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Building a Light Current Voltage Characterization Setup for Pulsed Laser Diodes

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Building a Light Current Voltage Characterization Setup for Pulsed Laser Diodes

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Submitted in Partial Completion of the Requirements for Departmental Honors in Physics

Bridgewater State University

May 8, 2020

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Physics

Building a Light Current Voltage Characterization Setup for Pulsed Laser Diode

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Building a Light Current Voltage Characterization Setup for Pulsed Laser Diode

Alec Milord

Supervisor: Dr. Elif Demirbas

Abstract

III-V laser dies are the main integrated light sources used in photonic integrated chips (PIC). Before incorporating these lasers in PICs, it is important to measure their performance and efficiency. The efficiency of these devices can be calculated from their light-current-voltage (L-I-V) characteristics. In this thesis, I will assemble the components of the probe station for the pulsed LIV setup, which are the pulse generator to drive the laser with current, temperature controller device to vary the laser’s operating temperature, and optical spectrum analyzer in order to characterize the laser’s emission wavelength. Initially this thesis was meant to report how the Setup for Pulsed Laser Diode was build in the new Photonics Laboratory space. Unfortunately, because of the unprecedented circumstances we are facing currently, the nature of my thesis has shifted. Now the thesis focuses on explaining how the Pulsed Laser Diode Characterization Setup ought to be built, so that any student in the future has a proper model and set of instruction to do it.
1. INTRODUCTION

Light emitting sources based on materials from column III and V in periodic table are the main light source used in photonic integrated circuits (PICs). III-V semiconductor lasers have been extensively researched in near-IR, mid-IR and terahertz regions and their recent developments over the past few decades have enhanced the use of emerging technologies in several major application areas, such as optical communication, sensing, spectroscopy, and imaging [1-4]. Different types of semiconductor lasers and various materials can be used for these applications. The wavelength of the semiconductor lasers is normally determined by the band gap of the gain materials. However, laser spectra can be different depending on the laser type even within the same materials. Fabry-Perot lasers, Vertical Cavity Surface Emitting Lasers (VCSEL), Distributed Feedback (DFB) lasers are some of the mainly used lasers for applications [5-7].

![Figure 1. A section of the periodic table showing the materials from Column III and V used in semiconductor lasers [21].](image)
The band-gap energy of materials used in epitaxial growth plays a key role in determining the operating wavelength of lasers based on interband transition [10-11]. GaN is the most commonly used substrate in devices that emit light in the visible region due to its wide band gap [10-11]. The relatively shorter band-gap material GaAs is used in the near infrared region [12]. For longer wavelengths, InP is an ideal substrate that can be used [13]. On the other hand, devices using intersubband transition mechanism such as Quantum Cascade Lasers (QCLs) have more flexibility in choosing substrate in longer wavelength range [14].

**Figure 2.** III-V materials used in epitaxial growth for semiconductor lasers [20].

**Figure 3.** a) III-V QD laser die size comparison to coin, b) Laser die bonded on C-mount for electrical testing.
Semiconductor lasers can be divided into two parts in terms of their operating mode: continuous wave (CW) and pulsed mode. Continuous wave lasers emit a continuous, uninterrupted beam with a very stable output power. However, in pulsed lasers, light is emitted in fraction of time with more powerful output power compared to the CW mode. Pulse response of any active devices, such as laser diodes, are critical in characterization of the true behavior of the active devices at bar-level by eliminating the Joules heating effect. Eliminating the thermal degradation in the device is important to improve laser performance and its efficiency.

Figure 4. Output Power VS Time for Continuous Waves Signal and Pulsed Wave Signal.

In Photonics, laser sources are one of the most important devices that are used in free space and integrated photonics applications. Performing an Optoelectronic characterization of these lasers is indispensable before using them in any application. One of characterization setups will be the Light-Current-Voltage (LIV) characterization system for pulsed laser at die level.

In this Honors Thesis, I am going to describe how to build current-voltage (I-V) and light-current-voltage (L-I-V) measurement setup and characterize III-V pulsed laser dies operating at 1550 nm. In order to ensure proper operation of the setup, a few things must be
determined. Operating threshold current, the efficiency of the device can be calculated from the Light-Current-Voltage plot of III-V laser operating at pulsed mode. From the spectral characterization of the lasers, peak emission wavelength and the bandwidth of the laser can be determined. This will help judge our confidence in the desired L-I-V characterization curves for the pulsed laser operating at 1550nm. Finally, it is critical to setup all the devices and equipment adequately in order to ensure smooth and optimal operation of the setup.
2. THEORY

Light Amplification by Stimulated Emission of Radiation (Laser), is becoming increasingly crucial to the sustenance of technology. The light emission mechanism in a laser is governed by the stimulated emission in which an incoming photon causes an upper level electron to decay, emitting a photon whose frequency is identical to the one of the incoming photons. Amplification takes place within an optical cavity where the emitted photons bounce back and forth and continue to stimulate photon creation in a gain medium at each round trip between two facets. One of the facets of the cavity is coated with high-reflective material to keep the maximum light inside the cavity while the other end partially reflective material to allow the light to come out of the laser cavity. The gain medium with refractive index $n_2$ is sandwiched between materials with a smaller refractive index $n_1$ to realize the total internal reflection and contain the light within the medium.

Figure 5. The total internal reflection and optical feedback within the laser cavity.

Light amplification starts when the gain in the medium is greater than the loss. Threshold gain $g_{th}$ can be determined by the sum of the internal loss $\alpha_i$ and the mirror loss $\alpha_m$. 
\[ g_{th} = \alpha_i + \alpha_m \]  

where mirror loss can be calculated as:

\[ \alpha_m = \frac{1}{L} \ln \left( \frac{1}{\sqrt{R_1 R_2}} \right) \]

L in the above equation is the cavity length, and \( R_1 \) and \( R_2 \) are the reflectivity of two facets. Threshold current is necessary to start the lasing in the gain medium and depends on the cavity length as well as the reflectivity of the medium. For example, laser with longer cavity length requires lower threshold current for lasing mechanism to take place. Threshold current can be determined from Light-Current-Voltage measurement. In this characterization, current and voltage is applied to the laser diode, where it starts emitting light beyond threshold current. Low threshold current is desired to achieve more efficient laser diode. Efficiency of the device can be calculated by

\[ \eta_i = \frac{P_{out}}{P_{in}} = \frac{P_{out}}{I \cdot V} \]

where \( P_{out} \) is the output power of the laser and \( P_{in} \) is the input electrical power which depends on the voltage and the current supplied to the laser.

Cavity length (L) and the refractive index of the medium also determines the optical mode of the laser. Individual laser mode inside a cavity can be calculated by

\[ \nu_q = q \cdot \frac{c}{2n_{eff} L} \]
where \( q \) is the number of modes and, \( c \) is the speed of light in vacuum and \( n_{\text{eff}} \) is the effective refractive index of the gain medium. Individual laser mode’s frequency linewidth \( \Delta \nu \) and wavelength linewidth \( \Delta \lambda \) of the laser can be written as

\[
\Delta \nu = \nu_{q+1} - \nu_q = \frac{c}{2n_{\text{eff}}L}
\]

\[
\Delta \lambda = \frac{\lambda^2}{2n_{\text{eff}}L}
\]

When there is only one mode confined in the optical cavity, laser is called single mode laser. Light intensity versus wavelength plot can be obtained from L-I-V setup. Peak emission wavelength can be determined from this plot by fitting the data with Gaussian distribution

\[
y(x) = y_o + \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{1}{2} \left( \frac{x-\mu}{\sigma} \right)^2}
\]

where \( \mu \) is mean which corresponds to peak emission wavelength, and \( \sigma \) is standard deviation which determines the bandwidth of the laser.

![Gaussian Distribution](image)

**Figure 6. Peak Emission Wavelength and Bandwidth.**
Building an L-I-V measurement set up for pulsed laser diode is essential to determine threshold current, efficiency, emission wavelength and bandwidth in order to characterize and evaluate the pulsed laser performance.
3. EXPERIMENTAL METHODS

As I am going to describe how to build a probe station, most of the methods will consist of setting up all the different needed devices properly and provide the communication between the devices successfully. Characterization setup is going to consist of three main parts: 1) electrical pump, 2) Temperature control, and 3) Optical Detection.

*Figure 7 illustrates the schematics of the final look of the setup:*

![Diagram of characterization setup](image)

*Figure 7. Light-Current-Voltage Characterization Set Up for pulsed diode laser.*

After building up two probe stages, the Keithley 2636B pulse generator controlled can be used to drive laser die with 10% duty cycle with 1 µs pulse width to electrically pump the laser die. Temperature control of the laser die will be provided by Temperature Controller (TEC), The
TEC's operation will be managed with the TEC power supply and the TEC Controller that will be connected to a computer using the RS-485 Converter. With the help of TEC software on the computer, it is possible to change the temperature from room temperature to 100°C. After electrically pumping the laser, use a power meter or lock-in amplifier to detect the laser emission optically. From the information gathered by the devices, a plot of Output Light vs Current and Output Light vs Voltage. Using the plots will help determine the threshold current and threshold voltage as well as to calculate the device efficiency. Additionally, by using Optical Spectrum Analyzer (OSA) (*Figure 42*), it is also possible to plot output power vs wavelength to determine the bandwidth of laser die operating at central wavelength of 1550 nm.

**List of Equipment:**

1) Pulse Generator, 2) TEC Device, 3) TEC Controller, 4) TEC Power Supply, 5) RS-485 Converter (Adapter Between Controller and Computer), 6) Computer for Controller, 7) 2 probe stages, 8) 2 magnetic precision positioners, 9) 1 copper sample holder, 10) 1 standing microscope, 11) Power meter, 12) Optical Spectrum Analyzer, 13) Lock-in Amplifiers

### 3.1 Electrical Pump

A critical part of putting together the L-I-V setup is the installation of its electrical component. The electrical component of the L-I-V setup will make it possible to plot the desired L-I-V characterization curves for pulsed laser operating at 1550nm. This plot is necessary to ensure that our system indeed follows the characteristics of an L-I-V pulsed laser die. Once the plot is obtained, the efficiency can then be calculated from the Light-Current-Voltage plot of III-
V laser. The laser will be operating at the pulsed mode and that efficiency calculation will be helpful to check on how well the system was built. The pulsed generator will drive current to the laser die.

The electrical pump setup is comprised of 2 probes, two probe mounts, two probe tips, and most importantly a pulse generator as a source for current. The pulse generator is essential to the setup for driving current to the laser die that will be mounted. More specifications are given throughout the following pages.

### 3.1.1 Pulse Generator Source: Keithley 2636B

*Figure 8* is that of the SourceMeter that is going to be used in the Electrical Pump Setup. It possesses medium-power source-measure units (SMUs) and simplifies test processes by combining source and measure capabilities in a single instrument. 2600B SourceMeter is scalable, and comes with precision Direct Current, pulse and low frequency AC source-measure testing.

![Figure 8. Keithley Series 2600B System Source Meter Apparatus [18].](image-url)
As you can notice in Figure 8, the numbers refer to different items. Those numbered items are:

1) Interlock DB-25 male connector Kit Hardware
2) One RJ-45 LAN crossover cable for the 2636B. Two RJ-45 LAN crossover cables
3) The Power Line Cord
4) On Triaxial to alligator clip cable for the. As well as two triaxial to alligator clip cables for the 2636B
5) 15 AWG black grounding wire
6) Three-pin screw terminal connector

After all the pieces of equipment are gathered, everything can now be connected.

**Step 1: Connect Line Power**

- First, the front-panel power switch must be in the off position
- Then the socket from the supplied power cord will can be connected to the power connection on the rear panel.
- Finally, the plug of the power cord can be connected to a grounded AC outlet

![Connect power line cord](image)

*Figure 9. Small display of the connect power line cord position [18].*
Step 2: Turning on the Instrument

There is a Turn on POWER switch on the front panel of the instrument to the ON position. *Figure 10* shows an image of the Power Switch ON button.

![Power switch ON position](image)

*Figure 10. POWER ON SWITCH BUTTON illustration [18].*

Step 3: Power-up Sequence

As the power up sequence is progressing there are a few things that can be seen on the screen:

- A series of dots
- All segments of the display light
- A brief display showing the instrument model. For example, if the instrument is a 2636B, the display shows “KEITHLEY Model 2636B.”
- Line Frequency detection and other startup checks.

The power up process will take about 30 seconds to complete. Once the initialization is finished the instrument’s default screen will appear as displayed below:
Now that the instrument is connected, the next step is to test it. Figure 11 shows the 26436B SourceMeter from the front as to see all the input essential to testing the instrument.

![DEFAULT SCREEN display](image)

**Figure 11. DEFAULT SCREEN display [18].**

The first test run will verify the basic operation of the 2636B. The front panel controls will be used to source voltage and measure the voltage output.

![Full front-panel Display of 2636B Keithley Series SourceMeter](image)

**Figure 12. Full front-panel Display of 2636B Keithley Series SourceMeter [18].**

Step 1: Set source function, range, and level

- Press the SRC key. There will then be a blinking character in the SrcA value field and mV will be displayed. If mV is not displayed, the key SRC must be pressed once more.
• While the character will still be blinking, the range keys up or down button should be pressed until 20V is showing on the screen and afterward, the main display screen should reappear as the set of images below illustrates.

![The main display screen reappears:]

Figure 13. Illustration of the two consecutive display Screens while Testing the Instrument [18].

• Next, the CURSOR keys need to be pressed in order to move the cursor to the 10s digit.

• Then the navigation wheel key as to enter the EDIT mode. The EDIT indicator will appear in the upper left corner of the display.

• Now the navigation wheel must be turned to set the source value to 20000V and then pressed once again in order to validate the selection and exit the EDIT mode.

The screen should show the new Source value set to 20000V as displayed in Figure 14:

![Source value set to 20.0000 V]

Figure 14. New Source value Set Display Screen [18].
Step 2: Setting the Source Limit

- First, the LIMIT key will be pressed. Then a blinking character will appear in the LimA value field.
- While the character blinks, the RANGE keys should be pressed as needed to select the 10Ma limit range. Afterwards, it is important to verify that the source limit value in the LimA field is 100000 mA as shown in Figure 14.

Step 3: Setting Measurement Function and Range

- The MEAS key needs to be pressed as many times as needed to select the voltage measurement function.
- Press the AUTO key as many times as necessary to select the AUTO range function. The series 2636B will automatically select the best range for the measure value. The screen will briefly display shown below before the main display screen reappears:

  ![AUTO Range brief display Screen](image)

  Figure 15. AUTO Range brief display Screen [18].

Step 4: Turning the Output on and Observing Measurements

The output can be turned on by pression the OUTPUT ON/OFF control. The ON/OFF indicator LED lights and measurements turn on. It is important to look at the voltage on the main
area of font-panel display. The readings will be very close to the 20V source value as they should be.

Finally, when the measurements are done, the output can be turned off by pressing the same cursor used earlier to turn it on. Then the output LED indicators will turn off.

**Other Specifications for the 2636B SourceMeter**

There are a few other specs for the 2636B SourceMeter that are worth mentioning. It possesses a current programming range from 1nA to 10A with the typical noise peak in the range of .1Hz and 10Hz. The 2636B has a maximum pulse width of 8.5ms for a minimum of 1ms. The maximum Duty Cycle stands at 100% for a 1% minimum Duty cycle at the second and third regions. *Figure 15*, the Duty cycle of the pulse level at time on and an arbitrary off time is illustrated as well:

![Figure 16. Time on Time-off Pulse Duty Cycle [18].](image-url)
Figure 17 displays the DC and the pulse in the different region in a plot with Current vs Voltage parameters.

Additionally, the 2636B SourceMeter possesses a Maximum Load Impedance in Normal mode of a typical 10nF, and in High Capacitance Mode a typical 50 μF.

3.1.2 Probe, Probe mount, Probe tips

This is a small section that will describes the specs for the Probes, Probe Mounts, and Probe Tips. The probes will be used in the setup as a path for the current from the Pulsed Generator. They will be used to deliver the electrical pulses to the laser diode.
Probe:

As mentioned above, there are two probes, one for positive contact, the other for the negative contact.

In *Figure 18.* is shown an image of a *DPP205 Probe*. It has for specifications the following:

- **Feature Resolution:** 3um (DPP205)
- **Travel Range (X, Y, Z):** 12.5mm / 12.5mm / 12.5mm
- **Screw Resolution* (X, Y, Z):** 500um / 500um / 500um
- **Mounting:** Vacuum, Magnetic
- **Footprint (W x D):** 90mm x 60mm
- **Station Compatibility:** Tesla, Elite 300, PA 300 MicroAlign, Summit
- **Application:** IV/CV probing and Failure analysis

For the *DPP205-S* the specifications are listed below:

- **Feature Resolution:** 3um
• *Travel Range (X/Y/Z):* 12.5mm/12.5mm/12.5mm

• *Screw Resolution X/Y/Z):* 500um/500um/500um

• *Mounting:* Vacuum, Magnetic

• *Footprint (W x D):* 90mm x 60mm

• *Station Compatibility:* PM5, PM8, PM300, PA200, PA300, BlueRay

• *Application:* IV/IC probing and Failure Analysis

**Probe Mount:**

![Figure 20. Image of a 151-287-DCP Probe Mount [17].](image)

**Features**

• Probe mount for DCP Probes

• Used on Elite 300

• Constructed with High-stability thermal materials

**Specifications:**
• Precision Industry Standard SSMC connectors
• 50-ohm characteristic impedance
• Breakdown voltage of more than 500 volts
• Maximum current is 1 Amp

**Kit Contents:**

• Probe to positioner mount
• Dual Triaxial adapter (Kelvin), mini triax (jack) to SSMC (m)
• EMI shielding cap
• EMI grounding Strap

**Compatibility:**

• Compatible with DPP2xx positioners
• Compatible with MicroChamber TopHat
• Compatible with Elite 300/AP and Elite 300/M
Probe tips:

Figure 21 displays a DCP-105R-DC Coaxial Probe. The prior figures that were described were that of the mounts onto which the coaxial probes will be mounted. This probe comes single lined with a replaceable tip and a .5µm radius. Some more Features and Specs are determined below:

Features:

- High-Quality Construction with low noise electrical performance.
- Great for modeling and characterization work.
- Dual precision SSMC 50-ohm connections that allow for Kelvin configurations to the probe body.
- Individual connectors for force sense connections.
- Configurable for Triax usage
**Specs:**

- Breakdown Voltage happens above 500V
- The Characteristic Impedance is 50 ohms
- The tip material is gold plated
- Connector type is SSMC

This DC coaxial probe is compatible with MicroAlign, Elite 300, Summit, S300, M150 and Alessi.

**Figure 22. An example of probe tips providing electrical pump to positive and negative contact of III-V laser chip.**

*Figure 22* shows probe station, which provides pulse drive to the negative and positive contact of the III-V laser chip by using probe tips that can be manually controlled. After the completion of electrical pump instruments, the next section will describe how to control the temperature of the laser chip.
3.2 Temperature Control

The temperature control setup is needed to manage the temperature of the laser die. Once the laser die is set up and running it will generate heat. It may end up generating a lot of undesired heat that might affect the proper operation of the system. Therefore, the acquisition and operation of a Thermoelectric Cooler (TEC) and a Temperature Control Device will be needed. The TEC can be operated through by the Temperature Control Device in order to cool down the laser see, or even heat it up when needed as well. This section will explain more clearly the details of how exactly these two devices operate together.

3.2.1 Thermo-Electric-Cooler: CP-200HT-TT

*Figure 23* that of the CP-200HT-TT Thermo-Electric-Cooler (tabletop version of CP-200HT). Its power Rating is 198 Watts when operating at a 0°C temperature difference. It encloses a fan and allows air into the heat sink, which is particularly useful when placed on a flat surface as shown in *Figure 23* [19-22].

*Figure 23.* The CP-200HT-TT Thermo-Electric-Cooler which will help increase the temperature of our laser die [22].
Use the High-Temperature (HT) version to allow us to increase the temperature of the laser die up to a maximum of 100°C. The CP-200HT-TT can also be used for both heating and cooling if it is used with a heat & cool / bipolar controller. Bipolar controllers are essentially devices that allow the user to operate the Thermo-Electric-Cooler as a heater as well. The device is equipped with threaded holes in the cold plate which makes it convenient to attach objects to be cooled down or heated up [18-22]. Use these threaded holes to attach our copper sample holder. There are also threaded holes on the side of the cold plates for attachment of a temperature sensor.

3.2.2 PS-24-25 Power Supply

The PS-24-25 shown in Figure 24 is the power supply to the Thermo-Electric Cooler device. It features a 24 V DC power supply, a Standard North American Power Cord. It possesses an input voltage ranging from 88 to 264 V AC and runs at a frequency between 47 and 63 Hz. The output Voltage is 24V DC and the Maximum Output Current is 25 Amps. When operating, the selection of the desired voltage can be achieved automatically, and it can be adjusted by setting the power level by using the software.

Figure 24. DC Power Supply to drive Thermo-Electric-Cooler [22].
This power supply possesses an output that enables connections on the terminal strip (R.C.G. & R.C.). When the included jumper is in place, the output read “on”; when excluded, it will read “off”. This signal is a low-current and low-current signal that will be used as a disabler in case the jumper is replaced with a switch or a thermostat. The thermostat is used as a safety switch for under-temperature and/or over-temperature; however, it can never be used as a means for actual temperature control.

This Power Supply is RoHS compliant. RoHS stands for Restriction of Hazardous Substances. For a product to be RoHS compliant signifies that this particular device follows the strict restrictions put on the use of specific hazardous materials found in electrical and electronic products. PS-24-25 possesses an input Voltage ranging from 88-264 V AC operating between 47 and 63 Hz. The Input voltage remains continuous within range. The Output Voltage is 24 V in Direct Current. It is possible to adjust the output voltage at +/-10% by using an adjustable potentiometer (a device that can measure and adjust voltage in a circuit or setup). The listed Maximum Output Current sits at 25 Amps. This power supply also comes with an Over-Current Protection for rated output power in the range of 105% to 135%. This device is cooled down by a fan whose speed is regulated via internal Temperature Sensors. The PS-24-25 Power Supply will function normally in ambient Temperatures no higher than 60 degrees Celsius. It is required for ambient Temperatures of above 45 degrees Celsius that we run the device at an output Current smaller by 2.7% per degree Celsius, and that for operation below 115 VAC, run the device at an output Current smaller by .74% per volt.
3.2.3 Model TC-36-25 Thermoelectric Cooler Temperature Controller

The Model TC-36-25 Thermoelectric Cooler Temperature Controller is the device that is used to manage the operation of the CP-200HT-TT Thermo-Electric Cooler driven by the PS-24-25 Power Supply. Connect the Controller to a computer by using an RS232 cable converter and the adequate previously downloaded and installed software on that computer (Link to software in [23]). The software in conjunction with the TC-36-25 Temperature Controller will grant program control as well as data graphing and data logging abilities.

![Figure 25](image)

*Figure 25. a) TC-36-25 b) TC-36-25 (sideview) c) TC-36-25 (rearview) d) Complimentary Cables e) Sensor Heads [22].*
The temperature Controller also provides bi-directional temperature control for thermoelectric devices and Resistive heaters. It can operate as a stand-alone controller or with a computer monitor. The high efficiency of the build and the internal fan system reduces the heat generated by the controller.

This device enables single or dual power supply configurations and allows for a wide range of output voltages. The single power supply configurations are listed as such: ≥12 VDC, <36 VDC input, powering both controller and TE device; and the Dual power supply configurations: ≥12 VDC, <36 VDC at 150 mA minimum for controller circuitry, ≥0 VDC, <36 VDC for TE device.

The maximum Output Current topped at 25 Amps as combined with the TE device and alarm current. It is important to note that the controller does not have current limiting capabilities. The cooling modes and heating modes of operation were selected via the software installed on the computer.

The temperature Control ranges from -20 degrees Celsius to 100 degrees Celsius via the supplied MP-3193 thermistor. This device also features an optional secondary thermistor input for sensing alarm conditions as well as two available alarm outputs capable of sinking up to 1A each used to trigger alarms based on the primary sensor and/or secondary sensor.

**Specific Parameters:**

It possesses a few specific parameters to define:

**Proportional (P) Bandwidth**

A Proportional Bandwidth is the amount of change needed in the input to generate variations in the control output, from 0% to 100%. It adjusts from .5 C to 100ºC.
**Integral gain (I)**

An Integral Gain is responsible for controlling how much of the Control output is generated. It can adjust from 0 to 10 repeats per minute.

**The derivative gain**

The derivative gain describes the amplitude of the derivative term, contributed to the overall control output. It adjusts from 0 to 10 cycles per minute with an output square wave of 337 Hz frequency, pulse-width modulated, with soft start.

With the TC-36-25 we have an Analog proportional output signal that controls the programmable linear power supply mentioned earlier.

It is possible to operate the TC-36-25 as a true linear-output control system by using the device as a control head for controlling high-power linear-output supplies such as basic switching power supplies. Operating the device in this way would generate a cheaper linear control system with much less waste heat than a regular linear system. The setup eliminates the Pulsed Width Modulated switching and is useful for applications that are very sensitive to electronic noise.

The operating Temperature of the Temperature Controller ranges respectively from 0 C to 48 C in horizontal orientation with 20 A output; 55 C vertical orientation with 20 A output; 53 C horizontal orientation with 17 A output; and finally, 59 C vertical orientation with 17 A output.
The TE device requires a specific average output voltage in order to maintain varied set temperatures. This average output voltage can be obtained through Pulse-Width Modulation (PMW). With PWM, the power can be switched “ON” and “OFF” at the constant frequency of 2700Hz. This generates a square wave “pulse “ whose width can be varied to create the desired output voltage (Figure 26).

The important advantage of PWM lies in the fact that it doesn’t generate a lot of waste heat, nor does it require a large heat sink. Additionally, it doesn’t cause extreme temperature excursions and consequently significantly extends the life and reliability of the TE devices.
3.2.4 Setup Instructions for TC-36-25

**Initial Setup**

The most important part of building the Light Current Voltage Characterization Setup for Pulsed Laser Diode is the initial setup of its multiple different devices. In this section I will go into details in how to set up the Temperature Controller. Use the controller wiring diagram to locate the pins in which connection will be made. One power supply will be provided; thus, use the controller wiring diagram in *Figure 27* designed for single power supply connections:

![Controller Wiring Diagram](image)

*Figure 27. RS-485 INPUT and CONNECTIONS Schematics [22].*

**Step 1:**

I have mentioned earlier that the TC can operate even without the use of a computer. However, in order to initially set up all the various operating parameters, a computer along with a RS485 port or converter is required. When setting it up, first make sure that the computer is off and the controller still un-powered [22-23]. Then use the RS-485 Communications Port from the controller and connect it to the RS-485 port adaptor on the computer.
Step 2:

Next, attach the thermistor to the temperature controller location. Attaching the thermistor to the cold side of the TE will provide better control stability. However, stay aware of the temperature difference between the TE device and what is being heated up/cooled down.

Figure 29. Standard Thermistor MP-3193 attached to cold plate of cooler [22].

Afterwards, connect the thermistor wires to the proper pins. Use one power supply for both the TE and TC devices. First make sure that the power supply was not energized while making
electrical connection to the controller. The substeps to installing the power supply are listed below:

a) Install the jumper across JP6-1 and JP6-2

b) Then connect the Constant DC Voltage Power Supply to the controller.

**Step 3:**

After properly connecting the power supply, proceed to download the software through the supplied CD and then locate and run “setup.exe” on the CD in order to install the controller software. Directions should pop up on the screen so they can be followed. What those on-screen given directions look like are illustrated by *Figure 30*:

![Initial Startup Screen Instructions](image)

**Figure 30. Initial Startup Screen Instructions [23].**

After installation, run the program from the START - ALL PROGRAMS - TC-36-25 RS485 location. Then proceed to setup the controller on the computer. When the software runs for the first time, it will prompt to select the communications port to which the controller was connected.
Step 4:

The next step is to add the controller to an existing network and apply power. Prior to doing that, place a jumper between JP2-1 and JP2-4. Power can then be applied to the new controller after which, enter “99” (without the quotations) in the SEARCH ADDRESS BAR. Click on the CONTROLLER SEARCH button to find the new controller. The screen on the computer will then show an interface that will inform you of the address that the controller is currently using as illustrated in Figure 32:

Figure 31. Initial Startup Screen Instructions [22].

Figure 32. Initial Startup Screen with Address Instructions [22].
When it becomes necessary to switch to a new Controller, click on the blue READ CONFIGURATION button located at the lower right corner of the software:

![READ CONFIGURATION button](image)

**Figure 33. Read Configurations Parameters Screen [22].**

**Step 5:**

This step is about the initial setup of the CONTROL TEMPERATURE on the software.

Click on the SELECT button in the CONTROL TEMPERATURE section to find the CONTROL TEMPERATURE options.

![CONTROL TEMPERATURE options](image)

**Figure 34. CONTROL TEMPERATURE Section Screen [22].**

Use the computer to set the CONTROL TEMPERATURE. Using the computer will allow fixing a percentage of output power. Next, enter in the SET TEMPERATURE box range from -5.11 to +5.11. These values are adjustable in .01 unit increment.
There are numerous other ways however to set the CONTROL TEMPERATURE as listed below:

a) **Through the Potentiometer on input 2:**
   a. By installing a 5K ohm potentiometer on JP2 at pins 1,2 and 3, the EXTERNAL SET RANGE temperatures were mapped out on the potentiometer.

b) **Varying the Voltage:**
   b. The set temperature can be changed by varying the voltage (up to 5Vdc) applied across JP2 at pin 2 and JP1 at pin 1.

b) **Varying Current:**
   b. Set temperature can be controlled using a 20mA current source with a 249 ohm resistor across pins JP2-1 and JP2-2.

Set the temperature values in degrees Celsius within the range of the selected input sensors and the high and low limits from the configuration setup from the controller. Then give separate offsets to the temperature sensors on input 1 and input 2. Doing that allows the correction of errors in the sensed temperature and the real temperature when needed.

From there define the maximum and minimum allowable set temperature values by using the HIGH EXTERNAL SET RANGE and LOW EXTERNAL SET RANGE. It becomes useful in where an external input would have to be used to set the control temperature.

The controller accepts different types of Thermistors. Select the desired sensor type that have the same temperature resistance curve as the thermistor used with the controller. The screen displaying these options is shown in **Figure 35:**
The option selected is the TS-67, TS132 15k since it is using the supplied M-3193 sensor. It provides me a control range of -20 °C to +100 °C.

Next enable the **Electrically Erasable Programmable Read-Only Memory (EEPROM)** option. EEPROM is a type of non-volatile memory to which the controller can transfer the last values recorded when it last turned on. Enable EEPROM so that the controller can run faster. Doing this also made it possible for the controller to run as a stand-alone controller, with no need from the computer. We used the computer, but it is a good idea to have that option in case any trouble running it through the computer arose.

While this option is enabled, all changes to software settings are stored in EEPROM as well as RAM. However, when it is turned off all changes to software settings are stored in RAM only. *Figure 36* display the screen to enable EEPROM:
Step 6:

The next objective is to set the control mode. The control mode is meant to determine how the controller will obtain a set stability point. There are three ways we can go about it:

a) PID CONTROL: This mode compares the actual temperature to the set temperature and adjusts the output power accordingly as a function of the primary temperature sensor feedback and PID PARAMETERS.

b) COMPUTER CONTROL: With computer control you can select a constant, fixed-duty-cycle output.

c) DEADBAND CONTROL: With this control mode, the controller behaves like a mechanical thermostat. Do not use this mode unless specifically to avoid the TE device from being damaged by excessive back and forth between cooling and heating.

*Figure 37. CONTROLLER OPTIONS display screen [22].*

*Figure 38 illustrates the CONTROL MODE screen display:*
Step 7:

After setting up the control display, set up the alarm status and controls. The alarm setup screen is shown in Figure 39:

Figure 38. CONTROL MODE display screen [22].

Figure 39. ALARMS CONTROL display screen [22].
First, the alarm status must be set up. Alarms in the controller whose address are in the address book will appear in the alarm status box. The alarm indicator always blinks when there is an active alarm. There are several alarm conditions to be aware of:

- **HIGH ALARM:** Which occurs when the Temperature is greater than the HIGH ALARM setting
- **LOW ALARM:** Which occurs when the temperature is lower than LOW ALARM setting
- **COMPUTER CONTROLLED ALARM:** Which occurs when the user activates the alarm via software.
- **OVER CURRENT DETECTED:** Which occurs when the TE devices attempts to draw more current than allowed by the set Over Current.
- **OPEN INPUT1:** Occurs when there is an issue with the primary sensor
- **OPEN INPUT2:** Occurs when there is an issue with the secondary temperature sensor
- **DRIVER LOW INPUT VOLTAGE:** Occurs if the controller doesn’t have enough voltage to operate

Next is the configuration of the ALARM MODE Settings. It essentially dictates what type of Alarms will be set.

- **FIXED VALUE ALARMS:** Allows for a fixed temperature for either above or below the sensor temperature.
- **COMPUTER CONTROLLED:** Allows the user to activate the alarm relay through the computer software. It can be turned on and on with the ALARM LATCH ENABLE button.
- **SET TRACKING ALARM:** Enables setting an alarm with respect to the set temperature.
- **NO ALARMS:** This mode means that no alarms will be monitored.
Which sensor will be used for which alarms must also be configured. There will be only two options in this particular case:

CONTROL SENSOR: Allows the primary sensor to be used for monitoring alarm conditions.

INPUT 2 SENSOR: Allows for a secondary sensor to be used for monitoring alarms conditions provided that there is a secondary Thermistor installed.

The most immediate task after setting up the ALARM MODE, is to set up the OUTPUT SHUTDOWN WITH ALARM. It can either be turned on or turned off. When turned on the controller keeps on supplying power to the TE device regardless of any alarm condition. When it is turned on, the controller will shut off power output to the TE device if there is an existing alarm condition.

**Step 8:**

Once finished with the ALARM MODE setup, OUTPUT setup is the next parameter that needs to be configured. *Figure 40* showcases the OUTPUT options screen.

![Figure 40. OUTPUT OPTIONS Display Screen [22]](image-url)
First, notice the on and off options. It can be easily deduced that when you press OFF the TE Device will shut off, and when you press ON the TE device will turn on and the controller will begin to operate to the set point temperature. Note that before initial Setup the output must be turned OFF.

Another option displayed on the screen is OUTPUT POLARITY HEAT. This option configures the polarity for the heating mode of the thermoelectric cooler. It allows us to reverse the current flow in the TE device without changing any wiring.

There is also the HEAT SIDE MULTIPLIER. The HEAT SIDE MULTIPLIER is a numerical multiplier that compensates for the asymmetrical responses between the heat and cool modes of the Thermoelectric Cooler. It goes from 0.00 to 1.00. In cooling mode, the computed PID output power value is multiplied by the COLD SIDE MULTIPLIER to derive the actual output level. Therefore, setting the value to 0 makes the controller a “heat only” controller.

The OVER CURRENT SET option selects the level at which the TE’s over-current protection turns off the output power. It is adjustable in 2.5A increments and allows level ranges from 0 to 40A. The controller will attempt to restarts the output, if it restarts a large amount of time, then the output will be disabled until a “LATCH CLEAR” signal is sent, or until the controller is manually reset (turned off and on again).

Note that that the value of the over-current is only an approximation. The real current value at which the controller will shut off will differ by 3A or more from the selected over-current level.

As mentioned earlier, the controller will attempt to restart the output, it will do so depending on the conditions set in the OVER-CURRENT RESTART ATTEMPTS/CONTINOUS boxes
displayed in *Figure 41*:

![Color of controller plot](image.png)

**Figure 41. DISPLAY SECTION screen [22].**

In this display section we can find the graphical display of samples taken of the controller in the SCAN LIST. The SCAN LIST contains the addresses of controllers to be sampled. It can be created when you enter up to eight addresses separating them with a comma. Once that is done, the PLOT LEGEND can be installed from the SCAN LIST and depicts each controller sampled with a different color. More graph options can be obtained by right clicking on the graph.

**Step 9: THE FINAL SETUP**

The final setup portion of the temperature controller is CONTROLLER TUNING. This method follows the Ziegler-Nichols closed-loop tuning principles. The Ziegler-Nichols closed-loop tuning method also known as the Ultimate Cycling Method, was designed for a $\frac{1}{4}$ amplitude decay response. That response will be oscillatory, the resulting loop will overshoot its set point after any disturbances or set point changes.
In order to perform the Ziegler-Nichols closed-loop tuning method, we must first be set to a high proportional bandwidth setting with an integral and derivative gain of 0. The bandwidth will slowly decrease, until the temperature reaches a set point at which there are small but sustained temperature oscillations that can be observed. There are other tuning parameters, they will be adjusted depending on the time period of the temperature oscillation and its generated proportional bandwidth.

Note that the improper tuning of the temperature controller will lead to excessive thermal cycling and overheating of the thermoelectric device.

When proceeding, only the TE device will be connected to the controller (the fans will cannot be connected to the controller). The positive TE device terminal will connected to WP2 and the Negative TE device terminal will be connected to WP1. *Figure 42* illustrates these connections:

![Temperature Controller Connection Diagram](image)

*Figure 42. TEMPERATURE CONTROLLER CONNECTION illustration [22].*

The TE’s standard thermoelectric cooling assembly (TAC) has one fan on the heat sink. These fans and modules are connected in parallel and are wired to a terminal block with jumpers.
across the terminals. When using the TCA with the temperature controller, the jumpers must be removed to allow the controller to control power to the thermoelectric modules. The fans and modules cannot be connected to each other, the fans must be connected directly to the power supply, not the controller.

There will be a drop in voltage of approximately 0.5 to 1.3V, from the power supply to the TE Device. Thus, there might be a need to adjust the power supply accordingly to make sure that full power is provided to the TE device if needed. Our next step is to turn on the output power and the controller will begin to send output power to the TE device.

After turning on the output power, a set of parameters must be entered:

- PROPORTIONAL BANDWIDTH: 20
- INTEGRAL GAIN: 0
- DERIVATIVE GAIN: 0

Over time, the TE device will reach steady state. When that happens, the bandwidth setting must be reduced incrementally in order to allow the controller to reach steady state at each increment until the temperature barely begins to oscillate. At this point, note the bandwidth setting that caused the system to oscillate and note the time period of oscillation in minutes. This information is used later in order to figure out the integral gain and the derivative gain settings.

Next is to multiply the current proportional Bandwidth setting by 2.2, and to enter it as a new PROPORTIONAL BANDWIDTH setting. The temperature will then stabilize and maintain a steady temperature near the set point.

Now calculation of the integral gain is given by \( I = 0.54/T \) with \( I \) as the integral gain and \( T \) as the time period in minutes. That value can be entered into the INTEGRAL GAIN. Next is the setup of the derivative gain. Usually the derivative gain can be left set to 0, especially since it
usually is more trouble and more difficult to apply than it is worth. However, if it ever needs to be set up, all other values will be adjusted first:

a) Multiplying the initial Bandwidth setting by 1.7 and entering that value as the new PROPORTIONAL BANDWIDTH setting.

b) The calculation of the integral gain will be different: \( I = \frac{1.2}{T} \). The value goes into the INTEGRAL GAIN setting.

c) Finally, calculate the derivative gain as follows: \( D = 0.075 \times T \), and enter that value into the DERIVATIVE GAIN setting.

The setup of the TC-36-25 RS485 is now complete.

### 3.3 Optical Detection

#### 3.3.1 Optical Spectrum Analyzer

For the Optical Detection Section, an Optical Spectrum Analyzer (OSA) will be used in our Setup. OSA can be used to measure input magnitude of any signal versus the frequency and can also be used to determine the spectrum of a variety of electromagnetic signals. We need the OSA to find the emission wavelength of the laser diode. From there we can explore the I-V curve and begin to deduce the proper diode characteristics.

*Figure 43* provides an example of what a I-V curve characteristic would look like, for HR 5-mm x 8.7\(\mu\)m laser measured at 293K:
Additionally, determining where the laser’s optical spectrum is peaking will make it possible to plot a light versus wavelength graph. From the created plot, the Full Width at Half Maximum can be calculated and the bandwidth within 2 sigma can also be found. For the Optical Detection Setup, obviously the devices need to be acquired first. An AQ6370D Telecom OSA with wavelength range from 600nm to 1700nm will be used.

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**Figure 43. Illustration of a Voltage VS Current Characteristic I-V Curve [14].**

![Graph showing Voltage vs Current Characteristic (I-V) curve with pulsed and CW labels.](image1.png)

**Figure 44. AQ6370D Telecom Optical Analyzer Frontal View [15].**

![AQ6370D Telecom Optical Analyzer](image2.png)
After obtaining the OSA equipment we must install it, then connect it to the setup. The OSA must be installed on a well ventilated and flat horizontal surface with no vibrations. It is recommended that there is approximately 20 cm or more of space around the device to allow for maximum flexibility of motion when connecting and operating it. The instrument must remain in ambient temperatures between 5 to 35ºC and cannot be moved from a hot location or vice versa, in order to prevent condensation.

The next step is to connect the OSA to the L-I-V setup. It will be connected to the already installed computer, which in turn is connected to the 2636B SourceMeter (Pulse Generator). The schematic shown below illustrates the overall setup that will be obtained once all the equipment is properly installed and connected.

Before connecting anything, it is important to make sure that the power is turned off first. AQ6370D OSA comes delivered with a connector adapter. Therefore, we can proceed right away to connecting the device to the computer.

First the mouse can be connected by suing a USB cable and attaching the Port to one of the USB interfaces on the front or rear panel of the instrument. As always, Power must be OFF.
Similarly, we can connect a keyboard through a USB as well, but once the device is connected to the computer, the keyboard on that computer can be used as well.

To turn on the AQ637D, first the three-prong outlet power cord provided must be attached to an outlet and then connected to the OSA. Make sure the Main Power in the rear panel is turned off before making the connection:

![Initial Power Off and Connection](image)

**Figure 46.** a) *Initially Turning the Main Power OFF*  b) *Connecting OSA to Power Supply* [15].

Finally pressing the power switch button on the front panel of the Optical Analyzer will fully turn it on. Once powered on, a few adjustments need to be made before making any measurements such as Wavelength Calibration and Alignment Adjustment.

When turning the power OFF the most important thing to remember is to NOT cut the power to the instrument through the MAIN POWER switch on the rear panel, especially when an operation is in progress. Doing so will corrupt the system configuration file which will result in malfunctions the next time the instrument is shut down.

To properly turn the OSA off, the POWER switch in the front panel of the instrument must be pressed. After confirming our action through the confirmation pop up message that will
be displayed, the power switch will change colors from green to orange. Finally, once the light
turns to orange, the MAIN POWER switch can be turned off, which will completely turn off the
OSA.

3.3.2 Power Meter

The power meter in this setup will be placed in the path of the light, and the beam will
enter the power meter’s cavity. From contact with the beam, the power meter is able to measure
the power of the laser die right before entering the Optical Analyzer.

![Image of a Power Meter](image)

Figure 47. Illustration of a Power Meter used in the L-I-V Setup [19].

It is a great way to measure the Power-in the OSA, as it will be needed to calculate the
efficiency of the pulsed laser die. By keeping an eye on the power of the laser, fluctuations can
be easily spotted and corrected. A few Photodetector Specifications are listed below on the next
page:

Spectral Range (µm): .2-1.1
Calibration Uncertainty: 4% at 200-219nm and 950-1100nm / 1% at 350-949nm

Rise Time (µs): ≤5.9

Reverse Bias: 5V

Material: Silicon-UV Enhanced

Active Diameter: 1.12cm

Attenuator: Built-In OD $3^{(4)}$

Calibration: Stored Internally

Once all these devices are finally properly installed and connected, then the L-I-V setup Characterization Setup for Pulsed Laser diode is effectively ready to be used for all and any student in the Photonics and Optical Engineering to use.
4. Conclusion

In order to properly setup an L-I-V characterized laser diode station a slew of appropriate devices was needed. These devices can be grouped into sections, the Electrical Pump Setup devices, the Temperature Control Devices and the Optical Detection Devices. Each Section is critical to the building and proper operation of the setup.

The Electrical Pump section is meant to drive the laser diode is the system. The pulse generator is a big part of the Electrical pump setup. The probes are connected to the pulse generator and mounted on probe mounts. Part of the devices present in the Electrical Pump setup are also replaceable probe tips should they be needed.

The next step was about building up the Temperature Control portion of the whole setup. There is a Thermo-Electric Collar device (TEC) placed under a sample holder carrying the laser die. The TEC will manage the temperature of the laser through a TEC Temperature Controller device connected to the computer that will be used in the setup. Most importantly, there is also a separate Power Supply meant to drive the TEC specifically. When all these are connected properly, the --L-I-V setup is two third of the way built.

Finally, the Optical Detection part of the setup will enable users to find the emission wavelength of the laser and graph an L-I-V Power vs Wavelength plot. Through the plots that can be created, the proper characteristics an L-I-V pulsed laser die setup can be tested. An optical Analyzer is used that is also hooked to the computer. To make things easier, there is also a power meter to determine the Output power of the laser Die.
The main characteristics we are looking for are at the threshold point which we really hope to measure, the emission wavelength and the bandwidth. The threshold point is shown in Figure 43, I have included it in this page for ease of access:

![Figure 43. Illustration of a Voltage VS Current Characteristic I-V Curve [14].](image)

I have also included the Gaussian Distribution Curve shown in Figure 3 that should be obtained by the OSA:

![Figure 6. Peak Emission Wavelength Illustration.](image)
Again, we are looking for the threshold point, and the Peak Emission Wavelength, as well as the FMWH that will allow us to find the bandwidth. These are the characteristics we want to analyze to ensure that we have a proper L-I-V Pulsed Laser Diode Setup. Ultimately, my thesis sets up the next student researcher to build the actual entire setup, and the measurements mentioned are the ones they will make in order to test and characterize III-V laser on dies.

When all put together, we obtain a reliable L-I-V Pulsed Characterization Setup for Pulsed Laser Diode that can be used in the future by the photonics department and paves the way for future research opportunities for incoming students with the hope of earning a Photonics or Optical Engineering Degree.
5. Bibliography


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