PSL Cassette Alignment Checker

Team #17: Josh Bestgen, Josh Buege, Tim Jaszewski, Nate Stone
Faculty Advisor: Bob Mahmoodi, Cheol-Hong Min
Project Sponsor: Matt Giddings, Polar Semiconductor Inc.

Executive Summary

The product was requested by Polar semiconductor to design a solution to wafer cassette warping, which leads to wafer scrap and production delays if left unchecked. The primary function of our product is to provide a machine which automatically measures how warped a cassette is and whether it is still production worthy.

Polar requested that the University of St. Thomas team create a design which satisfied several constraints. First, the product must be easy to use. The GUI (Guided User Interface) we have written to control the project is extremely simple, with only start, stop, and reset buttons available to control the machine. There are other quality-of-life features included, such as a 30-minute startup wait timer (laser accuracy is dependent on a 30-minute warm-up period), but they are not critical to product performance.

The second constraint is that the machine must deliver a result within one minute of starting to maintain efficiency.

The final constraint was that the machine must be small enough to sit on top of an average desk, as that is where the product will be mounted upon completion.

The primary competitor at this point is Rite Track and their EAGLEi line of wafer carrier inspection systems. The downsides of these two systems are that each take more than one minute to complete, and the starting price of each is around $100,000. Also, both the 200 and 300 models are much larger than Polar would like.

Although our design will not be as high-tech and precise as the EAGLEi products, it will satisfy the three criteria given by Polar for the product. Also, it will be less expensive than its EAGLEi equivalents. Polar may, however, wish to make improvements to our final design. First, the code may be better optimized, and different libraries or languages may prove more effective. As our team is not as well-versed in different programming languages, we opted to use the ones we were most comfortable with. The sensors we chose however, especially the laser distance sensors, are high-quality and will not need to be upgraded unless the company deems it necessary.

Table of Contents

1. Background

1.1 Problem Background

Polar Semiconductor manufactures various silicon semiconductor products onsite, in automotive and other automation semiconductors. When fabricating semiconductors, they initially are printed onto large wafers made of pure silicon. This involves moving these wafers through various processes, which layers various materials onto the wafers. To maximize efficiency, ease, and reliability, up to 25 wafers are carried in a single cassette. Robotic arms move the wafers from the cassettes to the manufacturing machines that etch various electrical components onto the silicon wafers.

During all of this, the cassettes are exposed to temperatures up to 81°C and harsh chemicals, which Polar has found to be deforming these cassettes over time. The problem created by this warping comes when the automation robotics attempts to remove or place wafers on these warped cassettes. Much of the automation equipment in the fabrication plant are running DOS (late 20th century operating system) and have limited fail-safe features or external sensors. This means they rely solely on accurate positioning of objects within their system to perform their tasks properly. When a warped cassette is place within one of these machines, there is a large possibility (often observed at this point) of the mechanical arms either being unable to grab, or worse yet, shatter the wafers contained on them. This has proven very costly, both in actual value of property destroyed and in time lost re-doing processes and making the machine operational again.

It is worth noting that cassette warping is a new phenomenon observed at Polar and seems to only occur on newer manufactured cassettes. Some significantly older cassettes continue to outlast newer cassettes. This adds incentive to not only prevent damages, but also identify which cassettes are warping before they cause manufacturing problems.

1.1.1 Sponsor Needs

Polar has expressed a desire to have a one-off device produced to facilitate an easier and more reliable method of determining which cassettes are warped. The current method, a hard flat slab, relies on the tech's ability to visually see the deformity, as well as only detecting certain horizontal warping. The desired device would need to be able to accurately detect warping, report this to a user (go/no-go) and be able to accomplish these tasks in under a minute after initial setup. Along with this, it needs to be safe to use in a clean room setting.

1.1.2 User Needs

The user (a laboratory technician) needs to be able to easily check cassettes sequentially, each under 1 minute time, and be reported a go/no-go status for each cassette. All this needs to be simple to do (technicians may not have much specific knowledge about what is being done) and needs to have information to be reported in an easy-to-understand fashion. The interface needs to be usable while wearing a cleanroom suit (gloves on hands).

1.1.3 Competing Products

The current competing product on the market is the Eagle-I series, manufactured by Rite Track. While this product fulfils Polar's operational requirements, it is priced around $100,000. This is considered far out of the desired price range for Polar at this time. It employs both measurement lasers and computer vision camera analysis and is specifically designed for checking semiconductor cassettes.

1.1.4 Applicable Standards

The product itself must follow the following standards:

- 5S Control
- ISO 10 Clean Room Standards
- Electronic Code of Federal Regulations (eCFR) Title 21 Chapter 1 Subchapter J Part 1040.1 (Performance Standards for Light-Emitting Products)
- National Electric Code (NEC) Article 310 (Conductors for General Wiring)

1.2 Statement of Work

The Statement of Work is the explanation and agreement of the expectations between Polar Semiconductor and the University of St. Thomas.

1.2.1 Problem Statement

200-mm pure silicon wafers are used to manufacture various semiconductors. A polymer-based cassette is used to transfer sets of up to 25 wafers between machines and used to position the wafers inside the machines. Due to manufacturing conditions the cassettes warp over time. This warping causes the wafers to not be aligned properly for the machines. This then causes the wafers to fall and shatter inside the machine. The location inside the machines this occurs varies and is not always obvious to the operator which makes it difficult to immediately identify problem cassettes. Currently the only method for detecting any warping is by visually inspecting the cassettes. This causes inconsistencies with detecting warped cassettes. A system is needed to check whether a cassette is too warped to be used in production as the cassette makes its way through the production line.

1.2.2 Deliverables

- SolidWorks models of the product
- Electrical schematics
- Bill of materials
- Well documented, operational code
- Eula information for all code libraries and API used
- Final report of work done with corresponding prototype

1.2.3 Requirements and Acceptance Plans

Eight key design requirements with validation requirements have been identified as soon in Table 1.

Table 1: System design and validation requirements

Requirement	Validation
The system shall be easy to use with minimal set up. A single operator should only need to insert the cassette and press a single button to start the machine.	Three people who are unfamiliar with the project will use the system after being instructed how to use it one time and give a binary rating on ease of use.
The system shall complete the process in under 1 minute.	A trained person will operate the machine from start to finish while being timed.
The system shall output a go/no-go result to the operator.	At the end of a successful analysis, the system will output either a pass or fail output to the user.
The system shall be made from durable components.	A fatigue simulation of at least 10,000 cycles will be conducted.
The system shall operate in a controlled cleanroom environment (35 to 40% humidity, 69.8 +/-2 degrees Fahrenheit), and from a 120-volt, 15-amp wall outlet.	Any fans will have a high efficiency particulate air (HEPA) filter on the output or be placed outside of the clean room environment.
Any part of the system that touches the cassettes will be made of stainless steel of at least 316L grade.	The material selection of the components will be verified by at least two team members and signed off on.
Any accessible portion of the machine must be resistant to isopropyl alcohol.	The material selection of the components will be verified by at least two team members and signed off on.
The system shall pass all relative standards as listed in this document.	The various safety standards will be listed and initialed as either pass or fail on a document.

2. Design

2.1 Solution Overview

Mechanical System

The mechanical portion of the design centralizes on linear actuators mounted on each side of the platform where the cassette will be placed. The platform itself is mounted on a stepper motor capable of rotating the cassette to precise degrees to gather measurements from different angles. The full 3D model is shown in Figure 1:

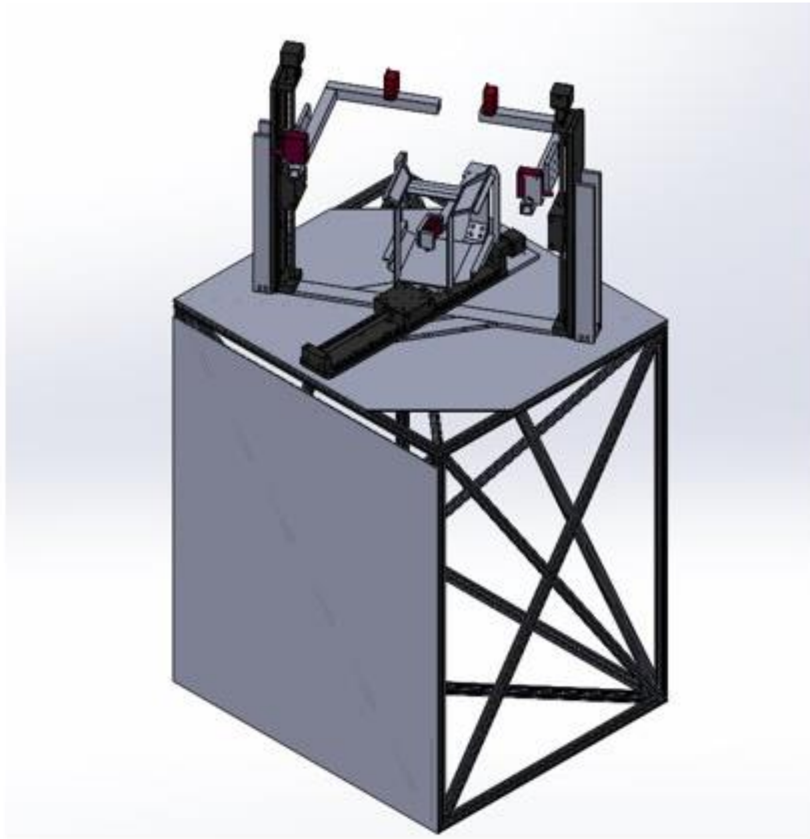


Figure 1: 3D model of the final solution. Mechanical parts are situated on top of a mounting platform.[1]

The cassette will be placed within the system on top of the stepper motor, where the side-mounted lasers will then take measurements at various heights on the cassette. The cassette will then be rotated so the lasers can retrieve measurements from all critical areas of the cassette.

Electrical System

The system will be powered by a standard wall outlet, which will then be fed into numerous other power supplies and amplifiers and be transformed into the forms needed for the various components throughout the system. The electrical setups in each of the two Hoffman boxes are shown below. (Figure 2)

[1] Mechanical System

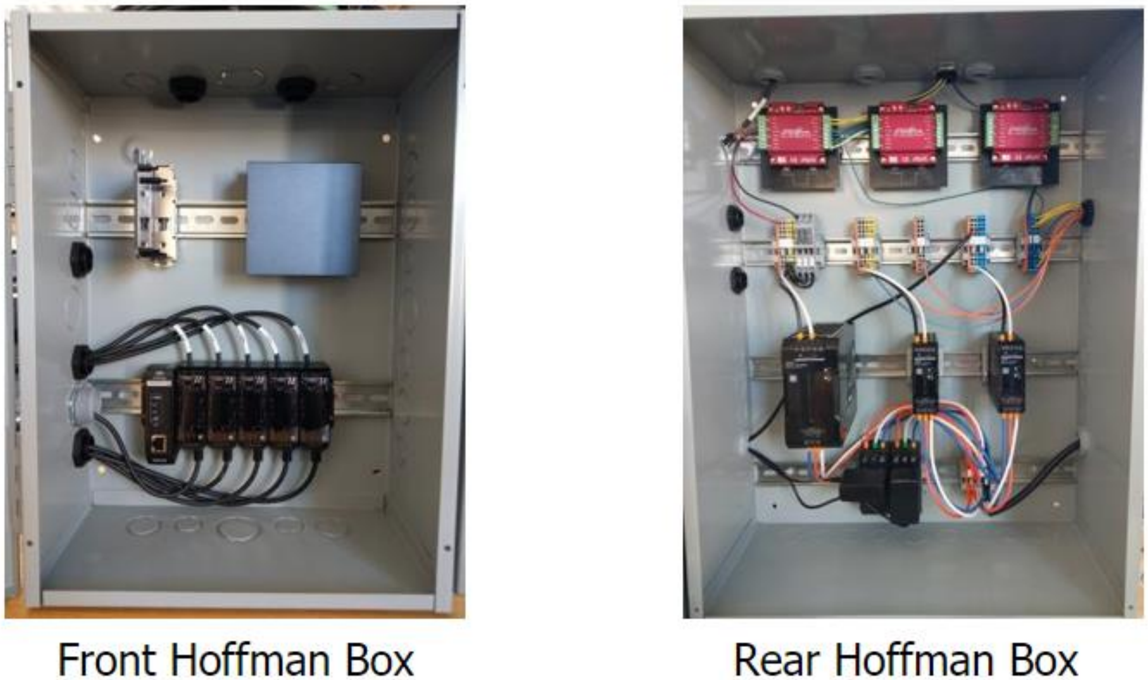


Figure 2: The contents of the two Hoffman boxes containing most of[2]

In the front Hoffman box, the top left item is the holding bracket for the BeagleBone Black – the main processing unit for the design. The top right item is a network switch for the ethernet cables used to connect the five IL-series lasers. On the bottom are the five amplifiers for the IL-series lasers themselves.

In the rear Hoffman box, the three red modules on top are the drivers for the three actuators. Underneath these are fuses used in case of a power surge. The three large black boxes near the center are power supplies for the three actuators. Finally, at the bottom are more fuses connected to a typical 120V wall outlet implanted within the machine.

Actuators

The linear actuators (Figure 3) and rotational actuators (Figure 4) will be used to move and rotate the lasers and cassette, respectively. Each model is precisely accurate, with the linear actuator accurate to 0.0006mm/mm of travel and the rotational stage to 0.034 degrees/degree of rotation.

[2] Electrical System

[3]

Figure 4: The rotational actuator used for rotating the cassette.

The precision of the actuators was chosen due to the nature of the problem being solved by the design. As a cassette can become unworthy for production if warped by even a millimeter, knowing the exact location of the actuators and thus the lasers and cassette is critical to obtain accurate measurements.

Laser measurement system with database

The measurement system itself relies on the IL-series of laser distance sensors manufactured by Keyence. Using a TCP/IP interface via ethernet connection, IL-300 and IL-100 lasers are connected via a network switch to a BeagleBone Black. The BeagleBone is the heart of the design, where sensors and actuators are controlled, and measurements are calculated. (Figure 5)

---

[3] Actuators

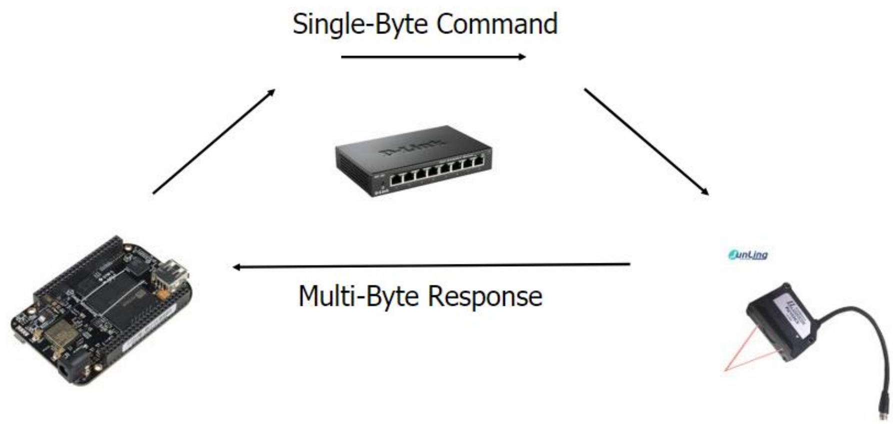


Figure 5: Diagram of interface between lasers, network switch, and BeagleBone[4]

Images: mouser.com, amazon.com[5]

GUI

The GUI is written in Python using the Tkinter library, and contains start, stop, and reset buttons. The system will be controlled by an operator via a 7-inch touchscreen attached to the BeagleBone Black. (Figure 6)

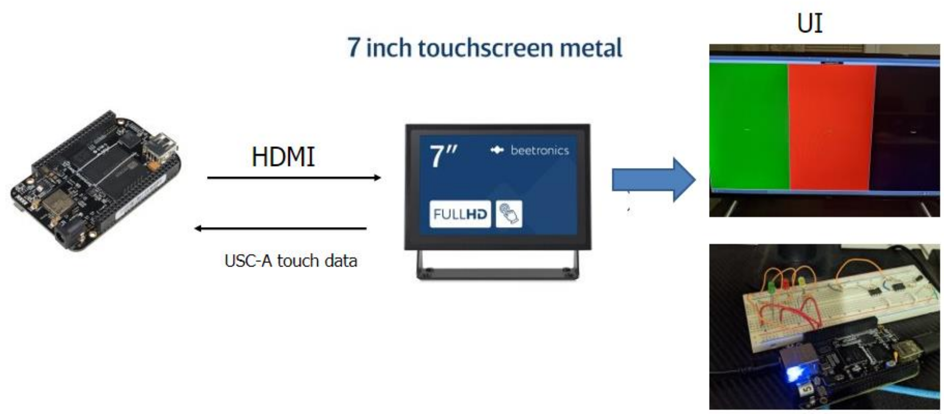


Figure 6: Diagram of interface between BeagleBone Black, 7” (177.8 mm) touch screen, and Graphical User Interface.

Images: mouser.com, beetronics.com

---

[4] Laser System

The program is set to begin on startup of the BeagleBone's native operating system, Debian. The last version of the GUI also includes a startup timer of 30 minutes, which is the recommended time for the lasers to warm up before use, and a debugging mode where more information can be found.

2.2 Design Details

This section covers the details of the measurement, actuator, electrical, and code solutions chosen for the design.

2.2.1 Key Measurement Areas

To determine the key measurement areas, an ideal model was created under the following assumptions.

- The largest wafer was present in the system as provided by the wafer manufacturer's tolerances (Table 2)
- The machines that withdraw the wafers have an infinitely small step when lifting the wafers and attempts to perfectly place the wafers in the middle of a perfect cassette.
- As soon as the wafer encounters the cassette, it results in a failed cassette.
- The averaged measurement of a single cassette never used in manufacturing represents a perfect cassette as the cassette manufacturer was not willing to provide detailed tolerance information on the cassette.
- The wafer always sits level in the cassette.

Table 2: Silicon wafer tolerances provided by the manufacturer.

Spec	200mm
Diameter	200 +/- 0.2mm
Thickness	725 +/- 20µm

We then identified three probable distortion conditions, a trapezoid, a twist, and a lean condition when viewed from the front.

The trapezoid condition is when the cassette is warping in the shape of a trapezoid when viewed from the front. Specifically, this occurs when the bottom of either side moves towards each other. This causes the H-Bar (Figure 7) to deflect downwards, which is the key measurement location as this deflection is more pronounced when compared to measuring the deflection from the sides along the bottom. This falls in line with the current procedure to check the H-Bar deformation by setting the cassette on a smooth surface.

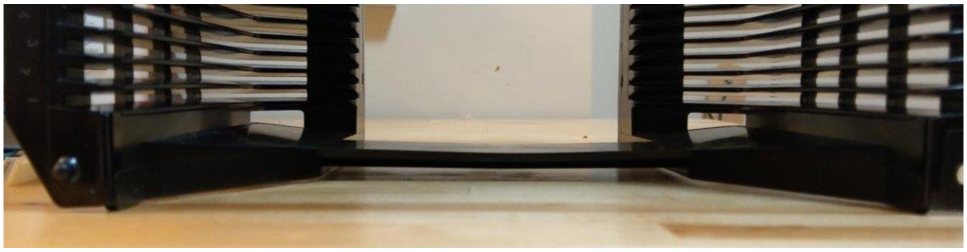


Figure 7: Bottom of the cassette viewed from the front showing the H-Bar bridging the gap between either side.

Since the H-Bar is not a flat surface, it is important to take multiple measurements across a small width near the center of the H-Bar to ensure that the peak deformation is measured.

An issue with our model was discovered here because the deformation needed would require the cassette to sit on the H-Bar, but the cassettes that are known to be bad are not at this point. The most probable cause of this is the arm that lifts the cassette does not have an infinitely small step, and it is unknown what the step size is for the arm. Because of the large disparity, the decision was made to simply measure all the cassettes that Polar must build a database of the current state of their inventory, as well as measure the known bad cassettes to build the specific tolerances experimentally.

Twist condition needs to be checked by measuring the front face as represented in Figure 8. This condition results in the teeth being offset from each other, which can cause the wafer to either drag along the teeth or it can cause the vacuum seal used to lift the wafer to fail causing the wafer to drop when the wafer is attempted to be withdrawn in the manufacturing process.

Figure 8: The key measurement locations to identify the twist condition as marked by the yellow dots.

The lean condition needs to be checked by measuring the side faces shown in Figure 9. This condition is not currently seen as a primary cause of failure, but its presence could amplify the effects of the other two conditions.

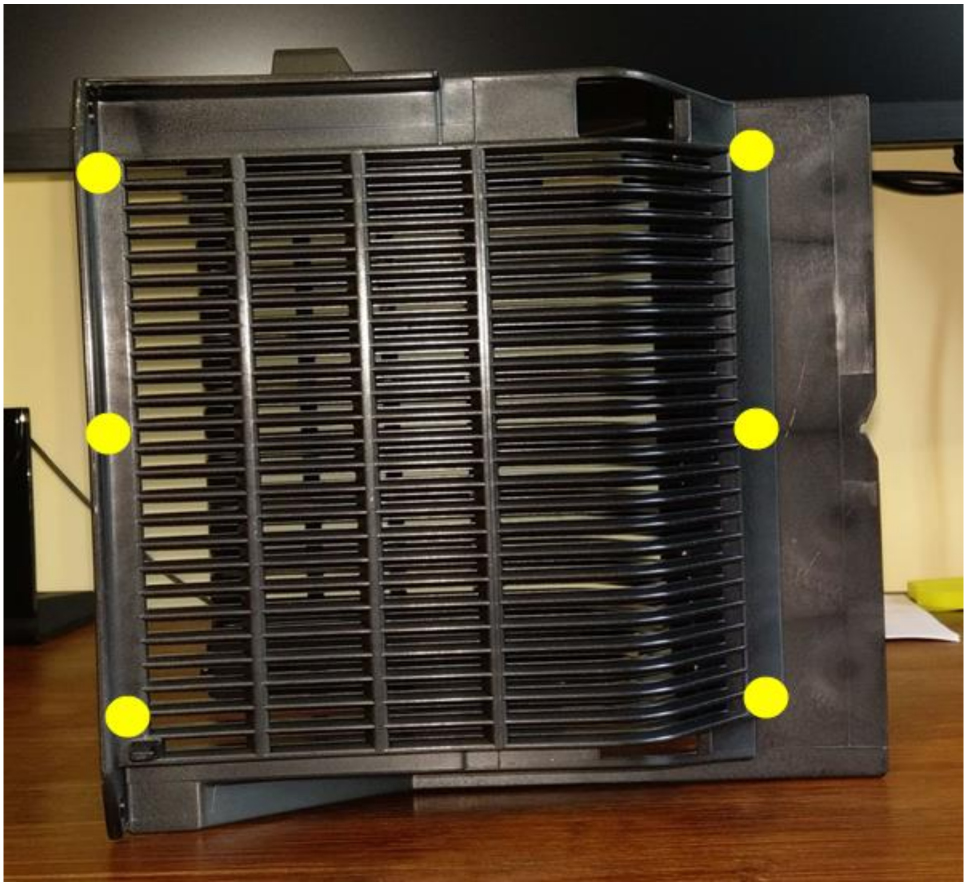


Figure 9: The key measurement locations to identify the lean condition marked by the yellow dots.

The top, bottom and middle levels are the critical locations for any deformation as it is unlikely for a cassette to deform in a sinusoidal manner. It is currently unknown if there is also any bowing condition which will be discovered by the middle level of measurement.

2.2.2 Measurement solutions

Various sensors including optical, touch, and laser sensors were given consideration in the design. The team developed a Pugh chart (Table 3) from research and meetings, and it was determined that the laser solution would be the best measurement technique.

Table 3: Measurement System Pugh Chart

	Accuracy	Repeatability	Axis of Movement	Resistance to External Interference	Ease of Calibration	Price	Invasiveness	Total
Score Weight	4	5	3	5	4	3	4	28
Internal Slide	2	4	2	1	2	3	2	16
Contact Sensors	4	5	1	4	3	2	2	21
Laser Sensors	4	5	2	4	3	2	4	24
Optical Sensors	3	4	2	4	2	2	4	21
Mechanical Key	1	3	1	0	4	3	1	15

The Keyence line of lasers was primarily chosen as they also had optical, and touch sensors we could look at and compare in a single meeting, and Polar already had an established relationship with them. The lasers are individually powered and controlled by a dedicated amplifier mounted on a 35mm din rail. These lasers are also accurate into the micrometer scale, which is one unit of measure more of accurate then we need as the current method of determining what a bad cassette is, is done by eye on the millimeter scale.

2.2.2.a Key Laser Settings

Each amplifier controls an individual laser, and all the amplifiers are controlled by an ethernet adapter. However, there are a couple key settings that are made in each amplifier.

- NPN – This sets the four input terminals to identify a ground signal as a logical high.
- Input 1 – Off
- Input 2 – Laser emission stop input; when logically high, stops the emission of the laser.
- Input 3 – Off
- Input 4 – Off

The decision to specifically utilize input 2 as the primary input was simply due to the color of the wire (yellow) being easily distinguishable to the colorblind members of the team.

See Appendix A for key data sheet information on the IL-065, IL-100, and IL-300 lasers as well as the IL-1000 and IL-1050 laser amplifiers.

2.2.2.b Laser Safety

The IL series lasers utilized in the design (65, 100 and 300) manufactured by Keyence utilize a 560µW laser with a wavelength of 655nm. This classifies the laser as a class 2 laser according to the Food and Drug Administration (FDA) in Table 4.

Table 4: Class 2 laser specifications as defined in the Electronic Code of Federal Regulations (eCFR) Title 21, Chapter I, Subchapter J

TABLE II

CLASS II ACCESSIBLE EMISSION LIMITS FOR LASER RADIATION

CLASS II ACCESSIBLE EMISSION LIMITS ARE IDENTICAL TO CLASS I ACCESSIBLE EMISSION LIMITS EXCEPT WITHIN THE FOLLOWING RANGE OF WAVELENGTHS AND EMISSION DURATIONS:				
Wavelength (nanometers)	Emission duration (seconds)	Class II-Accessible emission limits		
		(value)	(unit)	(quantity)*
>400 but ≤710	$>2.5 \times 10^{-1}$	1.0×10^{-3}	W	radiant power

*Measurement parameters and test conditions shall be in accordance with paragraphs (d)(1), (2), (3), and (4), and (e) of this section.

The Electronic Code of Federal Regulations (eCFR) Title 21, Chapter I, Subchapter J; further defines the safety aspects of a class 2 laser as follows.

- If the laser is in direct contact of a non-reflective surface, it is safe to look at the resulting dot on said surface.
- If an individual looks at the source of the laser while it is emitting, a normal blink reflex will prevent damage.
- Appropriate caution labels should be utilized on any panel or door.
- Interlocks should be used on any access door that is utilized under normal operations.

This led to define the interior of the system to be classified as a class 2 laser environment, however the need to maintain a class 1 laser environment outside of the system is needed as there will be untrained workers passing by the machine on a regular basis. The FDA further classifies class 1 lasers in accordance with Table 5.

Table 5: Class 1 laser specifications as defined in the Electronic Code of Federal Regulations (eCFR) Title 21, Chapter I, Subchapter J

TABLE I

CLASS I ACCESSIBLE EMISSION LIMITS FOR LASER RADIATION

Wavelength	Emission duration	Class I-Accessible emission limits		
(nanometers)	(seconds)	(value)	(unit)	(quantity)**
$\geq$180 but $\leq$400	$\leq 3.0 \times 10^{4}$----------------	$2.4 \times 10^{-5} k_1 k_2$*	Joules(J)*	radiant energy
	$>3.0 \times 10^{4}$----------------	$8.0 \times 10^{-10} k_1 k_2$*	Watts(W)*	radiant power
>400 but $\leq$1400	$>1.0 \times 10^{-9}$ to 2.0×10^{-5}--	$2.0 \times 10^{-7} k_1 k_2$	J	radiant energy
	$>2.0 \times 10^{-5}$ to 1.0×10^{1}---	$7.0 \times 10^{-4} k_1 k_2 t^{3/4}$	J	radiant energy
	$>1.0 \times 10^{1}$ to 1.0×10^{4}----	$3.9 \times 10^{-3} k_1 k_2$	J	radiant energy
	$>1.0 \times 10^{4}$----------------	$3.9 \times 10^{-7} k_1 k_2$	W	radiant power
	and also (See paragraph (d)(4) of this section)			
	$>1.0 \times 10^{-9}$ to 1.0×10^{1}---	$10 k_1 k_2 t^{1/3}$	$Jcm^{-2}sr^{-1}$	integrated radiance
	$>1.0 \times 10^{1}$ to 1.0×10^{4}----	$20 k_1 k_2$	$Jcm^{-2}sr^{-1}$	integrated radiance
	$>1.0 \times 10^{4}$----------------	$2.0 \times 10^{-3} k_1 k_2$	$Wcm^{-2}sr^{-1}$	radiance
>1400 but $\leq$2500	$>1.0 \times 10^{-9}$ to 1.0×10^{-7}--	$7.9 \times 10^{-5} k_1 k_2$	J	radiant energy
	$>1.0 \times 10^{-7}$ to 1.0×10^{1}---	$4.4 \times 10^{-3} k_1 k_2 t^{1/4}$	J	radiant energy
	$>1.0 \times 10^{1}$----------------	$7.9 \times 10^{-4} k_1 k_2$	W	radiant power
>2500 but $\leq 1.0 \times 10^{6}$	$>1.0 \times 10^{-9}$ to 1.0×10^{-7}--	$1.0 \times 10^{-2} k_1 k_2$	Jcm^{-2}	radiant exposure
	$>1.0 \times 10^{-7}$ to 1.0×10^{1}---	$5.6 \times 10^{-1} k_1 k_2 t^{1/4}$	Jcm^{-2}	radiant exposure
	$>1.0 \times 10^{1}$----------------	$1.0 \times 10^{-1} k_1 k_2 t$	Jcm^{-2}	radiant exposure

*Class I accessible emission limits for wavelengths equal to or greater than 180 nm but less than or equal to 400 nm shall not exceed the Class I accessible emission limits for the wavelengths greater than 1400 nm but less than or equal to 1.0×10^{6} nm with a k_1 and k_2 of 1.0 for comparable sampling intervals.

**Measurement parameters and test conditions shall be in accordance with paragraphs (d)(1), (2), (3), and (4), and (e) of this section.

From Table 5 the effective power of each laser needs to be 0.39 µW or less as we cannot guarantee how long someone will look through any viewing window. Utilizing Equation 1, it was calculated that for a viewing window to be installed, it must have an optical density of at least 3.2. If a single protective layer does not give a high enough density level, then multiple layers can be utilized as the equivalent density level is additive. To ensure that the protection level cannot be compromised, it is recommended to laminate the protective layer(s) with clear acrylic to minimize the risk of damaging the protective layers.

$$D_\lambda = \log\left(\frac{1}{T_\lambda}\right), \text{ or } T_\lambda = 10^{-D}$$

Equation 1: Optical Density Equation. T_λ is a percentage of transmission through the given item at a given wavelength. D_λ the optical density at a given wavelength.

Multiple companies were contacted inquiring about procuring testing samples, however none of the companies followed through with their emails. This issue was not pushed during this phase of the project as the access door has not been designed yet, and the future window could be blocked temporarily during the initial testing phases of the system.

To ensure that the lasers will not directly emit outside the door, a 2-step approach is recommended. The first aspect is to ensure an interlock is used to logically tell the laser amplifiers to not emit. For details of this circuit, please reference section 5.2.3. The second aspect is to position the lasers in a way where they cannot directly emit through the open door, however since we have not made it to this phase of the design, it is up to the next team to accomplish this.

2.2.2.c Current Laser Prototype

Since the casement for the system has not yet been completed, a pair of wooden fixtures shown in Figure 10 is still currently in use to provide a way to safely interface with the lasers.

Figure 10: Laser interface prototype. The extra piece of plywood on the right side is used to alter the measurement during testing.

2.2.3 Actuator solution

With a few options of measurement schemes which involve both static and moving sensors as well as static and moving cassettes, the compromise and optimal designed ended up including moving and static sensors and a moving cassette. Knowing this, the team had to decide how each part would move and where each part would be positioned. The final design utilizes three linear LC Series actuators and five IL Series laser sensors (Figure 11).

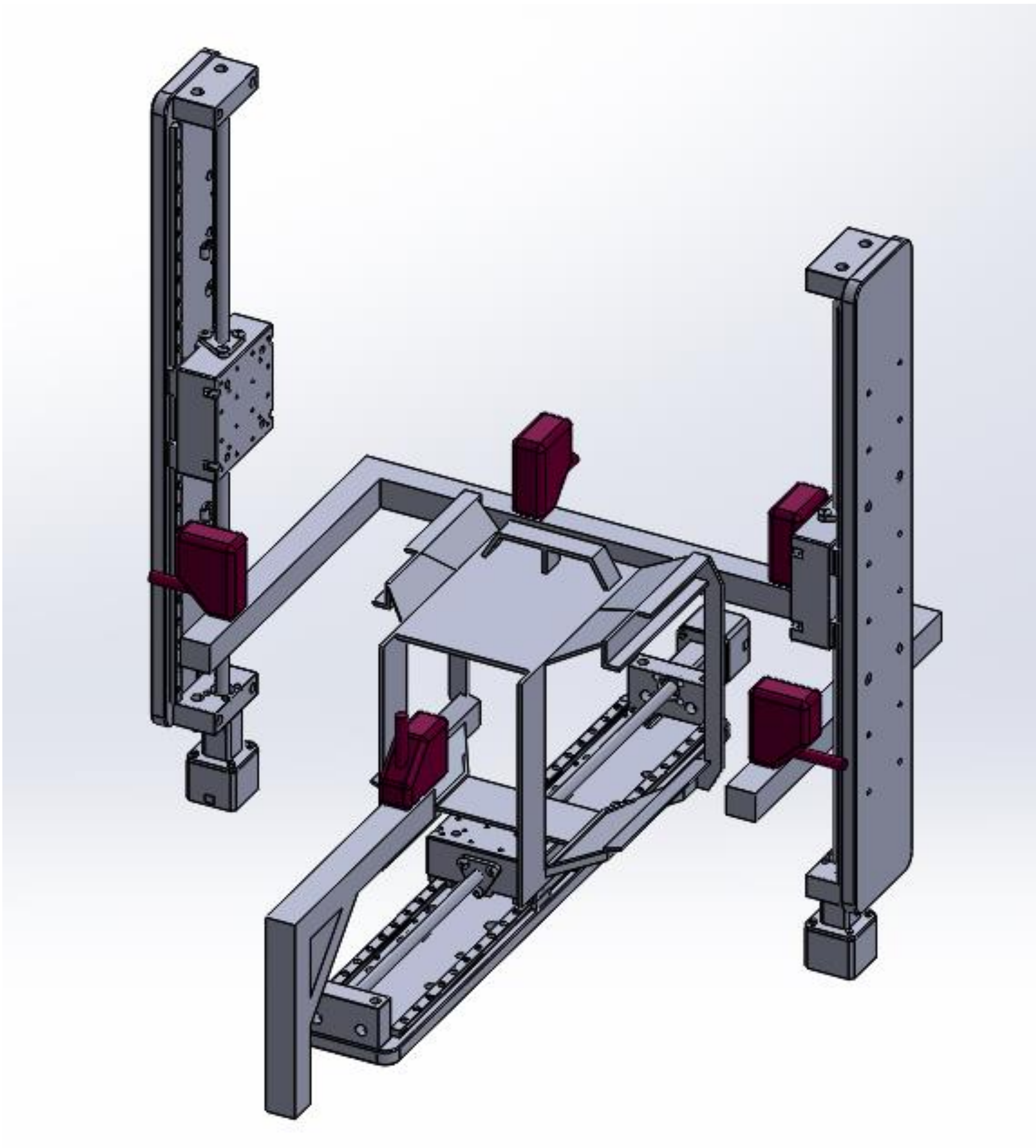


Figure 11: A simplified proposal of our final design for Design Review 2. This design features five laser sensors and three linear actuators. The lasers are the five red boxes shown above and the actuators are the vertical and horizontals apparatuses.

Two linear actuators are used to raise and lower two lasers each in the Z direction. These lasers can measure all the necessary points on the cassette in one movement, reducing the measurement time significantly. All points on the cassette are measured quickly and efficiently with little error. The cost of this design is higher than the cost of other designs, but it has the lowest error and the least complication which is why we continued with this design as our final design.

A way to reduce the number of laser sensors, and thus cost, was to implement a rotary actuator to rotate the cassette (Figure 12). By rotating the actuator and moving the lasers in the Z axis, all desired points would be measured. This was the basis to one of our proposed designs that we did not continue with.

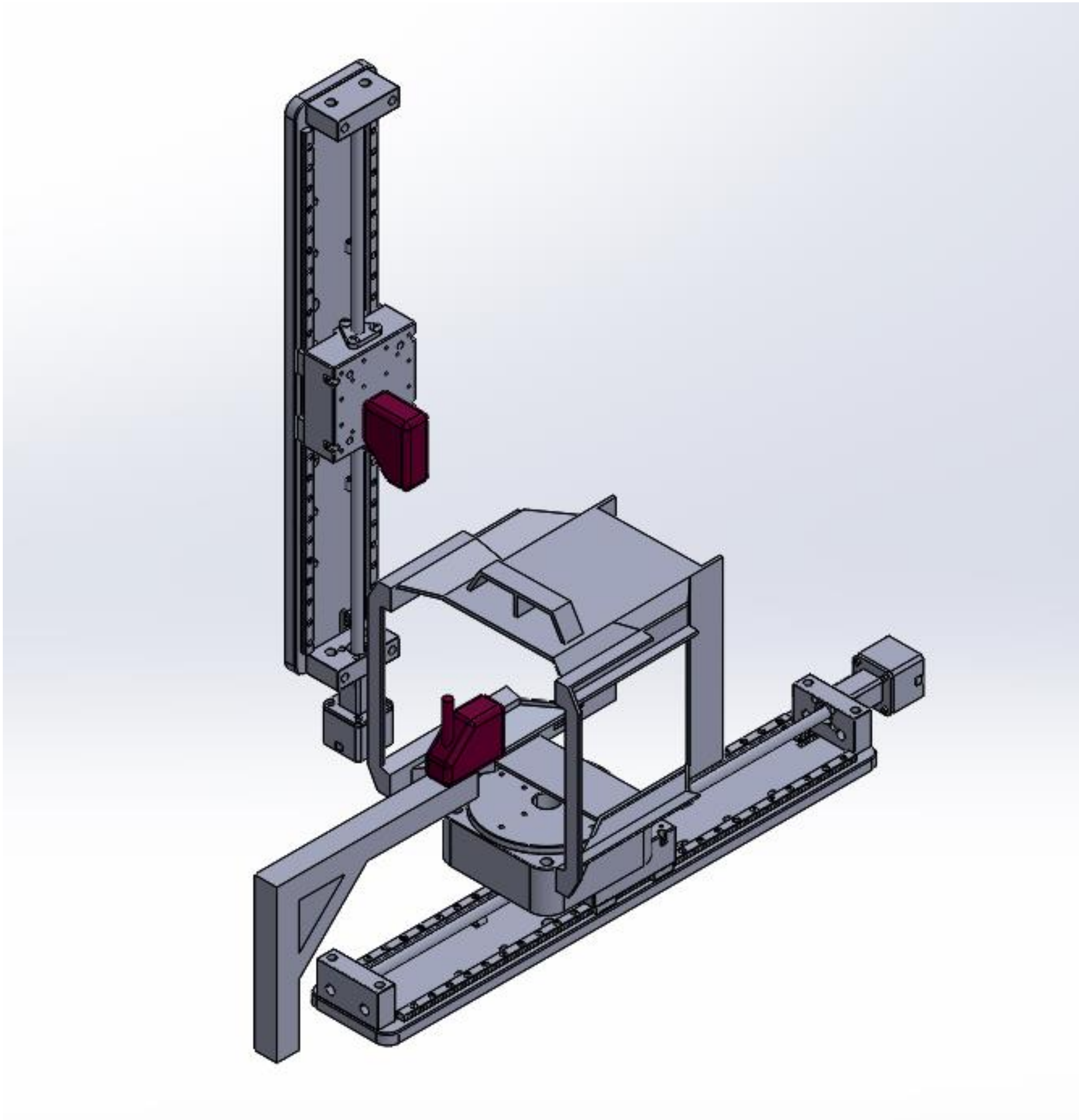


Figure 12: A proposed design for Design Review 2. This design features two linear actuators and a rotary actuator to rotate the cassette to be measured.

The introduction of the rotary actuator simplified the design and brought the costs down, but it introduced a significant amount of error. With a repeatability of 125 arc-sec, an error of 75 µm was introduced into the X and Y axes. Considering that the linear actuators have a repeatability of 15 µm, the error in the rotary actuator is revealed to be significant. Another downside of this design is the difficult control of the rotary actuator. With only one laser to measure values on the various faces of the cassette, the laser and cassette would need to be perfectly aligned. Measurement repeatability would be more difficult to define because of measurements being taken on non-perpendicular faces due to the nature of the rotary actuator. This design also requires many moves to complete all the desired measurements and because of this, measurement time would be exceedingly high. It is a design requirement that the measurements only take one minute so this problem alone would bring it off the table.

2.2.4 Electrical

The 2017 National Electric Code (NEC) 310 was utilized in sizing the wiring on the Alternating Current (AC) portion of the circuit. The estimated internal temperature was calculated to be 24.65^{o}C (See Section 2.3), which determined that the amperage rating would not need to be derated on the given wires as table 310.15(B)(16) is rated at 30^{o}C. This was then checked with what wiring was available on campus for the team to utilize with what wires would fit into the DC power supplies in conjunction with a design requirement of the system being plugged into a 120V circuit that is protected by a 15 Amp breaker. This led to the decision to use 12 Gauge wire for all the AC wiring, as well as the wiring to the terminal blocks that directly connect to the DC side of the DC power supplies as shown in Figure 13.

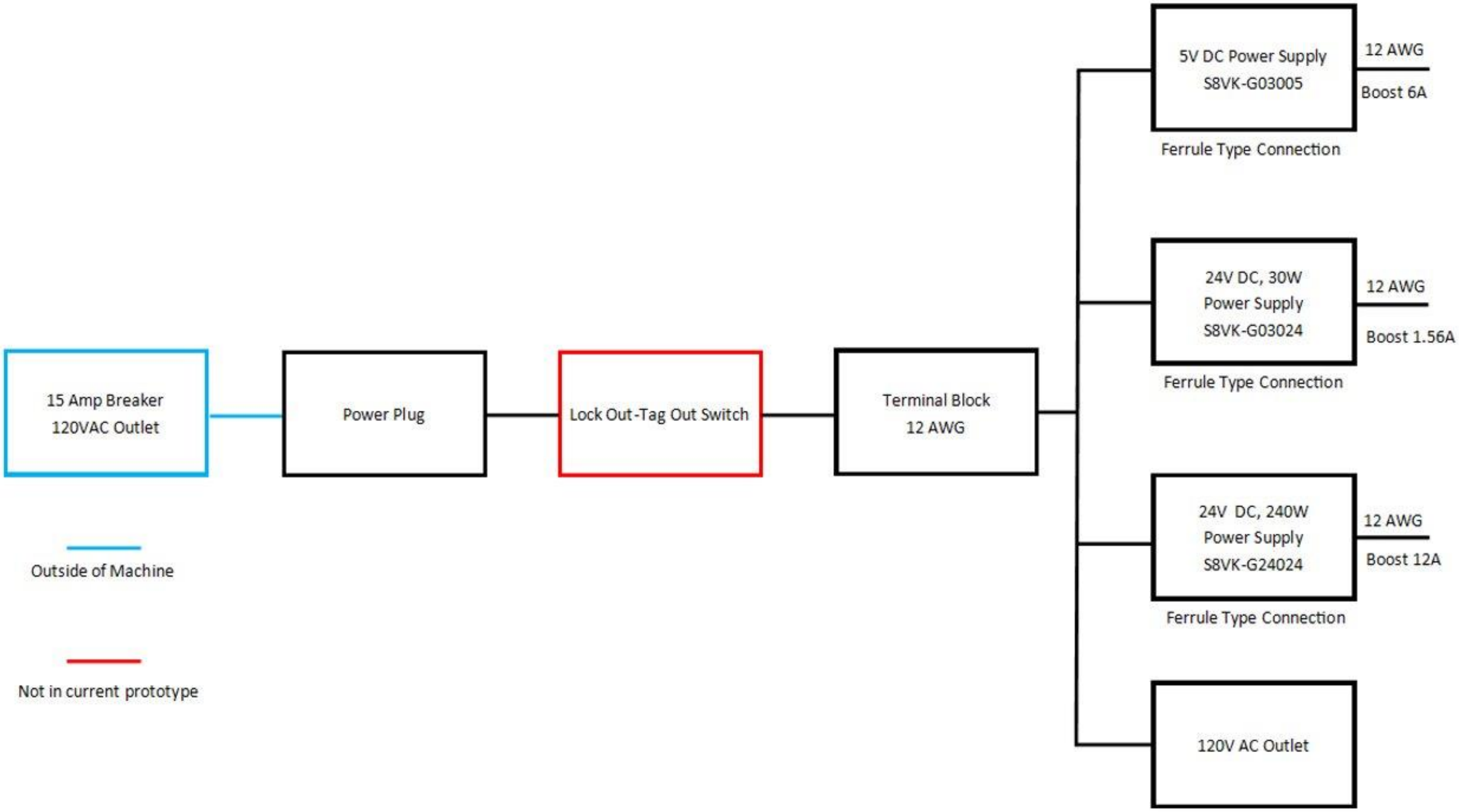


Figure 13: One line diagram of the AC portion of the circuit.

Table 6 was used for the rest of the amperage DC circuitry as it was provided to us by Professor Mahmoodi for use in lower amperage conditions as NEC 310 only covers common sizes found in wiring houses. This was again compared to what was readily available for use. 16 and 18-gauge wire was selected for use throughout the rest of the prototype.

Table 6: Low amperage conductor ratings

AWG	Diameter		Turns of wire, without insulation	Area			Copper wire Length-specific resistance[7]		Ampacity at temperature rating[a]		
									60 °C	75 °C	90 °C
	(in)	(mm)	(per in)	(per cm)	(kcmil)	(mm2)	(mΩ/m[b])	(mΩ/ft[c])	(A)		
12	0.0808	2.053	12.4	4.87	6.53	3.31	5.211	1.588	20	25	30
13	0.072	1.828	13.9	5.47	5.18	2.62	6.571	2.003			
14	0.0641	1.628	15.6	6.14	4.11	2.08	8.286	2.525	15	20	25
15	0.0571	1.45	17.5	6.9	3.26	1.65	10.45	3.184			
16	0.0508	1.291	19.7	7.75	2.58	1.31	13.17	4.016			18
17	0.0453	1.15	22.1	8.7	2.05	1.04	16.61	5.064			
18	0.0403	1.024	24.8	9.77	1.62	0.823	20.95	6.385	10	14	16
19	0.0359	0.912	27.9	11	1.29	0.653	26.42	8.051	—	—	—
20	0.032	0.812	31.3	12.3	1.02	0.518	33.31	10.15	5	11	—
21	0.0285	0.723	35.1	13.8	0.81	0.41	42	12.8	—	—	—
22	0.0253	0.644	39.5	15.5	0.642	0.326	52.96	16.14	3	7	—
23	0.0226	0.573	44.3	17.4	0.509	0.258	66.79	20.36	—	—	—
24	0.0201	0.511	49.7	19.6	0.404	0.205	84.22	25.67	2.1	3.5	—
25	0.0179	0.455	55.9	22	0.32	0.162	106.2	32.37	—	—	—
26	0.0159	0.405	62.7	24.7	0.254	0.129	133.9	40.81	1.3	2.2	—

2.2.4.a Power Supplies

Omron's S8VK-G power supplies were chosen as they had a wide range of voltages and wattages available in the line-up, while matching the power requirements of the system while being able to be mounted directly to a standard 35mm DIN rail.

The primary requirements for this build are:

- 24-volt supply that can supply at least 6 amps for the stepper motors
- 24-volt, 18-watt supply that has less than a 10% ripple for the lasers
- 5-volt, 25-watt supply for the microcontroller and the various logic circuitry that is powered through the 3.3-volt rails of the microcontroller
- AC outlet for the networking switch and touchscreen

Although the stepper motors and lasers are both run off a 24-volt power supply, the decision was made to keep them on separate supplies to keep the power as clean as possible for the lasers. This is because it was unknown how the voltage from the power supply would temporarily be affected from large delta currents from the stepper motor drivers potentially synchronizing their duty cycles.

See Appendix B for key datasheet details, and Section 7 for a link to the full datasheet.

2.2.4.b 240-watt 24-volt Circuit

This circuit is used to power the three linear actuators (Figure 14). Each NEMA 17 stepper motor is driven by a GR214V stepper motor driver. These drivers have a built in 7-amp fuse to protect the circuitry, however since this fuse is difficult to replace as it is soldered onto the board, a 2-amp automotive style fuse was also placed upstream of this fuse as each of the 2 phases of the stepper motors are rated at 0.95 amps each. This extra fuse also reduces the gauge requirement of the wires used downstream which makes wiring slightly easier.

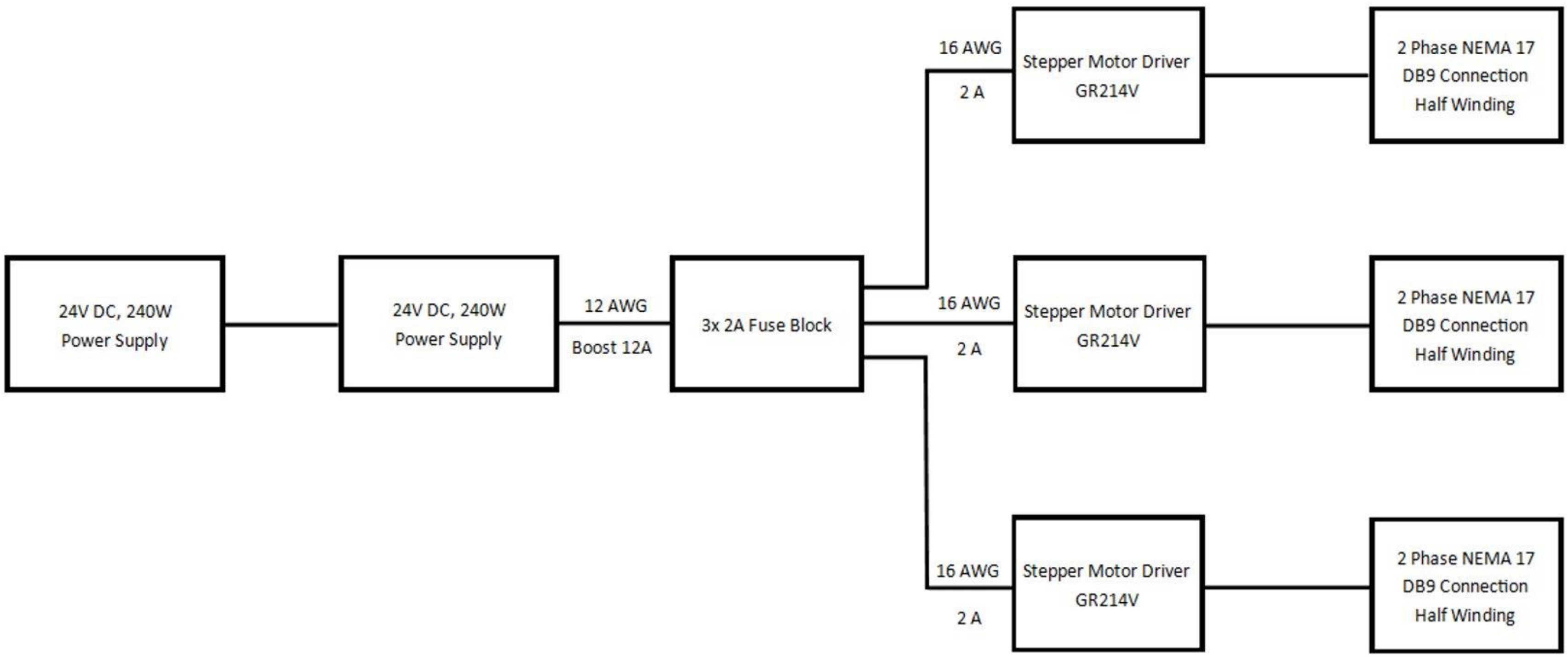


Figure 14: 24-volt, 240-watt circuit used to power the stepper motors.

The GR214V stepper motor drivers by Geckodrive Motor Controls were selected due to the following features of the driver.

- Ability to limit the current per phase in the motor by physical use of switches on the driver itself.
- Ability to wire the drivers to a safety circuit via the reset pin to prevent the driver from moving the stepper motor when either the emergency stop, or door interlock are tripped.
- Feedback of stepper motor position to the nearest full step via a pulse sent to the microcontroller.
- Adjustable holding torque when the driver is not actively moving the motor.
- No need for an additional heat sync when less than three amps is powering the motor.
- Driver will automatically reduce the amount of micro stepping as needed if we attempt to drive the motor quickly.

The only key setting on the driver that should not be increased is the phase current limiter. It is set to 0.8 amps per phase because the stepper motors can only handle up to 0.95 amps per phase, and to increase the margin of safety for the DB9 breakout cables currently being used to interface between the driver and the motor as there are four active current carrying conductors in the cable could cause the wires to be derated. This derating comes from the 2017 National Electric Code Table 310.15(B)(3)(a) causing the amperage to be scaled to 70% for this cable from Table 6.

See Appendix C for key aspects of the stepper motor data sheet, and Section 7 for a link to the full data sheet.

2.2.4.c 30-watt 24-volt Circuit

A second 24-volt power supply was chosen to be used to power the lasers to ensure the power remain as clean as possible for the lasers by isolating it from the potentially large current fluctuations that could cause voltage drops in the stepper motor circuit if all three motors happen to cycle on and off at the same time (Figure 15).

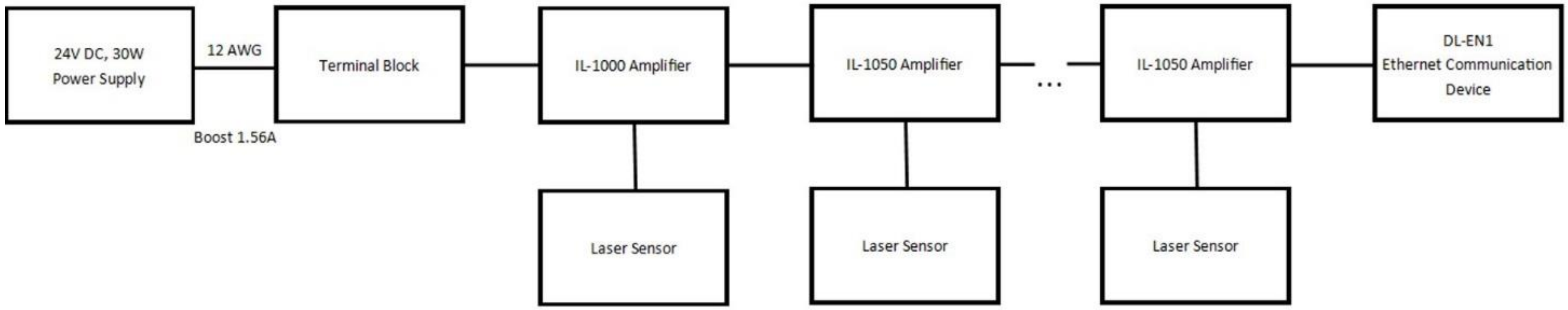


Figure 15: 24-volt, 30-watt circuit used to power the laser amplifiers. The single IL-1000 amplifier powers all the IL-1050 amplifiers connected in series with it along with the ethernet command block.

2.2.4.d 30-watt 5-volt and 3.3-volt Circuits

This circuit is used to power the microcontroller utilizing a 5 x 2.2 mm barrel plug with the appropriate amperage rating. The microcontroller then uses it is 3.3-volt rails to power the logic in the system (Figure 16).

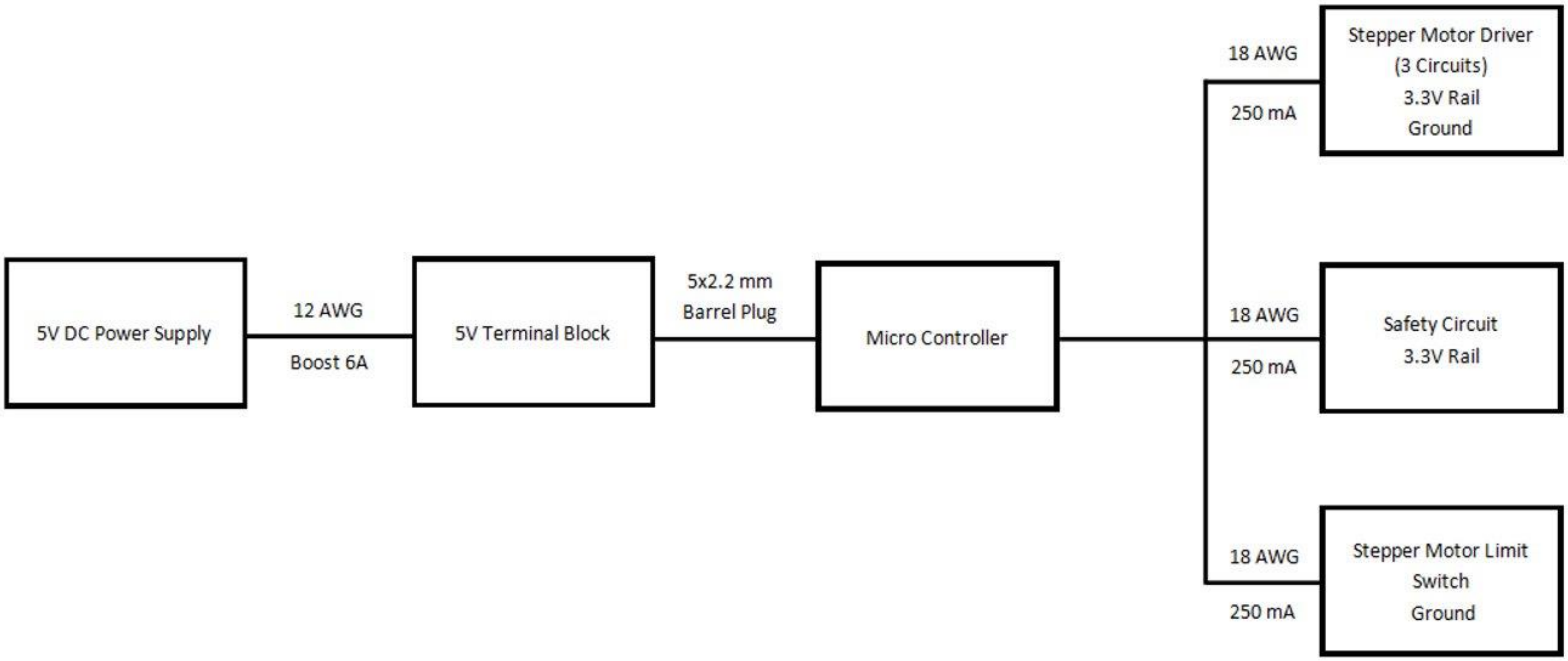


Figure 16: 5-volt and 3.3-volt circuits

2.2.4.e Safety Circuit

The emergency stop switch has a single normally closed (NC), and a single normally open (NO) switch that is activated by a single throw. The door interlock has a pair of NC, and a single NO switch as shown in Figure 17.

The emergency stop, and the door interlock switches are both wired to do the following.

- Logically disable the laser emissions
- Disable the stepper motors from moving.
- Logically tell the micro controller that either switch has been activated.

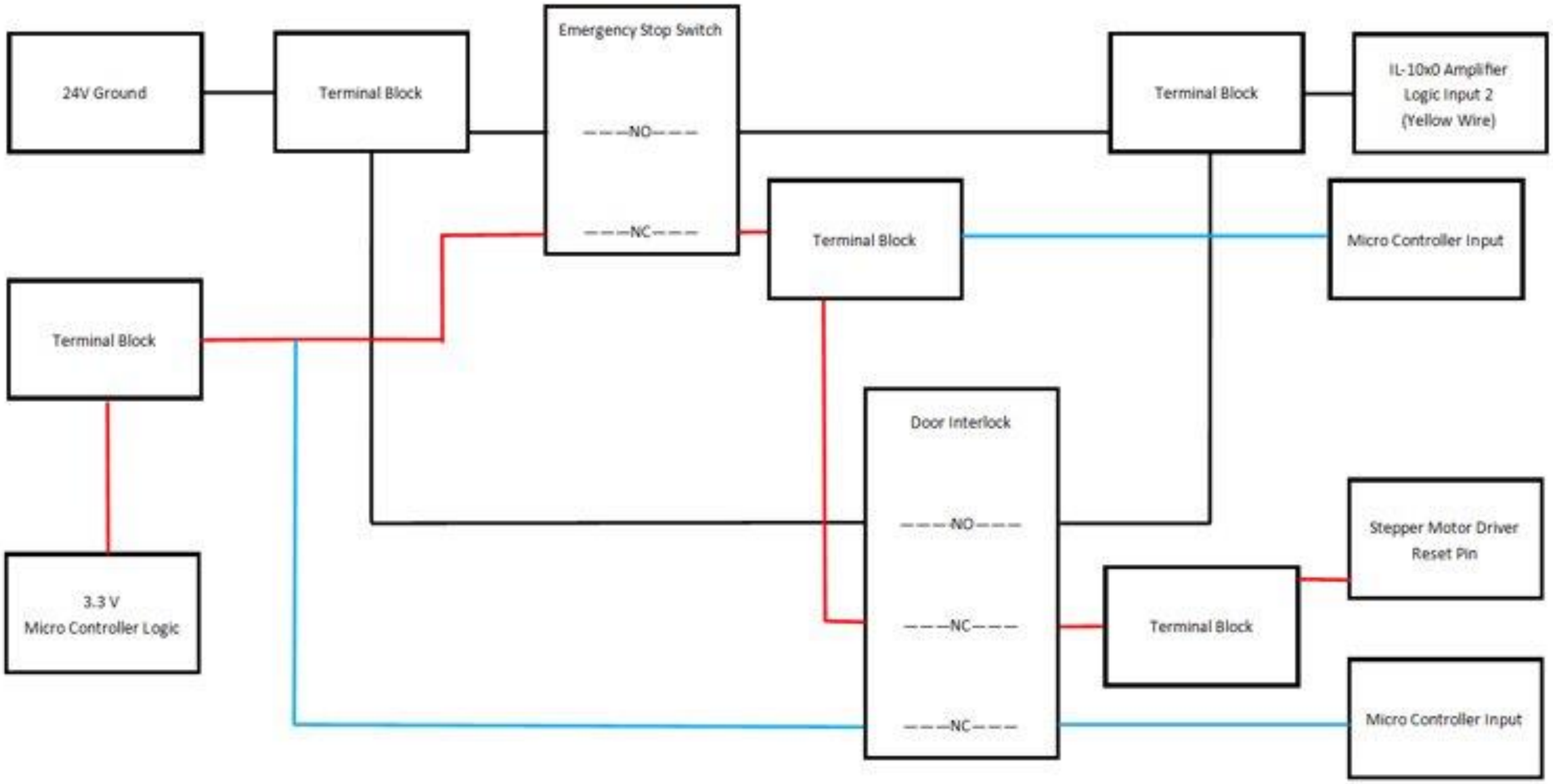


Figure 17: Full Safety Circuit Diagram

One of the optional input wires for each amplifier is wired parallel with each other with both the NO emergency stop and the NO door interlock wired in parallel to ground the input (Figure 18). When the input is grounded and the amplifiers are set to NPN mode, the lasers will not emit.

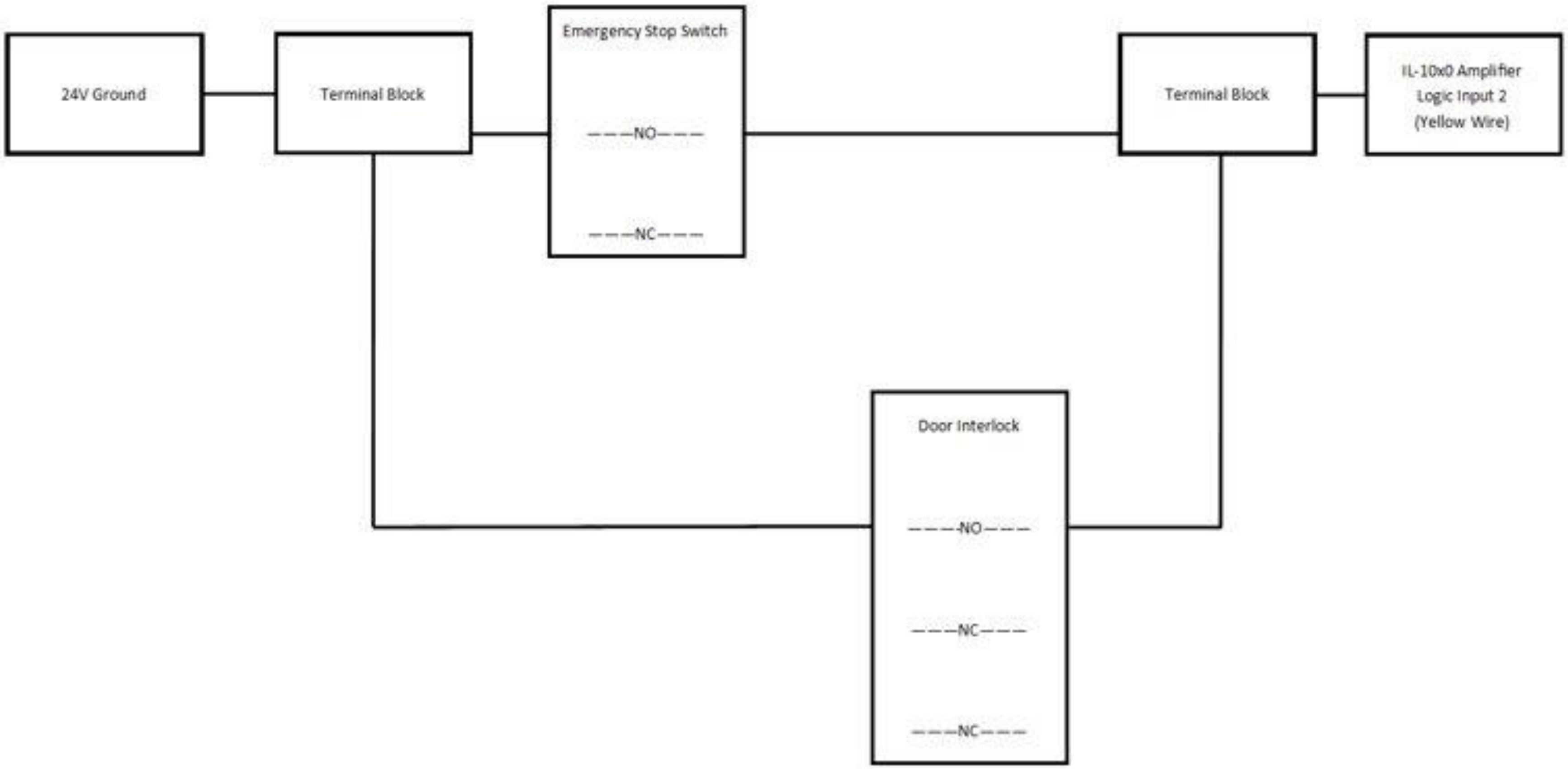


Figure 18: Laser emission safety circuitry. The ground used needs to be the ground from the 30W 24V power supply, and the amplifiers need to be set to NPN.

One of the 3.3-volt rails on the microcontroller will be utilized to power this portion of the circuit and the NC emergency stop, and NC door interlock switches wired in series are connected to the reset pins on the stepper motor drivers which will enable the motors to move (Figure 19).

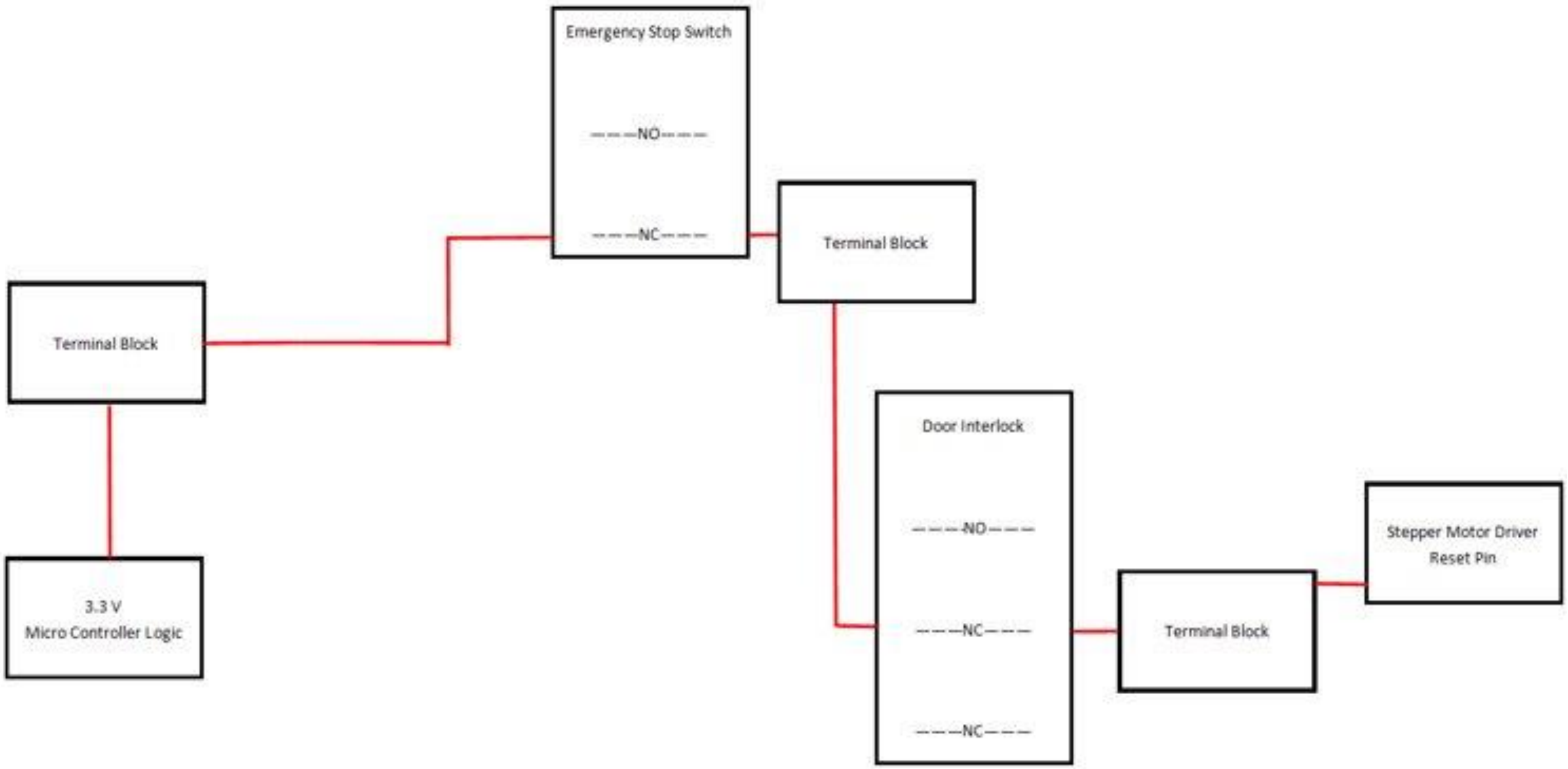


Figure 19: Stepper motor safety circuit. When the reset pin goes logic low then the driver deenergizes the coils of the motor.

After each NC switch, the 3.3-volt signal is sent to an input on the microcontroller to inform the microcontroller if one or both safety switches are activated (Figure 20).

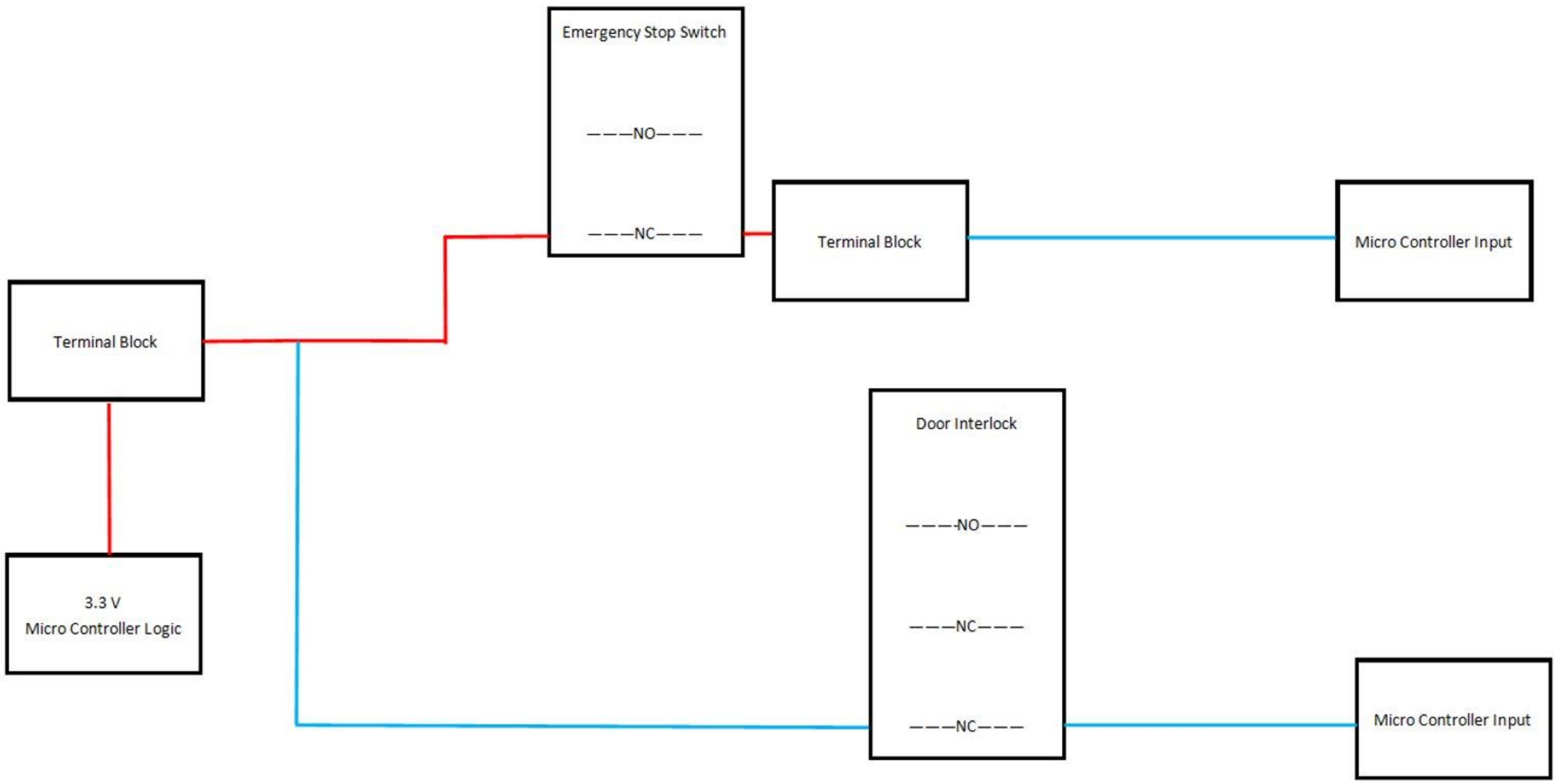


Figure 20: Logic feedback safety circuit. Allows the micro controller to know when either the emergency stop, or the door interlock is tripped.

2.2.4.f Terminal Block Layout

Two terminal block types were utilized throughout the system: Fused terminal block, and one-circuit/four-terminal blocks. Each of the terminal blocks are numbered and the role of each one is shown in Table 7.

Table 7: Terminal Block Reference Key

Number	Color	Jumper Present	Purpose
1	Orange		AC
2	Orange	Yes	AC
3	Gray		AC
4	Gray	Yes	AC
5	Black		AC
6	Black	Yes	AC
7	Gray		24V, 240W Ground
8	Gray	Yes	24V, 240W Ground
9	Yellow		24V, 240W Hot
10	Yellow	Yes	24V, 240W Hot
11	Gray		2 Amp Fuse for Actuator #1
12	Gray		2 Amp Fuse for Actuator #2
13	Gray		2 Amp Fuse for Actuator #3
14	Gray		24V, 30W Ground
15	Gray	Yes	24V, 30W Ground
16	Yellow		24V, 30W Hot
17	Yellow	Yes	24V, 30W Hot
18	Gray		Safety Circuit: 24V, 30W Ground
19	Gray	Yes	Safety Circuit: 24V, 30W Ground
20	Gray		5V, 30W Ground
21	Gray	Yes	5V, 30W Ground
22	Blue		5V, 30W Hot
23	Blue	Yes	5V, 30W Hot
24	Blue		Safety Circuit: 3.3V
25	Blue		Safety Circuit: 3.3V, Post E-Stop
26	Blue		Safety Circuit: 3.3V, Post Door Interlock

2.2.4.g Physical Wiring

The current prototype for the electrical system is displayed in Figures 21 and 22.

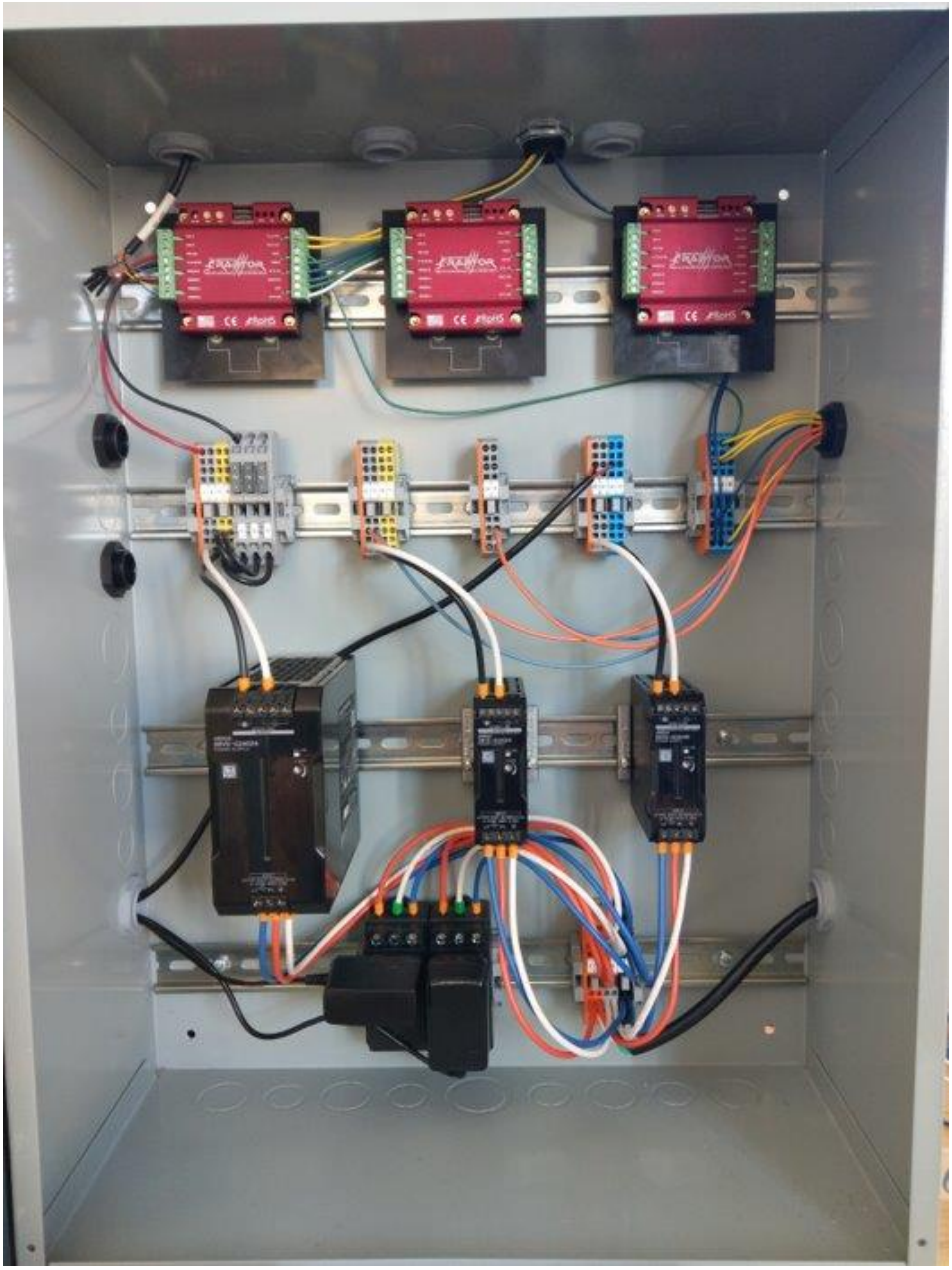


Figure 21: Rear Hoffman Box Wiring. From Top Rail to Bottom: stepper motor drivers, direct current (DC) power distribution, DC power supplies, alternating current power distribution.

Figure 22: Front Hoffman Box Wiring. From top to bottom rail: microcontroller mount and networking switch, laser amplifier.

The rear Hoffman box contains all the power distribution components and has a screw on door as regular access to this should not be needed. The front Hoffman box contains low the logic of the system that may need to be accessed on a semi regular and is secured with a latch.

The current prototype only has a single linear actuator, which is why only one of the stepper motor drivers is fully wired. We also do not currently have the structural components for the system, so the boxes are not mounted. As a result, the wires that would normally be ran between these boxes are currently not in place as the microcontroller sits in front of the box at our desk instead of on the DIN rail mount.

2.2.5 Computer Coding

The entire system is Linux based, and all controlling software was written in Python. Developing in Python allows complete 1-1 portability (the same code developed on Windows runs on Linux), and Linux allows for secure shell (remote) access. Python scripts coordinate communications over TCP/IP to the lasers, parses returned data and stores all of this in CSV format. The built in Python TCP modules allow for single line send/receive commands, vastly implying the code needed for communication. CSV was chosen rather than a traditional database structure due to its direct portability into Excel (which allows for easy analysis on the user end). The ‘database’ scripts simply store data into these CSV files in separate folders (See figure 23 for CSV Format).

```
time,Serial,M1,M2,M3,M4,M5,M6,GO/NOGO,DEV1,DEV2,DEV3,DEV4,DEV5,DEV6,FailFlag
Wed Apr 21 18:17:53 2021,N/A,1,2,3,4,5,6,NOGO,0,0,0,0,0,0,0
Wed Apr 21 18:19:57 2021,1111,1,2,3,4,5,6,NOGO,0,0,0,0,0,0,0
```

Figure 23: CSV Formatting

Python scripts also easily control the Beagle-Board’s I/O to manipulate the stepper motors on the linear actuators. All of this can be monitored and controlled both on a local screen, and by any computer with an internet connection to the to board. This means in the future, Polar could make this device accessible anywhere they desire. See Appendix D for TCP/IP Examples.

2.3 Design Analysis

The design analysis is to be validated through experimentation and error propagation. Because the sponsor only required that a go or no-go condition be met, exact error calculations are not necessary. The hardware selection and machine shop tolerances are all selected because of their low error. The sponsor company will be able to gather precise results and analysis of the wafer cassettes, but it will be more of a relative analysis than a perfect, true to reality analysis.

Another metric that will be measured to assure that the design goals are met is through the measurement time. One design requirement is that the equipment must be able to gather the results in under one minute. By timing a measurement cycle, we will be able to determine if this goal was met.

The wiring needed to be rated based on the ambient temperature of the chamber to avoid any safety concerns. The ambient temperature of the chamber was calculated to be 24.65^{o}C, elevated from 21^{o}C. This calculation is based on the efficiency of each electrical component to find out the heat generated by each component (Equation 2). The variables in Equation 2 are defined as the following: T is temperature at the two steady states on and off, P is power drawn by each component, h is the convective coefficient of heat transfer, A is the surface area of the chamber's aluminum shell, L is the thickness of the chamber's aluminum shell, and k is the conductive coefficient of heat transfer.

$$T_2 = \left(\sum Efficiency * P_{component}\right) * \left(\left(\frac{1}{h * A}\right) + \left(\frac{L}{k * A}\right)\right) + T_1$$

Equation 2: The final temperature of the chamber with all electronics running at full power.

2.4 Bill of Materials and Costs

At this time, the most recent Bill of Materials is shown below in Table 7. It is broken down by the two purchasers, UST and Polar.

Table 7: The Bill of Materials is shown below. The totals are broken down by parts ordered by the UST purchaser Dr. Min and by Polar Semiconductors.

Item	Source	Quantity	Price	Purchaser
LC-400 Linear Stage	Newmark Systems	1	$ 1,929.00	UST
BeagleBoard Black	Amazon	1	$ 115.45	UST
DC Power Supplies with mounts	Omron	1	$ 345.00	UST
Beaglebone Breakout Board	Amazon	1	$ 32.00	UST
Terminal Blocks	McMaster	26	$ 247.91	UST
Stepper Motor Driver	Digikey	1	$ 164.75	UST
DB9 Breakout Board	Mouser	2	$ 28.95	UST
Universal DIN Rail Mount	Winford	4	$ 40.00	UST
Beaglebone DIN Rail Mount	Winford	1	$ 12.00	UST
Laser Warning Decals	My Safety Sign	2	$ 21.00	UST
	Subtotal		$ 2,936.06	
	UST Budget Remaining		$ 63.94	

IL-065 Laser	Keyence	1	$ 790.00	Polar
IL-300 Laser	Keyence	2	$ 2,580.00	Polar
IL-100 Laser	Keyence	2	$ 1,580.00	Polar
IL-1050	Keyence	4	$ 2,600.00	Polar
IL-1000	Keyence	1	$ 650.00	Polar
DL-EN1	Keyence	1	$ 400.00	Polar
OP-87660	Keyence	5	$ 250.00	Polar
LC-300 Linear Stage	Newmark Systems	2	$ 3,130.00	Polar
Protolabs Parts order	Protolabs	1	$ 4,482.98	Polar
Hoffman Box	Mcmaster	2	$ 253.69	Polar
Emergency Stop	Mcmaster	1	$ 150.73	Polar
Door Interlock	Mcmaster	1	$ 84.26	Polar
Lock Out Tag Out Switch	Mcmaster	1	$ 67.14	Polar
Stepper Motor Driver	Digikey	2	$ 302.00	Polar
		Subtotal	$ 17,018.80	
		Total	$ 19,954.86	

3. Design Verification

Through communication with Polar Semiconductor, the design requirements are as follows:

- The system shall be easy to use with minimal set up. A single operator should only need to insert the cassette and press a single button to start the machine.
    - Solution: Simple GUI design with only start, stop, and reset buttons, and ease of inserting the cassette.
- The system shall complete the process in under 1 minute.
    - Solution: The system is planned to complete the process quickly, with 1 minute being an upper bound of performance time.
- The system shall output a go/no-go result to the operator.

    - Solution: The system will output either a pass or fail result upon completion of the process.
- The system shall be made from durable components.
    - Solution: The system is designed from high-quality sensors and milled components rated for high durability.
- The system shall operate in a controlled cleanroom environment (35-40% humidity, 69.8 +/-2 degrees Fahrenheit), and from a 120V wall outlet.
    - Solution: The system can be powered from only a 120V wall outlet, and all parts are durable enough to withstand cleanroom conditions.
- Any part of the system that touches the cassettes will be made of stainless steel of at least 316L grade.
    - Solution: All parts of the machine that could contact the cassettes, including the outer fixtures and cassette mount will be made from 316L grade stainless steel or higher.
- Any accessible portion of the machine must be resistant to isopropyl alcohol.
    - Solution: The durability of all sensors and components will be enough to resist contact with isopropyl alcohol.

All requirements are either met or planned to be met as of the time of writing this document.

4. Recommendations

Of the requirements given to us by Polar Semiconductors, the team completed many of the design requirements without full validation. The design has been created and validated to satisfy the following requirements: any part of the system that touches the cassettes will be made of stainless steel of at least 316L grade, any accessible portion of the machine must be resistant to isopropyl alcohol, the system shall operate in a controlled cleanroom environment (35-40% humidity, 69.8 +/-2 degrees Fahrenheit), and from a 120V wall outlet, the system shall be easy to use with minimal set up. A single operator should only need to insert the cassette and press a single button to start the machine, and the system shall be made from durable components. All these requirements have been validated by the team and the remaining requirements should be immediately validated after Polar assembles the chamber. The remaining design requirements include: the system shall complete the process in under 1 minute and the system shall output a go/no-go result to the operator. Additionally, loose wires are currently terminated using a temporary solution of electrical tape, therefore, a permanent solution is needed. Lastly, testing samples for viewing windows should be verified in their performance before implementation in the product.

A few recommendations the team would like to make to Polar Semiconductors as next steps for them to complete after the completion of the project are the following: Polar should analyze their entire cassette stock as soon as they can and Polar should integrate the testing chamber into the production line permanently.

Because the issue of warped cassettes is not visually obvious, testing must be done to assess the condition of any cassettes. Polar Semiconductors should analyze their whole inventory of cassettes immediately to avoid any failures as soon as possible. Polar should also analyze new cassettes to ensure that the supplier is supplying cassettes in good condition. It is a possibility that the supplier could be supplying warped cassettes from the factory. Any way that Polar can avoid manufacturing failures should be implemented.

Another way to ensure reliable manufacturing operation is to permanently fix the testing chamber into the production line. Currently the chamber is a free-floating chamber that can be moved at will. This can introduce error into the system and problems could be encountered. Polar Semiconductors should find a permanent location for the chamber so that no error is introduced. This will also ensure the safety of the user and passersby. Because of the use of lasers, safety is paramount when using and placing this equipment. If poorly placed, light could leak from the chamber and could damage ones' eyes.

4.1 Recommendations for Future Work

To improve on this system and satisfy the stretch goals of the sponsor, the following suggestions should be implemented.

An interlock system for the access door should be implemented with a controls halt to halt the testing in case of emergency. If the door is opened during the testing or is not closed prior to the start of the test, then the test will not continue. This will prevent the user from injuring oneself through laser exposure or crush points from the actuator.

Another recommendation is to add a passive camera system so that the user can monitor the progress of the test from the inside. Because of the laser exposure concern, it is difficult for the user to monitor the progress of the test. This camera system will passively watch the test so that the user can stop the test if a problem occurs or to verify if the laser sensors are aligned on the cassette correctly. This can be easily implemented into the chamber and then the software afterwards.

Another camera system could be implemented to optically analyze the condition of the teeth of the cassette. This additional information can give the user another metric of the condition of the cassette. The positions of the teeth will determine if the manufacturing tools at Polar Semiconductors will engage with the silicon wafers correctly.

Another quality tool to improve the assurance of production-ready cassettes is a serializing system to record and track specific cassettes. With a serial number and barcode or QR code, the values measured by the testing equipment can be tracked with the cassette. Any changes in the measurements will give PS the information to determine when the deformation is occurring and can prevent failures in the future. This system could be easily automated and integrated into the testing equipment. By implementing the previously stated camera systems, the barcode or QR code can be scanned, and the information can be stored with the cassette seamlessly.

5 Ethical Factors Analysis

5.1 Economic

The economic effects of our product are likely to be the most substantial. By determining whether a cassette is deformed before it enters the production line, fewer wafers will be destroyed during production. This will lead to decreased production loss for Polar and result in a net monetary gain due to not having to re-create as many wafers. This product will also be able to prevent tool downtime while the machines are recalibrated and maintained after a cassette collision. It is expected that Polar will save a substantial amount of money because of our product, allowing those funds to be put to better use in another part of the company.

5.2 Environmental

The environmental impact of the product will be regarding resource use. It will contain quite a bit of electronics, because of this, it contains quite a few heavy metals and is encased in a large amount of plastic and metal. Because this is a one-off product, not much consideration is needed to protect the environmental impact, since no more than one of these will be built at this time. The only real consideration would be that once this product is no longer needed, it will need to be disposed of properly, as to not let any of the materials leech into the ground. In terms of a positive impact, this device has the potential to eliminate a large amount of wasted silicon wafers. This outweighs any possible negative impacts currently.

5.3 Global

The potential global impact of our product is virtually zero. Because this is a one-off, single implementation prototype, it will only be used in-factory at Polar for their own use. They do not have any plans on manufacturing more than one, nor do they intend to sell the design for any form of profit. It is solely going to be used to make their own manufacturing processes more straightforward and to help eliminate their own cassette damage. With all this considered, any notable impact from the product is unlikely to be felt outside the fabrication plant floor, much less outside the United States. Therefore ethically, no real considerations are needed on a global scale.

5.4 Social

The Social effects of this project are major. Because this product makes the Polar employee's jobs easier and safer, it helps to prolong their working lives and avoid injury. This product will prevent machine failures which could result in dangerous debris and even projectiles which could harm a worker. Because of the design and purpose, failures will be detected before they happen and thus reduce risk.

5.5 Cultural

There are no cultural effects for this project because this product is only a one-off system for Polar Semiconductors.

6. Summary and Conclusions

The main goals of this project were to develop a solution to Polar's warping cassette problem by providing a simple method of testing cassettes for their production-worthiness. The final product was expected to execute in one minute or less and be simple to control even by an unskilled operator.

The project is planned to satisfy the basic requirements by the end of the semester but is currently held up by wait time from certain milled components and other orders. The project has taken two semesters to complete and still has features that can be added. The primary differences between our final product and the competitor are as outlines in the requirements: the cost is much lower, the size is smaller, and the execution time is down. However, there were many changes we had to make during the design process which led to differences from our original model. First, the components and sensors ordered were much more precise than we originally planned, but the precision was necessary. Our budget was much higher than expected as well due to the precise sensors, with the total cost of components clearing $10,000.

The team's recommendations for future development of this project are mostly software-sided due to our limited experience with practical programming languages for this type of problem. As such, we opted to use programming languages we were most familiar with rather than ones most suited to the problem. Otherwise, the sensors and actuators included are high-quality and unlikely need upgraded. The only exception to this would be if copies of the product were to be produced, in which case downgrading certain components would be recommended to lower the cost per unit manufactured.

7. References

2017 National Electric Code

https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=70

GR214V stepper motor datasheet

https://www.geckodrive.com/gr214v-bulletproof-high-resolution-stepper-drive.html

Omron power supply data sheet

http://www.ia.omron.com/products/family/3178/download/catalog.html

IL Series Laser and Laser Amplifier Datasheets

https://www.keyence.com/products/measure/laser-1d/il/downloads/?mode=ma

8. Acknowledgements

We thank Dr Hammer, Linn, and Orser for their critiques during our design reviews. We thank Dr Mahmoodi for his weekly advice regarding too many topics to cover in this section. We thank Professor Green for his guidance with respect to optical density.

Lastly, we would like to thank Matt Giddings and Polar Semiconductor Inc for sponsoring this project.

Appendix A

Laser and Laser Amplifier Datasheet – Key Information

SPECIFICATIONS

Sensor heads

Model		IL-030	IL-065	IL-100	IL-300	IL-600	IL-2000
Appearance							
Reference distance		30 mm 1.18"	65 mm 2.56"	100 mm 3.94"	300 mm 11.81"	600 mm 23.62"	2000 mm 78.74"
Measurement range		20 to 45 mm 0.79" to 1.77"	55 to 105 mm 2.17" to 4.13"	75 to 130 mm 2.95" to 5.12"	160 to 450 mm 6.30" to 17.72"	200 to 1000 mm 7.84" to 39.37"	1000 to 3500 mm 39.37" to 137.80"
Light source		Red semiconductor laser, wavelength: 655 nm (visible light)					
	Laser class	Class 1 (FDA (CDRH) Part1040.10) [1] Class 1 (IEC 60825-1)	Class 2 (FDA (CDRH) Part1040.10) [1] Class 2 (IEC 60825-1)				
	Output	220 μW	560 μW				
Spot diameter (at standard distance)		Approx. 200 × 750 μm	Approx. 550 × 1750 μm	Approx. 400 × 1350 μm	Approx. ø0.5 mm ø0.02"	Approx. ø1.6 mm ø0.06"	Approx. 1400 x 7000 μm
Linearity [2,3]		±0.1% of F.S. (25 to 35 mm 0.98" to 1.38")	±0.1% of F.S. (55 to 75 mm 2.17" to 2.95")	±0.15% of F.S. (80 to 120 mm 3.15" to 4.72")	±0.25% of F.S. (160 to 440 mm 6.30" to 17.32")	±0.25% of F.S. (200 to 600 mm 7.84" to 23.62") ±0.5% of F.S. (200 to 1000 mm 7.84" to 39.37")	±0.16% of F.S. (1000 to 3500 mm 39.37" to 137.80")
Repeatability [4]		1 μm	2 μm	4 μm	30 μm	50 μm	100 μm
Sampling rate		0.33/1/2/5 ms (4 levels available)					
Operation status indicators		Laser emission warning indicator: Green LED, Analog range indicator: Orange LED, Reference distance indicator: Red/Green LED					
Temperature characteristics [3]		0.05% of F.S./°C	0.06% of F.S./°C	0.06% of F.S./°C	0.08% of F.S./°C		0.016% of F.S./°C
Environmental resistance	Enclosure rating	IP67					
	Ambient light [5]	Incandescent lamp: 5000 lux	Incandescent lamp: 7500 lux		Incandescent lamp: 5000 lux		Incandescent lamp: 10000 lux
	Ambient temperature	-10 to +50°C 14 to 122°F (No condensation or freezing)					
	Relative humidity	35 to 85% RH (No condensation)					
	Vibration	10 to 55 Hz Double amplitude 1.5 mm 0.06" XYZ each axis: 2 hours					
	Pollution degree	3					
Material		Housing material: PBT, Metal parts: SUS304, Packing: NBR, Lens cover: Glass, Cable: PVC					
Weight		Approx. 60g	Approx. 75g		Approx. 135g		Approx. 350g

1. The laser classification for FDA (CDRH) is implemented based on IEC 60825-1 in accordance with the requirements of Laser Notice No.50.
2. Value when measuring the KEYENCE standard target (white diffuse object).
3. F.S. of each model is as follows. IL-030: ±5 mm ±0.20" IL-065: ±10 mm ±0.39" IL-100: ±20 mm ±0.79" IL-300: ±140 mm ±5.51" IL-600: ±400 mm ±15.75"
4. Value when measuring the KEYENCE standard target (white diffuse object) at the reference distance, sampling rate: 1 ms, and average number of times: 128. For the IL-300/IL-600, the sampling rate is 2 ms.
5. Value when the sampling rate is set to 2 ms or 5 ms.

Amplifier unit

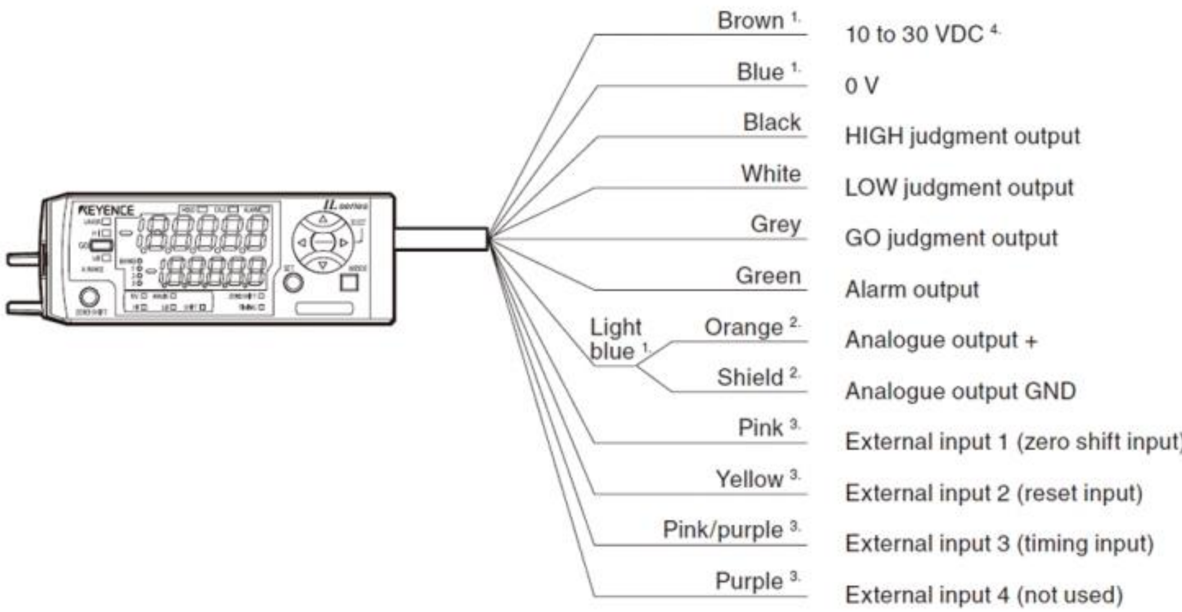
Model		IL-1000	IL-1500	IL-1050	IL-1550
Appearance					
Type		DIN-rail mount	Panel mount	DIN-rail mount	Panel mount
Main unit/expansion unit		Main unit		Expansion unit	
Head compatibility		Compatible			
Display	Minimum displayable unit	IL-030: 1 μm, IL-065/IL-100: 2 μm, IL-300: 10 μm, IL-600: 50 μm, IL-2000: 100 μm 3.94"			
	Display range	IL-030/IL-065/IL-100: ±99.999 mm to ±99 mm (4 levels selectable), IL-300/IL-600: ±999.99 mm to ±999 mm (3 levels selectable), IL-2000: ±9999.9 mm to ±9999 mm (2 levels selectable)			
	Display rate	Approx. 10 times/sec.			
Analog voltage output [1]		±5 V, 1 to 5 V, 0 to 5 V Output impedance 100 Ω		None	
Analog current output [1]		4 to 20 mA Maximum load resistance of 350 Ω			
Control input [2]	Bank switch input	Non-voltage input			
	Zero-shift input				
	Stop emission input				
	Timing input				
	Reset input				
Control output [3]	Judgement output	Open collector output (NPN, PNP changeover possible/N.O., N.C. changeover possible)			
	Alarm output	Open collector output (NPN, PNP changeover possible/N.C.)			
Current	Power voltage [4]	10 to 30 VDC ripple (P-P) 10% included, Class 2		Supplied by main unit	
	Power consumption	2300 mW or less (at 30 V: 77 mA or less)	2500 mW or less (at 30 V: 84 mA or less)	2000 mW or less (at 30 V: 67 mA or less)	2200 mW or less (at 30 V: 74 mA or less)
Environmental resistance	Ambient humidity	-10 to +50°C 14 to 122°F (No condensation or freezing)			
	Ambient temperature	35 to 85% RH (No condensation)			
	Vibration	10 to 55 Hz Double amplitude 1.5 mm 0.06" XYZ each axis: 2 hours			
	Pollution degree	2			
Material		Case / Front sheet: Polycarbonate; Key tops: Polyacetel; Cable: PVC			
Weight (including attachments)		Approx. 150g	Approx. 170g	Approx. 140g	Approx. 160g

1. Select and use one of ±5 V, 1 to 5 V, 0 to 5 V or 4 to 20 mA.
2. Assign an input of your choice to the 4 external input lines before using.
3. – The NPN open collector rated output is: 50 mA max./ch (20 mA when adding an expansion unit) less than 30 V, residual voltage less than 1 V (less than 1.5 V when adding over 6 units including the main unit)
   – The PNP open collector rated output is: 50 mA max./ch (20 mA/ch when adding expansion units), less than power voltage, and less than 2 V residual voltage (less than 2.5 V when adding over 6 units including the main unit)
4. If there are over 6 additional expansion units, please use a power voltage of 20 to 30 V.

I/O Circuit Connection diagram

* Download CAD file or product manual for larger image/text and more detail.

Wiring Diagram



1. The brown, blue, and light blue cables are not provided in a IL-1050/IL-1550 unit (expansion unit).
The power is supplied to the expansion unit from the IL-1000/IL-1500 unit (main unit).
2. For an analogue output, OFF (not used), 0 to 5 V, ±5 V,
1 to 5 V, or 4 to 20 mA can be selected.
3. For an external input, bank A input, bank B input, laser emission stop input, or OFF (not used) can also be selected.
For details, refer to the User's Manual.
4. If there are over 6 additional expansion units, please use a power voltage of 20 to 30 V.

Appendix B

GR214V Datasheet – Key Information

PIN#	FUNCTION	DETAILS
1	GND	Signal Ground
2	STP	The edge of step pulse on this input advances the motor one increment. The size of the increment is dependent upon the settings of the resolution.
3	DIR	This input is used to change the direction of the motor.
4	+5V	This +5VDC input is used to supply power to the isolated logic inputs.
5	ENABLE	This input is used to enable/disable the output section of the driver. When in a Logic HIGH state (open), the outputs are enabled.
6	RESET	When LOW, this input will reset the driver (phase outputs will disable).
7	FAULT OUTPUT	This output indicates that a short circuit condition has occurred. This output is active LOW.
8	FULLSTEP OUTPUT	This output indicates when the driver is positioned at full step. This output can be used to count the number of full steps the motor has moved, regardless of the number of microsteps in between.

PIN#	FUNCTION	DETAILS
1	REDUCE CURRENT	Phase Current Reduction Adjustment
2	CURRENT	Phase Current Adjustment
3	GND	Power Ground. The ground, or return, of the power supply is connected here
4	V+	Motor Supply Voltage. +12 to +80VDC
5	~PHB	~PHASE B of the stepping motor
6	PHB	PHASE B of the stepping motor
7	~PHA	~PHASE A of the stepping motor
8	PHA	PHASE A of the stepping motor

LED Fault Codes: Two LEDs give a status indication with either a solid color or a blink-blink-blink-off status code. A tertiary LED will only light in the event the fuse blows and is labeled on the PCB as "FUSE" above the LED as seen in Figure 1. The Status LED codes can be found below:

COLOR CODE	STATUS MEANING
RED-RED-RED-OFF	Motor Disconnected
GREEN-GREEN-GREEN-OFF	Normal, motor not moving
RED-RED-GREEN-OFF	Phase A disconnected
RED-GREEN-RED-OFF	Phase B disconnected
GREEN-RED-RED-OFF	Unassigned
RED-GREEN-GREEN-OFF	Unassigned
GREEN-RED-GREEN-OFF	Unassigned
GREEN-GREEN-RED-OFF	Unassigned
SOLID RED	Drive is in protect mode
SOLID GREEN	Normal, motor moving

STEP 2: SETTING MOTOR PHASE CURRENT

Motor phase current may be set one of three ways: The onboard DIP switches, an external current set resistor or an external voltage input. All current settings will be in reference to the single phase peak current of the stepper motor.

ONBOARD DIP SWITCH SETTING

Please consult the diagram below for the proper switch setting for your motor phase current. Leave CN1 PIN2 floating if this option is being used. RED = OFF, GREEN = ON in the current set diagram.

Appendix C

DC Power Supply Datasheets – Key Information

S8VK-G

Specifications

Ratings, Characteristics, and Functions

Item		Power rating / Output voltage (VDC)	15 W: 5 V	15 W: 12 V	15 W: 24 V	30 W: 5 V	30 W: 12 V	30 W: 24 V
Efficiency		230 VAC input *6	77% typ.	77% typ.	80% typ.	79% typ.	82% typ.	86% typ.
Input	Voltage range *1		Single-phase, 85 to 264 VAC, 90 to 350 VDC *10					
	Frequency *1		50/60 Hz (47 to 450 Hz)					
	Current	115 VAC input *6	0.32 A typ.	0.3 A typ.	0.31 A typ.	0.5 A typ.	0.57 A typ.	0.58 A typ.
		230 VAC input *6	0.2 A typ.	0.21 A typ.	0.2 A typ.	0.32 A typ.	0.37 A typ.	0.36 A typ.
	Power factor *6	230 VAC input, 100% load	0.42 min.			0.43 min.	0.42 min.	0.43 min.
	Leakage current	115 VAC input	0.14 mA typ.			0.13 mA typ.		
		230 VAC input	0.25 mA typ.			0.24 mA typ.		
	Inrush current *2 (for a cold start at 25°C)	115 VAC input	16 A typ			16 A typ		
		230 VAC input	32 A typ.			32 A typ.		
Output	Rated output current		3 A	1.2 A	0.65 A	5 A	2.5 A	1.3 A
	Boost current		3.6 A	1.44 A	0.78 A	6 A	3 A	1.56 A
	Voltage adjustment range *3		–10% to 15% (with V.ADJ) (guaranteed)					
	Ripple & Noise voltage *4	100 to 240 VAC input, 100% load *6	60 mVp-p max. at 20 MHz of bandwidth	50 mVp-p max.at 20 MHz of bandwidth	30 mVp-p max. at 20 MHz of bandwidth	30 mVp-p max. at 20 MHz of bandwidth	30 mVp-p max. at 20 MHz of bandwidth	30 mVp-p max. at 20 MHz of bandwidth
	Input variation influence *8		0.4% max.			0.4% max.		
	Load variation influence *7		0.8% max.			0.8% max.		
	Temperature variation influence	115 to 230 VAC input	0.05%/°C max.			0.05%/°C max.		
	Start up time *2	115 VAC input *6	530 ms typ.	520 ms typ.	580 ms typ.	550 ms typ.	550 ms typ.	600 ms typ.
		230 VAC input *6	330 ms typ.	400 ms typ.	400 ms typ.	430 ms typ.	490 ms typ.	480 ms typ.
	Hold time *2	115 VAC input *6	28 ms typ.	29 ms typ.	32 ms typ.	33 ms typ.	36 ms typ.	23 ms typ.
		230 VAC input *6	134 ms typ.	138 ms typ.	134 ms typ.	177 ms typ.	170 ms typ.	154 ms typ.
Additional functions	Overload protection		Yes, automatic reset			Yes, automatic reset		
	Overvoltage protection *5		Yes, 130% or higher of rated output voltage, power shut off (shut off the input voltage and turn on the input again)					
	Series operation		Yes (For up to two Power Supplies, external diodes are required.)					
	Parallel operation		Yes (Refer to *Safety Precautions*) (For up to two Power Supplies)					
	Output indicator		Yes (LED: Green), lighting from 80% to 90% or more of rated voltage					
Insulation	Withstand voltage		3.0 kVAC for 1 min. (between all input terminals and output terminals), current cutoff 20 mA					
			2.0 kVAC for 1 min. (between all input terminals and PE terminals), current cutoff 20 mA					
			1.0 kVAC for 1 min. (between all output terminals and PE terminals), current cutoff 20 mA					
	Insulation resistance		100 MΩ min. (between all output terminals and all input terminals/PE terminals) at 500 VDC					
Environment	Ambient operating temperature *12		–40 to 70°C (Derating is required according to the temperature. Refer to *Engineering Data*) (with no condensation or icing)					
	Storage temperature		–40 to 85°C (with no condensation or icing)					
	Ambient operating humidity		0% to 95% (Storage humidity: 0% to 95%)					
	Vibration resistance		10 to 55 Hz, 0.375 mm half amplitude for 2 h each in X, Y, and Z directions					
	Shock resistance		150 m/s², 3 times each in ±X, ±Y, and ±Z directions					
Reliability	MTBF		135,000 hrs min.					
	Life expectancy *9		10 years min.					
Construction	Weight		150 g max.			195 g max.		
	Cooling fan		No					
	Degree of protection		IP20 by EN/IEC 60529					
Standards	Harmonic current emissions		Conforms to EN 61000-3-2					
	EMI	Conducted Emissions	Conforms to EN 61204-3 Class B, EN 55011 Class B					
		Radiated Emissions	Conforms to EN 61204-3 Class B, EN 55011 Class B					
	EMS		Conforms to EN 61204-3 high severity levels					
	Approved Standards		UL Listed: UL 508 (Listing, Class2 Output: Per UL 1310) UL UR: UL 62368-1 (Recognition) cUL: CSA C22.2 No.107.1 (Class2 Output: Per CSA C22.2 No.223) cUR:CSA C22.2 No.62368-1 EN/VDE: EN 50178, EN 62368-1					
	Conformed Standards		PELV (EN 60204-1, EN 50178)					
			EN 61558-2-16					
			EAC (TR CU 004 / 2011, TR CU 020 / 2011)					
			RCM (EN61000-6-4)					
	Marine Standards		Lloyd's register *10 *11					
	SEMI		Conforms to F47-0706 (200 to 240 VAC input)					

*1. Do not use an inverter output for the Power Supply. Inverters with an output frequency of 50/60 Hz are available, but the rise in the internal temperature of the Power Supply may result in ignition or burning.
*2. For a cold start at 25°C. Refer to *Engineering Data* on page 9 to 11 for details.
*3. If the output voltage adjuster (V. ADJ) is turned, the voltage will increase by more than +15% of the voltage adjustment range. When adjusting the output voltage, confirm the actual output voltage from the Power Supply and be sure that the load is not damaged.
*4. A characteristic when the ambient operating temperature is between –25 to 70°C.
*5. Refer to *Overvoltage Protection* on page 10 for the time when input voltage shuts off and input turns on again.
*6. The value is when both rated output voltage and rated output current are satisfied.
*7. 100 to 240 VAC input, in the range of 0 A to the rated output current
*8. This is the maximum variation in the output voltage when the input voltage is gradually changed within the allowable input voltage range at the rated output voltage and rated output current.
*9. Refer to *Recommended Replacement Periods and Periodic Replacement for Preventive Maintenance* on page 23 for details.
*10. Safety Standards for a DC Input
The following safety standards apply to a DC input: UL 62368-1, cUR (CSA C22.2 No. 62368-1), EN 50178, EN 62368-1, and Lloyd's.
For a DC input, safety is ensured by an external fuse.
Select an external fuse that meets the following conditions.
S8VK-G015□□: 350 VDC min, 3 A
S8VK-G030□□: 350 VDC min, 4 A
*11. Clamp filter "ZCAT2035-0930" manufactured by TDK Corporation. or equivalent should be installed in the cable connected to the input - output terminals of S8VK-G series.
Noise filter "FN2080-10-06" manufactured by SCHAFFNER Corporation. or equivalent should be connected to the Input terminals of S8VK-G series.
*12. At –40 to –25°C, time will be required before the rated output voltage is output after the input voltage is input.
Also, the ripple noise value may exceed the value shown in the above table.

S8VK-G

Item		Power rating / Output voltage (VDC)	60 W 12 V	60 W 24 V	120 W 24 V
Efficiency		230 VAC input ✻6	85% typ.	88% typ.	89% typ.
Input	Voltage range ✻1		Single-phase, 85 to 264 VAC, 90 to 350 VDC ✻10		
	Frequency ✻1		50/60 Hz (47 to 450 Hz)		50/60 Hz (47 to 63 Hz)
	Current	115 VAC input ✻6	1.0 A typ.	1.1 A typ.	1.3 A typ.
		230 VAC input ✻6	0.6 A typ.	0.7 A typ.	0.7 A typ.
	Power factor ✻6	230 VAC input, 100% load	0.46 min.	0.45 min.	0.94 min.
	Leakage current	115 VAC input	0.16 mA typ.		0.24 mA typ.
		230 VAC input	0.30 mA typ.		0.38 mA typ.
	Inrush current ✻2 (for a cold start at 25°C)	115 VAC input	16 A typ.		16 A typ.
		230 VAC input	32 A typ.		32 A typ.
Output	Rated output current		4.5 A	2.5 A	5 A
	Boost current		5.4 A	3 A	6 A
	Voltage adjustment range ✻3		−10% to 15% (with V. ADJ) (guaranteed)		
	Ripple & Noise voltage ✻4	100 to 240 VAC input, 100% load ✻6	150 mVp-p max. at 20 MHz of bandwidth	50 mVp-p max. at 20 MHz of bandwidth	150 mVp-p max. at 20 MHz of bandwidth
	Input variation influence ✻8		0.4% max.		0.4% max.
	Load variation influence ✻7		0.8% max.		0.8% max.
	Temperature variation influence	115 to 230 VAC input	0.05%/°C max.		0.05%/°C max.
	Start up time ✻2	115 VAC input ✻6	570 ms typ.	650 ms typ.	790 ms typ.
		230 VAC input ✻6	430 ms typ.	500 ms typ.	750 ms typ.
	Hold time ✻2	115 VAC input ✻6	26 ms typ.	25 ms typ.	42 ms typ.
		230 VAC input ✻6	139 ms typ.	129 ms typ.	42 ms typ.
Additional functions	Overload protection		Yes, automatic reset		Yes, automatic reset
	Overvoltage protection ✻5		Yes, 130% or higher of rated output voltage, power shut off (shut off the input voltage and turn on the input again)		
	Series operation		Yes (For up to two Power Supplies, external diodes are required.)		
	Parallel operation		Yes (Refer to *Safety Precautions*) (For up to two Power Supplies)		
	Output indicator		Yes (LED: Green), lighting from 80% to 90% or more of rated voltage		
Insulation	Withstand voltage		3.0 kVAC for 1 min. (between all input terminals and output terminals), current cutoff 20 mA		
			2.0 kVAC for 1 min. (between all input terminals and PE terminals), current cutoff 20 mA		
			1.0 kVAC for 1 min. (between all output terminals and PE terminals), current cutoff 20 mA		
	Insulation resistance		100 MΩ min. (between all output terminals and all input terminals/PE terminals) at 500 VDC		
Environment	Ambient operating temperature ✻12		−40 to 70°C (Derating is required according to the temperature. Refer to *Engineering Data*) (with no condensation or icing)		
	Storage temperature		−40 to 85°C (with no condensation or icing)		
	Ambient operating humidity		0% to 95% (Storage humidity: 0% to 95%)		
	Vibration resistance		10 to 55 Hz, 0.375 mm half amplitude for 2 h each in X, Y, and Z directions		
	Shock resistance		150 m/s², 3 times each in ±X, ±Y, ±Z directions		
Reliability	MTBF		135,000 hrs min.		
	Life expectancy ✻9		10 years min.		
Construction	Weight		260 g max.		620 g max.
	Cooling fan		No		
	Degree of protection		IP20 by EN/IEC 60529		
Standards	Harmonic current emissions		Conforms to EN 61000-3-2		
	EMI	Conducted Emissions	Conforms to EN 61204-3 Class B, EN 55011 Class B		
		Radiated Emissions	Conforms to EN 61204-3 Class B, EN 55011 Class B		
	EMS		Conforms to EN 61204-3 high severity levels		
	Approved Standards		UL Listed: UL 508 (Listing, For 60 W only Class2 Output: Per UL 1310) UL UR: UL 62368-1 (Recognition) cUL: CSA C22.2 No.107.1 (For 60 W only Class2 Output: Per CSA C22.2 No.223) cUR: CSA C22.2 No.62368-1 EN/VDE: EN 50178, EN 62368-1		
	Conformed Standards		PELV (EN 60204-1, EN 50178)		
			EN 61558-2-16		
			EAC (TR CU 004 / 2011, TR CU 020 / 2011)		
			RCM (EN61000-6-4)		
	Marine Standards		Lloyd's register ✻10 ✻11		
	SEMI		Conforms to F47-0706 (200 to 240 VAC input)		

✻1. Do not use an inverter output for the Power Supply. Inverters with an output frequency of 50/60 Hz are available, but the rise in the internal temperature of the Power Supply may result in ignition or burning.
✻2. For a cold start at 25°C. Refer to *Engineering Data* on page 9 to 11 for details.
✻3. If the output voltage adjuster (V. ADJ) is turned, the voltage will increase by more than +15% of the voltage adjustment range. When adjusting the output voltage, confirm the actual output voltage from the Power Supply and be sure that the load is not damaged.
✻4. A characteristic when the ambient operating temperature is between −25 to 70°C.
✻5. Refer to *Overvoltage Protection* on page 10 for the time when input voltage shuts off and input turns on again.
✻6. The value is when both rated output voltage and rated output current are satisfied.
✻7. 100 to 240 VAC input, in the range of 0 A to the rated output current
✻8. This is the maximum variation in the output voltage when the input voltage is gradually changed within the allowable input voltage range at the rated output voltage and rated output current.
✻9. Refer to *Recommended Replacement Periods and Periodic Replacement for Preventive Maintenance* on page 23 for details.
✻10. Safety Standards for a DC Input
The following safety standards apply to a DC input: UL 62368-1, cUR (CSA C22.2 No. 62368-1), EN 50178, EN 62368-1, and Lloyd's.
For a DC input, safety is ensured by an external fuse.
Select an external fuse that meets the following conditions.
S8VK-G060□□: 350 VDC min, 6 A
S8VK-G12024: 350 VDC min, 5 A
✻11. Clamp filter "ZCAT2035-0930" manufactured by TDK Corporation. or equivalent should be installed in the cable connected to the input - output terminals of S8VK-G series.
Noise filter "FN2080-10-06" manufactured by SCHAFFNER Corporation. or equivalent should be connected to the Input terminals of S8VK-G series.
✻12. At −40 to −25°C, time will be required before the rated output voltage is output after the input voltage is input.
Also, the ripple noise value may exceed the value shown in the above table.

Item		Power rating / Output voltage (VDC)	240 W 24 V	240 W 48 V	480 W 24 V	480 W 48 V
Efficiency		230 VAC input *6	92% typ.		93% typ.	
Input	Voltage range *1		Single-phase, 85 to 264 VAC, 90 to 350 VDC *10			
	Frequency *1		50/60 Hz (47 to 63 Hz)			
	Current	115 VAC input *6	2.4 A typ.		4.7 A typ.	
		230 VAC input *6	1.3 A typ.		2.3 A typ.	
	Power factor *6	230 VAC input, 100% load	0.9 min.		0.97 min.	
	Leakage current	115 VAC input	0.23 mA typ.		0.3 mA typ.	
		230 VAC input	0.33 mA typ.		0.49 mA typ.	
	Inrush current *2 (for a cold start at 25°C)	115 VAC input	16 A typ.		16 A typ.	
		230 VAC input	32 A typ.		32 A typ.	
Output	Rated output current		10 A	5 A	20 A	10 A
	Boost current		12 A	6 A	24 A	12 A
	Voltage adjustment range *3		–10% to 15% (with V.ADJ) (guaranteed)			
	Ripple & Noise voltage *4	100 to 240 VAC input, 100% load *6	180 mVp-p max. at 20 MHz of bandwidth	350 mVp-p max. at 20 MHz of bandwidth	230 mVp-p max. at 20 MHz of bandwidth	470 mVp-p max. at 20 MHz of bandwidth
	Input variation influence *8		0.4% max.		0.4% max.	
	Load variation influence *7		0.8% max.		0.8% max.	
	Temperature variation influence	115 to 230 VAC input	0.05%/°C max.		0.05%/°C max.	
	Start up time *2	115 VAC input *6	250 ms typ.	290 ms typ.	380 ms typ.	
		230 VAC input *6	250 ms typ.	290 ms typ.	260 ms typ.	
	Hold time *2	115 VAC input *6	44 ms typ.	43 ms typ.	40 ms typ.	
		230 VAC input *6	44 ms typ.		50 ms typ.	
Additional functions	Overload protection		Yes, automatic reset		Yes, automatic reset	
	Overvoltage protection *5		Yes, 130% or higher of rated output voltage, power shut off (shut off the input voltage and turn on the input again)			
	Series operation		Yes (For up to two Power Supplies, external diodes are required.)			
	Parallel operation		Yes (Refer to *Safety Precautions*) (For up to two Power Supplies)			
	Output indicator		Yes (LED: Green), lighting from 80% to 90% or more of rated voltage			
Insulation	Withstand voltage		3.0 kVAC for 1 min. (between all input terminals and output terminals), current cutoff 20 mA			
			2.0 kVAC for 1 min. (between all input terminals and PE terminals), current cutoff 20 mA			
			1.0 kVAC for 1 min. (between all output terminals and PE terminals), current cutoff 20 mA			
	Insulation resistance		100 MΩ min. (between all output terminals and all input terminals/PE terminals) at 500 VDC			
Environment	Ambient operating temperature *12		–40 to 70 °C (Derating is required according to the temperature. Refer to *Engineering Data*) (with no condensation or icing)			
	Storage temperature		–40 to 85°C (with no condensation or icing)			
	Ambient operating humidity		0% to 95% (Storage humidity: 0% to 95%)			
	Vibration resistance		10 to 55 Hz, 0.375 mm half amplitude for 2 h each in X, Y, and Z directions			
	Shock resistance		150 m/s², 3 times each in ±X, ±Y, ±Z directions			
Reliability	MTBF		135,000 hrs min.			
	Life expectancy *9		10 years min.			
Construction	Weight		900 g max.		1,500 g max.	
	Cooling fan		No			
	Degree of protection		IP20 by EN/IEC 60529			
Standards	Harmonic current emissions		Conforms to EN 61000-3-2			
	EMI	Conducted Emissions	Conforms to EN 61204-3 Class B, EN 55011 Class B			
		Radiated Emissions	Conforms to EN 61204-3 Class B, EN 55011 Class B			
	EMS		Conforms to EN 61204-3 high severity levels			
	Approved Standards		UL Listed: UL 508 (Listing) UL UR: UL 62368-1 (Recognition) cUL: CSA C22.2 No.107.1 cUR: CSA C22.2 No.62368-1 EN/VDE: EN 50178, EN 62368-1			
	Conformed Standards		PELV (EN 60204-1, EN 50178)			
			EN 61558-2-16			
			EAC (TR CU 004 / 2011, TR CU 020 / 2011)			
			RCM (EN61000-6-4)			
	Marine Standards		Lloyd's register *10 *11			
	SEMI		Conforms to F47-0706 (200 to 240 VAC input)			

*1. Do not use an inverter output for the Power Supply. Inverters with an output frequency of 50/60 Hz are available, but the rise in the internal temperature of the Power Supply may result in ignition or burning.
*2. For a cold start at 25°C. Refer to *Engineering Data* on page 9 to 11 for details.
*3. If the output voltage adjuster (V. ADJ) is turned, the voltage will increase by more than +15% of the voltage adjustment range. When adjusting the output voltage, confirm the actual output voltage from the Power Supply and be sure that the load is not damaged.
*4. A characteristic when the ambient operating temperature is between –25 to 70°C.
*5. Refer to *Overvoltage Protection* on page 10 for the time when input voltage shuts off and input turns on again.
*6. The value is when both rated output voltage and rated output current are satisfied.
*7. 100 to 240 VAC input, in the range of 0 A to the rated output current
*8. This is the maximum variation in the output voltage when the input voltage is gradually changed within the allowable input voltage range at the rated output voltage and rated output current.
*9. Refer to *Recommended Replacement Periods and Periodic Replacement for Preventive Maintenance* on page 23 for details.
*10. Safety Standards for a DC Input
The following safety standards apply to a DC input: UL 62368-1, cUR (CSA C22.2 No. 62368-1), EN 50178, EN 62368-1, and Lloyd's.
For a DC input, safety is ensured by an external fuse.
Select an external fuse that meets the following conditions.
S8VK-G240□□: 350 VDC min, 8 A
S8VK-G480□□: 350 VDC min, 12 A
*11. Clamp filter "ZCAT2035-0930" manufactured by TDK Corporation. or equivalent should be installed in the cable connected to the input - output terminals of S8VK-G series.
Noise filter "FN2080-10-06" manufactured by SCHAFFNER Corporation. or equivalent should be connected to the Input terminals of S8VK-G series.
*12. At –40 to –25°C, time will be required before the rated output voltage is output after the input voltage is input.
Also, the ripple noise value may exceed the value shown in the above table.

S8VK-G

Precautions for Safe Use

Wiring

- Connect the ground completely. A protective earthing terminal stipulated in safety standards is used. Electric shock or malfunction may occur if the ground is not connected completely.
- Minor fire may possibly occur. Ensure that input and output terminals are wired correctly.
- Do not apply more than 75-N force to the terminal block when tightening it.
- Be sure to remove the sheet covering the Product for machining before power-ON so that it does not interfere with heat dissipation.
- Use the following material for the wires to be connected to the S8VK-G to prevent smoking or ignition caused by abnormal loads.

Recommended Wire Type/Cross-sectional Area and Stripping Length

Model	INPUT		OUTPUT		PE		Wire Stripping Length
	American Wire Gauge	Solid Wire /Stranded Wire	American Wire Gauge	Solid Wire /Stranded Wire	American Wire Gauge	Solid Wire /Stranded Wire	
S8VK-G01505	AWG24 to 12	0.25 to 4 mm^2 /0.25 to 2.5 mm^2	AWG20 to 12	0.5 to 4 mm^2 /0.5 to 2.5 mm^2	AWG14 to 12	2.5 to 4 mm^2/ 2.5 to 4 mm^2	8 to 10 mm
S8VK-G01512			AWG22 to 12	0.35 to 4 mm^2 /0.35 to 2.5 mm^2			
S8VK-G01524			AWG24 to 12	0.25 to 4 mm^2 /0.25 to 2.5 mm^2			
S8VK-G03005	AWG24 to 12	0.25 to 4 mm^2 /0.25 to 2.5 mm^2	AWG18 to 12	0.75 to 4 mm^2 /0.75 to 2.5 mm^2			
S8VK-G03012			AWG20 to 12	0.5 to 4 mm^2 /0.5 to 2.5 mm^2			
S8VK-G03024			AWG22 to 12	0.35 to 4 mm^2 /0.35 to 2.5 mm^2			
S8VK-G06012	AWG22 to 12	0.35 to 4 mm^2 /0.35 to 2.5 mm^2	AWG18 to 12	0.75 to 4 mm^2 /0.75 to 2.5 mm^2			
S8VK-G06024			AWG20 to 12	0.5 to 4 mm^2 /0.5 to 2.5 mm^2			
S8VK-G12024	AWG22 to 10	0.35 to 6 mm^2 /0.35 to 4 mm^2	AWG18 to 10	0.75 to 6 mm^2 /0.75 to 4 mm^2	AWG14 to 10	2.5 to 6 mm^2/ 2.5 to 4 mm^2	
S8VK-G24024	AWG20 to 10	0.5 to 6 mm^2 /0.5 to 4 mm^2	AWG14 to 10	2.5 to 6 mm^2 /2.5 to 4 mm^2			
S8VK-G24048			AWG18 to 10	0.75 to 6 mm^2 /0.75 to 4 mm^2			
S8VK-G48024	AWG16 to 10	1.5 to 6 mm^2 /1.5 to 4 mm^2	AWG12 to 10	4 to 6 mm^2 /4 mm^2			
S8VK-G48048			AWG14 to 10	2.5 to 6 mm^2 /2.5 to 4 mm^2			

Appendix D

Example Laser Script

laserDemo.py

```python
import LaserUTIL
from LaserUTIL import send
from time import sleep
from os import system
# This is not a multipurpose file. This works under various assumptions, such as the decimal placement

# These values are set by us outside of this file
host = "169.254.222.222"
port = 64000

print("Laser Demo prints formatted values")


while 1:
    _ = system('cls') # Clears screen
    print("Current Value: ")
    message = send("m0", host, port)  # sends a command, receives a string
    message = message.split(",")  # Splits the message at each ","
    message = message[1]  # takes the value from the second section of the message
    message = message.replace("+", "")  # Removes "+" from the string to make it an int
    message = (int(message))  # Converts message to int
    print(message/100)  # Prints the message as a float in mm
    sleep(0.1)  # Sleep for a period of time
```