ANALYSIS OF TWO CHANNEL SEQUENTIAL NITROGEN LASER CIRCUIT

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The undersigned hereby certify that they have read and recommend to the School of Graduate Studies for acceptance a project entitled “Analysis Of Two Channel Sequential Nitrogen Laser Circuit ”by Solomon Zerihun in partial fulfillement of the requirements for the degree of MASTER OF SCIENCE IN PHYSICS.

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Abstract

The analysis of two channel sequential nitrogen laser circuit is developed and scaling parameters are identified with Fortran.f90 programing so as to enable a study of the laser over its range of discharge modes. Results are presented for critically damped laser gap case and for the more typical case of critically damping factor 0.4. The analysis shows in a typical nitrogen laser the rate of rise of the laser gap voltage $\frac{dV_g}{dt}$ prior to laser gap breakdown is 0.5kv/ns and such a $\frac{dV_g}{dt}$ is required for a uniform breakdown across the laser gap for a good lasing action by comparing two channels. For effectively critically damping factor at $\alpha_{effL} = 0.4$ the normalized power absorption is increased from 0.00005 to 0.00015 for the first channel.For the second channel it increases from 0.005 to 0.017 at similar damping factor.

Chapter 1

INTRODUCTION

In this introductory chapter, the basic concept and types of laser based on their classification are presented in short and simplified form. Litrature review of nitrogen laser, objective of the project, Justification and structure of the project are also part of this chapter.

1.1 Basic concept of lasers

The word laser is actually an acronym for Light Amplification by Stimulated Emission of Radiation. The laser generates and amplifies light energy. It stimulates electrons to give off photons of light in an organized fashion and then channels them with mirrors to form a single beam. Instead of many colors of randomly directed light, like the light emitted from a light bulb, the light waves are emitted at the same wavelength, heading in the same direction at the same frequency. This coordinated beam of light may then be used for many applications. The process which makes lasers possible, Stimulated Emission, was proposed in 1917 by Albert Einstein. No one realized the incredible potential of this concept until the 1950's, when practical research was first performed on applying the theory of stimulated emission to making lasers. It wasn't until 1960 that the first true laser was made by Theodore Maimam, out of synthetic ruby. Many ideas for laser applications quickly followed. Still, the early pioneers of laser technology would be shocked and amazed to see the multitude of ways that lasers are used by everyone, everyday, in today's world. Now we have diffeerent type of lasers.There are many ways to define the type of laser. Based on its pumping scheme a laser can be classified as

- Optically pumped laser
- Electrically pumped laser

  On the basis of the operation mode, laser fall into classes of

- Continuous Wave Lasers
- Pulsed Lasers.

  According to the materials used to produce laser light, lasers can be divided into three categories:

- Gas Lasers
- Solid State Lasers
- Semiconductor Lasers
- Other Laser Devices

1.2 Litrature Review Of Nitrogen Laser

The nitrogen laser was developed in 1963 by H. G. Heard[1], who succeeded in producing 10-W pulses of UV light (which sounds impressive enough but with pulse widths in the nanosecond range, the average power of such a laser was incredibly low). Development continued and TEA (transverse electrical discharge at atmospheric pressure) nitrogen lasers capable of producing megawatt powers using nitrogen at atmospheric pressures appeared. This laser was an important milestone in UV laser development that led directly to the more powerful excimer laser. Among other things, development of the nitrogen laser led to advances in the production of high speed, high current discharges required for a high efficiency nitrogen laser and later for the excimer laser. Today, the nitrogen laser is found primarily in the lab and is still a useful source of coherent UV light, producing pulses with milli-joule energies and pulse widths around 10 to 20 ns. Owing to the ease of construction, it is also a favorite home-builtlaser for both amateur laser constructors and small labs on a budget.These inexpensive lasers are commonly used as work horses in biology and chemistry labs[2].For this rapid and extensive development,there were various modifications on the original work, reported by Leonard[2],Gerry[3],Shipman[4] and various researchers.Most of the information available from the field of nitrogen laser publications more or less deal with constructive details and also describe the dependance of the laser out put on different parameters, such as the gas pressure in the laser tube, the spark gap inductance, the characteristics impedance of transmission line, the discharging voltage and the nature of driving electrical circuit. Efficient operation of pulsed gas laser having very short upper state life times depend strongly on the property of the discharge circuit.Many papers have been published on the optimization of the energy transfer from the source to the laser channel. The realization of lasing action in N_2 second positive system was reported by H.G Heard in 1963. Heard has seen that the second positive system of N_2 i.e $(C^3{}_u \rightarrow B^3{}_u)$ at 337.1nm to be in the stimulated emission,and the theory of pulsed nitrogen laser system has been considered by Ali et.al[7]. A general rate equation analysis for three level laser UV laser system has been only done by Elton et.al [8]. By other researchers laser channel operates optimally at pressure of 7.48 kPa giving peack power of 163kW with pulse width 7.4ns to 2ns pressure 7.45kPa to 9.45kPa efficiency of power was 0.040 t0 0.050[11]. on optimizing the power the optimum power absorbed by nitrogen laser is around 70 percent for critically damped done before[14]. On parameric study of the nitrogen laser[9], measurement of nitrogen laser channel like current, inductance, and resistance[10]is also done on nitrogen laser. The transition $C^3{}_u \rightarrow B^3{}_u$ of N_2 is an example established by the lower state of the transition electron collision. Super radiant oscillation has been observed, in this transition at power level in excess of 2MW for a pulse length of 10ns. The calculation indicates that the preferential excitation of the nitrogen ${C^3}_u$ state is $\sim \mathit{\Pi}\alpha_0$ is near 15eV. Since the lower state of the transition is metastable state on the time scale of interest, a rapid rising high E/p discharge is required, in addition to direct excitation by collision, refined theoretical treatment of the nitrogen second positive system have included the effect of collisional ionization of the state ${C^3}_u$ [3]. Finally we observe that N_2 laser is increasing at times it is unfavorable , one way to over come this problem, and probably the best means is to develop home built lasers using locally available materials. It is hoped that researchers effort in this area will increase in the future. Laser vary in complexity from simple home built nitrogen laser which delivers only a pulsed 20kwatts of UV light at 337.1nm in a few nanosecond flashes to, elaborate every high power multi beam line system. In addition to its relative simplicity of construction, the nitrogen laser is one of the most useful becuase of its effectiveness as a pump for tunable dye laser and this combination is particularly powerful since it open ups the possibilitys relative and extensive laser based spectroscopy.

1.3 Objectives Of The Project

The objective of this project is to

- studying parameters of nitrogen laser
- establishing the value of nitrogen laser rate of rise voltage for the uniformity of discharge through the laser channel.
- establishing the value of nitrogen laser power absorption.

1.4 Justification

The out put of nitrogen laser is the result of different physical setting and internal parametric values in its design. Such as Laser channel, spark gap, capacitors setting and their parametric values.The laser channel discharge current in a Blumlein-type nitrogen laser is measured using electrical discharge by achieving an electrical pump in a given circuit in order to optimize the channel laser power absorption and the laser gap voltage which is explained as below. The transversally excited pulses of nitrogen laser depend for its operation on two important requirements:

1) A uniform discharge occurring throughout the length of the discharge channel. This uniformity depends on a sufficiently high rate of voltage $\frac{dV}{dt}$ across the laser gap

2) A sufficiently optimum (high) power absorption (rate of energy absorption) in the laser gap plasma during the main discharge.

1.5 Project Structure

This project consists of five chapters. In chapter one literature review and objective with justification are described which form the introduction to the project work. In Chapter two principle of nitrogen laser mainly on principle of laser action, population inversion, essential element of basic laser, and pumping mechanism, structure and out put characteristics of nitrogen laser are briefly described. Chapter three nitrogen laser parameters for both two channels with effective parameter and integration procedure are presented. Chapter four describes general analysis of nitrogen laser with result and discussion. Conclusion about the project and recommedations for future work are presented in chapter five.

Chapter 2

Principle Of Nitrogen Laser Action

Principle of laser action, population inversion, pumping mechanism are discussed in this chapter.In particular rate equations on the formation of laser action, essential elements of basic laser such as lasing medium, pumping source and resonator cavity with pumping mechanism of nitrogen laser will be discussed. In addition, the out put characteristics of nitrogen laser is also part of this chapter.

2.1 Principle of laser action

The interaction of light with matter involves three processes: photon absorption, spontaneous emission and stimulated emission. In the description through out these processes, we consider a simple two level energy system represented in Figure 2.1, where E_1 and E_2 are the lower and higher energy levels with populations N_1 and N_2 , respectively. Normally, atoms or molecules depending on the laser material undergo repetitive jumps from one level to the other by either the pump source or the emission of photons.

Photon absorption: When incident radiation is absorbed by the matter the atoms may jump from the lower level to the upper level, with a discrete amount of energy given by hν = E_2 - E_1 , as shown in Figure 2.1a. Due to the energy transfer from E_1 to E_2 , there is an absorption of photons, with the absorption rate given by

$$\frac{dN_1}{dt} = \frac{-dN_2}{dt} = -\beta_{12} N_1 \rho(\nu) \tag{2.1.1}$$

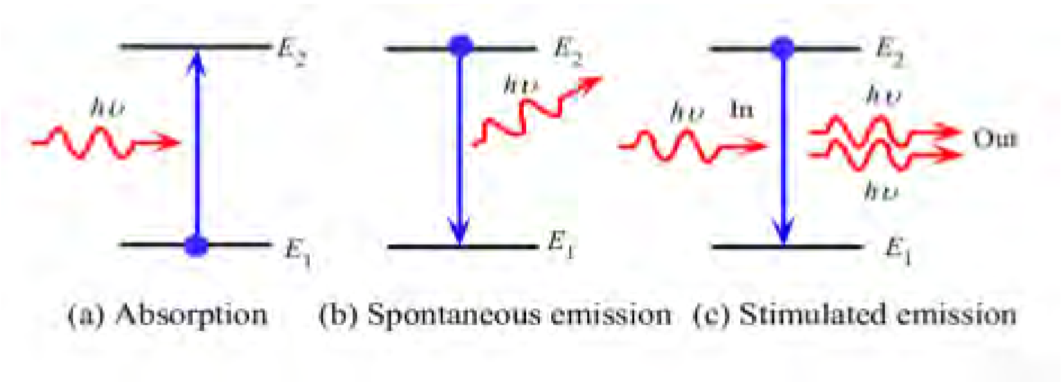

Figure 2.1: Energy conversion processes involved in laser action

where $\rho(\nu)$ is the spectral energy density (intensity) at a frequency ν, and β_{12} is Einsteins coefficient of absorption. In the absorption process, a photon is annihilated.

Spontaneous emission: The excited atoms in the upper level are unstable, thus they decay to the lower level by releasing some of their excess energy in the form of photons. The amount of excess energy is given by hν = E_2 - E_1 , as shown in Figure 2.1b. Spontaneous emission processes are random and isotropic in nature, thus occur without any external influence. The probability of the process to occur is defined in terms of the decay rate of the upper level population and the increase rate of the lower level population

$$\frac{dN_2}{dt} = \frac{-dN_1}{dt} = -A_{12}N_2 \tag{2.1.2}$$

where A_{12} is Einsteins coefficient which determines the probability of emission of a photon, the negative sign signifies the decreasing population of atoms in the upper level.

Stimulated emission: The atoms in the upper level can be brought to the lower level through an external influence. When a stimulating photon with exactly the same energy as the difference in energy between the upper and lower levels, in the same direction and polarization is made to strike the excitable laser material, the atom decays to the lower level and emits a photon. Both the emitted photon and the stimulating photon have an energy given by $h\nu$ = E_2 - E_1 , as shown in figure 2.1c, with the transition rate given by

$$\frac{dN_2}{dt} = \frac{-dN_1}{dt} = -\beta_{21}N_2\rho(\nu) \tag{2.1.3}$$

where B_{21} is Einsteins coefficient for stimulated emission, basically an intrinsic property of the system.
At equilibrium:
Rate of absorption = Rate of spontaneous emission + Rate of stimulated emission

$$(\frac{dN_2}{dt})_{stimulated} = \beta_{21}\rho(\nu)[N_2 - N_1] \tag{2.1.4}$$

Now, at steady state $N_2 = 0$. So, the rate stimulated emission is negative or absorption is greater this means that there is no stimulated emission. To have $N_2 > N_1$ we should have negative temperature.

2.1.1 Population inversion

One of the prerequisites for lasing to take place continuously, or to give an even pulsed output, is population inversion. A population inversion takes place when there are more atoms in the upper level than the lower level. Atoms are excited to the upper level through a process called pumping, which differs for different lasing media. Therefore, the pumping mechanism should in principle be able to excite atoms or molecules continuously to achieve a uniform output of the laser pulses. For any ideal population of atoms, not all of them are excited to the upper level since the probability of stimulated emission is very small and negligible. Thus at a thermal equilibrium, there will be a smaller number of atoms in the excited state than the ground state. The population between the two energy levels is given by Boltzmanns distribution

$$\frac{N_2}{N_1} = exp(\frac{-E_2 - E_1}{kT}) = exp(\frac{-h\nu}{kT}) \tag{2.1.5}$$

where N_2 and N_1 are the number of atoms in the excited state and the ground state respectively, k is Boltzmanns constant, and T is the absolute temperature of the material.

Under equilibrium conditions, the system acts as an absorber at a frequency ν, since

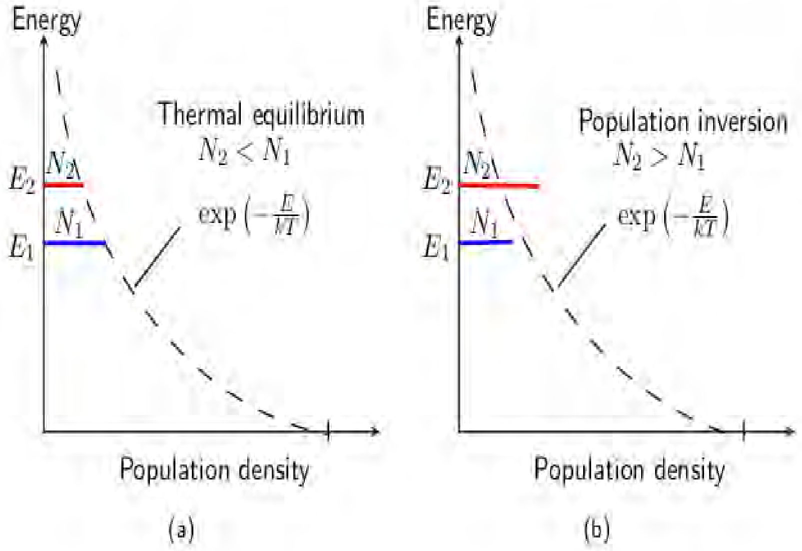

Figure 2.2: Population distribution between levels 1 and 2 for thermal equilibrium and population inversion conditions

$N_2 < N_1$. However, if the inversion condition is achieved $N_2 > N_1$, then the system acts as an amplifier. This is defined as population inversion.

2.1.2 Essential elements of a basic laser

The principle of laser action is based on three main features: a lasing medium, a pump source to provide excitation energy, and a resonator cavity. The general layout of a laser is shown in Figure 2.3.

Lasing medium: This is also called an active medium, where the atoms or molecules are pumped from the ground state to the excited state. The lasing medium can be a solid, liquid or gas. Examples of gas lasers include, carbon dioxide, argon, Helium-neon, nitrogen lasers and other lasers like Nd-YAG, raby, daylaser etc.

Pump source: A suitable pump source is required to create a population inversion, a necessary condition for the stimulated emission of photons. However, the question remains that how does the pump power required to acquire the population inversion is supplied to the active medium? The different types of pumping are: chemical pumping, which is basically a chemical reaction, optical pumping where the source of energy is light, basically used in solid state lasers, and electric pumping where energy is obtained from electricity. We use the latter for the excitation of gas lasers such as nitrogen, which shall be discussed in the next section.

Resonator cavity: This is sometimes called feedback mechanism. The arrangement consists of two mirrors. One mirror is completely reflective so that the desired emitted photons get back into the system for more amplification and the other mirror, is partially transparent for the output of the portion of the laser beam with the required threshold value. It is important to note here that not all lasers use a feedback mechanism. A nitrogen laser does not require resonator cavity (lases in air), since it has extremely high gain.

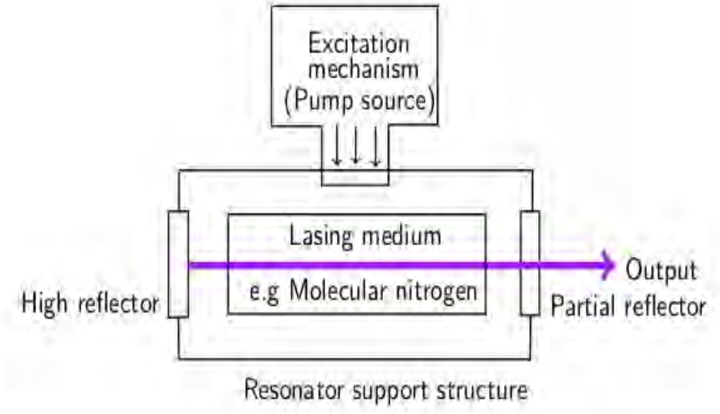

Figure 2.3: Schematic layout of the laser.

2.2 Pumping mechanism for a nitrogen laser

To creat population inversion in laser medium there are different pumping schemes like, electrical, chemical and gas dynamics pumping schemes. To excite the nitrogen laser molecule mostly we use electrical pumping

A nitrogen molecule like any other diatomic molecule, possesses vibronic energy levels that constitute both vibrational and electronic states. These energy states are mainly separated by the change in electron energy of the atoms, and a small contribution resulting from the vibrations within the nitrogen molecules themselves. The laser action therefore involves a series of the transitions, resulting from the changes in vibrational and electronic states of the nitrogen molecules, which are nearly spaced to favour the emission of ultraviolet radiation at 337.1 nm [1]. The pumping mechanism in a nitrogen laser, involves collision of high energy electrons with the gas molecules in a laser tube through electron impact excitation. The accelerated electrons in the laser tube strike the nitrogen molecules, thus exciting them to a higher electronic energy state. Figure 2.4 shows the energy level scheme for a nitrogen laser, with each level showing a series of vibrational energy level, which depends on the internuclear separation of the molecule. The laser normally starts when the nitrogen molecules become excited by an electric discharge in the lasing tube from the electronic ground state, labelled $X^1\Sigma^+$ energy band to the upper lasing level, labelled $C^3\Pi_u$ energy band. The molecules at the upper lasing level are unstable, thus they decay to the lower lasing level, labelled as $B^3\pi_u$ energy band, by emitting photons of ultraviolet radiation at 337.1 nm. This corresponds to only energy levels with the lowest vibration state, for which $\nu = 0$, and $\nu = 1$ corresponding to the upper vibrational state. However, other transition states are also possible. For example in a 1-0 state, where in this case the lower lasing level involved in the vibration state is at $\nu = 1$ and the upper lasing level is the same as the lowest, at $\nu = 0$ [1]. This results into a shorter jump during the transition state than before, thus an output with a lower energy at a wavelength of 358 nm is given off as shown in Figure 2.4. When a molecule emits a photon as it falls to the lower lasing level, it then decays to a metastable state where it stays. Thus a nitrogen laser is effectively a three-level laser. The biggest problem with a nitrogen laser is the lifetime of the upper lasing level, which is their greatest barrier in the laser development.

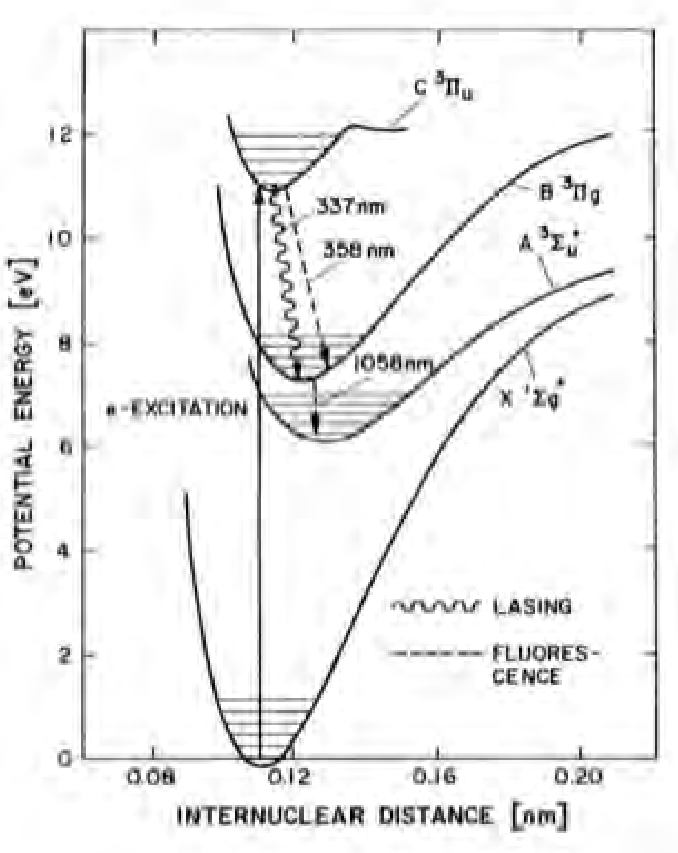

Figure 2.4: Energies of the molecular nitrogen, as a function of internuclear separation relevant for the nitrogen laser [1].

The upper lasinglevel has a lifetime that is pressure dependent according to

$$t = \frac{36}{1 + \frac{58}{P}} \tag{2.2.1}$$

where t is the upper lasing level lifetime in nanoseconds and p is the pressure in torr. The transition lifetime of the gas molecules from the upper lasing level to the lower lasing level is very short ($\leq 40ns$) as compared to lifetime for the transition between the lower lasing level and the metastable state (about 10 μs) [1]. Thus the population of the gas molecules at the lower level exceeds that at the upper lasing level. This means that the lasing process will terminate, since the condition for lasing to take place is violated. Creating a population inversion at the upper lasing level in this case, is only possible if the pump power from the source is sufficient to have the nitrogen molecules in the upper lasing level as quick as possible. Gas lasers in general, are pumped directly by electron-impact excitation. The gas molecules are excited from the ground level to the upper level through collisions with the electrons accelerated by the electric field set-up between the electrodes of the discharge chamber.

2.3 Nitrogen laser structure

The basic requirement for a practical nitrogen laser is to supply a massive electrical current (i.e., a huge quantity of electrons) with a fast rise time and short pulse length to excite the gas. To achieve this, most nitrogen lasers use an electrical configuration called a Blumlein configuration, which generates a massive over voltage of the laser channel (and subsequent large current through the lasing gas) with a rise time of nanoseconds. A Blumlein configuration is shown schematically in Figure 2.5, where we find two capacitors essentially in parallel separated by the laser channel itself. Both capacitors charge simultaneously through the charging inductor (which offers little electrical resistance to the charging current) until the spark gap fires when the breakdown voltage is reached (typically, about 10 kV for a small laser). In simplest form, a nitrogen laser may operate as a relaxation oscillator, repeatedly charging and firing; the use of triggered spark gaps or thyratrons allows the laser to be triggered as required. The gap now conducts essentially short-circuiting C_1 and draining charge from it, making the top terminal of C_1 negative. A massive voltage difference appears quite suddenly across the laser gap since the left side of the tube is now negative and the right side still positive. Charge from C_1 flows across the laser channel as a pulse of very high electrical current, in many cases thousands of amperes. The electrical dynamics of the laser are not as simple as a discharge, since the laser tube has long transverse electrodes over which the high current must be distributed. With a short discharge time necessitated by the short upper lasing level lifetime, the laser is best excited by a traveling electrical wave which starts at the rear of the laser and moves forward at the speed of light exciting nitrogen molecules as it progresses. To accomplish this, capacitors are fabricated as long, distributed capacitances parallel to the laser tube. The initiating spark gap is placed at the rear of one capacitor so that the electrical pulse begins at the rear of the laser first and travels toward the front of the laser. In many cases it is possible to design the laser as a transmission line for efficient transfer of electrical energy into the lasing volume. The sequence of events during firing of the laser is outlined in Figure 2.6 In this particular design, common for small laboratory-type nitrogen lasers, the capacitors are fabricated on an epoxy glass substrate. Two capacitors are formed with copper foil on the top of the board (there is a separation between the two capacitors underneath the laser tube, so they are not visible in the figure), and the bottom of the board is the common terminal for both. The spark gap that initiates electrical discharge is mounted on the left capacitor near the rear of the laser. In the simplified figure (in which details such as the charging inductor are omitted for clarity) both capacitors are charged to a high voltage equally, so no voltage difference appears across the laser channel. As the capacitors are charged, the voltage across the capacitors as well as the spark gap rises until breakdown occurs (in Figure 2.6b) and the spark gap conducts. Charge can be visualized in the figure as moving toward the spark gap in an arc centered around the spark gap. No voltage appears across the laser channel until the charge at the rear of the left capacitor for the laser has been drained and a

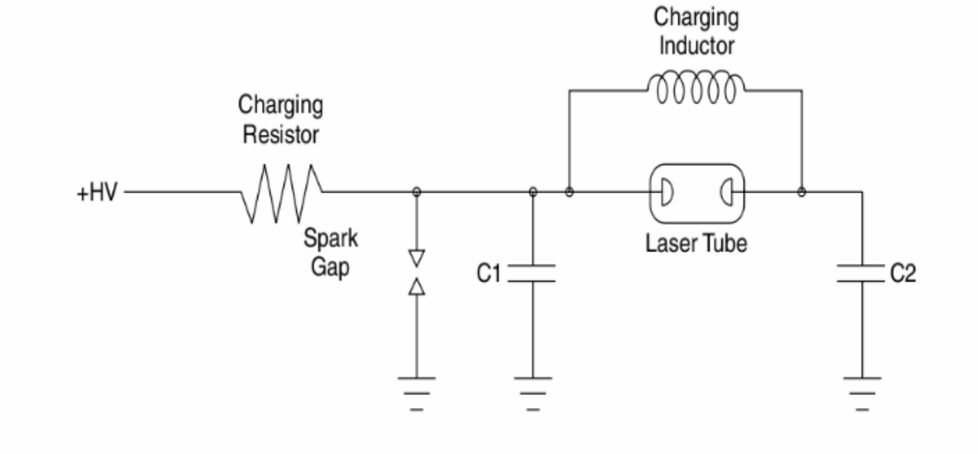

Figure 2.5: Electrical schematic of a Blumlein laser

voltage differential appears at the rear of the laser channel. The discharge in the laser thus begins here. As the traveling wave in the capacitor spreads, the voltage differential travels toward the front of the laser channel at the speed of light, generating a discharge that also travels toward the front of the laser. Light emission follows the discharge and a beam emerges from the laser. A practical nitrogen laser based on this design is seen operating in the authors laboratory in Figure 2.5 The initiating spark gap is visible in the upper-left corner. It emits an intense flash of light since high currents pass through it. As well as the gap, other visible features include the charging inductor, which bridges the laser tube and the charging resistor near the spark gap. This is a flowing gas laser in which nitrogen gas under low pressure flows slowly through the tube. A needle valve used to regulate flow is also seen in the lower left of this laser. After initiation of laser action by the spark gap and discharge through the laser channel, the laser pulse is generated and will continue until population inversion ceases. Laser action ceases regardless of how long the electrical pulse lasts, so it is pointless to design a laser with a longer discharge time than this. This parameter determines the size of the capacitors employed in the laser. The nitrogen laser may operate at atmospheric pressures in TEA configuration as well as

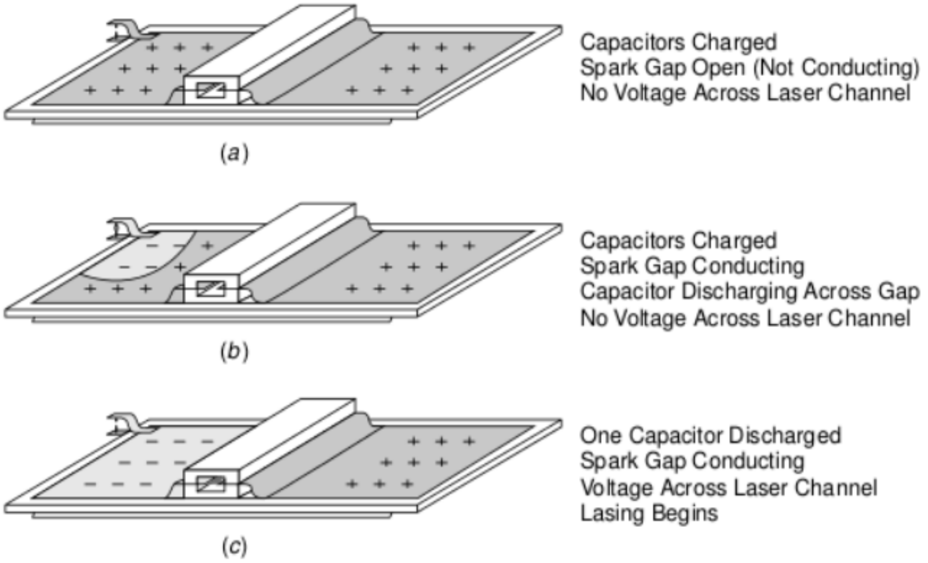

Figure 2.6: Nitrogen laser discharge sequence

at low pressure(generally, 20 to 60 Torr). These lasers are physically similar to the low pressure types and most use a Blumlein configuration. In the case of a TEA nitrogen laser, though, the lifetime of the ULL decreases to about 2.5 ns. The requirements for a fast discharge are even more pronounced in a TEA laser, which must be constructed to keep inductances in the discharge path to an absolute minimum. With this in mind, dielectrics for capacitors are kept very thin (since the intrinsic inductance of a transmission line capacitor is proportional to the thickness of the dielectric) and the laser channel is mounted directly on top of the capacitors. A practical TEA laser is pictured in Figure 2.8, in which the spark gap is located in the upper right corner of the photo and the long transverse electrodes are visible down the center of the laser. The laser pictured operates using open air as the lasing gas. This is possible since air is 78 percent nitrogen, although output power decreased by 80 percent over the use of pure nitrogen gas. A possible source of inefficiency is evident in that the discharge reveals hot spots or arcs. Unlike the low pressure laser, which features a consistent and even discharge between the electrodes, discharges in TEA lasers tend to concentrate and resemble individual sparks. For efficiency, measures must be taken to even out the discharge, including dilution of the nitrogen gas with helium, use of an electrode structure consisting of multiple points,

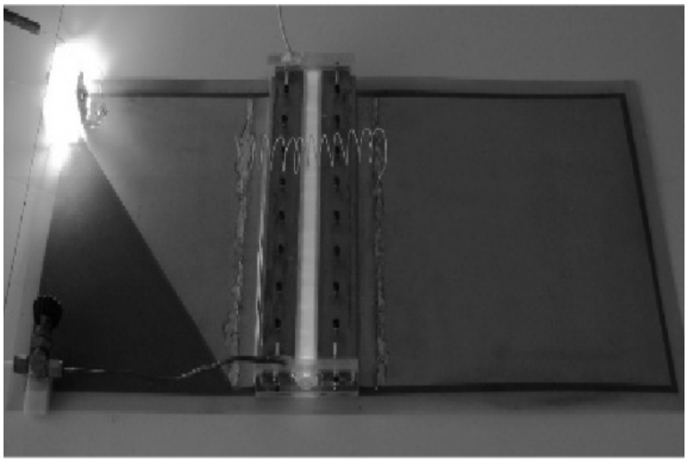

Figure 2.7: Practical nitrogen laser.

and preionization of the discharge channel with a high voltage corona or ultraviolet radiation before the main laser discharge ensues. Most small commercially available nitrogen lasers use spark gaps for their simplicity. These spark gaps are filled with nitrogen gas for reliable, predictable firing. In the case of a TEA laser, the gap may be placed inside the same pressure vessel as the rest of the laser. Filling with nitrogen also eliminates the objectionable production of ozone when the gap fires. In some larger lasers, thyratrons are used instead of spark gaps. Thyratrons are switching devices that use mercury vapor or hydrogen gas and feature incredibly fast rise times, many times faster than spark gaps. As well as faster switching times, thyratrons also allow triggering on command instead of simply triggering when the spark gap is over voltage, an important feature when this laser is used in a laboratory experiment requiring synchronization and precise timing. Because of the low inductance discharge path required, essential elements of the nitrogen laser, such as storage capacitors and switches (thyratrons or spark gaps), are an integral part of the laser itself. To charge the capacitors, a basic high voltage supply is required, the supply current of this supply limiting the maximum firing rate for the laser. Designs for high-voltage power supplies vary from simple neon sign transformers to efficient and compact switching power supplies. These supplies are usually housed in the main laser housing for safety. In many low pressure nitrogen lasers, gas flows continually through

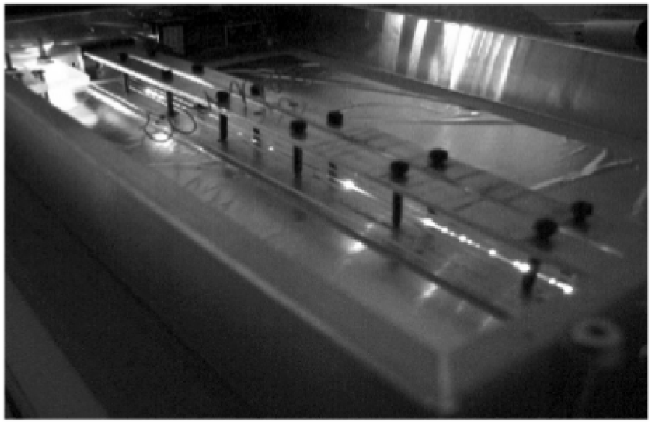

Figure 2.8: TEA Nitrogen laser

the lasing channel. This helps to eliminate impurities generated during the dis- charge as well as cool the laser. Gas flow is quite slow, so consumption is minimal. Many small commercial nitrogen lasers are of the TEA variety and use a sealed laser channel, so a gas supply and vacuum pump are not required, making a much simpler laser for laboratory use. With a fast enough discharge time, some low pressure nitrogen lasers can also operate using hydrogen gas (with a transition in the extreme UV at 160 nm) or neon gas (with a visible transition at 540.1 nm). Both of these alternatives have shorter upper-level lifetimes than nitrogen does, so an extremely fast laser discharge is required (much faster than normally required in a nitrogen laser).

Chapter 3

NITROGEN LASER PARAMETERS

Several parameters play an important role in the optimum operation of the nitrogen laser. A uniform discharge throughout the length of the laser discharge channel and a sufficiently high rate of energy absorption in the laser gap plasma during the main discharge are required for good operation. The uniformity depends on how fast the laser gap voltage rises as well as on laser surface conditions and gap setting while the energy absorption is characteristic of the nitrogen gas and achieved through the use of the flat plate capacitor. Experimentally, it is very stringent to achieve the required rise rate of laser voltage sufficient to cause the laser to breakdown uniformly. In order to achieve suitable design parameters that meet the minimum rate of rise of laser gap voltage, a parameteric model which employs an analysis of the laser circuit before and after uniform discharge has been developed for the nitrogen laser. The main operation of a nitrogen laser can be explained by refering to the Blumlein transmission line and the laser channel. When the laser channel breakdown there is plasma which is mainly inductive with a very small resistance. Those nitrogen laser parameters rate of current, laser gap voltage and power absorbed for sequential two channel laser with its effective parameters controlling discharge modes will be discussed under this chapter. The integraton procedure also mentioned here.

3.1 For The First Channel

A typical nitrogen laser circuit my be represented by fig.3.1. The fast parallel plate capacitors C_1 and C_2 with very low inductances L_1 and L_2 are charged by a constant voltage V_0 and connected to the laser gap represented by a resistance r_g and inductance L_{g0} as shown in the diagram fig.3.1. The inductance L_{g1} and L_{g2} represent the channel inductance on either side of the laser gap. The capacitor C_2 is connected to an exterenal spark gap represented by resistance r_e in the diagram and with inductance L_e. Typcally $C_1 \sim 100nF, C_2 \sim 50nF, L_1 \sim 0.40nH, L_2 \sim 0.18nH, L_{g1} = L_{g2} \sim 0.8nH, L_{g0} \sim 0.3nH$ and $L_e \sim 14.4nH$. The exterenal spark gap resistance r_e has a value such that the exterenal circuit i.e L_2 - L_e - r_e - C_2 is fairly oscillatory; whilst for good and fast energy transfer one would hope to design for r_g to have such a value that the laser discharge circuit i.e C_1 - L_1 - L_{g1} - r_g - L_{g0} - L_{g2} - L_2 - C_2 should be nearly critically damped. However, one would expect the typically this laser circuit would be less than criticly damped. When the external spark gap switches at $t = 0$ the voltage V_2 drops from its initial value V_0, swings negative towards $-V_0$ with a time constant given by $\sim \sqrt{L_e C_2}$ since $L_e >> L_2$, thus providing the rate of rise of gap voltage of the order of $\frac{2V_0}{\sqrt{L_e C_2}}$ which should cause the laser gap to not only breakdown, but to breakdown uniformaly at time $t = t_s$. The main discharge should then occur with a short time constant $\sim \sqrt{(L_1 + L_2 + L_g)(C_1 C_2)/(C_1 + C_2)}$, where $L_g = L_{g1} + L_{g2} + L_{g0}$, modulated with a shower

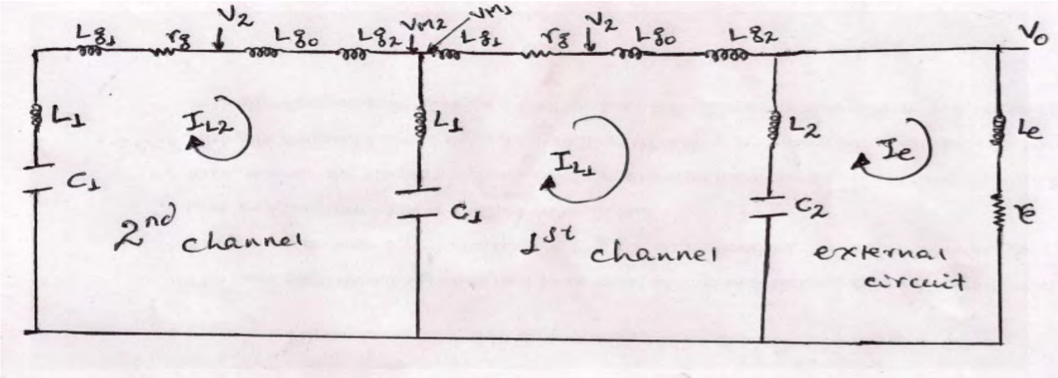

Figure 3.1: Two channel sequential nitrogen laser circuit

dischrge with a small time constant $\sim \sqrt{L_e(C_1 + C_2)}$ which subsequently removes all the stored energy through the external spark gap r_e.

The equations which describe the performance of discharge circuit are given below: For $0 \leq t \leq t_{s1}$ (before the laser gap breakdown)

$$I_{L1} = 0 \tag{3.1.1}$$

$$L_2 \frac{dI_e}{dt} + L_e \frac{dI_e}{dt} + r_e I_e = V_0 - \frac{\int I_e dt}{C_2} \tag{3.1.2}$$

where I_{L1} is the laser current through the first channel. I_e, L_e, and r_e are the laser spark gap current, inductance and resistance, respectively. C_2 and L_1 are the capacitance and inductance of the the second flat plate capcitor and t_{s1} is the time at which the laser gap breaks down in the first channel. Initial condition are obtained for Eq.(3.1.2) by setting $I_e = 0$ at $t = 0$.

$t = 0, I_e = 0, \frac{\int I_e dt}{C_2} = 0, \frac{dI_e}{dt} = \frac{V_0}{L_e + L_2}$. After the laser gap breakdown, the equations obtaining to the equivalent circuits are:

$t > t_{s1}$

$$L_2 \frac{dI_e}{dt} - L_2 \frac{dI_{L1}}{dt} + L_e \frac{dI_e}{dt} + r_e I_e = V_0 - \frac{\int I_e dt}{C_2} + \frac{\int I_{L1} dt}{C_2} \tag{3.1.3}$$

and

$$L_1 \frac{dI_{L1}}{dt} + (L_{g1} + L_{g0} + L_{g2}) \frac{dI_{L1}}{dt} + L_2 \frac{dI_{L1}}{dt} - L_2 \frac{dI_e}{dt} + r_g I_{L1} = V_0 - \frac{\int I_{L1} dt}{C_1} - V_0 - \frac{\int I_{L1} dt}{C_2} + \frac{\int I_e dt}{C_2} \tag{3.1.4}$$

At the moment of laser gap breakdown i.e $t = t_s$, the value of $(I_e)_{ts}, (\frac{I_e}{dt})_{ts}$, and $(\int I_e dt)_{ts}$ are known from the numerical integeration of equation (3.1.2) whilst the other values necessary to start the integeration of equations (3.1.3) and (3.1.4) are obtained by additionally setting $I_{L1} = 0$

$t = t_s, I_{L1} = 0, \int I_{L1} dt = 0$ and

$$\{\frac{dI_{L1}}{dt}\}_{t_s} = \frac{\{\frac{\int I_e dt}{C_2}\}_{t_s} + \{\frac{L_2 dI_e}{dt}\}_{t_s}}{(L_1 + L_2 + L_g)}$$

where L_g and r_g are the laser inductance and gap resistance respectively; L_1 and C_1 are respectively, the inductance and capacitance of the first capacitor. Eqs.(3.1.1) through (3.1.4) are then non-dimensionalised so that scaling parameters are identified. These scaling parameters are varied to cover a wide range of operation of the nitrogen laser. The computations are used to determine that the rate of rise of laser gap voltage $\frac{dV_g}{dt}$ for efficient working of nitrogen laser and the rate of energy absorption at the laser gap as a function of the scaling parameters.

The following relationships are used in the normalization process:

$\tau = \frac{t}{t_0}, i_e = \frac{I_e}{I_0}, i_{L1} = \frac{I_{L1}}{I_0}$, where $t_0 = \sqrt{(L_2 C_2)}$ and $I_0 = \frac{V_0}{\sqrt{\frac{L_2}{C_2}}}$,

This normalization procedure gives us the governing equations and conditions in the following form: $0 \leq \tau \leq \tau_s$

$$\frac{di_e}{d\tau} = \frac{(1 - \int i_e d\tau) - \alpha_e i_e)}{1 + \beta_e} \tag{3.1.5}$$

with starting conditions: $\tau = 0$, $i_e = 0, \int i_e d\tau = 0$, and $\frac{di_e}{d\tau} = \frac{1}{1+\beta_e}$ where the scaling parameters $\beta_e = \frac{L_e}{L_2}$, and $\alpha_e = \frac{r_e}{\sqrt{\frac{L_2}{C_2}}}$

For $\tau \geq \tau_s$

$$\frac{di_e}{d\tau} = \frac{(1 - \int i_e d\tau + \int i_{L1} d\tau - \alpha_e i_e + \frac{di_{L1}}{d\tau})}{1 + \beta_e} \tag{3.1.6}$$

and we also have

$$\frac{di_{L1}}{d\tau} = \frac{(\int i_e d\tau - (1 + \delta) \int i_{L1} d\tau - \alpha_e \alpha_1 i_{L1} + \frac{di_e}{d\tau})}{1 + \beta_e + \beta_g} \tag{3.1.7}$$

with the starting conditions for this phase given by:

$\tau = \tau_s, i_e = (i_e)_{\tau_s}, \int i_e d\tau = (\int i_e d\tau)_{\tau_s}, \frac{di_e}{d\tau} = (\frac{di_e}{d\tau})_{\tau_s}$, obtained from the numerical integeration of equation (3.1.5) upto $\tau = \tau_s$ and also at $\tau = \tau_s$, we have $i_{L1} = 0. \int i_{L1} d\tau = 0$ and $\{\frac{di_{L1}}{d\tau}\}_{\tau_s} = \frac{\{\frac{\int i_e d\tau}{C_2}\}_{\tau_s} + \{\frac{L_2 di_e}{d\tau}\}_{\tau_s}}{(L_1 + L_2 + L_g)}$

Where the scaling parameters are:

$\beta_1 = \frac{L_1}{L_2}, \delta = \frac{C_2}{C_1}, \alpha_1 = \frac{r_g}{r_e}$, and $\beta_g = \frac{L_g}{L_2}$

Besides the values of i_e and i_{l1} other important quantities to be obtained from these exercise are:

a) Laser gap voltage: For $\tau < \tau_s$;

$$v_g = \frac{di_e}{d\tau} + \int i_e d\tau \tag{3.1.8}$$

and for $\tau \geq \tau_s$

$$v_g = \frac{di_e}{d\tau} + \int i_e d\tau - \int i_{L1} d\tau (1+\delta) + (1+\beta_1+2\gamma\beta_g)\frac{di_{L1}}{d\tau} \tag{3.1.9}$$

where $\gamma = \frac{L_{g1}}{L_g} = \frac{L_{g2}}{L_g}$, or it is the ratio of channel inductance on either side of the gap to the laser inductance

It is worth while to note that the measured voltage across the channel is taken between the points V_{M1} and V_{M2} in figure 3.1, and is given by:

$$V_M = V_{M1} - V_{M2}$$

$$= \int i_e d\tau - \int i_{L1} d\tau + \frac{di_e}{d\tau} - \frac{di_{L1}}{d\tau} - \delta \int i_{L1} d\tau - \beta_1 \frac{di_{L1}}{d\tau} \tag{3.1.10}$$

It should be noted that before laser gap switching this voltage is equal to v_g the spark gap voltage

b) Power absorbed by the laser gap

The power absorbed by the laser gap $I_{L1}^2 r_g$ may be normalized to the average power of discharge of the $C_1 - L_1 - L_g - L_2 - C_2$ circuit. This average discharge power written as

$$P_g = \frac{\frac{1}{2}C_1V_0^2}{\sqrt{(L_1+L_2+L_g)(\frac{C_1C_2}{C_1+C_2})}}. \text{ or } I_{L1}^2 r_g,$$

3.2 Second Channel

For the second channel using the same procedure what is done for the first channel, when $t < t_{s2}$

$$I_{L2} = 0 \tag{3.2.1}$$

$$L_1\frac{dI_{L1}}{dt} + L_g\frac{I_{L1}}{dt} + L_2\frac{dI_{L1}}{dt} - L_2\frac{dI_e}{dt} + r_gI_{L1} = V_0 - \frac{\int I_{L1dt}}{C_1} - V_0 - \frac{\int I_{L1}dt}{C_2} + \frac{\int I_e dt}{C_2} \tag{3.2.2}$$

For $t_{s2} < t$ (after the laser gap break down) equation (1) and (2) are replaced

$$L_1\frac{dI_{L2}}{dt} - L_1\frac{dI_{L1}}{dt} + L_1\frac{dI_{L2}}{dt} + L_g\frac{dI_{L2}}{dt} + r_gI_{L1} = V_0 - \frac{\int I_{L2}dt}{C_1} - V_0 - \frac{\int I_{L2}}{d}tC_1 + \frac{\int I_{L1}dt}{C_1} \tag{3.2.3}$$

$$L_1\frac{dI_{L1}}{dt}-L_1\frac{dI_{L2}}{dt}+r_gI_{L1}+L_2\frac{dI_{L1}}{dt}-L_2\frac{dI_e}{dt}=V_0-\frac{\int I_{L1}dt}{C_1}-V_0+\frac{I_{L2}dt}{C_1}-V_0+\frac{I_edt}{C_2}-V_0-\frac{I_{L1}dt}{C_2} \tag{3.2.4}$$

The following relationships are used in the normalization process:

$\tau=\frac{t}{t_0}, i_e=\frac{I_e}{I_0}, i_{L1}=\frac{I_{L1}}{I_0}, i_{L2}=\frac{I_{L2}}{I_0}$ where $t_0=\sqrt{(L_2C_2)}$ and $I_0=\frac{V_0}{\sqrt{\frac{L_2}{C_2}}}$,

This normalization procedure gives us the governing equations and conditions in the following form: $0\leq\tau\leq\tau_{s2}$

$$\frac{di_{L2}}{d\tau}=\frac{\frac{di_{L1}}{d\tau}-\alpha_2i_{L1}+\frac{2\delta}{\beta_1}\int i_{L1}d\tau-\frac{2\delta}{\beta_1}\int i_{L2}d\tau}{2+\beta_n} \tag{3.2.5}$$

and we also have

$$\frac{di_{L1}}{d\tau}=\frac{\int i_ed\tau-(1+\delta)\int i_{L1}d\tau+\delta\int i_{L2}d\tau+\beta_1\frac{di_{L2}}{d\tau}-\alpha_e\alpha_1i_{L2}+\frac{di_e}{d\tau}}{1+\beta_1} \tag{3.2.6}$$

Where the scaling parameters are

$\beta_n=\frac{L_g}{L_1}$ and $\alpha_2=\frac{r_g}{L_1}\sqrt{L_2C_2}$

Beside the values of i_e , i_{L1} and i_{L2} other important quantities to be obtained from these exercise are:

$$V_g=\frac{i_{L1}}{d\tau}+\frac{\delta}{\beta_1}\int i_{L1}d\tau-(1+\frac{\delta}{\beta_1})\int i_{L2}d\tau+(2+2\gamma\beta_n)\frac{di_{L2}}{d\tau} \tag{3.2.7}$$

The measured voltage cross the channel is taken between the points V_{M1} and V_{M2}

$V_M=V_{M1}-V_{M2}$

$$\frac{di_{L1}}{d\tau}+\frac{\delta}{\beta_1}\int i_{L1}d\tau-\frac{2\delta}{\beta_1}\int i_{L2}d\tau-2\frac{di_{L2}}{d\tau} \tag{3.2.8}$$

Power absorbed by the laser gap

The power absorbed by the laser gap $I_{L2}^2r_g$ may be normalized to the average power of discharge of the $C_1-L_1-L_g-L_2-C_1$ circuit.

3.3 Effective parameters controlling discharge modes

The performance of the laser depends on the discharge modes of

a) the $C_2-L_1-L_e-r_e$, circuit (external circuit) and

b) the $C_1 - L_1 - L_g - r_g - L_2 - C_2$ circuit (the laser gap circuit).

The mode mentioned here refers to the degree of damping in the respective circuit ideally from the electrical parameters one would like to have the external circuit of current to be nearly undamped in order to have the biggest voltage reversal thus enhancing the maximum value of V_g. On the other hand for the laser gap circuit of the biggest power developed in the gap is for the case of critical damping.

The effective parameters controlling the damping of these two circuit are:

1. For the external circuit

$$\alpha_{eff-e} = \alpha_e \sqrt{\frac{L_2}{L_2 + L_e}} = \alpha_e \sqrt{\frac{1}{1 + \beta_e}} \tag{3.3.1}$$

2.. For laser gap circuit

$$\alpha_{eff-L} = \frac{\frac{r_L}{L_1+L_2+L_g}}{\frac{C_1C_2}{C_1+C_2}} = \alpha_e \alpha_1 \sqrt{\frac{1}{(1 + \beta_1 + \beta_g)(1 + \delta)}} \tag{3.3.2}$$

3.4 Integration Procedure

The computation of this model is performed by numerical integration using Euler Linear approximation method to solve the more complex integral-differential equations of the system and Fortran.f90 for the graphic results in the system. To begin the integration, I need to know the conditions at the start i.e $\tau = 0$. For this model, take the initial conditions as $\tau = 0$, $i_e = 0$, $\int i_e d\tau = 0$, and $\frac{di_e}{d\tau} = \frac{1}{1+\beta_e}$ for Eq.(3.1.5). Starting with known values of $\frac{di_e}{d\tau}$ and $\int i_e d\tau$ at $\tau = 0$, the values of $\frac{di_e}{d\tau}$, $\int i_e d\tau$ and i_e at $\tau = (\tau) + \triangle\tau$ are computed by using a linear approximation method. Thus

$$\int i_e d\tau = (\int i_e d\tau)_{perviousvalues} + (i_e d\tau)_{perviousvalues}. \triangle\tau + 0.5 * (\frac{di_e}{d\tau})(\triangle\tau^2) \tag{3.4.1}$$

$$i_e = (i_e)_{perviousvalues} + \frac{di_e}{d\tau}(\triangle\tau) \tag{3.4.2}$$

Similarly, the integration for other Equations (3.1.6) and (3.1.7) are computed as follow with starting conditions for this phase given by $\tau = (\tau_s)$, $i_e = (i_e)\tau_s$, $(\int i_e)d\tau = \int(i_e d\tau)\tau_s$

,$(\frac{di_e}{d\tau}) = (\frac{di_e}{d\tau})\tau_s$ being given by the numerical integration of the above two equations up to $\tau = (\tau_s)$ and at $\tau = \tau_s$, $i_{L1} = 0, \int i_{L1} = 0$, and $\frac{di_{L1}}{d\tau} = \frac{(\int i_e d\tau)(\tau_s) + (\frac{di_e}{d\tau})}{1+\beta_1+\beta_g}$ Then the values of $\frac{di_{L1}}{d\tau}$, i_{L1} and $\int i_e d\tau$ at $\tau = (\tau) + \triangle\tau$ are computed as:

$$\int i_{L1} d\tau = (\int i_{L1} d\tau)_{perviousvalues} + (i_{L1} d\tau)_{perviousvalues} . \triangle\tau + 0.5 * (\frac{di_{L1}}{d\tau})(\triangle\tau^2) \quad (3.4.3)$$

$$i_{L1} = (i_{L1})_{perviousvalues} + \frac{di_{L1}}{d\tau}(\triangle\tau) \quad (3.4.4)$$

and appling similar procedure for $\int i_{L2} d\tau$ and i_{L2} as what i done before we have the following and taking the initial condition $\tau = (\tau_s)$ and at $\tau = \tau_s$, $i_{L2} = 0, \int i_{L2} = 0$, and $\frac{di_{L2}}{d\tau} = \frac{(\frac{di_{L1}}{d\tau})}{1+\beta_n}$ Then the values of $\frac{di_{L2}}{d\tau}$, i_{L2} and $\int i_e d\tau$ at $\tau = (\tau) + \triangle\tau$ are computed as:

$$\int i_{L2} d\tau = (\int i_{L2} d\tau)_{perviousvalues} + (i_{L2} d\tau)_{perviousvalues} . \triangle\tau + 0.5 * (\frac{di_{L2}}{d\tau})(\triangle\tau^2) \quad (3.4.5)$$

and

$$i_{L2} = (i_{L2})_{perviousvalues} + \frac{di_{L2}}{d\tau}(\triangle\tau) \quad (3.4.6)$$

Then these values of rate of rise of current the time may now be incremented to $\tau = (\tau)$ $+ \triangle\tau$ and the process repeated using Fortran.f90. The other quantities, such as voltages, power absorbed by laser gap are also computed after evaluating the currents rate and currents.

Chapter 4

Result and Discussion

Several parameters depends the out put of nitrogen laser such as current, power and laser gap voltage. By various damping factors what will be the effect under such parameters on sequential two channels nitrogen laser with its result will be discussed graphically with in this chapter. All these parameters current, laser gap voltage, power are presented in normalized form.

To study the electrical behavior of the circuit as a function of α_{eff-e} and α_{eff-L} we choose typically the following values of circuit elements which are commonly used in practical nitrogen laser which are designated and available in literature [9], [10].

L_2 =0.18nH,

L_1 =0.4nH,

L_{g1} =0.75nH,

L_{g2} =0.75nH,

L_{g0} =0.3nH,

L_e =14.4nH,

C_1 =20nF,

C_2 =10nF,

And their ratio become

β_1 =2.2,

β_e =80,

δ=0.5,

β_g =10,

γ=0.42,

β_n= 4.5

$\alpha_2 = 3.97$

4.1 First Channel

If we take typical value for α_{effe} =0.3 where the external circuit is lightly damped

α_e	α_{effe}	α_{effL}	α_1
3.4	0.37	1.9	2.5
2.8	0.3	2	3.19
2.2	0.24	0.8	1.5
1.2	0.13	0.2	0.7
0.3	0.03	0.09	1.2

Table 4.1: slightly damped at α_e=2.8

Case:1 Laser gap voltage critically damped: $\alpha_{effL} = 2$

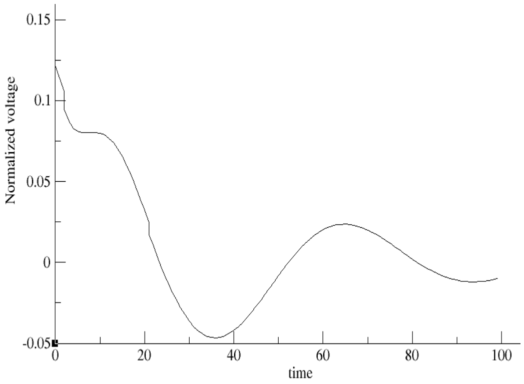

Figure 4.1: normalized voltage V_2 against normalized time

Choosing the case for which critically damped laser gap circuit at effective damping factor $\alpha_{effL} = 2$. From Eq.(3.3.2) This gives the value of $\alpha_1 = 3.19$ at α_e =0.3. Results for this case are shown fig 4.1 The normalized voltage V_2 follows from 0.124 to 0 at $\tau = 23.2$ to -0.04 at $\tau = 36.5$. When the laser gap is set to break down the voltage rises as the laser electrodes are momentarily separated only by the voltage $L_{g0}\frac{di_L}{d\tau}$, however, as i_{L1} rises quickly, the voltage drops across the electrode quickly dominated by the term $r_g i_{L1}$ so that V_2 drops once a gain to - V_2 .

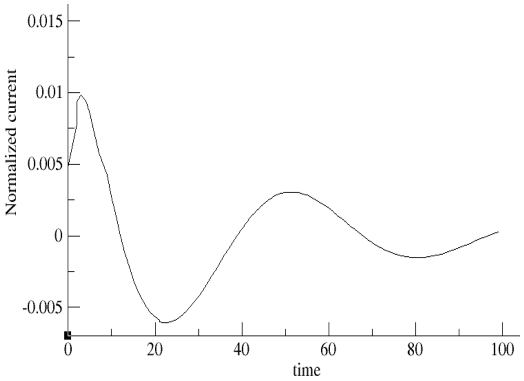

Figure 4.2: Normalized laser channel current I_{L1} for $\alpha_{effL} = 2$

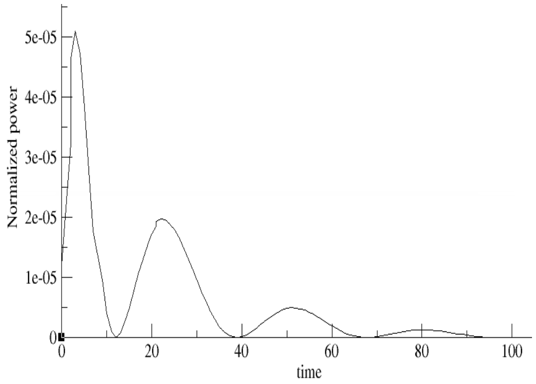

Figure 4.3: Variation in power for $\alpha_1 = 3.19$, and α_{effL}= 2

α_e	α_{effe}	α_{effL}	α_1
2.8	0.3	0.4	0.63
2.8	0.3	0.3	0.5
2.8	0.3	0.19	0.3

Table 4.2: more critically damped at $\alpha_1 = 0.63$

Case 2:Laser gap with effective damping factor of $\alpha_{effL} = 0.4$.

For this value of $\alpha_{eff-L} = 0.4$ we have $\alpha_1 = 0.63$. Results for this case are computed and shown in fig 4.4 V_2 drops from 0.14 to 0.04 at τ_s =30.0 then rises and oscillates.

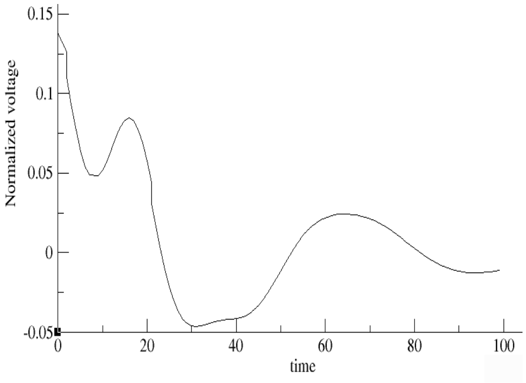

Figure 4.4: Variation in normalized voltage at α_{effL} =0.4

Although the critically damped case may be the mode for maximum power, there are absorption, yet indications that the typical case reported in the literature has damping factor that is close to $\alpha_{effL} = 0.4$. For this value of $\alpha_{effL} = 0.4$ we have $\alpha_1 = 0.63$.

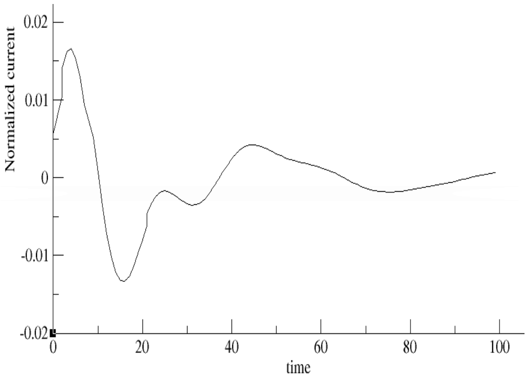

Figure 4.5: Variation in normalized laser gap channel current for more typical case of $\alpha_{effL} = 0.4$

Results for this case are computed and as shown fig 4.4 V_2 drops from 0.14 to 0.04 then rises on laser gap breakdown and continues with an oscillation of periodic time of $18t_0$ superimposed on the slower periodic time of $43.3t_0$ of the external circuit.

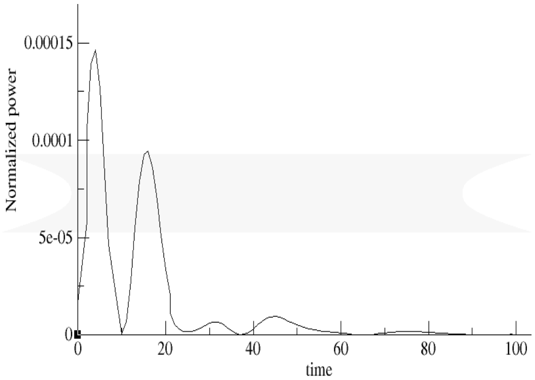

Figure 4.6: Variation in normalized Laser gap power at $\alpha_{effL} = 0.4$

The normalized laser gap current i_{L1} rises to a peak value of 0.016 in a time of $13t_0$ and oscillates in a damped mode with a periodic time of $18t_0$ the corresponding power developed across the laser gap resistance has a FWHM value of $5t_0$.

From the above results the value of $\frac{dV_g}{dt}$ for a typical nitrogen laser may be estimated. We know that a typical value of $t_0 = \sqrt{L_2C_2}$ is 1.3ns operating at a voltage of 15KV. The average $\frac{dV_g}{dt}$ is$\frac{(1.2\times15)}{30.0\times1.3} \sim 0.5\frac{kv}{ns}$. Such a value is experimentally known to be able to initiate the uniformity of discharge which is the first requirement in the nitrogen laser mechanism. The FWHM value for the power peak is $5t_0$ for the critically damped case and $2.123t_0$ for the more typical case of effective damping factor 0.4.

4.2 For The Second Channel

Case:1 Laser gap voltage critically damped: $\alpha_{effL} = 2$.

Choosing the case for which critically damped laser gap circuit that for $\alpha_{effL} = 2$. From the above eq.(3.3.2) This gives the value of $\alpha_1 = 3.19$ at α_e =2.8.

Results for this case are shown fig 4.7 The voltage V_2 follows from 0.13 to 0 at $\tau = 8.7$ to -1.4 at $\tau = 30$. When the laser gap is set to break down the voltage rises as the laser electrodes are momentarily separated only by the voltage $L_{g0}\frac{di_{L2}}{d\tau}$, however, as i_{L2} rises quickly, the voltage drops across the electrode quickly dominated by the term $r_g i_{L2}$ so that V_2 drops once a gain to a bout -V_2 .

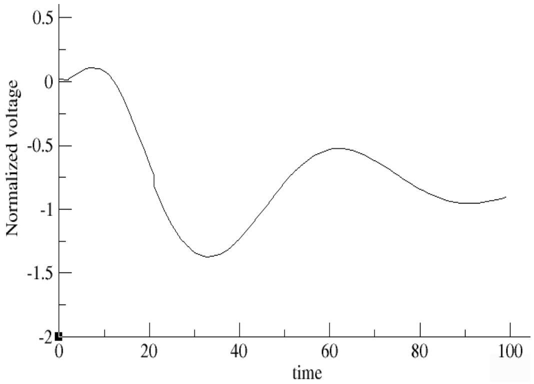

Figure 4.7: Normalized voltage for critically damped case

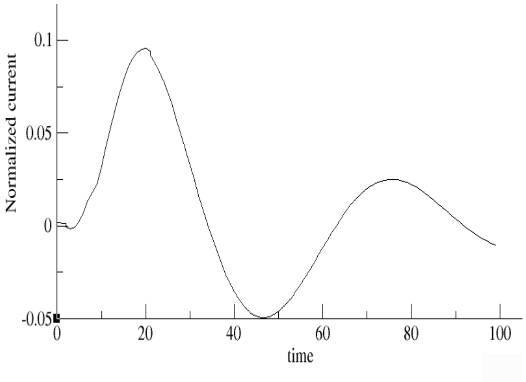

Figure 4.8: Normalized current I_{L2} for $\alpha_1 = 3.19$

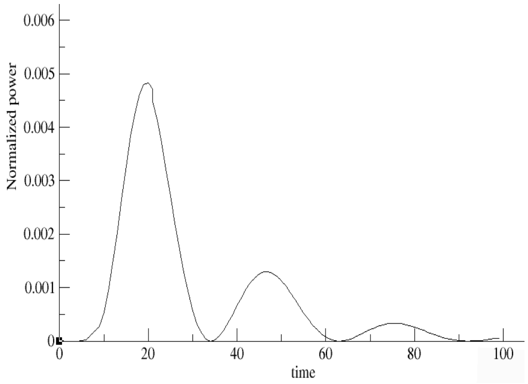

Figure 4.9: Normalized power for $\alpha_1 = 3.19$

Case 2:Laser gap with effective damping factor of $\alpha_{effL} = 0.4$. For this value of $\alpha_{effL} = 0.4$ we have $\alpha_1 = 0.63$.

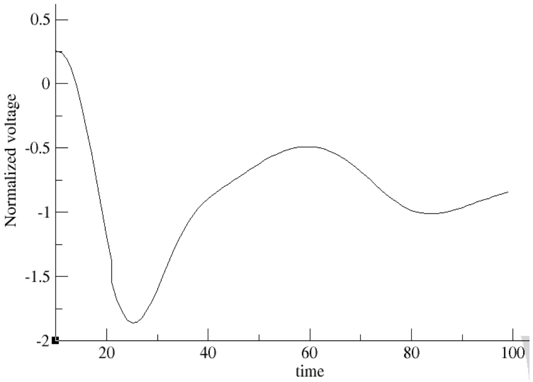

Figure 4.10: Variation in normalized voltage at effective damping factor parameterα_{effL} =0.4

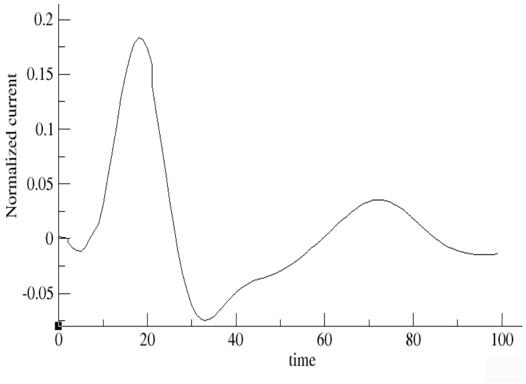

Figure 4.11: Variation in laser gap current for more typical case of effective damping factor $\alpha_{effL} = 0.4$

Results for this case are computed and shown fig 4.10 V_2 drops from 0.25 to -1.7 then rises on laser gap breakdown and continues with an oscillation of periodic time of $18t_0$ superimposed on the slower periodic time of $43.3t_0$ of the external circuit.

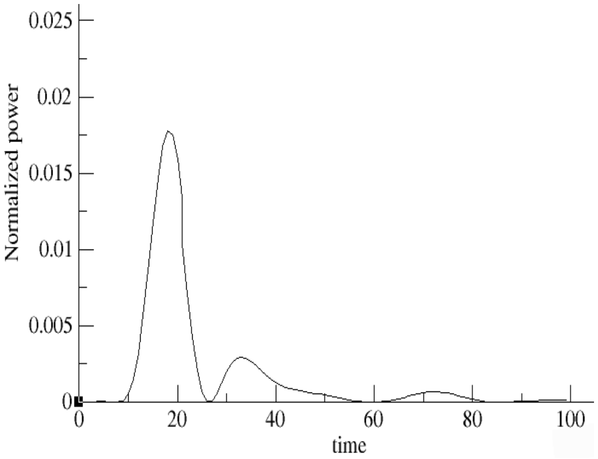

Figure 4.12: Variation in normalized laser gap power at $\alpha_{effL} = 0.4$

The laser gap current i_{L2} rises to a peak value of 0.16 in a normalized time of $\tau_s = 20$ and oscillates in a damped mode with a periodic time of $18t_0$ the corresponding power developed across the laser gap resistance has a FWHM value of $5t_0$.

Now, considering these two channels of the nitrogen laser circuit: In the first channel for critically damped case at $\alpha_1 = 3.19$ we have 0.00005 normalized power absorpition but for effectively critically damped case at $\alpha_{effL} = 0.4$ we have 0.00015 normalized power absorption. For the second channel the power absorption is from 0.005 to 0.017 form critically damped and and effectively critically damped case respectively.

Generally: In this sequential nitrogen laser the capacitors are connected in parallel and the inductors L_1 and L_2 with low inductance are also connected in parallel.

- The set up of the these components leads to have high impendance. This shows that we have high impendance means that more power is absorbed in the second channel.

- The value of the normalized current is 0.01 at $\alpha_1 = 3.19$ and 0.016 at $\alpha_{effL} = 0.4$ for the first channel and 0.1 at $\alpha_1 = 3.19$ and 0.175 at effective damping factor α_{effL} $= 0.4$ for the second channel

- The power also depends on the square of current this also can be the reason for more power absorption in the second channel.

- The normalized laser gap voltage also drop from maximum value of 0.25 to - 1.7 of the second channel at effective damping factor $\alpha_{effL} = 0.4$ with in a short normalized time $\tau = 25$.

Chapter 5

SUMMARY

In the frame of the present work, a detailed review of the principles behind laser action have been presented. This provided a background to the understanding of the necessary condition for lasing to take place, the population inversion. Unlike other gas lasers, nitrogen lasers have a shorter transition lifetime for the upper lasing level than the lower lasing level. Now, from the result as we discuss in chapter four at $\alpha_{effL} = 2$ it is critically damped having the value of α_1 i.e the ratio of the two resistance = 3.19. In here the voltage drop from 0.125 to 0 at τ= 23.2 then to -0.04 at τ= 36.5. In similar way for the second channel at the same damping factor α_{effL} values the voltage drop from 0.14 to 0 at τ= 22.7 and goes to -0.04 at τ= 30 then rise and oscillate. When we consider for both two channels for more critically damped case at $\alpha_{effL} = 0.4$ having $\alpha_1 = 0.63$ in here the voltage drop from 0.13 to -1.4 at τ=30. But for the second channel it drop from 0.25 to -1.7 atτ= 25.

When we see the power absorption for $\alpha_1 = 3.19$ the first channel power absorption is 0.00005 and 0.005 for the second channel at similar damping factor. If we consider for more criticallyl damping case at $\alpha_{effL} = 0.4$ the power absorption for the first channel is 0.00015 and 0.017 for the second channel.

In the future i propose to optimise the number of channels to be connected to have lasing action for a given set of parameters

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Declaration

This project is my original work, has not been presented for a degree in any other University and that all the sources of material used for the project have been dully acknowledged.

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Place and time of submission: Addis Ababa University, 2013

This project has been submitted for examination with my approval as University advisor.

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