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LASER Diode Pulse Driver

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Abstract

A Diode is a very useful nonlinear device that has a set of characteristics that are important in many applications. Laser Diodes are a particular type of diodes that are able to emit coherent light by stimulated emission. In order to drive a laser diode, a series of considerations needs to be taken into account, and for that it is important to understand how laser diodes work. This document summarizes all the work needed in order to design a Laser Diode Pulsed Driver. It begins by explaining the working principle of a general diode, it explains the modulation process by an input signal, and finishes in the design and production of a working prototype of a laser diode driver.

The document also has tutorials about the use of gEDA and Ngspice open source softwares for beginners. These tools allow the user to design circuit schematics, PCB layouts and to simulate circuits by having real components models. These tools are extremely helpful in the whole process, because they are able to provide a faster and cheaper way to test and design circuits.

Acknowledgments

This work was not possible without all the support of the company MWTech, that challenged me with this project, provided all the necessary equipment and support for the developing of this dissertation. I want to leave a special acknowledgment to Miguel Melo for all the advices and support given, Martin Ole Berendt for all the time spent with me, and the transmission of knowledge and experience during the project. Not less important were Hugo Barbosa, Job Tomé and Cecília Pinto for the all support, and patience to deal with my everyday dose of distractions.

I also want to acknowledge the professor Henrique Salgado, my supervisor, for all the time spent in order to improve this work with all the advices and experience.

Finally I want to leave a very special thank you message to my parents Madalena Dias e Fernando Dias, and my sisters Ana Dias and Maria Dias, which were without doubt the most supportive family and never failed to support me since the beginning of this degree even with all the set backs in between. This thank you message also spreads to all my friends that never stopped believing in my success.

Francisco Dias

“Hakuna Matata”

Timon and Pumbaa

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Symbols and Abbreviations

Abbreviations:

LASER	Light Amplification by Stimulated Emission of Radiation
WDM	Wavelegth-Division Multiplexing
LED	Light-Emitting Diode
gEDA	General public licensed suite and toolkit of Electronic Design Automation
AC	Alternating Current
DC	Direct Current
e.g.	abbreviation for *Exempli Gratia*: Latin phrase that means "for example"
LD	LASER Diode
LDD	LASER Diode Driver
CW	Continuous Wave
ITU	Telecommunication Standardization Sector (unit)
PCB	Printed Circuit Board
IC	Integrated Circuit
LIDAR	Light Detection And Ranging
OpAmp	Operational Amplifier

Symbols:

μ	micro	10^{-6}
m	mili	10^{-3}
V	Volt	Electric Tension unit
A	Ampere	Electric Current unit Unit
^{o}C	Celsius	Temperature Unit
W	Watt	Power Unit, (V*A)

Chapter 1

Introduction

The purpose of this chapter is to give the reader a brief introduction to laser diodes. The basics of how lasers operate is explained, their importance and applications.

The objectives and the structure of this dissertation will be explained as well as the contribution of this work.

1.1 Contextualization

The semiconductor laser has emerged as an important component in optoelectronic systems. Perhaps the most important emerging application is in the field of optical communications using fibers.

Parallel advances in laser diodes and LEDs, as well as fibers, promise to make optical systems viable and cost-effective communication channels.

The semiconductor laser diode offers considerably smaller size, potentially lower cost, and the unique ability to modulate the optical output up to Gigahertz rates by simply changing the current through the device. The unique properties of the laser diode make it an essential component of the emerging field of optical communications using glass fibers. The laser diode is also related to the low power visible light-emitting diode (LED), but the LED has a broader spectral emission, its emission is less directional, and its modulation capability is limited. [5]

Optical communications systems use high carrier frequencies in the visible or near-infrared region of the electromagnetic spectrum to carry information. The light travels through an optical fiber cable. Such systems have been deployed worldwide since 1980 and revolutionized technology in telecommunications. Light-wave technology together with microelectronics, is believed to be a major factor in the advent of the " information age ".
The research phase of fiber-optic communication systems started around 1975, and there was an enormous progress since then. [6].

The major component in these systems is the optical source, which converts an electrical input signal into the corresponding optical signal and then launches it into the optical fiber. Fiber-optic communication systems often use semiconductors optical sources such as LEDs *(Light-Emitting Diodes)* and semiconductor LASERs *(Light Amplification by Stimulated Emission of Radiation)*. The main advantages of lasers are their compact size, high efficiency, good reliability, right wavelength range, small emissive area, and possibility of direct modulation at relatively high frequencies. LEDs require less complex drive circuitry than laser diodes, since no thermal or optical stabilization circuits are needed [6].

1.2 Characterization of the problem

Electrically, a semiconductor laser diode behaves as a normal diode. It begins to lase at a current greater than the threshold current. A further increase in the injected current results in a proportional increase in laser optical output. Applications range from telecommunications, health care including laser imaging and opthalmology, areas of defense with an ever increasing commercial use, up to kilowatt level, gas and oil well drilling, cutting and welding in manufacturing industry and so on [7].

Semiconductor laser emit light through stimulated emission, and they have a superior performance compared with LEDs. As a result of the differences between spontaneous and stimulated emission they are capable of emitting high power and have other advantages compared with LEDs, such as a higher coupling efficiency (aprox. 50%) into single-mode fibers. A relatively narrow spectral width of emitted light allows operations at high bit rates. Semiconductors can be modulated directly at high frequencies (up to 25 GHz) because of a short recombination time associated with stimulated emission. Most fiber-optic communication systems use semiconductor lasers as an optical source because of their superior performance compared with LEDs. [6]

Laser diodes need a high performance laser driver, and this is the main goal of my dissertation, to design a high performance laser diode driver that can have applications is LIDAR[1] technologies.

It is the aim of this work to detail the process of develop a pulsed laser diode driver, and is important to refer that some information may not be provided in this document by reasons of confidentiality.

[1] is a surveying method that measures distance to a target by illuminating the target with pulsed laser light and measuring the reflected pulses with a sensor

1.3 Objectives

The objectives of this dissertation were proposed by MWTech, the company that hosted and provided all the material and the orientation needed for the development of this work.

The objective is to study different laser diode drivers, to acquire the knowledge needed to understand the pulse modulation and the operation of the drivers, and finally to propose a new circuit design for the pulse modulation part of the driver, and to drive the laser four times with one short pulse only and provide a maximum current of 1A to the laser, using the knowledge and tools provided during this period of work.

The work starts with the study of some existing LDDs, and how to use the different tools needed for the design and simulation of electric circuits. The software that will be used, is a Linux open source gEDA software (see chapter 3). For validation of the work, the proposed circuit will be printed in a PCB, the selected components will be soldered and then the circuit will be tested to conclude if the design is capable of successfully drive a laser diode.

1.4 Dissertation Structure

This dissertation was built having the premise that anyone with few or none experience in laser diode drivers can acquire enough knowledge needed to develop a laser diode driver by himself.

Chapter 2 starts with the study of the diode, some applications and behavior. It addresses the Light Emitting Diodes (LEDs), and LASER diodes, their main differences, strengths and weaknesses of each.

Chapter 3 intends to provide methods and tutorials for a first approach to some open source softwares of simulation and design of circuits, Ngspice for simulation, and the gEDA Tools, for circuit and PCB design together with the A.

Chapter 4 has the proposed circuit and the steps needed for the developing since the adaptation of the driver concept, until the development of a PCB design and the experimental tests of the PCB.

To finish, the chapter 5 has all the conclusions of this work, as well as future work.

1.5 Contribution

The main contributions of this work are, a document were the process of developing and planning a laser diode driver is detailed, not only in terms of electrical behavior but also an important help for those who are looking to use open source tools to develop other applications circuits, because in this document, we will have the more important steps on how to use the gEDA and Ngspice tools.

Another contribution expected from this work is to provide to MWTech a new LDD design that can be prototyped, tested, tuned and optimized so it may be helpful in some products produced by the company.

Chapter 2

Diodes and Drivers

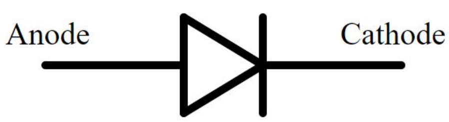
This chapter has a background on several components and concepts that are important to the understanding and development of this work. The aim is to facilitate the comprehension of this work, by introducing clarifications to several topics.

These concepts are, fundamentals of Diodes, how do they work, where they are used, the difference between LEDs and Lasers and different drivers concepts to operate them.

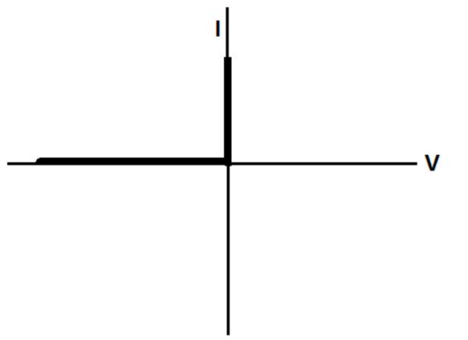
2.1 Diode

A diode is a fundamental nonlinear circuit element. It is a two terminal device having the $i-v$ characteristics shown in the Figure 2.1b. When a negative voltage is applied to the diode, no current flows (Figure 2.2a) and the diode behaves as an open circuit. Diodes operated in this mode, are said to be reverse biased, or operated in reverse direction. The ideal diode has zero current when operated in reverse direction and is said to be cut off or, just off.

On the other hand if a positive current is applied to the ideal diode (Figure 2.2b), zero voltage applies across de diode, in other words, it behaves has a short circuit in the forward direction. It passes any current with zero voltage drop. A forward biased diode is said to be turned on or, just on.



(a) Diode Symbol



(b) Ideal Diode $i-v$ Characteristic

Figure 2.1: Diode Characteristics

This was the case for the ideal diode, which does not have any other intrinsic parameters, actual forward biased diode does not apply zero voltage across the terminals, instead the anode will be more positive than the cathode, this is called *forward voltage drop*. When a reversed voltage is applied unlike the ideal diode, and the real diode will let some current go through in the order of the *nA*. This is almost never a problem, unless it hits the *reverse breakdown voltage* where the diode is subject to a high-current due to avalanche breakdown[1]. Unless this current is limited by circuitry, the diode may be permanently damaged due to overheating.

(a) Reverse Biased Diode (b) Forward Biased Diode

Figure 2.2: Two different Diode connections

The positive terminal of the diode is called the anode and the negative terminal is called cathode. The $i-v$ characteristic of the diode, that only conducts current in one way, should explain the choice of its arrow-like circuit symbol 2.1a. [8]

One fundamental application of the diode is a rectifier circuit 2.3, which consists of the series connection of a diode $D1$ and a resistor $R1$. When applied an input AC signal vi, the diode will let the positive current flow through him in its forward direction, but when negative, it will simulate an open circuit, with no current flowing through him. It is possible to have half-wave and full-wave rectifiers. The main application of this circuit is to generate DC from AC.

Diodes can have applications such as rectification, power-supply filtering, logic gates and many others.

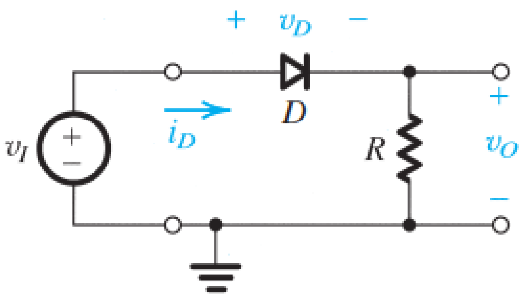
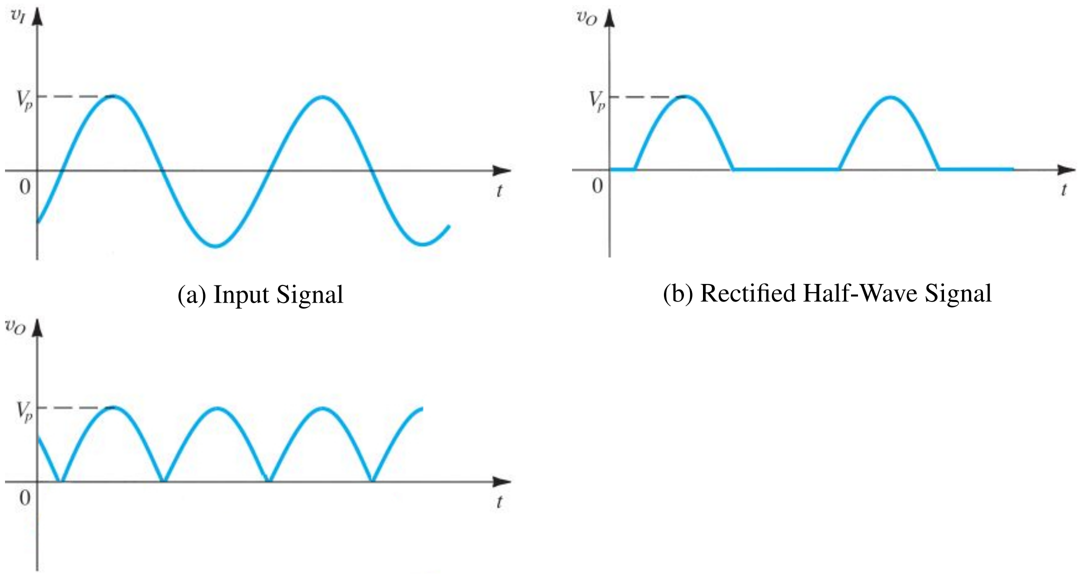


Figure 2.3: Half-Wave Rectifier Circuit, Source:[8],p.142

[1]Avalanche breakdown is a phenomenon that can occur in both insulating and semiconducting materials. It is a form of electric current multiplication that can allow very large currents within materials which are otherwise good insulators. It is a type of electron avalanche. The avalanche process occurs when carriers in the transition region are accelerated by the electric field to energies sufficient to create mobile or free electron-hole pairs via collisions with bound electrons



(a) Input Signal

(b) Rectified Half-Wave Signal

(c) Rectified Full-Wave Signal

Figure 2.4: Two rectifier types (with ideal diode), Source:[8],p.142

2.1.1 Working Principle

The semiconductor diode is basically a *pn* junction. A *pn* junction consists of $p-type$ semiconductor material (e.g., silicon) brought into close contact with $n-type$ semiconductor material (also silicon). Both p and n regions are part of the same silicon crystal, but each region has a different "doping". The $p-type$ is doped with an impurity, which has one less electron in his covalent band creating *holes* in the material, which can accept electrons. The $n-type$ is doped with an impurity, which has one more electron in his covalent band meaning that one electron is free to move.

There are two mechanisms by which holes and electrons move through a silicon crystal, *diffusion* and *drift*. **Diffusion** is associated with random motion due to thermal agitation. In a piece of silicon with uniform concentrations of free electrons and holes, this random motion does not result in current. When working with diodes, we have to consider that the I_{th} (threshold current) will suffer variations with the temperature and it's something to consider in some applications such has LASER Diodes and LEDs.
The other mechanism for carrier motion in semiconductors is **drift**. Carrier drift occurs when an electric field is applied across a piece of silicon. Free electrons and holes are accelerated by the electric field and acquire a velocity component called drift velocity.

The *pn* junction is the basic element of bipolar junctions transistors (BJTs) and plays an important role in the operation of field-effect transistors (FETs). [8]

2.1.2 Light Emitting Diodes

These diodes are made of single-crystal materials, and for the most part consist of heterojunction structures where $p-$ and $n-$type layers of different energy bandgaps are combined to produce the desired properties. In some kinds of materials, when in a forward-biased $p-n$ junction, as the electrons cross from the n region and recombine with the holes existing in the p region we observe the emission of light. In the Figure 2.5, free electrons are in the conduction band of energy levels, while holes are in the valence energy band. The level of the holes is less than the energy levels of the electrons, the excess energy is liberated as electromagnetic radiation having a specific wavelength or color. This wavelength corresponds to the difference in valence shell energies of the p and n dopants. So, some portion of the energy must be dissipated to recombine the electrons and the holes. This energy is emitted in the form of heat and light. [1]

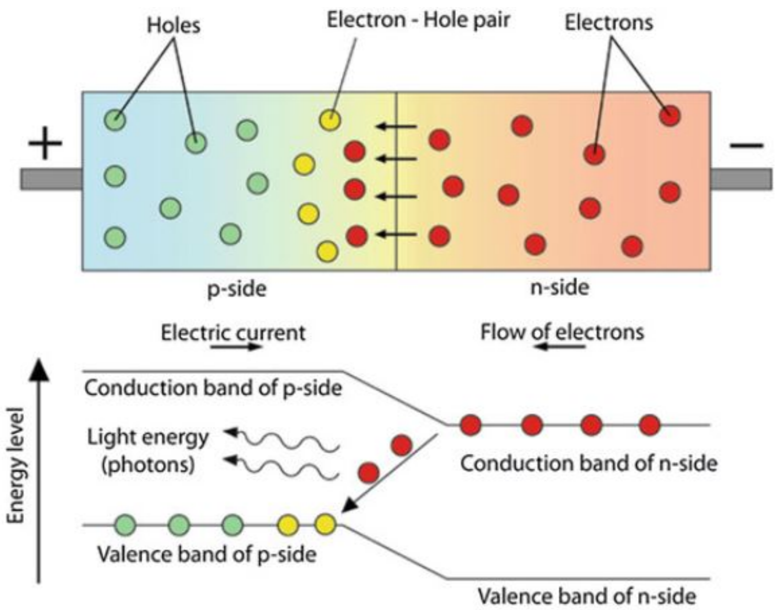


Figure 2.5: Working Principle of LED, Source: [1],p.15

2.1.3 LASER Diodes

The main difference between a LED and a LASER diode (LD) is that, the light emitted in the LED is incoherent, and in the LD is coherent. Coherent light is when all the waves emitted have the same wavelength and phase, and if not it is incoherent and we have multiple wavelength being emitted or the same wavelength with different phases.

Under normal conditions, all materials absorb light rather than emit it. The absorption can be understood by observing Figure 2.6.

The two-energy-level diagrams in the Figure 2.6 represents the three possible processes that can take place when light interacts with matter, where E_1 is the ground state energy and E_2 is the excited state of energy. According to Planck's law, a transition between these two states involves the absorption or emission of a photon of energy $h\nu_{12} = E_2 - E_1$. Normally a system is in the

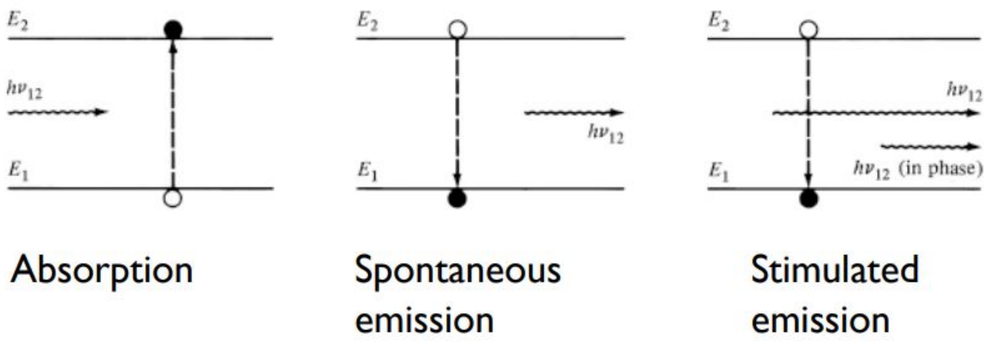


Figure 2.6: Three different interactions of matter with light, Source: [2], p.154

ground state, and if a photon of energy hv_{12} impinges on the system, an electron in the state E_1 can absorb the photon energy and be excited to the state E_2. Since this is an unstable state, the electron will return to the ground state, thereby emitting a photon of energy hv_{12}. This occurs without any external interaction, and is called **spontaneous emission**. When in spontaneous emission, photons are emitted in random directions and with no phase relationship among them.

The electron can also be induced to make a downward transition from the excited level to the ground-state level by an external stimulation. In the previous Figure we can see that if we have an electron excited in level E_2 and a photon of energy hv_{12} impinges on the system, the photon will be stimulated to drop to the ground state, and give off a photon of energy hv_{12}. This is called **stimulated emission**. Stimulated emission has some remarkable features like, the emitted photon matches the original photon not only in energy (or in frequency), but also in its characteristics, such as the direction of propagation. All lasers, including semiconductor lasers, emit light through the process of stimulated emission and are said to emit coherent light. In contrast, LEDs emit light through the incoherent process of spontaneous emission. [6, 2]

There is a threshold current ($I_{threshold}$) that, below that value a LASER behaves like a LED where the emission of light is spontaneous, and above that limit, we have stimulated emission and coherent light, and a small spectral width comparing to a LED. [9]

Stimulated emission may not be the dominant process since it has to compete with absorption process. The condition for stimulated emission to dominate is when $N_2 > N_1$, being N_1 and N_2 the atomic densities in the ground and the excited states, respectively. This condition is called **population inversion**, and it is a prerequisite for laser operation. [6]

2.2 Laser Diode Equivalent Model

Electrically it is possible to simulate the behavior of the LD by using some resistors, capacitors, inductors and of course, a diode. These components reproduce the behavior of the LD internal losses and internal parasitic effects.

The simplest laser diode model can be presented by a single resonant circuit with a parallel conductance, capacitance, and inductance, as shown in Figure 2.7. The energy stored in the cavity determines the inductance and the capacitance values, L and C, respectively. The gains and losses in the laser diode decide the conductance value, G. [3]

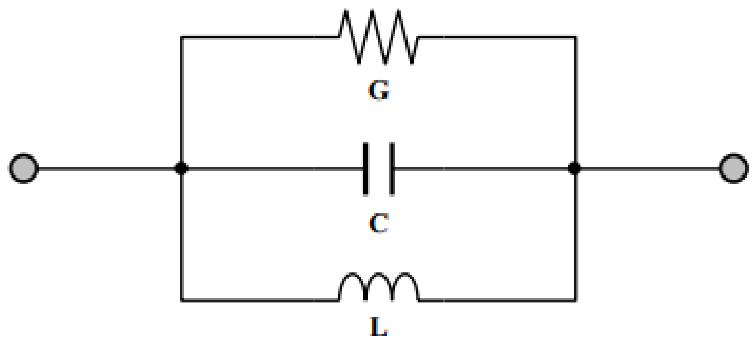


Figure 2.7: Basic Laser Diode Equivalent Model, Source [3],p.51

In Figure 2.8 we have an equivalent model for a laser diode with a butterfly package, that was provided by a manufacturer, whose identity and values are kept classified. The response of this circuit to pulse change in current is shown in Figure 2.9. The parasitic components include contact capacitance Cp, series resistance Rs between contacts, and bonding wire inductance Ls of laser within the capsule. The Cb and Rb correspond to intrinsic values of the LD itself.

To simulate the driver with conditions similar to the ones in the reality, a laser diode model was developed in chapter 4.

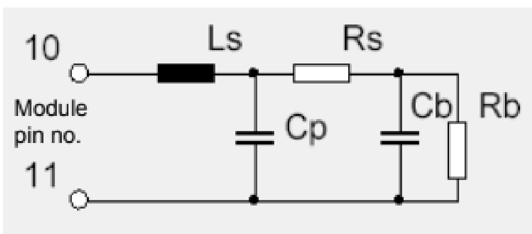


Figure 2.8: Laser Diode Equivalent Model Provided by the Manufacturer

There are several types of laser diodes structures, Double heterostructure lasers, Quantum well lasers, Quantum cascade lasers, Interband cascade lasers, Separate confinement heterostructure

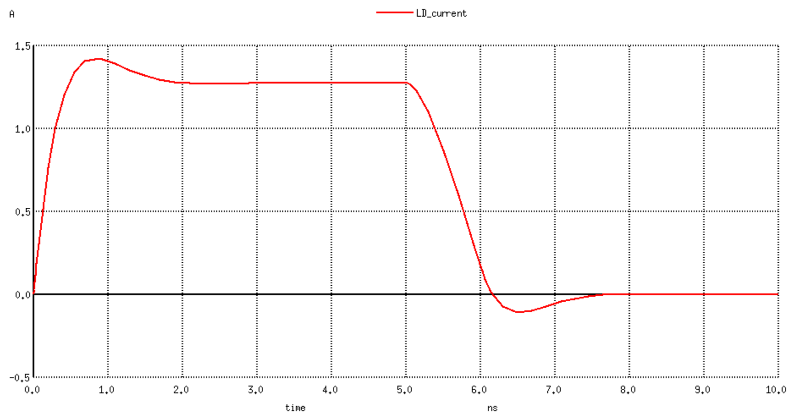


Figure 2.9: Response of the Laser Diode Equivalent Model Provided by the Manufacturer

lasers, Distributed Bragg Reflector lasers, Distributed feedback lasers, Vertical-cavity surface-emitting laser, Vertical-external-cavity surface-emitting-laser, External-cavity diode lasers. They have structural differences from each others, and have some different working properties. Those differences will result in different technologies, applications, rising times, threshold currents, output powers, or wavelengths.

2.3 LED Drivers

Has seen before, diodes need current sources to drive them, and the traditional circuit for controlling such currents is a bipolar transistor switch operated in the common-emitter configuration. This circuit offers current gain.

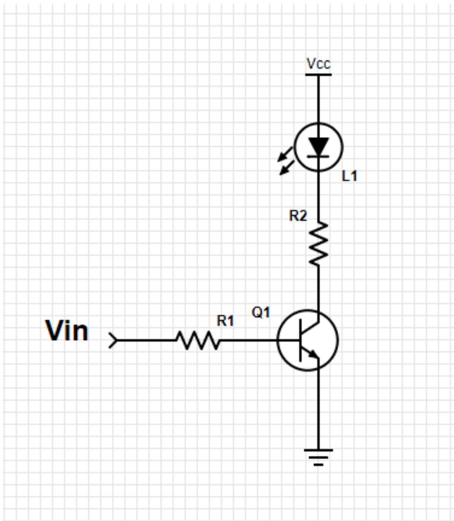


Figure 2.10: Basic LED Driver

For binary (2-level) digital applications, a current must be switched on and off at high speed through an LED in response to a low-level data-input signal. A small dc forward bias added to the switched current may prove advantageous in high-bit-rate applications by maintaining charge on the diode's capacitance.

2.4 Laser Diode Drivers

Unlike LEDs, which emit light approximately in proportion to the total device current, lasers are threshold devices, as described earlier. As such, light output is proportional to the incremental current above threshold. Several of the circuits discussed for LED applications can be used as laser drivers with only minor modifications. These changes are directed toward supplying the laser with a substantial bias (often called prebias) in the off state. It is desirable that this bias be just below threshold in the off state for several reasons. First, by keeping the laser close to threshold, turn-on delay and leading-edge overshoot of the optical output are minimized.

In the most ideal form, a laser diode driver is a constant current source: linear, noiseless, and accurate. It delivers exactly the current to the laser diode that it needs to operate for a particular application [4].

Diodes, are quite sensitive to current changes, and in order to ensure a greater life time of this component, it is important to avoid having abrupt changes in current. Spikes of current can occur randomly and when powering the circuit on and off.

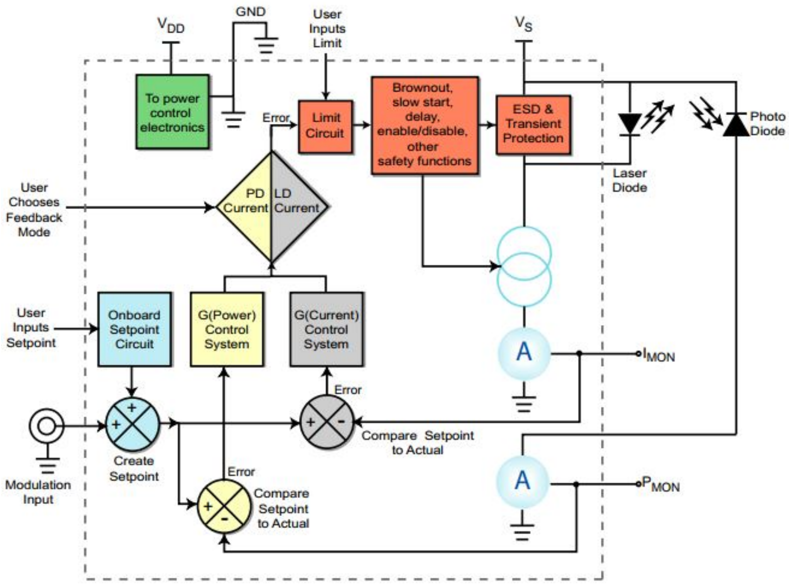


Figure 2.11: Basic LD Driver, Source: [4],p.1

In order to protect the diode from this, some mechanisms are implemented in diode drivers. One mechanism used is a delay on start up, meaning that the power supply will be increasing his voltage gradually, and will take some time to hit the desired supply voltage. This system combined with other filters, such has π filters, protects the component from being damaged by current spikes.

Has said before, diodes are also sensitive to temperature variations, and in the case of LD this is a critical factor that every driver has to deal with. In a LD the I_{th} typically changes $+1\%$ / ^{o}C. For instance, in a typical LD an increase of $30^{o}C$ results in a $30mA$ increment on the I_{th} current and the emission power can decrease significantly.

It is important to control the temperature of the LD in order to correctly drive the diode. One common solution, is to have a feedback circuit that monitories the optical output of the LD, through a photo-detector. This system can be combined with a *termistor* that will be used to the feedback part of the circuit and control a current to a cooler system to keep the LD temperature close to the desired.

The photo-receiver will convert the optical signal into electric, which is integrated through time, by an operational amplifier with high time constant. The resultant electric signal it is average of the emitted power. This signal will actuate in the current source that will provide the I_{th}.[9]

Another feedback circuit, rather than the photo-detector can exist and the user can select which one to use (depending on the circuit configuration). There usually is another circuit that has the function is to keep the current to the LD constant. By maintaining the current in the LD constant, the output optical power will also be constant (in theory) and will not change with the current input.

Another important aspect that should be taken in to account when designing a driver, is the time response of the laser.

The next sub chapters will show and explain some configurations for the pulse modulation circuit that can be used to drive a LD.

2.5 Direct Drive / Open Loop

This is the most basic configuration, it works by driving the Laser directly from a Mosfet, that will act as a current source.

Mosfets are three-terminal devices in which the conduction between two electrodes (Drain and Source) depends on the availability of charge carriers, which is controlled by a voltage applied to a third control electrode (Gate) [10]. It has a threshold value (that is variable depending on voltage between the drain and the source, V_{ds}) and when above that, the Mosfet drives current through the Drain into the Source. This behavior is quite similar to a current source, as the LD requires to drive. In the Figure 2.12 is possible to see the characteristic curve of the current of a Mosfet (STMicroelectronics PD84008-LE) to understand how the current varies with the gate to drain voltage, V_{gs} and V_{ds}.

Looking at the Figure 2.13, we see that this configuration uses an OpAmp due to the capacitive behavior of the gate of the mosfet causing charge injection. The control signal being applied to the gate can couple capacitively to the channel, putting ugly transients on the signal [10].The opamp provides a low output impedance to the gate of the transistor, and this results in a "filter" for this undesired transients.

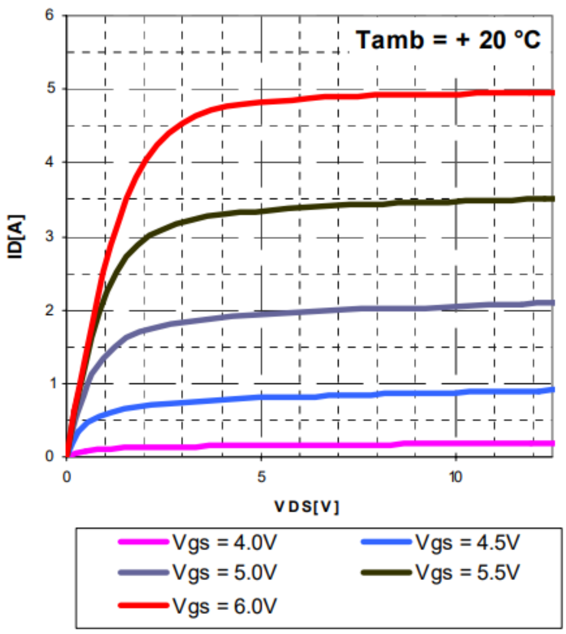


Figure 2.12: Example of Id vs Vds and Vgd Characteristic Curve

In Red on the Figure 2.14 is a 5V, 5ns pulse, with 3V of offset provided to the opamp non inverting input pin, in Blue is the signal that the mosfet gate sees, which is basically the opamp's response. In yellow is the current, in Amperes, that goes through the LD.

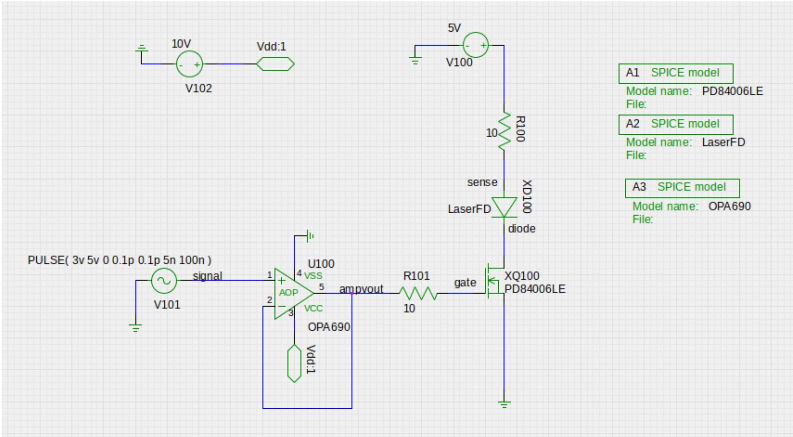


Figure 2.13: Direct Drive Schematic

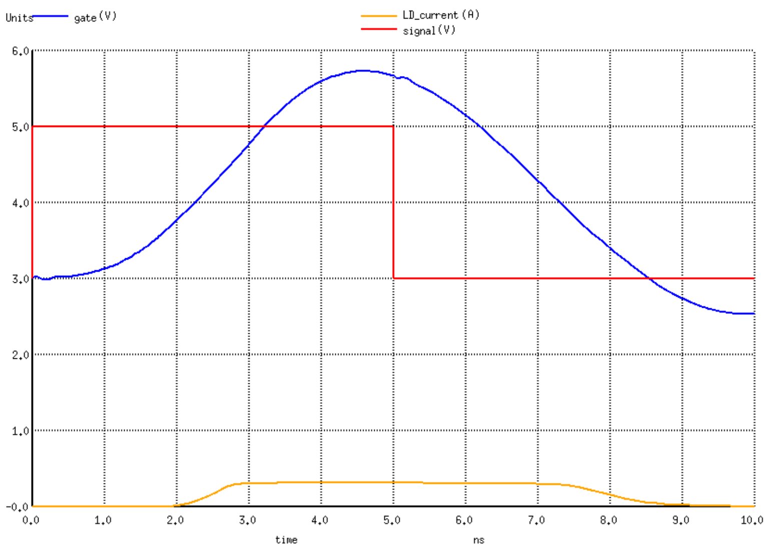


Figure 2.14: Direct Drive Laser Response

As expected the opamp only buffers the input signal and when his output reaches approximately 3.7V the mosfet starts to drive, meaning that he is pulling current through the LD. The reason that the input signal has an offset of 3V is for the signal to be near the threshold of the mosfet, optimizing the rising time of the signal in the gate of the mosfet so the rising time is really small making the laser's time response to be also faster.

2.6 Capacitive Discharge

This configuration works by the same principle of having a mosfet acting like a current source, but here a capacitor is included that charges when the mosfet is not driving. When the mosfet saturates and starts driving current, the capacitor is discharged through the laser diode.

By changing the value of the capacitor it is possible to change the rising time of the laser, the pulse width, and it is also possible to change the current that the laser will drive. This configuration can have a quite fast response of operation.

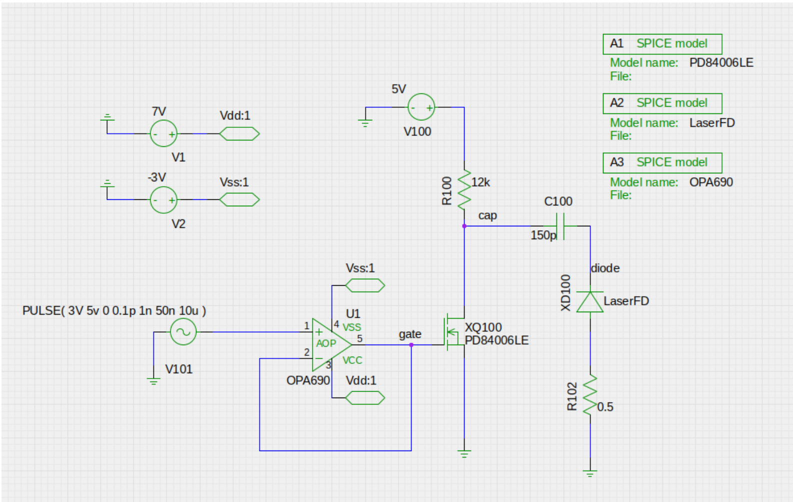


Figure 2.15: Capacitive Discharge Schematic

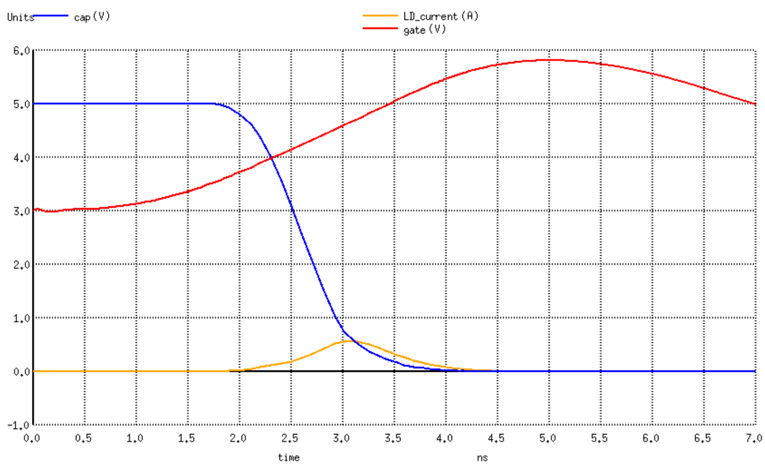


Figure 2.16: Capacitive Discharge Output

In Red on the Figure 2.16 is the signal that the mosfet's gate sees when a 5V, 5ns pulse, with 3V of offset provided to the opamp non inverting input pin, the behavior of this part of the circuit is exactly the same of the Direct Drive / Open Loop configuration. In Blue is the capacitor's voltage, and it is possible to observe its discharge. The capacitor is charged up to the bias voltage, 5V in this case, and as soon as the mosfet's gate reaches the threshold voltage it starts to discharge because the mosfet is now pulling current through the LD and the capacitor. In yellow is the current, in Amperes, that goes through the LD.

2.7 Constant Current / Closed Loop

This configuration is quite different from the others, now the opamp has a feedback circuit that comes from the source of the transistor. This circuit, will force the opamp to increase the voltage on the output, in order to have the same voltage in both input terminals. This characteristic allows the possibility to build a PID circuit to overcome variations on the behavior of the laser due to oscillations in the behavior of the LD. The main disadvantage on this circuit have, is a slower response time of the laser.

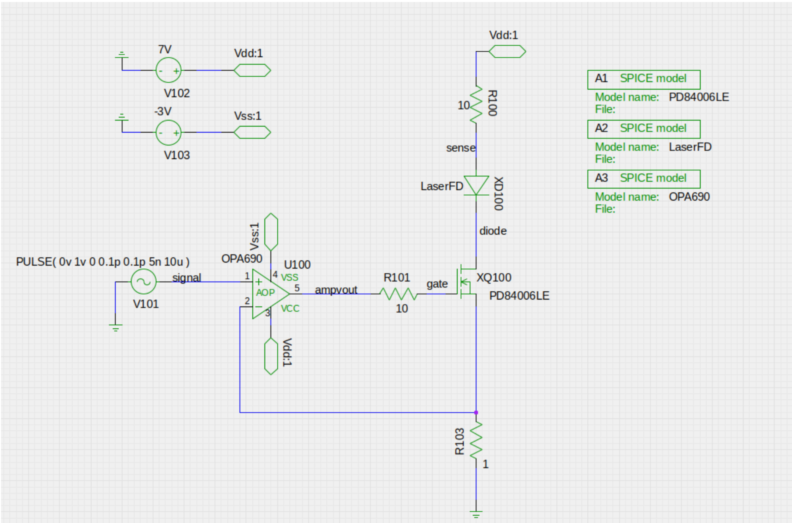


Figure 2.17: Constant Current Closed Loop Schematic

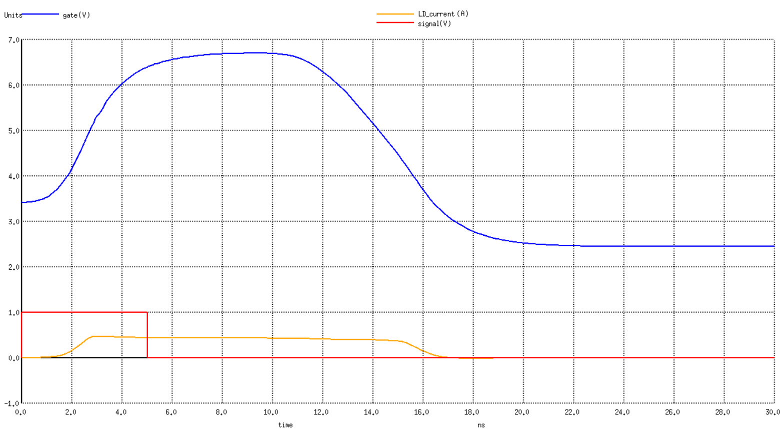


Figure 2.18: Constant Current Closed Loop Output

Observing the Figure 2.18, is possible to understand some differences in operation of this concept. The red line is the pulse input of the opamp, and with a smaller pulse this driver is able to drive the laser for a longer period of time (yellow line) because of the feedback net that forces the opamp to increase the voltage on the output, so instead of having a short pulse in the LD, it has a longer pulse.

As referred before, this configuration allows the possibility of building a control loop feedback mechanism, or a PID controler[2]. This means that we can control the signal in order to correct any variation on the response of the laser providing a more stable output.

In the schematic of the Figure 2.19 the circuit has a PI controller, meaning it has the Proportional control that allows the circuit to have a desired set point and calculate an error between the set point and the actual value, and with that compensate the circuit to bring it back to the desired set point. The integral term means that if there is a residual error after the application of proportional control, the integral term seeks to eliminate the residual error by adding a control effect due to the historic cumulative value of the error.

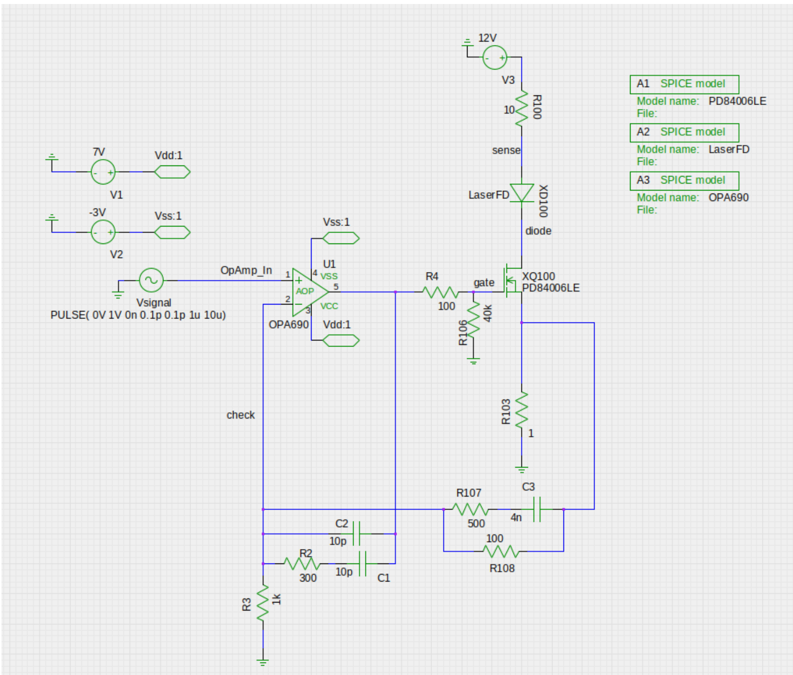


Figure 2.19: Constant Current Closed Loop with PI elements

[2]PID comes from proportional–integral–derivative, it is a net that automatically applies accurate and responsive correction to a control function. An everyday example is the cruise control on a car, where external influences such as slopes would decrease or increase speed

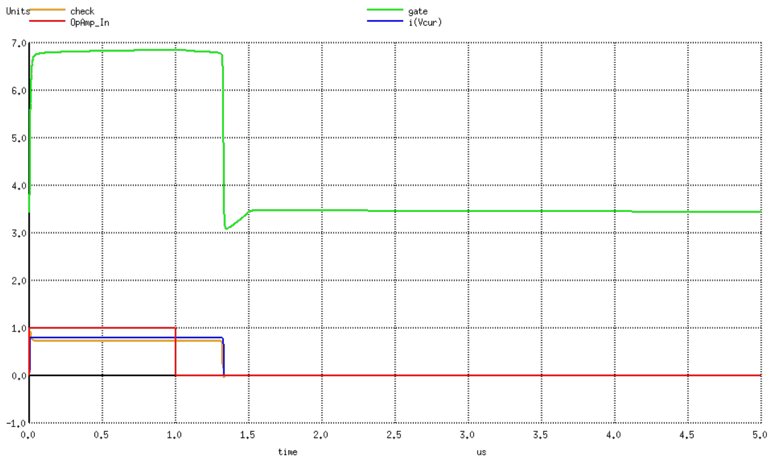


Figure 2.20: Constant Current Closed Loop with PI elements Output

2.8 Summary

Driving a LD is a trade off of functionalities, for every decision there is a compromise. It is important to take into consideration the working principle of a diode and to fully understand the requisites of the final application of the Laser which are, in this project, the ability to modulate a short pulse to drive a LD four times.

There are several ways to modulate a signal to provide to the laser, and each one has his advantages and disadvantages, and in order to decide which one to implement, it is necessary to comprehend which aspects our circuit may abdicate, and which aspects are indispensable.

It is also necessary to take in account that a diode laser is high sensitive to current spikes, and the effects of temperature on a diode.

Only after all those considerations that it is possible to move towards a design schematic and to simulate it.

Chapter 3

gEDA and Ngspice Software

The purpose of this chapter is to validate the models in spice, of the components used on the proposed driver, and others used in the process of learning to use the tools. It also has a brief explanation of the steps taken to learn how to use the several packages from the point of view of a beginner.

The gEDA project has produced and continues working on a full GPL'd[1] suite and toolkit of **E**lectronic **D**esign **A**utomation tools. These tools are used for electrical circuit design, schematic capture, simulation, prototyping, and production. Currently, the gEDA project offers a mature suite of free software applications for electronics design, including schematic capture, attribute management, bill of materials (BOM) generation, netlisting into over 20 netlist formats, analog and digital simulation, and printed circuit board (PCB) layout.

Ngspice is a mixed-signal[2] circuit simulator. Its code is based on three open source software packages: Spice3f5, Cider1b1 and Xspice. Is an open source successor of these venerable packages, as said in the Ngspice's website[3]. Some modifications had been added to the code, yielding a stable and reliable simulator. Ngspice is a ongoing project, growing everyday from users contributions, suggestions and reports.

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[1] **G**NU General **P**ublic **L**icense
[2] Mixed-signal is any integrated circuit that has both analog circuits and digital circuits
[3] http://ngspice.sourceforge.net/presentation.html

3.1 Tutorial

The first contact with gEDA was to follow a simple tutorial which is posted in the Internet[4]. The tutorial was to build a rectifier circuit on *gschem* with only a Power Source, a Diode, a Capacitor and a Resistor see Figure 3.1. Has described in the chapter 2, this circuit works as a rectifier. When applied a sinusoidal wave at the input, the diode only allows the positive waves to pass through and the capacitor keeps the voltage high until the next positive wave. See Figure 3.3. In the chapter 2 it is possible to find the working principle of a diode.

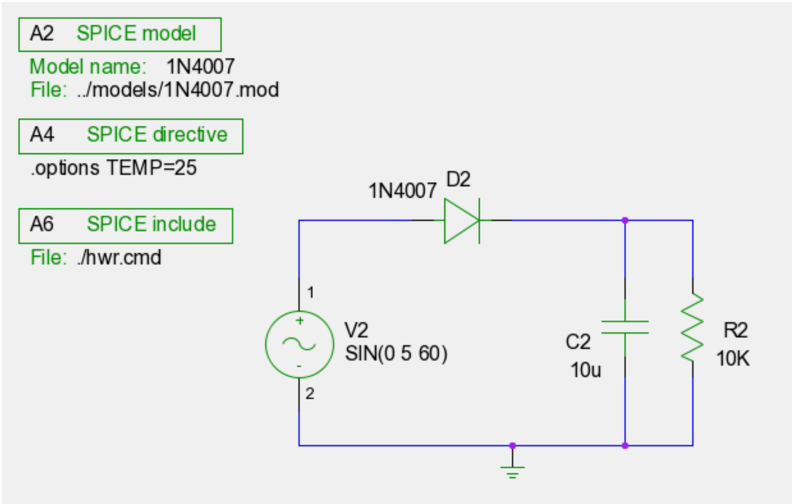


Figure 3.1: Tutorial Final Circuit

By following the tutorial, all the components were placed and connected. After the design of the schematic is done, Ngspice needs an instruction in order to create the netlist[5]. Then, the user needs to run the Ngspice software, and the simulation file. These instructions are present in the appendix A.1.

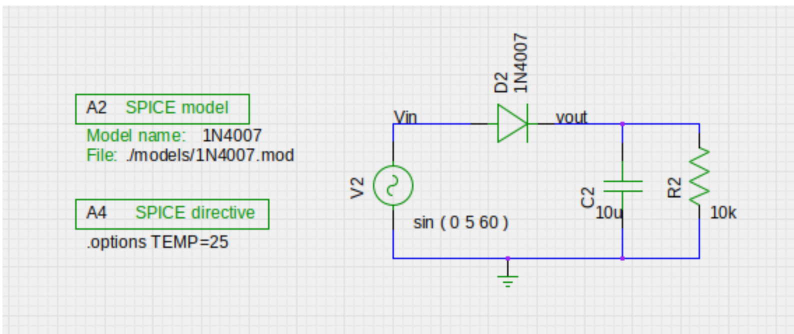


Figure 3.2: Schematic made as the tutorial

[4]https://ashwith.wordpress.com/2010/09/21/simulating-circuits-more-examples/

[5]A Netlist a *.net* file, generated by gEDA, where the designed circuit is coded into Spice programming language

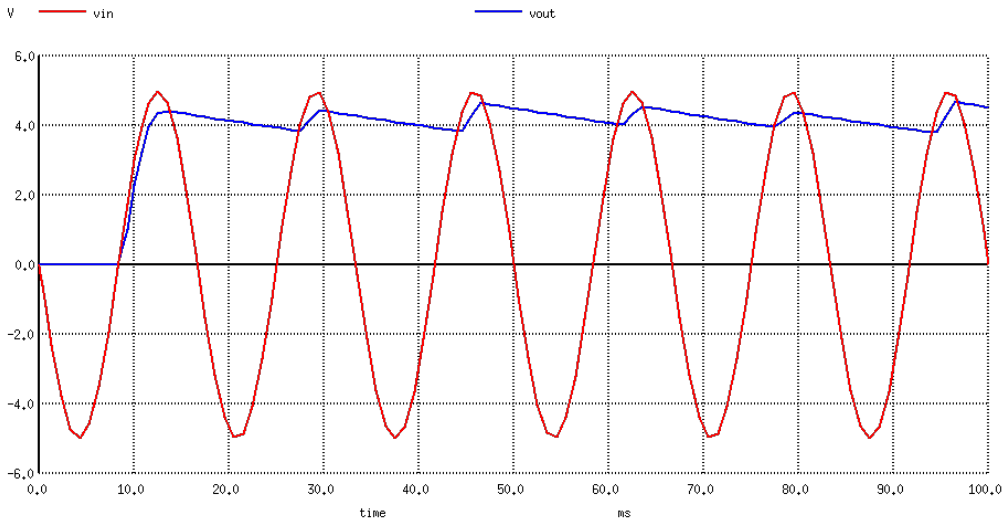


Figure 3.3: Tutorial circuit results

These results are coherent with the working principle of the circuit designed, which means that the first contact with the tool was a success.

3.2 Validation of the models

After some tutorials that are present in that website, and several hours of exploring the softwares it was time to start simulating some real components, considering that some were choosen to populate the final product.

While using this extremely helpful tool, it is important to have it clear that it works as a guideline, and that the results may not be exactly the ones that will happen in real life, because in a circuit there are a really high amount of variables and circumstances that can change the behavior of each component and impact the final result. Another important aspect to consider is the validation of each component model, such as transistors, opamps, diodes etc. These models may have limitations in several working conditions, usually when the manufacturer provides the model, his limitations are written in the top in a form of a note. It is important to make a validation of each component with the datasheet of the component, to understand if it is a trusty model, or if it needs to be optimized.

3.2.1 Mosfet PD84008L-E

One of the most crucial components of the driver, is the MOSFET that will drive the laser. So, the mosfet *PD84008L-E* from *STMicroelectronics* was choose to be simulated, because one very similar was used in a previous driver that was studied and it performed very well.

By accessing STMicroelectronics website it was possible to obtain the *model* [6] in *spice* for this component.

The model obtained for this transistor was for PSpice, which is a payed version of Spice, so it needed some modifications for Ngspice to understand it. For that, it is advised to read the Ngspice and the PSpice manual so the user can understand the differences in the syntax and adapt the downloaded model for Ngspice.

The schematic of the Figure 3.4 includes a sinusoidal voltage source of $5V$ in the gate of the transistor, and voltage source in order to bias the transistor.

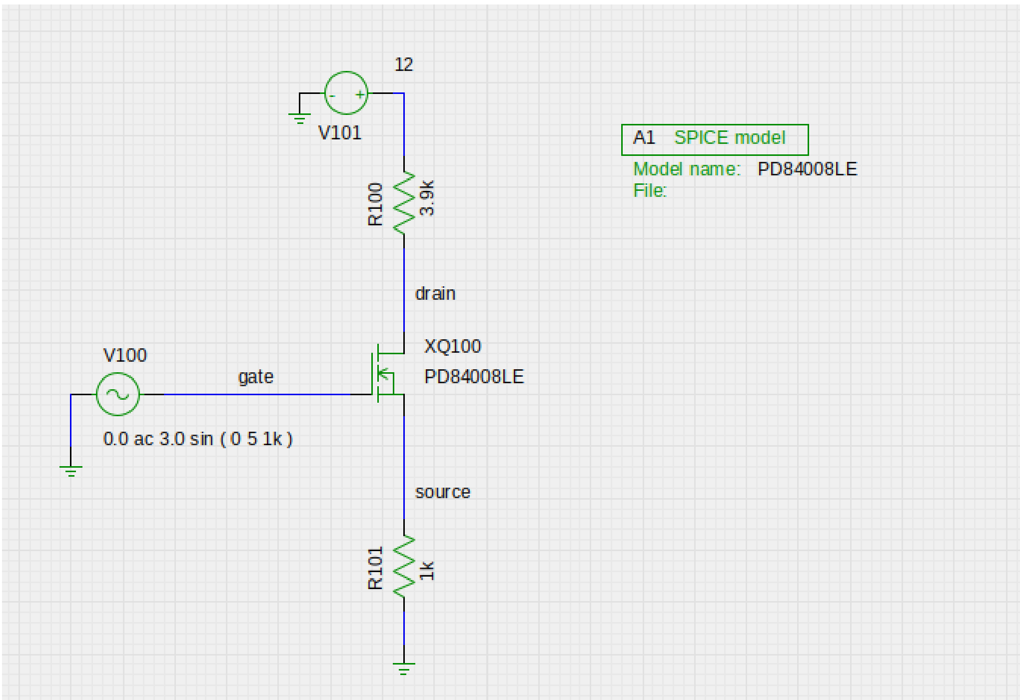


Figure 3.4: PD84008LE circuit schematic

[6] Model, is a file acknowledge by Ngspice as being the instructions that simulate the behavior of the each component. Each component has its own.

In the Figure 3.5 it is possible to see that the MOSFET only saturates with voltages V_{gs}, greater than approximately 3.5V, which is an expected result.

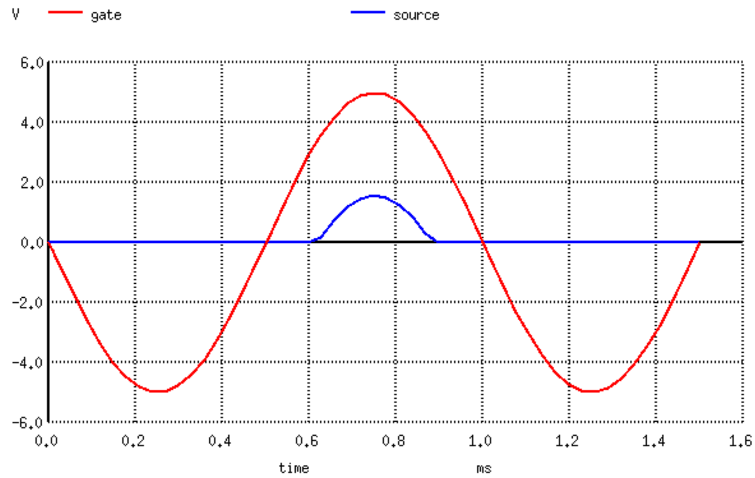


Figure 3.5: PD84008LE circuit results

3.2.1.1 PD84008L-E Spice Model and Datasheet Comparison

The next Figure has the simulation results for the current flowing through the transistors source, with different V_{gs} and V_{ds}.The schematic used for this simulation is the same as in the datasheet. By comparing with the Figure 2.12, which are the datasheet values that were simulated, we can observe that the model is able to reproduce the real values in a similar way.

With these results, and some others performed during the simulation of several circuits using this model we can confirm the validity of the model.

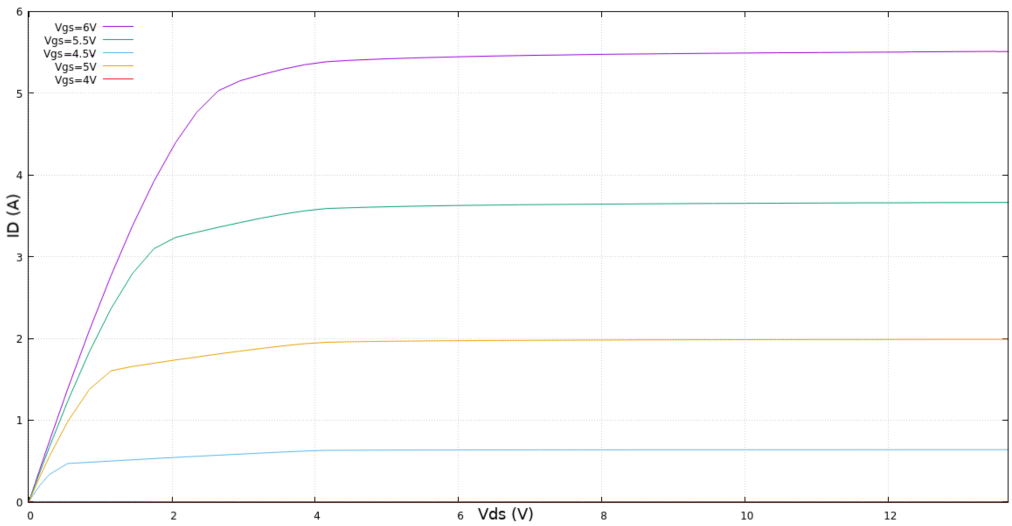


Figure 3.6: PD84008LE Simulation of ID, V_{ds} and V_{gs} as Datasheet Test Circuit

3.2.2 OpAmp LM741

One very common OpAmp *LM741* was added in the circuit, in order to amplify the input signal, and with this ensure that if we input a smaller amplitude signal in the OpAmp, it outputs to the gate of the transistor a signal that goes above the threshold voltage.
Figure 3.7 shows the schematic of this circuit and Figure 3.8 plots the Ngspice results. The mosfet used in the following simulations, the PD84006-LE is from the same family as the one presented before, the PD84008-LE. The difference between the two of them is the maximum current it can handle, the PD84008-LE can handle 7A, instead of 5A (which is the maximum current the PD84006-LE can handle). The intention was to use the PD84006-LE because it had shown proofs of a good operation, but at the time of the fabrication of the final project the component was not available in the store, only the PD84008-LE, and given the similarity between both of them was considered as an option because it should not make a difference in the end result.

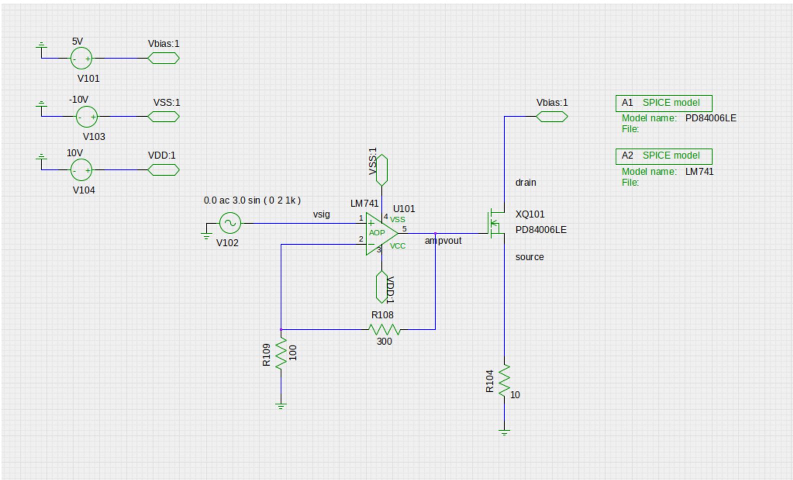


Figure 3.7: Circuit schematic for PD84006LE + LM741 simulation

Looking at the Figure 3.8, in red, we see the input signal that is connected to the non-inverting pin of the LM741, which is a 1kHz sinusoidal wave of 2V. In blue we have the output of the LM741 with a gain of 4 V/V, remembering the non inverting OpAmp configuration gain:

$$\frac{V_{out}}{V_{in}} = \frac{R_1 + R_2}{R_1} = \frac{100+300}{100} = 4V/V$$

In orange, is the signal seen in the MOSFET source, by the resistor R104, we can call it the *Sensing Resistor*.

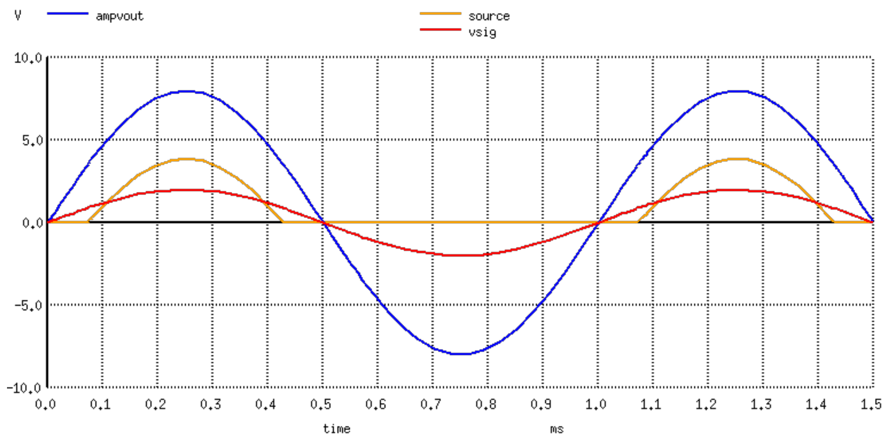


Figure 3.8: Ngspice result for PD84006LE + LM741 simulation

3.2.3 OpAmp OPA690

The next step, was to fit an OpAmp fast enough that could be used in a LD. *Texas Instruments* has the OPA690, and it provides a netlist for the spice model of this component in their website. It needed some adaptations in order to work with Ngspice.

A closed loop configuration was designed, with and without resistor. The configuration that doesn't have a resistor is called a follower, or just Buffer. It has gain = 1 V/V and his main characteristics are high input impedance and low output impedance.

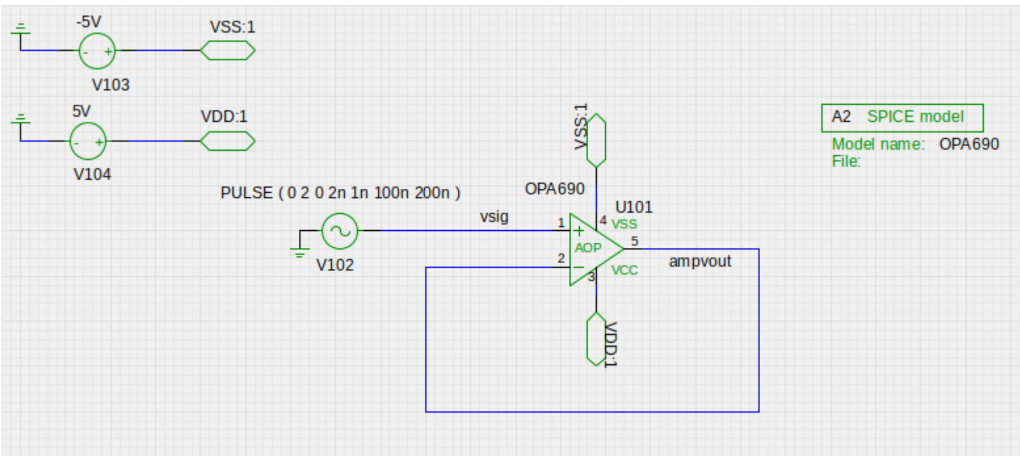


Figure 3.9: OPA690 follower circuit schematic

The final product has to be capable of driving pulse signals, so instead of the initial sinusoidal signal, the input of this circuit is now a 100 ns, 2V pulse with a 2 ns rising time. Figure 3.10 shows the output signal of this OpAmp for the pulsed signal. In red it's represented the input signal, and in blue the output of the OpAmp.

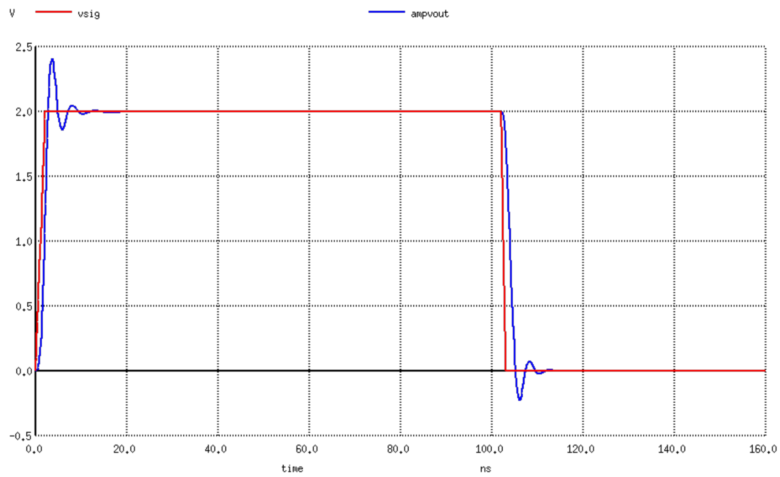


Figure 3.10: OPA690 follower circuit output

The opamp is most prone to instability when it is configured as a unity-gain follower, either because there is no attenuation in the loop, or large common-mode swings, though not substantially affecting accuracy of the signal gain, can modulate the loop gain into unstable regions.

After this, a couple of resistors were added to the configuration, to obtain a gain of 2,25 V/V.See Figures 3.11 and 3.12.

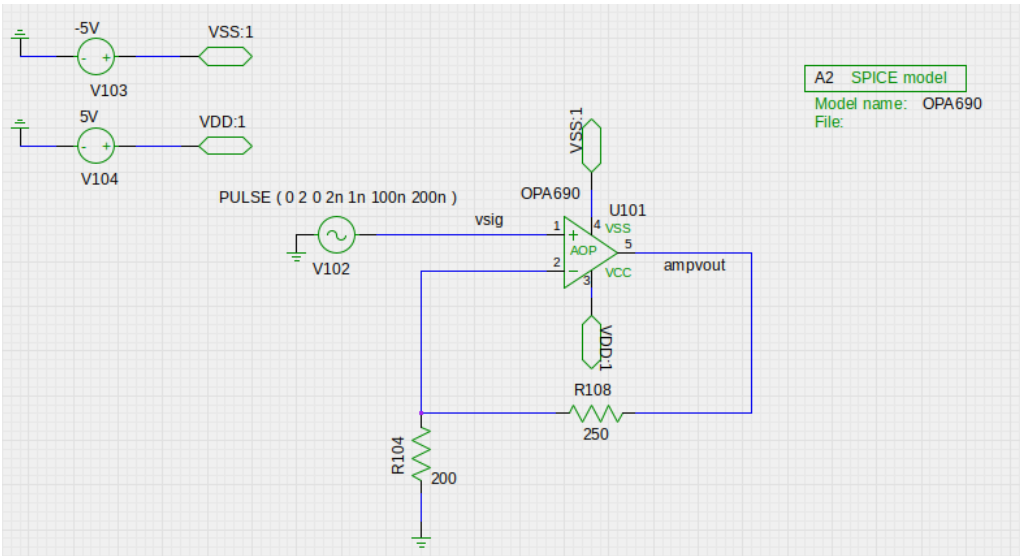


Figure 3.11: OPA690 circuit schematic with resistors

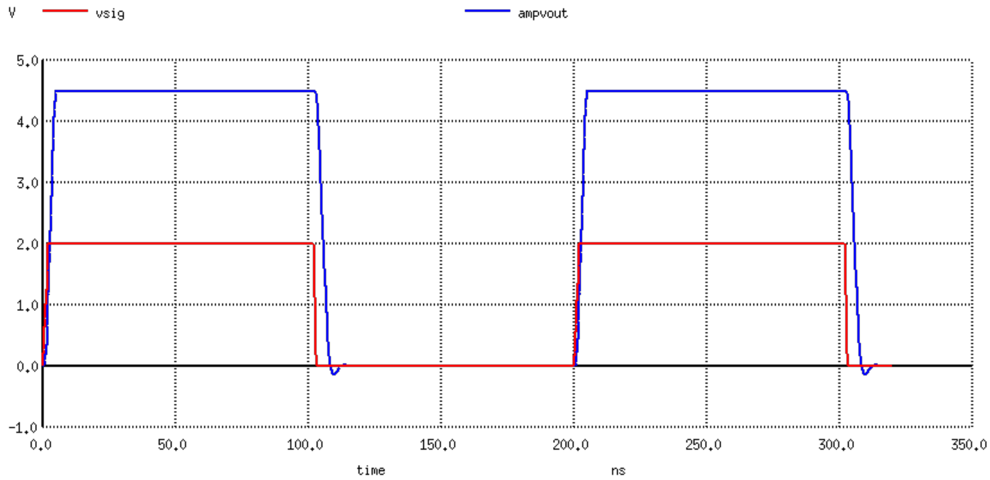


Figure 3.12: OPA690 circuit schematic with resistors

Next step, was to test the combination of the OPA690 and the PD84006-LE.With the Figure 3.14 it is possible to see that the transistor source is working near the threshold voltage, making it more sensitive to the input signal given by the OpAmp and being able to replicate it. As before, the red signal is the input, and in blue we have the OpAmp output. In red it is the transistor source. Some oscillations can be observed, which can be solved by adding additional components, making a PID feedback net. This configuration was tested with the PI circuit previously in the chapter 2.4.

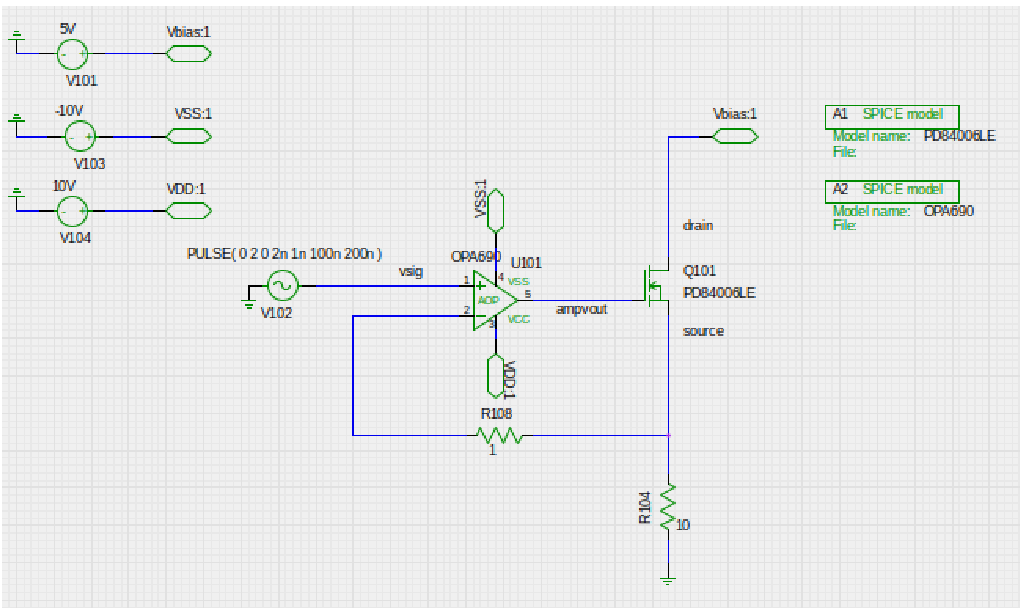


Figure 3.13: OPA690 and PD84006LE circuit schematic

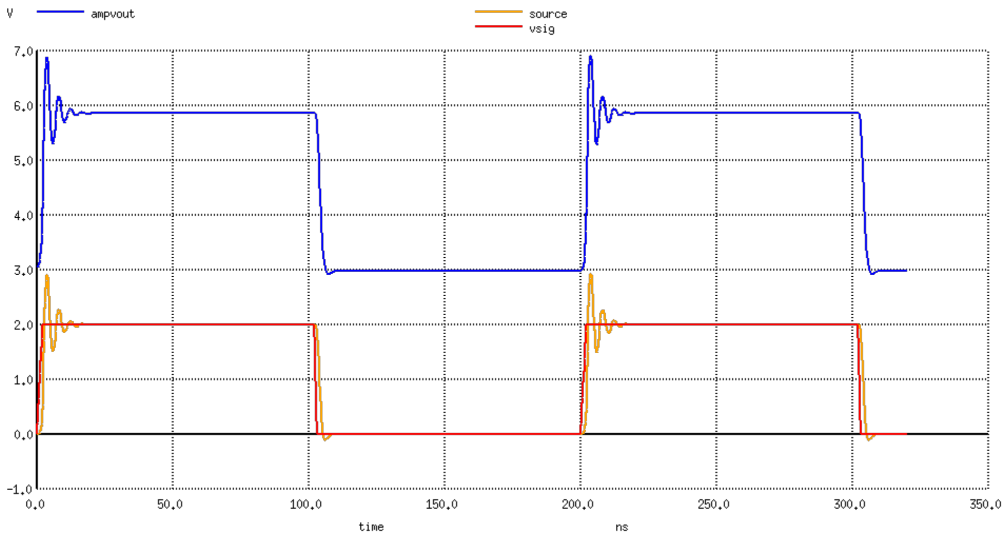


Figure 3.14: OPA690 and PD84006LE circuit results

3.2.3.1 OPA690 Spice Model and Datasheet Comparison

After having the Spice model working, is important to understand if the simulation's result is equal or similar to the response of the real component. One parameter tested was the Slew-Rate which is defined by Texas Instruments, as the rate of change in the output voltage caused by a step input. Generally is given in $V/\mu s$. It is measured by applying a signal step to the input of the opamp, and measuring the rate of change from 10% to 90% of the signal's amplitude.

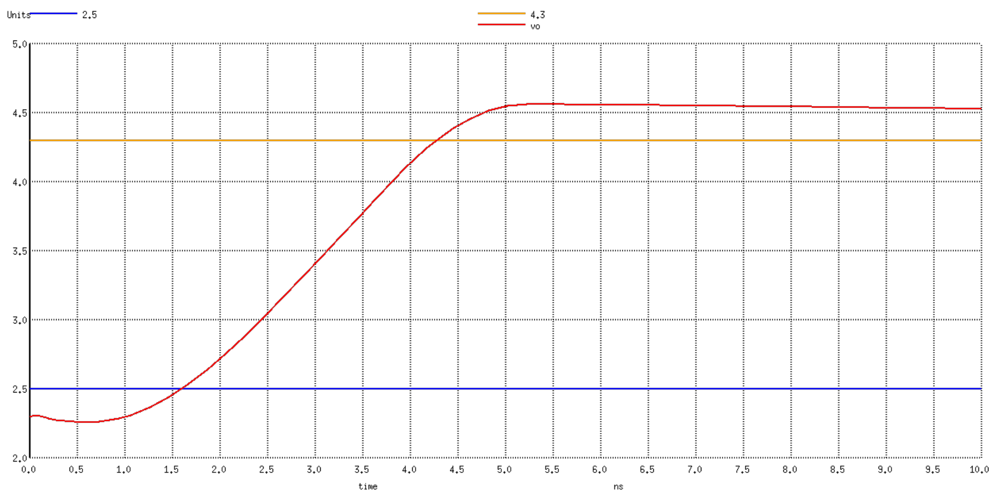


Figure 3.15: Slew-Rate Measurement

The datasheet says that for a 2V step the Slew Rate should be around 700 V/μs. The Figure 3.15 was used to calculate the slew-rate of the model. A 2V step was given to the input of the opamp, as the datasheet specifies and the following results were obtained:

$$\frac{4.3 - 2.5}{4.2833e^{-9} - 1.5833e^{-9}} = 667V/\mu s$$

3.2.4 OpAmp OPA695

The next OpAmp that has been simulated was the OPA695 also from *Texas Instruments*. This configuration has gain G=8 V/V. And the results of Figure 3.17 confirm that the gain corresponds to the calculations, with a $200mV$ input wave, we obtain an output of approximately $1.6V$.

$$G = 1 + \frac{R_f}{R_g} = 1 + \frac{402}{56.2}$$

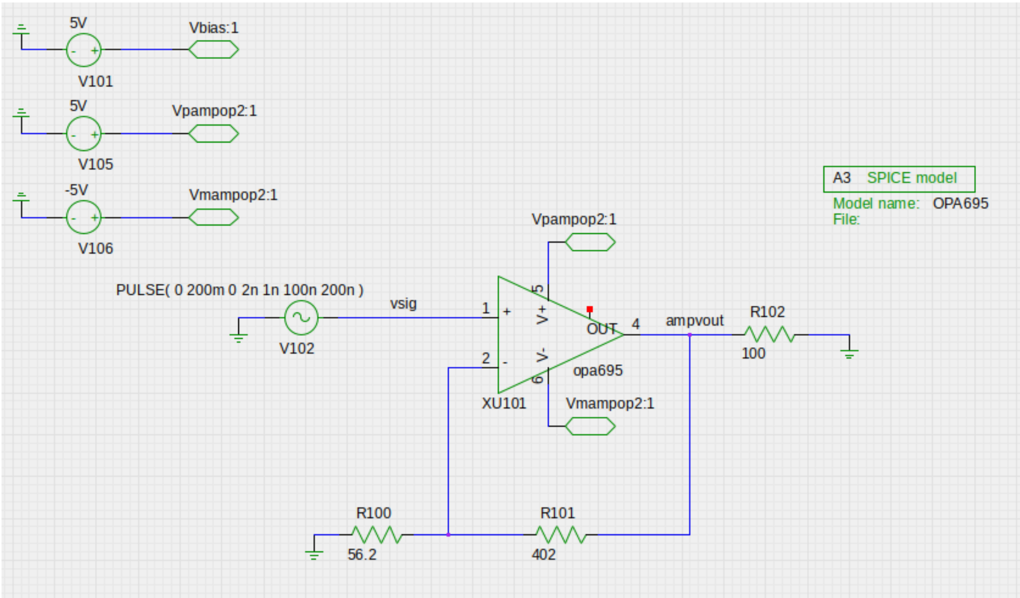


Figure 3.16: OPA695 circuit schematic

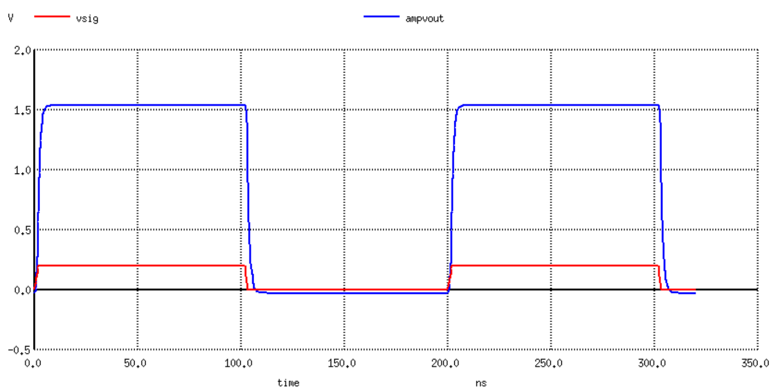


Figure 3.17: OPA695 circuit schematic

As before, the PD84006L-E was added in the circuit :

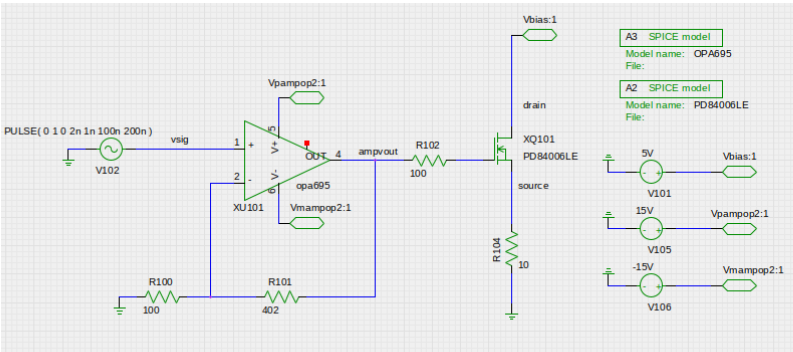


Figure 3.18: OPA695 + PD84006L-E circuit schematic

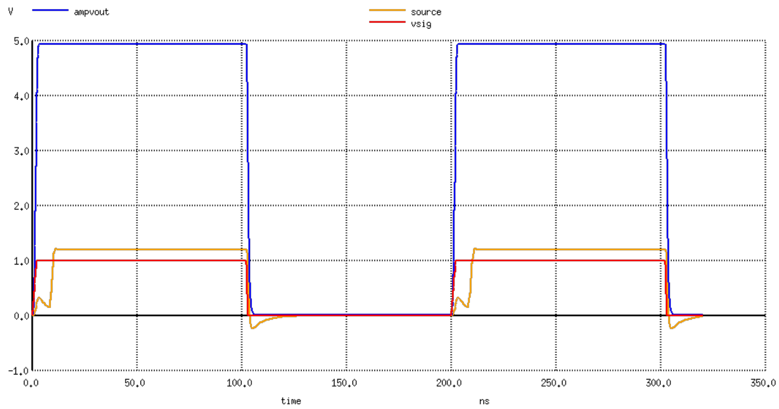


Figure 3.19: OPA695 + PD84006L-E circuit results

3.2.4.1 OPA695 Spice Model and Datasheet Comparison

With this model it is explained with Ngspice how to run a AC Sweep analysis to see the frequency bandwidth operation of the model, and compare it to the datasheet results. Bandwidth is the range of frequencies, where the opamp is able to operate. The bandwidth experimental measurements are made by having a frequency sweep from a start and stop frequency. The Spice commands were:

```
> ac dec 10 1 10G
```

Where 1Hz and 10GHz is the starting and stopping frequency respectively. A measurement was made for G=1, G=2, G=4, G=8 and G=16 V/V as in the datasheet.

With these results it is possible to see that the model has some differences when compared to the real model, specially in a unitary gain operation, which indicates that this model was built with some approximation values that do not simulate the real behavior of the component with this gain. These conclusions need to be considered if the use of this opamp is planned.

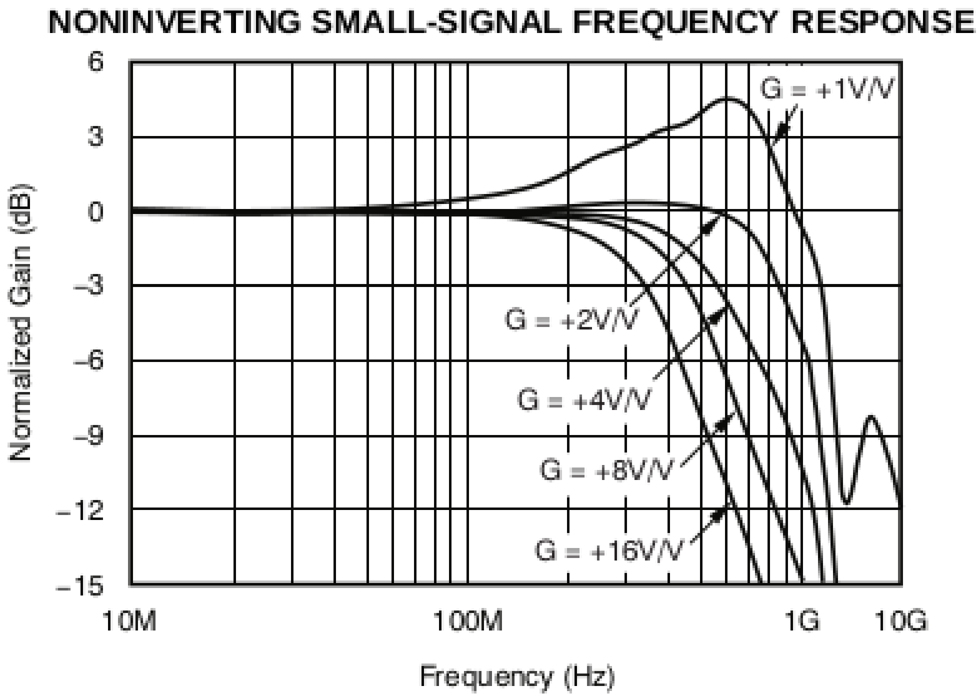


Figure 3.20: OPA695 Bandwidth plot from product Datasheet

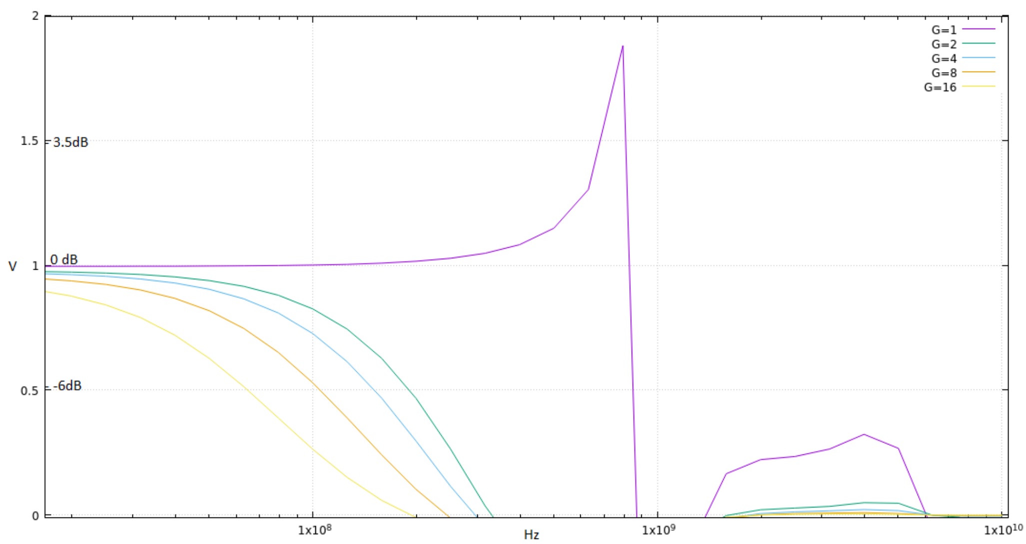


Figure 3.21: OPA695 Bandwidth Simulation

3.3 First Contact with PCB Layout Tool

The first layout drawn with this tool was a test board for the PD84006L-E transistor. This circuit is included in the component datasheet and was replicated as similar as possible. A schematic is needed for the PCB software, which is also provided by the datasheet. By applying the knowledge acquired in the previous step, that schematic was built, see 3.22.

In this schematic the components values were not needed, because the results simulation process was not the aim. For the PCB software, it is needed to define the *footprints* of each component. A footprint is the pattern on a circuit board to which the component is attached, see 3.23 where it is included an image of the *SOIC8* footprint used for some ICs with 8 pads, such as for the Delay Line that was used, and also a *0603* footprint, commonly used for resistors, capacitors, inductors etc. This includes the copper, silk, solder mask and paste information. It can also be referred as "land pattern".

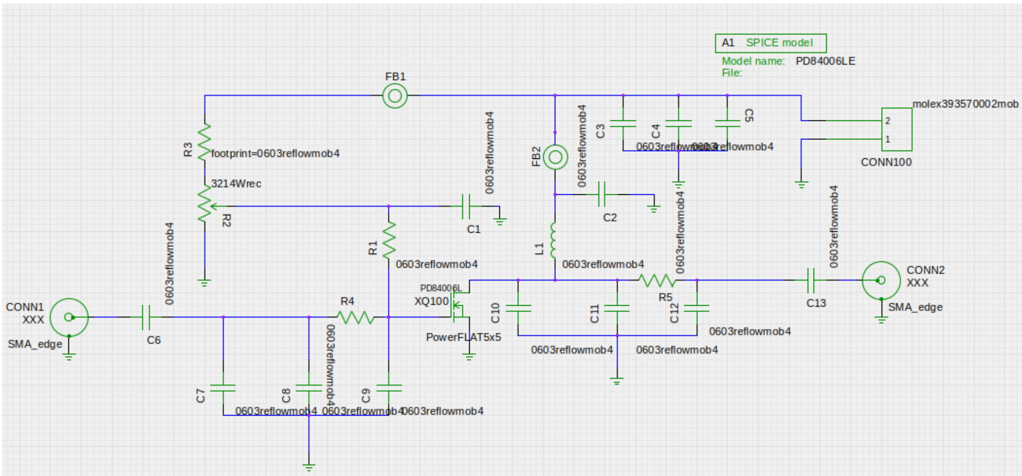
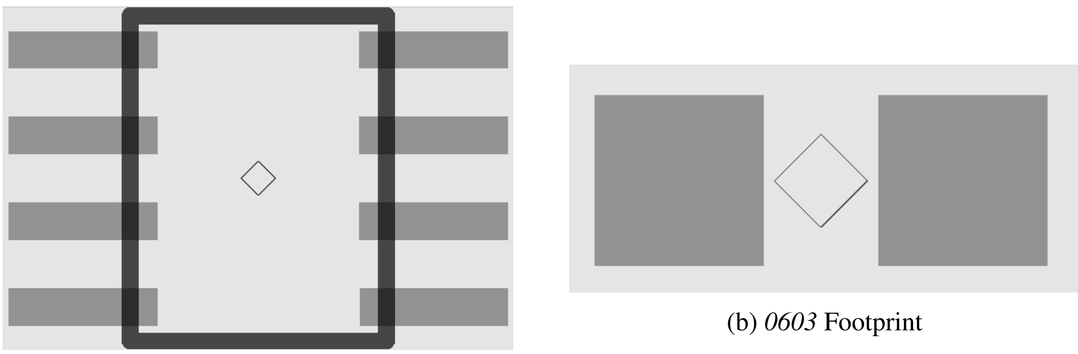


Figure 3.22: Schematic for the PD84006L-E PCB test



(a) SOIC8 Footprint

(b) *0603* Footprint

Figure 3.23: Footprint Images

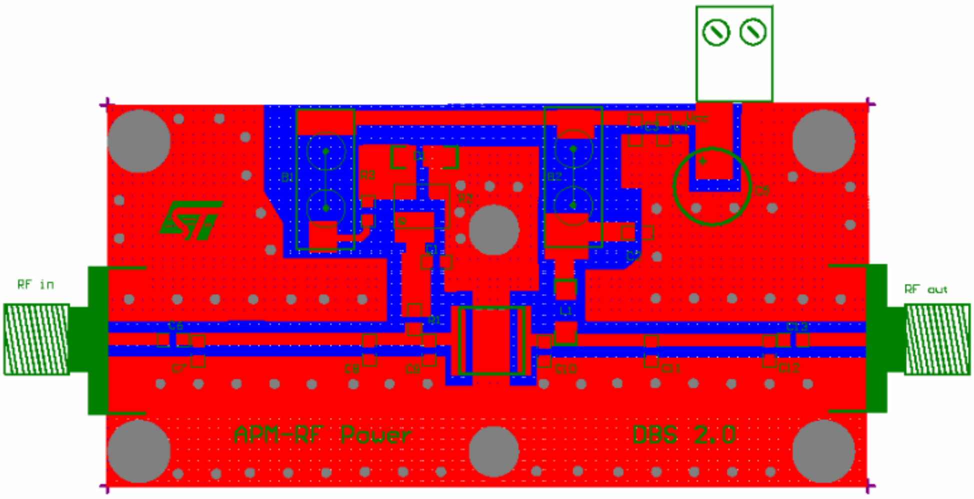
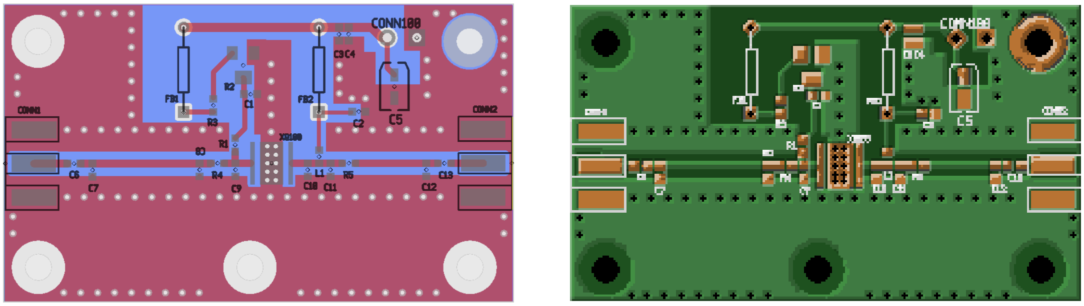


Figure 3.24: PCB Layout from Datasheet



(a) PCB Layout (b) PCB Generated Image

Figure 3.25: Developed PCB

3.4 Summary

Simulation tools are a powerful help in the development of any project. Although they can save a lot of time, to start using them, some time of learning is needed, and to achieve better and faster results is easier to start with simple simulations and with time make it more complex.

Although the idea of having circuit simulations as similar as the real ones, it is important to be aware that these tools are not perfect, and to acknowledge their limitations. Every result should be questioned and analyzed theoretically, because every simulation, and every model, is an approximation to the real system.

Chapter 4

Laser Diode Pulsed Driver

This chapter describes the process of the design of the proposed Laser Diode Driver, using the gEDA schematic tool, and taking advantage of the drivers concepts studied in the chapter 2.4. The circuit will be simulated with Ngspice in order to validate the concept and to tune some values. In the end a PCB will be designed also using the gEDA tools, the PCB designer.

4.1 Equivalent Model Laser Diode

In chapter 2.2 one equivalent model of a laser diode that was provided by one manufacturer, is presented. That model, does not include a diode, meaning that his response will not be the same as a real Laser Diode, it will drive in both directions, the voltage drop is not similar, and other characteristic behaviors from a diode.

To solve this problem, and to have a more accurate model, a diode was added in the circuit. The other components related to the capsule parasitic elements were left in the circuit to preserve those characteristics.

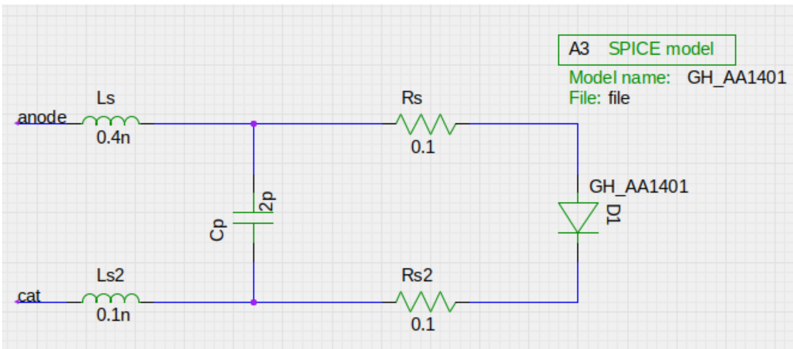
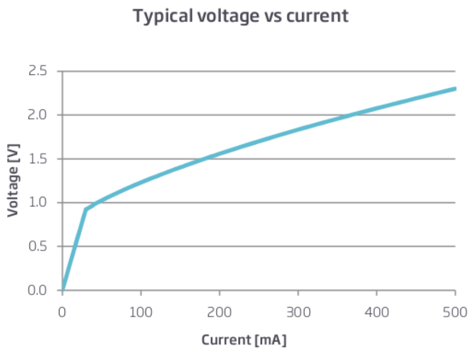


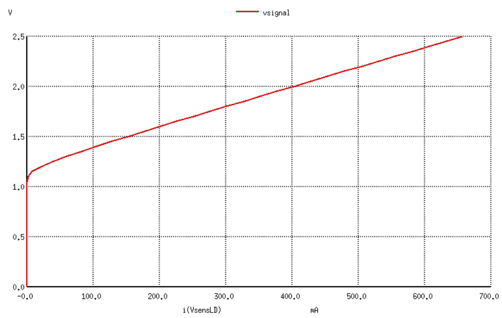
Figure 4.1: Laser Diode Equivalent Model Developed

A Gooch&Housego AA1401 laser diode was choose as a model to replicate with this equivalent model, and the passive elements values were achieved by trial and error by looking at the behavior of the model. The VI characteristics of the G&H laser diode were reproduced as close as possible (see 4.2) using spice parameters such as the Saturation Current, Emission coefficient, Ohmic resistance, Reverse breakdown voltage and other parameters. Worth to mention that the developed VI characteristics are more accurate in the conduction zone.

The new model needed some tunning and the components related to the intrinsic parasitic effects of the package were tuned to better fit the response of the Laser Diode, this part was made by trial and error in order to have a final response similar to the initial, but with the effects of the new diode model.



(a) G&H LD



(b) Tuned LD Spice Model

Figure 4.2: VI Characteristics

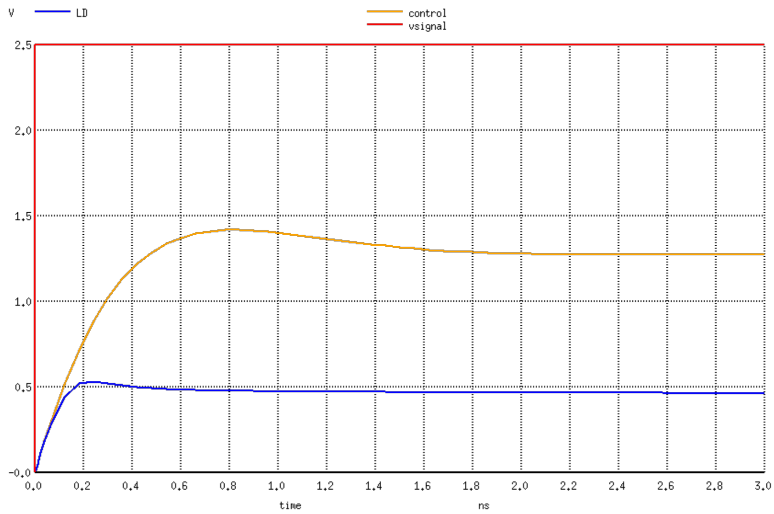


Figure 4.3: Laser Diode Equivalent Model Developed to the Manufacturer Equivalent Model: response to a current step

Figure 4.3 gives the comparison between the developed model for the LD (in blue) and the developed by the manufacturer (in yellow). It corresponds to the voltage at the diode terminals when applying a current step of amplitude of 500mA.

4.2 Proposed Driver

The driver concept chosen as the driver to develop as final product of this dissertation was the Capacitive Discharge, because it provides a fast laser response and an extra functionality was conceived, and emerged the curiosity to test the performance of this circuit. The idea is to drive the laser several times with only one pulse, or to have the laser driving for a longer period of time with only a short pulse, depending on the components that tune the circuit.

To perform this requirement, more capacitors and mosfets were added to the circuit. In this way, we could have more capacitors discharging and more mosfets pulling current, thus the Laser will be driven for a longer period of time, with one pulse only. It can be seen has having several identical drivers working with just one pulse, to drive one single Laser.

To study the possibility of this circuit, the schematic of the Figure 2.15 was adapted to the idea of having 4 drivers working together to drive one laser, and to perform some simulations in Ngspice. In the circuit schematic of the Figure 4.4 is a schematic of such circuit, and it is possible to see different signal sources, all of them with the same signal but each one delayed by 0.15ns. This series of signal sources could be replaced with a component, a Delay Line, which is a component with one input and several outputs, each output delays the input signal the same amount of time. In the Figure **??**, we have a symbol that represents a delay line. It was not possible to find, or develop any delay line model for spice in time to simulate this component, before the developing of the PCB in order to respect the timings for this project. His behavior is straight forward, so it was assumed that there will be no major impact on using the schematic developed with several signal sources, with simulated time delays.

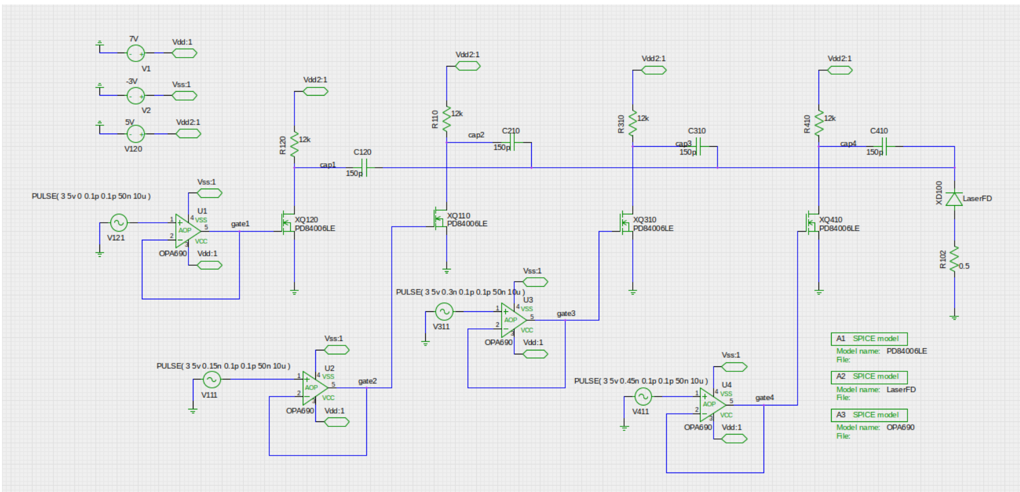


Figure 4.4: Multiple Capacitor Discharge Schematic

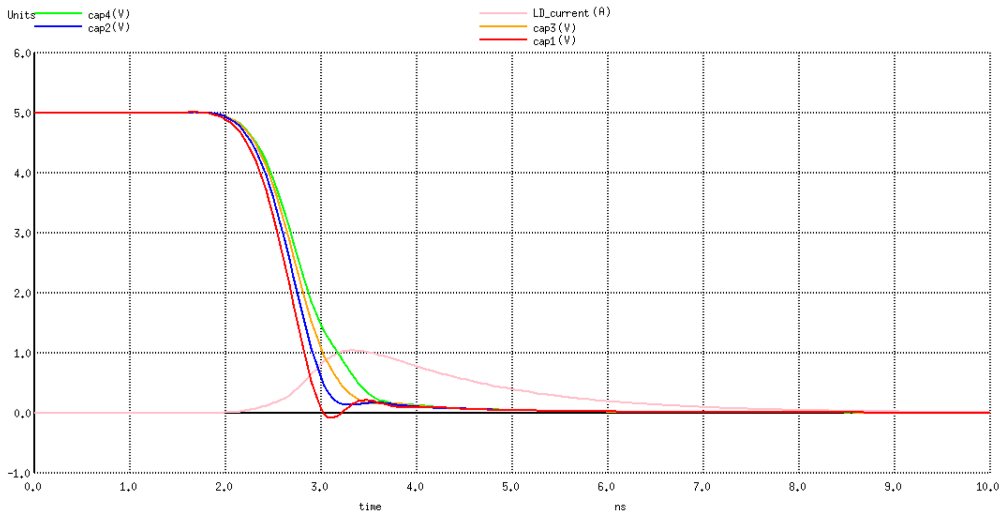


Figure 4.5: Multiple Capacitor Discharge Output

The Figure 4.5 shows the result of the simulations of the Multiple Capacitor Discharge concept. The green, blue, orange,and red, lines correspond to the voltage in the capacitors where it is possible to observe the discharge of the four capacitors. The capacitors are biased for 5V, and then as explained before, when transistor starts to drive the capacitors discharge, pulling current through the LD. Has expected, each capacitor discharge has a delay in time from the discharge of the previous one. The pink line represents the current that goes through the laser. It is possible to see that the laser is being driven by a pulse of 1A peak. The laser was driving with a response of about 0.5ns of rising time for about 3ns.

Overall, the simulation of this concept seemed to have a potential and gave confidence to test different values to test the tuning options. By decreasing the capacitors values, it is possible to have smaller values of current, and a smaller output pulse, due to the fact that the driving time of the capacitor is smaller. That change also reduces the time the capacitor takes to charge again.

4.2.1 Schematic

The process of developing the schematic started with the single Capacitive Discharge, where, as in Figure 2.15 we had the buffer to reduce the charge injection of the transistor. The OpAmp will drive the signal to the mosfet's gate, which in turn, when above certain voltage, will discharge the capacitor driving current through the laser. The mosfet starts to drive when the voltage drop from the gate to the source, V_{gs}, is around 3.7V.

Figure 4.6 is the first of the four drivers designed. In this case, the aim was to experiment four capacitors driving the laser. So we also need to have four OpAmps and four Mosfets. So the circuit in the Figure was replicated four times.

The capacitor C100, charges with the 7V bias source when the mosfet is not driving, this voltage will bias the mosfet as well. When the mosfet starts to drive, the capacitor will discharge.

The next step was to offset the input signal by 3V so we can have the mosfet near the threshold. This was done with two resistors, R101 and R104, and a power source, forming a simple voltage divider.

The decoupling capacitors C103, C105 and C106 were added by recommendation of the datasheet of the opamp.

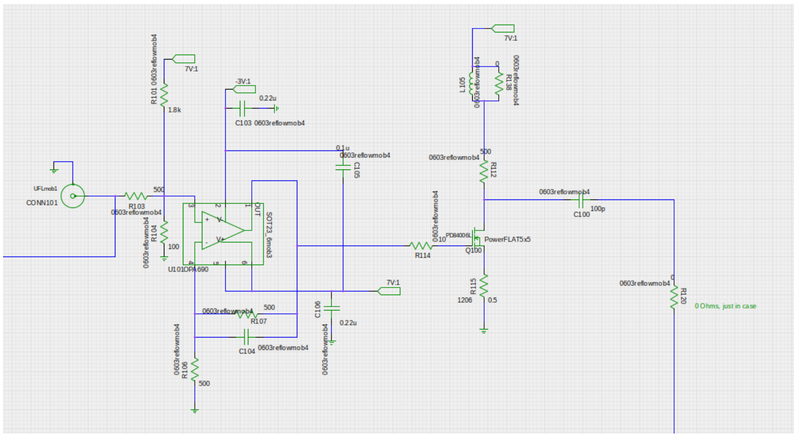


Figure 4.6: Schematic of the Driver 1

Biasing the Laser is also important, to have it near the lasing point, this change improves the time response of the laser because it will take less time to go from the current under the threshold, to a value above, that can make the diode start lasing. The bias can be tuned by using the resistor R134 present in the Figure 4.7. A diode and an inductor, D101 and L103 respectively, was added to the circuit to prevent the current from leaking through these branch when the LD is driving.

Because the OpAmps and Mosfets are such vital components to this circuit, the chosen models to populate this driver, were previously used in some drivers, and they have given good proofs of quality and operation in real life, so the idea to use them again, was to eliminate the possibility of having a component that would not perform as well in such application. In the chapter 3 the main characteristics of this components, and the validation of the spice models for simulation is summarized.

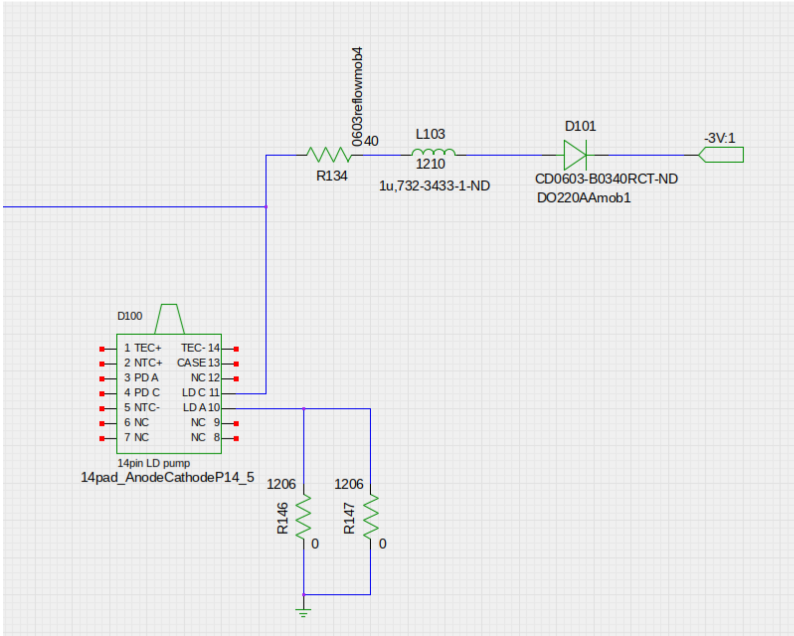


Figure 4.7: LD Biasing Circuit

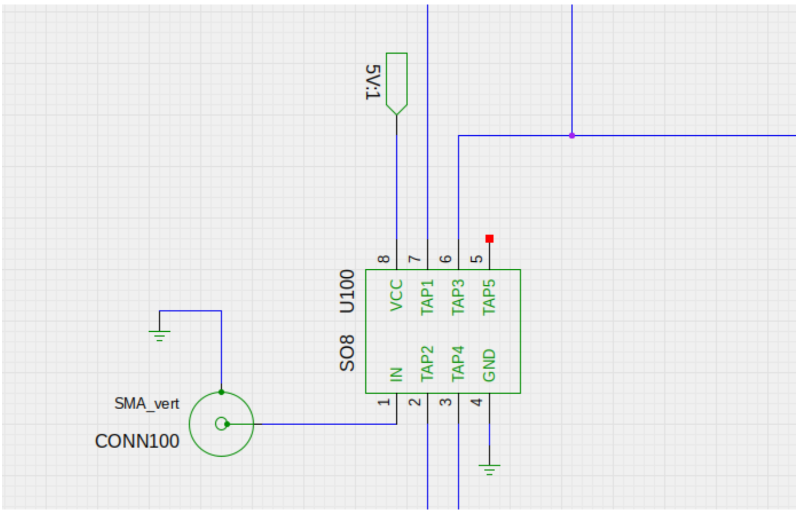


Figure 4.8: Delay Line Connections

The delay line connections are presented in the Figure 4.8. Pin 1 has the signal input, where a SMA vertical connector will be soldered. Pins 2, 3, 6 and 7 connect to the four drivers. Each one with the input signal delayed by 20ns from the previous. Pin 5 also has another delayed output, that is not used. Pins 4 and 8 are for power.

4.2.2 PCB

To design the PCB, a second schematic was built from scratch, the reason of this is being that of the need to include connectors and to match the footprint with the schematic (e.g. the opamps,

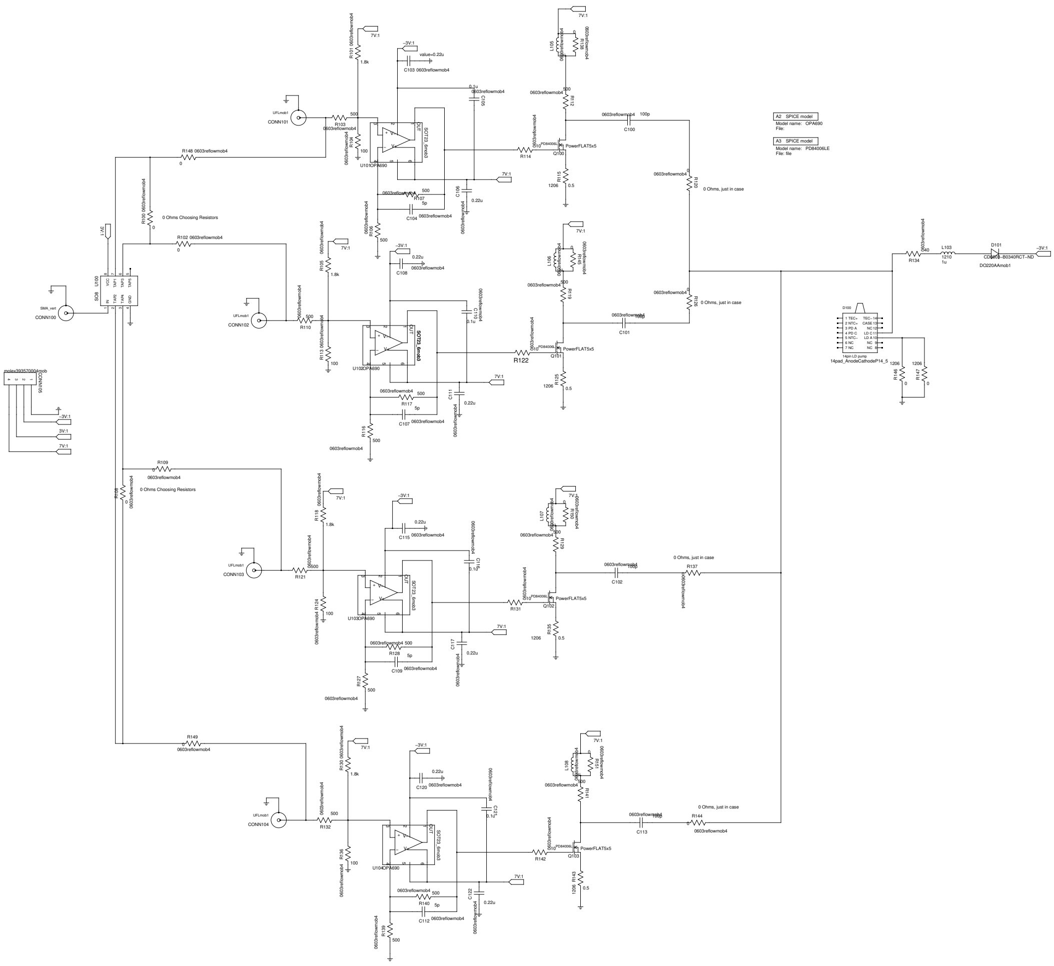


Figure 4.9: Complete Schematic

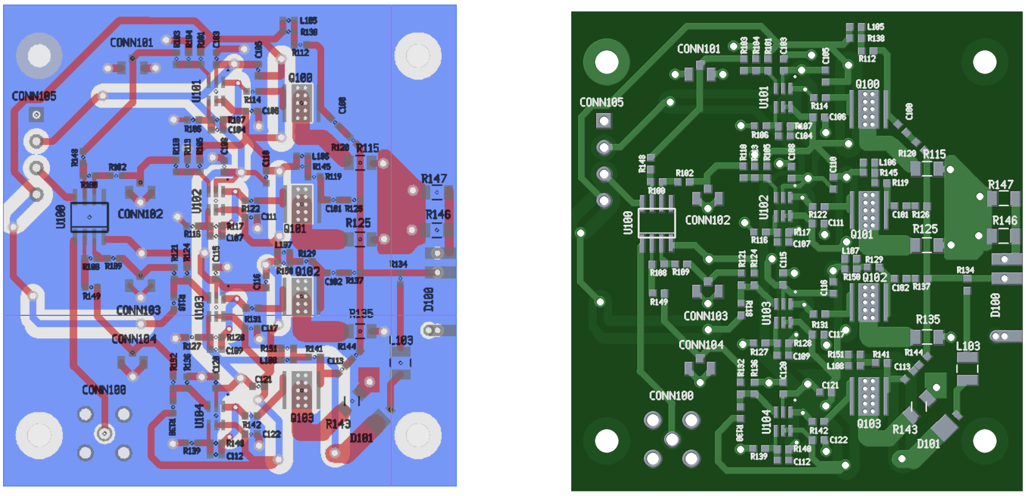
the real ones have six pads, whereas the ones used in the simulation only have five), and by having a new schematic, the other one can be saved to just for simulations.

The PCB was built accordingly to the working circuit designed previously. Some modifications were made to the schematic in order to the PCB to be able to work with every one of the four drivers independently by adding some 0 Ω resistors so it is possible to disconnect each driver from the others, and also from the delay line, and one UFL connector for each driver. This way it is possible to have one circuit working at the time, and the signal input going directly to it. The delay line uses an SMA vertical connector as input.

The PCB has two layers of copper, one of them (in blue in Figure 4.10a) is a ground plane. This layer allows the circuit to have a big area of ground, which prevents the build up of noise in the signal. The other layer has most of the signal paths, which were designed to be as small, and as straight as possible.

It was important to know the exact size of each component package, so the placement of the footprints can be done respecting their size. This way we prevent that when soldering the components they do not make any short circuit, or overlap with another one.

The four big holes in each corner of the PCB, are 5cm apart from each other, this was a requirement from the company. The top left one is also a ground pin, so if the PCB is mounted in a case, the structure will also act has ground.



(a) Final PCB Layout

(b) Final PCB Generated Image

Figure 4.10: PCB design of the purposed circuit, size: 5x5cm (hole to hole)

4.2.3 Soldering the Components

The first step after the PCB arrived was to inspect if there was any defect visible on the board. After this validation, the components were soldered using proper equipment (solder paste, tweezers, vacuum pick-up tool and a oven). The solder paste was applied using a stencil[1].

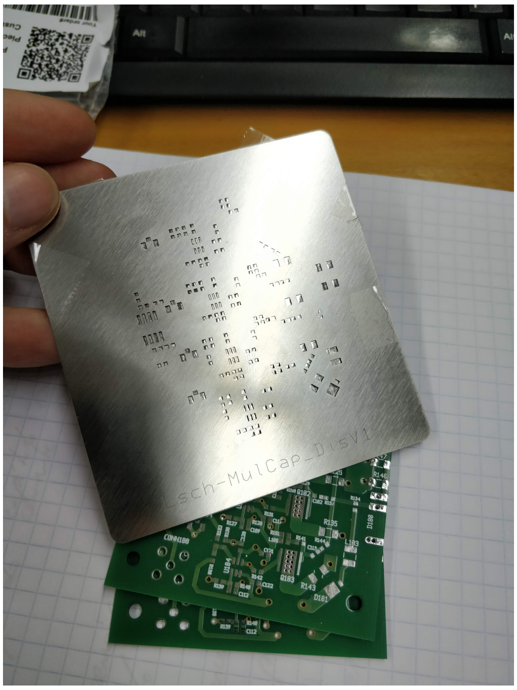
When soldering in the oven it is important to take the time needed to gradually heat the oven and the PCB, so the recommended steps given from the company were to preheat the oven until 140^{o}C/150^{o}C, then insert the PCB inside the oven and slowly rise the temperature until 180^{o}C for about 2 minutes, calling it the soak time. Then rise the temperature until the peak, 230^{o}C, which is called the reflow and here the solder paste becomes shiny and liquid, and all the components are attracted to their pads evenly and after about 30 to 45 seconds. The final step is to turn down the oven, and let the PCB cool down slowly and naturally inside the oven for about 2 minutes, and then open the door and let it become cool at the touch to take the PCB out and inspect the quality of the solders.

Soldering the components in the oven saves a big quantity of time, and also provides a better quality of soldering if done properly. It is important to inspect the PCB after coming out of the oven to check if any component slided and is touching other components that it should not, and also for some other events like tombstoning. Tombstoning, simply, is the wetting of one side of a component before the other side, which causes the setting forces of the solder to lift the component like a drawbridge. Sometimes, it even cause the component to complete stand, like a tombstone.

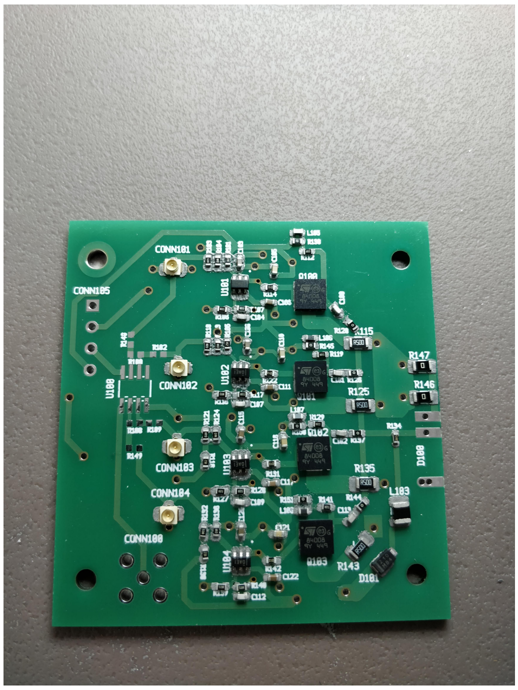
In the Figure 4.11 are photographs of some steps of the process.

At this point, the delay line was not soldered in place, so every driver can be tested independently. The delay line will be soldered only after guarantying that the four drivers work correspondingly to the expected.

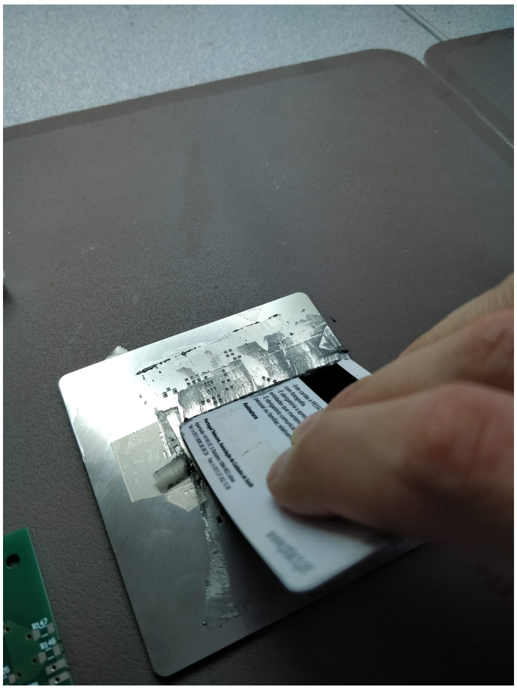
[1]Stencil is a metal foil that has holes matching the pads of the PCB, is using to save time while spreading the solder paste into the pads of the PCB



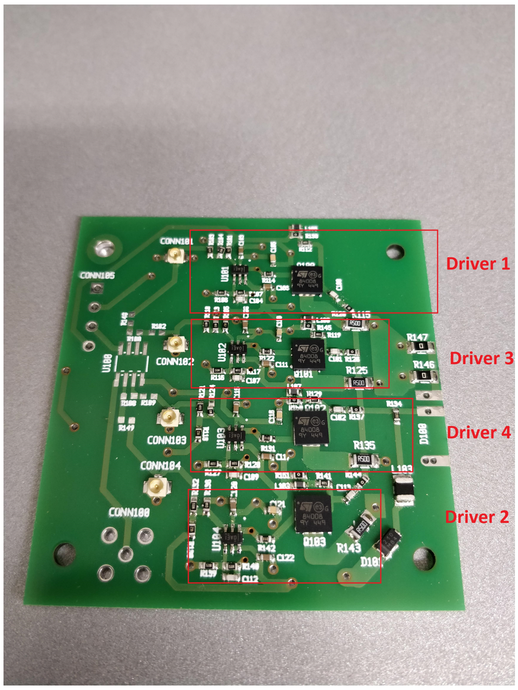
(a) Stencil and PCBs without Components



(c) With the Components, Before going into the Oven



(b) Applying Solder Paste



(d) With Components Soldered

Figure 4.11: PCB Soldering Process Photographs

4.2.4 Board Functional Test

Having the components soldered in place, it is time to test the circuit for short circuits, before powering the system. This was done using a FLUKE 179 multimeter, by measuring the impedance in some critical spots such as power inputs in the OpAmps, Mosfets the other passive components, and also input and output pins.

It is time to finally power up the circuit, for caution the power source was limited to around 200mA to protect the components in case of the existence of some short circuit not detected before.

A resistor of 5.6Ω was soldered in place of the diode laser, to replicate load the of the laser to test the board response to the pulses, without the risk of damaging a LD in this initial step.

First time powering up, the board did not show signs of any problem, it was time to test if the power was getting to every component the way it should. Every pin was tested, and everything was indicating that was safe to input a pulse.

The input signal was a 50kHz, 2.5V, 30ns pulse provided by a Hewlett-Packard 8116A function/pulse generator, and was connected with a SMA connector with 50Ω termination.

The signals were measured with the Oscilloscope LeCroy WavePro 7300 and an active probe LeCroy HFP2500 of 2.5GHz, 0.7pF, 100kΩ. The primary benefit of an active probe over a passive one is higher bandwidth and high signal fidelity performance. The trigger was provided to the oscilloscope directly from the pulse generator by having a 3-way "T" shaped BNC connector distributing the signal from the generator to the oscilloscope and to the board, making this signal the input signal to the board. See Figure 4.12.

The setup of the experiment is shown in Figure 4.13a.

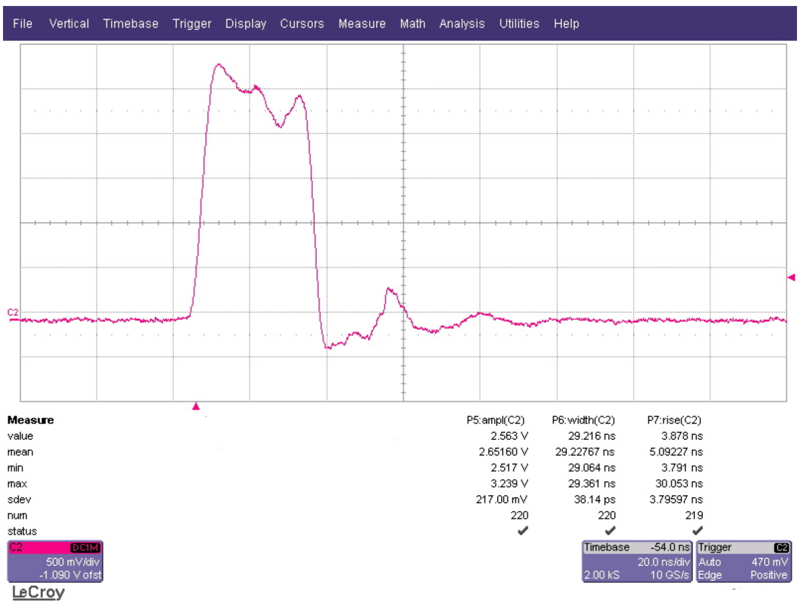
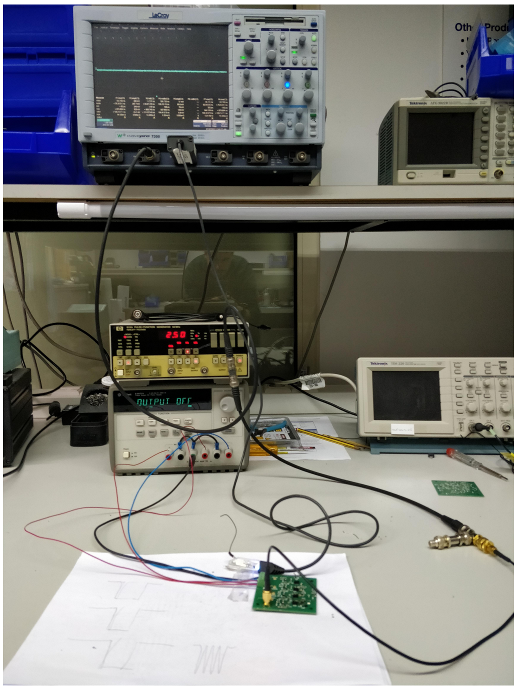
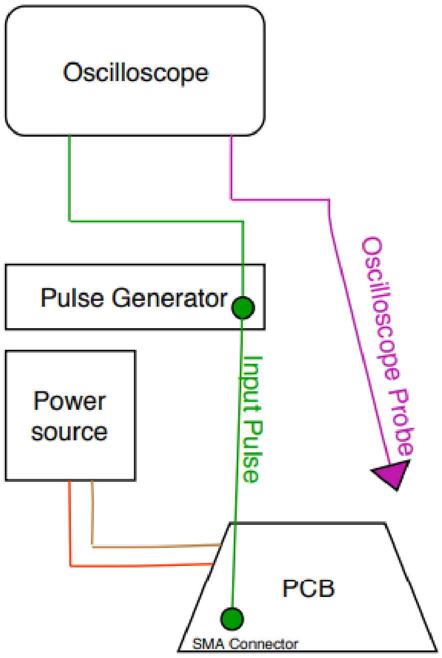


Figure 4.12: Trigger Signal/Input Signal



(a) Fotograph of Setup

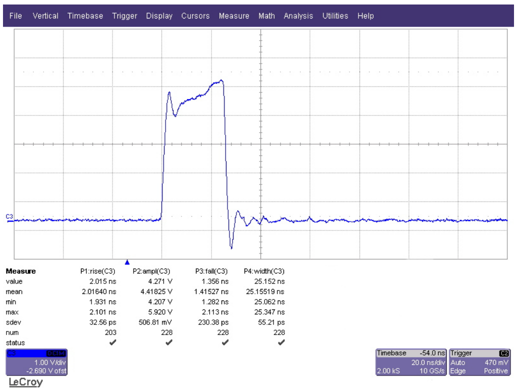


(b) Diagram of the Experiment

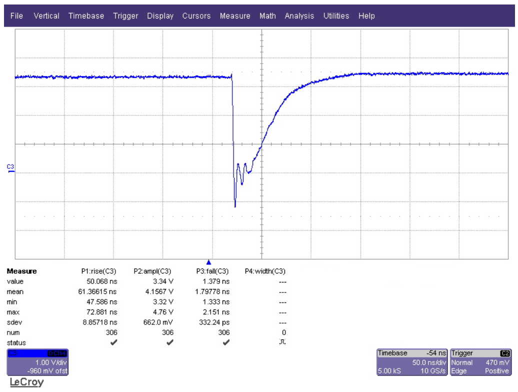
Figure 4.13: Testing Setup

The signal was measured and tested in every significant point of the modulation of the signal, in the four drivers, each one working independently at this point. The circuits had 1.5nF capacitors driving the signal.

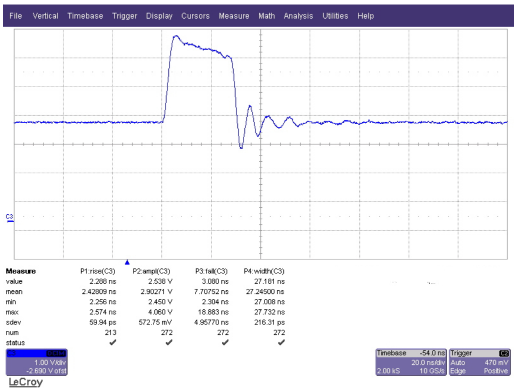
In the next Figures, the pulse modulation of the first driver will be followed until the output of the driver, the LD cathode pin. The other drivers are equal, and work in the same way.



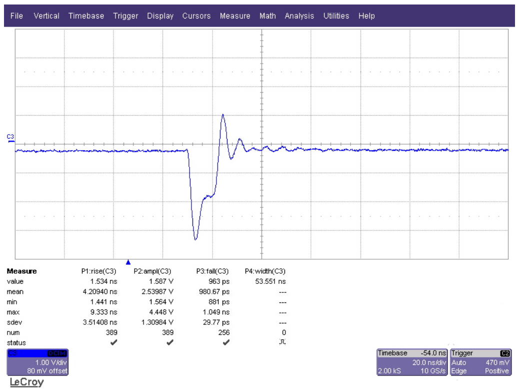
(a) OpAmp 1 Input



(c) Mosfet 1 Drain



(b) OpAmp 1 Output



(d) Capacitor 1 Discharge

Figure 4.14: Different Steps of the Modulation of the Signal with the Driver 1 working alone

Figure 4.14a is the signal that comes from the delay line. To remember, the delay line receives a 50kHz, 2.5V, 30ns pulse (Figure 4.12). The delay line has both Leading and Trailing-Edge accuracy, which means that both rising and falling edge will be as fast as possible independently from the input rising and falling time, the datasheet of this component specifies 3ns maximum for both parameters, which is about 2ns faster than the pulse generator. The smaller the rising time of this signal, means a faster response from the opamp, (the opamp has about 1.8ns of rising time), which in turn will provide a faster response from the whole circuit. By analyzing the Figure, we have an output of the delay line of about 5V[2] and approximately 3ns of rising time and a pulse of about 20ns.

The next step in the pulse modulation, is the opamp output, represented in Figure 4.14b. This output is biased at approximately 3V, and edges at almost 6V. The gain of the opamp is near 2V/V recording the formula of the non inverting gain:

$$G = 1 + \frac{Rf}{Rg}$$

Considering that the power supply is 7V it can never go beyond that value and this explains

[2]The reference of the signal is the horizontal trace in the left side of the image, where it says "C3".

why we only have an output of 6V with an 5V input and gain 2V/V. Remembering the characteristics of the mosfet, it starts to drive when the gate voltage hits 3.5V approximately, and this is the reason why the opamp output is biased around 3V, to have a faster response, so that the time needed to reach the threshold voltage is not necessary because the signal is near that value.

Figure 4.14c represents the signal measured in the drain of the mosfet, where the capacitor that provides the discharge necessary to drive the laser is connected. This pin is biased around 7V, so that the capacitor is able to charge, and also to bias the mosfet so it can drive current when the gate voltage rises from the threshold value. By analyzing the Figure, it is possible to see that the signal is around 3.5V. The intended value was about 7V, so this is a opportunity to optimize the driver, that will be explained in the next section. Then, continuing the analysis, the voltage drop corresponds to the response of the mosfet to the pulse arriving to the gate of the mosfet. The mosfet started to drive current, and that lead to the discharge of the capacitor which in turn, pulled current from the laser diode cathode (which was replaced by a load for this initial experiment). After the voltage drop, the capacitor ran out of charge and stopped driving current and the pulse ended in the mean time, so the capacitor charged again to the biasing voltage.

Figure 4.14d represents the other pin of the capacitor, the one that is connected to the laser driver cathode. This signal is near the 0V, and when the capacitor discharges it drops, in this case, for around -5V, which corresponds to a current of approximately 1A. This voltage drop and having the laser anode connected to the ground, will pull current from the laser, making it drive as expected. It is possible to see some ringing in the signal, when it recovers again to the zone near the 0V, that can be reduced by increasing the value of the feedback capacitor of the OpAmp, but it should not be a problem when the laser is connected because it behaves like a diode, and will not drive that current and it is far from the maximum breakdown reversed voltage of the lasers, which is 2V.

This modulation happens in the four drivers in the same way, being the only difference the delay between each driver. Each driver receives the same signal, but with a 4ns delay from the previous.

Figure 4.16 represents the signal seen from the LD with only one driver. This means that each driver will deliver to the cathode of the laser diode that signal with different delays which, as explained before, will pull the current through the laser.

Figure 4.17 represents the signal that arrives to the laser diode cathode from the four drivers. This signal is also biased, with the same principle as before, so the laser is near the threshold voltage to reduce the time it takes to start driving, providing a faster response time of the laser. The biasing can be tunned accordingly to the laser threshold value by changing the resistor R134.

Figure 4.18 has the simulation of this circuit, so by comparison the circuit is behaving very similarly as predicted. The pink line represents the voltage drop in the LD cathode, represented in the Figure 4.17. The main differences are probably due to some crosstalk[3] between the four

[3]Crosstalk is any phenomenon by which a signal transmitted on one circuit or channel of a transmission system creates an undesired effect in another circuit or channel. Is usually caused by undesired capacitive, inductive, or conductive coupling from one circuit or channel to another.

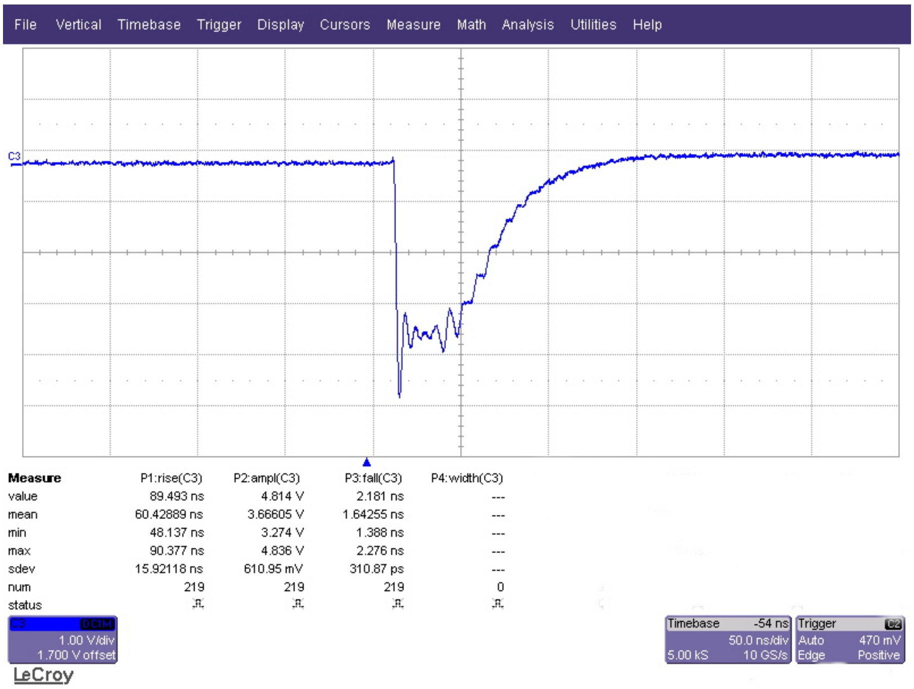


Figure 4.15: Capacitor 1 Discharge, with the 4 drivers working

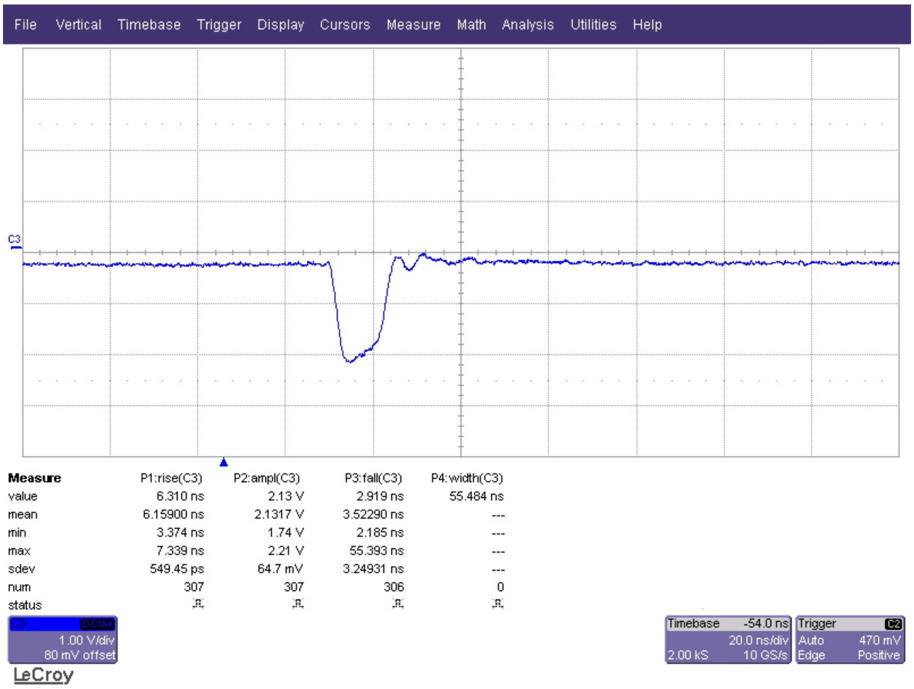


Figure 4.16: LD Cathode Pin with load resistor One Driver Only with 1.5nF capacitor

drivers and also because the size of the capacitor, 1.5nF which is a larger value than the needed, the signals are overlapping. The light red curve represents the expected current in the Laser.

As said before, while the four drivers are working together to drive the laser, the circuit showed signs of crosstalk, and Figure 4.17 shows the difference in the capacitor discharge of the driver

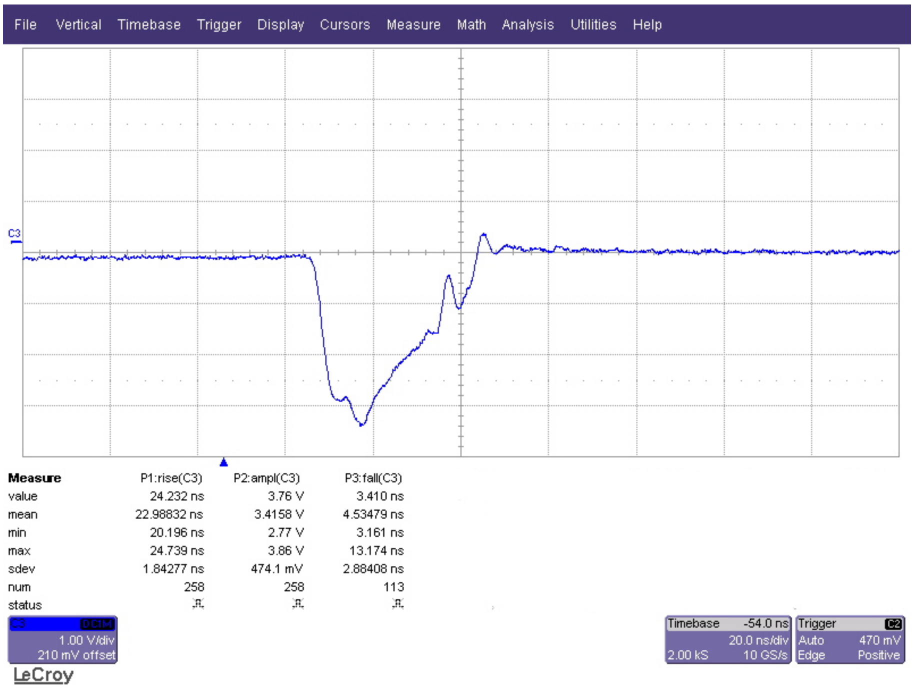


Figure 4.17: LD Cathode Pin with load resistor and the 4 Drivers working with 1.5nF capacitor

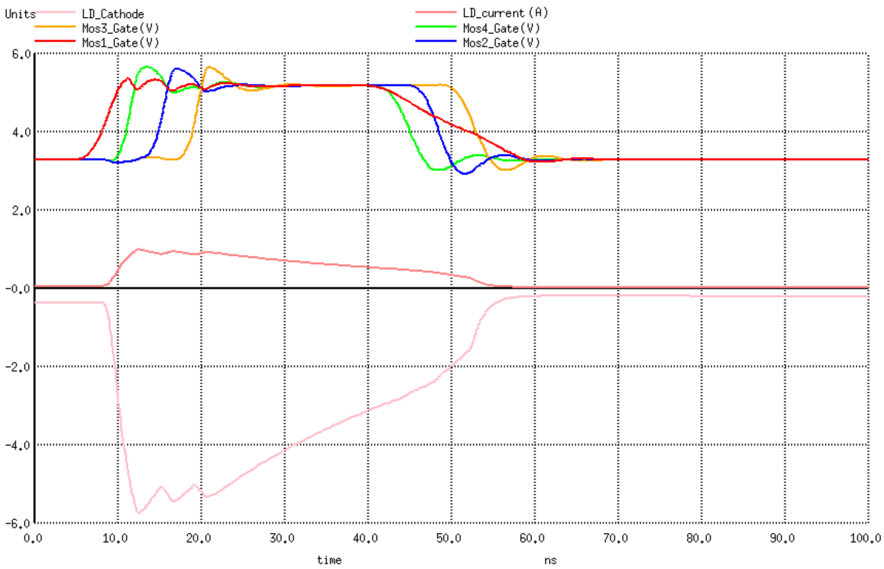


Figure 4.18: Simulation of 1.5nF Capacitor and the 4 Drivers

1. With this figure, it is possible to compare the signal when we only have one driver working (Figure 4.14d)

4.2.5 Optimizations

The first optimization that was implemented was the biasing of the drain of the mosfet, and the capacitor. Before, in the validation tests the biasing was not as expected. Around 7V biasing voltage was planned, and with the resistor R112 of the Driver 1 (and the equivalent resistor in the other drivers) it is possible to tune the biasing. A 240Ω resistor was soldered in place of the original one of 500Ω. With the new one, there is a smaller voltage drop, and it was possible to have more than the previous result which was around 3.5V. The new resistor is now providing around 5V of biasing as the Figure 4.19 shows (this Figure is equivalent to the 4.14c, but with a better bias).

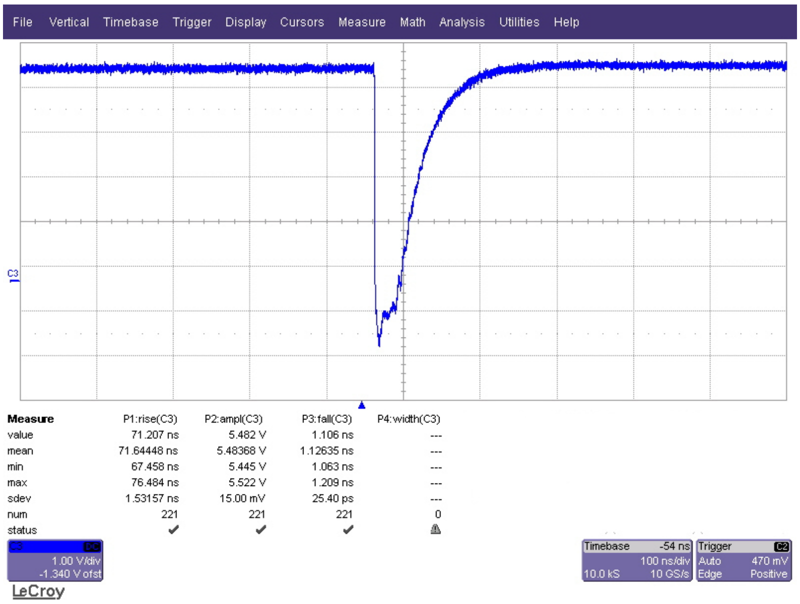
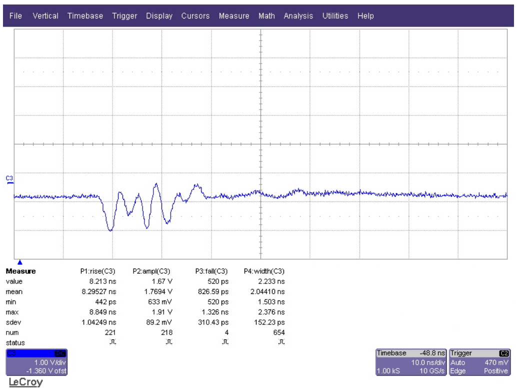


Figure 4.19: Capacitor and Mosfet Optimized Biasing

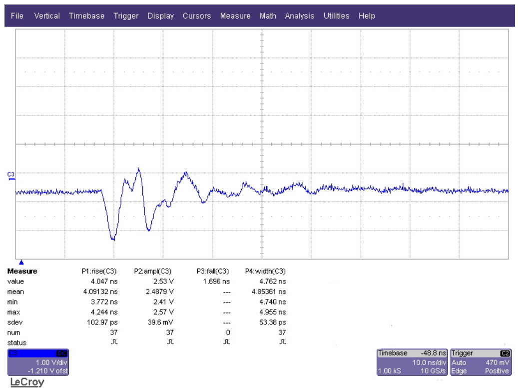
Here different capacitors were tested to understand the differences in the behavior of the signal, and to better understand the limitations of the circuit. The experimented values were 47pF, 56pF, 82pF, 100pF and 200pF.

With the 47pF capacitor is possible to see the 4 pulses, each from a different driver. Although this result is not perfect, and that is probably because of the crosstalk between the different drivers. This phenomenon could be because of the inductance created by the resistor connected in the LD pins, but that would improve the capacitance in that spot so only testing. Ideally a LD should be connected there. Also, some ringing is happening in the output, and that could be reduced by replacing the capacitors from the feedback of the OpAmps. The circuit with these capacitors can provide to the laser currents of about 300mA.

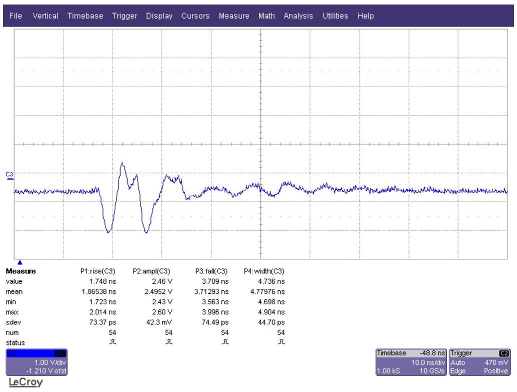
By the time this conclusion was achieved and the 200pF capacitors were soldered in place, the board started to show signs of instability and was pulling the maximum current allowed from the power source, and that suggested that some component or connection could have been damaged by the heat of the soldering iron. See Figure 4.21. However, there was not enough time to debug and



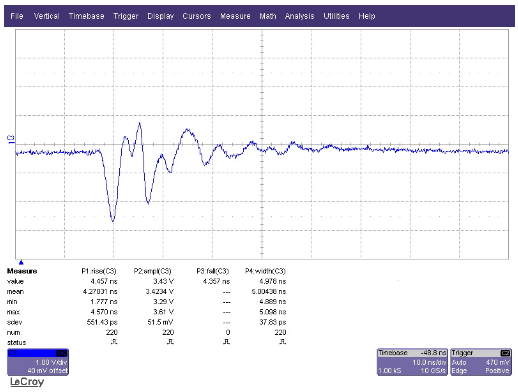
(a) Laser Diode Cathode Pin with 47pF Capacitor



(c) Laser Diode Cathode Pin with 82pF Capacitor



(b) Laser Diode Cathode Pin with 56pF Capacitor



(d) Laser Diode Cathode Pin with 100pF Capacitor

Figure 4.20: LD Cathode Pin Signal with Different Capacitor Values

experiment other components or even to connect a Laser Diode to the pins some positive results could be concluded.

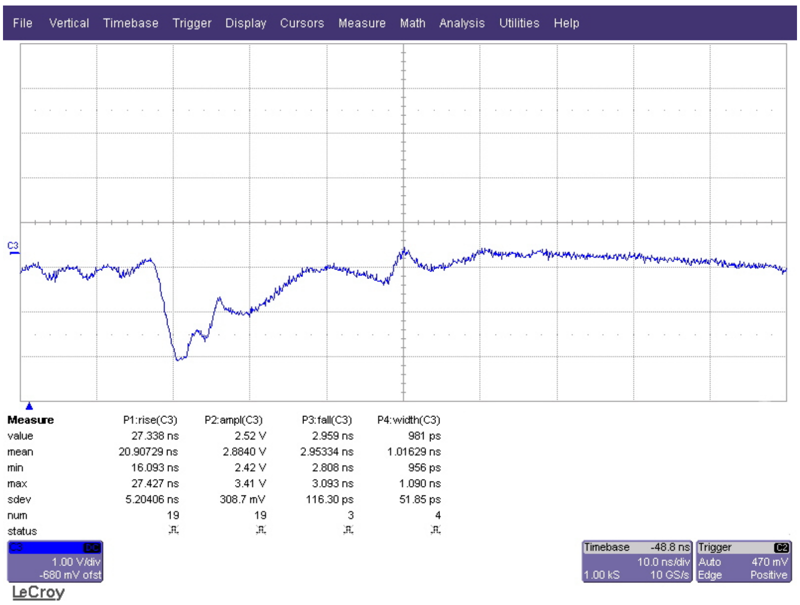


Figure 4.21: Laser Diode Cathode Pin with 200pF Capacitor

4.3 Summary

This circuit was built to be able of driving the laser diode four times with only one short pulse. It has four drivers, all similar. Each one is capable of delivering the signal to the laser diode in the same way, but with different delays. Each driver works perfectly when used independently. When the four drivers work together some crosstalk interferes with the signal, that could be probably reduced if some better ground planes were designed in the PCB. During the realization of this project, there was not enough time to test the board with the LD but electrically the signals were the expected to be able to drive the laser although if a LD was used the behavior could have small differences assuming that the LD connections have different inductance, capacitance and impedance values than the resistor soldered in its place.

Chapter 5

Conclusions and Future Work

This chapter contains the summary of all the objectives that were accomplished, the strengths and weaknesses of the driver that was developed. It also has some considerations related to the circuit developed, and some aspects that could improve the behavior of the driver in a future work.

5.1 Conclusions

The main objective of this work was to study different laser diode drivers to acquire the knowledge needed in order to understand the pulse modulation that a laser diode requires to operate, so a laser diode driver could be proposed, simulated and tested. This part of the work started by studying some existent drivers produced by the company, for a first contact to the pulse modulation and some drivers concepts.

After this process, some topologies were synthesized and simulated to understand their differences and working method. The use of open source software was a requisite of this work, only for validation of the use of license free softwares and the usability of these.

The final objective was to have a document that summarizes the work and could be used by a unexperienced reader to have an introduction in the topics of lasers diodes, laser diode drivers and also the gEDA tools.

All these objectives were accomplished. The introductory knowledge of the topics is presented in the Chapter 2 where the fundamentals of diodes are explained, and the differences between light emitting diodes and laser diodes. In this chapter there is also a compilation of different laser diode drivers concepts. Chapter 3 collects the first contact with the gEDA tools, and the precaution needed to work with them correctly, and to validate the results. While working with simulation software it is important to have in mind that it is a useful tool but it is necessary to test the validity of the models depending on the complexity and the availability of existent models of the components. Chapter 4 summarizes the process of developing a driver from the concept until the PCB designing, and finishes with the assembly of the components and the experimental work. The circuit proved to be working within the expected and the signal is modulated as required to drive the laser diode with each driver independently and also with the four drivers working together, although some unexpected effects were present.

While developing this work, the fabrication and shipping of the PCB delayed the process in a few weeks, and was one of the main reasons that was not possible to test the board with a laser diode connected for a more interesting conclusion. Another PCB should have been populated for backup in case of the main one stopped working during the process. This was another reason for this work to not have results with a laser diode, which could be more fulfilling. An important improvement could have been the population of several PCBs, and tested in case some of them break or had a malfunction, which was the case. The only one populated, probably burnt one or more components when applying the heat of the solder iron several times to implement the optimizations. This could probably be also avoided if the components were more distant from the others, but ideally they should be closer to avoid interference from the paths. Having a more planned work order in order to test the PCB was also an improvement that could have lead to a better exposition of results.

5.2 Future Work

The bigger improvement this work could have, is the reduction of the crosstalk present in the signal by planning a better ground plane and different inductance values in the path of the laser. It could also have been better predicted. Another improvement in this work could have been a better methodology when simulating the circuits, because there was a lot of time invested in debugging the netlists from some components models, and it was due to the use of an incorrect methodology.

Future work might involve the development of a more adequate model of the laser diode, one that would be based on the extraction of the laser parameters from measurements of the reflection coefficient for estimation of the parasitics elements of the package and measurements of laser transfer function for estimation of intrinsic laser parameters. A simple linear model might be sufficient for smaller currents, but since the requirements of the driver is to operate with large currents a large signal model would be required. This by itself would constitute a master thesis by itself, but this would probably be very valuable to MWTechnologies.

Appendix A

Software Instrutions

Here will be summarized, the instructions that need to be written in the terminal, in order to use the several softwares used in this work.

A.1 Ngspice

After the schematic is finished, a *netlist* is needed, so Ngspice can run the simulation. To do that, the terminal must be opened (in the folder where the schematic is saved) and run the following command:

```
> gnetlist -g spice-sdb -o netlist_file.net schematic_file.sch
```

To get the results from the Ngspice simulator, we just have to run in terminal:

```
> ngspice
```

After this, the netlist needs to be loaded in the simulator as follows:

```
ngspice 1 -> source netlist_file.net
```

After this, the netlist is loaded into the simulator and we just have to proceed to the analysis.

If we look closely the *"SPICE include"* symbol present in 3.1 was not included in the schematic, because his objective was to include a file with Spice instructions namely following command, which was used directly in the terminal:

```
> tran 1m 100m
> plot vin vout
```

This Spice commands perform a transient analysis, with a step size of 1ms and a duration of 100ms, and then plot the results of the nodes *vin* and *vout*, see 3.3.

A.2 PCB Layout Tool

After the schematic is built, we need to create a *.prj* file, containing this instructions:

```
elements-dir ./footprints
schematics schematic_file.sch
output-name name_of_PCB_file
```

The *" ./footprints "* is the path to the folder where the footprints are, (the example fits when the footprints are in a directory that is inside the same directory has the schematic).

After this, in the terminal we should write:

```
>gsch2pcb -v name_of_file.prj
```

After this, several files will be generated. The one we will look for is the *name_of_PCB_file.pcb*, that we should open with the PCB software. Opening that file, we will see all the footprints present in the schematic.

The terminal should display a message like the following:

```
1. Run pcb on your file name_of_PCB_file.pcb.
You will find all your footprints in a bundle ready for you to place
or disperse with "Select -> Disperse all elements" in PCB.

2. From within PCB, select "File -> Load netlist file" and select
name_of_PCB_file.net to load the netlist.

3. From within PCB, enter

:ExecuteFile(name_of_PCB_file.cmd)

to propagate the pin names of all footprints to the layout.
```

Now, we should follow the instructions given by the terminal message.

In the gEDA website, is possible to find a " Getting Started with PCB " link [1], where we can find the most relevant, and important information for a beginner to start designing a PCB.

[1] http://www.delorie.com/pcb/docs/gs/gs.html

A.3 Gnuplot

Open gnuplot by writing in the terminal:

```
>gnuplot
```

Then, to produce graphics just right in the terminal:

```
>plot "file.txt" using 1:2 title 'yaxis' with lines
```

Here the file.txt has values separated by columns, and we are seeing the values of the first and second columns. The file can have more columns, or it is even possible to see graphics from different files by writing:

```
>plot "file.txt" using 1:2 title 'yaxis' with lines, \
>"file2.txt" using 1:2 title 'yaxis' with lines
```

Appendix B

Lasers to Drive

This appendix has the main specifications of the Lasers intended to drive with the developed driver. The driver was built taking in consideration these lasers characteristics.

B.1 II-VI Laser Enterprise CM97A1064

This Laser module has been designed as a light source for pulsed fiber lasers and CW (Continuous Wave) applications that require 1064nm single mode light. Processes and techniques of coupling the fiber to the laser allow high output powers that are very stable with both time and temperature. Devices achieve high kink free output powers of 1.5W pulse peak.

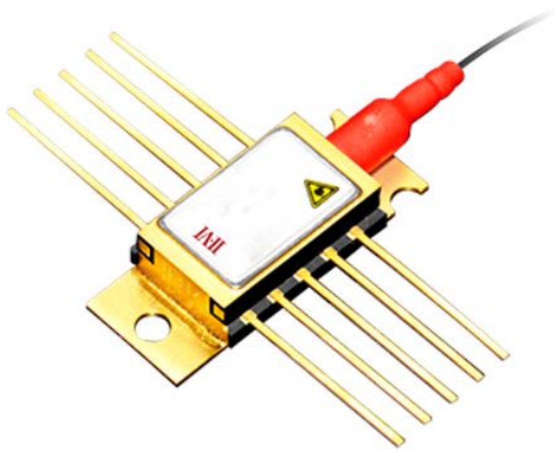


Figure B.1: II-VI Laser Enterprise CM97A1064 laser module

His top features are:

- High kink free pulse output power, up to 1.5W peak
- Wavelength: 1064 ± 5nm
- Short pulse operation of 5ns-500ns
- Polarization maintaining singlemode optical fiber
- Internal thermoelectric heat pump and monitor diode
- Hermetically sealed 10-pin mini-butterfly package

B.2 G&H AA1401 series

This module is ideal in applications where low relative intensity noise (RIN) and stable polarization-maintaining properties are needed.The module contains a thermo-electric cooler,thermistor, and monitor detector and is designed and built using G&H's high reliability platform for defense applications.

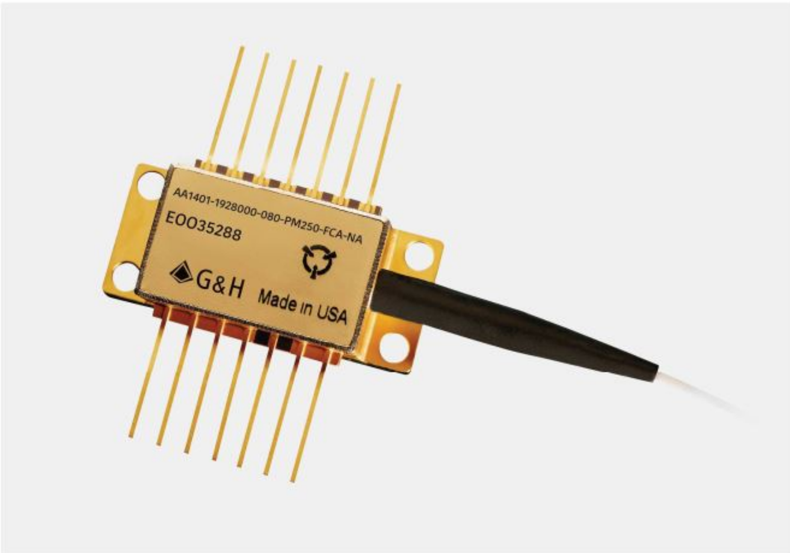


Figure B.2: G&H AA1401 serie laser module

His top features are:

- C-band and L-band wavelengths 1537-1565 and 1565-1617 nm
- 40-100 mW ex-fiber output power options
- ITU grid wavelengths, 50 or 100 GHz spacing
- Low RIN

- PM or SM fiber
- High isolation option
- Laser welded, hermetically sealed
- Built in thermistor and monitor photodiode
- Optional Bias-T[1]

B.3 Innolume LD-10XX-YY-p1200

This fiber coupled laser diode may be configured to operate in CW (up to 600mW) or in pulsed mode and may optionally be equipped with a Fiber Bragg Grating (FBG) for spectrum stabilization. Especially designed for seeding application, Innolume pulse laser diode features up to 1.2W of low noise peak optical power, broadened spectrum allows to suppress Stimulated Brillouin Scattering (SBS) in high power fiber lasers.

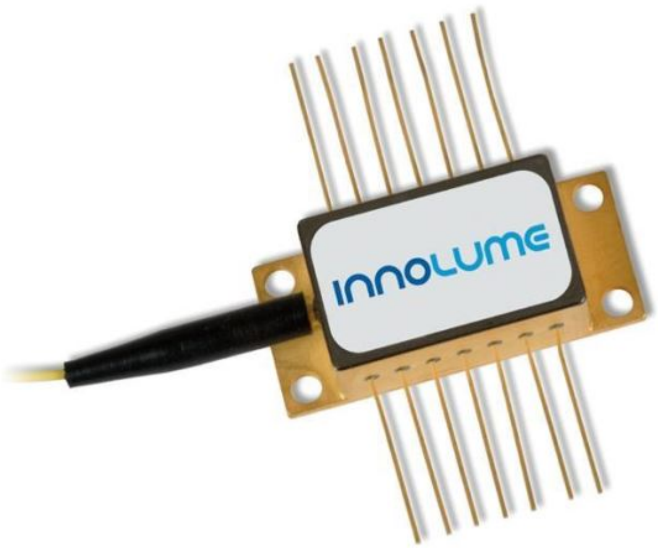


Figure B.3: Innolume LD-10XX-YY-p1200

His top features are:

- High power (1200mW) low noise optical pulse
- 600mW CW output power

[1] A bias tee is a three-port network used for setting the DC bias point of some electronic components without disturbing other components.The low-frequency port is used to set the bias; the high-frequency port passes the radio-frequency signals but blocks the biasing levels; the combined port connects to the device, which sees both the bias and RF. It is called a tee because the 3 ports are often arranged in the shape of a T.

- Broadened spectrum to exclude Brillouin scattering
- Any wavelength from 1030-1090nm range available
- Proprietary mirror coating technology enabling long life-time

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