SLICE-QTC Four-Channel Temperature Controller

Model No. SLICE-QT and SLICE-QTC

Document Revision: 1

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Please read Limited Warranty and General Warnings and Cautions prior to operating the SLICE-QTC.

Links

Click here for the SLICE-QTC Quick Start Guide.
Click here for the SLICE-QTC API.
Click here for the Ziegler-Nichols loop tuning instructions.
Click here for the SLICE-QTC web page.
Click here for the Github page for SLICE-QTC GUI
Click here for the Github page for SLICE-QTC firmware revisions
Please check back for added functionality. Contact sales [at] vescent [dot] com for questions and corrections, or to request added functionality.

Description

The SLICE-QTC is a high-precision temperature controller (see figure 1). It will control up to four thermal plants with sub-millikelvin precision.

Fig. 1: The SLICE-QTC



Purchase Includes

- SLICE-QTC Temperature Control Unit
- AC power cord with appropriate wall plug for you location (if known)
- Four single-ended 6-ft control cables[1)]

Absolute Maximum Ratings and Power Input

Note: All modules designed to be operated in a laboratory environment.

Parameter	Rating
Environmental Temperature	>15°C and <30°C
Environmental Humidity	<60%
Environmental Dew Points	<15°C
Maximum AC Line Input Current	2 A

Tab. 1: Absolute Maximum Ratings

The SLICE-QTC will accept input line voltages within the ranges shown in table 2.

Parameter	Value	Units
Input Line Voltage	100-240	VAC
Frequency	50-60	Hz
Phase	1 phase	
User-serviceable fuse[2)]	T 2.0 A L 250V	

Tab. 2: Input Voltage Specifications

Proper Usage

	If this instrument is used in a manner not specified by the manufacturer in this manual or other relevant literature, protection provided by the instrument may be impaired.

List of Symbols

	Warning. Pay special attention to procedures and notes. If procedure is not followed carefully, damage to the SLICE-QTC or devices connected to it may occur.
	Potential for electrical shock hazard.

Specifications

Performance[3]	
Parameter	**Value**
Channels	4
Loop FIlter	PID, adjustable corners and proportional Gain
Control Range[4]	-10 to +120°C
Compatible Transducer	TEC or resistive heater
Compatible Sensor	NTC thermistor [5]
Temperature Stability	±0.2 mK over 1 hour[6]
Precision	~1 mK
Control Capacity	35 W[7]
Current Capacity	6 A per channel[8]
Compliance Voltage	≤18 V[9]
Input & Output	
I/O Voltage Range	±10 V
Triggering	TTL
Control Interface	
Control	Front-panel touch screen, GUI, Serial API
Connections	Host control: USB Type B

Tab. 3: Specifications of SLICE-QTC

Front Panel

An image of the front panel is shown in figure 4. The functions and connections are as follows:

1. Parameter input adjustment knobs
2. Control signal inputs
3. Signal monitor outputs
4. Touch screen with view of CH 2 Details screen
5. ΔT plotted as a function of time (blue line)
6. System locked range (yellow dashed lines)

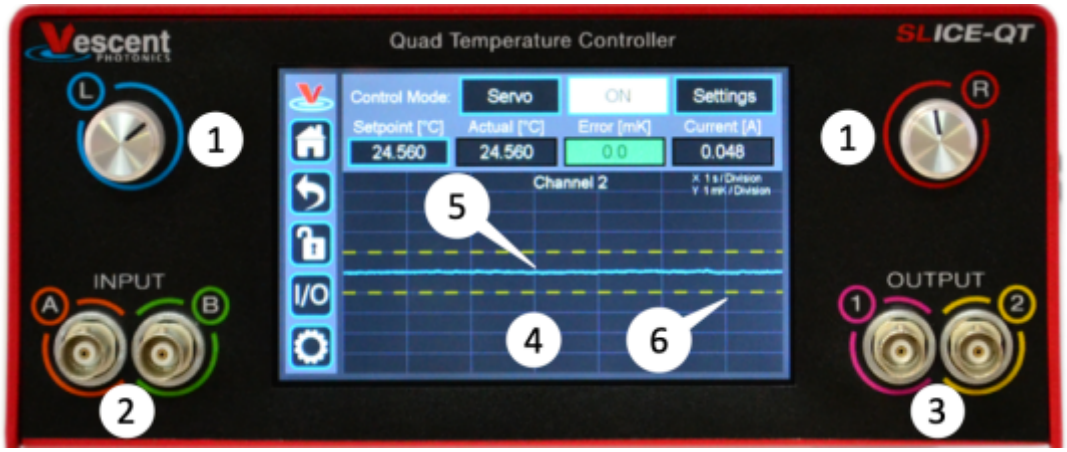


Fig. 4: Front of SLICE-QTC

Rear Panel

An image of the rear panel is shown in figure 5. The functions and connections are as follows:

1. Main On/Off power switch
2. AC line power in[10)]
    1. User-serviceable fuse (T 2.0 A L 250V)
3. Output trigger (BNC)
4. Input trigger (BNC)
5. USB port (Type B)
6. Connections to thermal plants[11)12)]



Fig. 5: View of rear of SLICE-QTC

Interface Connections

Connections to the thermal plants are made from the rear panel. Four cables for this purpose are provided with the SLICE-QTC. Each has one end terminated with a CUI Inc. PDP-40 connector for connecting to the CUI Inc. CP-7240-ND connector on the SLICE-QTC. The other end is unterminated and is for connecting to your specific plant. The pin out for connecting the cable (Beldon 1502R 010500) to your specific plant is given in table 4.

Connector Pin Number	Color	Function	AWG
1	Red	TEC/Heater+	18
2	Black	TEC/Heater-	18
3	White	Thermistor+	22
4	Blue	Thermistor-	22
Metal Sleeve	Ground Shield		24

Tab. 4: Cable pinout

	Do not have servo loop engaged when connecting Servo Output to your plant.
	Use caution grounding the shield (drain) at the transducer end of the interface cable as ground loops may be formed, degrading performance. Consider floating the plant or not connecting the shield to the plant chassis.

You may purchase more cables separately from Vescent Photonics. We do not recommend making cables, but if you do so, make sure the metal sleeve is well grounded to provide proper shielding to the signal cables.

Operating the SLICE-QTC

Screen Navigation

The touch screen interface and the Host GUI operate in a substantially similar way, except touch is substituted for a click in the touch screen interface.

When presented with a given view, it is possible to select the functionality or edit the values in a field bordered in blue. When a particular field is actively being edited, its border will change to yellow. The Home Screen of the SLICE-QTC is shown in figure 6. From the Home screen, summary control over the four channels is possible, including setting T_{set}, initiating lock, or entering an individual channel's Detail screen.

In general, the status displayed in an editable field is the current status (not the result of touching the button). Touch the field to select a new value/status. For instance, in figure 6 all of the channels are in stand by. Touching the OFF button to initiate servo control over a plant will change this button to read ON (figure 17).



Fig. 6: Home screen of SLICE-QTC

Control Bar

On the left edge of the screen is the Control Bar. At any given time, these buttons will have the following effect.

Home Button



Fig. 7: Home button Returns to Home screen (figure 6).

Back Button



Fig. 8: Back button Returns to previous screen. Changes will be lost if not accepted before using the Back button.

Lock Button



Fig. 9: Lock button (shown in unlocked mode) Locks out further modification of parameters. Touch to lock or unlock parameter entry. It is still possible to engage the temperature control loops when system is locked, but it is not possible to change the set point temperature or loop parameters, etc.

I/O Button



Fig. 10: I/O button Enters the screen for programming the front-panel I/O.

System Settings Button



Fig. 11: System settings button Enters screen for system control settings (brightness, volume, etc.).

Entering Values

In order to afford maximum resolution, the least significant digit will not necessarily change to precisely your target value and will be coerced to the nearest acceptable value, which is limited by the digitization scheme for the set point. For instance, you may select a set point temperature of 17.000°C, but the closest allowed digitized value may be 16.999°C.

In most instances, there are two methods for entering parameter values: the physical rotary knobs on the front panel and the pop-up keypad on the touch screen. When using the knobs to change the value of a parameter, changes take effect immediately. When using the keypad, changes do not take effect until the enter key is depressed.

Rotary Knobs

If you touch an editable field for a brief moment, a cursor will appear under one of the digits of the parameter value. By turning the right knob, it is possible to increase (cw) or decrease (ccw) the value of the underlined digit. Turning the left knob will change which digit is editable (cw to move to the left and ccw to move to the right).

Keypad

If you touch and hold an editable field such as the set point temperature, a numeric keypad will appear as seen in figure 12. You can enter in the full value of the desired parameter with this keypad.

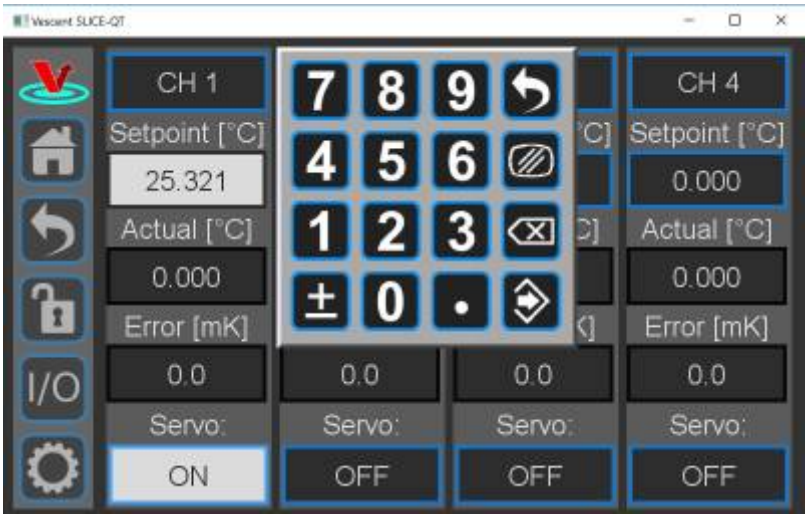


Fig. 12: Pop-up Keypad

The action initiated by each button is described below.

Escape



Fig. 13: Escape button Exits keypad without accepting changes.

Clear



Fig. 14: Clear button Clears value in field being edited.

Delete



Fig. 15: Delete button Deletes last character entered.

Enter



Fig. 16: Enter button Accepts edits and exits keypad.

Home Screen

The Home screen summarizes the status of all four channels (figure 6). The data for each channel is arranged vertically. At a glance, for each channel, T_{set}, T_{act}, and ΔT can be read, as well as whether servo control is engaged. If the loop is engaged and ΔT is smaller than a user-defined range, the Error value field will be green, indicating a locked state. If ΔT is outside this user-defined range, this field will turn yellow.

Setting the Temperature

To set the temperature set point from the home screen, touch the Setpoint window for the desired channel (circled in red for CH 1 in figure 17). A long touch will cause a keypad to appear. Enter desired value and touch the accept button.

A short touch will highlight the Setpoint window in yellow (figure 18). Use rotary knobs to select digit to edit (right knob) and value for digit (left knob).

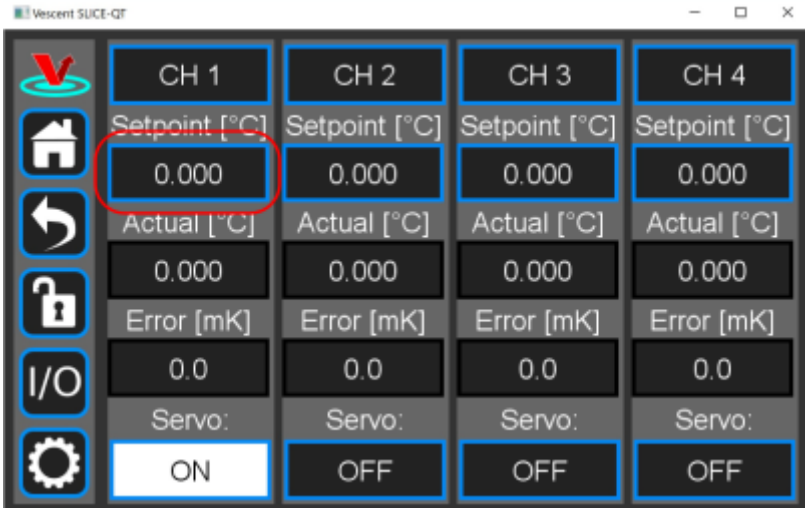


Fig. 17: Select Temperature setpoint for CH 1



Fig. 18: Knob adjustment of Temperature setpoint for CH 1

Enabling Feedback

Touch the OFF button at the bottom of the column for the desired channel. The button will turn white and read ON to indicate the SLICE-QTC is actively controlling the temperature for that channel. In figure 17 and figure 18 CH 1 is active and CHs 2-4 are inactive.

When the system is locked (as defined by the user in the CH X > Settings > Limits screen) the Error window will display ΔT with a green background. As the system approaches lock, it will display ΔT on a yellow background.

Channel Detail Screen

You can set how individual channels behave in the Channel Detail screen. To enter a Channel Detail screen from the Home screen, touch the CH button for the appropriate channel (figure 6). figure 21 shows the CH 1 Detail screen. From this screen, you can change T_{set}, and initiate temperature control as from the Home screen. You can also visually monitor the performance of the loop. When the lock is engaged, the graph in the lower right of the screen displays ΔT (T_{act} - T_{set}) on a rolling basis. The yellow dashed lines indicate the user-defined “lock range” (see figure 24). In figure 21, the lock range is set to ±3 mK. If ΔT is outside of this range, the Error field background will change from green to yellow.

- Change the speed of the rolling display: touch the 

button and select from 1 to 20 s/div.
- Change the scale of the vertical axis: touch the 

button and select from 1 mK/div to 10 K/div.
- Pause and restart the rolling screen: touch the  button.
- Turn on & off cursors on the graph: touch the 

button. It is possible to drag the cursors across the display of ΔT to measure an oscillation period. This function will be helpful when tuning the loop parameters to your plant.

Display of Transducer Current, Voltage, and Power

As shown in figure 21, the current being delivered to the transducer is displayed in the blue box on the right margin labeled Current [A]. If you touch the blue box, the box will rotate through displaying current through, voltage across, and power delivered to the transducer.

From this screen, you can also set the various parameters for how the loop will behave.

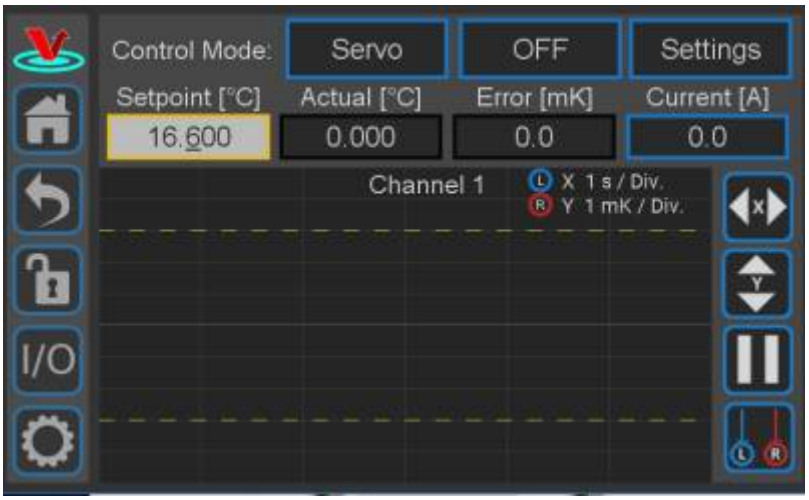


Fig. 21: Initial view of CH 1 Detail screen

Setting Control Modes

Touch the Settings button in the top right of the window. The sub-menu shown in figure 22 will appear.

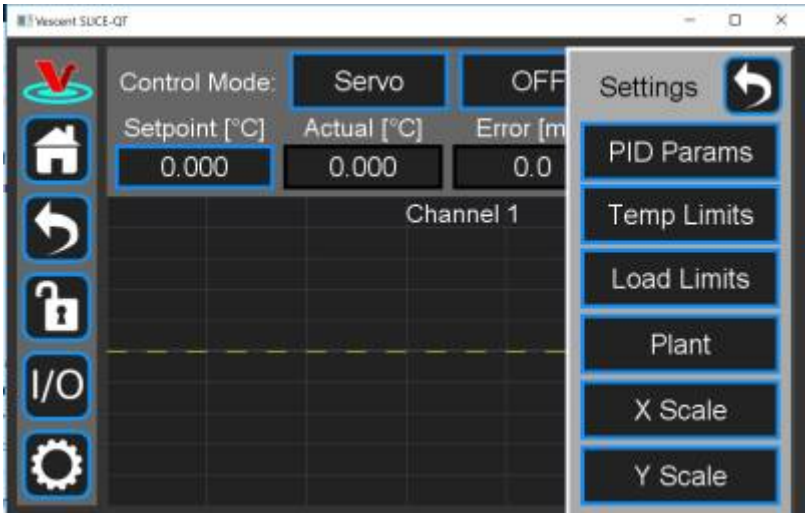


Fig. 22: Menu of settable parameters

Adjusting the Graph

To adjust the vertical range (ΔT) of the graph from the Details screen, touch Settings > Y Scale. Select the appropriate setting (figure ##).



Fig. ##: Setting the y-scale on ΔT vs. t graph

To adjust the time base of the graph from the Details screen, touch Settings > X Scale. Select the appropriate setting.

Channel Settings

PID Filter and Slew Rate Adjustment

PID Settings

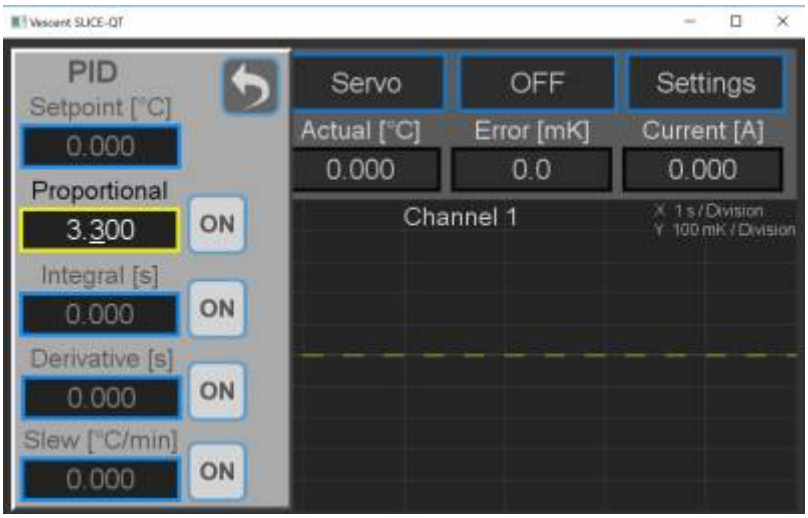


Fig. 23: Screen for adjusting PID parameters for individual channel

To set the PID loop filter parameters from the Home screen, select CH X > Settings > PID Params and the screen in figure 23 will appear. The parameters for the PID loop filter are set in this popup screen. These parameters control the closed-loop behavior of the feedback. Each of these parameters will need to be tuned specifically for your plant. There is an option to enable or disable each parameter in the loop filter. There are a number of methods to tune a loop. We recommend the Ziegler-Nichols method.[13] Instructions on using this method can be found here.

Slew Rate Limit

For applications where the rate of change of the temperature of the plant needs to be controlled, it is possible to set an upper limit on the slew rate. This can also be done through the PID Params screen.

Setpoint	°C	Sets the setpoint temperature of the plant.
Proportional	V/V	Sets the proportional gain of the loop filter.
Integral	sec	Sets the integral time constant of the loop filter.
Derivative	sec	Sets the derivative time constant of the loop filter.
Slew (Rate)	ºC/min	Sets the maximum slew rate for the plant temperature.

Tab. 5: Setting loop parameters

	If appropriate, make sure to turn the Slew Rate Limit off when changing use case!

Power Limits

The User can limit the control power available to individual channels. To adjust control capacity from the Home screen, select CH X > Settings > Load Limits and the screen shown in figure 25 will appear.



Fig. 25: Screen for adjustment of control power capacity

Transducer and Thermistor

To set the properties of the transducer (TEC or heater) and thermistor for an individual channel from the Home screen, touch CH X > Settings > Plant. The menu in figure 26 will appear. Select TEC/Bipolar (as seen) or by touching TEC/Bipolar, select Heater/Unipolar.

From this screen, it is also possible to set the polarity of the TEC. Touch Polarity Positive/Polarity Negative to toggle between the two states. The polarity is already set correctly to POSITIVE for use with NTC thermistors.

The thermistor data has been configured at the factory for a typical NTC thermistor that is 10 kΩ at 25°C. Only NTC (Negative Thermal Coefficient) thermistors can be used. You can enter a new Beta value, reference temperature, and resistance value and the Steinhart-Hart constants will be calculated automatically or vice versa.

NOTE: The SLICE-QTC can achieve sub-millikelvin stabilities over a very wide set point temperature range. For most applications working near room temperature, an NTC thermistor with a nominal value of 10 kΩ at 25°C will work fine. For temperatures far from room temperature, best results will occur by choosing a thermistor that has a resistance of 10 kΩ at your desired set point temperature. The input bridge circuitry is configured to have maximum sensitivity at a 10-kΩ resistance.

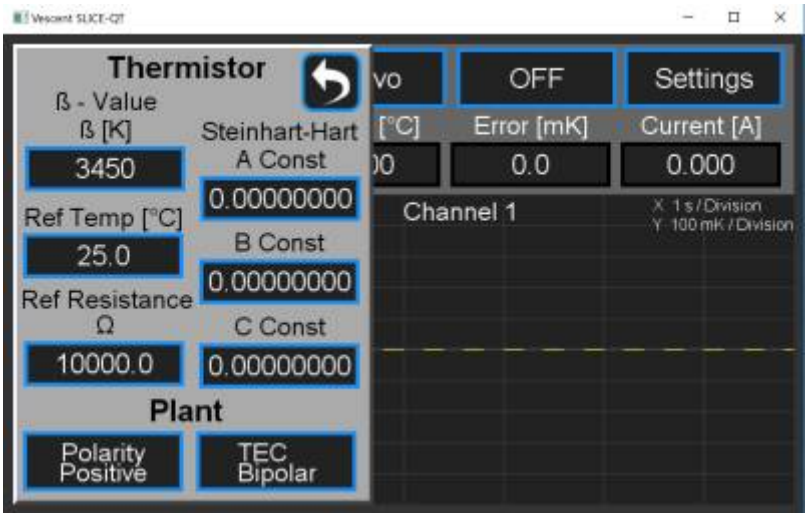


Fig. 26: Set Thermistor and Plant Information

	WHEN USING A RESISTIVE HEATER, be sure to set the transducer type (CH X > Settings > Plant) to Heater/Monopolar. If set to TEC/Bipolar, attempts by the SLICE-QTC to actively cool your plant will result in a thermal runaway condition.

Maximum & Minimum Temperature, Lock Range

Set Maximum & Minimum Temperature

The maximum and minimum allowable temperatures (T_{max} and T_{min}) can be set as well as the range of ΔT where the system is considered to be locked. From a Channel Detail screen (figure 21), tap Settings > Temp Limits and the screen in figure 24 will appear. It is advised to set T_{min} above the dew point temperature for your ambient conditions to avoid condensation on your plant surface. If the temperature of the plant exceeds the range set by T_{max} and T_{min}, the temperature will be displayed in a flashing red field.

Set Lock Range

In the view shown, the lock range has been defined to be ±3 mK. If -3 mK ≤ ΔT ≤ +3 mK, ΔT will be displayed on a green field. If outside this range, ΔT will be displayed on a yellow field. The graph in the bottom right of the Channel Detail screen plots ΔT vs. time. The dashed yellow lines on this plot represent the lock range limits as set in this screen.

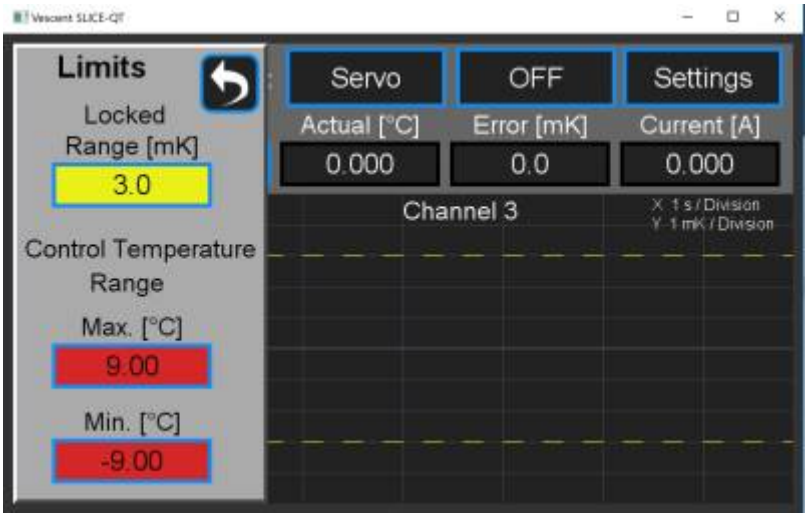


Fig. 24: Screen for setting absolute extrema and lock range

Warning Window	ºC	Defines the nominal operating temperature range for the plant. When the actual temperature is within this window (±value), the temperature error will be displayed on a green background. When the error in the temperature is outside this window, the temperature error will be displayed on a yellow background.
Maximum Temp	ºC	Sets the maximum and minimum operating temperatures of the plant. The user will be prevented from adjusting the setpoint temperature to outside this range. If the actual temperature exceeds this range, the temperature will be displayed on a flashing red background.
Minimum Temp	ºC	

Tab. 6: Warning and Max/Min

	If your plant is exposed to the atmosphere, use an abundance of caution in setting T_{min} below the dew point for your ambient conditions! Water will condense on surfaces that are below the dew point temperature.

Front-panel Inputs & Outputs

The front panel of the SLICE-QTC has two analog inputs (channels A & B) and two analog outputs (channels 1 & 2, not to be confused with the temperature control channels) available for use. The two analog outputs can be configured to output useful monitor signals, while the two analog inputs can be configured to provide additional functionality. A schematic of the input and output functionality is shown in figure 29, with the light blue boxes indicating the front panel I/O. The voltage range of the analog I/O on the SLICE-QTC is ±10 V.

To program the functionality of the front panel I/O, from any screen, touch the I/O icon on the left

sidebar. You will be presented with the screen shown in figure 27. Touch the blue-framed window to the right of the I/O channel you wish to program. Upon doing so, you will be presented with a pull-down menu of the various options available for that channel. For instance, if you select channel A input, you will be presented with the screen shown in figure 28. You can select the input to be any of the signals shown in table 7 for any of the four temperature-control channels.

Each selected function for inputs and outputs will have settings that you can adjust, specific to the chosen functionality. To access these settings, select the Settings ("gear") icon that is just to the right of the selection window. A pop-up window will be presented that displays the various settings that can be adjusted for that feature.

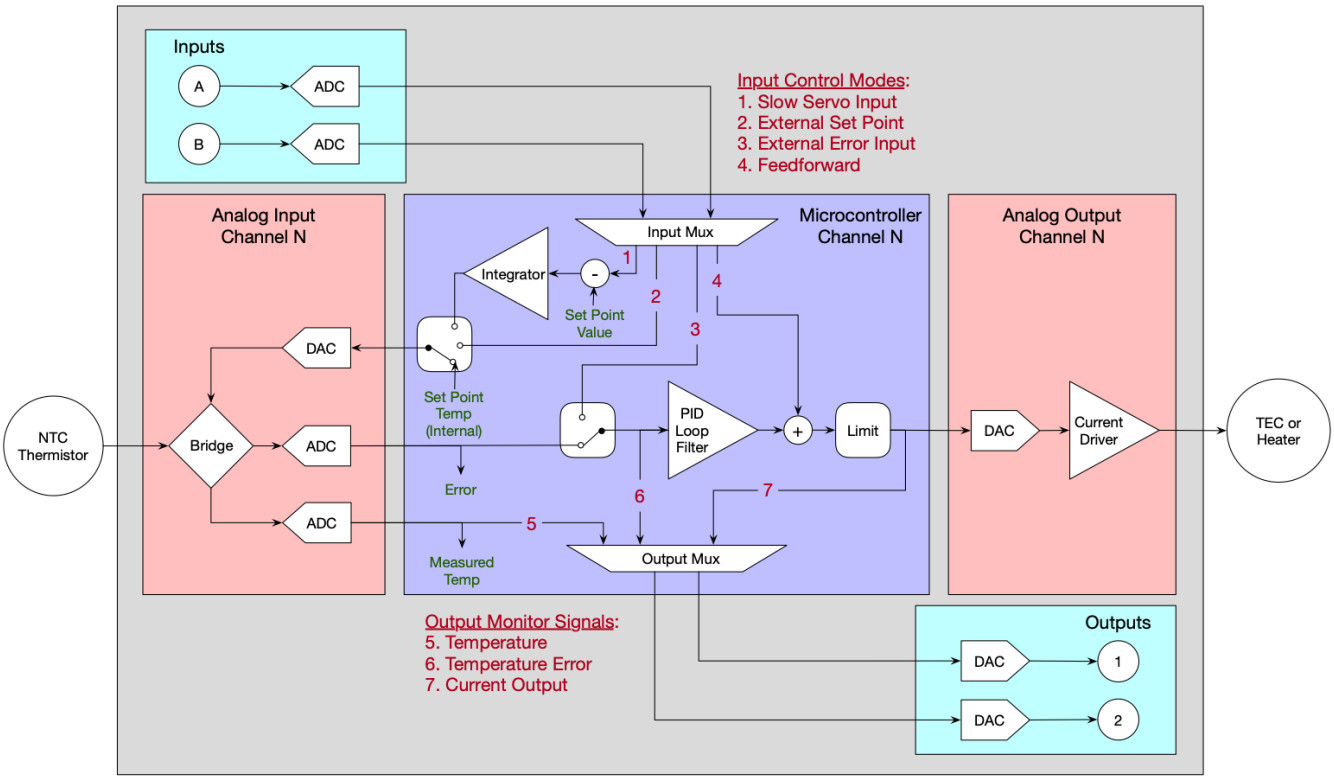


Fig. 29

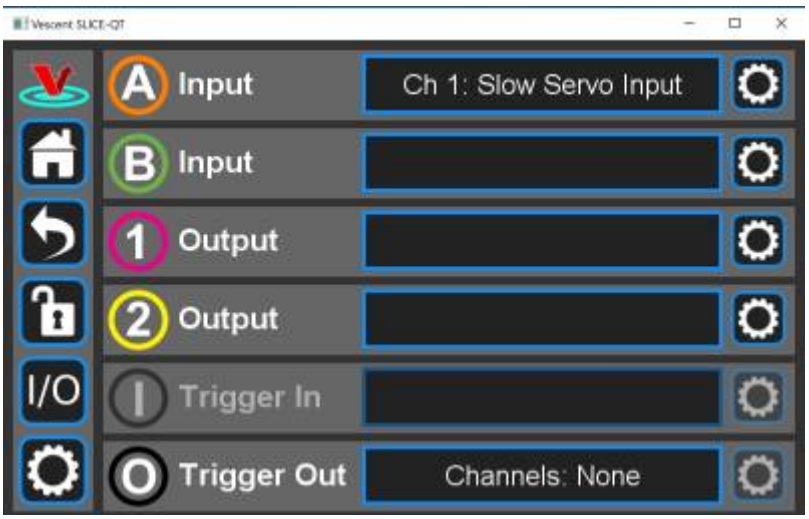


Fig. 27: Programming the front-panel I/O

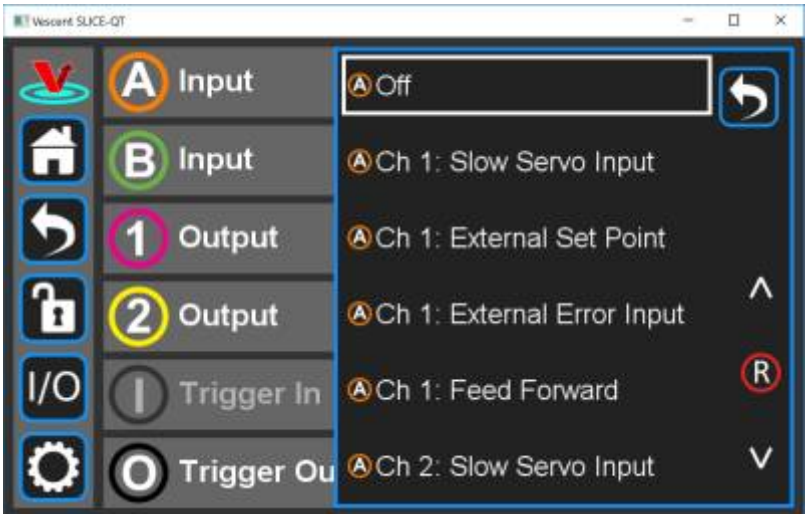


Fig. 28: Programming the input on Channel A Input

Input Channels A & B

Slow Servo Input

In some use cases, it is convenient to have the temperature set point automatically adjusted to keep another external parameter (which depends on temperature) at a certain value. For instance, the frequency of a laser might be controlled by adjusting the cavity length via a piezoelectric transducer (PZT). Over time, the cavity length may drift outside the range of the PZT, causing the laser to unlock. In this case, the laser cavity might have its temperature automatically adjusted so as to center the PZT voltage in the middle of its operating range.

When this mode is active, the input signal is compared with a set point voltage (settable by the user) to derive an error signal that is input to a single integrator loop filter. The output of the integrator automatically adjusts the the temperature set point to maintain the input voltage signal at set point voltage. Manual touchscreen adjustment of the temperature set point is disabled when this mode is active. Touch the Settings icon for the I/O channel to set the Set Point Voltage, the Integrator Gain, and the Polarity for the slow servo feedback.

External Set Point

In this mode, an external signal can be used to supply the set point temperature of the plant. The set point temperature is related to the input voltage Vin by: Set Point Temp [˚C] = Gain [˚C/V] x Vin + Offset[˚C]. Touch the Settings icon to the right of the channel selection to adjust the Gain and Offset.

External Error Input

This mode allows the temperature error to be derived from an external temperature transducer. In this mode, the thermistor and associated signal processing electronics are not used. The temperature error is related to the input voltage Vin by: Temperature Error [˚C] = Gain [˚C/V] x Vin + Offset [˚C]. Touch the Settings icon to the right of the channel selection to adjust the Gain and Offset.

Feedforward

This mode allows a feedforward signal to be summed into the output of the PID loop filter. The feedforward signal current is related to the input voltage Vin by: Feedforward Current [A] = Gain[A/V] x Vin + Offset[A]. Touch the Settings icon to the right of the channel selection to adjust the Gain and Offset.

Choice	Comment
Off	Value not read
Slow Servo Input	Input is routed through an integrator and then used to control the set point
External Set Point	Externally control the set point temperature
External Error Input	Alternate input path for error signal (bypasses wheatstone bridge)
Feed Forward	Sums input value with loop filter output.

Tab. 7: Front-panel input signals

Output Channels 1 & 2

Similarly, you can program the output signals for the Output Channels 1 and 2. For each channel, the actual (measured) temperature, the temperature error, or the current output can be chosen as the output signal. For instance, if you select Channel 1 Output from figure 27 you will be presented with figure 32. You can choose any value from table 8 to be delivered to the Channel 1 Output output on the front panel. Touch the Settings icon to the right of the channel selection to adjust the Gain and Offset for these output signals as in figure 33. When porting the Temperature of a given loop to an Output, setting the Gain equal to 0.1 V/°C and the offset to 0 V will give a convenient 2 V output at 20°C.

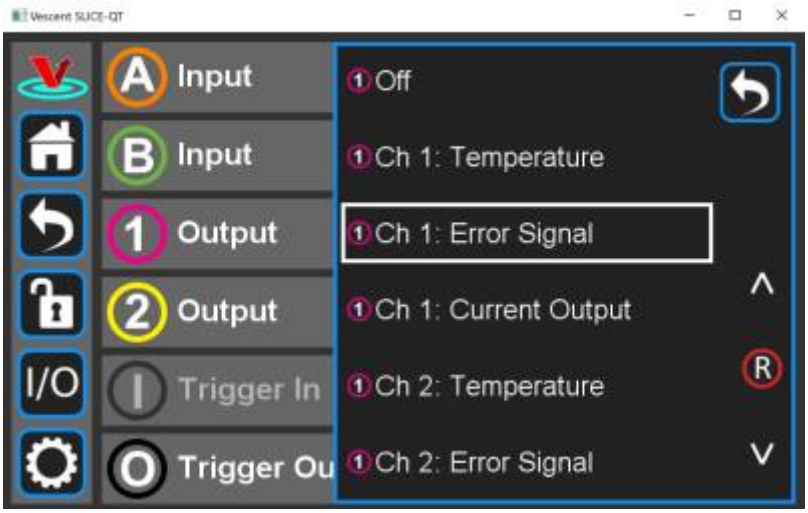


Fig. 32: Programming the output on Channel 1 Output

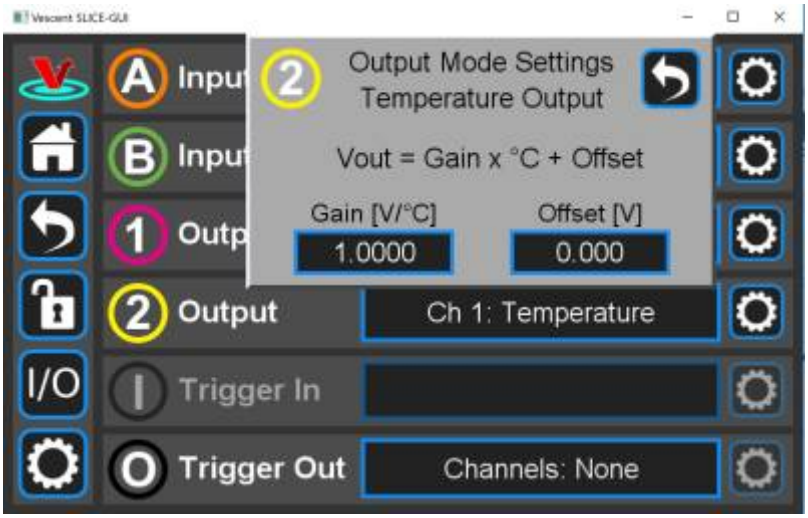


Fig. 33: Adjusting the Gain & Offset of Channel 2 Output

When the SLICE-QTC is programmed to deliver data to an output port, the data that is being delivered will be indicated on the Channel Detail screen as seen in figure 34. The numeral 1 in the magenta circle in the upper right-hand corner of the green Error [mK] display field indicates that the error in temperature for CH 4 is being delivered to the front-panel I/O port ch 1.



Fig. 34: CH 4 ΔT data is being delivered to front-panel I/O channel 1

Choice	Comment
Off	No data delivered to output channel
Temperature	Actual temperature measured by thermistor
Temperature Error	Temperature error $\Delta T = T_{act} - T_{set}$: Actual temperature minus set point temperature
Current Output	Current being delivered to specified temperature control channel

Tab. 8: Front-panel ouput signals

Triggering

External control of the SLICE-QTC is accomplished via a TTL trigger.[14)] 0 to 0.8 V TTL is low and 2 to V_{CC}

is TTL high.

Trigger Out

The Trigger Out on the back panel of the SLICE-QTC can be forced to go high to alert an external device to a status change. To program the trigger, from any screen touch I/O > Trigger Out. You will be presented with the screen shown in figure 35. Select those events on the desired channels for which you want the trigger to go high. A logical OR is performed on the set of selected events to determine the state of the output trigger. In the example, the trigger will go high if the minimum temperature set for CH 1 is exceeded, the maximum temperature set for CH 2 is exceeded, the maximum slew rate set for CH 3 is exceeded, or when CH 4 reaches its set point temperature.

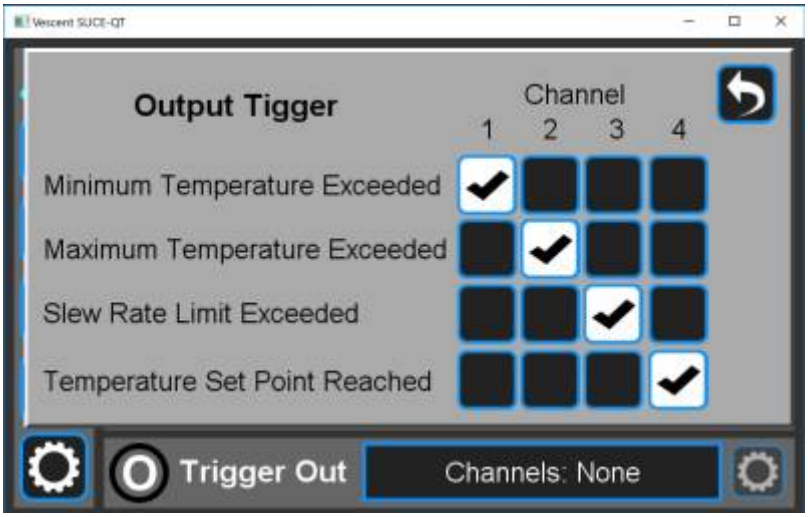


Fig. 35: Programming the rear-panel trigger out

Trigger In

Currently, there are no input triggers allowed for the SLICE-QTC.

System Settings

Touching the System Settings button on the Control Bar (figure 11) will open the System Settings screen as seen in figure 41.

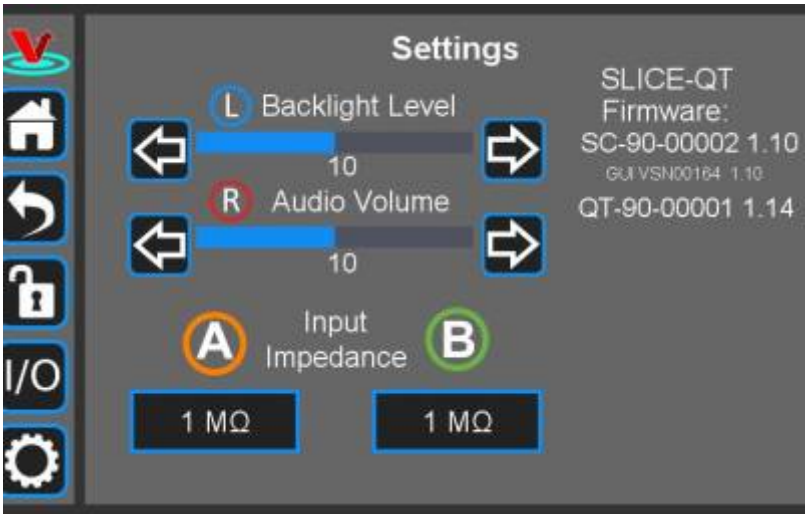


Fig. 41: User-programmable system settings

User Interface Appearance

From this screen, adjustments to the brightness of the screen and the volume of the audio feedback can be made.

Input Impedance

Change the input impedance of the two front-panel input ports. Select either 50 Ω or 1 MΩ.

Firmware Version

Current firmware versions are reported here.

Firmware	Version Level	Release Date
System Controller	1.24	23 May 2019
QTC	1.38	23 May 2019

Tab. 9: Most recent firmware versions

From time to time, Vescent will upgrade the firmware for controlling the SLICE-QTC. The procedure to upgrade the firmware is given here.

Host GUI

If accessed through a PC Host GUI, the Settings screen (figure 42) also has the ability to assign the COM port for the device. If viewed through the GUI, there are no brightness or volume controls as these should be set on the PC directly.



Fig. 42: User-programmable system settings from host GUI

Servo/Manual Modes

Under most circumstances, the system will control the current to the transducer in order to minimize temperature fluctuations of your thermal plant. From time to time, it may also be desirable for the user to directly control the current to the transducer. This is done in Manual mode (open-loop control). To toggle between Servo and Manual modes, touch Servo on the Channel Detail screen (figure 21). In Servo mode (closed-loop control), it is possible to adjust the set point temperature, but not the current. In Manual mode, it is possible to adjust the current, but not the set point temperature. Caution should be exercised when using Manual mode as it is possible to create a thermal runaway condition where the transducer heats or cools without being limited.

	In Manual mode, it may be possible for a thermal runaway condition to exist. Use caution when using Manual mode.

Using the Host GUI

It is possible to control the SLICE-QTC from a Windows®-based PC using a GUI. In order to use the GUI, you must first download the latest version, connect the PC to the SLICE-QTC, and assign a COM port to the SLICE-QTC. The following describes the steps involved.

1. Download and store the latest GUI executable from the FTP site (Request copy of executable GUI from sales [at] vescent [dot] com).
2. Connect the SLICE-QTC to the PC using a USB type B cable.
3. Turn on the SLICE-QTC.
4. On the PC, double click on the SLICE-QTC GUI to start the GUI.
5. On your PC, go to Start > Control Panel > Device Manager > Ports
    1. Identify which COM Port is labeled “STMicroelectronics Virtual COM Port (COMXX)” or similar. Note the value of XX.

6. On the SLICE-QTC GUI, click on the Settings icon  to get to the window shown in figure 43.

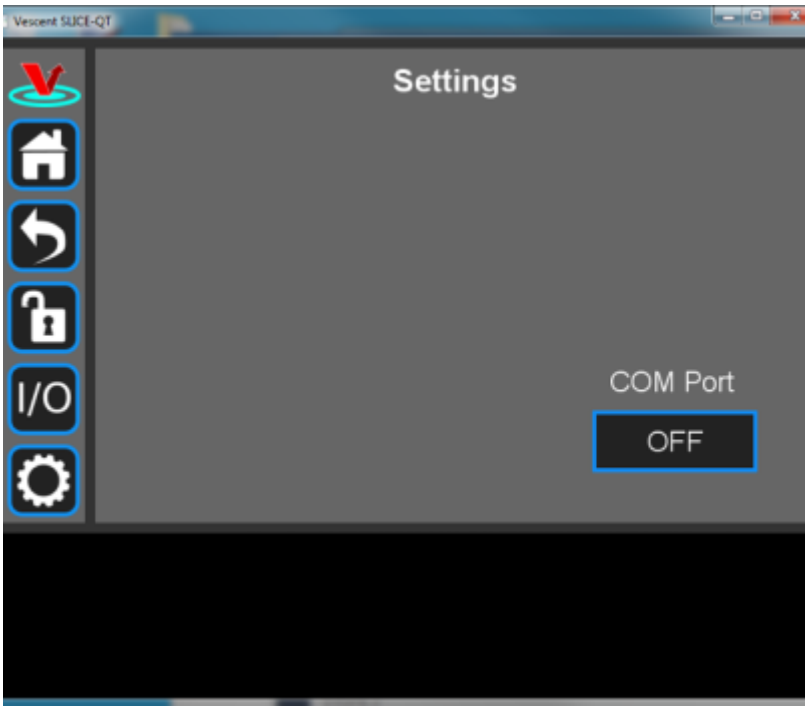


Fig. 43: Settings screen when viewed by GUI

7. Click on the OFF button below COM Port. You should see a menu similar to the one shown figure 44. NOTE: The COM port numbers may differ from those shown below.

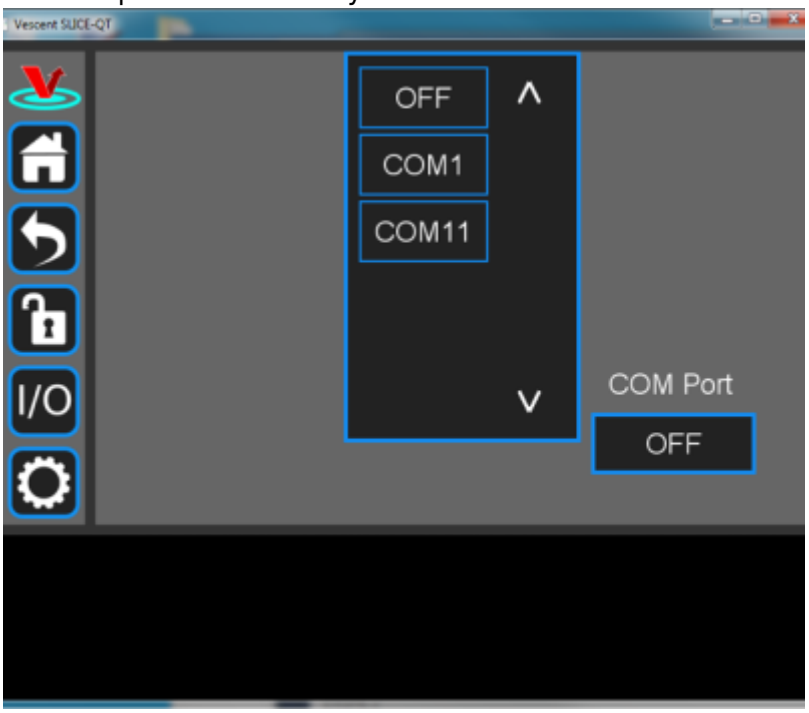


Fig. 44: COM port selection

8. Select the COM port identified in the step above (usually the last COM port in the list; COM11 in this example). The window in figure 45 should appear if the connection is successful.

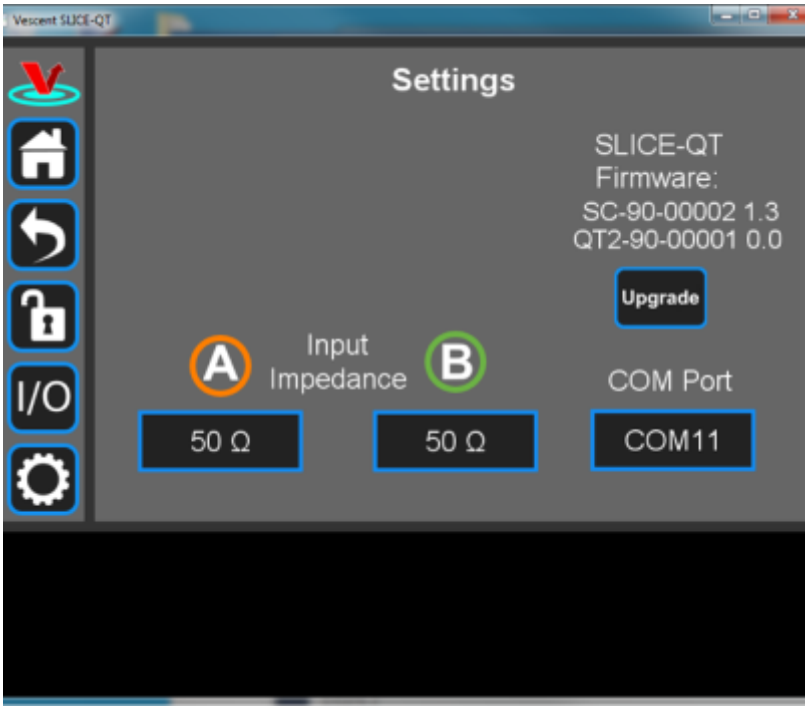


Fig. 45: Ready to upgrade

The GUI should now actively control the SLICE-QTC. You should only have to do the above steps once from a given PC. After assigning the COM port, the system will recognize the device in the future (unless you reassign the COM port to another device).

Firmware Update

From time to time, Vescent will upgrade the firmware for controlling the SLICE-QTC. The procedure to upgrade the firmware is given here.

Serial API

It is possible to control the SLICE-QTC through serial commands. Click here to access the SLICE-QTC API.

More information coming soon. Please contact sales [at] vescent [dot] com for information.

Maintenance

There are no user-serviceable parts inside this instrument. Refer all repairs to the manufacturer. Work performed by persons not authorized by Vescent Photonics may void the warranty.

1)

More cables may be purchased separately; order p/n 50-00005

2)

Located in power receptacle on rear panel

3)

Subject to change without notice
4)

Lower precision may be realized above 50°C. Consider using a thermistor with 10 kΩ at higher temperature than nominal.
5)

Nominal value 10 kΩ at room temperature. Precision at temperatures removed from room temperature can be improved by selecting a thermistor whose resistance is ~10 kΩ near the target temperature.
6)

Plant-dependent; value specified for D2-100 laser
7)

User-distributable over four channels
8)

Subject to 35 W overall maximum
9)

automatically adjusted
10)

See table 2 for acceptable input ranges
11)

Four-pin DIN connector
12)

In some early versions of the SLICE-QTC, the order of these connectors is reversed.
13)

Optimum Settings for Automatic Controllers, by J.G. Zieger and N. B. Nichols and Wikipedia
14)

https://en.wikipedia.org/wiki/Logic_level

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