Laser Controller

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General Warnings and Cautions

The following general warnings and cautions are applicable to this instrument.

WARNING

This instrument is intended for use by qualified personnel who recognize shock hazards or 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.

CAUTION

There are no serviceable parts inside the instrument. Work performed by persons not authorized by Vescent Photonics may void the warranty.

CAUTION

Although ESD protection is designed into the instrument, operation in a static-fee work area is recommended.

WARNING

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.

WARNING

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

Limited Warranty

Vescent Photonics warrants this product to be free from defects in materials and workmanship for a period of one year from the date of shipment. If this product proves defective during the applicable warranty period, Vescent Photonics, at its option, either will repair the defective product without charge or will provide a replacement in exchange for the defective product. The customer must notify Vescent of the defective product within the warranty period and prior to product return. The customer will be responsible for packaging and shipping the defective product back to Vescent Photonics, with shipping charges prepaid.

Vescent Photonics shall not be obligated to furnish service under this warranty from damage caused by service or repair attempts made without authorization by Vescent Photonics; from damage caused by operation of equipment outside of its specified range as stated in either the product specification or operators manual; from damage due to improper connection to other equipment or power supplies.

This warranty is in lieu of all other warranties including any implied warranty concerning the suitability or fitness of the product for a particular use. Vescent Photonics shall only be liable for cost of repairs or replacement of the defective product within the warranty period. Vescent Photonics shall not be liable for any damages to persons or property resulting from the use of the product or caused by the defect or failure of this product. Vescent Photonics' liability is expressly limited to the warranty set out above. By accepting delivery of this product, the purchaser expressly agrees to the terms of this limited warranty.

Vescent Photonics

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Absolute Maximum Ratings

Note: All modules designed to be operated in laboratory environment

Parameter	Rating
Environmental Temperature	>15°C and <30°C
Environmental Humidity	<60%
Environmental Dew Point	<15°C

1. Laser Controller

Model No. D2-105 / D2-105-500

Document Revision: 3

1.1. Description

The laser controller has two temperature controllers capable of sub-mK stability[1] and a 200 mA or 500 mA precision current source based on the Libbrecht-Hall[2] circuit. The laser controller is designed for very fast current modulation via the servo input enabling high-speed servo control of the laser's frequency. The current servo input can accommodate input frequencies over 10 MHz and is limited by the 1 kΩ input impedance. Additionally, an RF port is available for higher frequency modulation.

[1] Sub-mK stability requires a proper thermal design and proper tuning of the temperature controller to the thermal plant. If you did not purchase the Laser Controller with a Laser Diode, please read the section on tuning the temperature controller.

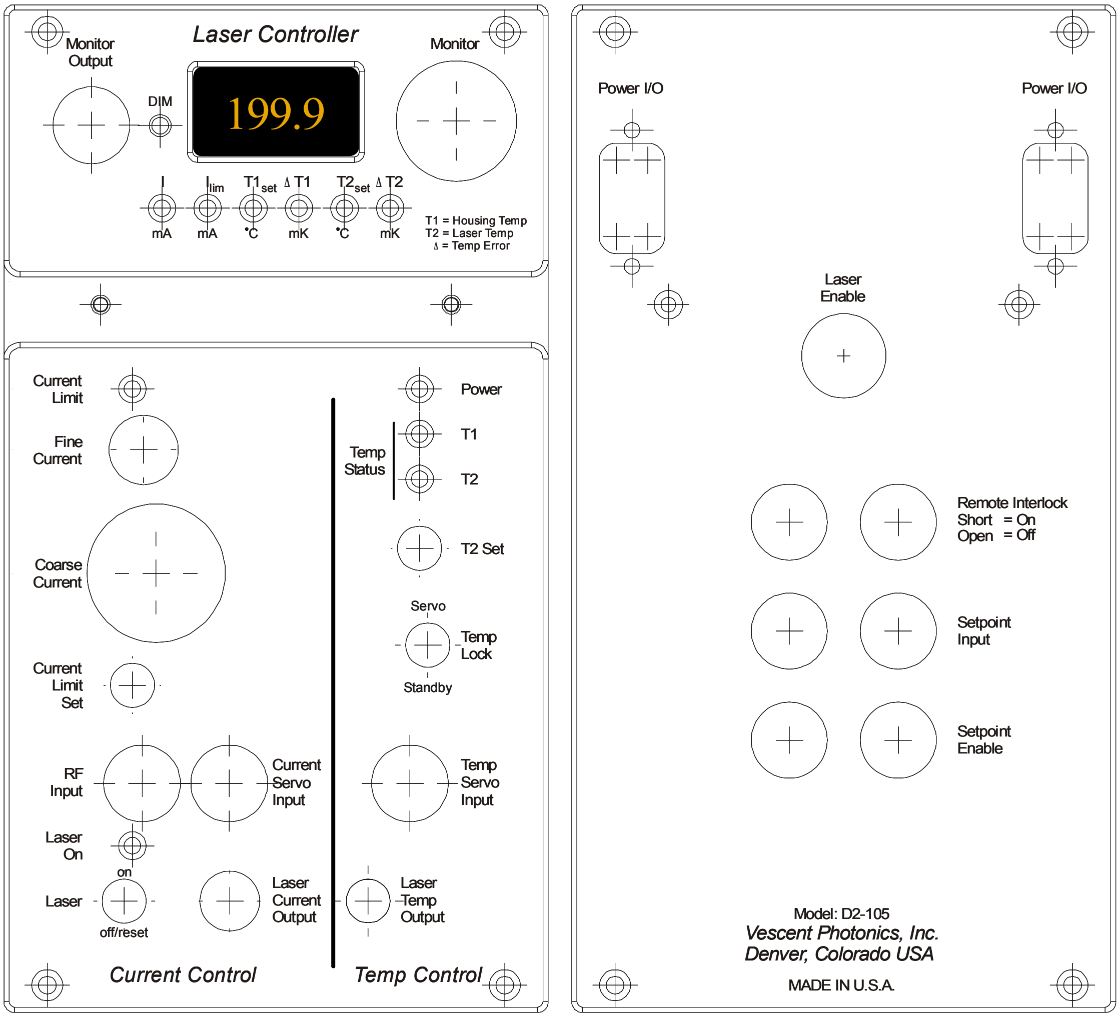
[2] Libbrecht and Hall, *A Low-Noise, High-Speed Current Controller,* Rev. Sci. Inst. 64, pp. 2133-2135 (1993).

1.2. Specifications[3]

	D2-105	D2-105-500	Units
Current Source			
Current range	0-200	0-500	mA
Current noise density	<100	<200	$pA/\sqrt{Hz}$
RMS Noise (10Hz - 100kHz)	<50	<100	nA
RMS Noise (10Hz - 1MHz)	<100	<150	nA
RMS Noise (10Hz - 10MHz)	<300	<500	nA
Monitor Resolution (Display)	0.1	1	µA
Absolute accuracy	2	2	%
Temperature coefficient	<1	<5	µA/°C
Current Servo Input			
Input impedance	1000	1000	Ω
Bandwidth	>10	>10	MHz
Modulation coefficient	1	1	mA/V
RF Input Bandwidth	0.5 - TBD	0.5 - TBD	MHz
Temp Servo Input			
Input impedance	100	100	kΩ
Temp modulation coefficient			
Gain = Low	-20	-20	mK/V
Gain = High	-600	-600	mK/V
Temperature Control			
Temperature setpoint range	1-50	1-50	°C
Temperature isolation (T2)[4]	TBD	TBD	mK/°C
Long term stability (T2)	~1	~1	mK/day
Temperature coefficient [5] (controller, T2)	TBD	TBD	mK/°C
Max TEC current (voltage)	1 (4)	1 (4)	A (V)

[3]All current noise measurements made with Laser Controller powered by D2-005 placed 5ft away from Laser Controller. Placing D2-005 closer to Laser Controller may increase 60 Hz noise and their harmonics. Specifications not guaranteed when Laser Controller is powered by device other than D2-005, or when placed near power supply or other noise source..
[4]Laser module temperature changed while Laser Controller module held fixed.
[5]Laser module temperature fixed while Laser Controller temperature change.

1.3. Inputs, Outputs, and Controls



Front Back

1.3.1. Monitor Section

The monitor section contains a 3 ½ digit display and an output BNC for monitoring by an oscilloscope or voltmeter. A selector knob controls which of six signals are relayed to the display and BNC. An LED indicator is below the display to show which signal is being displayed and its units.

Name	Symbol	Units	Resolution
Current	I	mA	0.1 mA / 1mA[6]
Current limit	I_{lim}	mA	0.1 mA / 1mA[6]
Housing Temperature Set	$T1_{set}$	°C	0.1 °C
Housing Temperature Error	ΔT1	mK	0.1 mK
Laser Temperature Set	$T2_{set}$	°C	0.1 °C
Laser Temperature Error	ΔT2	mK	0.1 mK

NOTE: When the Laser Switch is in the "Off / Reset" position, the laser diode is shorted to ground and no current is flowing through the laser diode. However, the Current Monitor will read up to 30 mA of current flowing through the short. This is normal. When the switch is in the "ON" position, the current monitor accurately measures the current flowing through the laser diode.

1.3.2. Current Control

Current Lim (LED)

The current limit indicator lights when the current limit circuit is activated. If the user attempts to set the current over the current limit setpoint the circuit shunts the excess current through a transistor to ground

Fine Current (knob)

The fine current adjusts the diode injection current by ½-1 % of the course control setting. Use this control for fine positioning of the laser frequency prior to locking.

Course Current (Scale Dial)

The course current control sets the laser diode injection current between 0 and 200 mA (0 and 500mA for 500mA version). To set the current, switch the selector knob in the monitor section so that the current LED *(I)* is lit. Then adjust the course current to the desired setting.

Current Limit Set (Trimpot)

The current limit set is a front panel trimpot adjustment. Set the selector knob to the I_{lim} position and adjust the trimpot to the desired value. The Current Limit should be set below the maximum current for the laser diode.

RF Input (BNC)

The RF input is ac coupled to the laser diode through a 10 nF capacitor. Over ~3 MHz the impedance of this input will approach the ac impedance of the laser diode of ~5Ω. This input is normally connected to the RF output from the Laser Servo module, which applies FM sidebands at 4 MHz to the laser output.

Note: a large voltage transient to this input could possibly cause damage to the laser diode. If you are connecting other equipment to this input do not exceed 0.25 Vrms from a 50 Ω *source or 1 mW of power.*

Current Servo Input (BNC)

The current servo input adds or subtracts current though 1 k Ω connected to the laser diode giving a modulation coefficient of 1 mA/V. A bias circuit sets the voltage of the current servo input to

[6] 1mA resolution with D2-105-500

zero volts. (Normally, a connection to the laser diode would place this voltage at ~ 2V or equal to the forward diode drop.) Therefore, leaving the input open or grounded does not alter the current to the laser diode.

The bandwidth of the current servo input is >10 MHz.

Laser On (LED indicator)

Turns ON 5 seconds before laser light turns on. If light is on, laser is on (or will be in <5secs).

Laser ON-Off/Reset (switch)

When the switch is in the Off/Reset position, the laser diode is turned off and the laser is shorted to ground. When flipped into the On position, the Laser ON (LED indicator) will turn on and 5s later, the laser will turn on. If the laser diode is turned off from the laser enable or remote interlock, this switch must to placed into the Off/Reset position and then into the ON position to turn the laser back on.

Laser Out (SMA)

The laser current is output through an SMA connector and returns through the cable shielding to ground.

1.3.3. Temperature Control

Power (LED indicator)

All electronic modules have a blue LED power indicator on the top right side of the front panel control section. The LED requires +15V and 5V in order to light.

Temp Status (dual LED indicators)

The temperature status LED indicators turn red whenever the temperature servo loop has been disengaged. The temperature servo loop will disengage when the temperature is below -1°C, above 50°C, or the thermistor is shorted or open. Additionally, when the TEMP LOCK is in standby mode, the servo loop is off and the LED's will be red.

The temperature status LED indicators will turn green when the temperature is within a narrow temperature window of the setpoint. The window is usually set to a 10's of mK. See spec sheet included with your order for the setting of this window.

T2 Set (Trimpot)

The temperature of the laser diode (T2) is set with a front panel trimpot. T2 is factory set to put the laser on transition with the Rb D2 hyperfine lines and should not need trimming. However, as the diode ages the user might need to adjust this value. Set the display selector knob to read $T2_{set}$ and set to the desired value.

T1 is also set at the factory and should not require further adjustment. However, the T1 trimpot can be accessed by removing the right panel from the enclosure.

Temp Lock (Dual position switch)

The temperature servo can be placed into standby mode if desired. In this mode no current is supplied to the TEC elements.

Temp Servo Input (BNC)

The temperature servo input is summed to the T2 temperature setpoint signal and can be used to make electronic perturbations to the laser diode temperature. The Temp Servo Input, has two settings: “Low” and “High” gain. The default settings in “Low” but can be changed by a switch accessible on the right side panel.

When the gain is set to “LOW”, the slope for changing the setpoint is ~-20 mK/V.

When the gain is set to “HIGH”, turn the setpoint to the lowest desired temperature. Apply a voltage between 0V and 10V to TEMP SERVO INPUT to raise the setpoint temperature. With this configuration, you can sweep the setpoint all the way from the low temperature limit (-1°C) to the high temperature limit (58°C). *NOTE that the Vescent Photonics Lasers should not be operated above 50°C.* The slope for changing the setpoint is ~-600 mK/V.

The “Low” mode is designed for slow temperature feedback for long-term (days) stability of the locked laser. Normally the Temp Servo Input is used to drive the dc value from the Current Servo Ouput on the Laser Servo to zero over long time scales. In other words, temperature tuning is used to remove large, slow variations in the laser frequency. To accomplish this connect the Temp Servo Output from the Laser Servo module to the Temp Servo Input of the Laser Controller (with TEMP SERVO INPUT Gain is set to “Low”). This connection is only important if the user is trying to maintain a laser lock continuously over many days or even weeks. Without feedback to Temp Servo In the Laser Servo can eventually run out of range. (The Current Servo output of the Laser Servo is clamped at 1.2 V. See discussion in the Laser Servo manual.)

Laser Temp Output (8-pin connector)

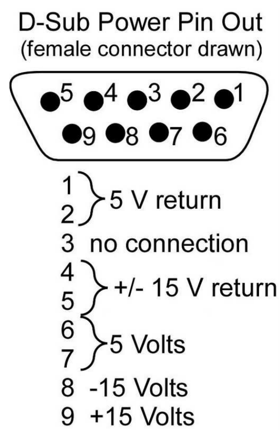
An 8-pin Hirose connector (HR25-7TR-8SA) carries the signals for the temperature control of the Laser module. The wiring diagrams are shown in the table below, where 1 (2) refer to stage 1 (2) temperature control, which stabilizes the Laser Housing (Laser Diode). Rth and Rth_Rtn are the two ends of a 10k thermistor.

Pin	Signal
1	TEC1+
2	TEC1-
3	Rth1
4	Rth1-RTN
5	TEC2+
6	TEC2-
7	Rth2
8	Rth2-RTN

1.3.4. Back panel I/O

Power I/O (9-pin D-sub)

The power to each electronics module is through a 9-pin D-sub connecter through a power bridge unit. The unit can also be powered through any serial cable with 9-pin D-sub connectors, which is convenient when the unit must be taken out of line for access to the side panels. The pin outs are shown in the following figure:



Laser Enable

This key-switch is required to be in the enable position for the laser to turn on. Normally, the key is left in the enable position.

Remote Interlock

The remote interlock can be used to disable the laser diode output via an interlock control. When this input is shorted the laser diode output is ON. When the input is open the diode output is OFF. If not used, leave a shorting cap over this BNC. Once the interlock has been tripped, the laser will stay off until it is manually reset with the front panel switch.

Setpoint In

SETOINT IN is an analog input. When the SETPOINT ENABLE is LOW (0V) the SETPOINT IN voltage value sets the injection current instead of the front panel dial. Zero volts sets zero current and 6V sets the maximum value of 200 mA (500mA for 500mA version).

This input is rolled off at 1 kHz, which is a much higher frequency than the front panel dial, which rolls off at 8 Hz, with a second pole at 4 Hz. Therefore, noise can enter the circuit at this point and this input should be used with caution. It is primarily intended for sweeping the current in order to measure PI curves and threshold values of laser diodes. We do not recommend using this input for computer control of the injection current.

Setpoint Enable

SETPOINT ENABLE is a TTL input. 5V puts the front panel dial in control of the injection current and 0V gives control to SETPOINT IN.

When disconnected, the SETPOINT ENABLE is at 5V.

1.4. Turning on the Laser Diode

In compliance with FDA requirements for a Class 3B laser, the Laser Controller has two safety interlocks. If either interlock is tripped, the laser will turn off and stay off until the interlocks are reset AND the laser switch is switched from the “off / reset” position to the “on” position. Additionally, if the Laser Controller loses power, the laser diode will remain off when power is restored.

To turn on the laser diode, follow these instructions:

1) Flip the Laser switch into “off/reset” position
2) Insert the key into the keyhole and rotate the key 90 degrees (keyhole located on back panel)
3) Place grounding BNC terminator on “Remote Interlock” BNC (located on back panel)
4) Flip the Laser switch into the “on” position. The green light above the switch should turn on and after a 5 second delay, the laser will turn on.

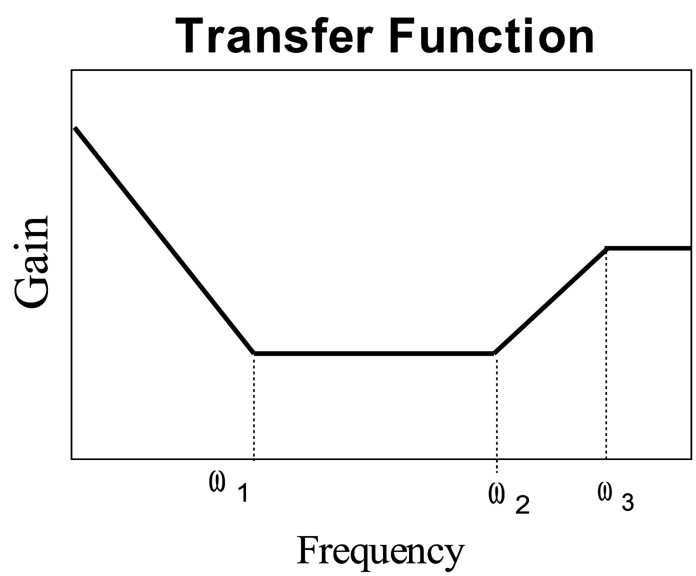
1.5. Tuning the Temperature Controller

If you purchased the Laser Controller with a Laser Module, then the Laser Controller is properly tuned for the Laser Module's thermal load and you can skip this section. This section will describe the basic theory about tuning the temperature servo response and provide step-by-step instructions for tuning the servo response to your thermal load.

To get good temperature stability, the temperature servo response needs to be tuned to match the thermal load. Access to tuning the temperature response is provided on the right side panel of the Laser Controller and requires removing that side panel to access the controls. The Laser Controller provides two independent temperature controllers that are nominally identical. However, stage 2 has front panel adjustment of the temperature set-point, while the stage 1 temperature set-point is a side-panel adjustment. Additionally, the front panel TEMP SERVO INPUT adjusts the stage 2 set-point while stage 1 does not have an equivalent function. Stage 2 is accessed in the middle of the side-panel, while stage 1 is near the back of the side panel. Typically, stage 2 is used to control the laser temperature and stage 1 is used to control the temperature surrounding stage 2. In this way temperature gradients between the laser diode and the thermistor measuring the laser temperature are stabilized and temperature changes caused by room temperature drift is greatly reduced.

1.5.1. Transfer Function and Poles

Each stage of temperature control has a transfer function shown below:



The three poles (ω_1, ω_2, ω_3) and the overall gain can be adjusted using trimpots and click-switches on the side panel. The first pole (ω_1,) is the Proportional-Integrator (PI) pole, or the frequency where the gain switches from being an integrator to proportional. The second pole (ω_2,) is the Differential (D) pole, or the frequency where the gain becomes differential. The final pole, (ω_3,) is where the differential gain ends and the gain becomes proportional again.

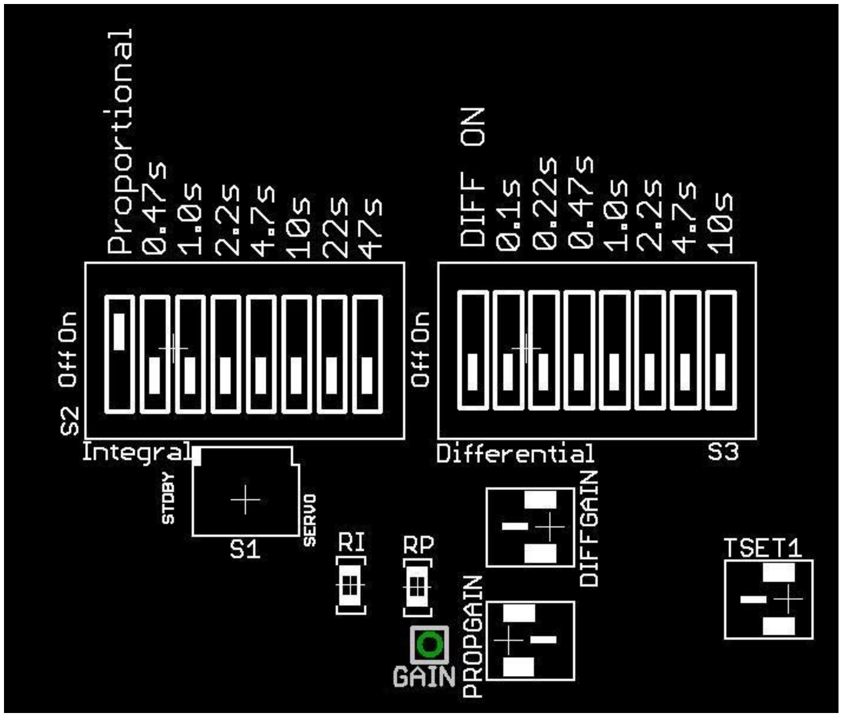


Figure 1: Side Panel Adjustments for Temperature Control.

1.5.2. User Control of the Poles and Gain

If you remove the right side panel on the Laser Controller, for each stage of temperature control, you will see the panel shown in Figure 1. The set of click switches labeled "Integral" control the PI (ω_1,) pole. Clicking the first switch, labeled "proportional", into the on position removes the integral gain. If the "proportional" switch is in the off position, then the sum of the times for all switches in the on position gives the RC time-constant for the PI pole. For example, if the 2nd (0.47s) switch and the 4th (2.2s) switch are in the on position (and the rest off), then the time constant is 2.7s and $\omega_1 = 1/2.7s = 0.37$ Hz.

Similarly, the switches labeled "Differential" control the D (ω_1,) pole. If the first switch, labeled "Diff On" is in the off position, then there is no differential pole. If the "Diff On" switch is on, then the D pole has an RC time-constant given by the sum of the times of all the switches in the on position, same as with the Integral bank of switches.

The "DiffGain" trimpot tunes the third pole (ω_1,) from $\omega_2/1.25$ to $\omega_2/25$. Turning up (CW) the trimpot moves the pole to a higher frequency, yielding more differential gain.

The "PROPGAIN" trimpot tunes the overall gain of the system and is adjustable by a factor of 200.

Additionally, the TSET1 trimpot is used to adjust the set-point temperature for stage 1 (stage 2 is controlled on the front panel).

The "STBY / SERVO" switch can disable temperature controller for either stage by placing the switch into STBY (standby) mode. In this mode, a red light will be shown on the front-panel to show that the stage has been disabled.

1.5.3. Tuning the Thermal Loop

Although there are numerous methods for tuning the loop parameters, these instructions will use the Ziegler-Nichols tuning method.

For nested stages (one stage is inside a housing whose temperature is controller by another stage), we recommend tuning the outside stage first with the inside stage turned off. Then tune the inside stage while the outside stage is turned on. For the stage directly controlling the laser temperature, we recommend running the tuning procedure while the laser is on. For each stage, follow the below steps to tune the plants according to the Ziegler-Nichols tuning method:

1) Connect thermal load to Laser Controller
2) Place Loop in proportional-only mode: Switch labeled “Proportional” is on, switch labeled “Diff On” is off
3) Turn the gain all the way down (trimpot labeled “PROPGAIN” all the way CCW)
4) Turn on temperature loop
5) Adjust set-point to approximately desired temperature
6) Turn up the gain. Keep increasing the gain until the temperature error (front panel BNC) just start to oscillate or ring with very little damping. If oscillation too large, reduce gain. Measure the period of oscillation.
7) Turn off Laser Controller. Measure resistance between “GAIN” testpoint and “GND” testpoint. 7. Turn down the “PROPGRAIN” until this resistance reads 1.7 time less than its original value (i.e. from 500Ω to 295Ω)
8) Take the measured oscillation period in step 6 and divide by two. Set the Integrator time constant to this value. If you measured a period of oscillation of 14 seconds, turn on the 4th (2.2s) and 5th (4.7s) switches in the integrator bank, to get a time constant of 6.9s.
9) Turn off the “proportional” switch.
10) Turn the “DiffGain” trimpot all the way CW.
11) Set the “Differential” switches to the same position as the “integral” one. This works out to setting a D time-constant roughly equal to 1/8 of the period of oscillation. For the previous example, set the 4th (0.47s) and 5th (1.0s) switches on to get a time constant of 1.5s
12) Turn on the “Diff On” switch
13) Your thermal loop is now tuned. Power and Laser Controller wait for temperature to stabilize. Change the setpoint and observe the temperature error and verify that the oscillations of damped and the temperature stabilizes. You may be able to get better performance by tweaking the poles and gain.

NOTE: Depending on the thermal design, nested temperature loops can fight each other, causing oscillations and instability. If you observe this, you will need to reduce the gain and/or increase the time-constants on the slower stage.