Opus One™ Superconducting Nanowire Single-Photon Detection System

Installation and Operation Manual

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General Information

Warranty

This Quantum Opus product is warranted against defects in materials and workmanship for a period of one (1) year from the date of shipment.

Service

For warranty service or repair, this product must be returned to a Quantum Opus authorized service facility. Some components may be serviceable directly from the supplier. Contact Quantum Opus before returning this product for repair.

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All Quantum Opus products are intended for use by properly trained users. In no event shall Quantum Opus be liable for any direct, indirect, punitive, incidental, special consequential damages, to property or life, whatsoever arising out of or connected with the use or misuse of our products.

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Document Information

Safety Notices

WARNING

A WARNING notice identifies a hazard. This type of notice identifies a procedure, practice, or similar, that, if not properly performed or adhered to, could result in damage (possibly significant) to persons or property. Do not proceed past a WARNING notice until the indicated conditions are fully understood and met. If there is any question about proper performance of the procedure or practice, contact Quantum Opus support for guidance.

NOTE

A NOTE notice identifies a procedure, practice, or similar that if not properly performed or adhered to, could result in degraded system performance, reduced system "up-time," or increased frequency of system maintenance. Although adherence to a NOTE is not safety critical, adherence is required to ensure system performance meets specifications. If there is any question about proper performance of the procedure or practice, contact Quantum Opus support for guidance.

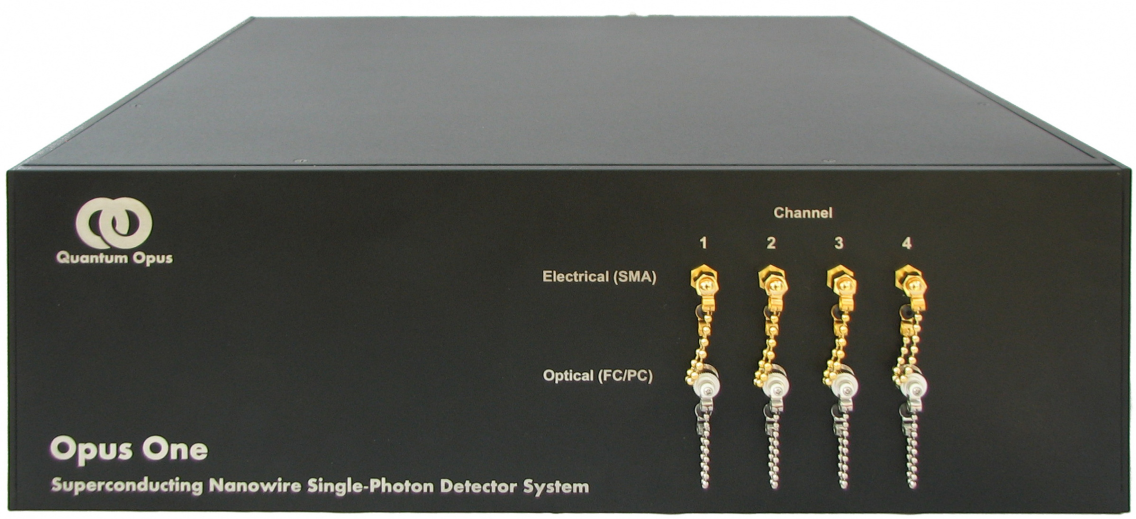

Figure 1: Photo of a typical four-channel Opus Oneunit containing four superconducting nanowires, cryogenic vacuum system, and fiber optic couplers. Various configurations are available with up to 16 detector channels in the above 19-inch rack configuration (3U height). Specific options and configurations may vary.

1 Introduction

The Opus Oneis a high-speed, high-efficiency, fiber-coupled, single-photon detection system using superconducting nanowire technology. The system can contain between one and sixteen nanowire detectors, depending on configuration.

1.1 Overview

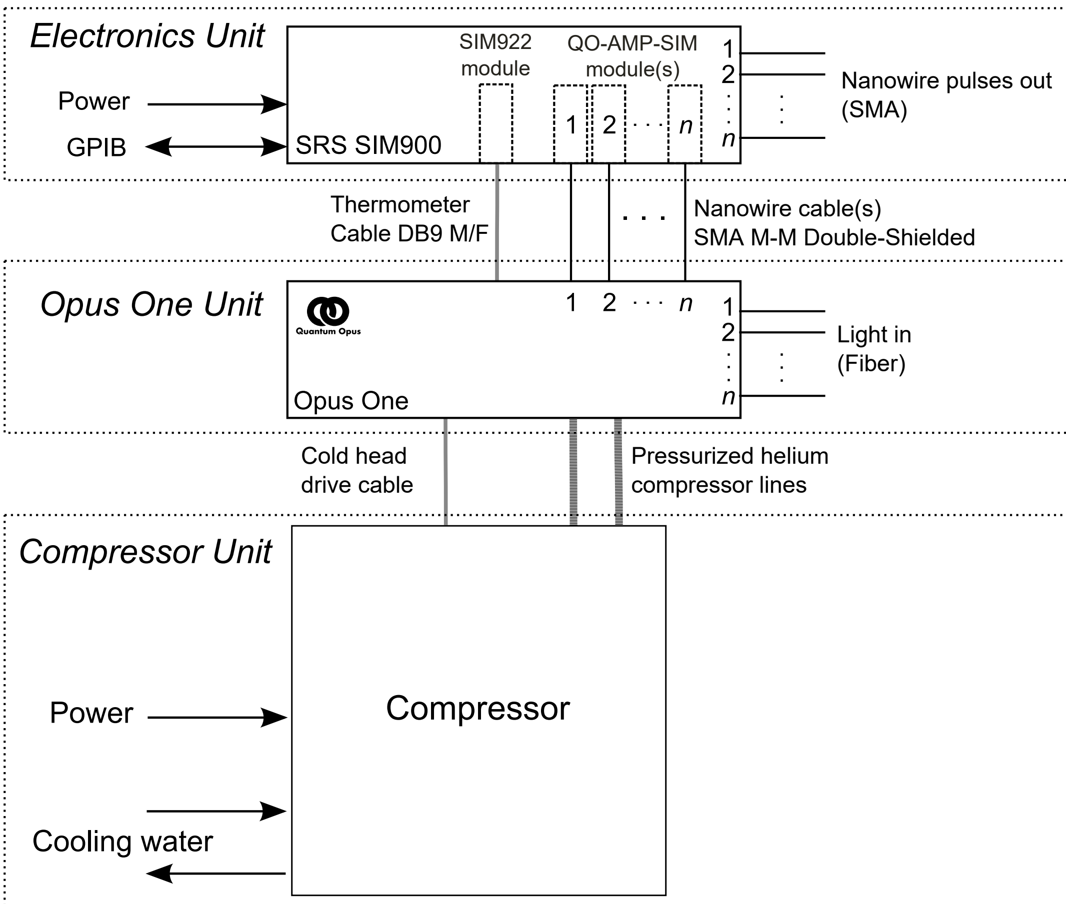

Figure 2: Nanowire system schematic showing Opus Onehead unit, electronics unit, and compressor with all connections.

The nanowire system has three main physical components, as identified in Figure 2:

1. The "Electronics Unit" that provides system thermometry and nanowire device con-

trol and monitoring.

2. The “Opus One Unit” consisting of the vacuum and cryogenic components, nanowire detectors, and nanowire optical and electrical connections.
3. The “Compressor Unit” that provides the high-pressure, high-purity helium and valve control signals to obtain and maintain the low temperatures required for superconducting nanowire operation.

2 Installation

This section covers unpacking and installing your new nanowire detector system.

WARNING
Several system components contain high-pressure helium gas. Follow manufacturer recommendations for installation. Eye protection is recommended during installation. Follow local regulations and recommendations for proper personal protective equipment (PPE) when working with high pressure gases.

WARNING
Ensure the system has been powered off for 24 hours before opening the vent valve or making changes to the high-pressure connections between the detector head and the compressor.

2.1 Preparation for Installation

Before unpacking your Opus One system head, the compressor must be installed. Carefully consider the placement of the compressor and Opus One head unit. For this discussion, refer Figure 2 on page 5.

WARNING
It is normal for the high-pressure helium lines to move slightly during system operation. Ensure the lines do not rub on sharp corners or on other objects that may become damaged from abrasion with the metal tubing such as electrical wiring or water lines.

NOTE
Distances over 3m between the detector head and compressor may reduce detector performance because of decreased system cooling power.

1. Determine compressor and high-pressure helium location appropriate for proper proximity to your water and power connections.

   NOTE
   Because of the polarization sensitivity of the nanowire devices, it is important to minimize uncontrolled polarization drift between your source and

the detector unit. Polarization drift can be made worse with long optical fibers, fibers that continually change position (e.g., due to vibration or air currents), or fibers that change temperature.

2. Determine the Opus One unit location appropriate for your source of photons, ensuring that the pressurized high-purity helium lines will move freely and will not be under tension. Minimize the distance between your optical source and the detector unit.
3. Determine the best location for the electronics unit (SIM900 plus associated modules), noting that it is intended to be operated either directly above or below the Opus One detector head to minimize the introduction of noise between the electronics and the Opus One unit.

2.2 Compressor Unit Installation

WARNING
As per manufacturer recommendations, inspect all gaskets and o-ring surfaces to ensure they are present, undamaged, and clean. A missing or damaged o-ring could result in rapid, catastrophic release of high-pressure helium. Do not use any lubricants on the connectors. Always ensure connectors are mated properly to avoid any loss of high-purity helium.

WARNING
Do not install the helium lines to the detector head until instructed to do so in the order given below. Installation of the helium lines in the wrong order, or to the wrong ports, may require factory repair of the Opus One unit.

1. Establish the proper electrical and water connections to the compressor according to documentation provided separately by the compressor manufacturer. Be sure to comply with all manufacturer recommendations and local laws, codes, and building recommendations.
2. Perform any recommended compressor run testing. See provided compressor manufacturer documentation.
3. After any required compressor run testing, install the high-pressure helium lines onto the compressor SUPPLY and RETURN connections, as described in the compressor manufacturer documentation.

2.3 Opus One Unit Installation

WARNING
Do not lift or position the detector head by putting force on the front panel connectors or on the rear valve, port, high-pressure tubing connections, or wiring connectors.

WARNING
Do not rest the unit, even temporarily, on its front (i.e., on the electrical and optical connections) or rear (i.e., on the valve, port, high-pressure tubing connections).

WARNING
Do not attempt to mount the detector head into a rack enclosure without both support from both front and back rail flanges. Damage to the system is likely.

Refer to the diagram of the Opus One unit shown in Figure 3 on the next page for the procedures in this section.

1. Determine how to properly lift the detector head. Avoid lifting by any valve, port, electrical, or tubing connections. As long as you avoid the tubing lines, you *may* lift by the central solid aluminum block at the rear of the unit, as shown in Figure 3 on the next page.
2. Carefully remove the Opus One unit from its packaging. Note that the unit has a significant fraction of its weight toward the back.
3. Remove any protective wrapping around the Opus One unit and on the front panel.
4. For rack-mount operation, contact Quantum Opus support for guidance on the selection of an appropriate shelf mount.
5. If desired, apply the provided adhesive feet near the corners of the bottom panel of the detector head. The head may be set temporarily on its top, bottom, right or left sides to facilitate applying the feet.
6. Temporarily place the Opus One unit in a location near its operation location so that, after the high-pressure helium lines are connected, it can be positioned into its final installed location with minimal strain on the high-pressure helium connections at the rear of the unit.
7. The pressurized helium lines must be connected in the following order.

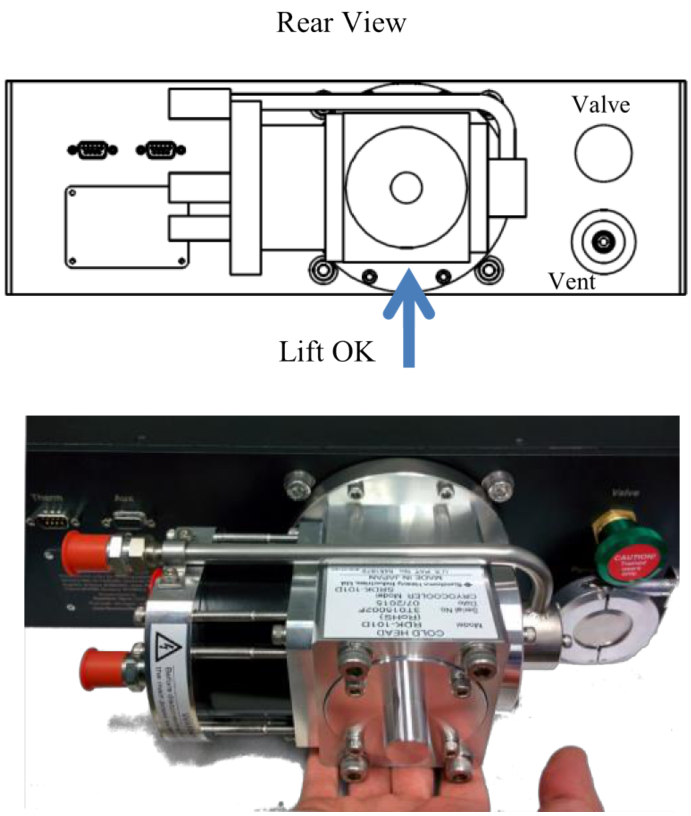

Figure 3: Rear view of the Opus One detector unit showing a suggested lift point for installation.

a) Ensure the SUPPLY and RETURN lines are already connected to the compressor and properly labeled SUPPLY and RETURN.

b) If (optional) pressurized right-angle adapters are to be used, contact Quantum Opus for the proper installation procedure.

> ⚠ **WARNING**
> Using the improper method of connecting the helium lines, connecting in the improper order, or erroneously interchanging the RETURN and SUPPLY lines may result in permanent damage to the tubing lines or necessitate service to the Opus One unit. Adhere to the following procedures carefully.

c) First, using the proper “three-wrench” procedure as described in the Sumitomo SRDK Operations Manual (provided by Quantum Opus, upon request), connect the “RETURN” high-pressure helium line to the “RETURN” connector on the rear of the Opus One unit.

d) Second, again using the proper “three-wrench” procedure, connect the “SUPPLY” high-pressure helium line to the “SUPPLY” connector on the read of the Opus One unit.

e) Connect the provided electrical drive cable between the compressor and the Opus One unit.

3 Electronics Unit Installation

WARNING
The Opus One devices and electronics are sensitive to Electrostatic Discharge (ESD). Ensure you are properly grounded before changing cable connections of any type. Ensure that the QO-AMP-SIM modules are **powered on** and the "STATUS" light is illuminated **green** (●) when connecting the SMA cables between the QO-AMP-SIM module and the Opus One.

WARNING
Do not overtighten the SMA or optical connectors. Finger-tight connections are recommended for fiber connections. Slightly tighter than finger-tight connections are recommended for SMA connections. Overtightening the connectors may loosen the internal connectors in the Opus One unit or cause damage to the connectors, damage to cables, or increased system losses and noise.

NOTE
Use only the provided double-shielded SMA cables between the Opus One unit and the QO-AMP-SIM modules to reduce the possibility of increased electrically induced noise counts.

1. Depending on the options purchased with your system, various Stanford Research Systems SIM-compatible modules (including QO-AMP-SIM modules) have been provided with your system. With the SIM900 power off, insert all desired modules firmly into the SIM900 rack, as per documentation on the SIM900 rack available from Stanford Research Systems at `www.thinksrs.com`. Note that, if installing fewer than eight QO-AMP-SIM modules, it is typically most convenient to place the QO-AMP-SIM modules in the farthest right (highest numbered) slots to keep the SMA connections close to the Opus One unit SMA connectors.
2. If seven or fewer QO-AMP-SIM modules are to be used, install the provided SIM922 Diode Temperature Monitor into an unused slot in the SIM900 rack. If eight or more QO-AMP-SIM modules are to be used, attach the provided 15-pin (DB15 male to DB15 female) extension cable between the rear of the SIM922 module and the rear DB15 connector labeled "Remote SIM (Port 9)" on the SIM900 rack unit.
3. Attach the provided 9-pin (DB9 male to DB9 female) filter adapter to the upper DB9 connector on the back of the SIM922 Diode Temperature Monitor.
4. Attach the provided 9-pin cable between the filter and the "Therm" connector on

the rear of the Opus One unit.

5. Power on the SIM900 rack and ensure that the SIM922 module reads a voltage of approximately 0.6 Volts on both channel 1 and channel 2 thermometers. You may need to press the small "Units" button at the bottom of the SIM922 front panel to switch to "V" from "K" to see the thermometer voltages.

6. At this time all QO-AMP-SIM modules should have their "STATUS" light illuminated **green** (●). The green status light indicates a safe, standby mode for connecting and disconnecting the Opus One unit SMA cables.

7. With the SIM900 unit still powered and the QO-AMP-SIM status lights green, connect the Opus One to the QO-AMP-SIM modules using the provided 12-inch double-shielded SMA cables. For each detector, connect one cable from the "Electrical" SMA connector on the Opus One unit to the "NW" input on a corresponding QO-AMP-SIM module in the SIM900 rack. Tighten the SMA connectors slightly tighter than finger tight using a small SMA wrench (desired torque should be 0.3 to 0.6 N·m, 3 to 5 in·lbs).

8. Once all QO-AMP-SIM modules are connected to their respective nanowire connectors, the SIM900 rack may be powered down. All connections may be left in place when powering up and power down the SIM900.

4 System Operation

This chapter details the "Cool down" and "Warm up" procedures for the cryogenic components of the Opus One nanowire system.

WARNING

If either the compressor or Opus One unit operate in a seemingly erratic or unsafe manner, turn off the power to the compressor and the electronics unit and contact Quantum Opus for additional help.

WARNING

Whenever using a vacuum pump to evacuate a system, ensure there is adequate "slack" in the pumping line to allow for line contraction (sometimes very significant) during pumping. Inadequate line length can cause unsafe forces on the pump, pumping lines, or Opus One unit and can cause equipment to be damaged or to move in undesired ways (e.g., tip over, fall off of shelving).

4.1 Cool Down Procedure

The procedures in this chapter should be accomplished for first-time operation and repeated any time that the system has been allowed to warm above approximately 45 Kelvin, for example in case of accidental power failure, cooling water loss, or intentional system shutdown.

NOTE

The system should be in its warm state before starting this procedure to ensure proper cool down. A "warm" state is indicated on the SIM922 Diode Temperature Monitor SIM module by both channel 1 and channel 2 thermometers reading above 280 K. This state should be achieved within 24 hours after the system has been powered off. For the system warm-up procedure, see Section 4.2 on page 16.

NOTE

A vacuum pump that reaches a pressure below approximately 1 mbar (0.75 Torr) is required for the cool down procedure, but is not required for continuous operation. A dry, or oil-free, pump is preferred to prevent the possibility of oil backstreaming that could contaminate the cryogenic system.

WARNING
When closing the green vacuum valve (labeled "Valve") on the rear of the Opus One unit, do not overtighten. This valve should be close only until finger tight. Never use pliers or tools to close the valve. Using excessive force to close the valve can permanently damage the valve mechanism.

The cool down procedure steps should be completed in the following order:

1. Evacuate the Opus One unit according to the following procedure.
   a) Ensure the green vacuum valve (labeled "Valve") on the rear of the Opus One unit is closed by gently applying clockwise torque. The valve should not turn under light torque. Do not overtighten.
   b) Remove the NW25 cap and o-ring from the vacuum port (labeled "Pump/Vent") loosening the clamp screw and removing the clamp.
   c) Inspect the o-ring to ensure it is dust-free and has no cracks or flaws. If so, replace the o-ring before proceeding.
   d) Using the o-ring and clamp, connect the vacuum pump via an appropriate NW25 vacuum tube (not provided) to the vacuum port and tighten the clamp securely.
   e) Follow the vacuum pump manufacturer's recommended procedure for starting the pump and evacuating the pump tube.
   f) Slowly open the vacuum valve on the Opus One unit. The valve is fully open once rotated counterclockwise approximately two (2) full turns.
2. Ensure the compressor is ready for use, including turning on any required cooling water or electrical breakers.
3. Turn on the electrical power to the compressor. The hum of the compressor and the approximately 1 cycle-per-second "hiss" of the Opus One unit should begin immediately. If the 1 cycle-per-second sound from the Opus One is not heard, turn off the compressor and confirm that the helium line and electrical connections between the Opus One unit and the compressor are correct, as per Section 2.3.
4. Confirm that the temperature reading of the channel 1 thermometer on the SIM922 Diode Temperature Monitor indicates the temperature has begun to decrease.
5. Wait until the temperature of the channel 1 thermometer drops below approximately 50 K, then close the vent valve by turning the green valve knob clockwise until finger tight.

   NOTE
   If using a dry pump with strong pumping capabilities such as a turbo-molecular drag pump (i.e., "turbo" pump), you may choose to wait until

i the system is fully cold to close the green vacuum valve as there is low risk of backstreaming contaminants such as air or pump oil into the cryogenic space of the Opus One unit.

6. Once the vacuum valve is closed you may disconnect the pumping line and turn off the pump, according to the process recommended by the pump manufacturer.
7. Seal the NW25 Pump/Ventport using the NW25 o-ring, cap, and clamp.
8. Wait until the temperature of the channel 2 thermometer (on the SIM922 Diode Temperature Monitor) indicates the system is at is “base” temperature (typically below 2.7 K). The cool-down takes approximately three (3) hours from the time the compressor is turned on.
9. The Opus One devices are now ready to be used. Refer to Section 5.1.

4.2 Warm Up Procedure

WARNING
Ensure the system has been turned off for a minimum of 24 hours before opening the vent valve or making changes to any of the high-pressure helium line connections. Unsafe conditions can be created if the system is vented or the helium lines are disconnected from the compressor or Opus One unit while the either internal temperature is 280 K.

5 Detector Operation

This chapter describes the process of turning on the detectors and describes basic front panel commands for the QO-AMP-SIM electronic control modules.

5.1 Setting Up the Detectors

> **NOTE**
> The output pulses from the nanowire electronics are positive pulses of amplitude 150 mV or higher. If negative pulses are required, use of a passive pulse inverter such as the PicoQuant SI100 is recommended.

The superconducting nanowire detectors operate by applying a DC bias current slightly below a threshold "switching current." Upon absorption of a photon, the nanowire switches from a low-resistance superconducting state to a high-resistance "normal," or non-superconducting, state resulting in rapid increase in output voltage. The detector recovers during a "dead-time" before it is ready to detect another photon. The bias current to the each detector is supplied through the electrical connections to the "NW" port of the respective channel's QO-AMP-SIM module. The voltage pulses generated by photodetection are amplified by the QO-AMP-SIM module and output from the "OUT" ports. Before biasing a nanowire, first make sure it is connected to a QO-AMP-SIM module as described in Chapter 3 and that the module is in standby mode (indicated by a green light). Use the following steps to bias and operate the device.

1. Connect the QO-AMP-SIM "OUT" SMA connector to a counter with a 50 Ω input impedance set to 50 mV threshold.
2. The counter should read near zero counts per second at this point. If you are seeing high counts, there is likely a ground issue or electrical noise from the lab environment. Please see Chapter 6 for advice on how to correct this.
3. Press and hold the **plus** (+) and **minus** (−) buttons until the light turns yellow. Upon release of the buttons, the QO-AMP-SIM will autobias the device to a high dark rate and the light will go off.

   > **NOTE**
   > The electronics perform an "autoreset" operation upon detecting a latch condition on the device. If the count rate of the device is too high (due to a high bias current, too strong optical flux, or grounding/noise issue) the light will blink continuously as the electronics continually attempt to reset the device. Simply decreasing the bias by repeatedly pressing the **minus**

(−) button should stop this. The autoreset function can be disabled by serial command if desired.

4. Reduce the dark count to ∼100 to 200 counts per second by repeatedly pressing the **minus** (−) button. The nanowire should now be ready for use. If you are unable to reduce the dark counts to this level, there is most likely a grounding/electrical noise issue. Please see the troubleshooting advice in Chapter 6.

NOTE
The nanowires are polarization sensitive and will only achieve peak detection efficiency for photons at the optimal polarization. Photons polarized orthogonal to optimum polarization will be detected with approximately 50% lower efficiency.

5.2 Front Panel Command Reference

The QO-AMP-SIM modules perform the basic control tasks for nanowire operation, and can do so without serial control via front-panel operation. Below is the list of operations which may be performed using only front-panel control.

Bias ON/OFF Press the **red** (●) button to turn the bias current on or off. When the bias is turned on, the device bias current will be set to the most recent bias setpoint since the module has been powered up. The bias resets to zero upon power up.

Increase Bias Press the **plus** (+) button to increase the bias current by one step. The bias increment is approximately 0.4% of the present bias setting. Holding the button will rapidly increase the bias.

Decrease Bias Press the **minus** (−) button to decrease the bias current by one step (in DAC units). The bias decrement is approximately 0.4% of the present bias setting. Holding the button will rapidly decrease the bias.

Autobias Press and hold both the **plus** (+) and **minus** (−) buttons until the indicator light turns yellow to autobias the nanowire. The bias current will be ramped up until the nanowire enters a latched state, the bias is then decreased by approximately 6% so the device can operate with high efficiency near the maximum switching current. Note that this bias point should be considered a good starting point for biasing the device but is unlikely to be the optimum point for your application. Also note that because of slight differences in the measured switching current the autobias function may not return to the same bias point each time it is run.

Store Bias With the bias enabled, press and hold the **red** (●) and **plus** (+) buttons to store the current bias level into nonvolatile memory for later use. This stored value is retained during power off.

Load Bias With the bias disabled, press and hold the **red** (●) and **minus** (−) buttons to revert the bias level to the value stored in nonvolatile memory.

6 Troubleshooting

If electrical glitch-noise seems to be contributing to the dark count rate, please try the following suggestions to reduce this effect. Note that while the goal is to reduce noise, it is also important to note if something makes the noises increase as it may indicate where noise is entering the system

1. Ensure that there is a good connection between the ground terminal on the back of the SIM900 (banana plug/screw terminal on the rear of the system) and the stainless steel helium lines on the back of the Opus One unit.
2. Double check that you are using the provided 12-inch double-shielded SMA cables to connect between the "NW" SMA connector and the Opus One unit. This is the most critical electrical connection in the system, so the high-quality cables are essential here.
3. Tighten the SMA connectors on the QO-SIM electronics and the Opus One just tighter than hand-tight (very gently tighten with a small wrench or SMA torque wrench). If this connection is slightly loose, the noise can be significantly worse.
4. Remove any switching power supplies from the AC circuit that powers the Opus One system and SIM900 rack. Major culprits are small, cheaply made power supplies that run LED light strips, mobile-phone chargers, and laptops.
5. Disconnect the GPIB cable from the back of the SIM900 and monitor the noise. If the noise drops, work on improving the grounding between the computer and the SIM900. In particular try both configurations of powering the computer from the same circuit that runs the SIM900, and from a different circuit to see the change in noise.
6. Try moving other electronics off of the circuit that powers the SIM900 and monitor the noise.
7. If all other suggestions fail: work to move grounding straps or "banana" cables around to try various grounding connections between the SIM900 and the Opus One. Try many grounding locations including the Opus One front SMA connector shields, the shelf the system sits on, etc. Ground-loop issues can be time-consuming to debug, but doing so may yield significant reductions in electrical noise.