Opus One™ Superconducting Nanowire Single-Photon Detection System

Installation and Operation Manual

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Contents

General Information

Warranty

This Quantum Opus product is warranted against defects in materials and workmanship for a minimum 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.

Proper Use

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.

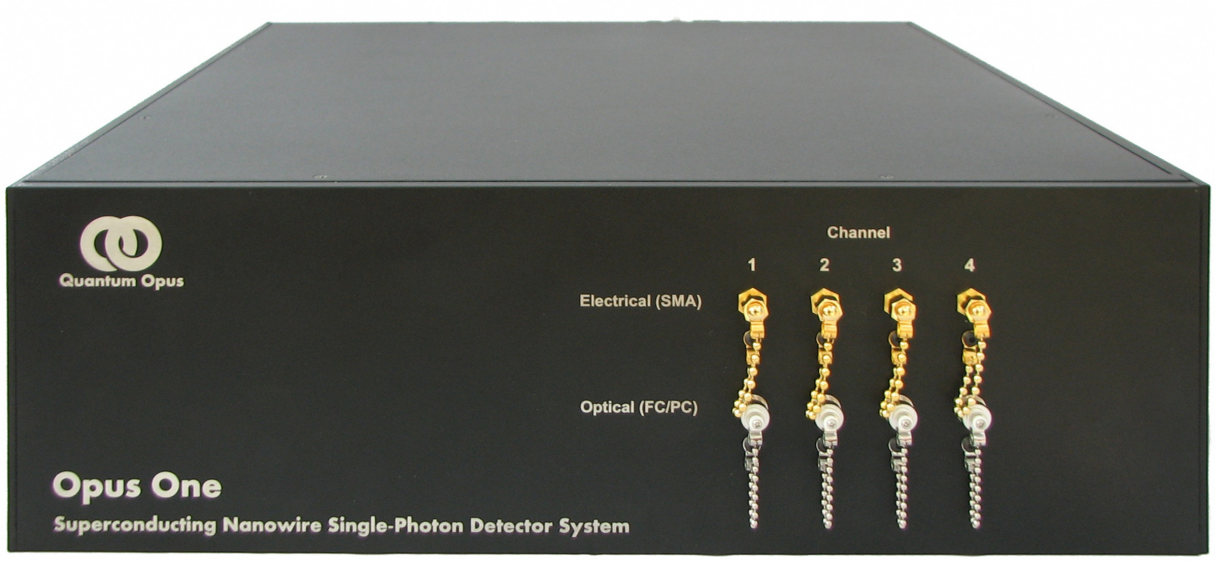

Figure 1: Photo of a typical four-channel Opus One unit containing four superconducting nanowires, cryogenic vacuum system, and fiber optic couplers. Various configurations are available with up to 32 detector channels in the above 19-inch rack configuration (3U height). Specific options and configurations may vary.

1 Introduction

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

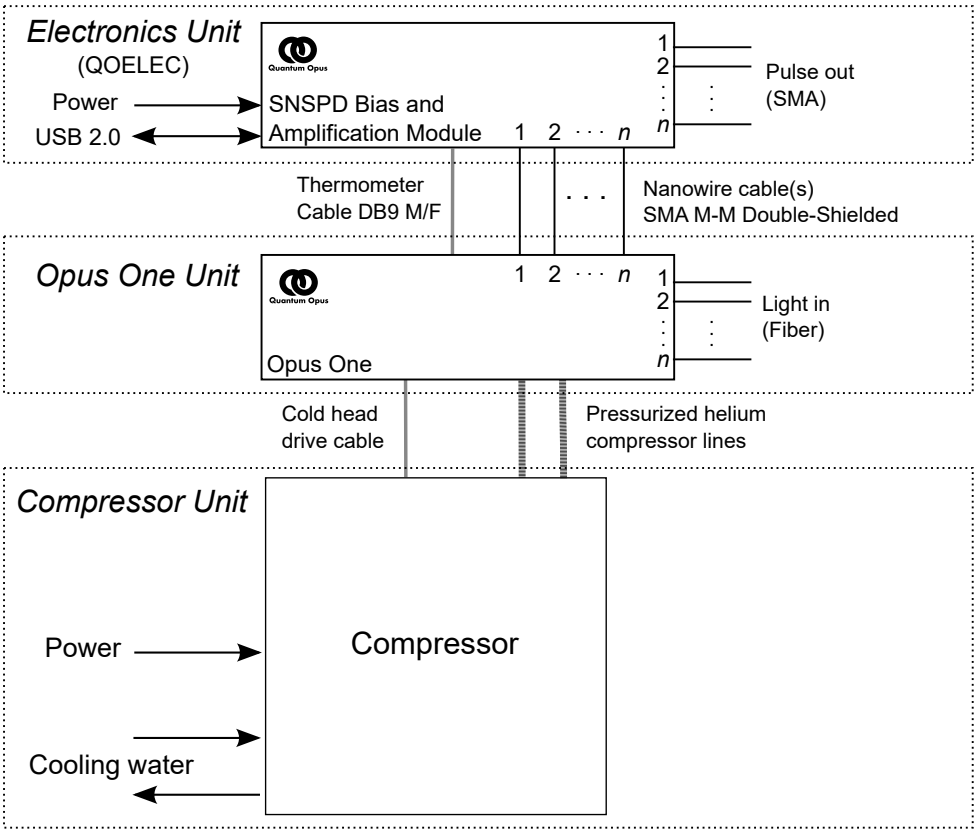

Figure 2: Nanowire system schematic showing Opus One head unit, electronics unit, and compressor with all connections.

1.1 Overview

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

1. The "Electronics Unit" that provides system thermometry and nanowire device control 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 helium gas at pressures up to 250 PSI (1.7 MPa). 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 pressurized gases.

WARNING

Ensure the system has been powered off for 24 hours before opening the vent valve or making changes to the helium connections between the Opus One and the compressor unit.

2.1 Preparation for Installation

Before unpacking your Opus One unit, the compressor must be installed. Carefully consider the placement of the compressor and Opus One. For this discussion, refer to Figure 2 on page 6.

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.

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 helium lines can 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 noting that it is intended to be operated either directly above or below the Opus One unit 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 Opus One 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 Opus One 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 Opus One unit into a rack enclosure without both support from both front and back rail flanges or support from a rack-mounted shelf. Damage to the system is likely if the unit is supported only by the front rack flanges.

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

1. Lift and position the Opus One according to the following guidelines. 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 Opus One. The unit 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.
   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 illustrated on page 26 of the Sumitomo Cryocooler Operations Manual (available in the Support section of our website), 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 rear of the Opus One unit.
   e) Connect the provided electrical drive cable between the compressor and the Opus One unit.

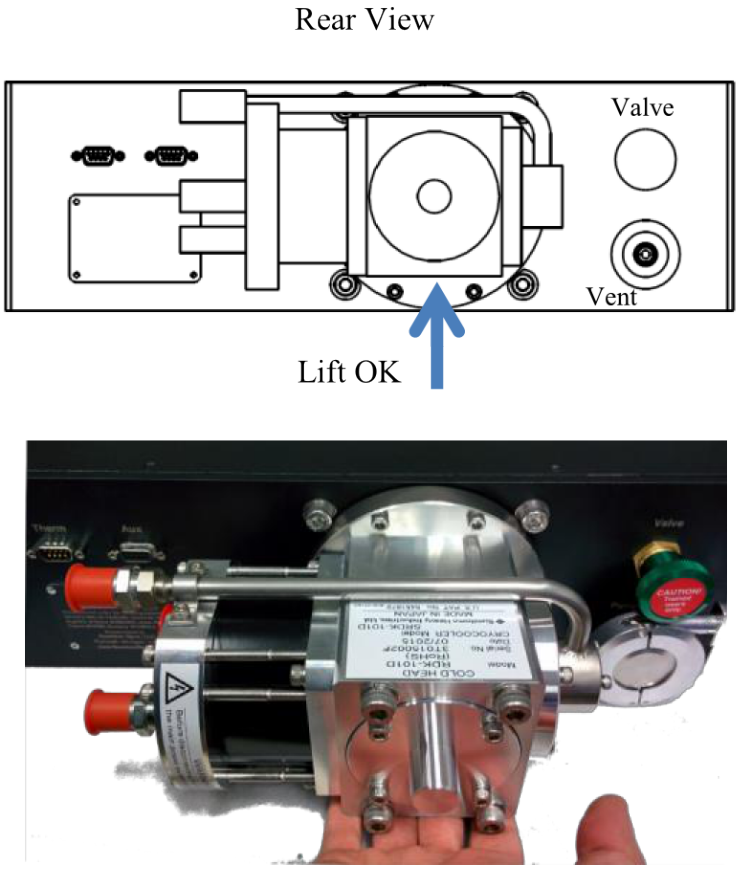

Figure 3: Rear view of the Opus One detector unit showing a suggested lift point for installation.

3 Electronics Unit Installation

Quantum Opus nanowire electronics unit is labeled on the front panel "SNSPD Control and Readout Module" and is abbreviated as "QOELEC" in the instructions below.

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 QOELEC is powered OFF when connecting the SMA cables between the QOELEC 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 QOELEC to reduce the possibility of increased electrically induced noise counts.

3.1 Connecting the electronics to the Opus One

1. With the QOELEC powered OFF, connect the Opus One to the QOELEC using the provided double-shielded SMA cables. For each detector, connect one cable from the "Nanowire" port on a QOELEC channel to the corresponding "Electrical" SMA connector on the Opus One unit with desired channel number. 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).
2. Attach the provided 9-pin (DB9 male to DB9 female) filter adapter to the DB9 connector on the back of the QOELEC. Then attach the provided 9-pin cable between the filter and the "Therm" connector on the rear of the Opus One unit.
3. Connect the provided USB cable between the QOELEC and the computer interface.
4. Connect the spade connector of the provided ground strap to the grounding terminal on the back of the QOELEC. Use the provided zip ties to strap the free end of the grounding strap to the stainless tube at the top-rear of the Opus One.

Figure 4: A typical 16-channel Quantum Opus SNSPD Control and Readout Electronics (QOELEC) module. Configuration may vary by system.

5. Plug in the provided power supply to the back of the QOELEC and turn the power on. The power indicator light near the power switch will turn on. The light will be orange if no valid USB connection is made to the unit, and green if a valid connection is made. All connections should be left in place when powering up and powering down the QOELEC. Therefore, any changes made to the cabling should be made with the QOELEC powered OFF.

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 to a point at which both stages are above 50 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 fully "warm" state is defined as both thermometers (Stage 1 and Stage 2) read above 280 K. This state should be achieved within 12 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 0.1 mbar (100 mTorr) 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 closed 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 hand 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. The valve should remain open and the pump on until the system has reached 50 K.
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 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 Stage 1 thermometer indicates the temperature has begun to decrease.
5. Wait until the temperature of the Stage 1 thermometer drops below approximately 50 K, then close the vent valve by turning the green valve knob clockwise until (gently) finger tight. Do not overtighten.

   NOTE
   If using a dry pump with strong pumping capabilities such as a turbomolecular drag pump (i.e., "turbo" pump), you may choose to wait until 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 from the Opus One 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 Stage 2 thermometer indicates the system is at its "base" temperature (typically below 2.5 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 12 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 either internal temperature is much below room temperature.

To warm the system, turn off the compressor. If using a water-cooled compressor, the water cooling can be turned off at this time as well.

5 Detector Operation

This chapter describes the process of operating the detectors using the QOELEC with a computer interface.

5.1 Setting Up the Detectors

NOTE

The output pulses from the nanowire electronics are ac-coupled pulses of positive amplitude > 150 mV (without cryogenic amplifier option) or negative amplitude < -500 mV (with cryogenic amplifier option). If opposite polarity pulses are required, we recommend the use of a passive pulse inverter, such as the PicoQuant SI100, on the output of each channel. Other pulse output options are available (e.g., TTL output).

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 each detector is supplied through the electrical connections to the "Nanowire" port of the respective QOELEC channel. The voltage pulses generated by photodetection are amplified by the QOELEC and output from the corresponding "Pulse Out" port. After properly connecting all Opus One nanowire channels to the QOELEC (see Chapter 3). Use the following steps to bias and operate each device.

1. Using a 50 Ω-impedance, low-noise cable, connect the QOELEC channel "Pulse Out" SMA connector to a pulse counter with a 50 Ω input impedance. For the standard option system (no cryogenic amplifier) set the counter to trigger on rising-edge pulses with a threshold of +75 mV. For negative pulses (cryogenic amplifier option) set the threshold to falling-edge pulses with a threshold of −500 mV. For the TTL output option, set the threshold to rising-edge with a threshold of 500 mV.
2. The counter should read zero counts per second of electrical noise 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 electrical interference.
3. Install and launch the QOELEC Control Panel software. Instructions on obtaining and installing this software are available on our website in the Support section. More detailed instructions for the sample web interface are given below in Section 5.2.
4. Setting the Device Bias: With the fiber input on the Opus One, gradually increase the device bias until the dark counts are at the highest acceptable level (typically a few hundred counts per second). The device efficiency slightly increases as you increase the bias, so the optimal bias point will vary by application.
5. The device is now ready for use. To test if the device is functioning, remove the fiber cap to let ambient light into the biased channel. At this point, you should see a significant increase

in the measured count rate. Scientists at Quantum Opus enjoy helping you optimize the system for your application, so please reach out to us for any desired assistance.

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 lower efficiency, but all other device performance metrics are unchanged (e.g., dead time, jitter, pulse amplitude).

5.2 Web Interface Example

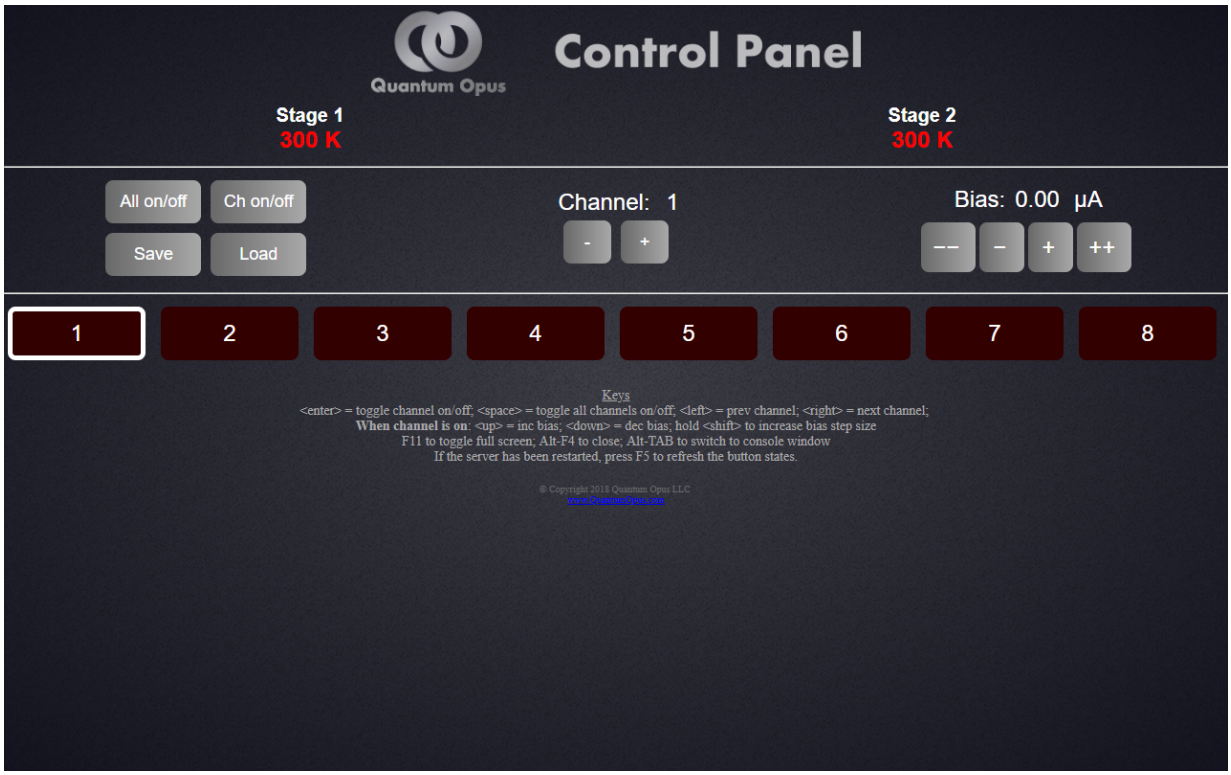

Figure 5: Sample web interface discussed below.

The QOELEC is controlled using a computer interface. A sample web-based interface with associated Python, HTML, and JavaScript code may be provided upon request. The following list of basic operations may be performed using this interface.

Channel ON/OFF Each channel has a corresponding button. Press the button to turn on the desired channel(s). When it is highlighted **green**, the channel is on. Each channel stores the most recent set bias. If the channel is turned off after setting a bias, when turned back on, it will set the chosen bias.

Increase Bias Press the **plus** (+) button or the (++) to increase the bias current. The (+) button has a bias increment of approximately 1% of the present bias setting, while the (++) button has a bias increment of approximately 10%. Holding either button will rapidly increase the bias.

Decrease Bias Press the **minus** (-) button or the (- -) to decrease the bias current. These buttons decrease the bias at the same increment the plus buttons increase the bias. Holding either button will rapidly decrease the bias.

Save Bias When all channels are turned on with their respective biases (at the same time), press the **Save** button. This will store all of the biases to their respective channels.

Load Bias Press the **Load** button to load previously stored biases from using the Save button.

Keyboard Operation The above functions may be activated by keyboard if available.

- Right and left arrow keys move between channels.
- Up and down arrow keys increment and decrement the bias of the selected channel; holding Shift while pressing up/down arrows will change bias in larger steps.
- Enter toggles the On/Off state of the selected channel.
- Space bar toggles all channels On/Off.

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 noise worse, 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 QOELEC (screw terminal on the rear of the system) and the stainless steel helium lines on the back of the Opus One unit.
2. Ensure that you are using the provided double-shielded SMA cables to connect between the "Nanowire" 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 QOELEC and the Opus One just tighter than hand-tight (very gently tighten with an 8-mm 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 electronics. Major culprits are small, cheaply made power supplies that run LED light strips, mobile-phone chargers, and laptops.
5. Disconnect the USB cable from the back of the QOELEC while monitoring the noise. If the noise drops, work on improving the grounding between the computer and QOELEC. In particular try both configurations of powering the computer from the same circuit that runs the QOELEC, and from a different circuit to see the change in noise.
6. Try moving other electronics off of the circuit that powers the QOELEC.
7. If all other suggestions fail: work to move grounding straps or "banana" cables around to try various grounding connections between the QOELEC 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.