CHAPTER 1

Introduction

Introduction to Volumetric Generation using GALVOS and LASER.

The project focuses on building a cost effective laser galvos projector. The most important component of the conventional laser projector system is the X-Y scanner. The X-Y scanner is the most generic component which can control the beam vector at will. Two galvos are mounted in orthogonal, incoming laser beam is bounced by X-axis galvo mirror and bounced again Y-axis galvo mirror and the beam goes into rendering space. The beam direction can be determined by combination of deflection angle of two mirrors. The scanned laser beam creates laser sheets or tunnel as beam effect, or draws laser graphics on the screen. For the screen effect, scanning speed is particularly required of X-Y scanner because it must scan fast and exactly as possible for good quality of the picture. So to obtain faster scanning speed we need faster switching action which is not feasible by using motor hence we use laser galvos. In galvos system closed loop is used to produce more crisp and accurate images which are not obtained using the open loop system. Hence only closed-loop galvos is currently used for screen effect, and for simple abstract graphics, open-loop galvos and resonant galvos are sometimes used.

Another major requirement in the system is the Laser Intensity Control, as if the intensity of light is high it will penetrate the smoke screen and image might be formed on the physical screen present behind the smoke screen and if the intensity is low then an image might not be obtained at all. Hence the Laser Intensity Control Module is used to achieve desired level of laser beam intensity.

Chapter 2 explains the basic working principle and functional description of the project and also component selection and design aspects are justified.

Chapter 3 explains the working of position detector circuit, Proportional-Derivative (PD) circuit and power op-amp motor driver circuit with their schematic diagrams and actual hardware circuitry. Also it gives brief idea about software algorithm.

Chapter 4 deals with problems faced during functioning and testing of the circuit.

The Limitations, future improvements and Conclusion to the project are mentioned in the 5^{th} chapter.

CHAPTER 2

Functional description and design criteria

2.1 Top level Block Diagram

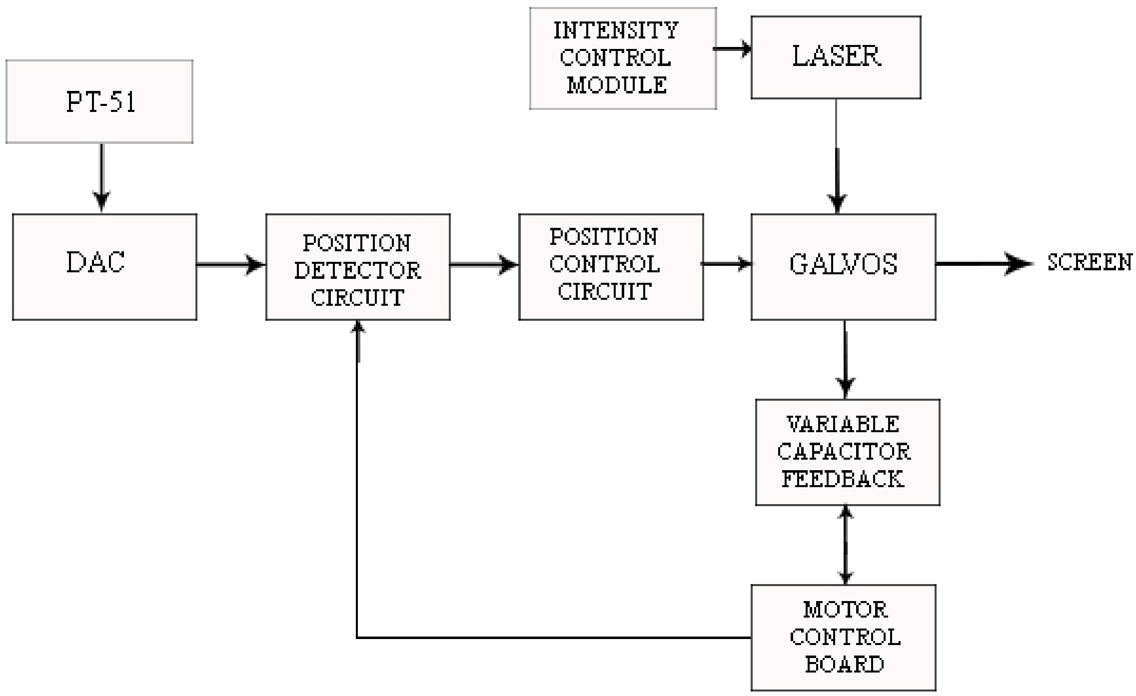


Figure 1. Functional Block Diagram.

The position coordinates are given as input to the DAC by PT-51 as required. The DAC is interfaced with position detector circuit which compares the current position of Galvos with the required position and gives the output accordingly in voltage form. This voltage signal is converted to proportional current signal by the position control loop and current signal is then passed on to Galvos. The variable capacitor feedback keeps the track of position of Galvos. Its capacitance changes according to the change in position of Galvosrotor assembly and the motor control board provides the necessary oscillatorycircuit for the capacitor and also it provides the necessary shift in the range of feedback voltage.

The laser intensity control module is used to vary the intensity as and when needed. The intensity of the laser beam is controlled manually by changing the pot position.

2.2 Design Criteria

2.2.1 Why Closed Loop?

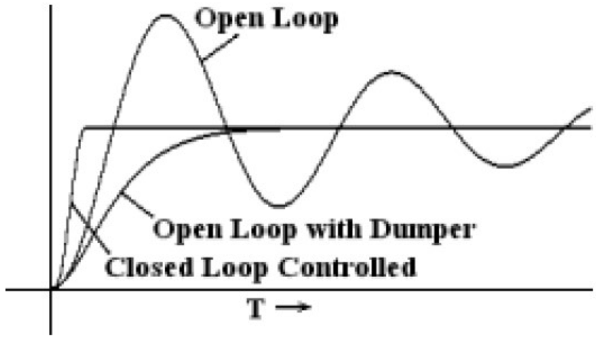


Figure 2. Step Response of Galvos.

The open-loop galvo's shaft is held with a torsion-rod spring, the rotor moves to a position where balancing between generated torque of the rotor and restoring torque of the torsion-rod spring. This is same principle as traditional galvanometer. It can be controlled one-way, rotor moves to a position that proportional to the coil current. However the control bandwidth of open-loop galvos is limited because it has a resonant frequency determined by rotor inertia and spring constant. In closed-loop control, rotor position is detected with a position detector, it is compared to commanded position and the rotor position is controlled to track the commanded position. This is also called *feed-back control* or *servo control*. It can improve scanning speed and accuracy compared to open-loop control .

Power efficiency is also improved because there is no power loss due to a torsion-rod spring. However the closed-loop control requires cost of position detector, servo amplifier and related. In this project we build the closed-loop controlled galvos.

2.2.2 Why Proportional derivative and not PID?

We built servo amplifier and proportional-derivative feedback control using op-amps.

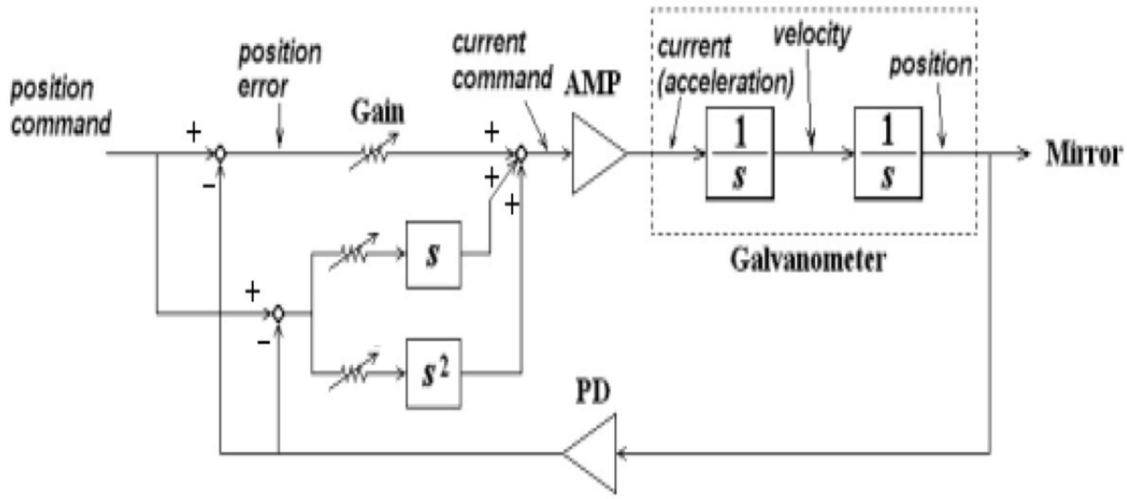


Figure 3. Servo Operation Diagram (Simplified)

Figure 3 shows the block diagram of the servo amplifier for this project. In position servo system, delay order at the controlled object becomes high and it cannot be controlled stably unless any phase compensation suitable for the servo system. The control method for the closed-loop galvo is PD-control, as for D-control, compensation of current-velocity delay and velocity-position delay each are done separately. I-control is omitted because it can affect servo stability. In this system, there is hardly any neither friction nor static torque so that it seems there is no problem for positioning accuracy even if without the I-control.

2.2.3 Why Galvos and not motors?

The Laser scanner cannot be built using dc motors as due to rotary inertia we cannot stop the scanner at required position. The Scanner can be built using servos or steppers motors but due to the limiting switching actions & low speed of these motors a continuous image is not obtained. Also there is a method where we use audio speaker woofers and attach mirrors to the speaker cone but this method cannot be used to produce distinct or predefined image.

2.3 Hardware Description

This section describes the hardware components that are implemented for this project.

- PT-51 board (805131A Microcontroller board).
- Dual power supply op-amp (LM358N).
- Power op-amp (LM1875) which is voltage controlled current source.
- Voltage regulator IC (LM317 & LM337 complementary pair).

2.3.1 PT-51 Microcontroller Board

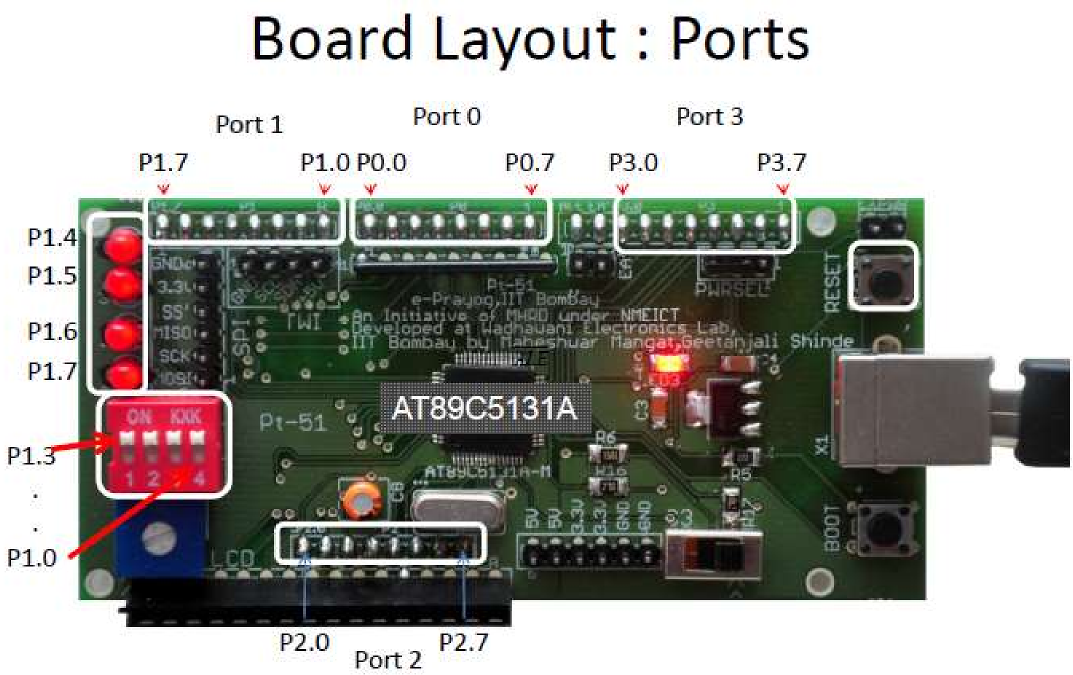


Figure 4. Physical appearance of PT-51

2.3.1.1 General Description

PT-51contains Atmel AT89C5131A Microcontroller. The Atmel AT89C5131A is an 8051-based microcontroller with Full Speed USB Device, Dual Data Pointers, Enhanced UART, 3 16-bit Timers, 5 Channels PCA, WDT, 34 I/O lines, SPI, USB Module, 32 Kbytes ISP Flash ROM, 1280 Bytes RAM.

AT89C5131 is a high-performance Flash version of the 80C51 single-chip 8-bit microcontrollers with full speed USB functions. AT89C5131 retains the features of the Atmel 80C52 with extended Flash capacity (32- Kbyte), 256 bytes of internal RAM, a 4-level interrupt system, two 16-bit timer/counters (T0/T1), a full duplex enhanced UART and an on-chip oscillator.
In addition, AT89C5131 has an on-chip expanded RAM of 1024 bytes (ERAM), a dual data pointer, a 16-bit up/down Timer (T2), a Programmable Counter Array (PCA), up to 4 programmable LED current sources, a programmable hardware watchdog and a power-on reset. AT89C5131 has two software-selectable modes of reduced activity for further reduction in power consumption. In the idle mode the CPU is frozen while the timers, the serial ports and the interrupt system are still operating. In the power-down mode the RAM is saved, the peripheral clock is frozen, but the device has full wake-up capability through USB events or external interrupts.

Operating modes:

• It operates in 2 modes –

1. Boot loader mode: In this mode the Board communicates with the PC and the flash memory can be programmed.

2. Application mode: The board runs the code which has been programmed into its flash memory.

2.3.1.2 Suitability for the project

The PT-51 has 4 ports. It fulfills the requirements for interfacing the required galvos and sensors. The other microcontrollers of AVR and Pic series could be used for the same. The programming of the PT-51 can be easily done using KEIL software used for programming Atmega 16. Hence, we choose to use the same.

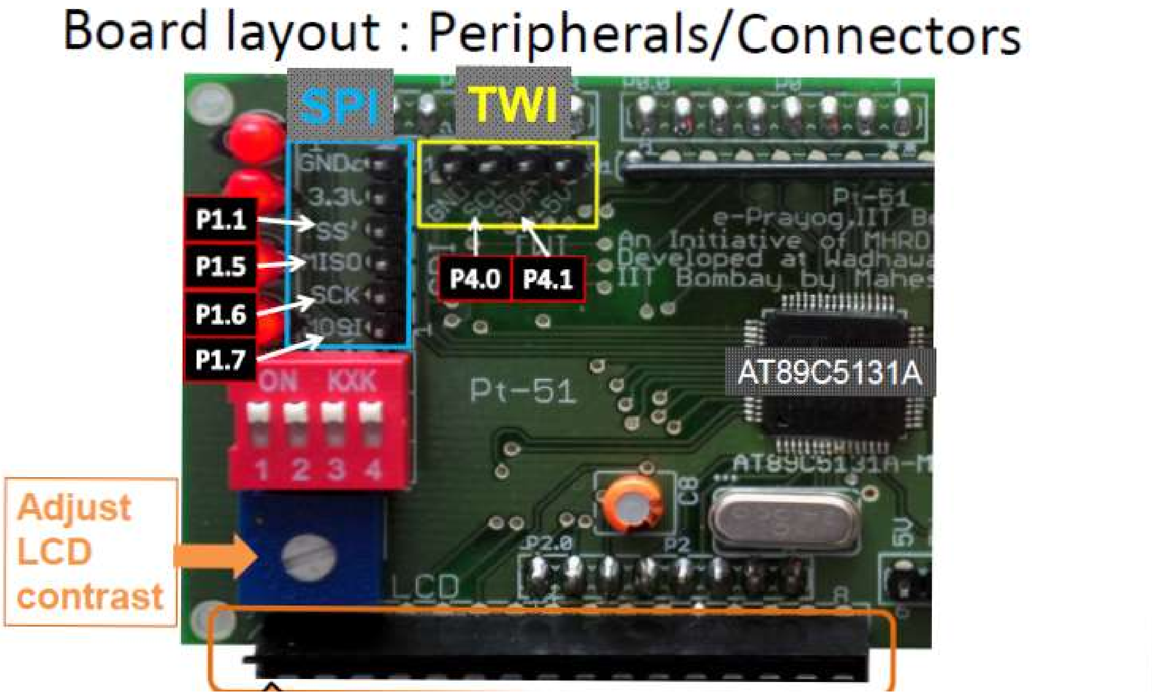


Figure 5. Peripherals provided in PT-51

FEATURES OF PT-51

- 24MHz Crystal clock generator.
- 4 LEDs and 4 Switches for simple programs.
- LCD connection port.
- Type B USB connector.
- All ports accessible.
- Can be mounted on breadboard

2.3.2 LM-358 OP-AMP

2.3.2.1 General description

The LM358 consists of two independent high gains, internally frequency compensated operational amplifier. It can be operated from a single power supply and also split power supplies. It has some features like Internally frequency compensated for unity gain, Wide power supply range 3V - 32V, Input common-mode voltage range include ground, Large DC voltage gain etc.

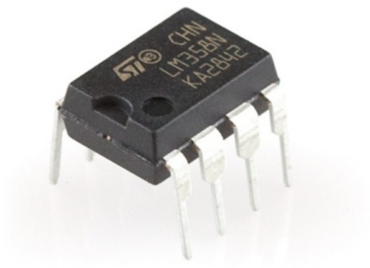


Figure 6. Dual Channel op-amp LM358

2.3.2.2 Suitability for the project

LM358 has a wider output voltage swing, operates down to a lower supply voltage, has lower noise, dual power supply and is also a dual channel (two in one package). It's the obviously preferable part as we require voltage swing in both the directions and important feature of this IC is that we do not require independent power supply for working of each comparator for wide range of power supply. Also as it contains dual channel, less number of op-amp IC's are used which can be easily accommodated in GPB.

2.3.3 LM-1875

2.3.3.1 General Description

The **LM1875** is a monolithic power amplifier offering very low distortion and high quality performance for consumer audio applications. The **LM1875**'s output is current which is voltage controlled. Some of the features include high gain, fast slew rate and a wide power bandwidth, large output voltage swing, high current capability, and a very wide supply range.

Figure 7. Physical appearance of LM-1875 power amplifier

2.3.3.2 Suitability for the project

The LM1875 is a power op amp. As the motors were expected to draw 2-3A, depending whether we were driving from a power supply or from batteries, the op amp we used to drive the motor needed to be able to source this amount of current. The op amp also served as a gain stage, multiplied the input by 10x to achieve the maximum swing of +/-30V.
Note: by keeping one side of the motor constantly grounded and simply modifying the other side to be positive or negative for direction, we were able to reduce the logic and delays required to switch directions.

2.3.4 LM-317 AND LM-337

2.3.4.1 General Description

The LM317 device is an adjustable three-terminal positive-voltage regulator capable of supplying more than 1.5 A over an output-voltage range of 1.25 V to 37 V. It requires only two external resistors to set the output voltage.

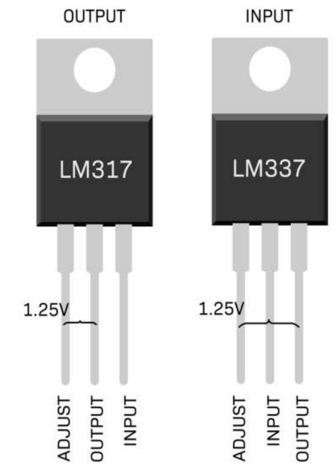


Figure 8. LM-317 and LM-337 variable voltage regulator

2.3.4.2 Suitability for the project

LM317 and LM337 are complementary pair of variable voltage regulator. In the sense they output voltage can be from 1.25V to 37V & -1.25V to -37V respectively depending upon the two resistors connected to the output pin. In laser diodes the energy is pumped into the semiconductor by passing a current through the depletion region. With increase in current light output increases. Thus variable voltage regulator IC is used to vary the intensity of laser diode.

The formulae to calculate output voltage is

Vo = +/- 1.25 (1 + R2/R1)

2.3.5 CA 3130

2.3.5.1 General description

CA3130 is op amps that combine the advantage of both CMOS and bipolar transistors. A CMOS transistor-pair, capable of swinging the output voltage to within 10mV of either supply-voltage terminal (at very high values of load impedance), is employed as the output circuit. The CA3130 Series circuits operates at supply voltage ranging from 5V to 16V.

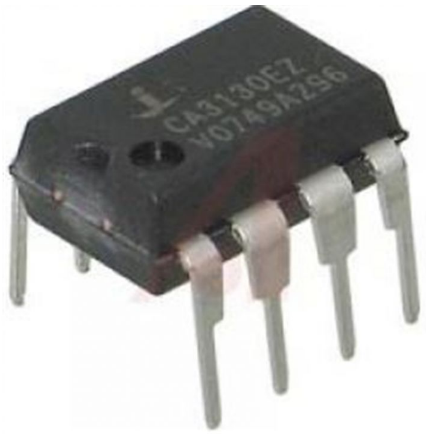


Figure 9. High Frequency CMOS op-amp

2.3.5.2 Suitability for the project

8MHz of frequency is provided to the capacitor feedback which is provided using wien bridge oscillator circuitry. A rail to rail op-amp which operates at high frequency is required for this purpose. As CA3130 has advantage of CMOS transistor it can be used up to 16MHz and is suitable for our project. Thus CA3130 provides high bandwidth and also has low current consumption.

2.3.6 IC 0808

2.3.6.1 General Description

The DAC0808 is an 8-bit monolithic digital-to-analog converter (DAC) featuring a full scale output current settling time of 150 ns while dissipating only 33 mW with ±5V supplies. No reference current (IREF) trimming is required for most applications since the full scale output current is typically ±1 LSB of 255 IREF/256.

Figure 10. 8-bit Single channel DAC

2.3.6.2 Suitability for the project

Each motor control board takes in a voltage which is used as a set point. In order to output two voltages the microcontroller must drive a DAC. We use the DAC 0808 8-bit single-channel DAC to achieve this. This DAC was selected based on its quick set time as well as its ability to update at the desired frequency. In order to drive two Galvos we used two 0808 DAC.

2.4 Functional Flow Charts

2.4.1 Flow chart of Intensity Control Process

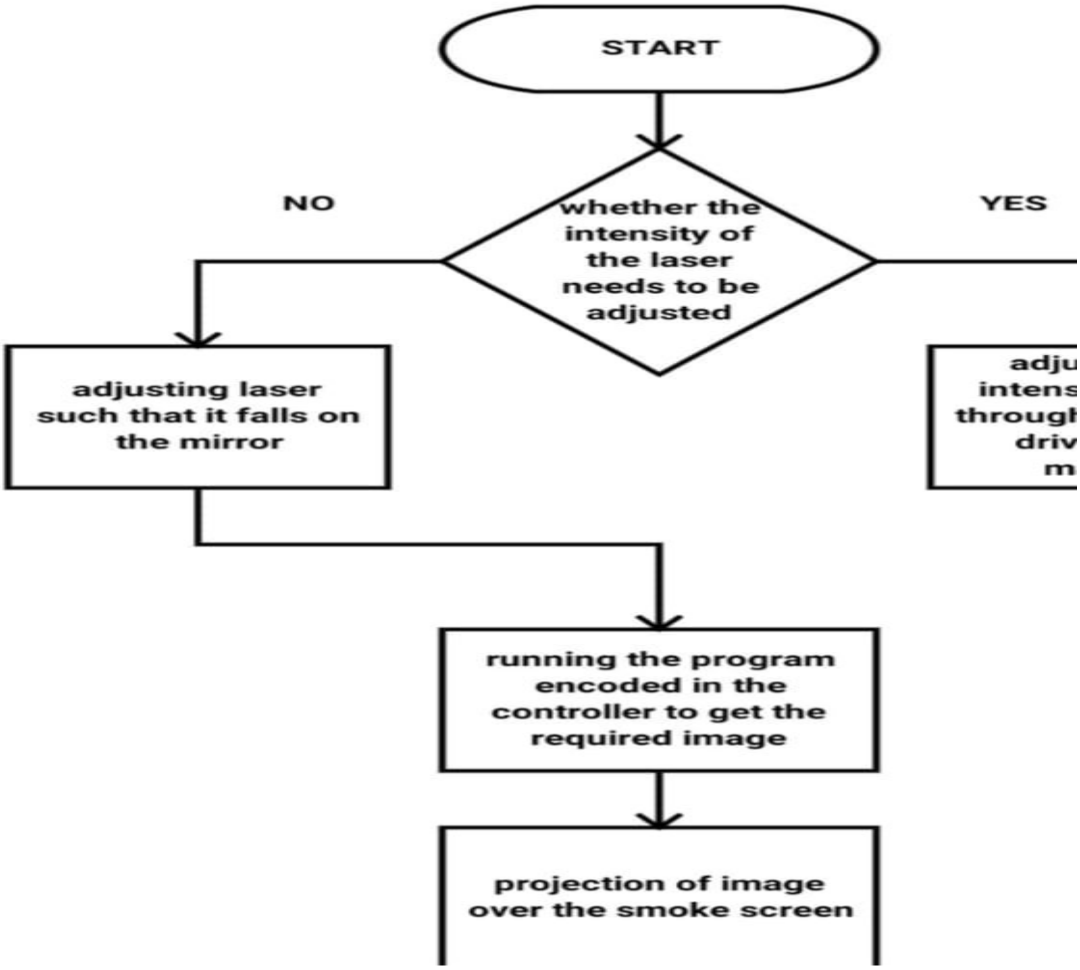


Figure 11. Intensity Control Flow Chart

Description:-

Initializes the laser and checks whether the intensity is as required. If the intensity is as required then we adjust the beam such that it falls on the Galvos mirrors. If intensity is higher or lower than required than intensity is adjusted using the laser diode circuit manually. After adjusting the intensity again set the laser beam so that it falls on the mirror.

2.4.2 Flowchart of Position Detection Process

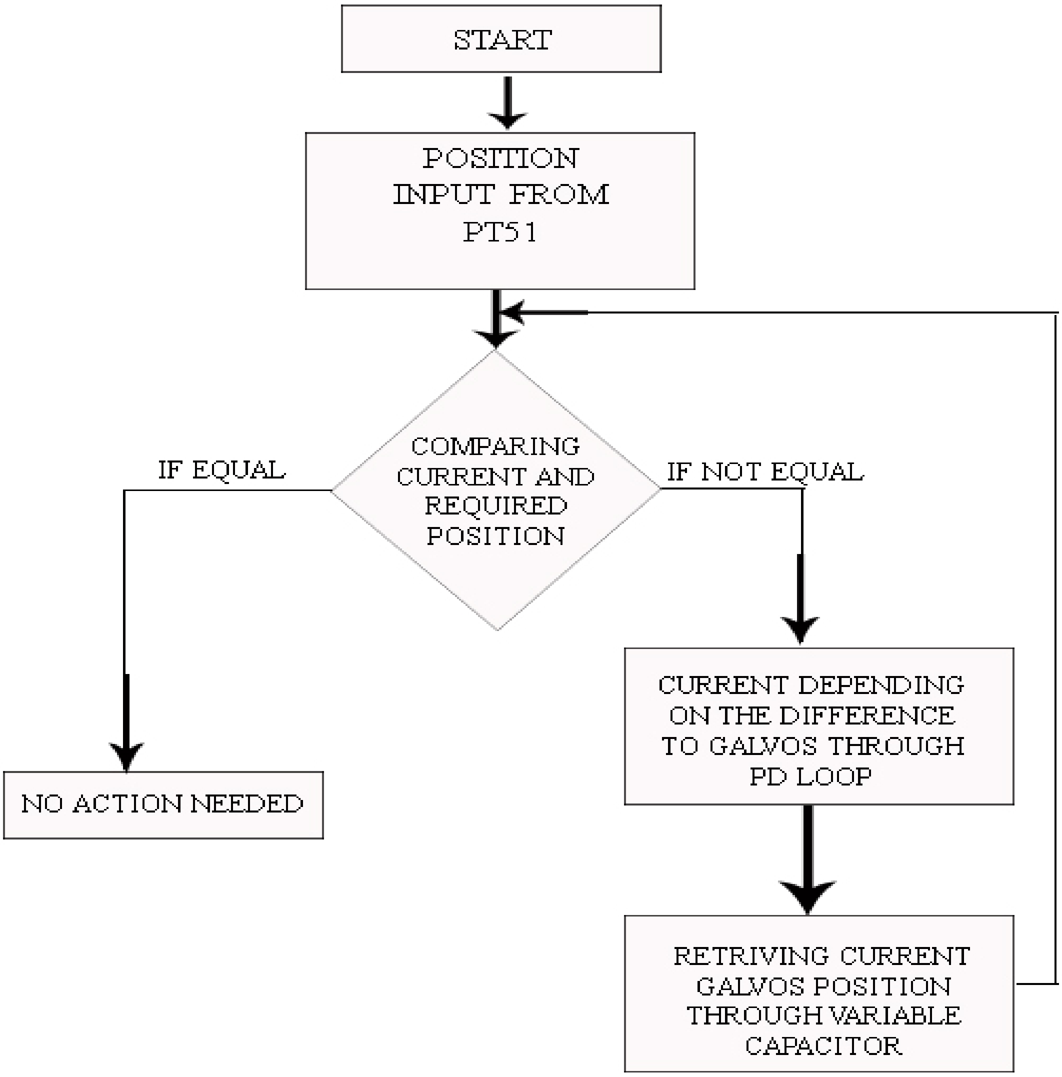


Figure 12. Position Detection Flow Chart

Description:-

Next step is to assign position coordinates as input to DAC through PT-51. Compare the current position and the required position of galvos. If the positions are equal the supply current goes to zero and the position is locked. If the current and required positions are different then current proportional to the difference is supplied and positions are compared again.

Chapter 3
Implementation Details

3.1 LASER GALVOS

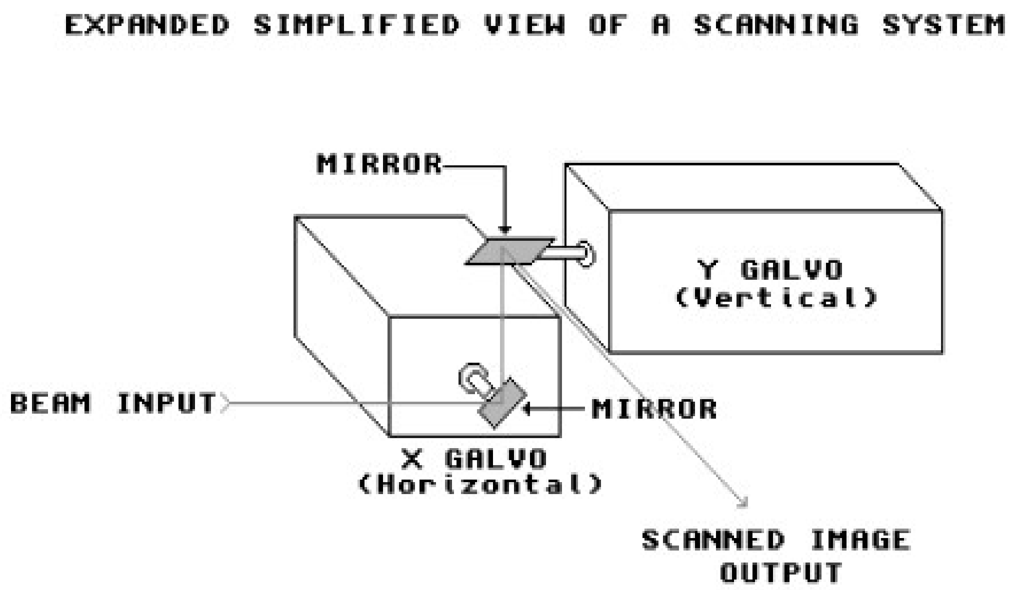


Figure 13. Galvo Scanning System

The galvanometer is one of the electrical instruments used to detect small current, its schematic symbol is (G). When detect very small current, the galvanometer had being used with attached mirror and light source instead of needle to enlarge the deflection, and current existing galvos also inherits this principle. The galvos have very thin rotor to minimize the rotor inertia for fast movement. The moving coil is replaced with high rigidly solid rotor, such as moving magnet and moving iron, and the armature coil is moved to stator to increase heat radiation. This structure can be said similar to Servo Motor.

3.1.1 Mechanical Construction

For this project, the main challenge was designing and fabricating the magnet-rotor combination, to which both the position detector circuit and mirrors are attached. Another challenge was the galvo enclosures that house the hand-wound coils and magnet-rotor assembly. The coils used in this project were also wound using custom hardware that allowed us to wind coils that are rectangular in the center to optimize the space in which the magnets rested between and within the coils. Finally, each of the printed circuit boards for the electrical side were also made by in-house.

Magnet / Rotor Assembly

In order to design and fabricate the magnet/rotor assembly, hard drive magnets were cut to size, epoxied to a shaft, and then ground down to size. The first gripe was that hard drive magnets are c-shaped, which meant that they had to be ground down to a rectangular shape first. This would not have been a problem if neodymium magnets weren't so brittle (they shattered extremely easily) and would catch on fire at 150 C. Both of these characteristics made altering these magnets a pain. A second difficulty we encountered was that occasionally, the epoxy used to hold the magnets to the rotor shaft was not enough to keep the magnets in place while the assembly was being ground to a cylinder. A final complaint we had with this method was that grinding the magnets down to a symmetrical cylinder sometimes left much less magnet than we would have liked on the rotor.

Based on the complications we ran into, we decided to instead invest in a pair of diametrically magnetized cylindrical neodymium magnets (1/4" diameter, 1" long), one for each rotor. This allowed for us to not have to worry about keeping the rotors balanced or having to grind down fragile magnets. In order to attach the magnets to the shaft, custom steel caps were designed and fabricated. The design can be seen in the figure to the right. The magnet is epoxied into one end of the cap, and the cut shaft is pressed into the other end. Two of these caps were machined for each for magnet, and the two steel caps cover the magnet completely while maintaining the magnetization. The cap was designed so that the bearings that suspend the shaft are pressed to the ends of the cap and are spaced exactly the distance used in the galvanometer enclosure. Once the rotors were pressed onto the bearings and assembled in the enclosure, the mirror and position detector electrode were attached to the ends using epoxy. both the cut mirror and electrode were attached to a shaft collar using epoxy and then adjusted on the shaft.

3.1.2 Galvanometer Enclosures

We also based the galvanometer enclosures off of ChaN's design, though the main differences are that the enclosures were machined entirely out of wood. n detector board fabrication), and we also altered the mechanism for grounding the motor shafts. The enclosures house the magnet/rotor combination, bearings, position detector circuit boards (electrode and detector), and the hand-wound coils. Two enclosures were fabricated, one for each axis of the scanner (X and Y).

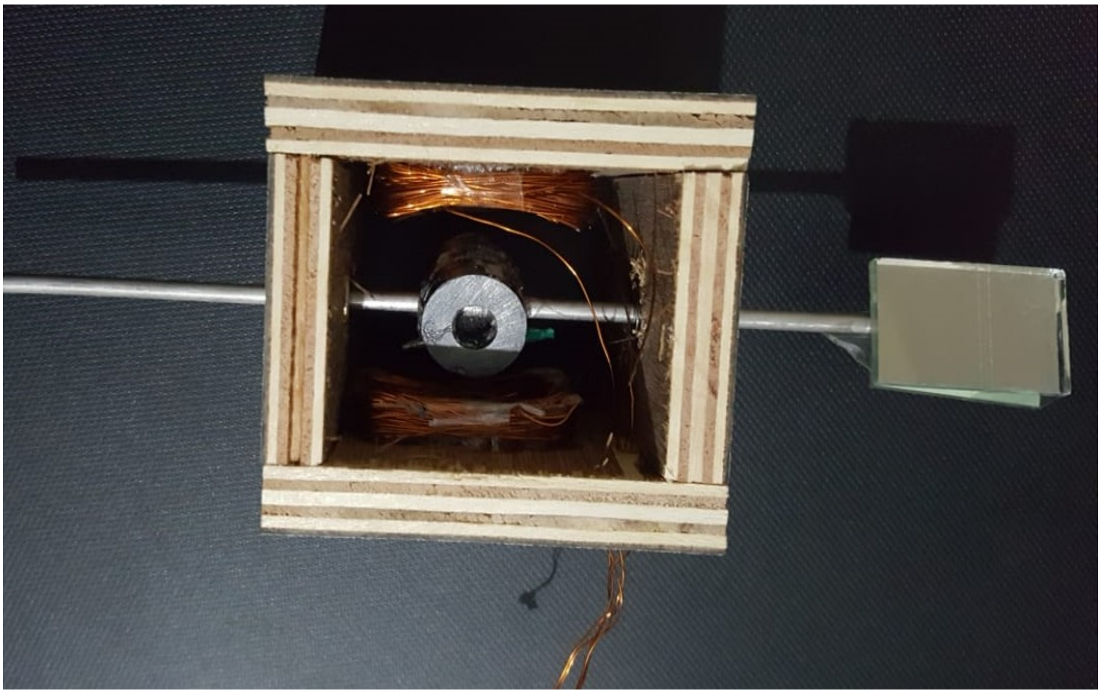


Figure 14. Physical Galvo

3.1.3 Capacitor Plate Circuitry

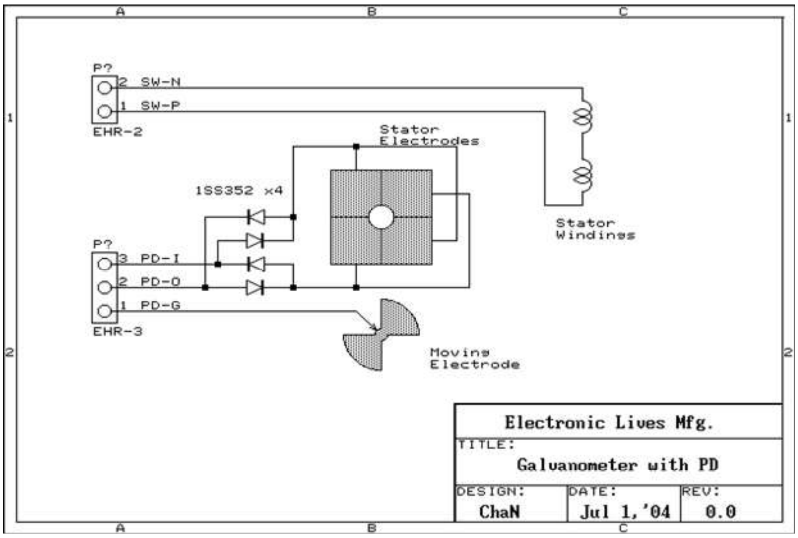


Figure 15. Capacitor Plate Circuitry

For electrical structure of Capacitive feedback the stator plate is divided into 4 quadrant and rectified signal is applied, using four diode, from wien bridge oscillator circuit. Here the moving rotor plate is grounded. The Electrodes used here are of butterfly capacitor type. Similar to the one used radio tuning.

3.1.4 Characteristics of Position Detector

The stator electrode of the position detector is divided in four quadrants and the working angle range becomes ±45° like shown in **Figure 16**. The servo system locks in the painted area that polarity of rotation and PD output matches for proper servo operation. It can lock at gray area that is incorrect position, but when apply scanner power with position command of center, rotor returns to the center wherever it is. Normal operating range is set to ±20° (±40° optical deflection) that sufficient for galvanometer scanners.

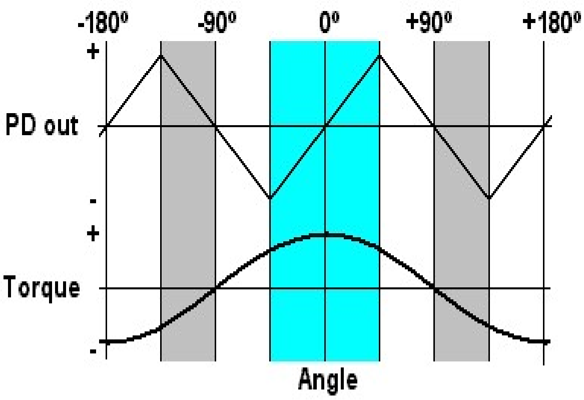


Figure 16. Characteristics of Position Detector

3.2 LASER Intensity control circuit

Laser diode driver circuit:

- It is a constant current source, linear, noiseless, and accurate, that delivers exactly the current to the laser diode that it needs to operate for a particular application.
- The user chooses whether to keep laser diode or photodiode current constant and at what level.
- Then the control system drives current to the laser diode safely and at the appropriate level.

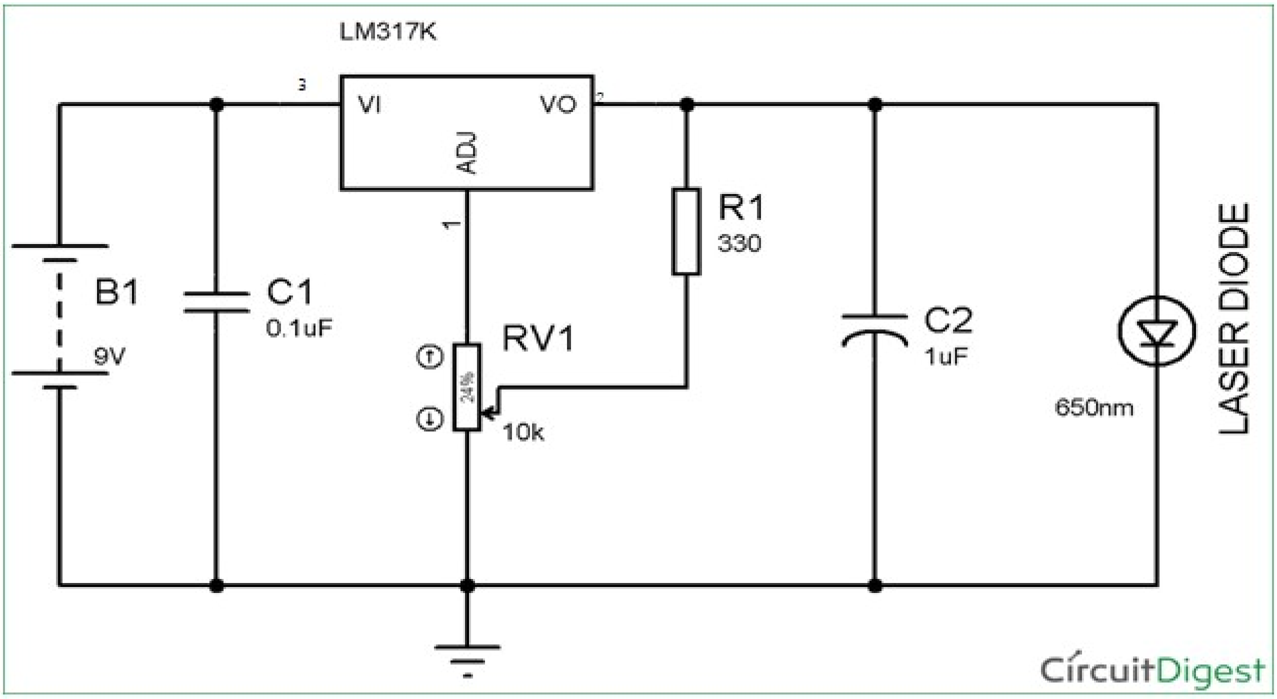


Figure 17. Schematic diagram of Driver Circuit

3.2.1 Working of Driver circuit

The first capacitor, the 0.1µF ceramic capacitor, serves to filter out high-frequency noise from the DC power supply. The second capacitor, the 1µF electrolytic, serves as a power load balancer to smooth out fluctuating signals. The two resistors R1 and R2 serve to determine the output voltage of the LM317 regulator. Usually R1 is a fixed 240Ω resistor, as specified by the manufacturer. R2, on the other hand, is decided by the design engineer, based on the amount of voltage he wants the regulator to output. In this case, with the laser diode we have selected, it has an operating voltage of about 2.7V. Therefore, we want the LM317 to output around 2.7V or a little higher. Therefore, we must choose the R2 resistor value so that it outputs this desired voltage.

The project requires to control the intensity of laser so that the virtual image is directly formed on the smoke screen. Without controlling the intensity the image might be directly formed on the screen behind the smoke screen. To avoid that Laser Diode Intensity Circuit is used and the above circuit fulfills all the requirements.

3.2.2 Photos of Intensity Control Circuit

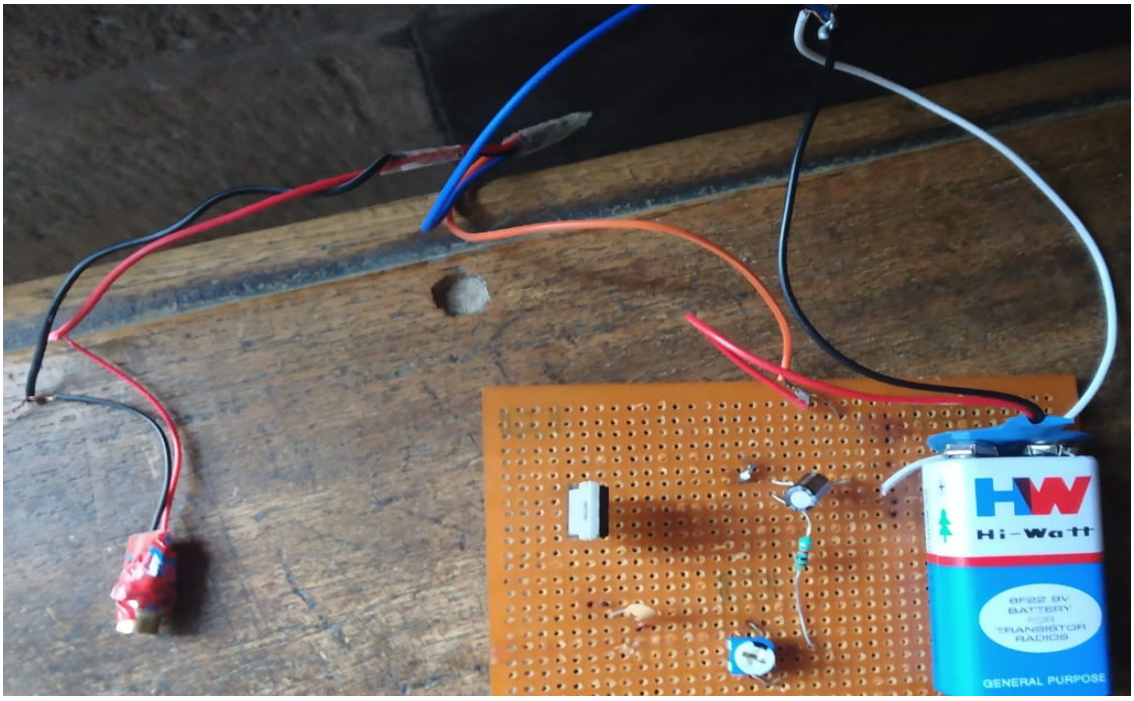


Figure 18. Physical Intensity Control Circuit

3.3 Closed-Loop Feedback Control

The system implements closed-loop control of the motors to stabilize the step response. Therefore there are two main parts to the motor controller: the position detector and the PD, proportional-derivative, feedback loop. Much like a servo, the motors are set with absolute position information, where two electrodes allow for 90 degrees of precision. The second portion is the PD feedback loop which uses the error in position to stabilize the output and improve the step response of the system. Due to symmetry, it is able to detect precise positions within 90 degrees.

3.3.1 Position Detection Circuit

3.3.1.1 Schematic Diagram

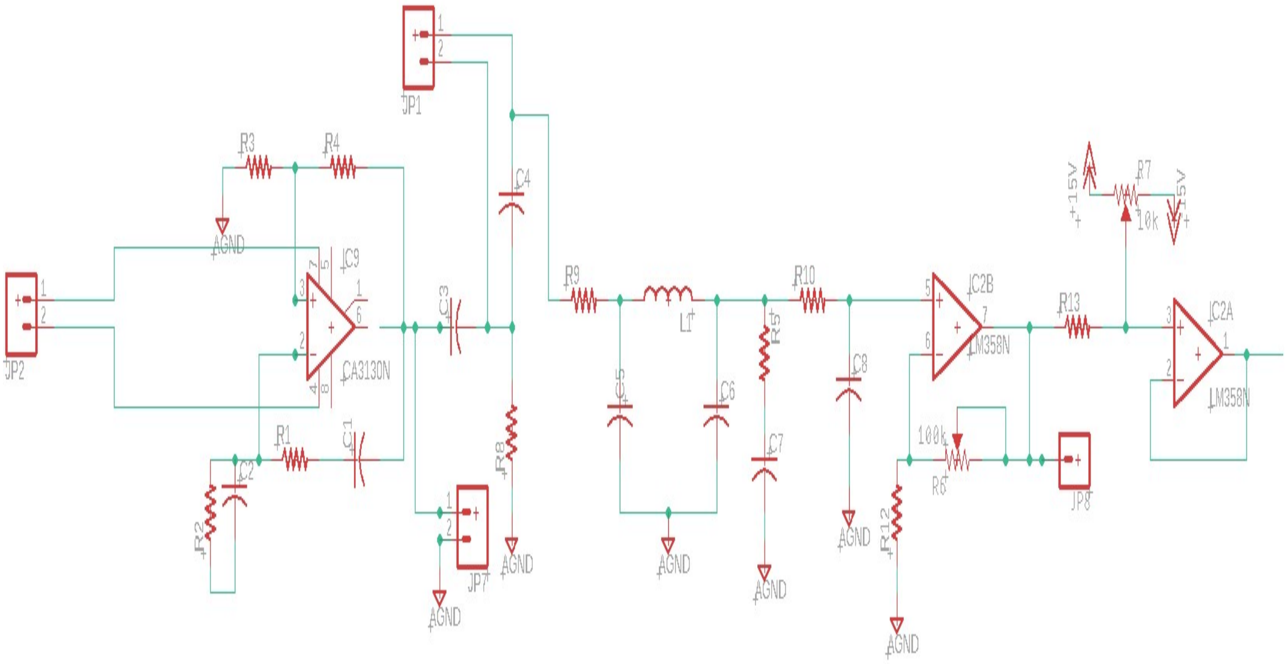


Figure 19. Schematic Diagram of Position Detection Circuit

3.3.1.2 Working

The position detector is used for absolute position information. However based on the scope of the project, we only needed to drive the motors within a 90 degree deflection range. We explored a few options, the potentiometer would cause undesired friction on the shaft, magnetic rotary encoders would create noise and would be highly susceptible to rapidly changing magnetic fields caused by the motors and as we did not need that great of a range, many devices were ruled out. Therefore, we decided to use a capacitive position detector. The detector uses two electrodes: one is moving and mounted to a shaft collar, the pads are grounded to provide the capacitance with the stationary electrode. The stationary electrode is arranged in 4 quadrants for 90 degrees position detection without aliasing. An 8MHz sine wave is applied to the pads with diodes rectifying the signal with positive diagonally arranged and negative region of the signal on the opposite diagonal.

When held in a specific position, the electric field will point toward the grounded electrode in the positive region and away in the negative portion. As the shaft rotates, this electric field changes in strength and direction inducing a current across a resistor thereby causing a potential. This voltage drop across the resistor corresponding to a specific position of the shaft corresponds to its specific position. The oscillating signal is important as a DC signal would simply charge the capacitor when the electrode is stationary and would thereby cause the position to spike randomly.

The signal from the position detector was then passed through a pi filter for noise, and a gain stage to get the output signal on the range of 1V pk-to-pk. We found that a gain higher than 10 would cause the signal to become unstable. Therefore, we were able to remove the potentiometer R6 for the second revision of the board. Then the signal was passed through an offset stage to adjust the DC offset in order to center the position signal. If the position signal was not centered correctly, the motor would become unstable and easily switch quadrants.

While not used in the final demonstration, a sine wave oscillator was built for the position detector. Arranged in a wien bridge, we were able to get the oscillations up to 5MHz with 2V peak-to-peak. As the frequency was on the correct order of magnitude, we found that this oscillator would have been sufficient, what was more important than the frequency is the amplitude, the higher the amplitude of the signal, the stronger the signal on the output. One important thing to note is the frequency response of surface mount versus through hole components. We found pretty early on that surface mount resistors could not handle the MHz oscillations we were trying to achieve and would produce no oscillations. Therefore we switched to through hole components on the position detector circuit.

3.3.2 Proportional-Derivate Feedback control circuit

3.3.2.1 Schematic diagram

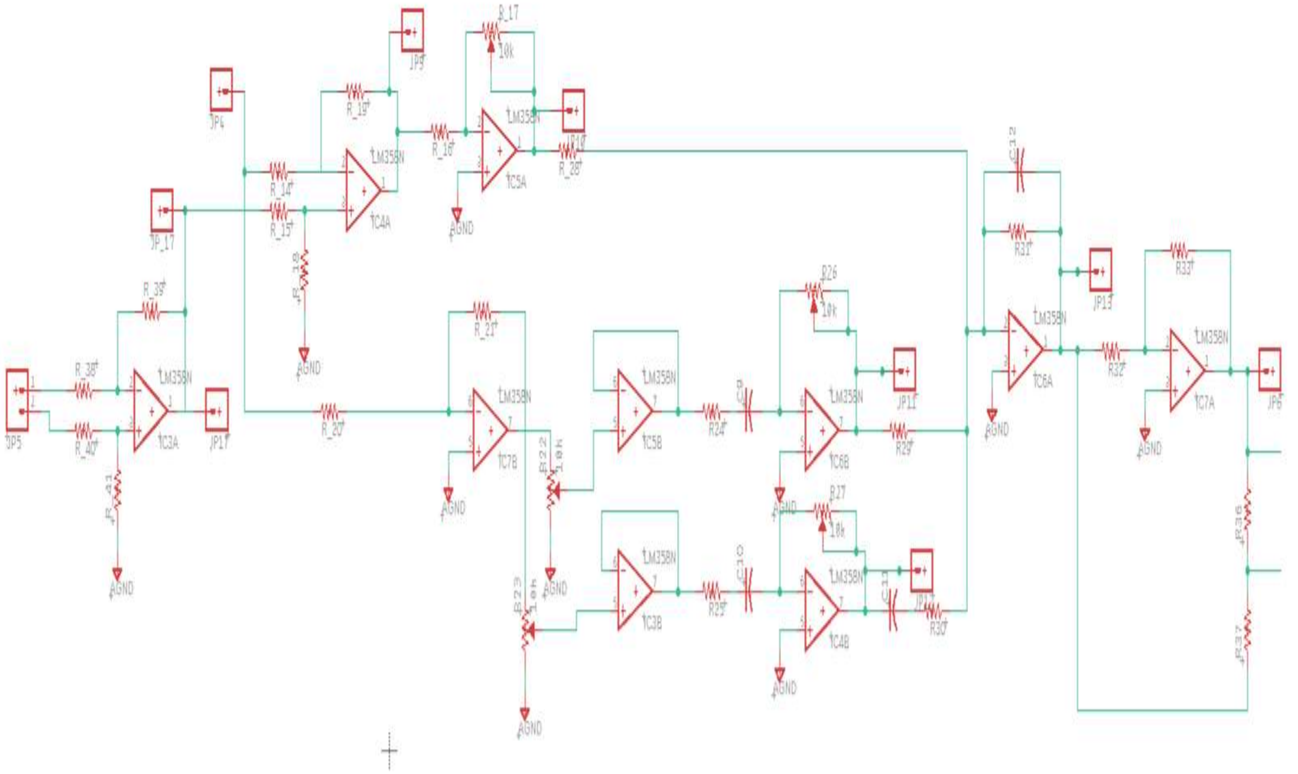


Figure 20. Schematic Diagram of Proportional-Derivate Feedback control circuit

3.3.2.2 Working

In general with PID control, the controller calculates the error between the desired and actual position. Then, it uses those to calculate the proportional, integral, and derivative (PID) values which are the constant parameters to see how the signal changes over time in order to better adjust and predict the error of the signal. The weighted sum of the three parameters are used to adjust the actual output to the desired output and reduce the error. One of our main concerns when designing the project was, how to achieve the best step response time. In order to achieve this, the motor would need a good gain term, however due to the Gibbs phenomenon, a very short rise time would also cause oscillations on the output. Therefore a PD controller was used to tune the output and reduce the error caused by these oscillations. Note that the integral term was removed from the controller, as discovered in previous labs, the integral term would cause additional instability to the control and the derivative term was sufficient to remove the ringing.

The DAC, desired, output from was first passed through a differential amplifier to offset the voltage range from 0V to 5V to -2.5V to +2.5V. This was necessary as the position detector output positions centered around zero. Two of the resistors on the op amp were also replaced with potentiometers in order to adjust the gain on the DAC output, this step was necessary to approximately match the amplitude of the position detector. As the error term looked at the DC difference between the DAC and position detector, if the DAC and position detector were on different scales, this error would show up and be amplified on the output to the motors. During testing, we found this DC difference to cause instability on the motor, where the position would frequently change quadrants. R14 and R18 were tuned to the same resistance in order to adjust the amplitude symmetrically. This tuning was accomplished by monitoring the amplitude of a symmetric square wave.

For the proportional term of the controller, there were two parts: the error term, and the proportional gain. The error was a simple differential amplifier which took the difference between the position detector, the actual motor behavior, and the DAC, the desired output. After the error term, the signal passed through the proportional gain stage to adjust the DC value of the signal. Increasing the proportional term also allowed us to get a faster step response on the motor which was ideal to draw sharp images and move the motor quickly for precision.

The differential portions rely on the properties of a capacitor, more precisely the relation between voltage and current, to differentiate the signal. The differential portion is separated into the low and high frequency components of the signal. For tuning purposes, we mainly relied on the low differential portion to stabilize the signal and remove ringing, however as the proportional term increases, the high frequency components appear on the signal. Recall the Gibbs phenomenon which tells us that signals with a quick step response generate high frequency oscillations on the edge of the signal as a result of a sudden rise or fall in the signal. Potentiometers R22 and R23 choose the amount of the signal that is passed to each channel. Next the signal is passed through a buffer for impedance matching so the potentiometer value does not affect the filter and gain stage. For the low frequency differential portion, R24 and C9 were used to determine the cutoff frequency for the signal, and R26 was used to further determine the gain of the channel. However 3 of the op amps could be eliminated simply by passing the signal from the position term to the high and low frequency terms. Finally all of the portions of the signal were passed through a summing amplifier before being passed to the power op amp

3.3.3 Power op-amp motor driver

3.3.3.1 Schematic Diagram

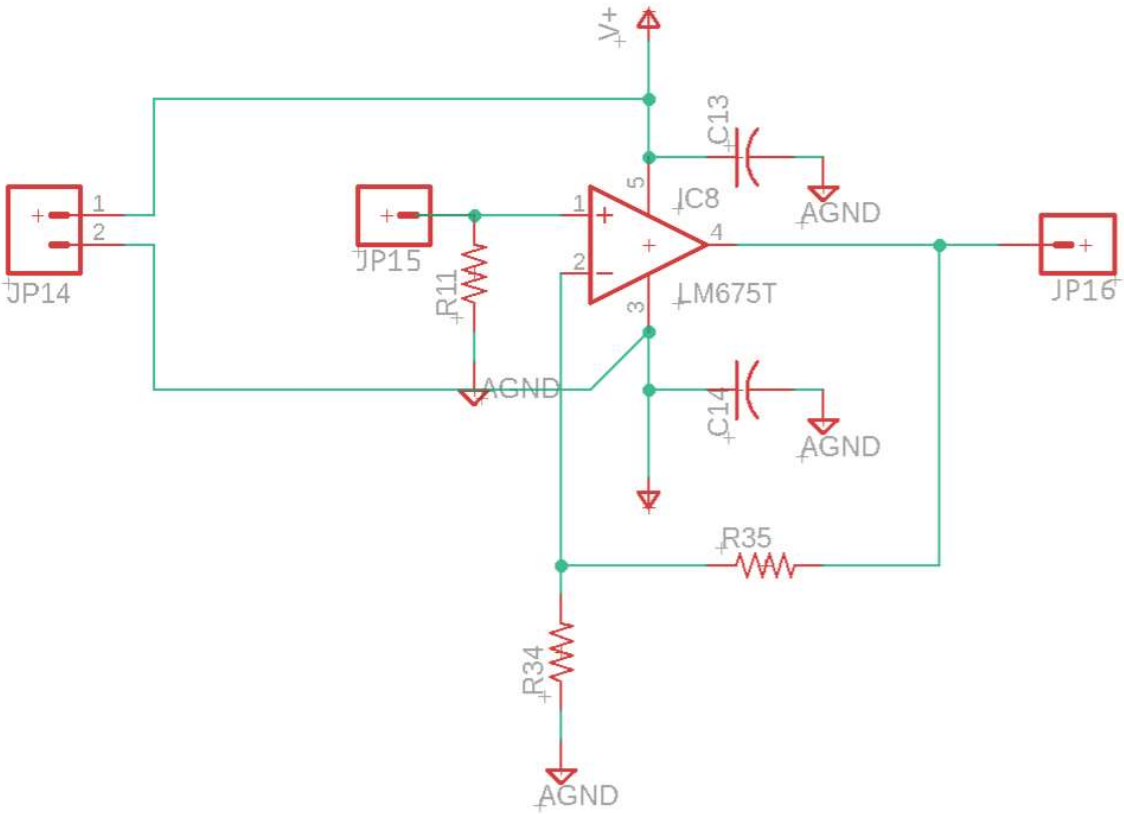


Figure 21. Schematic Diagram of Power op-amp motor driver

3.3.3.2 Working

The LM1875 is a power op amp from TI. As the motors were expected to draw 2-3A, depending whether we were driving from a power supply or from batteries, the op amp we used to drive the motor needed to be able to source this amount of current. The op amp also served as a gain stage, multiplied the input by 10x to achieve the maximum swing of +/-30V. Note: by keeping one side of the motor constantly grounded and simply modifying the other side to be positive or negative for direction, we were able to reduce the logic and delays required to switch directions. During testing, we encountered problems using the LM1875 which were eventually traced to input coupling. This would result in strange input signal degradation when under load. We were able to fix this issue by moving away from a breadboard to a soldered prototype.

One problem we found was the magnetic coupling due to the proximity of the motors. To cost effectively shield against magnetic fields, we provide shielding through a low carbon steel sheet. The steel sheet was cut and bent to create an enclosure around one of the galvanometers. A metal with a relatively high permeability allows magnetic fields to be redirected through the steel and therefore reduce coupling onto the other motor.

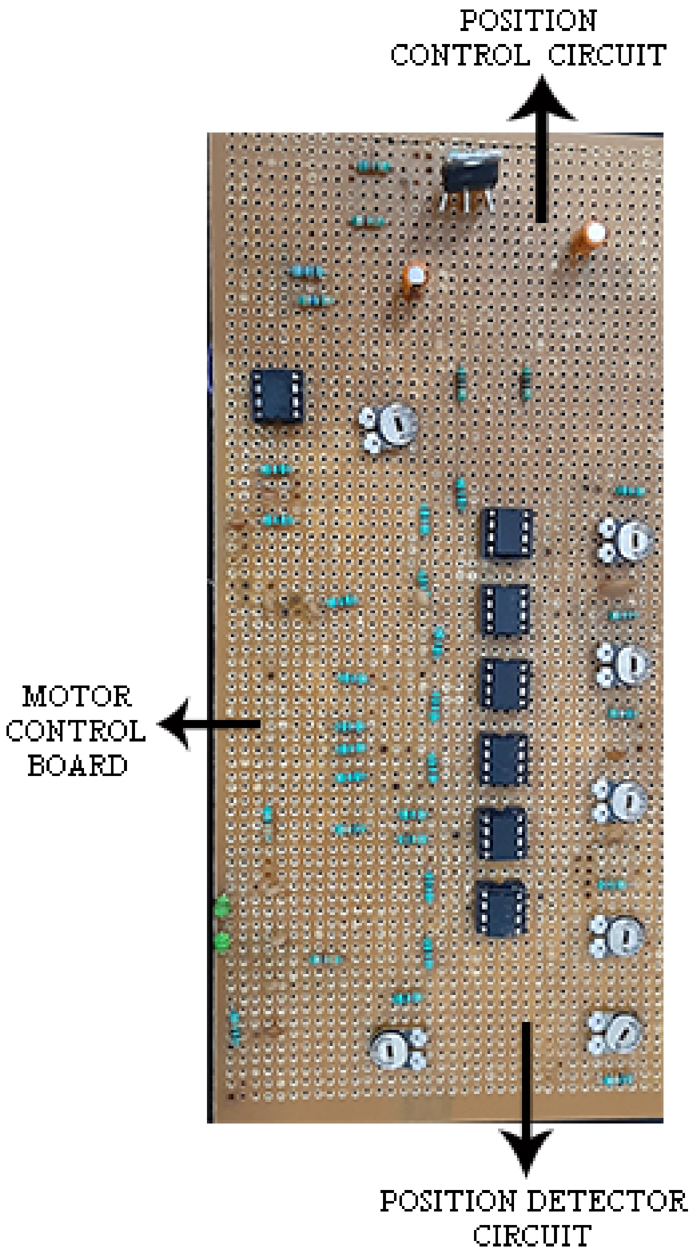


Figure 22. Physical Feedback Circuit.

The circuit above contains position detector circuit, Proportional-Derivative (PD) circuit and power op-amp motor driver.

3.4 Voltage Regulator Circuit

3.4.1 Schematic Diagram

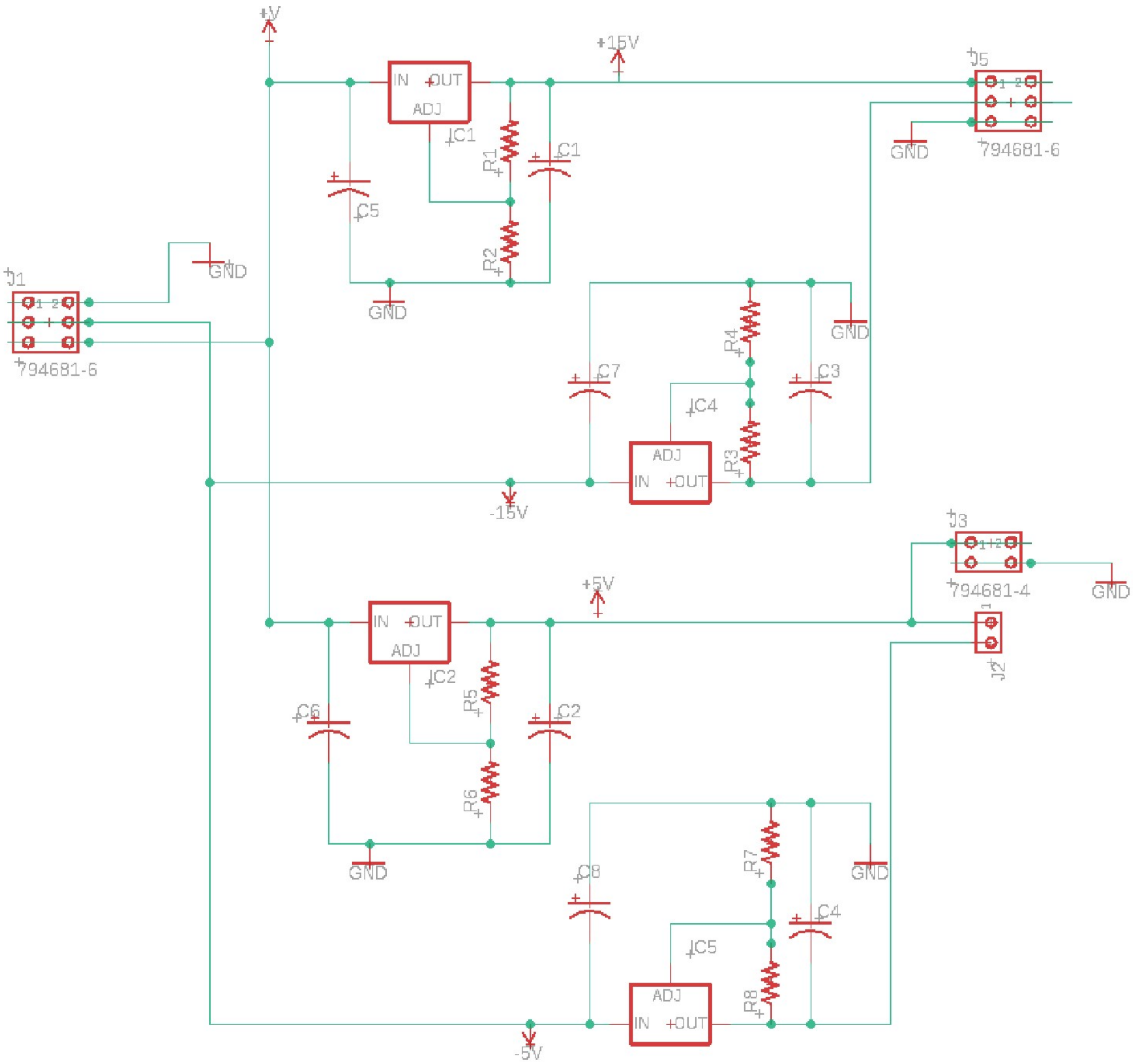


Figure 23. Schematic Diagram of Voltage Regulator Circuit

3.4.2 Requirement

The voltage regulator board consists of several LM317 and LM337 circuits in order to provide the +15, -15, +5 and -5 rails needed for the rest of the project. These chips operate by linear voltage regulation and should be cooled to avoid heat damage.

The LM337 and LM317 are complimentary voltage regulators from TI. In order to run all of the op amps, we needed to have positive and negative voltage rails. We used the +/-5V for the oscillator and the +5V for the microcontroller and FTDI chip. The PD controller board required +/-15V for the op amps. The power op amp simply used the +/-30V straight from the batteries. Power regulators were used for the components where it was important that the voltage remained fairly constant. For example, we needed the oscillator to be very precise or else it would greatly affect the amplitude of our position signal output which would propagate as error in the pd controller. Therefore we could not simply hook up the rail to a battery as that power supply would change over time. Notice, the power op amp was placed on the batteries as we expected a fairly high current draw and did not care as much if the power to each motor decreased by 1V or so.

3.4.3 Photo of Voltage Regulator Circuit

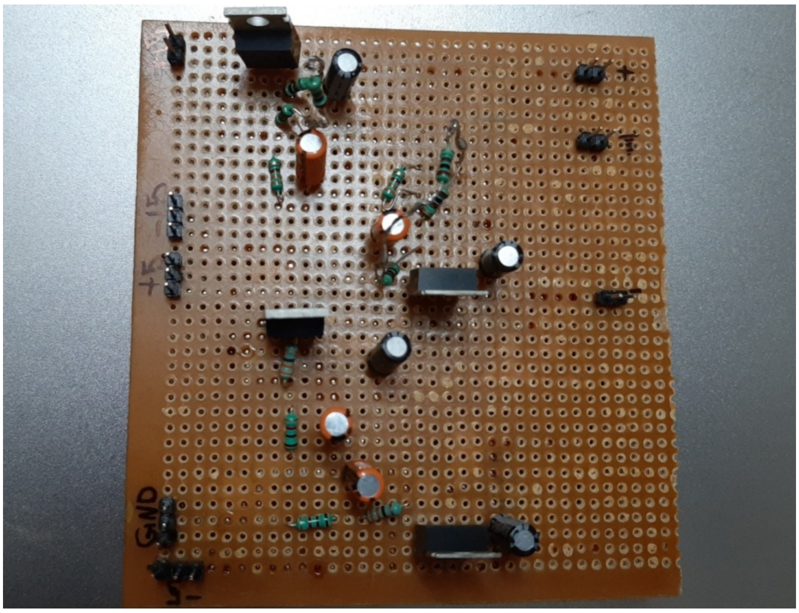


Figure 24. Physical Voltage Regulator Circuit

Chapter 4
Simulation and Testing

4.1 Debugging

Types of Position Feedback

A Number of Feedback can be used like

1. Rotary Encoder (M274 module).
2. Hall Effect sensors.
3. Optical sensor.
4. IR sensor.
5. Capacitive sensor

From the above list we tried each sensor but failed in every case due to some reasons which are further elaborated.

Rotary Encoder (M274 module) produced unnecessary friction due to the coupling used to attach the module and galvos. And thus the speed of the operation of galvos was affected and continous image was not obtained.

Hall effect sensors which work on the basic principle of magnetism produced stray magnetic field which distorts the magnetic field created by the coils and rotor assembly.

Optical sensors increased the complexity of the feedback loop and thus it was not feasible for the project.

IR sensor provided ON/OFF type of feedback and the output images were not precise. The ON detection of IR sensor passed full current through the coil which seldomly rotated the mirror by 180 degree.

So, we used capacitive sensor.

We chose a simple capacitive method which utilizes a principle that when an AC voltage is applied to a capacitor, current flow through the capacitor proportional to the capacitance value. Its structure is similar to tuning capacitor used in radio. In practical design, one electrode is grounded because it is convenient considering the structure, but a consideration is needed to circuit design when measure the capacitor current in such structure.

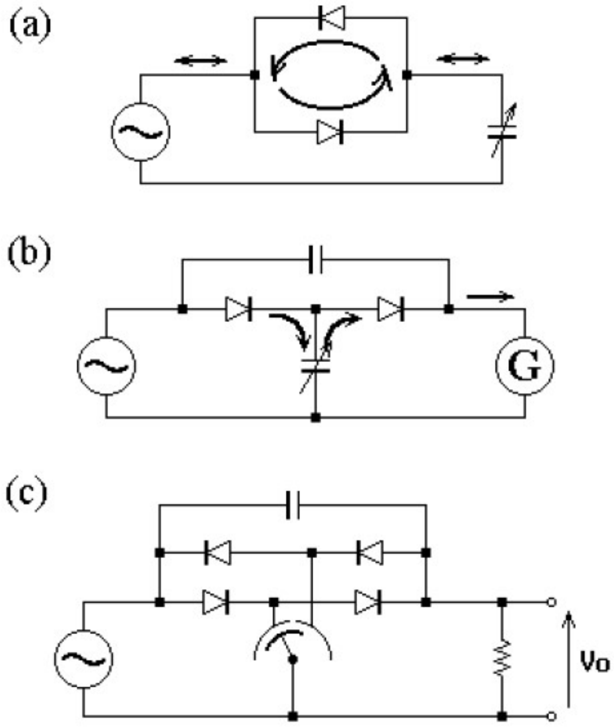


Figure 25. Need of rectification in capacitor feedback

The schematic shown in *Figure a*, a DC component indicated with arrows is generated, and open the DC current path as shown in *Figure b*, the rectified DC component will able to be detected by the galvanometer(G). In fact the capacitance change is very small and it will not able to be detected stably due to parasitic capacitance and any interference. *Figure c* shows the schematic used for practical design, two differential electrodes and diodes are joined in opposite polarity each other. Sum of the rectified currents becomes difference between them, any factor affects accuracy can be cancelled and it can be detected stably. In this figure, when the moving electrode moves to left, positive voltage will appear at the Vo, and vice versa. The position detector built in this project changes the difference capacitance only several pF in full scale (90° mechanical deflection), and a sufficient output voltage change could be got.

4.2 Testing

4.2.1 LASER Intensity control circuit

Varying the resistor pot from minimum to maximum position, which is connected to the adjust pin of LM317, the intensity of laser diode varied from its minimum to maximum as shown below:-

Minimum Intensity

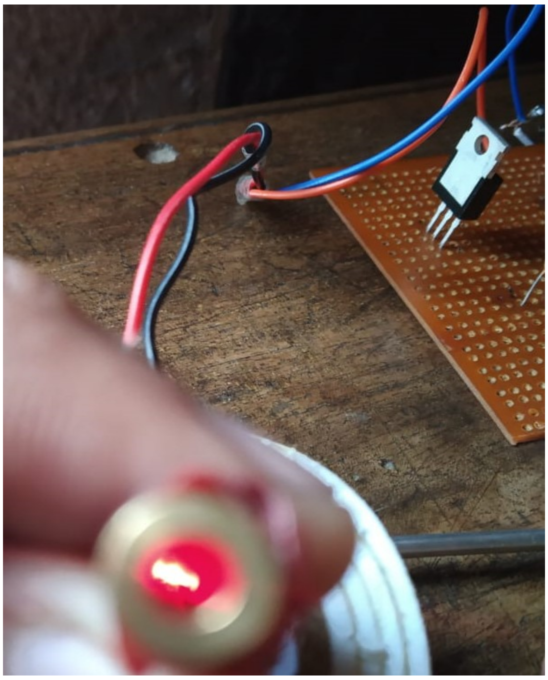


Figure 26(a). Minimum intensity

Maximum Intensity

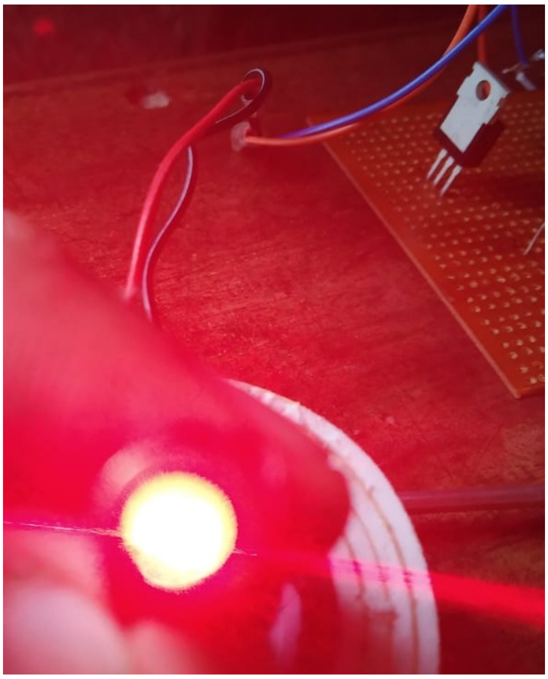


Figure 26(b). Maximum intensity

4.2.2 Voltage Regulator circuit

The Voltage regulator circuit made on GPB according to the **Figure23**. and Regulated output voltage was tested and measured using CRO. The images of the same displayed below:-

Figure 27.(a) -15V, (b) +15V, (c) +5V, (d) -5V

The Black line in the pictures above indicates DC ground line and each 1cm block indicates 5V along the Y-axis. Thus pictures show -15, +15 +5 and -5V respectively.

Chapter 5
Conclusion

5.1 Conclusion

The laser-Galvos system successfully generates a 2-D image which can further be projected on a smoke screen to get a virtual 3-D projection. Compared to open loop circuit, the closed loop counter part gives better locking of the laser beam as required. This becomes possible due to the feedback capacitor module that anticipates the required current and sets the feedback accordingly. Hence most of the laser-galvos system in present times offers closed loop control. The images with more complexity can be generated by increasing the number of mirror in the X-Y scanner.

5.2 Limitations

The capacitance produced by the feedback capacitor is in terms of pF and the range of capacitance value obtained is too small. This limits the precision of the laser projector system. And also the laser used in this project is semiconductor type laser, it can be replaced by using high end lasers (like He-Ne lasers) for more clearer images.

5.3 Future Scope

The future improvements can be made on the front of Graphical User Interface. In current project the required image is obtained by taking the position inputs directly in form of coordinates from the PT-51 module. This can be replaced by introducing graphical user interface where a frame editor software decodes the vector values of required image and can provide direct coordinates to DAC for further processing. This would make the project more user friendly.

Chapter 6

Appendix

6.1 Pin-out's of IC's used

❖ AT89C5131A

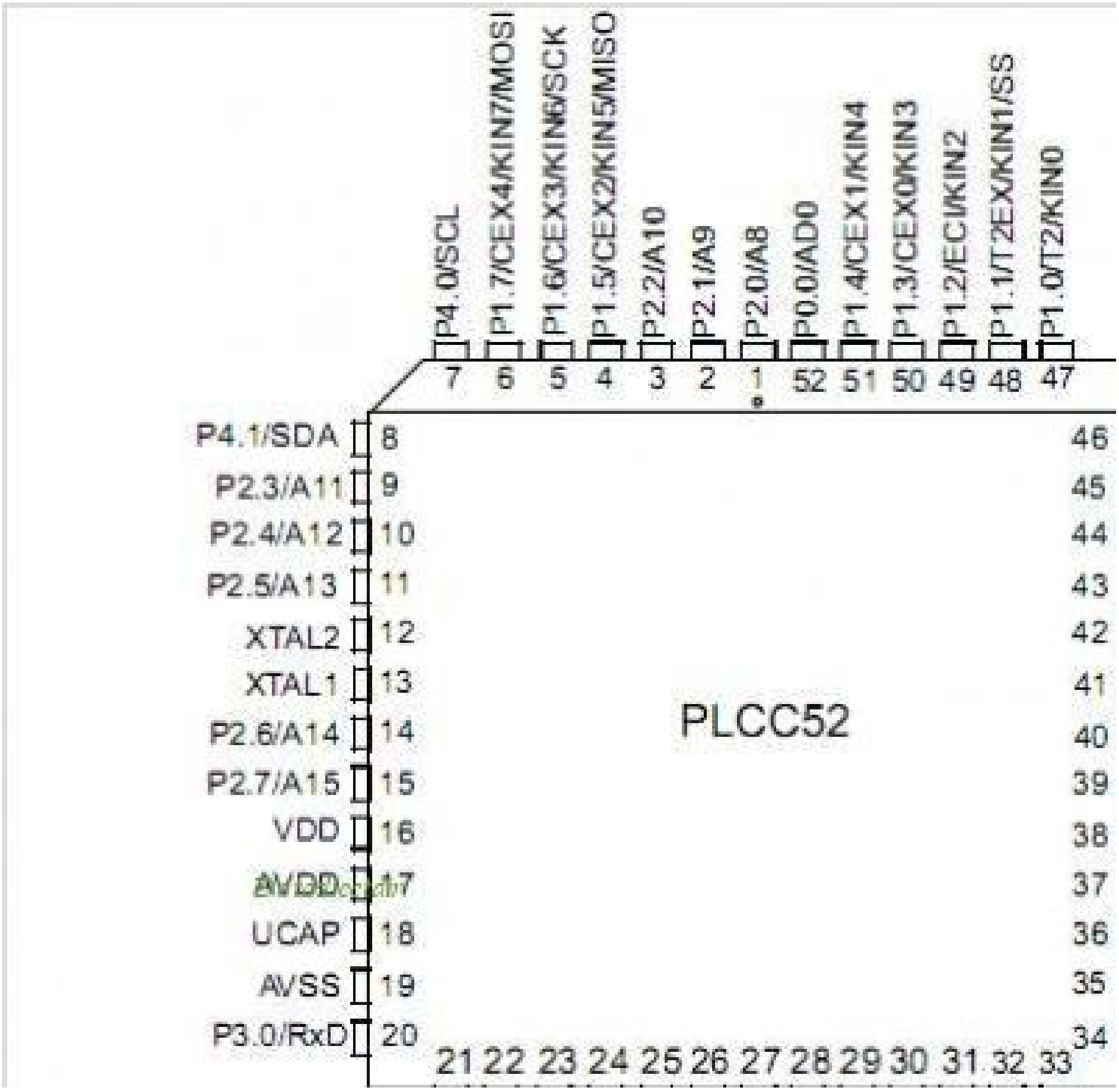


Figure 28. Pinout of AT89C5131A

❖ LM358

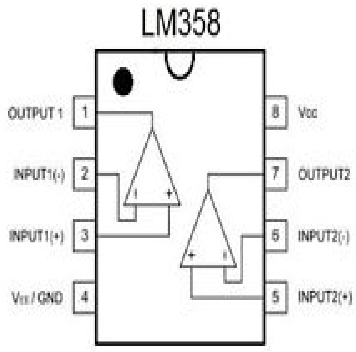


Figure 29. Pinout of LM358

Pin No	Function	Name
1	Output , Channel A	OUTA
2	Inverting Input, Channel A	-INA
3	Non-Inverting Input, Channel A	+INA
4	Ground	GND/V-
5	Output, Channel B	OUTB
6	Inverting Input, Channel B	-INB
7	Non-Inverting Input, Channel B	+INB
8	Positive Supply	V+

Table1. Pin Function of LM358

❖ LM1875

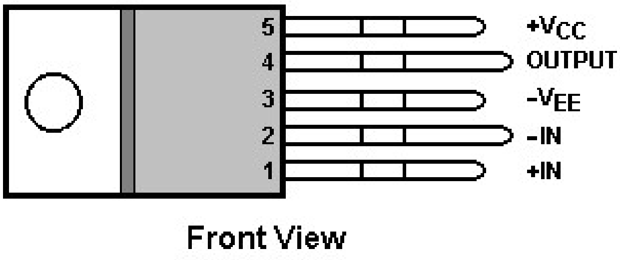


Figure 30. Pinout of LM1875

Pin No	Function	Name
1	Non-Inverting Input	+IN
2	Inverting Input	-IN
3	Negative Supply	V-
4	Output	OUT
5	Positive Supply	V+

Table2. Pin Function of LM1875

❖ CA 3130

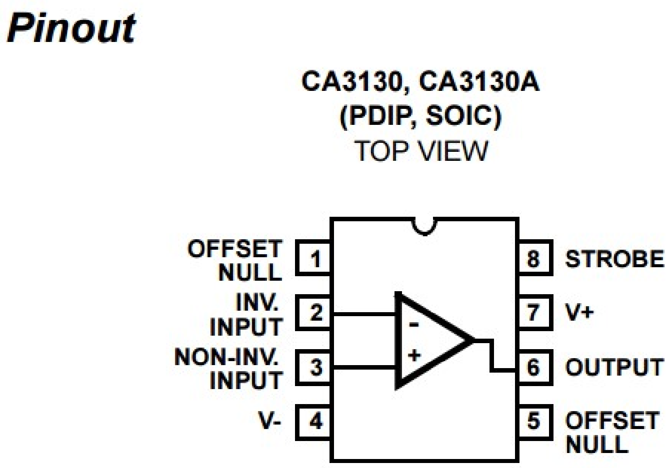
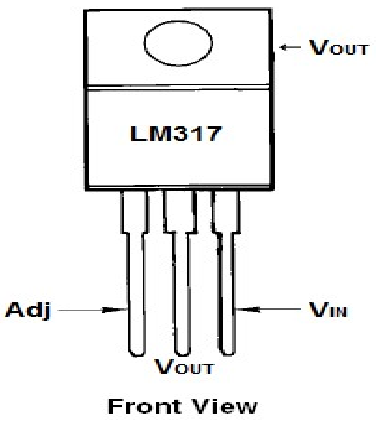


Figure 31. Pinout of CA3130

Pin No	Function	Name
1	Offset Null	-
2	Inverting Input	-INA
3	Non-Inverting Input	+INA
4	Negative supply	V-
5	Offset Null	-
6	Output	OUT
7	Positive supply	V+
8	Strobe	-

Table3. Pin Function of CA3130

❖ LM 317 and LM 337



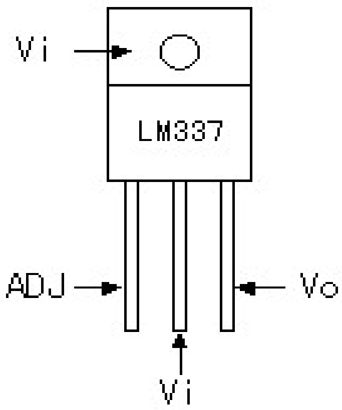


Figure 32. Pinout of LM317 & LM337

LM337

Pin No	Function	Name
1	Adjust	ADJ
2	Input Voltage	Vi
3	Output Voltaget	Vo

Table4. Pin Function of LM337

LM 317

Pin No	Function	Name
1	Adjust	ADJ
2	Output Voltage	Vo
3	Input Voltage	Vi

Table5. Pin Function of LM317

6.2 Parts List

Circuit	RefDes	Value
OSCILLATOR	IC1A	CA 3130
	R1, R2	1k
	C1, C2	100pF
	R3	180
	R4	360
POSITION DETECTOR	C3, C4, C5, C6, C7	1nF
	C8	220pF
	R8	1k
	R9, R5	330
	R10	10k
	R12	10k
	R6	100k
	R13	1k
	R7	10k
	L1	220uH
DAC	R39, R40	1k
	R38, R41	10k
P Term	R14, R15, R18, R19, R16, R28	1k
	R17	10k
D Term	R20, R21, R29, R30	1k
	R22, R23, R26, R27	10k
	R24, R25	100
	C9	220nF
	C10	33nF
	C11	4.7 nF
Sum	R31	1k
	C12	1nF
Inverter	R32, R33	1k
Power OP Amp	C13, C14	0.1uF
	R11	3k
	R34	820
	R35	10k
LM317 +15 IC1	R2	3k
	R1	270
	C1	1uF
LM337 - 15v IC2	R4	3k
	R3	270
	C3	1uF
LM317 +5 IC3	R6	1k
	R5	330
	C2	1uF
LM337 -5v IC4	R8	1k
	R7	330
	C4	1uF

Chapter 7

Bibliography

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2. https://people.ece.cornell.edu/land/courses/ece4760/FinalProjects/f2013/hl577_jeh295_msh276/hl577_msh276_jeh295/index.html#results

Datasheets

- AT89C5131A
- LM358 OpAmp
- LM1875 Power OpAmp
- LM337 Negative Regulator
- LM317 Voltage Regulator