- There should be sufficient disk space for saving acquired data.

All real-time data processing is done on the RC5 CPU, meaning that it is not necessary to use the fastest computer hardware available. However, using obsolete hardware might result in poor user interface performance, TCP timeouts, or data losses.

The requirements for the host PC hardware are listed in the table below.

Parameter	Minimum requirements	Ideal configuration
CPU	Intel Core i3-4XXX 3 GHz or equivalent or better	Intel Core i5-4XXX 3 GHz or equivalent or better
RAM	4 GB	8 GB or better
Hard Drive	500 GB	2 TB 7200 rpm
Graphics card	Dual-head graphic card with digital output (DVI or DisplayPort) (no 3D acceleration required)	Dual-head graphic card with digital output (DVI or DisplayPort) (no 3D acceleration required)
Network adapter	Gbit Ethernet	Gbit Ethernet
Screens	One screen: 21" 4:3, resolution 1600 × 1200 24", 16:10, resolution 1920 × 1200 Two screens: 19" 5:4, resolution: 1280 × 1024 22" 16:10, resolution: 1680 × 1050	Two screens: 21" or 22" 4:3, resolution 1600 × 1200 24", 16:10, resolution 1920 × 1200
Operating System	Windows 7 32-bit or higher	Windows 7 64-bit or higher

Note: Data streaming to disk into a database requires relatively high data transfer speeds. If this option is used, it is recommended to use a dedicated hard drive for data storage (7200 rpm with large cache or SSD) and 16 GB RAM or more.

Note: The number of software installations is not limited, meaning that the software can be installed in parallel on different computers. However, only one software instance can connect to the RC5 at a time. If there are multiple RC5 in use, the license file determines to which of the instruments the software will connect.

Note: The software runs under both 32-bit and 64-bit Windows operating systems. 64-bit operating systems are recommended, since the software can allocate 2 GB of non-fragmented memory if sufficient RAM is installed (4 GB or more).

Note: A Laptop can be used for running the control software. However, due to limited screen resolution and physical screen size only a limited number of software modules can be visible at the same time, and the workflow will be considerably impaired.

Note: If an internet connection is necessary, two network adapters must be installed in the host computer, one for the internet connection, and one for the connection to the RC5.

Host computer network configuration

This section describes how to configure the network adapter of the host computer. It is necessary to be logged on with administrator rights, or at least to have a valid administrator password.

Configure the Network adapter of the host computer (the one connected to the RC5) using the following settings:

IP address: 192.168.236.X

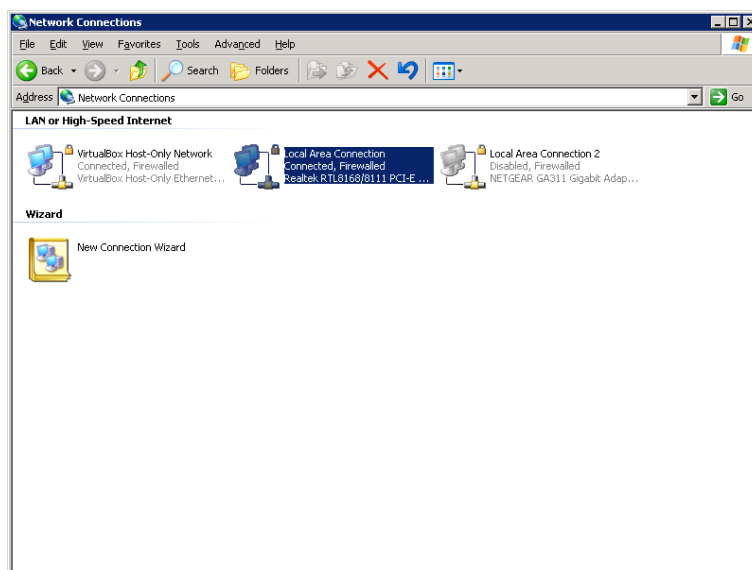
Subnet mask: 255.255.255.0

With X being 1-99 and 111-255. Do not use IP addresses between 192.168.236.100 and 192.168.236.110, since these IP addresses are reserved for the RC5. Do not use IP addresses already in use by other instruments, since this will lead to an IP address conflict. In case the IP address of the RC5 needs to be changed (e.g. if the second network adapter is in the same subnet), please contact SPECS. The following sections explain in detail the configuration for each operating system. Please note that the appearance of dialog windows might be slightly different than shown in the pictures below. The instructions refer to the Nanonis SPM Control System software, but the same procedures apply also to the Nanonis Tramea™ software.

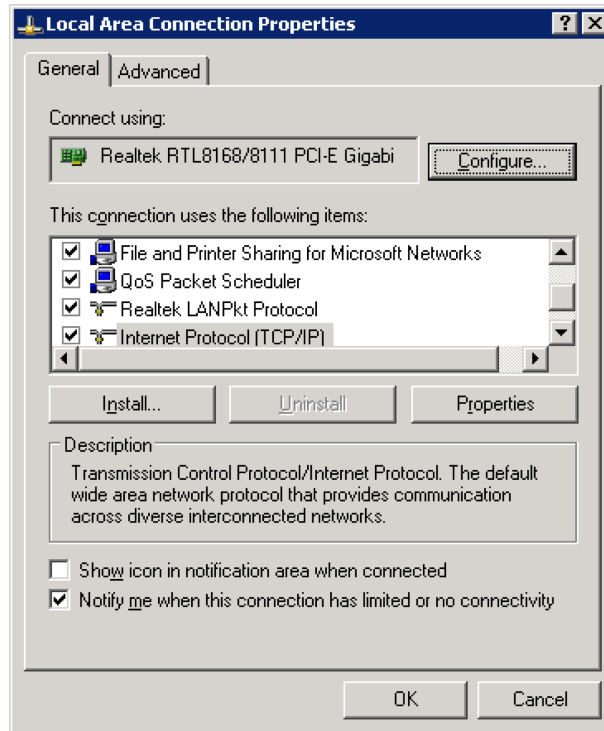
Windows XP

Note: Support and updates for Windows XP from Microsoft are not available anymore.

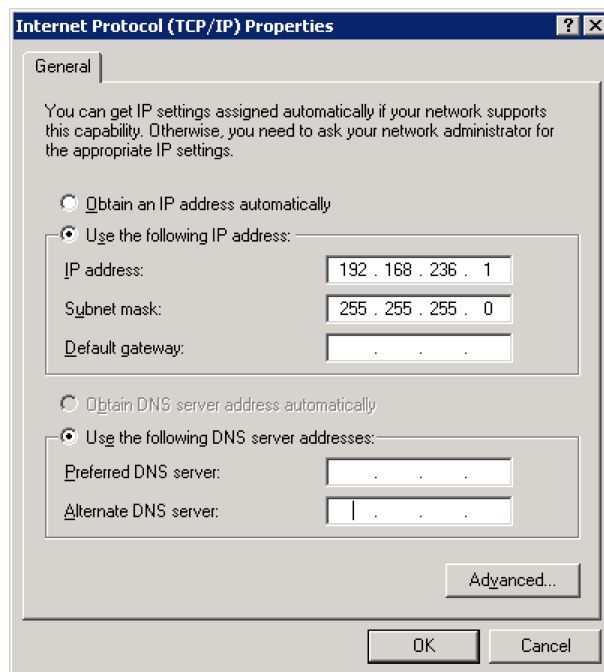
In the Start menu, open *Settings*, then *Control Panel* and choose *Network Connections*. Right-click on the network adapter to which the RC5 is connected, and select *Properties*.



Select *Internet Protocol (TCP/IP)* and click on the *Properties* tab.



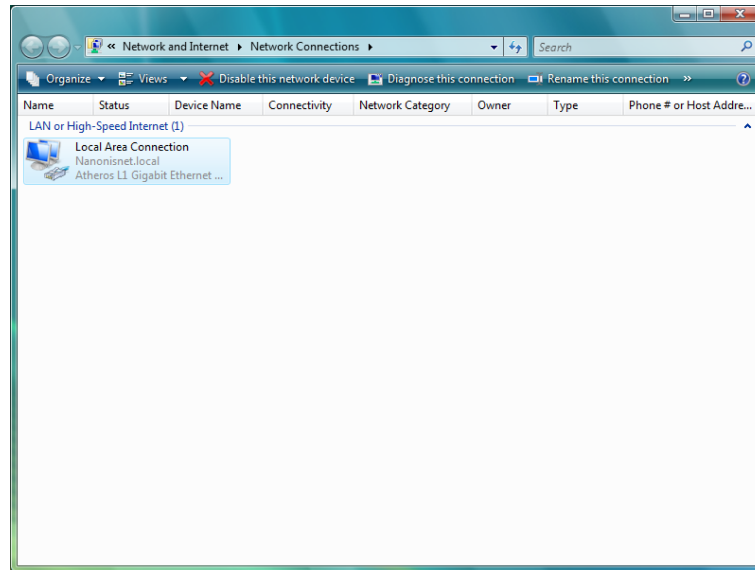
In the configuration window, select *Use the following IP address*, and set the IP address to 192.168.236.X and the subnet mask to 255.255.255.0, as shown below.



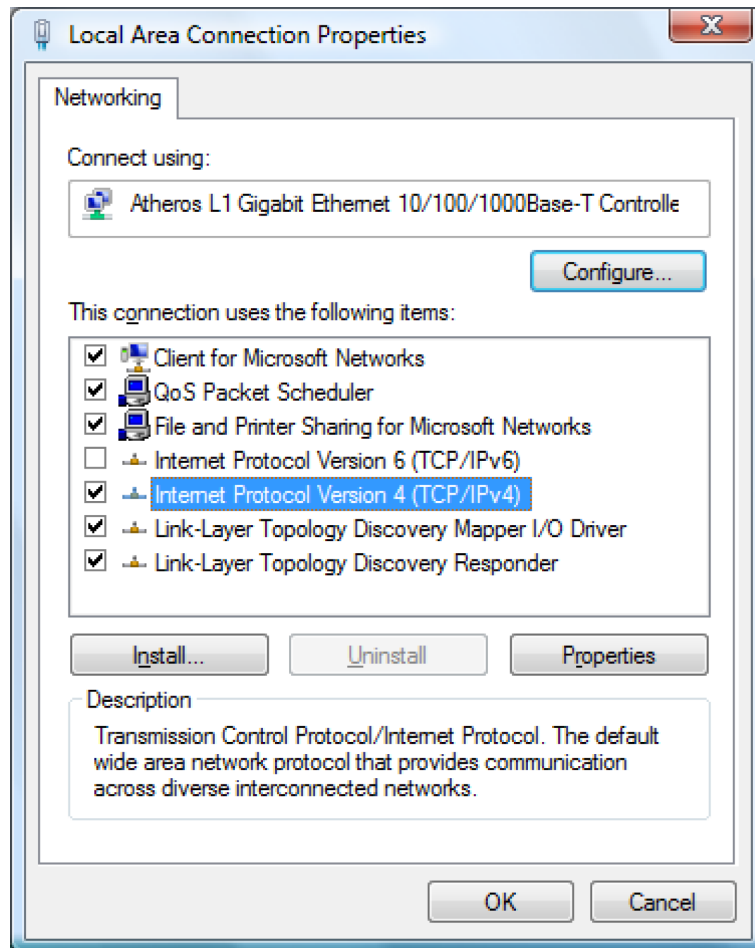
Click *OK*, then click *OK* again on the *Local Area Network Properties* window to close the window and apply the new setting.

Windows Vista

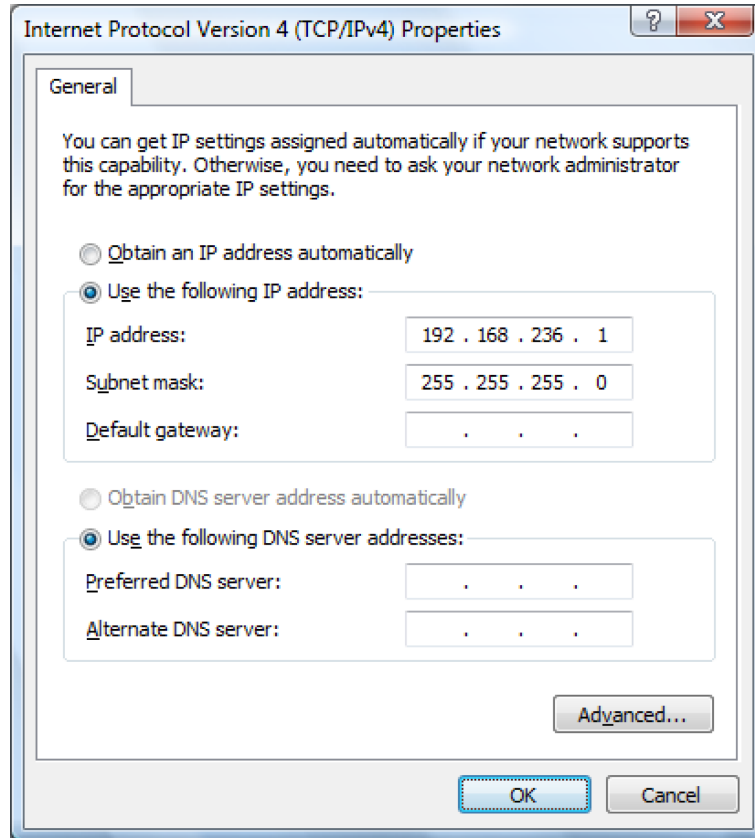
In the Start menu, open *Control Panel* and choose *Network and sharing center* (in classic view) or *View network status and tasks* (normal view). Then select *Manage network connections*. Right click on the network adapter to which the RC5 is connected and select *Properties*.



Select *Internet Protocol Version 4 (TCP/IPv4)* and click on the *Properties* tab.



In the configuration window, select *Use the following IP address*, and set the IP address to 192.168.236.X and the Subnet mask to 255.255.255.0, as shown below.

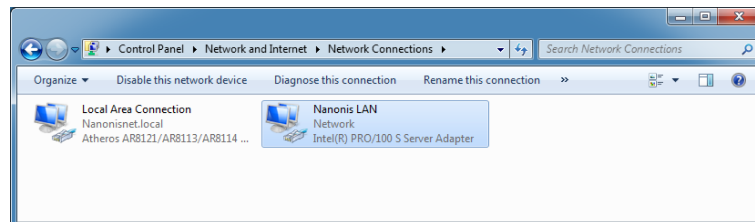


Click *OK*, then click *OK* again on the *Local Area Network Properties* window to close the window and apply the new setting.

Windows 7 and later

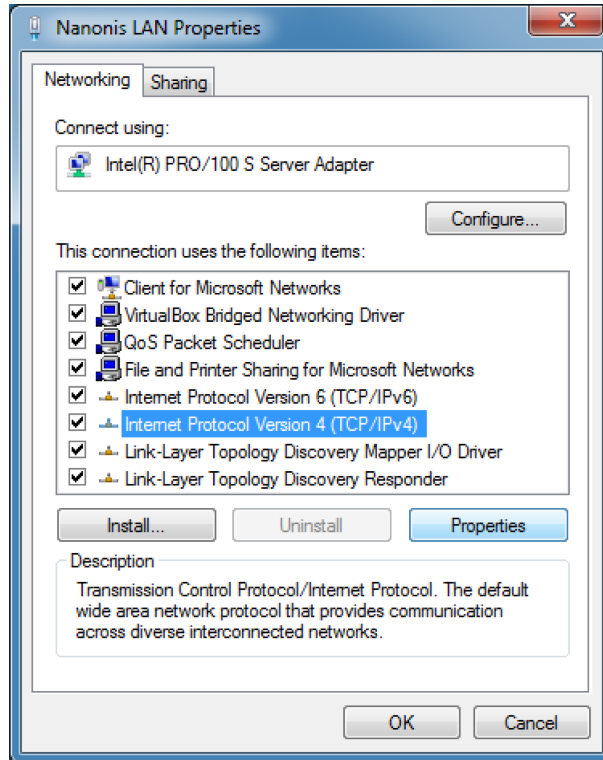
Note: The procedure for Windows 7 is also valid for Windows 8 and Windows 10

In the Start menu, open *Control Panel* and choose *Network and sharing center* (in classic view) or *View network status and tasks* (normal view). Then select *Change adapter settings*.

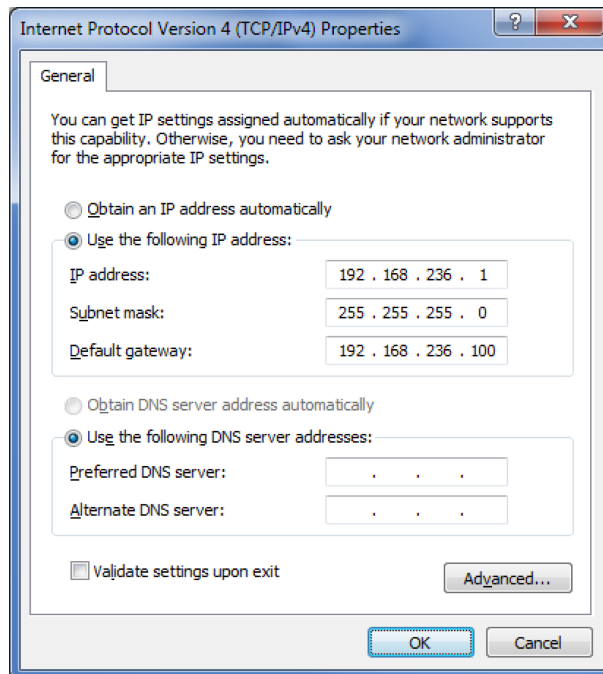


Right click on the network adapter to which the RC5 is connected (renamed to *Nanonis LAN* in this guide) and select *Properties*.

Select *Internet Protocol Version 4 (TCP/IPv4)* and click on the *Properties* tab.

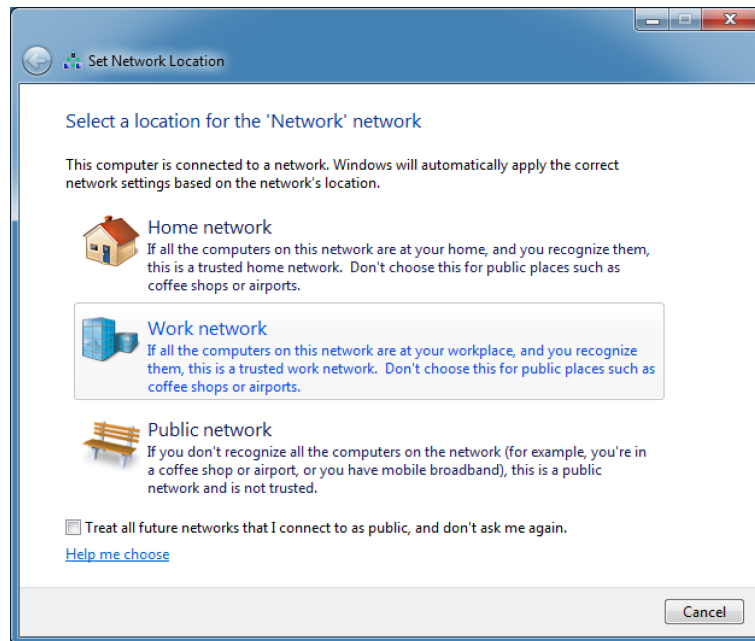


In the configuration window, select *Use the following IP address*, and set the IP address to 192.168.236.X, the Subnet mask to 255.255.255.0, and the Default gateway to 192.168.236.100 (the IP address of the RC5), as shown below.

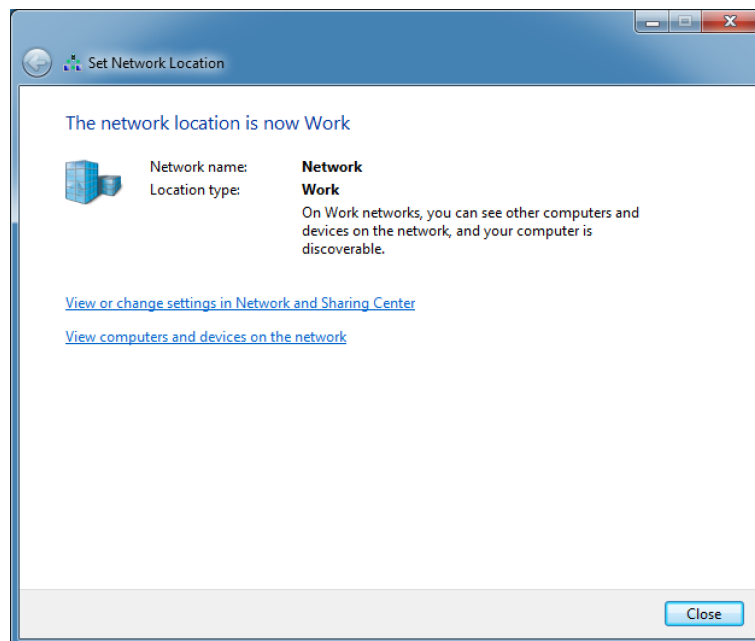


Click *OK*, then click *OK* again on the *Nanonis LAN Properties* window to close the window and apply the new setting.

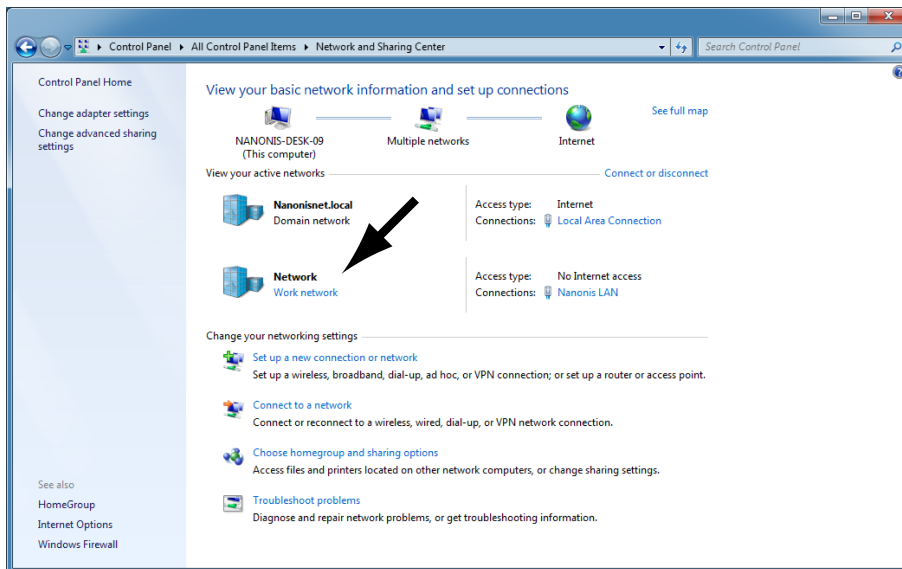
Make sure that the RC5 is switched on, and connect it to the host computer with a crossover Ethernet cable. Make sure that it is connected to the correct network adapter! After connecting, the RC5 should be recognized, and the following window will appear.



Select *Work network*. Do not select *Public network*! The communication between RC5 and host PC might be blocked if *Public network* is selected.

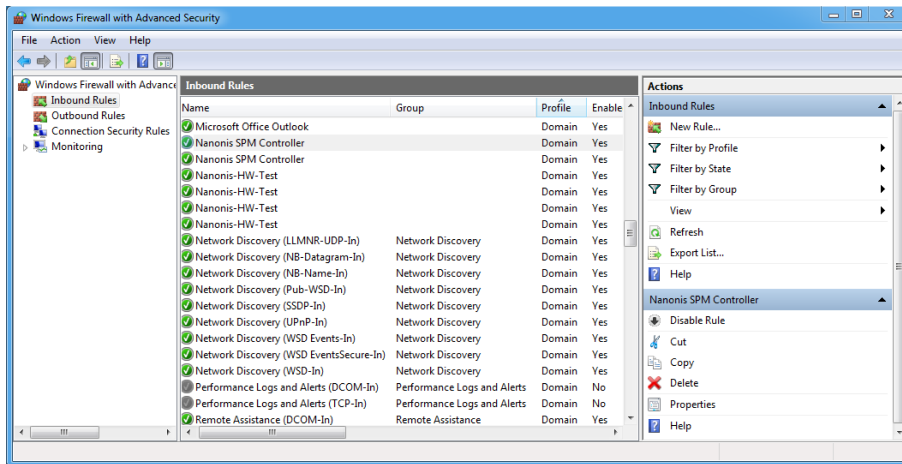


If you are not prompted to select the network location, it can be accessed from the *Network and sharing center*, as shown below.

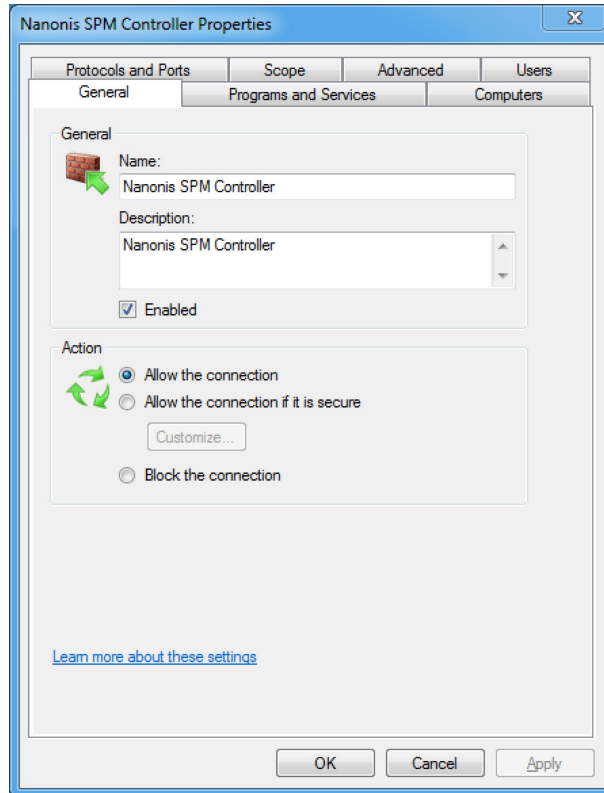


Firewall configuration

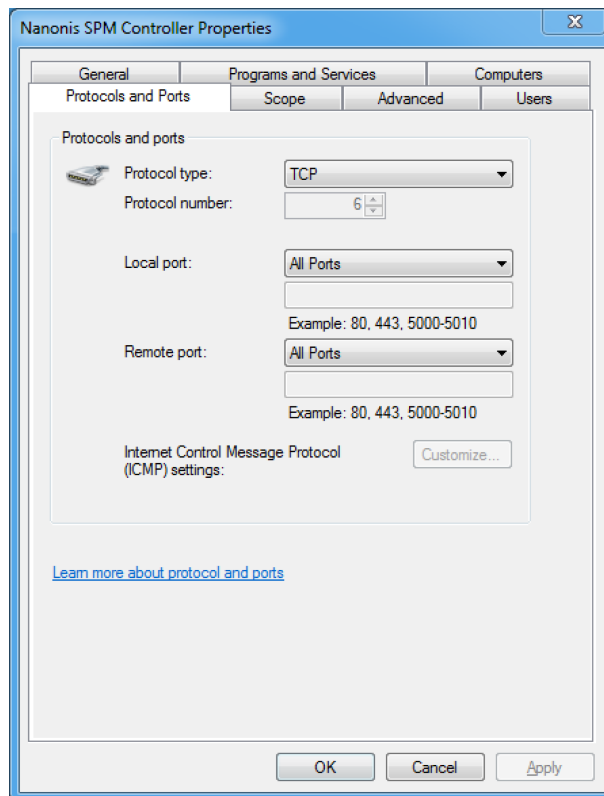
In the Start menu, open *Control Panel* and choose *Windows Firewall* (in classic view) or *System and Security* and then *Windows Firewall* (normal view). Then select *Advanced settings*, and select *Inbound rules* for the *Nanonis SPM controller*.



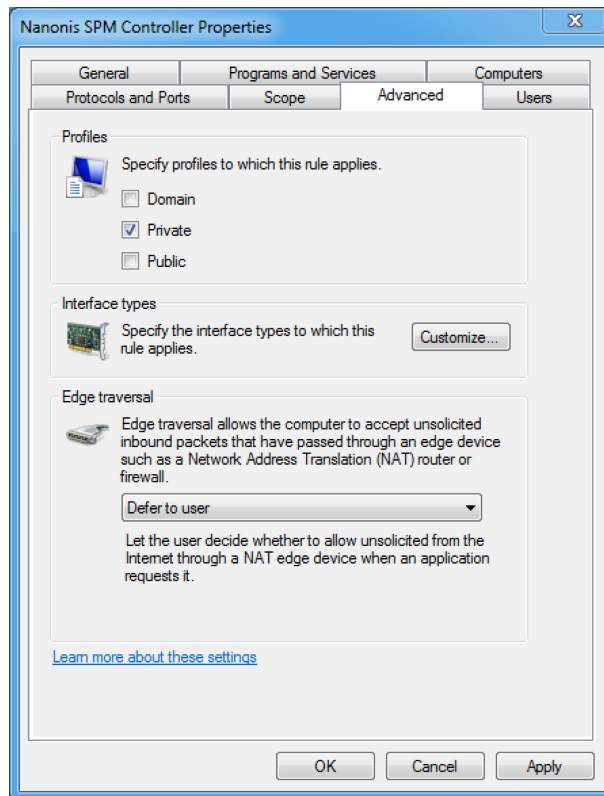
Double-click on both *Nanonis SPM Controller* items, and make sure that the connection is enabled and allowed for both items, as shown below.



Switch to the *Protocol and Ports* tab for both *Nanonis SPM Controller* items and make sure that *All ports* is selected for both the TCP and UDP tab (TCP shown below).



Switch to the *Advanced* tab, and verify that *Private* is checked.



Note: As an alternative the firewall for the network adapter used by the Nanonis System can be disabled.

Nanonis software installation

Installation of the Nanonis software requires two files:

- **Nanonis SPM Controller Installer V5 RXXXX or Nanonis Tramea Installer V5 RXXXX**
- **Nanonis license file**

The Installer file has to be downloaded from the SPECS extranet website:

<http://www.specs-zurich.com/en/extranetlogin.html>

under the *Software V5 SPM* or *Software V5 QT* tab. The login credentials are provided by SPECS, and sent by email after purchasing a Nanonis system.

The license file is also provided by SPECS. Make sure to have both files ready before starting the installation of the Nanonis software.

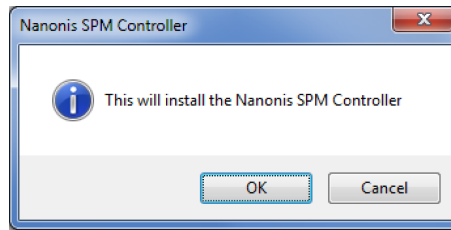
Note: The license file determines which modules of the Nanonis software will be available once the software is installed.

Note: The installer for Nanonis Tramea™ software found in the *Software V5 QT* tab does not contain any SPM functionality. Therefore it is not possible to start the Nanonis Tramea™ software with a license file intended for a Nanonis SPM Control System, or a Nanonis OC4.5-S. The installer for the Nanonis SPM Control System found in the *Software V5 SPM* tab, on the other hand, contains both functionalities, meaning that it is possible to start the Nanonis SPM Control System software with a Nanonis Tramea™ license file. Only quantum transport functionality will be enabled in that case.

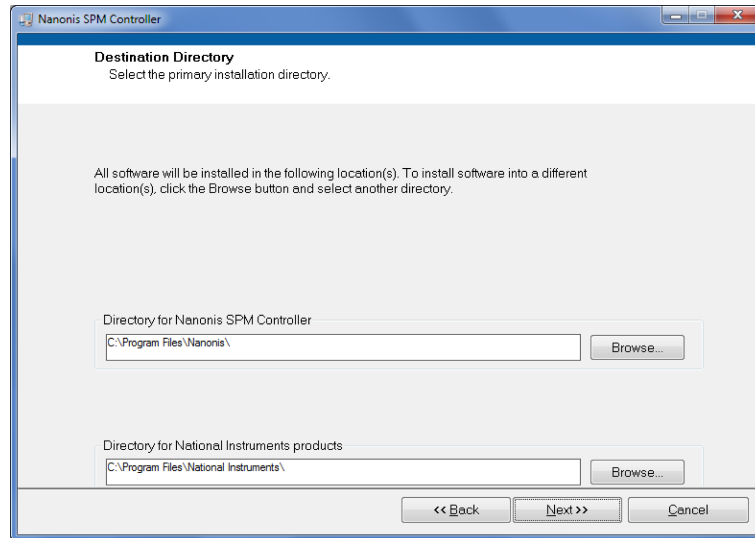
Note: The installation procedure described below is valid for both a first installation of the software, as well as for an upgrade to a higher release.

Note: The appearance of dialog windows might be slightly different to those shown in the pictures below.

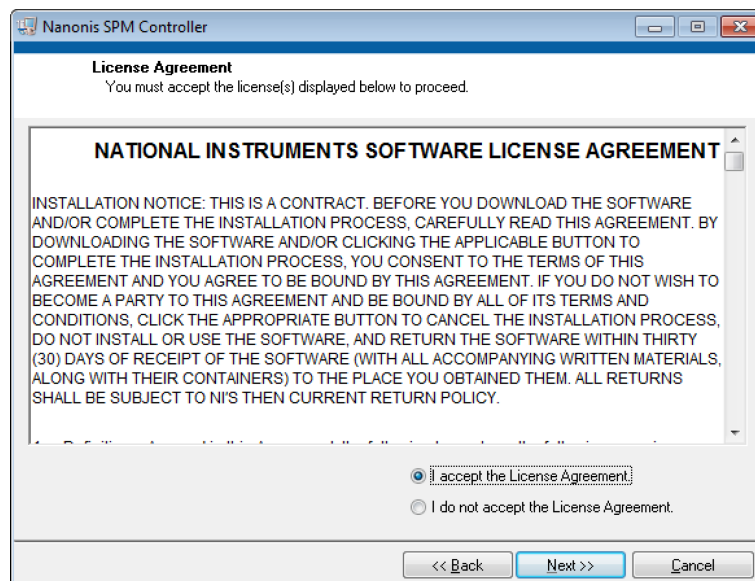
For starting the installation process, double-click on the *Nanonis SPM Controller Installer V5 RXXXX* or *Nanonis Tramea Installer V5 RXXXX.exe* file. The following message will appear:



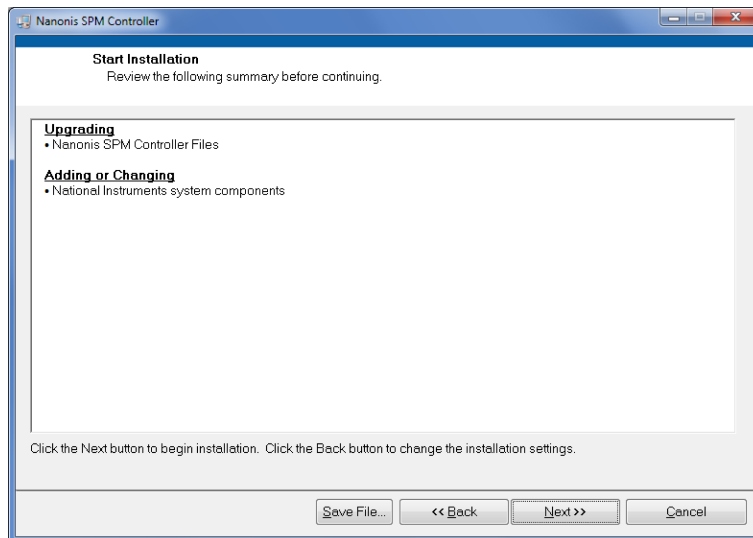
Press *OK* to start the installation. After the installer has initialized, the following dialog window will appear:



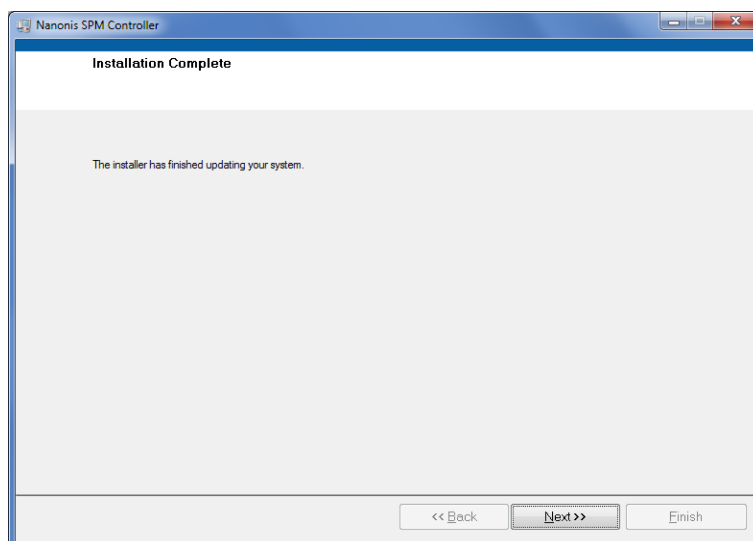
If different installation directories compared to the ones shown are preferred, indicate a different directory in the corresponding field. Otherwise press *Next >>*.



Read the license agreement and select *I accept the License Agreement*, then click *Next >>*. The following window will appear. Depending on the installation type (first installation or upgrade), a different summary will be displayed. The following picture is for an upgrade installation.



Press *Next >>*, and the installation will start. Once the installation is finished, the following dialog window will appear:



Press *Next >>* to finish the installation.

License files

Each RC5 is delivered with a license file. The license file is usually sent by email, together with the login credentials to the extranet website <http://www.specs-zurich.com/en/extranetlogin.html>, and is required for the correct functioning of the Nanonis hardware and software. The main functions of the license file are:

- Ensure that the hardware is configured properly, according to the system configuration
- Manage the software modules loaded when starting the Nanonis software

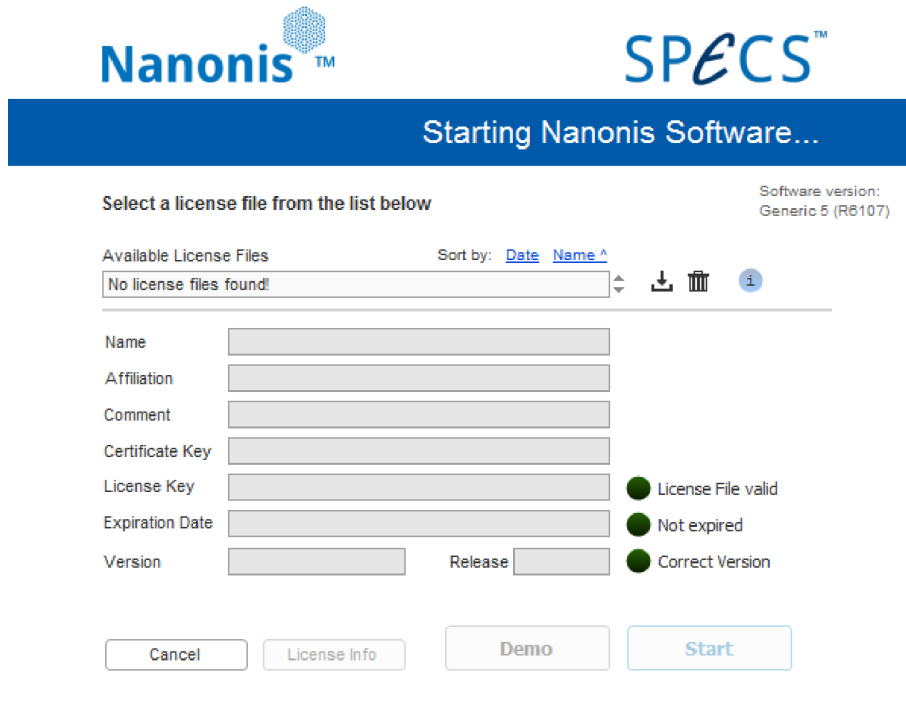
The license file is bound to the MAC address of the network adapter of the RC5, therefore each license file is specific to a given RC5, and can't be used with a different one. The license files are protected, meaning that by changing entries, the license files become unusable.

Always keep the license file at a known location so it can be retrieved quickly. When contacting SPECS by email, please always send the license file since this can contribute to speeding up the troubleshooting processes or facilitate the addition of hardware and software modules.

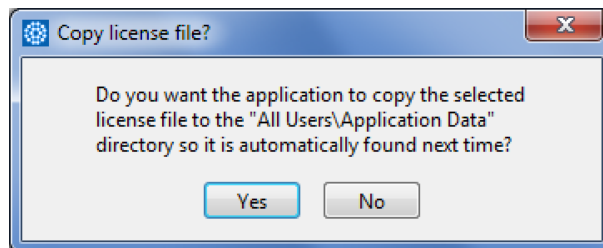
Note that the license file needs to be changed if the real-time unit is replaced.

First time startup

In order to start the Nanonis software, double-click on the Nanonis software icon, or select the Nanonis software from the Start Menu. The following startup screen appears:

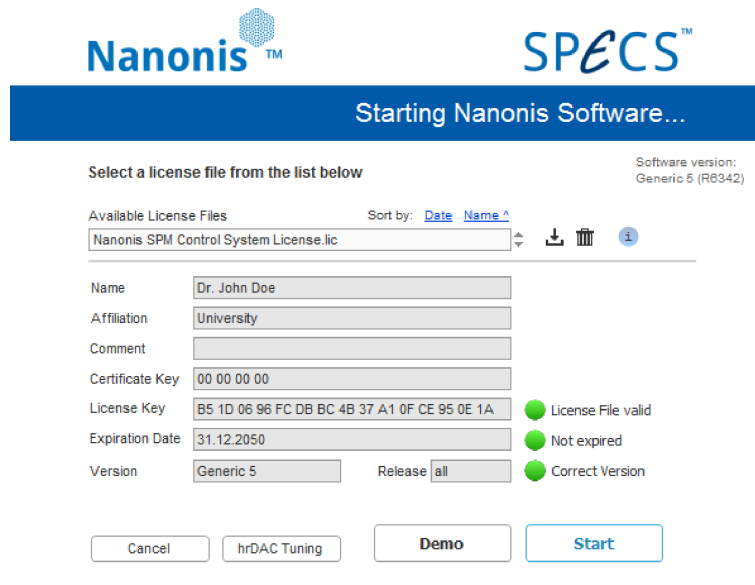


Click on the “No license file found!” drop-down list and select “Browse...”. A dialog window appears, asking to specify the license file to be used and its location. Select the correct license file (see the next section for details) and click “OK”. Another dialog will appear, asking if the file should be copied into a directory where the software can find it automatically, see below.



It is recommended to click “Yes”, since the license file will then be automatically selected at the next start of the software. Note that it is possible to copy multiple license files to the Application Data directory. The files can then be accessed directly from the software startup screen shown above, by clicking on the “Available license files” drop-down list.

After clicking “Yes” the license file appears in the “Available license files” drop-down list, as shown below.



All three indicators next to the License File, Expiration Date, and software version should be green to indicate no errors occurred.

Note that the file can be saved to a different location by clicking on the save icon, or can be deleted from the list by clicking on the trash icon. The Information icon provides information on the file when hovering the mouse over it.

In order to start the software for normal operation, click on the “Start” button.

Note: At this point a Windows Firewall warning might pop up, informing that the Firewall has blocked some features of the program. Depending on the operating system, click on “Unblock” or “Allow access” in order to proceed. This requires administrator privileges. If a different firewall is used, make sure that also that firewall does not prevent the Nanonis software from running. Antivirus software might also interfere with the startup process of the Nanonis software. Please make sure that all antivirus software is deactivated at the first start of the Nanonis software. The software then needs to be configured in such a way, that the Nanonis software is not recognized as a threat to the computer.

After clicking on the “Start” button, the software will load the modules specified by the license file. However, if the real-time software is outdated, it might be necessary to update it by following the on-screen instructions explained in the following section. After that, the following information appears:

Working with Sessions

The Nanonis SPM Control Software works session-oriented. That means you select a directory where, by default, the settings and all measured data is saved to. You can change that directory in the main window, the selected directory will be stored in the Windows registry for each user. To start working with the software, you will now be prompted to select a session directory.

Note: when you browse for a session directory, you have to go into the directory and press "select current directory". Just selecting the directory does not work.

[Please refer to the online help for more information.](#)

OK

Read the text, and if necessary click on “Refer to the online help for more information” in order to access the online help (does not require an internet connection). Then click on “OK”. In the next dialog window, browse for a directory to be used as a session directory, then click on “select current directory” at the bottom right of the window. Note that it is not possible to select “cancel”.

The software is then ready to use.

Note: This procedure is necessary only during first time startup of the software or when using a new license file. Otherwise the software automatically selects the last used session directory.

If the software should not start as described above, please refer to the [Troubleshooting section](#).

There are three other options available in the startup screen: *Cancel*, *hrDAC tuning*, and *Demo*.

Cancel closes the startup screen without starting the software.

hrDAC tuning starts the hrDAC™ calibration procedure. Note that during calibration the analog outputs are internally connected to the analog inputs. This means that output and input connectors will be electrically floating. For more information about hrDAC™ and the calibration procedure, please refer to the *SC5 user manual*.

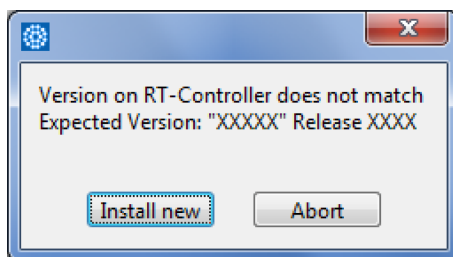
Demo starts the software in simulation mode. This means that the software will not connect to the hardware, but will only start the host application. The simulation mode can be used for familiarization with the software without the risk of damaging samples, or for testing and debugging measurement routines written in the *Programming Interface*. Only the modules licensed in the license file will be loaded, and a license file is necessary for starting the software in simulation mode. It is not necessary to have the hardware connected to the host computer.

Real-time software update

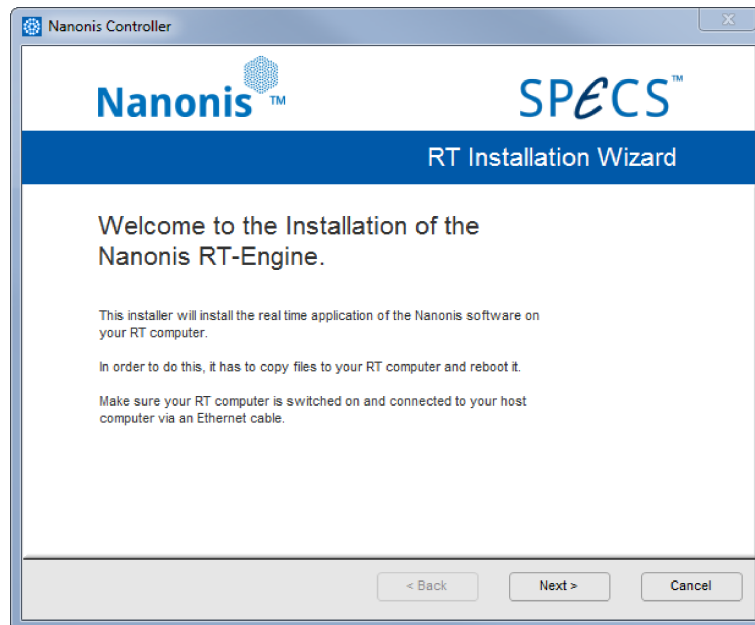
The Nanonis software running on the host computer requires a specific release of the real-time software installed on the RC5. If the latter is older than the required release, a real-time software update is necessary. This is the case when:

- The Nanonis software has been updated between testing of the RC5 at SPECS and delivery of the instrument
- A newer release of the Nanonis software has been downloaded and installed

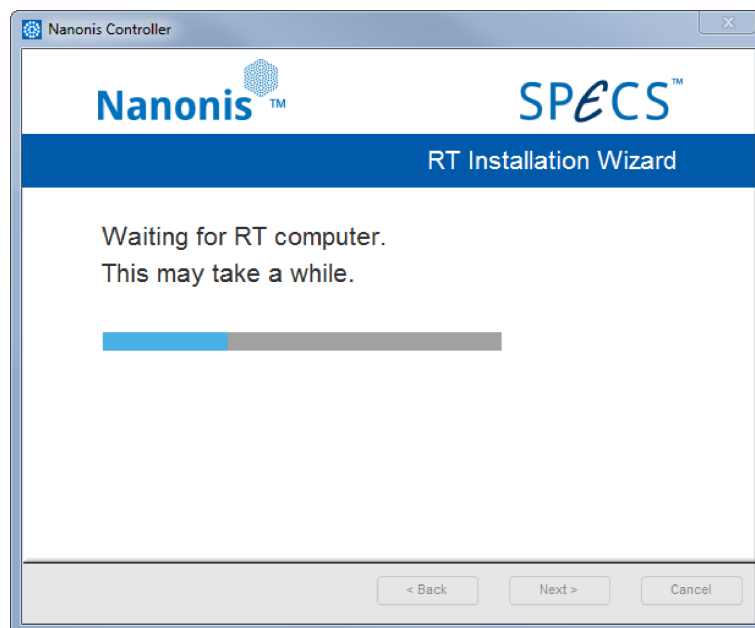
If the update is necessary, a dialog window appears automatically after pressing the “Start” button in the startup screen:

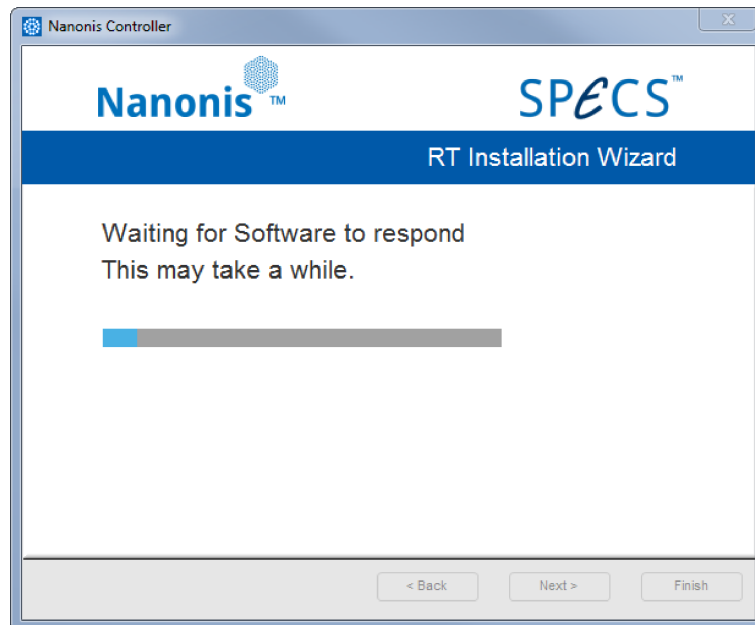


Press “Install new” in order to install an updated release of the real-time software. The following information window is displayed:

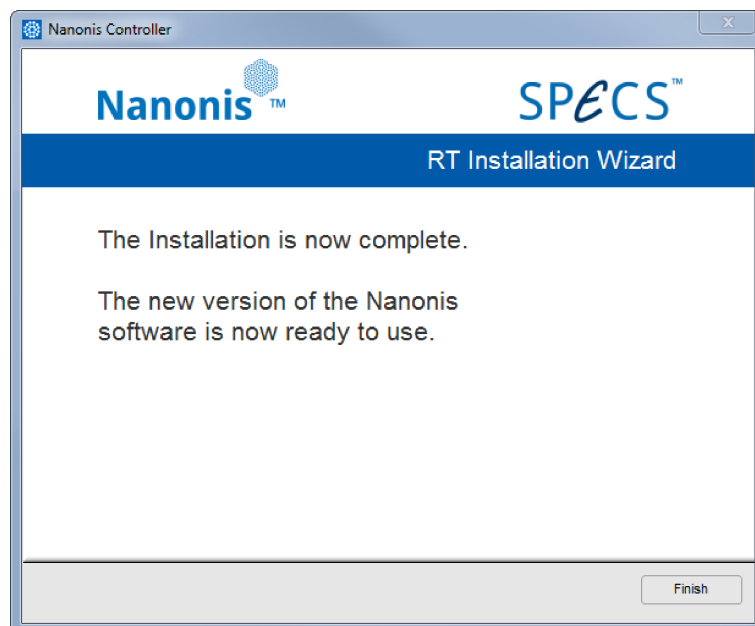


Click "Next" in order to start the installation. The following two progress windows are displayed:





The procedure takes approximately 2 minutes. Once the update process is completed, the following window appears:



Press "Finish" to end the real-time update. The startup screen appears again, and the software can now be started normally. If the update process should stop, please refer to the [Troubleshooting section](#).

Troubleshooting

Network and software issues

SYMPTOM: The instrument turns on, but does not respond when starting the software. There is no indication of faults. The following window appears after starting the software.

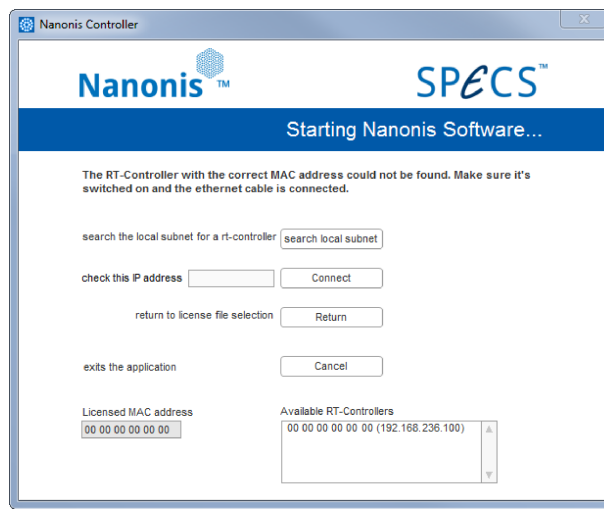


Figure 34: This error window appears if no communication between the RC5 and the host computer is possible.

- REASON:** The real-time controller has not finished booting.
- SOLUTION:** Wait about 20 seconds and try again. It takes about 30 seconds for the RC5 to finish its boot process.
- REASON:** Missing Ethernet cable. In this case there is no entry in the “Available RT-Controllers” field.
- SOLUTION:** Make sure that an Ethernet cable is connected to both the correct *Ethernet connector* (5) of the RC5, and the correctly configured Ethernet port of the host computer.
- REASON:** Wrong Ethernet cable. In this case there might be no entry in the “Available RT-Controllers” field.
- SOLUTION:** Make sure that the RC5 is connected to the host computer with a crossed Ethernet cable. A crossed cable is not necessary if the RC5 is connected to the host computer over a switch, hub, or router.
- REASON:** The RC5 is connected to the host computer over a router with incorrect configuration. In this case there is no entry in the “Available RT-Controllers” field.
- SOLUTION:** Make sure that the router is not acting as a DHCP server. The RC5 has a fixed IP address. Also make sure that all devices connected to the router have IP addresses in the range 192.168.236.X, with X being 1-99 or 111-255. The IP addresses from 192.168.236.100 to 192.168.236.110 should not be used. Please contact SPECS if the IP address of the RC5 needs to be changed.
- REASON:** Firewall or antivirus software is blocking the communication between RC5 and host computer.
- SOLUTION:** Disable the Windows firewall, or any other active firewall. If the RC5 is connected directly to the host computer, a firewall is not necessary. Disable any active antivirus software installed on the host computer. If this solves the issue, enable the antivirus software, but make sure to configure it so that the communication is not blocked. Note that system dialog windows requesting an authorization for connecting to the RC5 or for a firewall exception might be displayed behind another window. Please make sure that no authorization request is pending.

NOTE: Connection issues related to firewalls, or operating system TCP/IP issues can be solved by entering the IP address of the RC5 (192.168.236.100, if it has not been previously changed from the default value, otherwise the changed IP address) in the “check this IP address” field, and then click “Connect”. If a connection is still not possible, please check all possible reasons listed here.

REASON: No software or corrupted software installed on real-time controller. A dialog window appears, informing that the RT-Controller did not respond.

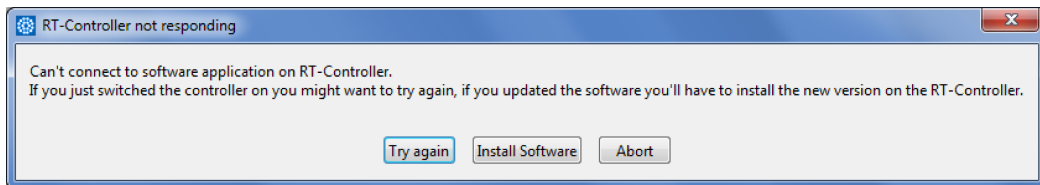


Figure 35: Dialog window informing that no connection to the real-time software is possible.

SOLUTION: Click on “Install Software” to reinstall the real-time controller software. If the software has been started less than 60 seconds before the RC5 has been powered on, please click on “Try again” first.

REASON: Outdated software installed on real-time controller. The following dialog window appears.

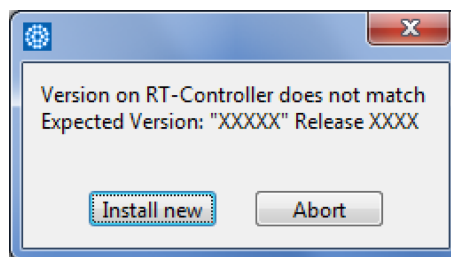


Figure 36: Dialog window informing that the software installed on the real-time controller needs to be updated.

SOLUTION: Please follow the instructions given in the [Real-time software update](#) section above.

REASON: Wrong license file. The MAC addresses in the field “Licensed MAC address” and “Available RT-Controllers” (see above) are different.

SOLUTION: Make sure that the correct license file has been selected. The license files are bound to a specific RC5, therefore license files for other RC5s will not work.

License file issues

SYMPTOM: The “License file valid” LED in the startup screen of the software is dark.

REASON: The license file has been tampered with, or has been generated incorrectly.

SOLUTION: Retrieve the original license file and try again. If this does not solve the issue, please contact SPECS.

SYMPTOM: The “Not Expired” LED in the startup screen of the software is dark.

REASON: The license file has expired. This is the case for time-limited licenses.

SOLUTION: Use a license file with no time limitation. If not available, please contact SPECS.

SYMPTOM: The “Correct Version” LED in the startup screen of the software is dark.

REASON: The license file is intended for a different version of the software.

SOLUTION: Use the license file sent with the RC5. If the file cannot be found, please contact SPECS.

Instrument doesn't power up correctly

SYMPTOM: The **Power LED (1)** does not light up.

REASON: Fuses blown.

SOLUTION: Disconnect the RC5 from the mains. Remove and check the **fuses (3)**. If the fuses are blown, replace them with fuses of the same rating (T2A), and try powering up the RC5. Should the fuses blow again, please contact SPECS.

REASON: RC5 damaged.

SOLUTION: Disconnect the RC5 from the mains. Remove and check the **fuses (3)**. If the fuses are intact, but the unit is still not working, please contact SPECS.

SYMPTOM: The instrument turns on, but does not respond when starting the software. The “DRIVE” LED (see picture below) at the back of the RT-unit does not light when powering the RC5.

REASON: Hard drive failure.

SOLUTION: A hard drive failure is very unlikely, but cannot be ruled out. In the case of a hard drive failure, the “DRIVE” LED at the back of the RT-unit does not light up when powering the RC5 (see picture below for the location of the LED). Please note that during normal operation the LED is always off, therefore a hard drive failure can only be detected by observing the LED when powering the RC5. If the hard drive has failed, please contact SPECS.

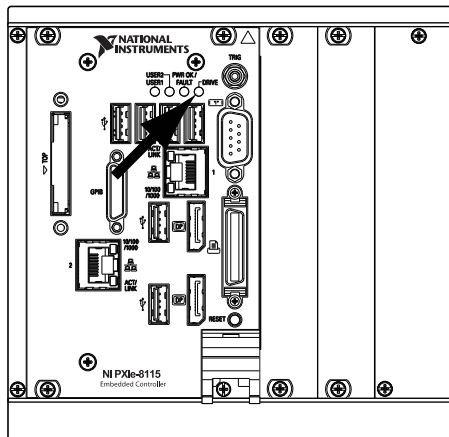


Figure 37: Location of the "DRIVE" LED indicating normal functioning of the hard drive during start-up of the RC5.

SYMPTOM: The instrument turns on, but does not respond when starting the software. There is no indication of faults.

REASON: Corrupt file system, or network-related issue (see above).

SOLUTION: Connect a computer screen to the DisplayPort connector as explained in the [Connection to computer screen](#) section. The status information shown on the screen should appear as shown in the picture below. If the displayed information should be different, please take a picture of the screen and contact SPECS.

```

CPU#   Total Load   ISRs   Timed Structures   Other Threads
CPU 0: 82% ████████ 0% |-----| 75% ████████ 5% |-----|

Dev|Op M|Link|Driver|MAC Address |IP Address |/Mask|Adapter Mode
* 1:|Int :|U R :|i1000e:XXXXXXXXXXXX |192.168.236.X |/24:|TCP/IP (static)
2:|Int -|: :|i1000e:XXXXXXXXXXXX | - | - |Disabled

LabVIEW Real-Time Executive
Build Time: Month X YYYY hr:min:sec
(C) Copyright 2002-2016 National Instruments Corporation

MAX system identification name: RC5-XXXX
LabVIEW Real-Time Single-Core Kernel
Initializing network...
System Web Server started
NI-RIO Server 15.1.0b4 started successfully.

Welcome to LabVIEW Real-Time 15.X.X

NI_VISA Server 15.0 started successfully.

Starting Nanonis RT Engine

MAC Address is XX:XX:XX:XX:XX:XX

loading FPGA...Version: Generic 5, RT Release: XXXX, RT Type: V5

is running now

connected to 192.168.236.Y
    
```

Figure 38: Status screen of the RC5 during normal operation (NI PXIe-8840 version). CPU load might be different than shown in the picture.

```

CPU#   Total Load   ISRs   Timed Structures   Other Threads
CPU 0: 82% ████████ 0% |-----| 75% ████████ 5% |-----|

Build Time: Month X YYYY hr:min:sec
(C) Copyright 2002-2012 National Instruments Corporation

MAX system identification name: RC5-XXX
LabVIEW Real-Time Single-Core Kernel
Initializing network...
Device 1 - MAC addr: XX:XX:XX:XX:XX:XX - 192.168.236.X /24 (primary - static)
Device 2 - MAC addr: XX:XX:XX:XX:XX:XX - disabled
System Web Server started

Startup Application: c:\startup.rtexe
NI-RIO Server 4.1 started successfully.

NI_VISA Server 5.1 started successfully.

Welcome to LabVIEW Real-Time 11.X.X
Starting Nanonis RT Engine

MAC Address is XX:XX:XX:XX:XX:XX

loading FPGA...Version: Generic 4, RT Release: XXXX, RT Type: V45

is running now

connected to 192.168.236.Y
    
```

Figure 39: Status screen of the RC5 during normal operation (NI PXIe-8115 version). CPU load might be different than shown in the picture.

Instrument is overheating

SYMPTOM: Response of the software user interface is sluggish. TCP communication breaks down or error messages appear.

REASON: Ventilation is insufficient or the environment temperature is above specified operating conditions.

SOLUTION: Relocate the RC5 to an open space, if it was previously put in a rack or at a location with poor ventilation. Make sure that the cooling-air exhaust at the back of the unit is not obstructed, and that warm air is not redirected to the cooling-air intake at the bottom of the RC5. If the environment temperature exceeds the specified operating conditions, turn on air conditioning, if available.

REASON: Air intake at the bottom of the RC5 is obstructed.

SOLUTION: Make sure that the air intake at the bottom of the unit is not covered by any object, and that there is no object placed anywhere between the RC5 bottom panel and supporting table. Make sure that the plastic feet supporting the instrument have not been removed.

REASON: Air intake at the bottom of the RC5 is obstructed by dust.

SOLUTION: Make sure that there is no dust covering the air intake at the bottom of the RC5. If there is dust on the intake cover, remove the dust carefully with a dry cloth. Take measures to avoid that dust can reach the air intake.

REASON: Cooling fins of the CPU heatsink are filled with dust. The top cover of the instrument needs to be removed in order to verify this. Instructions for how to remove the cover are given in the *Optional OCXO clock mounting instructions* section.

SOLUTION: Remove the instrument top cover as explained in the *Optional OCXO clock mounting instructions* section. The location of the heatsink is shown in the figure below. Remove the dust with a plastic tool. Do not use a cloth (electrostatic discharge!) or a vacuum cleaner for this purpose. Note that, if dust has accumulated inside the CPU heatsink, it is highly probable that the air intake cover at the bottom of the RC5 is also obstructed by dust. Clean that air intake as explained above, and take measures to avoid that dust can reach the air intake.

Alternatively, remove the complete RT-unit as shown below, in order to facilitate the removal of the dust.

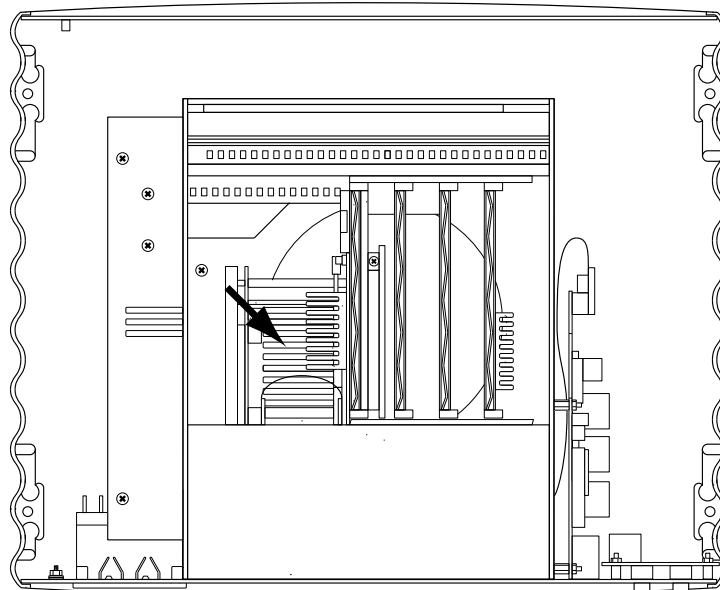


Figure 40: Location of the RC5 CPU heatsink.

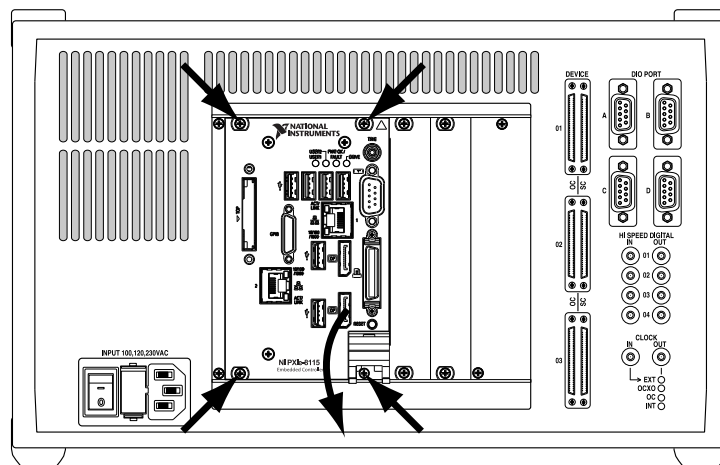


Figure 41: Removal of the RT-unit: After loosening the four screws marked by the arrows, the lever at the lower right can be pushed down, and the RT-unit pulled out of the RC5 enclosure.

Clock issues

- SYMPTOM:** The instrument turns on, but does not respond when starting the software. An external clock source is used and none of the *Clock source LEDs* (12) is on.
- REASON:** The clock signal generated by the external clock source does not have the correct frequency or amplitude, its rise time is too slow, or the duty cycle is different than 50% by a too large amount. The RC5 recognizes that a signal is applied to the *CLOCK IN connector* (12), but is not able to lock on it.
- SOLUTION:** Make sure that the clock signal complies with the frequency, amplitude, rise time, and duty cycle specifications given in the *Clock ports specifications* section above. If the source does not comply, either use the internal clock or a different clock source. If the source does comply, but the RC5 does not lock on the clock signal, please switch off the RC5 and switch it on again. If the clock signal is still not recognized, please contact SPECS.
- SYMPTOM:** A Nanonis OC4 is connected to the RC5, but the INT *Clock source LED* (12) is on instead of the OC LED.
- REASON:** The OC4 is not connected to *OC4 device connector 01* (7).
- SOLUTION:** Make sure that the OC4 is connected to the *OC4 device connector 01* (7). Only the OC4 connected to this connector can be used as a clock source for the RC5.
- REASON:** The OCXO inside the OC4 is disabled, or the OC4 is configured for the use of an external clock.
- SOLUTION:** Please contact SPECS for instructions on how to change the clock settings of the OC4.
- SYMPTOM:** An OCXO has been installed in the RC5, but the INT *Clock source LED* (12) is on instead of the OCXO LED.
- REASON:** Incorrect frequency or voltage specifications of the OCXO.
- SOLUTION:** Please make sure that the OCXO has a frequency of 10 MHz and operates with a voltage of 3.3 V.
- REASON:** The OCXO has been mounted upside down.
- SOLUTION:** Please check that the OCXO has been mounted as described in the *Optional OCXO clock mounting instructions* section. The sharp edge of the OCXO marked by a dot must show towards the rear panel of the RC5.

Specifications

General

Casing	Wavetronics, stackable
Power	Internal power supply
Power consumption	Approx. 120 VA typical, 200 VA maximum
Power supply	100-230 V $\pm 10\%$, 50/60 Hz $\pm 5\%$, Fuses 250 V 2AT
Device connectors	6 (3 \times SC5, 3 \times OC4, maximum 4 devices)
DIO ports	4 ports, 8 bidirectional lines per port
High speed digital ports	4 inputs, 4 outputs
Clock I/O	1 input (autoselect), 1 output (active clock source)
Isolation between GND and PE	30 V peak, limited by ESD suppressors
EMC-Protection	According to EN61326-1, Table-1, for cable length < 3 m
Operating temperature	+5 °C to +35 °C
Dimensions	33.0 \times 26.5 \times 20.7 cm (W \times D \times H)
Weight	Approx. 7.8 kg

DIO ports specifications

Lines set to input

Pull-up resistance	100 k Ω $\pm 40\%$
Low input threshold	< 0.8 V
High input threshold	> 2.0 V
Maximum input voltage	5.5 V
Input capacitance	< 10 pF
Input leakage current	± 10 μ A

Lines set to output

Nominal output level	3.3 V
High output voltage	> 2.6 V (@ 8 mA load)
Low output voltage	< 0.5 V (@ 8 mA load)
Maximum current per line	25 mA (max. 100 mA per connector)

Timing

Maximum sampling frequency	500 kHz
----------------------------	---------

High speed digital inputs specifications

Electrical parameters

Nominal high input level	3.3 V (5 V TTL tolerant)
Low input threshold	< 0.8 V
High input threshold	> 2 V
Maximum input voltage	6 V
Input capacitance	< 10 pF

Timing

Maximum sampling frequency	200 MHz
----------------------------	---------

High speed digital outputs specifications

Electrical parameters

Nominal output level	3.3 V
Output impedance	≅ 50 Ω
High output voltage	> 2.0 V @ 33 mA load
Low output voltage	< 0.4 V @ 33 mA load
Maximum current per line	33 mA

Timing

Maximum sampling frequency	200 MHz
----------------------------	---------

Clock specifications

Internal Clock

Accuracy	±50 ppm
Maximum jitter	5 ps RMS phase jitter (10 Hz – 1 MHz range)

Optional OCXO

Accuracy	±4 ppm
Maximum jitter	5 ps RMS phase jitter (10 Hz – 1 kHz range)
Phase noise (bandwidth = 1 Hz)	-70 dBc/Hz @ 1 Hz -100 dBc/Hz @ 10 Hz -130 dBc/Hz @ 100 Hz -140 dBc/Hz @ 1 kHz
Short term stability	< 5E-10 (0.1 s to 30 s), 5E-11 typical @ 1 s
Frequency stability over temperature	±0.075 ppm (0.15 ppm p-p) 0 to 60°C
Frequency stability over time	First year: < ±0.7 ppm After 10 Years: < ±4.0 ppm

Electrical parameters (input)

Nominal high input level	3.3 V (5 V TTL tolerant)
Low input threshold	< 0.8 V
High input threshold	> 2 V
Maximum input voltage	6 V
Input capacitance	< 10 pF

Timing requirements (input clock)

Required clock frequency	10 MHz
Signal rise and fall time requirement	< 5 ns
Duty cycle range	40% - 60% minimum

Electrical parameters (output)

Nominal output level	3.3 V
Output impedance	≅50 Ω
High output voltage	> 2.0 V @ 33 mA load
Low output voltage	< 0.4 V @ 33 mA load
Maximum current	33 mA

Timing (output)

Clock frequency	10 MHz
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Operating conditions

Environment	The RC5 is designed for indoors dry laboratory use only
Ambient temperature	5 °C to 35 °C in accordance with IEC-60068-2-1 and IEC-60068-2-2
Humidity	10-50% relative humidity, non-condensing in accordance with IEC-60068-2-56
Maximum altitude	2000 m
Pollution degree	2 (indoor use only)
Installation category	II
Mains supply voltage fluctuations	Are not to exceed ±10% of nominal supply voltage

Storage and transportation conditions

Ambient temperature	-20 °C to 70 °C in accordance with IEC-60068-2-1 and IEC-60068-2-2
Humidity	5-95% relative humidity, non condensing in accordance with IEC-60068-2-56
Pollution degree	2 (indoor use only)

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Declaration of Conformity



1

CE Declaration of Conformity

- 1.1 Manufacturer:** SPECS GmbH
Voltastraße 5
13355 Berlin / Germany
- 1.2 Designation of the products:** Nanonis Real-time Controller
Nanonis Tramea Real-time Controller
- 1.3 Model:** RCS, TRC
- 1.4 Part Number:** 2060015068, 2100005280, 2100007954

We declare under our sole responsibility that the product mentioned above fulfills all the relevant provisions of following EC directives:

- 2014/30/EU Electromagnetic Compatibility
- 2014/35/EU Low Voltage Directive
- 2011/65/EU RoHS 2

Applied harmonized standards:

EN 61326-1: 2013	Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 1 : General requirements.
Emission:	EN 55011, CISPR 16-2-1 Conducted Emission
	EN 61000-3-2 Harmonics
	EN 61000-3-3 Voltage changes, fluctuations and flicker
Immunity:	EN 61000-4-2 Electrostatic discharge
	EN 61000-4-3 Radiated rf electromagnetic field
	EN 61000-4-4 Burst immunity test
	EN 61000-4-5 Surge immunity
	EN 61000-4-6 Immunity to conducted disturbances
	EN 61000-4-11 Voltage dips and interruptions
EN 61010-1: 2010	Safety requirements for electrical equipment for measurement, control, and laboratory use - Part 1: General requirements.

Berlin, 15.11.2016
Dr. Oliver Schaff
Chief Technical Officer (CTO)

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