User Manual

RUBRIColor™ Wavelength Extension Chassis

Revision 02

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Contents

1 Introduction

This manual contains information for operating the Vescent RUBRIColor™ Wavelength Extension Chassis. Each RUBRIColor chassis is customized with up to four wavelength extension modules. The extension modules provide off-the-shelf solutions for extending, filtering, amplifying, and mixing frequency comb light. By including repeater extension modules, RUBRIColor units can be chained together to increase the total number of extension modules in one frequency comb system. In combination with the RUBRIComb®, the RUBRIColor provides an extensible commercial platform for transferring frequency stability to any set of selectable wavelengths from the visible to the near-infrared (NIR).

This section has information for safely operating the RUBRIColor. Please carefully read this section before using the RUBRIColor. Section 2 introduces the user to the instrument and defines all hardware connections. Section 3 discusses the graphical user interface (GUI) for the RUBRIColor. Section 4 helps users immediately get started using the RUBRIColor in their application by showing an example of typical setup and operation. Section 5 provides specific details about each model of extension module that may be installed in the RUBRIColor chassis. Section 6 contains further detail about the operation of the RUBRIColor. Section 7 covers remote operation of the RUBRIColor. Section 8 gives instructions for updating the RUBRIColor firmware. Troubleshooting help can be found in Section 9. For further information, including product specifications, additional resource links, and warranty information, see the appendices.

1.1 Symbol Definitions

The following symbols may be encountered in this manual or on the device.

Symbol	Description
	Caution: Follow instructions to avoid injury or damage to equipment
	Caution: Risk of electric shock
	Caution: Laser beam
	Alternating Current
	Fuse
	Chassis Terminal
	The user manual should be referenced when operating this device
	WEEE: Separate collection for waste electric and electronic equipment is required
	Circle Indicator: Indicates relevant item in image
	Pointer Indicator: Points to relevant item in image

1.2 Safety

1. This instrument is intended for use by qualified personnel who recognize shock hazards and laser hazards and are familiar with safety precautions required to avoid possible injury. Read the instruction manual thoroughly before using to become familiar with the instrument's operations and capabilities.

2. 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.

3. Always operate the RUBRIColor within the temperature and current ranges specified in the unit's final test documentation or Certificate of Conformity (CoC). Improper usage can cause irreparable damage to the laser system.

4. For indoor use only up to 2000 m altitude, within a (maximum) Pollution Degree 2, Overvoltage Category II, 30°C ($T_{amb,max}$), with the RUBRIColor installed on a flat, level surface.

5. When rack mounting the RUBRIColor, follow AV Rack Cabinet manufacturer instructions, and use only AV Rack Cabinets with proper approvals.

6. Never look directly into any fiber port! Do not stare into the beam! Never use a fiber scope to view any outputs of the RUBRIColor while the unit is powered or when there is any light input from other sources.

7. Use of controls or adjustments or performance of procedures other than those specified herein may result in hazardous radiation exposure.

8. The RUBRIColor is not intended for fail-safe operation in hazardous environments or life-threatening situations. The user assumes full responsibility for correct and safe usage of the RUBRIColor in accordance with any applicable laws, codes, regulations, and standards pertaining to their specific application. Vescent is not liable for any consequential damage due to misapplication or failure of the RUBRIColor.

9. To avoid electrical shock hazard, connect the instrument to properly earth-grounded, 3-prong receptacles only. Failure to observe this precaution can result in severe injury or death.

10. This instrument is to be used with the included power cord-set. Do not use a power cord-set with inadequate rating.

11. This equipment is intended to be protected by certified over-current protection of 16/20 A.

12. Before replacing the fuse on the RUBRIColor, turn off the power switch and disconnect the unit from mains power.

13. Except the fuse, there are no field-serviceable parts inside the instrument. Maintenance performed by persons not authorized by Vescent will void the warranty.

14. Do not obstruct the fan exhaust or ventilation holes. Leave clearance around fan for proper ventilation.

15. Always clean optical fibers before making connections at optical ports. Use the provided optical fiber connector cleaner to clean the optical fiber connector. Cleaning fiber facets *every time* fibers are connected keeps ports free of debris that may damage RUBRIColor bulkhead fibers.

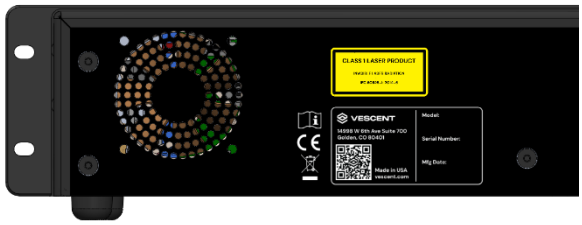
16. Always keep protective caps on optical fiber ports when not in use.

17. Never avoid or interrupt the thermal cool down process by using the rear power switch to turn off the unit. Wait for the cool down process to complete and the RUBRIColor to enter SYSTEM OFF mode before using the rear power switch to shut off the RUBRIColor.

18. Do not remove input frequency comb light while LASERS ON mode is active.

1.3 Affixed Labels

The following labels are affixed to the RUBRIColor housing:

Label	Location
	
Laser classification label and invisible laser radiation warning.	
	
Warns the user about the laser emission hazard at the front of the RUBRIColor.	

2 Chassis Hardware

This section discusses the hardware features and connections of the RUBRIColor and the other items that are shipped with the unit.

2.1 Package Contents

The RUBRIColor is shipped in a package designed to provide excellent protection. The shipping box should be saved for future transportation or storage needs.

Carefully remove and inspect the following items that are contained in the shipping box:

- RUBRIColor™ Wavelength Extension Chassis
- Polarization-maintaining (PM) FC/APC Fiber Optic Patch Cable, 0.4 m
- Four SMA cables, 3 ft
- Two operator keys
- AC power cord, region-specific
- USB-A to USB-B cable
- Final test documentation including certificate of conformance (CoC)

2.2 Controls and Connections

This section introduces the hardware controls and connection ports on the RUBRIColor.

2.2.1 Making Connections at Optical Fiber Ports

To avoid damage to the ports of the RUBRIColor, it is important to take care when mating optical fibers. To keep optical fiber ports free of debris that could damage the RUBRIColor bulkhead fibers, ***always*** clean optical fiber connectors prior to making connections. Even when a fiber is disconnected and immediately reconnected to the same port, it is important to follow proper cleaning procedures. A fiber optic connector cleaner is provided with every RUBRIC system (see RUBRIComb) for this purpose.

Refer to this procedure every time a fiber optic cable connection is made at a fiber optic port:

1. Turn off all light sources feeding into the fiber optic cable.
2. Turn off all light sources feeding into the RUBRIColor.
3. Clean the RUBRIColor fiber optic bulkhead with the supplied fiber optic connector cleaner in accordance with the manual for that device.
4. Clean the fiber optic cable connector with the supplied fiber optic connector cleaner in accordance with the manual for that device.
5. Use a fiber optic inspection scope to verify the cleanliness of the fiber optic cable facet.
6. When connecting to a RUBRIColor input port, always check the power level of the incoming light to verify it will not exceed the power limits of the port. Attenuate input signals as necessary.

2.2.2 Front Panel

1. Touchscreen

The primary way to interact with the RUBRIColor is via its front panel touchscreen. General instructions for touchscreen control are discussed in Section 3.

2. Parameter Input Adjustment Knobs

Two rotary knobs allow the user to quickly cycle through parameter list settings and enter numeric inputs. In general, the right knob changes the current selection or the value of a digit, and the left knob changes the selected digit. Additionally, an L or R symbol (see left) on the touchscreen display indicates the matching knob control can be used.

3. Extension Module

The RUBRIColor is populated with up to four extension modules. Each module may have up to two optical ports (PM FC/APC) and two radio-frequency (RF) ports (SMA). The function of each port depends on the type of extension.

Descriptions of the typical extension ports are given below. For port descriptions specific to each model, see Section 5.

4. Optical Input (PM FC/APC)

Most extension modules require either CW laser light or an optical heterodyne of CW laser light and frequency comb light to operate. The required light is input on this port.

Light may be visible on this port whenever the RUBRIColor is powered, or whenever input light is provided to the RUBRIColor from other sources. Never look directly into fiber ports!

Always clean an optical fiber connector before making a connection at this port. Keep protective cap on port when not in use.

5. Primary Optical Output (PM FC/APC)

Most extension units have a primary optical output. The type of output light depends on the extension module model.

Light may be visible on this port whenever the RUBRIColor is powered, or whenever input light is provided to the RUBRIColor from other sources. Never look directly into fiber ports!

Always clean an optical fiber connector before making a connection at this port. Keep protective cap on port when not in use.

6. Optical Heterodyne RF Output (SMA)

RF output port for the optical heterodyne signal, f_{opt}. Most extension modules have a photodiode for converting an optical beat frequency signal to an electrical RF signal output on this port.

7. Repetition Rate RF Output (SMA)

RF output port for the frequency comb repetition rate, f_{rep}. Several harmonics of the repetition rate are observable.

8. Comb Input (PM FC/APC)

Input port for frequency comb light. The RUBRIColor requires a minimum of 4 mW of input frequency comb light. The comb light must originate from one of the following ports:

a. RUBRIComb Frequency Comb, AMP OPT OUT

b. RUBRIColor, Extension Module EXT-R, REPEATER OUT

The upstream port connection used in final testing is specified in the RUBRIColor CoC. To achieve the performance shown in the CoC, use the provided 0.4 m PM 1550 optical fiber to connect Comb Input to the indicated port. The RUBRIColor is designed to manage the optical dispersion originating from this fiber length.

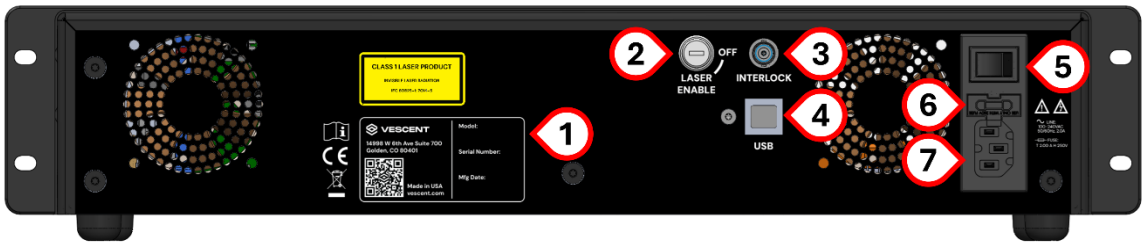
Do not remove the input light while the RUBRIColor is in LASERS ON mode.

Always clean an optical fiber connector before making a connection at this port. Keep protective cap on port when not in use.

9. Front Panel Rack Mounting Brackets

Use these brackets to mount the RUBRIColor inside a 19” server rack. With its feet removed, the RUBRIColor chassis height is 2U.

2.2.3 Rear Panel



1. Unit Information

Unit information includes the unit model, serial number, and manufacturing date.

2. Access Control Lock

This access control restricts use of the RUBRIColor to authorized operators. The RUBRIColor will only output light if an Operator Key is inserted and oriented vertically ("Laser Enable"). When the key is removed or oriented horizontally ("Off") the RUBRIColor Safety Interlock System (SIS) will trigger.

3. Remote Interlock (BNC)

This port is for disabling the laser output via a remote interlock control. The RUBRIColor will only output light if this port is shorted. When the connection is broken, the RUBRIColor Safety Interlock System (SIS) will trigger.

If not using a remote interlock, leave a 50 Ω BNC terminator on this port.

4. Serial Port (USB-B)

Use a standard USB-A to USB-B cable to connect the RUBRIColor to a computer for remote operation and updating firmware. For further information see Section 7 and Section 8.

5. Power Switch

While the Power port is connected to mains power toggle this switch from O to | to turn on the RUBRIColor.

Only use the Power Switch to turn off the RUBRIColor when the unit is in SYSTEM OFF mode and any COOL DOWN routine has completed. Do not interrupt the COOL DOWN routine.

6. Fuse

The RUBRIColor has a factory-installed fuse. To replace the fuse, follow the procedure below:

- Flip the RUBRIColor Power switch off.
- Disconnect the RUBRIColor from mains power.
- Remove the fuse cover.
- Replace the blown fuse with a high breaking capacity 5mm x 20mm fuse rated to 250 V and 2A.
- Replace the fuse cover.

7. Power Port

Use the provided AC power cord to connect this port to a properly grounded mains receptacle.

3 Graphical User Interface

This section discusses how the user interacts with the graphical user interface (GUI) and introduces the different types of buttons, windows, and screens a user will see on the touchscreen display.

3.1 Control Bar

On the left edge of the RUBRIColor touchscreen is the Control Bar. The table below briefly explains the functionality of each Control Bar button.

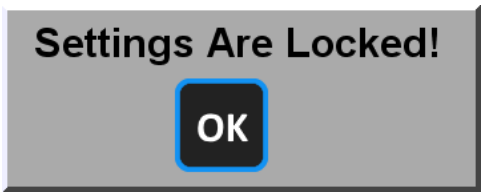
Symbol	Button Name	Function When Tapped
	Home	Returns to Home screen. Home is the screen which appears when the user powers up the unit. See Section 3.3.1.
	Back	Returns to previous screen.
	Parameter Lock	Toggles the Parameter Lock. The Parameter Lock prevents certain fields from being edited. See Section 3.1.1.
	System Settings	Enters the System Settings screen. See Section 3.3.2.

3.1.1 Parameter Lock

The Parameter Lock is a toggle button which helps prevent accidental settings changes.

The symbol to the left indicates the Parameter Lock is in the unlocked state. In the unlocked state, it is possible to interact with any field bordered in blue. Tap the symbol to switch the Parameter Lock to the locked state.

The symbol to the left indicates the Parameter Lock is in the locked state. In the locked state, certain fields will be locked so they cannot be changed until the lock is released. Interacting with a locked button will open the following alert window:



Navigation buttons and many toggle buttons will still be operable in the locked state. Tap the symbol to switch the Parameter Lock to the unlocked state.

3.2 Button Types

The types of GUI buttons and their functionality are discussed here.

Tap a button to interact. It is possible to select the functionality or edit the values of a field bordered in blue. Some buttons have a second parameter edit mode that activates after touching and holding the button for a couple of seconds. Interacting with a button will cause the unit to beep.

3.2.1 Navigation Buttons

Navigation buttons change the screen shown on the display.

Tapping a Navigation button will take the GUI to the corresponding screen. Most Navigation buttons are in the Control bar (see Section 3.1) located on the left of all screens.

3.2.2 Toggle Buttons

Toggle buttons allow the user to switch a parameter between two states.

Tapping a toggle button will switch its state between two options or between a disabled and an enabled state.

For a toggle button which toggles between enabled and disabled states, the button background and text indicate the current state of the button. White text on a black background indicates the toggle is in the disabled state. Black text on a colored background indicates the toggle is in the enabled state.

3.2.3 Dropdown Menus

Dropdown menus allow the user to choose a parameter setting from a list of values.

Tapping a dropdown menu will reveal the list of available choices. The current selection will be bordered in white. Tapping one of the choices selects it and closes the dropdown menu. Tapping outside the dropdown menu closes the dropdown menu and retains the original choice.

3.2.4 Numeric Fields

Numeric fields allow the user to choose a custom numeric value for a given parameter.

Tapping a numeric field will change its border from blue to yellow. Rotary knob editing mode is active while the border is yellow. The underlined digit is the currently active digit. Rotating the L-knob changes the currently active digit. Rotating the R-knob changes the value of the currently active digit. Tap anywhere on the display to disable rotary knob editing mode and change the field border back to blue.

If the rotary knob editing mode is active for 60 consecutive seconds without user input, then the unit will beep and rotary knob editing mode will deactivate. The border of the choice selector will turn red momentarily before returning to blue.

Touching and holding a numeric field launches the numeric keypad. The desired value can be typed into the numeric field by using the keypad. Tapping the Confirm key confirms the value and updates the parameter. When an invalid value is entered into a keypad, the value will be coerced to the nearest valid value. Keypad buttons are described in the table below.

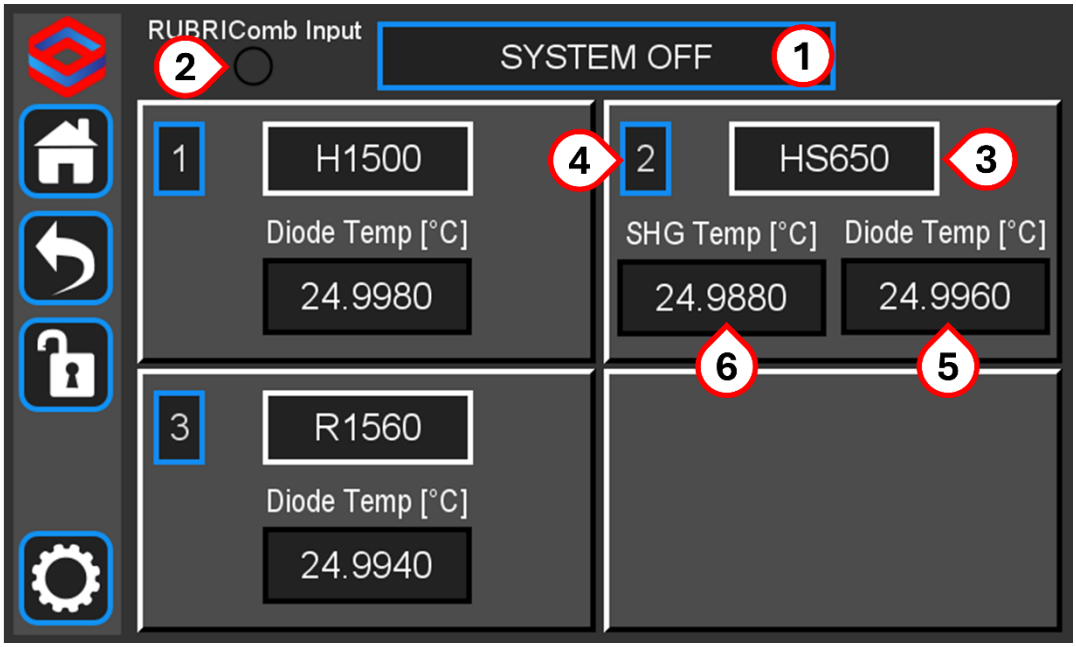
Numeric Keypad Buttons

Symbol	Button Name	Function When Tapped
	Plus/Minus	Changes sign of the value
	Numeric	Inputs tapped number as the next digit
	Decimal Point	Inputs decimal point as the next digit
	Delete	Deletes last digit in the numeric field
	Clear	Clears numeric field
	Back	Exits keypad without accepting changes
	Confirm	Accepts value in numeric field and exits keypad

3.3 Screens

Each of the following sections introduces a screen encountered during operation of the RUBRIColor and describes the function of the contained displays and controls.

3.3.1 Home Screen



After start-up the RUBRIColor will display the Home screen. This view summarizes the current state of the RUBRIColor and its extension modules. While the RUBRIColor can be populated with up to four extension modules, in the example above the RUBRIColor is populated with only three extension modules.

Extension modules may have up to two temperature plants. For each temperature plant, a temperature indicator is shown in the extension module summary. The background color of each indicator changes depending on the state of the corresponding temperature plant.

Black - The temperature plant is not under active control.

Red - An error has occurred. Please contact Vescent.

Yellow - The temperature plant is under active control and the measured Temperature Error magnitude is outside the target range.

Green - The temperature plant is under active control and the measured Temperature Error magnitude is within operational temperature limits.

1. ***RUBRIComb Input Indicator:*** Turns green when laser power is detected at the Comb Input port. If the RUBRIComb stops detecting input, the RUBRIColor will automatically exit LASERS ON mode.

   When operating the RUBRIColor, ensure that the input power is at least 4 mW. Performance of the unit will suffer if the input power is below this level.

2. Operation Mode Selector: Dropdown menu for the RUBRIColor mode setting. The behavior while in each mode is as follows:

SYSTEM OFF - Initial mode when starting up the RUBRIColor. All temperature and current controls are in the off state.

STANDBY - In STANDBY mode, the RUBRIColor will stabilize the temperature of the extension module pump diodes and second-harmonic generation (SHG) submodules.

Upon starting STANDBY mode, the Operation Mode button flashes white, and temperature indicators turn yellow. When the temperature controllers stabilize around their setpoints, their indicators turn green. Once all temperatures stabilize, and the RUBRIComb Input indicator is lit, the Operation Mode selector stops flashing. At this point it is possible to switch to LASERS ON mode.

LASERS ON - In LASERS ON mode, the temperature and current controls are in the on state and all pump diodes are active.

This mode is only available after all temperature controllers have stabilized and the RUBRIComb Input indicator is lit. Upon switching to this mode, the Operation Mode selector will flash for 5 seconds. After the conclusion of this safety delay, the RUBRIColor will begin supplying current to the pump diodes.

Do not remove input frequency comb light while LASERS ON mode is active.

COOL DOWN – In order to protect hardware from thermal shock during shutdown, a gentle cool down process is implemented whenever the RUBRIColor switches to SYSTEM OFF from one of the other operational states. The cool down process uses the temperature servos to slowly decrease the temperature of any high temperature plants until they are cool enough to shut off.

Never avoid or interrupt the thermal cool down process by using the rear power switch to turn off the unit. Wait for the cool down process to complete and the RUBRIColor to enter SYSTEM OFF mode before using the rear power switch to shut off the RUBRIColor.

ERROR - If an error condition is triggered, the RUBRIComb will enter an error state. The Operation Mode selector will flash red and display an error message. No other operation mode can be selected.

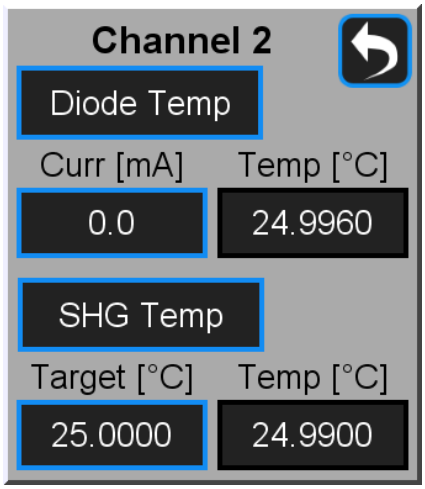
To exit the error state, the condition causing the error must first be resolved. Then tap on the error message to return to normal operation. For more information on error states, see Section 6.2.

3. Extension Module Model: Shows the model code of the extension module installed on this channel. All the controls sharing a box with this label belong to this extension module.

4. Pump Diode Temperature Indicator: Measured temperature of the pump diode.

5. SHG Submodule Temperature Indicator: Measured temperature of the second-harmonic generation submodule housed within the extension module.

6. Extension Module Controls Window: Tap this button to access additional extension module monitors and controls, if any exist on this channel. In the example Extension Module window that follows, a full complement of controls is shown. Many extension modules have fewer controls.



Diode Temp – Tap on this button to navigate to the Diode Temperature Detail screen (see Section 3.3.3).

Diode Current Setpoint – Setpoint for the diode current in milliamps.

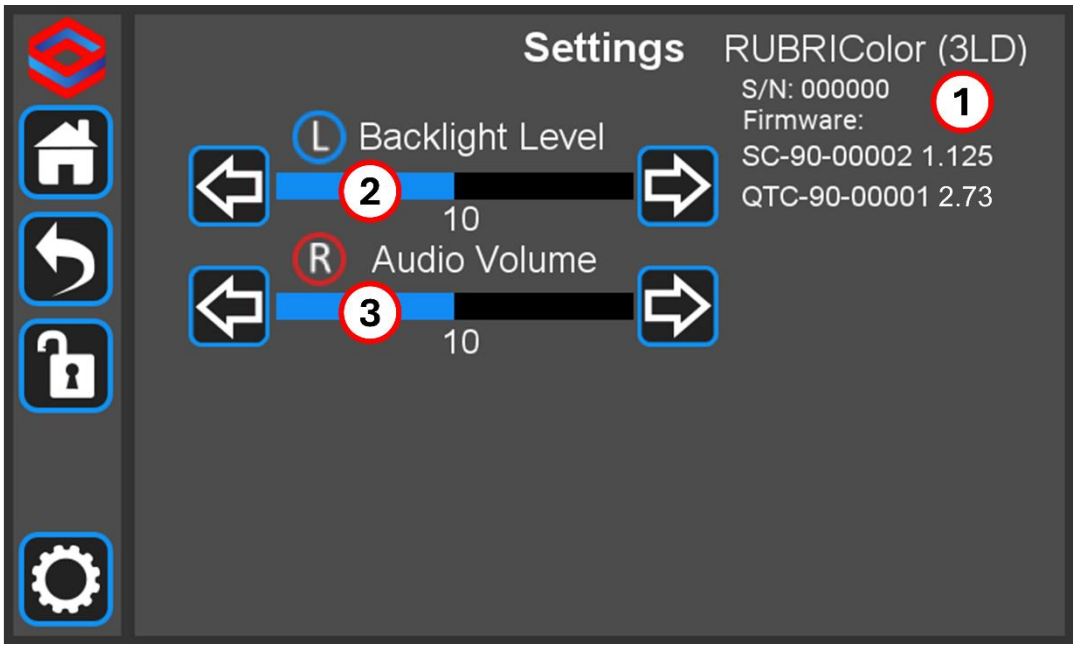
Pump Diode Temperature Indicator – Measured temperature of the pump diode.

SHG Temp – Tap on this button to navigate to the SHG Temperature Detail screen (see Section 3.3.3).

SHG Temperature Setpoint – Temperature Setpoint for the SHG submodule. Changing the temperature of the SHG submodule changes the output wavelength of the extension module. See the extension module CoC for further details.

SHG Temperature Indicator – Measured temperature of the SHG submodule.

3.3.2 System Settings Screen



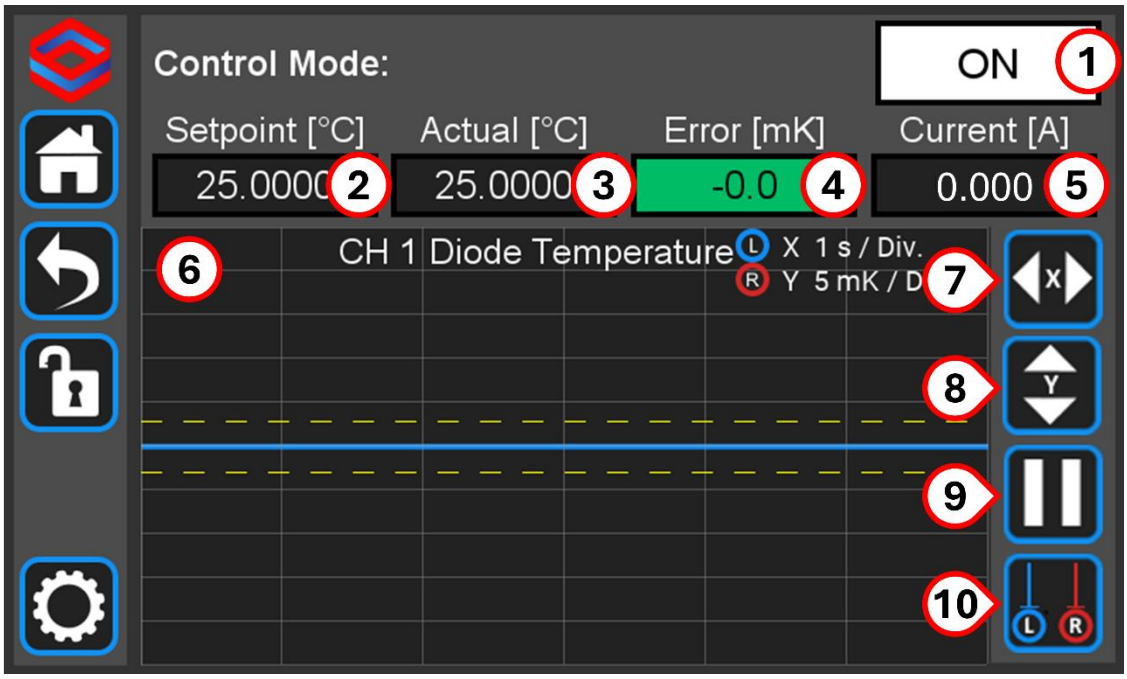
The System Settings (gear) icon navigates the user to the System Settings screen. This screen displays information specific to the unit and has controls for general settings.

1. Unit Information: Includes the Serial Number (S/N) of the unit, and the system controller (SC), temperature controller (QTC), and laser driver (LD) firmware versions.

2. Backlight Level: The arrows adjust the backlight level of the touchscreen display. The Left knob also adjusts the backlight level.

3. Audio Volume: The arrows adjust the volume of the feedback beeps. The Right knob also adjusts the volume. To completely mute the unit, turn the volume down all the way.

3.3.3 *Temperature Detail Screens*



The RUBRIColor regulates the temperature of all extension module pump diodes and SHG submodules. The temperature servos are optimized in the factory and activated exclusively via the Operation Mode selector. The Temperature Detail screens can be used to monitor the performance of the temperature controllers.

1. Temperature Controller State indicator: Shows the present state of the temperature servo.

2. Setpoint Temperature: Temperature setpoint for the temperature plant.

3. Actual Temperature indicator: Measured temperature of temperature plant. If the actual temperature exceeds the temperature limits, the background of this indicator will turn red.

4. Temperature Error indicator: Temperature difference between the temperature setpoint and actual temperature. The background color of this box changes depending on the current state of the temperature plant:

Black - The temperature plant is off.

Red - An error has occurred. Please contact Vescent.

Yellow - The temperature plant is under active servo control and the present Temperature Error magnitude is outside the target range.

Green - The temperature plant is under active servo control and the present Temperature Error magnitude is within operational temperature limits.

5. Current Indicator: Shows the electrical current through the temperature transducer in amps.

6. Temperature Error Graph: Displays a rolling update plot of the Temperature Error as a blue line. The solid white horizontal line at center represents no temperature difference between the Setpoint Temperature and Actual Temperature.

Up to four horizonal dotted lines may be visible on the display. The yellow dotted lines show the operational temperature limits (see Temperature Error indicator above). The red dotted lines (not visible) show the factory-defined temperature limits.

The X- and Y-axis scaling are shown in the top right corner of the plot.

7. Adjust X Scale: Tap to see additional scaling options for the X-axis of the Temperature Error Graph.

8. Adjust Y Scale: Tap to see additional scaling options for the Y-axis of the Temperature Error Graph.

9. Pause/Restart: Tap to pause updates to the Temperature Error Graph. Tap again to resume updates.

10. Cursor Display: While active (white background), two cursors are displayed on the Temperature Error Graph. Turn the Parameter Adjustment Knobs to change the position of the cursors.

4 Getting Started

This section explains typical use of the RUBRIColor Wavelength Extension Chassis for new users. A brief overview of RUBRIC system architecture is followed by general setup instructions and examples of typical use configurations. Keep in mind that the following are general guidelines for operating the RUBRIColor. Exact settings will vary for your application and hardware.

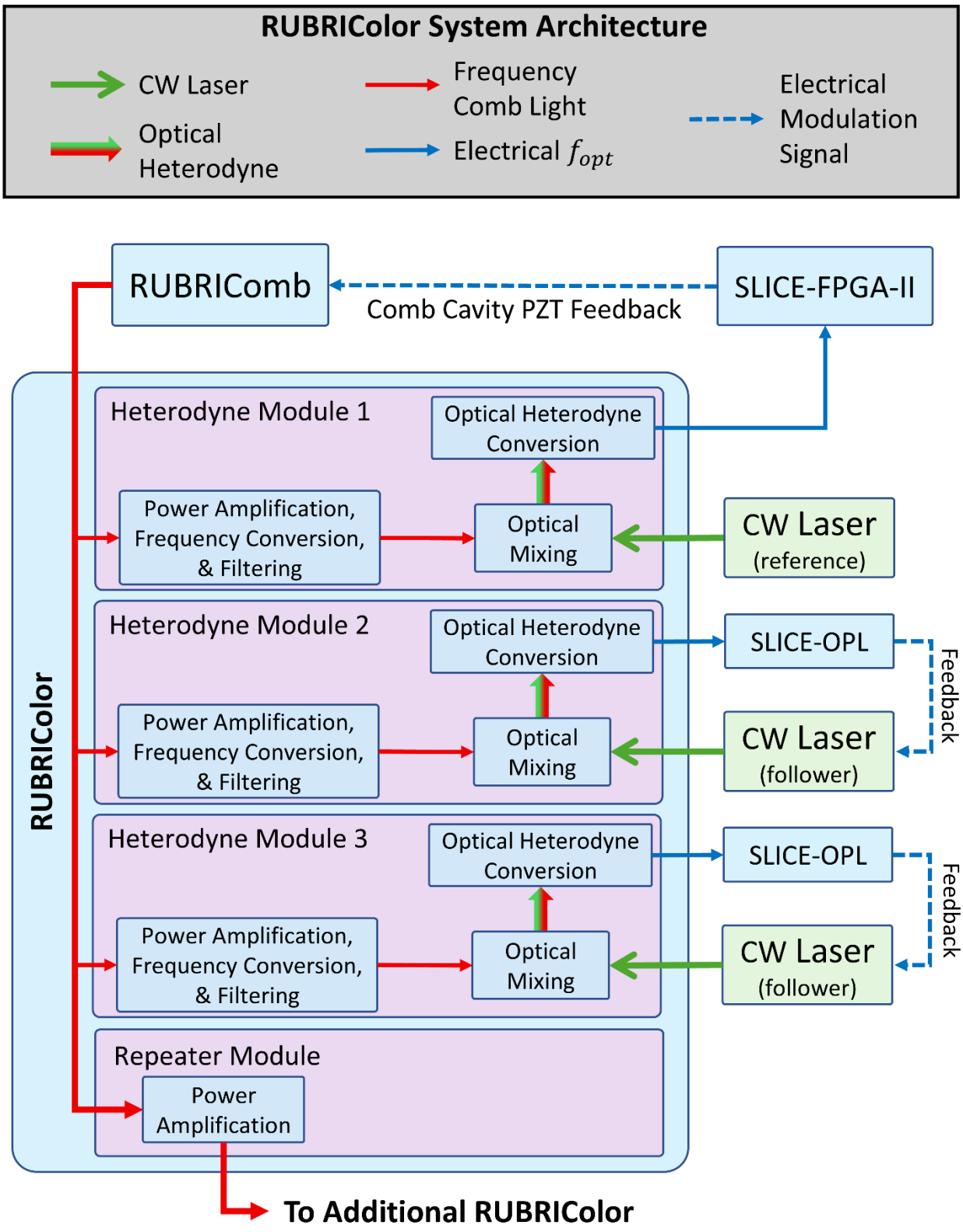
4.1 Frequency Comb System Architecture

The block diagram schematic on the following page shows the general architecture of a frequency comb system that includes a RUBRIColor. The diagram is meant to be a guide and it does not show all inputs/outputs. System layouts will vary depending on the extension modules installed in the RUBRIColor and the ultimate goals of the system operator.

All RUBRIC frequency comb systems start with optical frequency comb light generated by the RUBRIComb Frequency Comb. The comb light is supplied to the RUBRIColor Wavelength Extension Chassis which houses up to four extension modules. The RUBRIColor and its various extension modules can handle the complexities of dispersion compensation, frequency conversion, power management, optical mixing, and beat frequency detection. The signal architecture of the extension modules is discussed in depth in the later sections.

Most RUBRIColor extension modules are variations of a heterodyne extension module. Heterodyne extension modules receive CW laser light, mix it with filtered comb light, and convert the optical beat frequency to an RF beat frequency. An offset phase lock controller uses this signal to generate a control signal for either stabilizing the frequency comb (see Section 4.3) or the frequency of follower lasers (see Section 4.4). Frequency comb stabilization requires the SLICE-FPGA-II and follower laser stabilization uses the SLICE-OPL Offset Phase Lock Servo.

For customers who require additional wavelength extension modules, Vescent offers a repeater module that can seed additional RUBRIColor units (see Section 4.2.2).


RUBRIColor System Architecture
CW Laser
Optical Heterodyne
Frequency Comb Light
Electrical f_{opt}
Electrical Modulation Signal
RUBRIComb
Comb Cavity PZT Feedback
SLICE-FPGA-II
RUBRIColor
Heterodyne Module 1
Optical Heterodyne Conversion
Power Amplification, Frequency Conversion, & Filtering
Optical Mixing
CW Laser (reference)
Heterodyne Module 2
Optical Heterodyne Conversion
SLICE-OPL
Feedback
Power Amplification, Frequency Conversion, & Filtering
Optical Mixing
CW Laser (follower)
Heterodyne Module 3
Optical Heterodyne Conversion
SLICE-OPL
Feedback
Power Amplification, Frequency Conversion, & Filtering
Optical Mixing
CW Laser (follower)
Repeater Module
Power Amplification
To Additional RUBRIColor

4.2 General Setup

This setup applies to all RUBRIC systems that include RUBRIColor Wavelength Extension Chassis. Start with these instructions before performing any application specific setup.

4.2.1 RUBRIC System Layout

Start by identifying a suitable location for the frequency comb system. All the units provided with your shipment should be kept close together. The frequency comb system must have access to at least one mains power connection per unit in the system. All CW lasers that are to be connected to the system must be within reach by fiber optic cable.

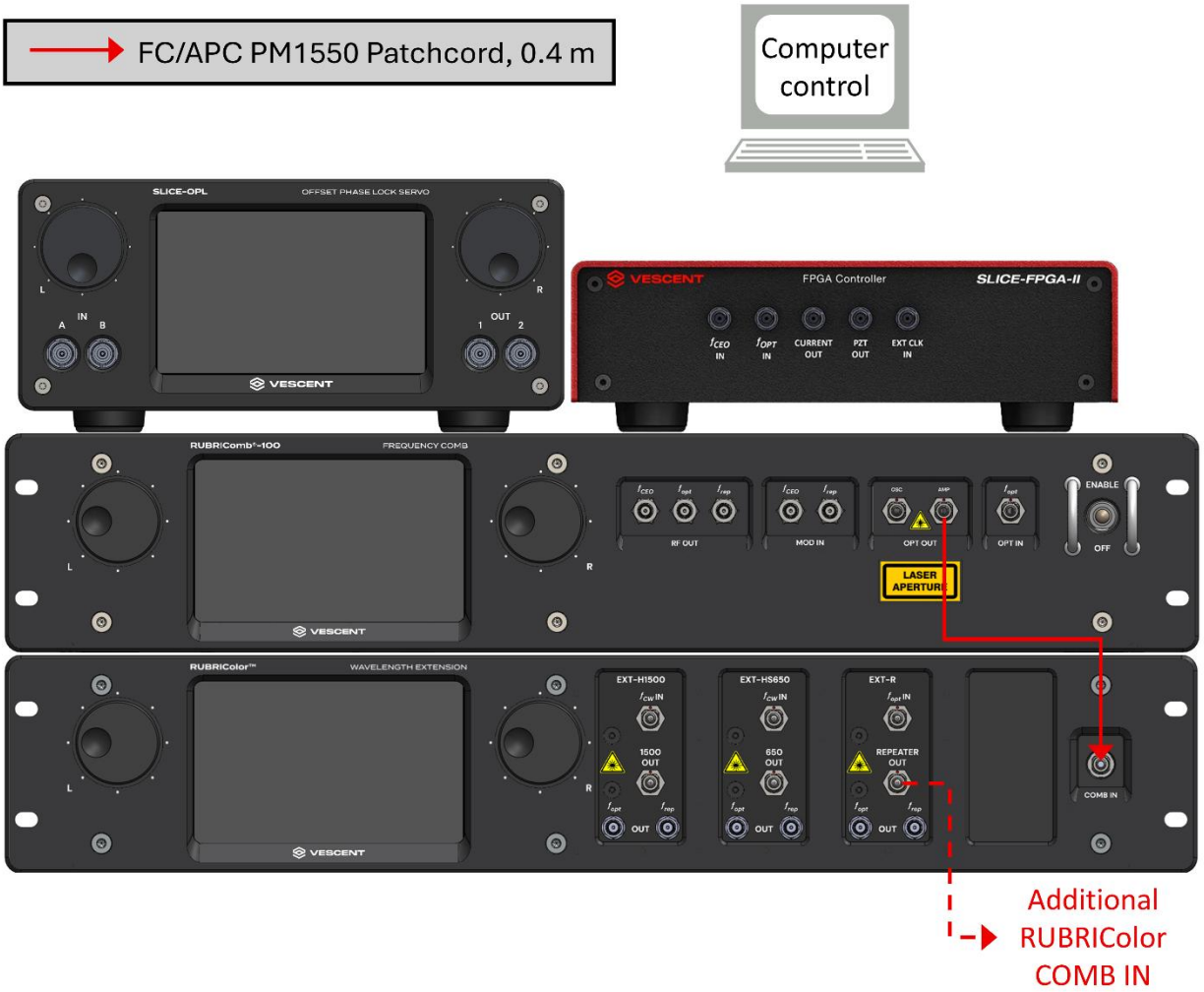
It is recommended that all RUBRIC units are rack mounted into a 19” server rack. When rack mounting units or shelves, use the appropriate rack mounting hardware for the server rack. Mount the RUBRIC units by their front panel mounting brackets. Optionally, the feet of the RUBRIColor and RUBRIComb units may be removed to reduce the height of the unit to 2U. To remove a foot, grab and turn it in a counterclockwise direction.

If there are a limited number of additional SLICE units included with the frequency comb system, then they may sit on top of the RUBRIComb. Otherwise, first mount any purchased shelf units to the server rack and then place up to two SLICE units on each shelf.

An example layout is shown below.

4.2.2 RUBRIColor Hardware Setup

This section details hardware setup for the RUBRIColor. Note that several RUBRIColor units can be cascaded to increase the number of available extension modules.



A hardware connection diagram for the for RUBRIColor setup is shown above. The following instructions detail the initial steps for RUBRIColor setup.

1. Use the provided AC power cord to connect the RUBRIColor to mains power.
2. Use the Remote Interlock port to implement any required safety interlocks.
    a. If interlocks are not required to comply with local safety requirements, place a 50 Ω BNC terminator on the RUBRIColor Remote Interlock port.
3. Insert the Operator key into the Access Control Lock and turn to Laser Enable.

⚠ Follow the cleaning instructions in Section 2.2.1 before mating each optical fiber to a RUBRIColor optical port.

4. Use the provided 0.4 m PM 1550 optical fiber to connect the RUBRIComb AMP OPT OUT port to the RUBRIColor COMB IN port (see above).

    a. If the system includes multiple RUBRIColor, refer to the CoC documentation to see which unit connects directly to the RUBRIComb.

5. For each additional RUBRIColor, connect a repeater extension REPEATER OUT port to the next RUBRIColor COMB IN port.

    b. Refer to the RUBRIColor CoC to see which unit connects to each repeater.

4.2.3 RUBRIColor Startup

Follow these instructions to turn on and start the RUBRIColor.

1. Flip the RUBRIColor Power switch on.

2. Set the RUBRIColor operation mode to STANDBY. Waiting for the extension module temperature servos to stabilize may take several minutes.

    a. You may proceed with any additional hardware setup while waiting (see following sections).

    b. You may proceed with RUBRIComb turn on (see following steps) while waiting.

3. Turn on the RUBRIComb and start frequency comb emission.

    a. Flip the RUBRIComb Power switch on.

    b. Set the RUBRIComb operation mode to STANDBY.

    c. Wait for the STANDBY mode selector to stop flashing.

    d. Set the RUBRIComb operation mode to LASERS ON.

4. Starting with the RUBRIColor directly receiving frequency comb light…

    a. Check that the RUBRIComb Input Indicator has turned green.

    b. Wait for the STANDBY mode selector to stop flashing.

    c. Set the RUBRIColor mode to LASERS ON.

    d. Repeat step 4 for each RUBRIColor until all RUBRIColors are turned on.

4.2.4 RUBRIColor Shutdown

Since the RUBRIColor must be seeded by frequency comb light during operation, it is important to shut down the RUBRIColor units in reverse order. Follow these instructions to shut down the RUBRIColor in the proper order.

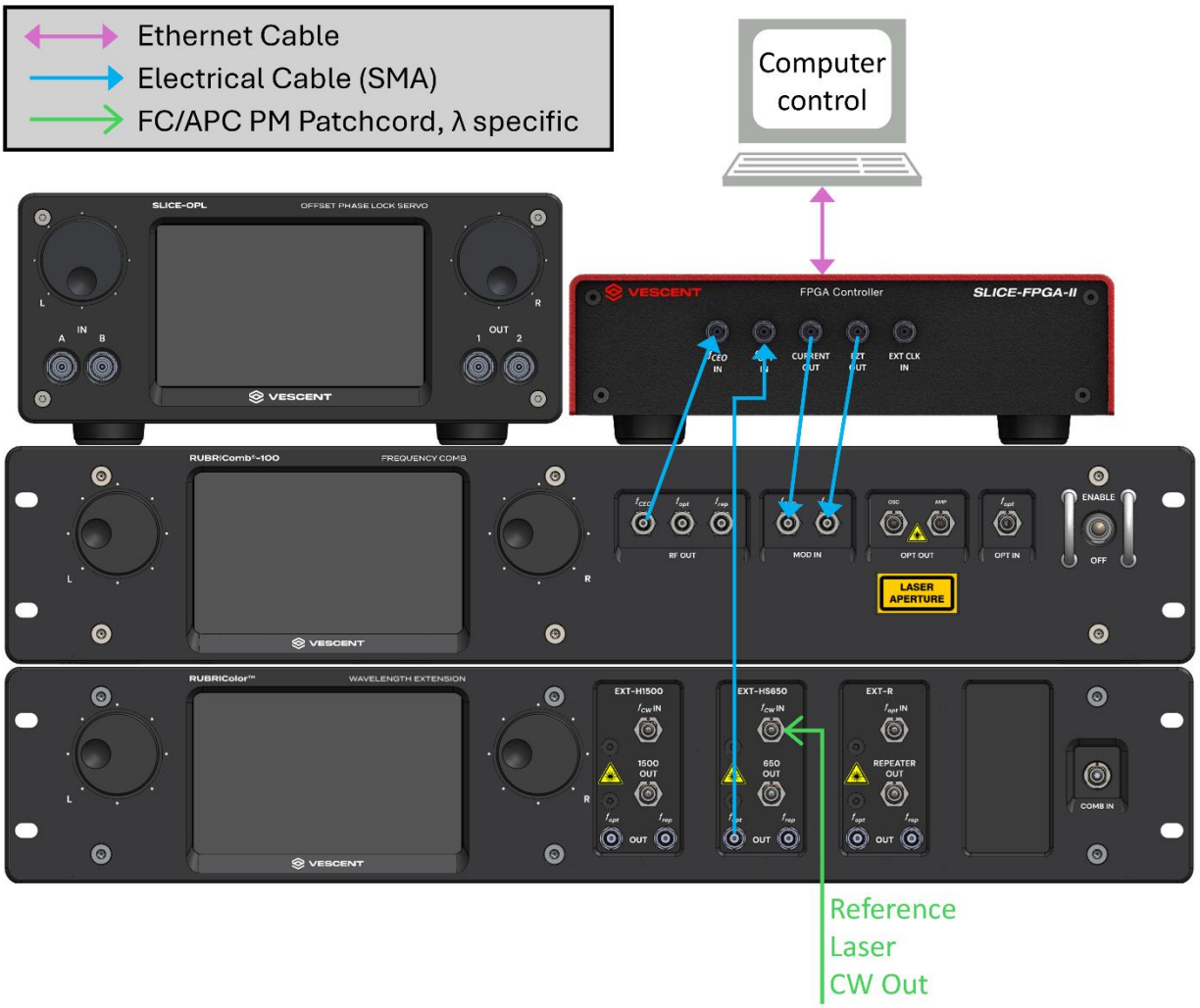
1. Turn off all follower laser offset phase lock servos.
2. Turn off the RUBRIComb slow servo controls.
3. Turn off the RUBRIComb f_{CEO} and f_{opt} lock servos in the SLICE-FPGA-II GUI.
4. Starting with the furthest downstream RUBRIColor unit receiving frequency comb light…
    a. Set the RUBRIColor operation mode to STANDBY.
    b. Repeat step 1 for each RUBRIColor until all RUBRIColor are in STANDBY mode.
5. Once all the RUBRIColor are in STANDBY mode, the RUBRIComb can be set to STANDBY or SYSTEM OFF mode.
6. Use the mode selector to set each RUBRIColor to SYSTEM OFF mode. This will initiate the COOL DOWN routine.

    a. Do not shut off a RUBRIColor with the rear Power Switch while it is in COOL DOWN mode.

7. Wait for the RUBRIColor units to complete their COOL DOWN routines.
8. Flip the RUBRIColor Power Switch off.

4.3 Using RUBRIColor f_{opt} to Stabilize the RUBRIComb to a Reference Laser

The RUBRIComb can be stabilized to a single CW laser via an optical beat frequency lock. This section describes how to perform an optical beat frequency lock to a reference laser using a RUBRIColor extension module with internal heterodyne (e.g. H- or HS-).



A hardware connection diagram for the optical beat frequency lock is shown above. The following instructions detail the procedure for setting up the optical beat frequency lock.

4.3.1 Hardware Configuration

1. Check that the RUBRIComb and RUBRIColor emissions are off before starting this setup.

2. Prepare the CW reference laser light in a wavelength appropriate FC/APC PM optical fiber.

a. The CW laser wavelength must be consistent with the design wavelength of the extension module.

3. Turn on the reference laser and measure the light at the free end of the fiber.

a. Verify the light level is appropriate for the extension by referring the RUBRIColor CoC. Excess power may damage the RUBRIColor. Attenuate the laser output as necessary.

4. Turn off the reference laser.

Follow the cleaning instructions in Section 2.2.1 before mating each optical fiber to a RUBRIColor optical port.

5. Connect the free end of the optical fiber to the f_{CW} IN port of the matching heterodyne extension (see above).

6. Complete the following electrical connections to the SLICE-FPGA-II using SMA cables (see above).

a. RUBRIComb f_{CEO} RF OUT → SLICE-FPGA-II f_{CEO} IN

b. RUBRIColor Heterodyne Extension f_{opt} OUT → SLICE-FPGA-II f_{opt} IN

c. SLICE-FPGA-II CURRENT OUT → RUBRIComb f_{CEO} MOD IN

d. SLICE-FPGA-II PZT OUT → RUBRIComb f_{rep} MOD IN

7. Connect the SLICE-FPGA-II to the control computer with an ethernet cable.

4.3.2 f_{opt} Lock Startup

1. Startup the RUBRIColor by following the instructions in Section 4.2.3.

2. Turn on the CW reference laser.

3. Turn on the SLICE-FPGA-II.

4. Launch the SLICE-FPGA-II GUI on the control computer.

5. Follow the instructions in the RUBRIComb manual for locking f_{CEO} (section 4.2.4).

6. Follow the instructions in the RUBRIComb manual for locking f_{opt} (section 4.2.5, skip step 1).

a. The PID parameters need to be tuned to the CW reference laser. Start by tuning the proportional gain (K_p) value while using the phase noise power spectral density (PN-PSD) plot as the figure of merit.

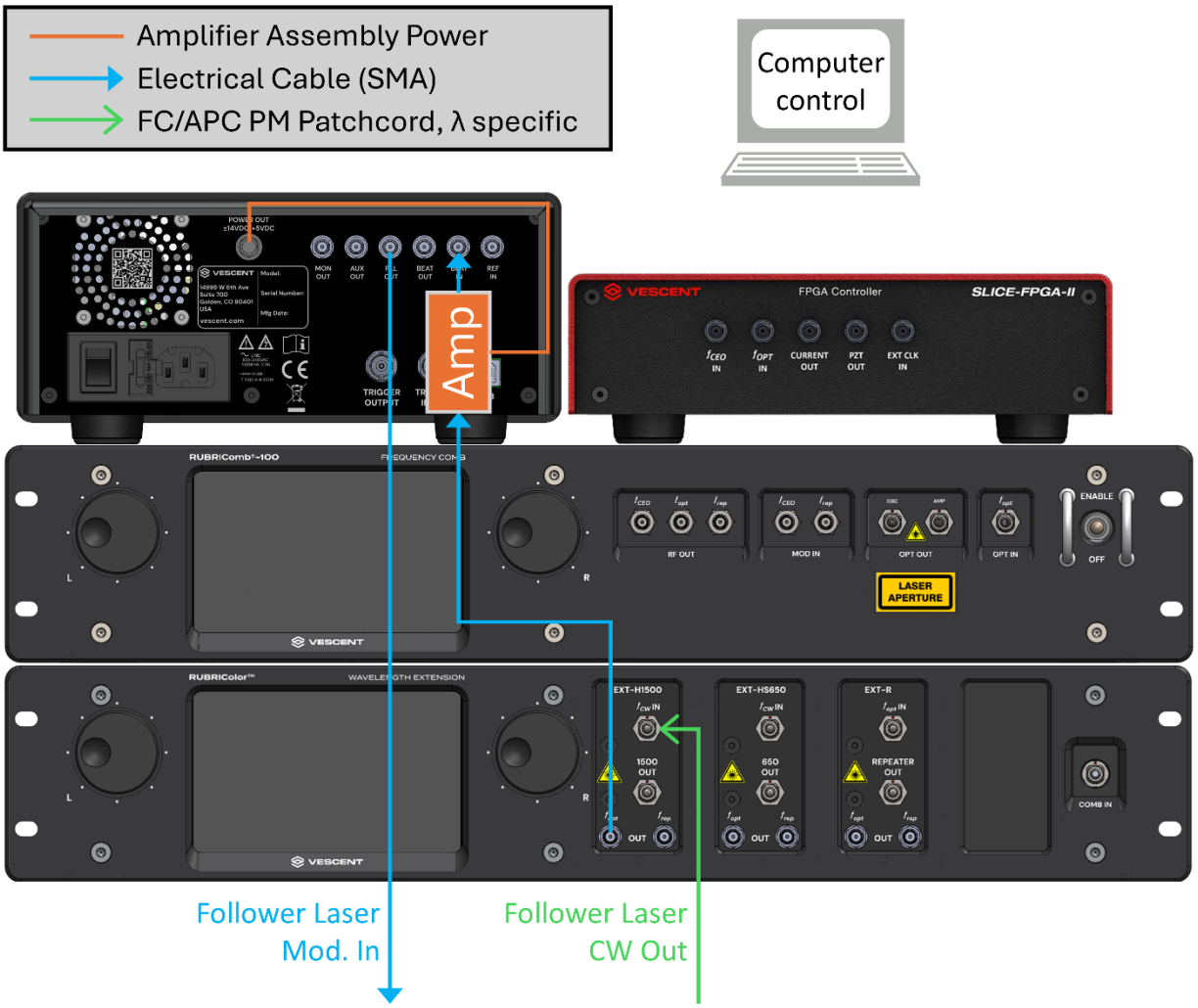
b. The integrator and derivative parameters can also be tuned to optimize the value of PN-PSD. The minimum achievable value will depend on the laser and the quality of the lock.

7. Once both locks have been established, turn on the RUBRIComb slow servos.

4.4 Using RUBRIColor f_{opt} to Offset Phase Lock a Follower Laser to the RUBRIComb

CW follower lasers can be offset phase locked to a RUBRIComb frequency comb. This section describes how to perform a follower laser offset phase lock using a RUBRIColor extension module with internal heterodyne (e.g. H- or HS-).

Each follower offset phase lock requires one SLICE-OPL and one RF amplifier assembly. Each SLICE-OPL purchased with a RUBRIColor comes with an RF amplifier assembly.



A hardware connection diagram for the offset phase lock is shown above. The SLICE-OPL has been reversed only to show the connections on its rear port. During normal operation the screens of all Vescent products will face the same direction (i.e. forward). The following instructions detail the procedure for setting up the offset phase lock.

4.4.1 Hardware Configuration

1. Check that the RUBRIComb and RUBRIColor emission are off before starting this setup.

2. Prepare the CW follower laser light in a wavelength appropriate FC/APC PM optical fiber.

    a. The CW laser wavelength must be consistent with the design wavelength of the extension module.

3. Turn on the follower laser and measure the light at the free end of the fiber.

    a. Verify the light level is appropriate for the extension by referring the RUBRIColor CoC. Excess power may damage the RUBRIColor. Attenuate the laser output as necessary.

4. Turn off the follower laser.

Follow the cleaning instructions in Section 2.2.1 before mating each optical fiber to a RUBRIColor optical port.

5. Connect the free end of the optical fiber to the f_{CW} IN port of the matching heterodyne extension (see above).

6. Configure the SLICE-OPL output for follower laser modulation.

    a. Turn on the SLICE-OPL.

    b. Navigate to CH1→Settings.

    c. Set the PLL Output Voltage Limits to match the modulation limits for the follower laser.

    d. Turn off the SLICE-OPL.

7. Plug the RF amplifier assembly Hirose connector into the SLICE-OPL Accessory Power Output port (POWER OUT).

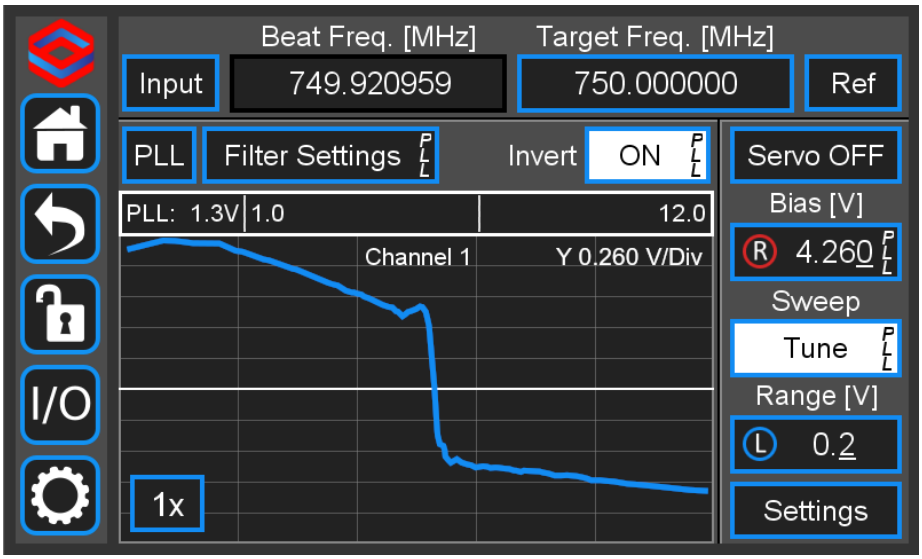
8. Connect the output of the RF amplifier assembly to the SLICE-OPL BEAT IN port with an SMA Male to SMA Male adapter.

9. Connect the RUBRIColor Heterodyne Extension f_{opt} OUT port to the input of the RF amplifier assembly with an SMA cable.

10. Connect the SLICE-OPL PLL OUT to the follower laser modulation input with an SMA cable.

4.4.2 Offset Phase Lock Initialization

1. Startup the RUBRIColor by following the instructions in Section 4.2.3.
2. For best results, stabilize the frequency comb before initializing a follower laser offset phase lock.
    a. Follow the instructions in Section 4.3. If they do not apply to your configuration, refer to Section 4 of the RUBRIComb manual.
3. Turn on the CW follower laser.
4. Enable modulation on the follow laser, if applicable.
5. Turn on the SLICE-OPL.
6. Set the SLICE-OPL Target Freq. to 25 MHz.
7. Tune the PLL Bias Voltage until the Beat Freq. is approximately 25 MHz.
8. Identify the correct state for invert.
    a. Set the SLICE-OPL sweep range to a value that corresponds to a few MHz frequency sweep in the laser.
    b. Turn on the Sweep
    c. The phase error on the display should start high and go low (see below). If not, press the invert button.



    d. Turn off the Sweep.

9. Prepare the PID filter parameter in the PLL Filter Settings. While the optimal values for every laser system will vary, the following configuration typically helps when searching for initial lock parameters.

    a. Set PD Corner to OFF.

    b. Set LFGL to OFF.

    c. Turn the PI Corner on to a low value, e.g. 1k Hz.

    d. Start with the Gain low, e.g. -100 dB.

10. Turn on the Servo.

11. In PLL Filter Settings, slowly turn up the Gain. At some point, the error line on the Phase Error Graph should move toward zero.

12. Once there is a rough phase lock, use the PLL Filter Settings to further tune the PID Parameters.

    a. For additional information, refer to the Filter Transfer Function description in the SLICE-OPL manual (Section 5.3).

5 Extension Modules

There are several models of extension modules that can be installed into a RUBRIColor chassis. The behavior of each extension module model is covered in this section.

5.1 General Information

A RUBRIColor chassis can house up to four extension modules. The extension modules provide off-the-shelf solutions for extending, filtering, amplifying, and mixing frequency comb light.

The collection of extension modules installed in a chassis are selected by the customer before the RUBRIColor is built. Each extension module is labeled according to the alphanumeric code defined below:

EXT-(ALPHA)(NUMERIC)	
ALPHA	Extension module model. Models include: H – Heterodyne IR HS – Heterodyne SHG R – Repeater
NUMERIC	If applicable, the design wavelength of the extension module in nm.

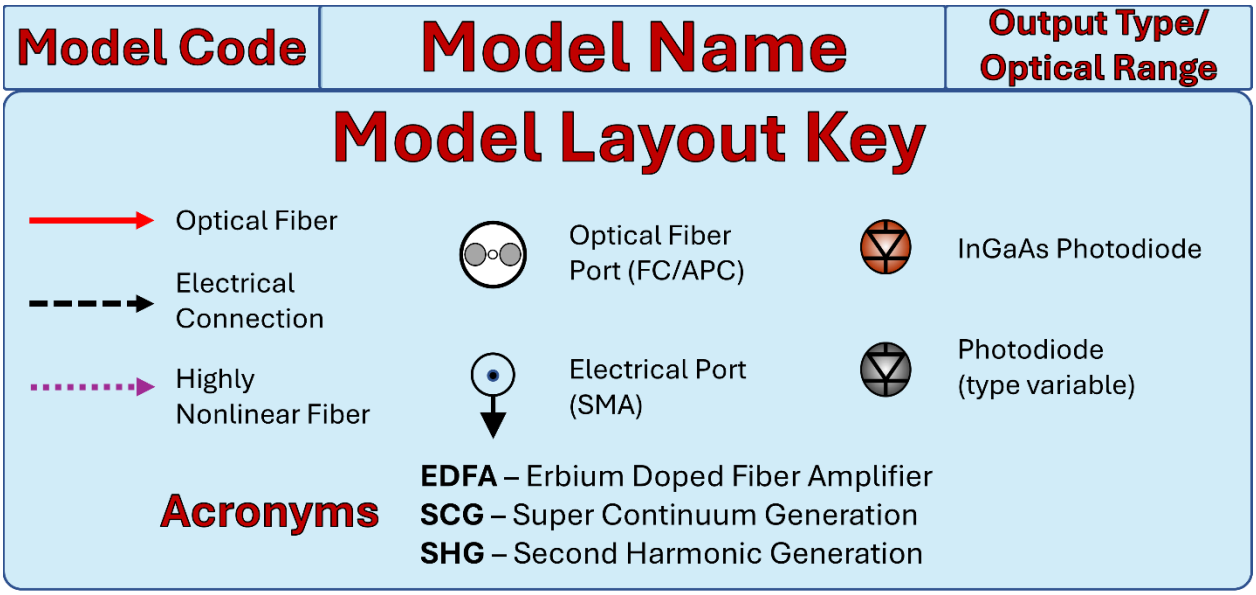
Heterodyne modules simplify the process of generating optical heterodyne signals from comb and CW laser light.

Repeater modules make it possible to chain several RUBRIColor units together to add many extension modules to one RUBRIC system.

Should any extension modules need to be changed or added to a chassis, the RUBRIColor will need to return to the factory for the upgrade.

5.2 Extension Descriptions

The following sections detail the behavior of the various extension module models. The sections include descriptions of the extension model inputs and outputs plus GUI controls and indicators. Each section starts with an extension model summary diagram that outlines the model design, according to the template that follows:



Model Name: The full name of the model being summarized.

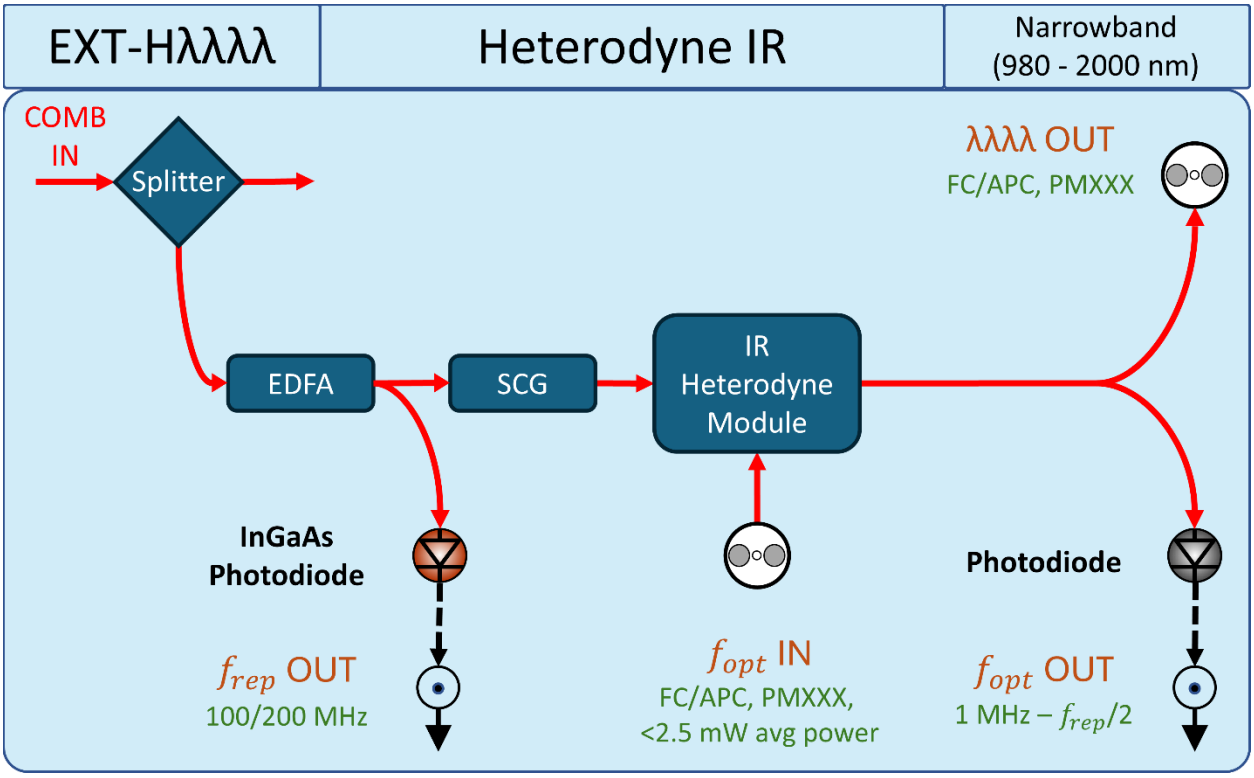
Model Code: Shorthand name for the model that is printed on the front of the extension module and displayed on the RUBRIColor GUI. For built modules, all instances of 'λλλ' are replaced by the design wavelength of the module e.g. EXT-H1315.

Output Type/Optical Range: The types of optical output can either be broadband, narrowband, or none.

> *Broadband* – The output bandwidth is 10s or 100s of nm and spans the listed optical range.
>
> *Narrowband* – The output is filtered to a limited bandwidth. The bandwidth typically varies between 1 nm and 13 nm depending on the customer-specified design wavelength. The design wavelength is incorporated into the model code.
>
> The model can be factory configured for wavelengths within the listed optical range.

Model Layout (Key): A block diagram of the model hardware is shown here. In the template above, the block diagram symbol key is shown instead.

5.3 Heterodyne IR (EXT-H)



The Heterodyne IR model has a built-in IR heterodyne submodule that combines frequency comb light with user-supplied continuous-wave (CW) laser light at the design wavelength.

The optical heterodyne light is split. Part of the optical heterodyne beat frequency is converted to an electrical RF signal with a photodiode. The rest of the heterodyne light exits the optical output. The output bandwidth (3 dB) is ~1 THz. See the CoC for further information.

5.3.1 Heterodyne IR Inputs/Outputs

1. CW Laser Input (PM FC/APC):

This port generates an optical heterodyne, f_{opt}, by mixing frequency comb light with input CW laser light at the design wavelength. The operator supplies CW laser light at the design wavelength to this port. For best performance, use a CW reference laser with < 100 kHz linewidth.

Always clean an optical fiber connector before making a connection at this port. Keep protective cap on port when not in use.

The input power limit of this port depends on the design wavelength of the module. For design wavelengths in the range 980 – 1749 (1750 – 2000) nm the input limit is 0.8 (1.25) mW. Exceeding these limits may damage or degrade the RUBRIColor.

2. Optical Heterodyne Output (PM FC/APC):

The comb-CW optical heterodyne is output on this port.

Always clean an optical fiber connector before making a connection at this port. Keep protective cap on port when not in use.

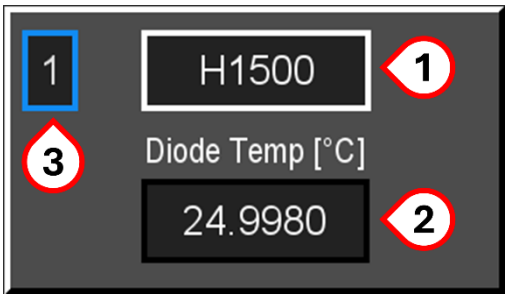
3. Optical Heterodyne RF Output (SMA):

RF output port for the optical heterodyne signal, f_{opt}. The comb-CW optical heterodyne is converted to an electrical RF signal output on this port.

4. Repetition Rate RF Output (SMA):

RF output port for monitoring the frequency comb repetition rate (f_{rep}). Several harmonics of the repetition rate are observable.

5.3.2 Heterodyne IR GUI



1. Extension Module Model: Shows the model code of the extension module.

2. Pump Diode Temperature Indicator: Measured temperature of the pump diode. The indicator background color changes depending on the state of the temperature plant.

Black - The temperature plant is not under active control.

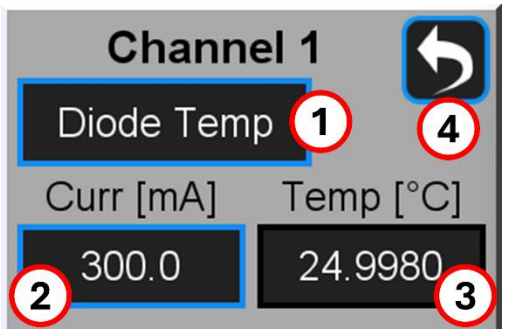
Red - An error has occurred. Please contact Vescent.

Yellow - The temperature plant is under active control and the measured Temperature Error magnitude is greater than 10 mK.

Green - The temperature plant is under active control and the measured Temperature Error magnitude is less than 10 mK.

3. Extension Module Controls Window: Tap this button to access additional extension module monitors and controls (below). Number indicates RUBRIColor channel where this module is installed.

5.3.3 *Heterodyne IR Controls Window*



1. Diode Temp: Tap on this button to navigate to the Diode Temperature Detail screen (see Section 3.3.3).

***2. Diode Current Setpoint*:** Setpoint for the diode current in milliamps.

This value was optimized during final testing and/or installation. The relationship between diode current and Optical Heterodyne Output power is non-monotonic. There may be local maxima in the power output. Contact Vescent before changing this value.

***3. Pump Diode Temperature Indicator*:** Measured temperature of the pump diode. The indicator background color changes depending on the state of the temperature plant.

Black - The temperature plant is not under active control.

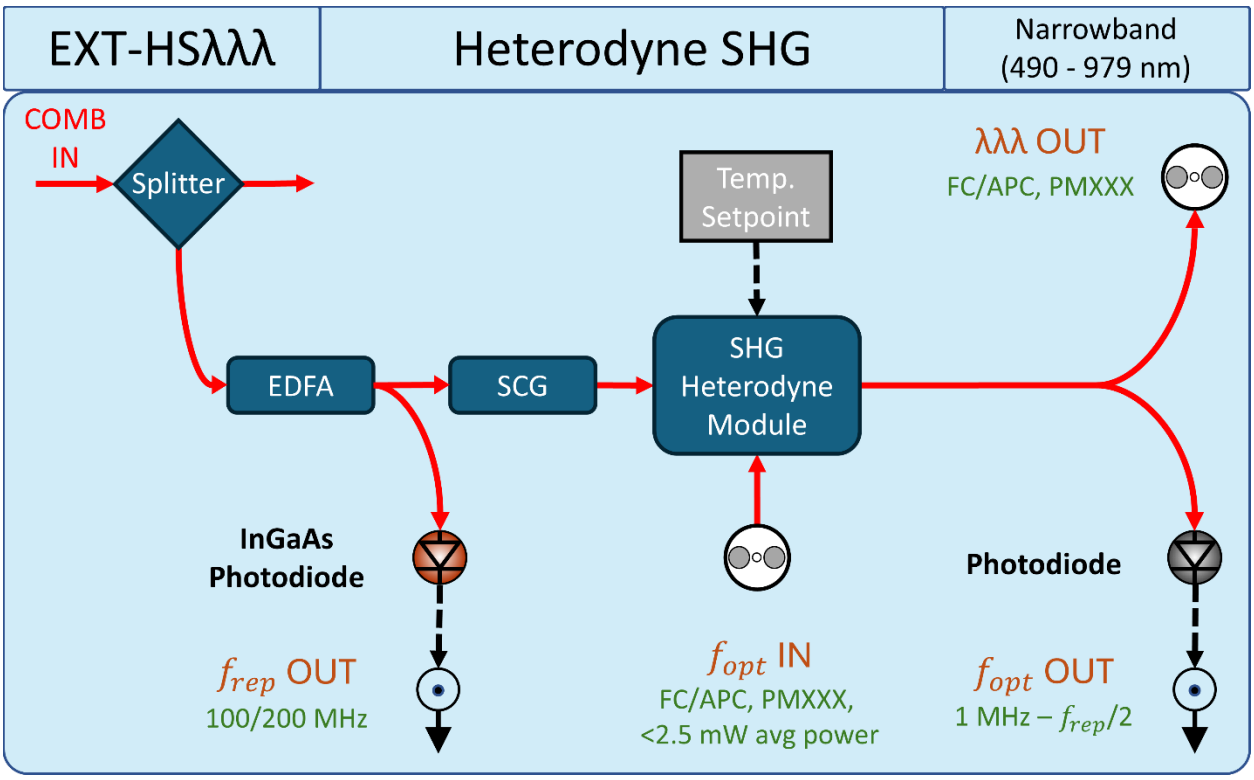
Red - An error has occurred. Please contact Vescent.

Yellow - The temperature plant is under active control and the measured Temperature Error magnitude is greater than 10 mK.

Green - The temperature plant is under active control and the measured Temperature Error magnitude is less than 10 mK.

4. Back: Tap to close window.

5.4 Heterodyne SHG (EXT-HS)



The Heterodyne SHG model has a built-in SHG heterodyne submodule that generates frequency doubled comb light via second-harmonic generation. The center frequency of the SHG comb light is tunable over ~5 nm via the SHG Temperature Setpoint control.

The SHG comb light is combined with user-supplied continuous-wave (CW) laser light at the design wavelength to create an optical heterodyne. The optical heterodyne light is split. Part of the optical heterodyne beat frequency is converted to an electrical RF signal with a photodiode. The rest of the heterodyne light exits the optical output. The bandwidth (3 dB) of the optical output is ~1 nm.

5.4.1 Heterodyne SHG Inputs/Outputs

1. CW Laser Input (PM FC/APC):

This port generates an optical heterodyne, f_{opt}, by mixing frequency comb light with input CW laser light at the design wavelength. The operator supplies CW laser light at the design wavelength to this port. For best performance, use a CW reference laser with < 100 kHz linewidth.

Always clean an optical fiber connector before making a connection at this port. Keep protective cap on port when not in use.

The input power limit of this port depends on the design wavelength of the module. For design wavelengths in the range 490 – 899 (900 – 979) nm the input limit is 1.25 (0.8) mW. Exceeding these limits may damage or degrade the RUBRIColor.

2. Optical Heterodyne Output (PM FC/APC):

The comb-CW optical heterodyne is output on this port.

Always clean an optical fiber connector before making a connection at this port. Keep protective cap on port when not in use.

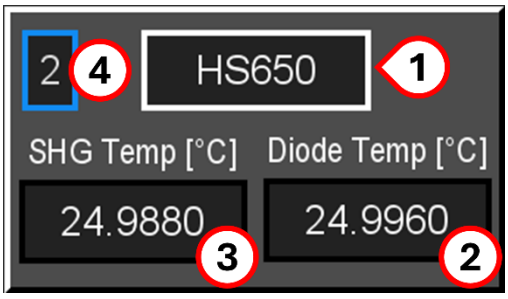
3. Optical Heterodyne RF Output (SMA):

RF output port for the optical heterodyne signal, f_{opt}. The comb-CW optical heterodyne is converted to an electrical RF signal output on this port.

4. Repetition Rate RF Output (SMA):

RF output port for monitoring the frequency comb repetition rate (f_{rep}). Several harmonics of the repetition rate are observable.

5.4.2 Heterodyne SHG GUI



1. Extension Module Model: Shows the model code of the extension module.

2. Pump Diode Temperature Indicator: Measured temperature of the pump diode. The indicator background color changes depending on the state of the temperature plant.

Black - The temperature plant is not under active control.

Red - An error has occurred. Please contact Vescent.

Yellow - The temperature plant is under active control and the measured Temperature Error magnitude is greater than 10 mK.

Green - The temperature plant is under active control and the measured Temperature Error magnitude is less than 10 mK.

3. SHG Submodule Temperature Indicator: Measured temperature of the second-harmonic generation submodule housed within the extension module. The indicator background color changes depending on the state of the temperature plant.

Black - The temperature plant is not under active control.

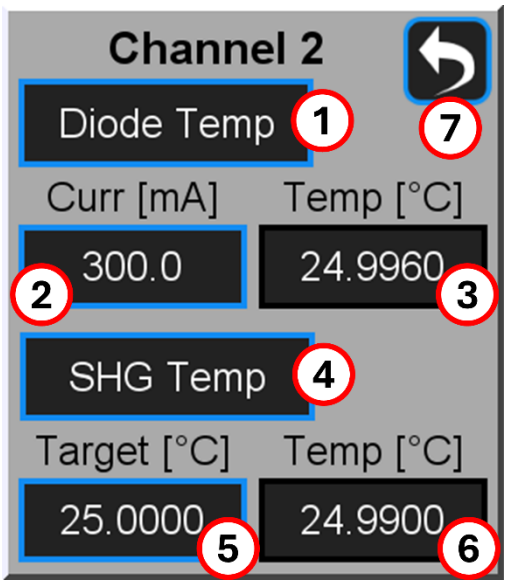
Red - An error has occurred. Please contact Vescent.

Yellow - The temperature plant is under active control and the measured Temperature Error magnitude is greater than 50 mK.

Green - The temperature plant is under active control and the measured Temperature Error magnitude is less than 50 mK.

4. Extension Module Controls Window: Tap this button to access additional extension module monitors and controls (below). Number indicates RUBRIColor channel where this module is installed.

5.4.3 Heterodyne SHG Controls Window



1. Diode Temp: Tap on this button to navigate to the Diode Temperature Detail screen (see Section 3.3.3).

***2. Diode Current Setpoint*:** Setpoint for the pump diode current in milliamps.

This value was optimized during final testing and/or installation. The relationship between diode current and Optical Heterodyne Output power is non-monotonic. There may be local maxima in the power output. Contact Vescent before changing this value.

***3. Pump Diode Temperature Indicator*:** Measured temperature of the pump diode. The indicator background color changes depending on the state of the temperature plant.

Black - The temperature plant is not under active control.

Red - An error has occurred. Please contact Vescent.

Yellow - The temperature plant is under active control and the measured Temperature Error magnitude is greater than 10 mK.

Green - The temperature plant is under active control and the measured Temperature Error magnitude is less than 10 mK.

4. SHG Temp: Tap on this button to navigate to the SHG Temperature Detail screen (see Section 3.3.3).

5. SHG Temperature Setpoint: Temperature Setpoint for the SHG submodule. Changing the temperature of the SHG submodule changes the output wavelength of the extension module. See the extension module CoC for further details.

6. SHG Temperature Indicator: Measured temperature of the SHG submodule. The indicator background color changes depending on the state of the temperature plant.

Black - The temperature plant is not under active control.

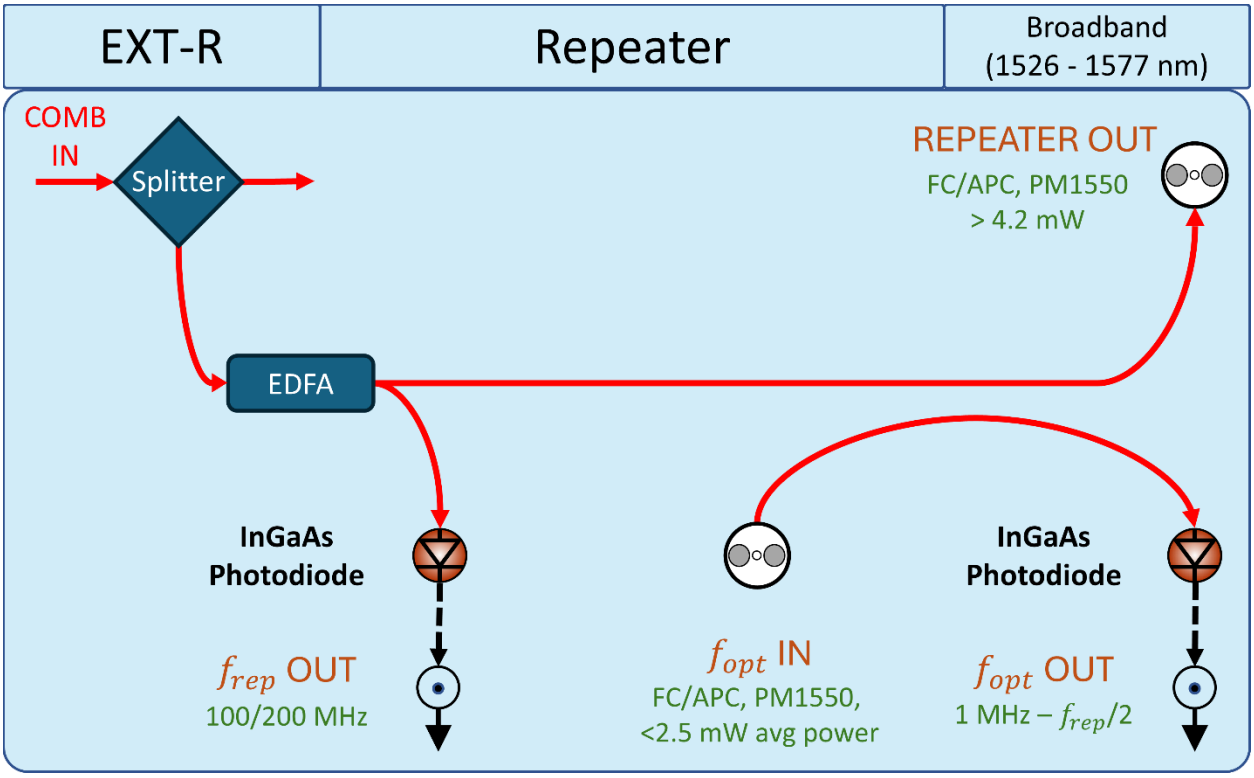
Red - An error has occurred. Please contact Vescent.

Yellow - The temperature plant is under active control and the measured Temperature Error magnitude is greater than 50 mK.

Green - The temperature plant is under active control and the measured Temperature Error magnitude is less than 50 mK.

7. Back: Tap to close window.

5.5 Repeater (EXT-R)



The Repeater model is a telecom C-band module repeater for seeding downstream RUBRIColors with frequency comb light. In standard operation, the Repeater Output is connected to the Comb In port on another RUBRIColor.

Alternatively, the Repeater Output comb light can be externally mixed with compatible CW light to generate an optical heterodyne. The repeater can detect suitable optical heterodyne light on the f_{opt} Input port and convert it to an electrical RF beat frequency using its internal photodiode.

5.5.1 Repeater Inputs/Outputs

1. Optical Heterodyne Detection Input (PM FC/APC):

This input port is designed to detect an optical heterodyne signal, f_{opt}, and generate an RF signal for optical comb stabilization. The operator is responsible for combining CW laser and repeater output light to generate a suitable optical heterodyne. For best performance, use a CW reference laser with < 100 kHz linewidth.

Always clean an optical fiber connector before making a connection at this port. Keep protective cap on port when not in use.

The input power limit of this port is 0.8 mW. Exceeding this limit may damage or degrade the RUBRIColor.

2. Repeater Output (PM FC/APC):

Amplified frequency comb light is output at this port. The output is at least 4 mW and can be used to seed downstream RUBRIColor units via their COMB IN ports.

Always clean an optical fiber connector before making a connection at this port. Keep protective cap on port when not in use.

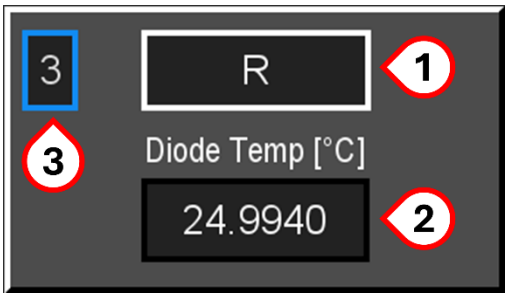
3. Optical Heterodyne RF Output (SMA):

RF output port for the optical heterodyne signal, f_{opt}. The signal supplied on the Optical Heterodyne Detection input is converted to an electrical RF signal output on this port.

4. Repetition Rate RF Output (SMA):

RF output port for monitoring the frequency comb repetition rate (f_{rep}). Several harmonics of the repetition rate are observable.

5.5.2 Repeater GUI



1. Extension Module Model: Shows the model code of the extension module.

2. Pump Diode Temperature Indicator: Measured temperature of the pump diode. The indicator background color changes depending on the state of the temperature plant.

Black - The temperature plant is not under active control.

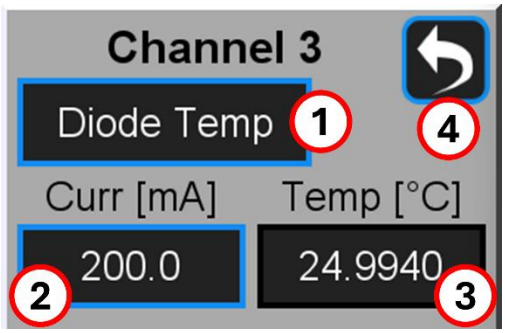
Red - An error has occurred. Please contact Vescent.

Yellow - The temperature plant is under active control and the measured Temperature Error magnitude is greater than 10 mK.

Green - The temperature plant is under active control and the measured Temperature Error magnitude is less than 10 mK.

3. Extension Module Controls Window: Tap this button to access additional extension module monitors and controls (below). Number indicates RUBRIColor channel where this module is installed.

5.5.3 Repeater Controls Window



1. Diode Temp: Tap on this button to navigate to the Diode Temperature Detail screen (see Section 3.3.3).

***2. Diode Current Setpoint*:** Setpoint for the diode current in milliamps.

***3. Pump Diode Temperature Indicator*:** Measured temperature of the pump diode. The indicator background color changes depending on the state of the temperature plant.

Black - The temperature plant is not under active control.

Red - An error has occurred. Please contact Vescent.

Yellow - The temperature plant is under active control and the measured Temperature Error magnitude is greater than 10 mK.

Green - The temperature plant is under active control and the measured Temperature Error magnitude is less than 10 mK.

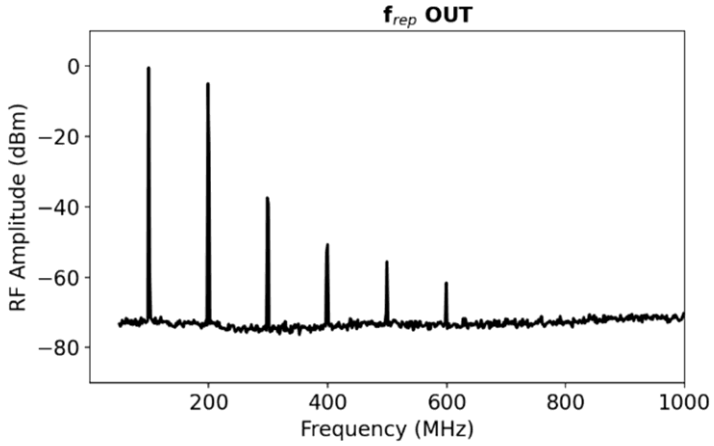
4. Back: Tap to close window.

6 Detailed Operations

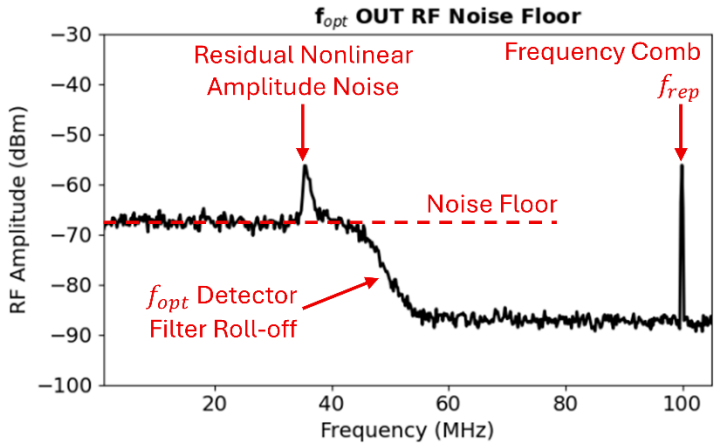
This section provides additional details about the operation of the RUBRIColor.

6.1 RF Outputs

A monitor inside each extension module collects amplified frequency comb light on a photodiode. The output contains the fundamental frequency mode and harmonics of the frequency comb repetition rate, f_{rep}, and can be used to confirm that frequency comb light is reaching the extension module. An example of the f_{rep} spectrum is seen below.



A second detector is dedicated to capturing the optical beat frequency, f_{opt}. During final testing, the f_{opt} OUT noise floor is generated for the RUBRIColor CoC documentation (example below). For heterodyne-style extension modules, the optical spectral power output is maximized under the constraint that the f_{opt} noise floor remains below -65 dBm. This balance ensures that there is adequate power headroom left on the detector for the CW input.



6.2 Errors

When an error is triggered, the Operation Mode selector flashes red and warning text appears on the button. Use the warning text to identify the error from the section titles below.

6.2.1 Interlock Error and the Safety Interlock System

The Safety Interlock System (SIS) is designed to limit laser hazards and reduce risk of injury to human operators and damage to connected equipment. The SIS is designed to satisfy typical laser interlock requirements.

The first element of the SIS is the Access Control lock that restricts use of the RUBRIColor to authorized operators. The provided Operator Keys should only be given to operators who have read this manual and have a working knowledge of laser safety. If a key is removed at any point during operation, the SIS system will be engaged.

The second element of the SIS is the Remote Interlock port that allows the user to install a remote interlock system. If a remote interlock system is not required, install the provided 50 Ω BNC terminator on the port. To operate the RUBRIColor, the inner and outer conductors of the port must be electrically connected. If this connection is broken, the SIS will be engaged. Proper use of the Remote Interlock requires that the circuit does ***not*** connect to ground as this may also engage the SIS.

The final element of the SIS is the Laser Enable Switch. When this toggle switch is flipped into the OFF position, the SIS is engaged.

When the SIS is engaged, the RUBRIColor first returns to STANDBY mode. Then the Operation Mode selector flashes red, and the text changes to “INTERLOCK” to indicate that the RUBRIColor has entered Interlock mode.

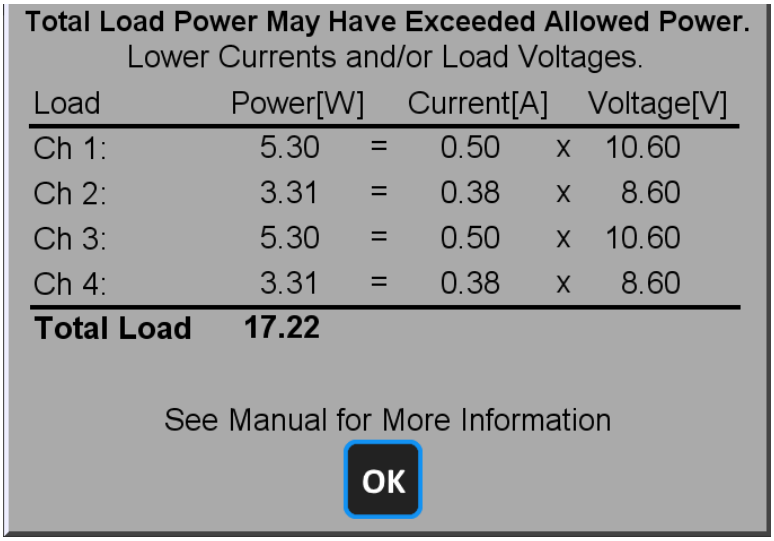
To exit Interlock mode, the cause of the interlock must first be resolved. Then the operator can tap on the Operation Mode selector to return to normal operation.

6.2.2 No RUBRIComb Input

If comb light is no longer detected at the Comb Input port while the unit is in LASERS ON mode, then a No RUBRIComb Input error is triggered. The Operation Mode selector flashes red and the text changes to “NO RUBRIComb INPUT”.

To exit No RUBRIComb Input mode, tap the flashing Operation button to return to STANDBY mode. Before continuing, check the power of the frequency comb light being provided to the Comb Input port.

6.2.3 *Load Power Limit Exceeded*



If the load power exceeds the limits set for the RUBRIColor temperature controllers, then a Load Power Limit Exceeded error is triggered.

During a Load Power Limit Exceeded error, the RUBRIColor initiates the Safety Shutdown Protocol and opens the window shown above. The window displays the approximate power, current, and voltage at the time of the error. During this process the RUBRIColor shuts off its pump diodes and temperature controllers, much as it would to return to SYSTEM OFF mode. The Safety Shutdown Protocol is enacted to minimize the risk of harm to the operator and damage to the RUBRIColor.

Record the window and Contact Vescent before continuing operation.

7 Remote Operation

This section describes how to set up a remote connection for the RUBRIColor.

7.1 Setting up a Remote Connection

Start by connecting the RUBRIColor to a computer with a USB-A to USB-B cable. Plug the USB-B connector into the USB port on the RUBRIColor and the USB-A connector to a free port on the computer.

In Windows systems, the RUBRIColor will appear as a COM Port. In UNIX-like systems (Linux, MacOS), it will appear as a serial port in the /dev/ folder.

Using a serial terminal application such as Tera Term or Putty, connect to the RUBRIColor with the following parameters:

- Speed: 115200
- Data Length: 8-bit
- Parity: None
- Stop Bits: 1
- New Line Receive: AUTO
- New Line Transmit: CR

Test your connection by sending a command, such as "***IDN?"**

You should see a response like: **Vescent,RUBRIColor-1LD,065535,S-V1.124,QTC-V2.73**

You are now ready to control the RUBRIColor via serial API commands. For a complete list of commands, see the RUBRIColor Serial API Guide.

8 Firmware Upgrades

From time-to-time Vescent will issue firmware releases for the RUBRIColor. This section describes how to perform a firmware upgrade for the RUBRIColor.

8.1 Firmware Upgrade Utility

The SLICE-FFC Firmware Upgrade Utility is required to upgrade the RUBRIColor firmware.

If you have not already installed the SLICE-FFC Firmware Upgrade Utility, or your computer is running a version of the upgrade utility that is older than configuration 1.44, go to:

https://github.com/Vescent/SLICE-FFC_Firmware_Upgrade_Utility

and follow the instructions to install or update the upgrade utility.

8.2 Firmware Upgrade Instructions

Once the SLICE-FFC Firmware Upgrade Utility has been installed/updated, follow these instructions to upgrade the RUBRIColor firmware.

1. Connect the computer to the RUBRIColor Serial Port with the provided USB cable.
2. Launch the SLICE-FFC Firmware Upgrade Utility.
3. Carefully follow the instructions displayed on the SLICE-FFC Firmware Upgrade Utility console. The upgrade utility console will close when the firmware upgrade is complete.

Do not shut off the RUBRIColor during a firmware upgrade. Only disconnect the RUBRIColor from your computer when instructed or once the upgrade is complete.

9 Troubleshooting

The following table describes typical issues that may be encountered while using the RUBRIColor and recommended actions to solve the problems.

Problem	Recommended Actions
Numeric field does not increase when right rotary knob is turned clockwise -or- Numeric field does not decrease when right rotary knob is turned counterclockwise.	Value likely exceeds a software or user-defined limit. For user-defined limits, adjust the limit to increase the parameter range.
Unable to exit Interlock Error mode.	1. Check the Remote Interlock circuit continuity, the Access Control Lock state, and the Laser Enable Switch state. 2. Ensure the Remote Interlock does not have a path to ground. 3. An Operator Key inserted into the Access Control Lock is grounded. Ensure the key does not conduct to the Remote Interlock port.
f_{opt} RF output signal disappears or shows significantly reduced signal-to-noise (SNR).	Verify that the f_{CW} or f_{opt} input signal power does not exceed limits stated in CoC. Turn off all light sources and check the cleanliness of the optical fibers. If necessary, clean the fibers with the fiber optic cleaner provided with the RUBRIC system.
f_{opt} RF output signal linewidth significantly broadened.	Check CW laser performance. Ensure the laser is still locked, and the locking servo is not railed to its maximum or minimum voltage. Optimize the lock servo gain settings. Check the status and quality of the frequency comb stabilization lock, if different.

A RUBRIColor Chassis Specifications

A.1 General Specifications

Parameter	Value
Laser Classification	1

A.2 Size, Weight, and Power

Parameter	Value	Units	Comments
Input Line Voltage	100 - 240	VAC	50/60 Hz
Overvoltage Category	II		
Power Consumption	55/80	W	Typical/Maximum
Weight	8.5	kg	
Chassis Volume	17	L	Not including rackmount ears and feet
Dimensions	19 W x 19 D x 3.875 H	in	2U 19" rack mount
	48.3 W x 48.3 D x 9.8 H	cm	

A.3 Environmental

Parameter	Min.	Max.	Units	Comments
Indoor or Outdoor Use	Indoor Use Only			Dry Location Only
Pollution Degree of Environment		2		
Operating Temperature	15	35	°C	
Operating Relative Humidity		93	%	Non-condensing
Storage Temperature	-10	70	°C	

B Extension Module Specifications

B.1 Extension Model Designation

EXT-(ALPHA)(NUMERIC)	
ALPHA	Extension module model. Models include: H – Heterodyne IR HS – Heterodyne SHG R – Repeater
NUMERIC	If applicable, the design wavelength of the extension module in nm.

B.2 Heterodyne IR Specifications

INPUTS

Parameter	Design Wavelength (nm)	Max.	Units	Comments
f_{CW} Optical Input Power	980 – 1749	0.8	mW	CW Laser; average power
	1750 – 2000	1.25	mW	

OUTPUTS

Parameter	Min.	Typical	Max.	Units	Comments
f_{opt} RF Output Noise Floor			-65	dBm	Over span 5 to frep/2 MHz
f_{rep} RF Output Power Level	-10	0	5	dBm	

B.3 Heterodyne SHG Specifications

INPUTS

Parameter	Design Wavelength (nm)	Max.	Units	Comments
f_{CW} Optical Input Power	400 – 899	1.25	mW	CW Laser; average power
	900 – 979	0.8	mW	

OUTPUTS

Parameter	Min.	Typical	Max.	Units	Comments
f_{opt} RF Output Noise Floor			-65	dBm	Over span 5 to frep/2 MHz
f_{rep} RF Output Power Level	-10	0	5	dBm	

B.4 Repeater Specifications

INPUTS

Parameter	Max.	Units	Comments
f_{CW} Optical Input Power	0.8	mW	Heterodyne; average power

OUTPUTS

Parameter	Min.	Typical	Max.	Units	Comments
f_{opt} RF Output Noise Floor			-65	dBm	Over span 5 to frep/2 MHz
f_{rep} RF Output Power Level	-10	0	5	dBm	
REPEATER OUT Power Level	4		6	mW	
REPEATER OUT Bandwidth	30			nm	At -10 dB

C Additional Resources

QR Code	Details
	Vescent Home vescent.com Additional resources are available at vescent.com

D Service & Maintenance

The RUBRIColor is designed to be maintenance free. No user-serviceable parts are inside the unit. No further calibrations are necessary for the RUBRIColor to meet its accuracy specifications over the lifetime of the product. Opening the instrument case voids the warranty and exposes the user to hazardous voltages that are present inside the instrument case.

Cleaning instructions: Do *not* clean outside surfaces of any Vescent products with solvents such as acetone. Front panels on electronics modules may be cleaned with a mild soap and water solution.

For service or repairs:

1. Contact Vescent customer service via telephone at (+1) 303-296-6766, online at vescent.com/support, or via email at info@vescent.com. Customer service will determine if the equipment requires service, repair, calibration, or replacement. Factory office hours are 9:00 am - 5:00 pm MST.

2. If the unit must be returned to Vescent, ask for a Return Merchandise Authorization (RMA) from customer service. **Never send any unit back to Vescent without a completed Return Merchandise Authorization (RMA).**

3. Pack the unit in its original shipping material (if possible) with at least 1 inch of compressible packing material on all sides. Be sure to include an ownership tag and enter a description on the RMA form fully detailing the defect and the conditions under which it was observed.

4. Return the unit, postage prepaid, to Vescent. Do not forget to return a hard copy of the completed RMA form with the unit and write the RMA number on the shipping label. Vescent will refuse and return any package that does not bear an RMA.

5. After repair, the equipment will be returned with a repair report. If the equipment is out of warranty but operates within specifications, a test set-up fee will be charged to the customer. If the equipment is not under warranty, the customer will be invoiced for the cost appearing on the repair report.

6. Vescent is responsible for shipping the unit back to the customer if the unit is under warranty. **Shipping damage is not covered by this warranty,** and shipping insurance, which Vescent recommends, is at the customer's expense.

E Warranty

Vescent hereby warrants to Buyer, that during the applicable Warranty Period (as defined below) the Products will conform to Vescent's published specifications and will be free of defects in materials or workmanship when used, installed and maintained in accordance with Vescent's published specifications. Vescent's sole liability and Buyer's sole and exclusive remedy for breach of warranty shall be limited to, at Vescent's option, either repairing or replacing the defective components of the Product or crediting Buyer for the amount Buyer has paid to Vescent for the applicable Product. Vescent's liability shall apply only to Products which are returned to the factory or authorized repair point, with shipping charges prepaid by Buyer, and which are, after examination, determined to Vescent's satisfaction to be defective due to defects in materials or workmanship. Vescent will only accept returns authorized by a Vescent customer service representative and with a valid RMA number. This warranty does not apply to Products which are designated by Vescent as "Pre-Production Products", e.g. Alpha, Beta or Prototypes or are Products which have been repaired or modified without Vescent's written approval, or subjected to unusual physical, thermal, optical or electrical stress, improper installation or cleaning, misuse, abuse, accident or negligence in use, storage, transportation or handling. The "Warranty Period" during which this warranty applies varies with Product type as follows:

a. For standard Vescent lasers in which a counter is incorporated (i.e. lasers with counters for which Vescent has published a datasheet and which have not been obsoleted by the time of order placement): one (1) year after the date of original shipment or 3,000 hours of use, whichever occurs first;

b. For standard Vescent products other than lasers with counters, (i.e. products for which Vescent has published a datasheet and which have not been obsoleted by the time of order placement): one (1) year after the original shipment;

c. For any other Product including, without limitation, all product types as set forth in sections a. and b. of this clause 5 which are in any way customized, build-to-order, otherwise non-standard and/or are subject of a blanket purchase order: one (1) year after the date of original shipment unless otherwise agreed to in writing on a case by case basis. If, in relation to any Product Vescent offers as an additional purchase option, a warranty period over and above that which is set out in sections b. and c. of this clause 5 ("Extended Warranty") and Buyer exercises such option then the Warranty Period shall be the duration as specified on such Extended Warranty commencing on the date of original shipment. Any Extended Warranty option is only available at the time of and on the same order as the original Product purchase.

d. For any non-warranty Product that has been repaired, Vescent will extend the applicable Warranty Period by sixty (60) calendar days for the specific characteristic of the Product that is repaired by Vescent. Other characteristics of the non-warranty Product will remain uncovered by any warranty.

e. For Products that are discontinued, Vescent's liability shall terminate at the end of the applicable Warranty Period or one (1) year from the date of discontinuity, whichever occurs first.

f. Except for the warranty stated herein and to the extent permitted by applicable law Vescent specifically disclaims any and all warranties, express or implied, including, but not limited to, any warranties of merchantability, fitness for a particular purpose, or noninfringement.