Small Projector Array Display System

Team # 7

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Section 1: Executive Summary

Today's flight simulators have benefited greatly from recent technological advances. High resolution projectors have brought bright, high quality images to military flight simulators. New display technologies such as the collimated and dome display screens have allowed for a depth and realism previously never seen from a video image. However, the combination of these technologies has brought about new issues in the simulator world.

Simulators can come with any number of projector channels, some common configurations being 3, 5, 7, and 10 channel systems. Single input projectors are limited in picture quality, by the ability of the projector to spread these millions of pixels across a screen. Even the high resolution projectors we see today are limited by this lens deficiency. Slight changes in the geometry and light output across the viewing area have proven to cause significant problems for many simulator companies. The collimated and dome display units only stand to intensify this deficiency. Both display systems utilize curved and spherical display systems and therefore warp our original image. This distorts pixels and greatly decreases the light intensity at the edges of our image. This requires the need for warping hardware, software or a combination of the two. The greater the distortion require more man hours needed to warp and align the picture once installed in the system. The warping and distorting of the image will essentially cause a "loss" of pixels, and therefore picture quality.

The use of high quality, high definition projectors also comes at a great cost. Your average projector used simply for home theater systems can cost upwards of $5,000. The custom and top of the line projectors used on most flight simulators can greatly exceed this, reaching the $20,000+ range. If you multiply this across a standard five or seven channel system, the cost of the projector system alone can approach $150,000, not including any cost and labor put into the system on installs. A lower cost solution that can be implemented simply with existing setups can yield hundreds of thousands of dollars of savings, especially for sites with multiple simulator setups.

Our immediate idea to alleviate these issues is to look for a different kind of imaging system. Projectors are clearly still the solution to placing our image on the screen, however a different projector or projector setup may allow us to eliminate or at least lessen the effect of these problems.

To combat the degradation in image quality we propose to simply use more projectors. As more projectors are introduced to the system their required coverage of the screen is decreased. Geometry tells us that if we decrease the area of any one spot of a spherical surface to an infinitesimal level, we eventually are left with a planar surface. Therefore if we introduce more projectors we can approach a more planar surface and limit the amount of warping and distorting of pixels. Figure 1 below shows the effect of using multiple projectors as opposed to a single one:

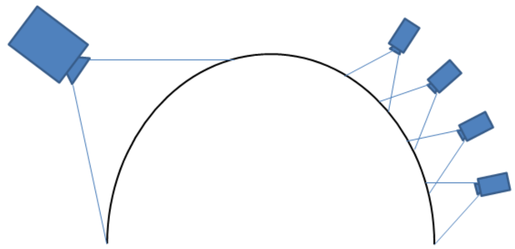

Figure 1: Advantage of using more projectors

Using more projectors will also eliminate some of the lens issues facing the larger more powerful projectors. Instead of using one say 4 inch diameter lens to display an image, we will now be using five or six 3 inch diameter lens to display the exact same image. This gives more area to spread our pixels around and small minute discrepancies in the geometry of each lens will be rendered negligible to the overall quality of our image.

An array of projectors may sound costly considering most quality projectors can cost thousands of dollars; however the emerging pico projector market offers a suitable alternative to their larger counterparts. Coupling a pico-projector array to the back-projection-screen (BPS) of a WIDE display is highly efficient in terms of physical space and display performance. The individual projectors of the array will shine directly onto the section of BPS in front of them, which means there will be no cross-reflections. This design also allows baffles to be placed between individual projectors to further prevent secondary reflections and stray light from washing out native image contrast. The number of pico-projectors needed to fill up a field-of-view is more than needed using traditional projectors; however the pico-projectors will be far less expensive on a unit basis, at a cost of only a few hundred dollars each. They will also be essentially maintenance-free with excellent color and brightness uniformity over their life cycle, particularly when controlled by an auto-alignment system. These projectors have low power and heat output and will not require any special cooling systems.

Our overall system will encompass a box representing a single projector. However, inside of our box we will implement an array of four to six pico projectors.

Section 2: Specifications

2.1: Overall

As previously stated, our design will encompass a box representing a single projector. This box will contain an array of four to sixpico projectors. Ideally we will want to contain all of the image processing, warping, and alignment inside of our box as a single system. For the sake of this design process, however we will bring the computer system outside of our box. A single host computer will be used for image generation, warping, alignment, and control of the system.

Our projector box will need to imitate a single projector as much as possible. This will allow for easy implementation on existing systems, as well as implementation of new systems using older designs. This includes frame rates, aspect ratios, and power consumption. While attempting to imitate a single projector we also need to maximize the number of pixels being projected. This is the simple concept of more pixels equals a better image.

Our host computer system will need to be able to output a minimum of six digital image signals. Ideally we would like to use DVI signals as opposed to HDMI signals, as DVI connectors have screws on the connectors to keep them in place on moving simulators where vibrations and movement are regular occurrences during operation.The graphics card of this system will also require the ability to overlap images. This is necessary to allow the alignment software to edge blend and warp the image for a single seamless image from the multiple projectors.The computation power of the computer must also be maximized. Handling four to six separate image signals, as well as warping those signals, will require a great deal of computation on the computers part. Maximizing this computation power will ensure we will not have any issues here as well as testing the feasibility of the system. We will outfit this computer with a Windows based operating system, as that is what most alignment and warping software on the market requires for operation.

Our projection screen will utilize existing designs and technology already implemented by Q4 Services on existing simulators. An acrylic subsection of a sphere will act as our projection surface. A rear projection film will be placed on the subsection to allow for our image to be clearly projected onto the surface. This will act as our BP of a collimated display system and will be explained further later in this report. We will investigate various rear projection films for an ideal candidate. The ideal candidate will have a gain of less than 1 while also maintaining the highest resolution and clarity of our image.

2.2: Interface/Control

Our design will require a great deal of control and interface elements. There is the need for individual control of each projector, an interface with the host computer system to keep the system synchronized,analog to digital conversions are needed for our light sensor array, and a simple easy to use user interface.

Our specifications from our sponsor for control were quite simple. We have free design reign on the interface and projector control sections. Our analog to digital converters however, had very detailed specifications. It was quickly identified that this component could be implemented across many systems already in production for Q4 Services. For our design purposes we need a simple micro-controller to handle the calculations from our analog sensors. We can treat the inputs as static therefore not needing to consider sampling theory nor Nyquist criterion. However, for the additional system requirements given by the sponsor we need to take these things into consideration in choosing the correct controller interface.

A simple Micro-controller will be selected to handle the analog to digital conversion. The conversion is necessary not just for interfacing with a digital control system but also due to the potential distance the signal will need to be transmitted. Analog signals diminish over long distances where as digital signals allow for longer wires to be implemented. We will require nine analog inputs on our controller for each one of our nine analog sensors. We will also need a certain amount of digital outputs. This will be decided later in the design process once the resolution of the sensors is determined. Each digital output will represent a binary place holder. How many we need will depend on the output range of our sensors. If our sensor outputs values representing between 0 and 100 lumens we will need seven digital outputs, if we can output values between 0 and 250 lumens we will need eight digital outputs. This follows the theory of seven digital outputs can represent a number up to 2^7 power or 128, if we have eight digital outputs we can represent a number up to 2^8 power or 256. Our most power projector being considered can output 500 lumens at maximum, so a rough starting number will be nine digital outputs to represent numbers up through 512. The light sensors will require digital outputs capable of producing Pulse Width Modulation (PWM) signals for power. These same PWM signals could be required if automation of the light sensor array is also needed.

The analog to digital conversion component will be a separate unit from the main projector box. We will implement it on the light sensor array. This will help to recreate the scenario it will be used for on other systems for Q4 Services. There will be a simple analog filter included in this design to help with the analog signal processing.

Inside of our projector box we will need to have another microcontroller. This controller will only require digital I/O. We will need enough inputs to handle our digital signals coming down from our analog to digital converter. We will also need a few digital outputs to control any relays we may decide to use on our power system. An ideal candidate for this controller will be one will a wide array of digital I/O pins preferably with bi-directional ports that we can configure as we see fit through the design process.

The controller inside the box will also need a way to interface with the host computer system. Many micro/controllers include one or more serial transfer ports for easy interfacing with computer or other electrical components. This will be a necessary component on our controller in order for proper synchronization with our host system. Ideally more than one port will be desirable. Many projectors come standard with Serial or Ethernet control systems. Some of the projectors we are considering include these types of control ports. Serial controls tend to be more common than Ethernet ones, so an extra serial transfer line to allow for this type of control will be necessary with this particular controller. If the projector can only take Ethernet controls then we can move the projector controls to the host computer system instead.

The host computer system will also require a means to interface with the microcontroller inside of our box. The simple connection can be made simply through some serial port, whether that is a Db9 connector or a USB connector. This will allow for simple and easy communication to and from the box using well known programming API's.

There will also need to be a user interface. A simple graphical user interface (GUI) system will be created for implementation on the host computer system. This can easily be created using one of many GUI toolkits available online (www.foxtoolkit.org). The extent of control for the GUI will be determined once a projector is picked, since there is a difference in control protocol and even the ability for remote control. If remote control of the projectors is available, an easy to use interface will be created to control the projectors via the GUI. These controls will include, powering on and off the projectors, changing settings in the projector, and image correction via the projectors menu options. The main purpose of the GUI will be to give a visual representation of our light sensor data. A simple button will be placed on the screen and when pressed will call out to the various controllers for the output of the analog light sensors. We will then display those values in a well organized and easy to understand format for use by the user.

2.3: Power

For our design, we will need to come up with a design that is capable of plugging into a traditional wall outlet and providing power to all of the essential parts of our design. The power system will need to be able to power the pico projectors, the microcontroller, the host computer system, the alignment system, and any other electronic devices that may be used in our design. At this point, it is obvious that there will need to be some alternating current to direct current conversion circuitry in our power system design, as we will be drawing the 110V alternating current power that is available at any traditional electrical outlet, and many of the components of our design will depend on low level direct current power. There are multiple different methods in which this is done, some being traditional and less complex as well as the modern, more efficient as well as complex methods. We will investigate all of these methods and make the most reasonable choice for our design requirements.

The microcontroller will definitely be using either a 3.3V or 5V direct current input. In order to achieve this we will need to design some type of circuitry in which the high level alternating current voltage is stepped down to a reasonable level and then converted into a direct current power source. Then from there, as mentioned earlier, the direct current voltage level must be adjusted to meet the power demands of the microcontroller, as well as the current itself.

Also, depending on the pico projectors that we decide to use, and whether or not we choose to power the projectors from the circuit board or not, we may have direct current power requirements to power all six of the pico projectors. The pico projectors will need to have a dedicated line to each projector, which means six dedicated power lines, in order to power the display system. These lines could possibly all need to be voltage regulated in order to ensure that each projector is getting the precise voltage level to avoid any distortion of the overall display. Due to the nature of the design, if one of the projectors is underpowered or overpowered, it could make a significant difference in the quality of the display output. For instance, if a projector is underpowered it may have a “dimmed” display which would be easily detectable to the user, since we will be warping the six images of the projectors together.

Using a single large projector would just cause the overall image to dim, rather than a single section of the display. For this reason, the power demands of the projectors are essential to our design. In the case that our projectors will run off of alternating current power, we may be able to simplify our circuit design as the dedicated lines to the projectors will not need to be converted to direct current, and also may not even need the voltage levels to be manipulated. This could significantly simplify the circuit design for this aspect of the project. Another simplification of the design would involve simply creating a power block inside our enclosure, off the circuit board, that all of the pico projectors are run to, in order to satisfy their power requirements. This would again be possible if we go with the pico projectors that can take in AC power.

The alignment system power requirements will depend on what we choose to do for our final design. If we intend to use an automated alignment system that will be governed by our analog light sensors, we will more than likely have small servo motors that move the projectors as indicated by the light sensors. This would require a dedicated power line to each of the small servos as well. Again, depending on the final design, there are servo motors available that are powered by direct current as well as alternating current. If the part we choose to go with is a direct current powered servo, then we will have to design circuitry similar to the method we intend to use for the microcontroller. The voltage will be brought into the circuit board, stepped down via a transformer, and then converted to direct current via current converting circuitry. From there, depending on what voltage level is required, we may have to either amplify or decrease the voltage level as necessary in order to ensure that the servos are properly powered. Also, depending on the load of the servos as well as the other requirements in our circuit board, voltage regulation may be necessary to ensure a constant voltage level for the devices.

For the host computer system that will serve as our user interface, there are not any significant power requirements that will need to be implemented into our printed circuit board design. Seeing as how the host computer system has it's own power cord that already contains all of the electronics that it needs to operate, we do not intend to change this design. From our standpoint we have two options on how to power the host computer system. One option includes just running a parallel, separate line from the input to our printed circuit board to an output dedicated to the host computer system on our printed circuit board. This way there is no alteration of the incoming signal to the outgoing signal to the computer system and we be essentially the same thing as plugging the computer system into the wall outlet, except now that outlet is integrated into our power system.

The other option would be to just plug the computer system into the wall itself which would reduce the cost of the printed circuit board and alleviate the need to of having a high voltage line running thorough our circuit board adding heat and cost to the design. The only reason this may be an issue is if there is only a single outlet available at the site on which the unit is installed, but this problem could also be avoided through the use of a power strip which is a very low cost solution.

A block diagram of our design requirements is given in Figure2 below. This diagram gives a representation of the signals that are required for each of the essential elements of our design. This diagram is subject to change as our design requirements become more clear during our research section, especially as we begin to understand the parts that are available on the market.

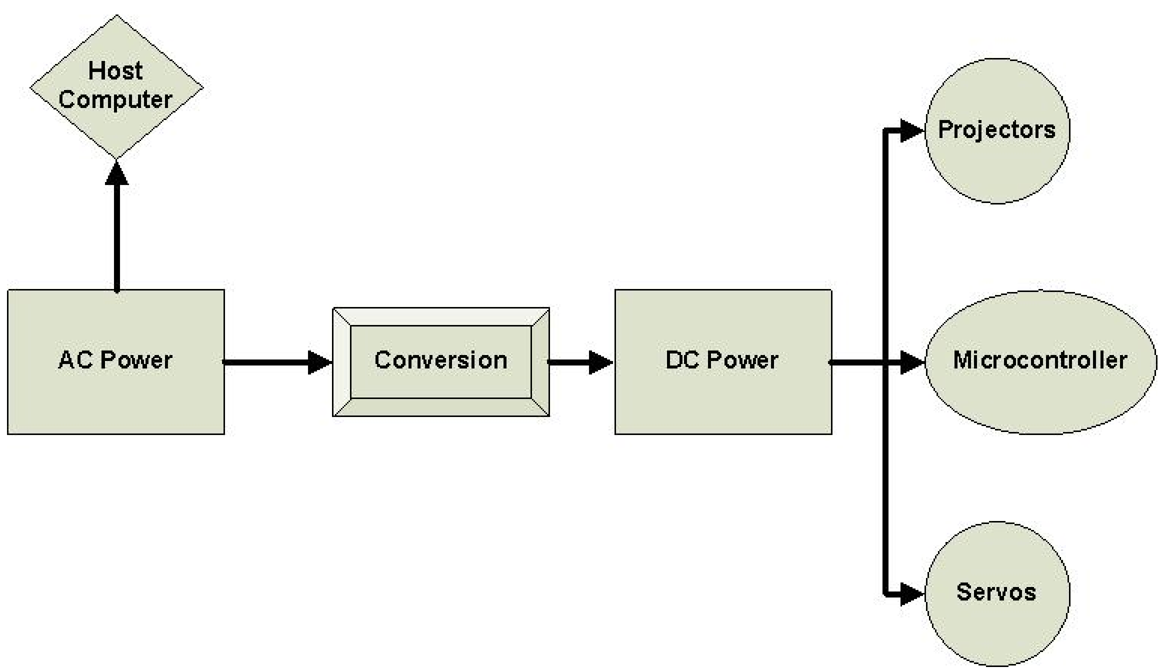

Figure 2: Initial Power Requirement Block Diagram

Overall, at this point in our design, we have laid out the specifications for the power requirements of our system. In this initial phase we have concluded that we will need to investigate many different aspects in power engineering. The most important concepts that we will investigate is power transformation, which, as discussed will be stepping the incoming 110 V alternating current down to a reasonable level depending on what size step down transformers are available in the industry. We will also investigate the best solutions of alternating current to direct current transformation, which will probably be done through the use of a rectifying circuit that uses diodes. We need to investigate direct current voltage amplification/modification techniques for the converted signal in order to achieve the different levels of direct current power we will need to power the different components of our system. It is essential that the proper circuitry is designed to deliver the correct voltage and current requirements to maintain the most efficient mode of operation to our entire system.

Also, we will need to investigate voltage regulation techniques and devices to ensure that the proper voltage and current is being supplied even if we have fluctuations in our system. This regulation is crucial to our design as any fluctuations going into our components could mean a dramatic undesirable effect to our display system.

We also need to investigate electrical protection systems as well as noise reduction circuitry to ensure we do not damage any of the essential components in our design during a power surge or any other electrical issue, as well as interference or damage due to feedback from high noise levels within the design.

In order to gain a very broad overview of the power requirements of the system, Figure 3below gives a block diagram of all of the components that will be included in the Linear power supply approach if we choose to use this method. There are multiple options on how to achieve the transformation and rectification of the AC signal to DC. These methods will be discussed later on in the research section of the document.

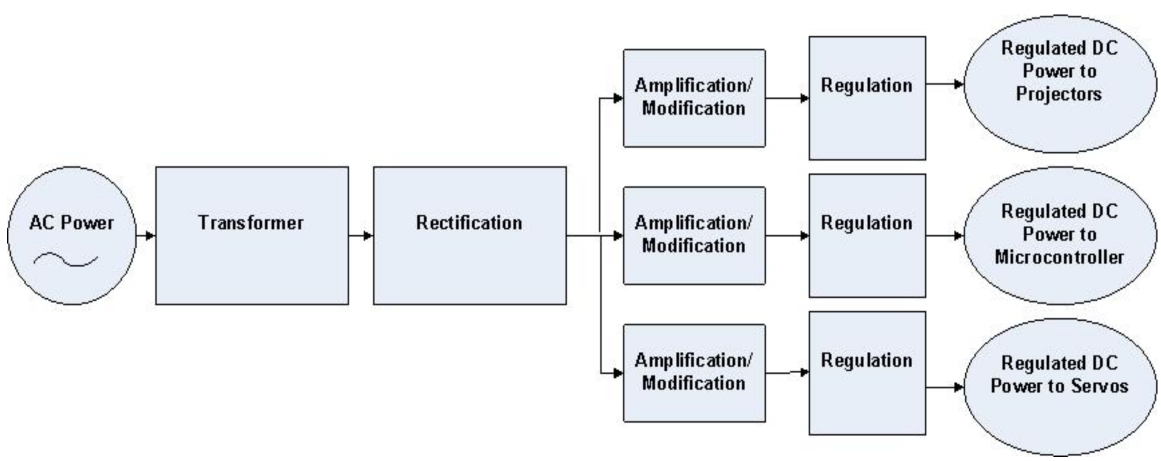

Figure 3: Power Flow Block Diagram of Linear Power Supply

This figure gives a broad overview of all of the “black boxes” that will need to be designed in our project. These “black boxes” represent each area of our power system that will require additional electronic design through the use of various parts and circuit elements. Smoothing components, such as capacitors, as well as electronic protection circuitry may be included in some of, or each area of our design.

The “Transformer” block will be the part of the circuit in which the high level alternating current is stepped down to a lower level alternating current. This will be done via a small step down transformer, or possibly through the use of an alternating current to direct current chip that would also take care of the rectification portion of our design, as the chip is capable of taking high level alternating current power and stepping it down to a low level direct current power which achieves two very important tasks in our circuit design. As more research is done on these two methods, the cost effective and efficient decision will be made with regards to transformation.

The “Rectification” block of the diagram will be the area in which the alternating current voltage is converted into a direct current voltage allowing us to power our direct current devices. In this area of the circuit, we will use diodes and create a rectifying circuit in order to obtain a direct current voltage. Depending on the requirements of the devices that will be used in our design we would like to have a safe direct current voltage level at the output of our rectification circuit, but not too low or too high of an output that would require a lot of amplification and or modulation to be used in each component. Somewhere around 24 volts would be an ideal output at this stage in our design.

The smaller “Amplification/Modification” boxes that are seen throughout the diagram are areas of the circuit that will either increase or decrease the direct current voltage level in order to meet the power requirements of each respective component that is being powered. Since we will only have one level of direct current voltage coming out of the rectification circuit, it is obvious that we will need to adjust that voltage level accordingly.

The “Regulation” boxes in the diagram could be used as a steady power supply input to the components. For instance, if the voltage coming out of the rectifier circuit is 20 volts and that signal is reduced to 5 volts going into the microcontroller portion of the circuit, if there were any sudden fluctuations in the voltage level, the voltage could drop and not deliver enough power to the microcontroller. For this reason, voltage regulation may be a more effective method of delivering power to certain “essential” components. If the voltage is reduced to 10 volts going into the 5 volt voltage regulator powering the microcontroller, a sudden drop to 8 volts going into the regulator would still produce an output of 5 volts on the regulator and there would be no performance interference to the microcontroller. Although a drop of two volts is not likely to occur in our design, it is a very cheap and effective solution to the problem if it were to occur.

Figure4gives a simple example of a general design that is capable of powering all electronic devices. This will be the basis of our design and a good reference for us going forward.

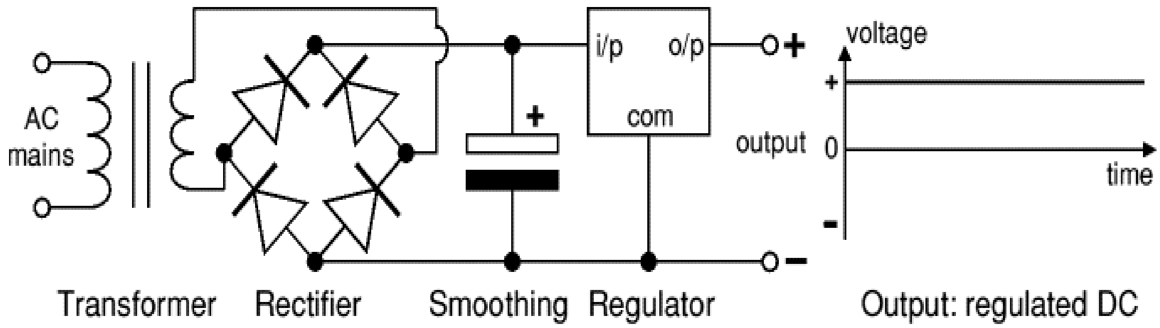

Figure 4: Basic schematic for power supply
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2.4: Analog Sensor Circuitry

When dealing with projectors in simulators the most notable feature is the brightness of the image being projected. The brightness not only affects how easily the image can be seen, but the brightness of the bulb highly affects the actual lamp life of the projector. a projector with a lamp running at fifty percent will be much less brighter than a lamp running at one hundred percent; however, the trade off for brightness will give you a light source that will last for an extended amount of time. Most simulators have an advantage of being relatively dark which allows the brightness to be reduced without sacrificing image quality.

Having the brightness lower in a dark room not only increases lamp life, but the health benefits of the viewer are also better. This is due to the fact that when a bright image is viewed in a dark room the eyes will have a hard time focusing on the image because the iris of the eye is constantly adjusting from light to dark or dark to light. This causes the person's eyes to tire, become agitated making the eyes water, or even causes the person to develop headaches. This makes it very important to keep the brightness at an appropriate level with respect to the ambient light level of the room.

The problems associated with projectors and the eyes of a person being agitated are often further made more complex when dealing with large simulators where there is a need for more than one projector to fill the entire screen for a given simulator. When dealing with a single projector, a system designer only has to deal with the ambient light level of the room and the brightness of the image being projected. This type of problem is easily corrected by adjusting the brightness of the projector to allow a person to look at the projected image inside the simulator for extended amounts of time. When dealing with just a single projector this calibration is relatively simple and quick to accomplish; however, this procedure becomes increasingly difficult as more projectors are added to a projector system.

As more projectors are added to the system the numbers of variables are also increasing making it very hard to adjust all projectors to a certain light level. This is due to the fact that each projector, even if all the projectors are the same model, has a deviation in its brightness level. To correct the brightness for each projector and get the brightness to a level that will not bother a person's eyes is very hard to accomplish. The amount of time it would take a person to calibrate a system running six projectors would take a rather long time, and even if the images look to be the same brightness level they may not be. When dealing with a checkerboard orientation of images with each image at a slightly different brightness, even if not noticeable by a person looking at all of the images, a person can develop headaches or even become nauseous.

In order to decrease the time to calibrate a system with multiple projectors, and increase the precision of matching each projector to the same brightness level it becomes beneficial to use optical light sensors to calibrate the system automatically. However, this can only be done if the projector has a data port that will allow a command to be sent from a host computer to the projector to tell it to increase or decrease the brightness. If there is no data port then each projector must be calibrated manually with the aid of light sensors.

By using an array of optical light sensors being driven by a microcontroller the system would be able to increase the accuracy of the projector array as a hole by taking multiple readings at the same time. With the extra data being fed into a microcontroller an average can be taken in order to get a higher degree of accuracy for the brightness of each projector which will translate into a higher degree of accuracy for the projector array as a whole.

Having multiple optical light sensors for each projector reduces the error in the light readings since not every sensor will be exactly the same. One sensor reading the light intensity may read a lumen level of fifty while another will read fifty five. It is beneficial to have sensors that read a given light level at the same intensity, but by increasing the number of sensors the error of one sensor to another can be reduced to give a more accurate reading by increasing the number of sensors to achieve a reasonable amount of error. It will be impossible to match all the projectors to output the same brightness; however, if the error is reduced low enough to a point that will not affect a person using the system then the system will be operating in a satisfactory manner.

The light sensor array will also let us draw a firm conclusion for how much light is being emitted from the projector array versus a single projector producing the same image. To accomplish this project we hope to at least get a light level close to single projector; however, a greater light level would be outstanding.

2.5: Analog Sensor Mechanics

In order to test the lumen output from our projector box some sort of an array would have to be used to be placed in front of our projector screen. From the ANSI Lumens test we know that 9 points from the projector screen have to be measured to get the correct lumen output from our projector box. Through this information we know that any sort of array system that is considered would have to have a 3X3 dimension.

The materials of our array would have to be sturdy so that it can be stationary so that measurements can be taken. Also our array would have to be moveable because it is our plan to first test the image that is projected from our projector box from one side of the screenand then this array would have to be moved to the other side of the screen to test the single projector display. So whatever materials that are used must light enough so that it can be picked up and moved to the other side of the projector screen.

Also what must be taken under consideration is how we will place the sensors on our array system. We will either manually place the sensors at the 9 points needed for measurement or we will somehow mount them onto the display system itself. Below lists exactly the specifications needed for the array

1. The sensor array must be in a 3 X 3 format to correspond with the ANSI Lumens test.
2. When measurements are taken the array must be sturdy to stay stationary long enough so that the measurements are accurate.
3. The array must be either light or moveable by some means so that the array can be moved from side of the projector to the other.
4. The sensors themselves will either be placed manually at the 9 points needed for measurements or will be somehow mounted on the array system.
5. The output wires coming from the sensors must not intrude with measurement or while the array is being moved.

Section 3: Research

3.1: Power

There are many essential parts to the design of our power system that will provide the power requirements to all of the components of our system. We will research and discuss many potential solutions to each area of our design and then make decisions based on cost, availability, feasibility, efficiency, and precision. We would like to create the most cost efficient, as well as electrically efficient system as possible, which would then translate into an overall high performance solution to our design requirements.

3.1.1: Methods of Power Transformation

One technique of creating a power supply is known as a linear power regulator. This is a more traditional method that has been used for a long time in converting AC power into low level DC power to drive small electronics. In the first area of this design, the goal is to taking the incoming 110 V alternating current signal, and step it down to a lower, safer alternating current voltage level.

One potential solution to this requirement would be to use the traditional methods of AC to DC conversion via a transformer followed by a rectifying circuit. This is a classical solution to our problem and has been done for many years. The incoming AC signal is stepped down to a lower level via the step down transformer. So for Instance, the incoming 120 volt alternating current signal is stepped down to a 24 volt alternating signal. This signal would then be run through a rectifying circuit. A rectifying circuit is an arrangement of diodes, which only allow current to pass one way during each cycle it completes. This allows for the signal to be “transformed” into a direct current signal. Depending on the configuration of the rectifier circuit, whether it be half-wave or full-wave and the configuration of the connection to the transformer will dictate how strong of a DC signal you get. Also the use of a smoothing capacitor at the output of the rectifier circuit, in parallel with the load, is essential to take the ripple voltage out of the DC signal and smooth it out.

Once you have successfully transformed the incoming signal into a DC signal, then the traditional methods of DC voltage modification can be used. From the output of your transformation and rectification stage of the design, you know have a DC signal that can be manipulated and used to drive small electronics. The signal can be amplified for devices that require a higher voltage level and require more power. Voltage dividers can be used to step the voltage level down for smaller devices that do not consume as much power, such as a microcontroller.

Another key factor in this design however is the use of voltage regulators. Without the use of voltage regulators, any sudden changes in the main power are going to have an effect on everything in your circuit. For instance, if the main power rises from 110V to 120V, the turns ratio on your transformer is not going to be adjusted automatically. That means that you now have a proportionally higher AC signal on the secondary side of the transformer which ultimately leads to a higher DC signal coming out of the rectifier circuit and running through your circuit than you designed it for. Your amplifiers as well as voltage dividers also operate on a ratio that varies with the incoming voltage level, so if the input increases, then the output increases by the same ratio you have designed it for. This is where voltage regulators come in use.

Voltage regulators create a steady output voltage over a range of input voltages. So for small fluctuations that occur on the power plant end of things that we can't take into account in our design, voltage regulators may alleviate our problem. Voltage regulators will be essential to us, especially since we will be using microcontrollers in our design that require a pretty steady DC voltage supply in order to maintain accuracy. Without the voltage regulators in our design, we run the risk of over powering our electronics and burning them during an upward fluctuation of the incoming signal, or under powering our devices, thus compensating our design performance during a downward fluctuation of the incoming signal.

Another potential solution to this issue would be to go with a "switched mode power supply" approach to the solution. In this method of power supply, the incoming 50 or 60 Hz 110-220 volt AC input is immediately rectified, and then smoothed using a smoothing capacitor, to a DC voltage. This DC voltage is then run through an inversion stage in which the DC voltage is converted back into an AC signal through a power oscillator. The advantage of this method allows us to convert back into AC signal, but we can vastly increase the frequency of that AC signal which will allow us to use a much more efficient and smaller transformer to step the voltage back down and again, rectify and smooth it to a DC signal. The method previously described uses a MOSFET amplifier that allows us to be able to create this AC signal with a very high frequency which in turn makes the transformer process much more efficient than the first methods describe in this section. A block diagram of this method is shown in Figure5 below.

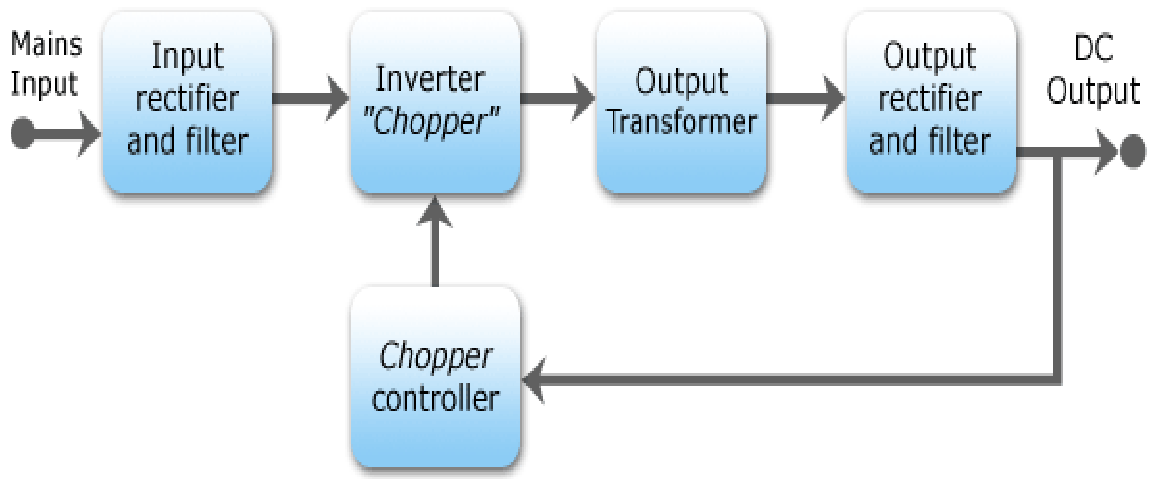

Figure 5: Block diagram of a Switched Mode Power Supply
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Although the circuitry governing this type of design is more complex than that of Linear Power supply, whose power flow diagram is show in Figure 5 above, the switched mode power supply has some significant advantages over its counterpart. The switched mode power supply is almost two times more efficient than it's linear power regulator counterpart and is more commonly being used today because of this. Also, since there is no need for an initial transformer, which is usually designed for a specific frequency 50 or 60 Hz and is very inefficient, this allows for a single circuit design to be used in any part of the world. The transformer of the switched mode power supply uses a frequency that is chosen during the design stage and is completely independent of the voltage and frequency of the main power supply to the system which ranges from 110-240 V AC and 50-60 HZ respectfully.

The feedback loop is often used as a control or monitor for the output voltage. This is not always used in this type of power supply and can be bypassed if the circuit is designed correctly. Also, many times the feedback circuit needs additional power and would require creating a more complex circuit design. Without the feedback loop, changes in the power delivered by the main line could cause an issue within the power supply, as well as the fact that the transformers operate at very high frequency which causes additional undesired electronic noise and interference within the circuit and nearby components. Careful placement of the transformer and other high frequency components is essential in this design.

A third approach to this problem is to use some traditional transformation and rectification methods to get a small DC voltage, and then use a step down DC to DC converter to regulate the output to the electronics at a steady voltage. The general circuitry and concept for the AC to DC conversion is given in Figure6below, where the circle labeled “AC Voltage Source” is actually the secondary winding of the step down transformer. A smoothing capacitor is placed in parallel with the load to take out the DC ripple that is shown in the output.

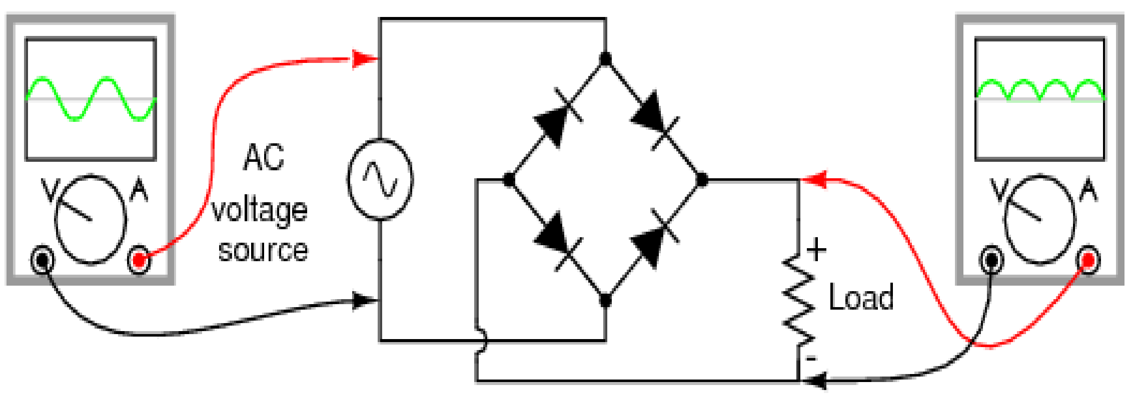

Figure 6: AC to DC conversion circuitry
Permission Granted by Michael Stutz, Author of “All About Circuits”

This design can be considered switched mode if the initial step down transformer is designed to handle both 50/60 Hz, 110-240 volt alternating current signals. The incoming signal is transformed via the transformer and then rectified using a full wave rectifier circuit. From here, the DC signal is input into the step down DC regulator circuit containing the DC to DC regulator chip. The advantages of this approach over the switched mode power supply is that there are no high frequency components involved, which reduces excess electrical noise in our circuit. Also, this approach is far less complex than that of the switched mode power supply.

Although there may be a little less precision than the true switched mode power supply discussed earlier, the difference is very small. The advantages over the linear regulator depend on the approach. If we were to use the same transformation to rectification technique over the AC to DC converter chip, then our losses in this stage of the circuit will be identical. However, if we use the step down DC to DC converter, which is highly efficient, we reduce the amount of amplification and voltage regulation techniques that we would be required to include. Also, the built in circuit protection on the DC to DC converter part is an added feature that will not need to be designed. A schematic of the DC circuitry including the DC to DC converter is shown in Figure7 below.

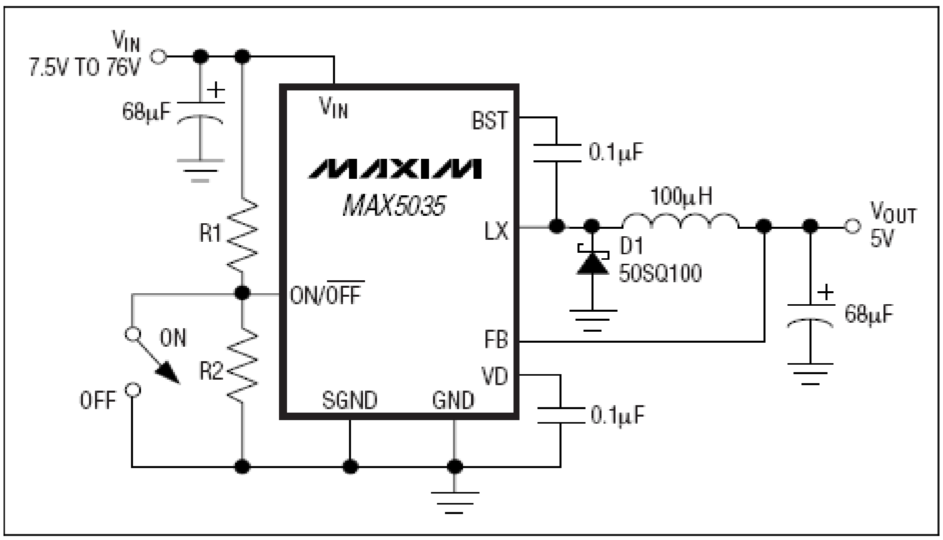

Figure 7: DC circuitry of the step down DC to DC converter
Permission Granted by Maxim-ic.com

The last option we would consider using for our design is another cross between switched mode and linear power supply. This method uses an AC to DC converter. These devices are produced by multiple companies and are a relatively cheap solution for this part of the design.

These devices provide many benefits to us when you consider our design requirements, as they have the ability to not only step down the voltage level, it also takes care of the rectification process as well. These parts are able to take high level alternating current and produce a significantly lower direct current voltage. Most manufacturers create the part with the following specifications:

- An input tolerance anywhere from 85-264 volts AC,
- Operate on signals of 50-400 Hz incoming
- Produce output power anywhere from 3 to 1,000 watts,
- Produce output voltage level anywhere from 3 to 380 volts DC,
- Produce an output current of.1 to 6,000 amps DC (positive or negative).

Some extra features that could be useful in our design, is that some of the devices are manufactured with multiple DC outputs. For instance, if we needed 5 volts DC to our microcontroller and 12 volts DC to power our projectors, we could order an AC to DC converter device that is capable of supplying both of these outputs from a single input and a single chip. This part could potentially satisfy 3 different areas of our main power flow diagram shown earlier. This AC to DC converter device is capable of transformation, rectification, and due to the adjustable nature of the design, may simplify much of the amplification and modification portion of our project depending on the power requirements of the components that we choose to use. An added benefit of these devices is also the voltage regulation factor. The AC to DC converter devices regulate a steady DC output over a very wide range of inputs. That way, no matter what type of fluctuations occur in the incoming signal, the output of the converter remains constant. This greatly simplifies the DC circuitry required in our design as we will not need to purchase multiple voltage regulators to regulate at each specific DC level that our design requires. Instead we would be able to use mostly amplification and voltage division techniques in the DC side of our design as we will always know what the DC signal from the converter devices is going to be. More positive features for this part are that the part has built in circuit protection including overcurrent, overvoltage, and short circuit protection. The converters also boast power factor correction, in order to overcome the poor power factor that most of the switching AC to DC conversion devices have in common.

3.1.2: Parts Research

In all three of the main approaches to our power supply there are a few things that will obviously be included in all of them. All of the designs, as most all circuits do, will include resistors, capacitors, inductors and diodes. With that in consideration, obviously we will opt to go with the parts that have the highest degree of accuracy that are currently available on the market. A more thorough analysis will be conducted once we have our design finalized and are able to begin looking at what values of resistors, capacitors, inductors and diodes we will need to optimize our design.

For the linear power supply approach, there are a few main parts that we will look at and compare the different suitable parts that are available in the industry. The two main parts for this design outside of the traditional circuit elements are:

- AC Step Down Transformers
- Linear Voltage Regulators

For our design, we will need a transformer that is small enough to fit on a printed circuit board, able to take in both 50 and 60 Hz signals anywhere in the voltage range from 100-250 volts, and step the voltage down to lower level, preferably around 12 volts. This is known as a step down transformer where the incoming voltage level on the primary side is reduced to a much smaller level on the secondary side of the transformer. The first product that appears to meet our need is the transformer created by Signal Transformer ®, part 14A-10R-28. The specs are given in Table1below.

Manufacturer	Part Number	Cost/Unit	Specs
Signal Transformer	14A-10R-28	$12.45	Input: 115/230V AC @ 50 or 60 Hz Output: 14V AC @ .72 A Power: 10 VA

Table 1:Specs for part 14A-10R-28

As shown in the Table, this part meets our design requirements for the transformer. This part is a through hole board mounted piece and is 1.87” x 1.56”. These products can be purchased as a single unit through Digi-Key®. Another potential transformer for this purpose is a part created by Triad Magnetics ®, part number VPP28-270. The specifics are given inthe table below.

Manufacturer	Part Number	Cost/Unit	Specs
Triad Magnetics	VPP28-270	$6.68	Input: 115/230V AC @ 50/60 Hz Output: 14V AC @ 1.44 A Voltage Reg.: 25% Power: 20 VA

Table 2:Specs for part number VPP28-270

As you can see from the Table shown above, this part takes a similar input as the first part, and gives a similar voltage output. However, the current output is higher on the second device allowing it to deliver more usable power to the circuit, assuming a unity power factor. Also, this device is roughly half the price of the first part that was considered. At this point, both parts match our design requirements and until we fully understand what kinds of loads the power system will be subjected to, no decision will be made.

The next imperative piece to the linear power supply design is the use of voltage regulators to adjust the voltage level coming from the rectifier circuit for components that may a different voltage level than what is being supplied. There are multiple ways to achieve this task such as simple techniques like voltage division, and the strategic placement of resistors. However, the need to supply a constant voltage to the load may be imperative to our design. We can alter the voltage level of the signal coming into the voltage regulators through the use of resistors and voltage divider circuits, but if there is any fluctuation in the main power signal, that causes fluctuations throughout our entire circuit if there is no type of regulation. That is where voltage regulators come in to use for our design. The first part we are considering is from Texas Instruments® and is part number UA78L05ACDR. This linear voltage regulator regulates the output voltage at 5 volts for a range of input voltages. The specs are given below in Table**3**, which also gives the specs for UA78L12ACDR which is a 12 volt regulator made by the same company.

Manufacturer	Part Number	Cost/Unit	Specs
Texas Instruments	UA78L05ACDR	$0.16	Input: 7-20V DC Output: 5V DC Op. Temp.: 0-125 °C Voltage Reg.: 8%
	UA78L12ACDR	$0.17	Input: 14.5–27V DC Output: 12V DC Op. Temp.: 0-125 °C Voltage Reg.: 8%

Table3:Specs for the 7805 and 7812 linear voltage regulators

These parts, as well as most of the parts that have been quoted so far can also be purchased in single units from Digi-Key®. Another linear regulator of interest for us is a product offered by Rohm Semiconductor® and has a positive adjustable output. This regulator is different in the fact that that it has a wide range of outputs for a wide range of inputs, but is able to regulate at certain output levels through input fluctuations. The part number for this device is BD3572FP-E2 and is also available through Digi-Key®. Table4 below gives the details on the part.

Manufacturer	Part Number	Cost/Unit	Specs
Rohm Semiconductor	BD3572FP-E2	$1.42	Input: 4.5-36V DC Output: 2.8-12V DC Op Temp: -40-125 °C Current Out: .5 A (max)

Table 4:Specs for the BD3572FP-E2 linear regulator

As you can see from the data given in the Tables above, it appears that the 7805 and the 7812 are much more cost efficient choices if we do not absolutely need the adjustable regulator. There is really no sacrifice in efficiency or PCB space either, as both devices are close to the same size and have similar efficiencies.

The second option for our power supply is to create a more modern switched mode power supply. In this type of design, there a couple essential pieces that must be researched, outside of the normal circuit elements, in order to assure the best possible design. For the switched mode power supply there are two main parts of interest outside the traditional circuit elements that are required such as diodes, resistors, capacitors and inductors. Although this is the most complex circuit design due to the fact that we will be rectifying form AC to DC twice, inverting DC to AC, and transforming signals to lower voltage levels, this design only needs two circuit elements that are not considered basic circuit elements. These main elements that will require a little research are as follows:

- Power Oscillator or Power MOSFET (create the high frequency AC signal)
- High Frequency Step Down Transformer

The Power Oscillator is a very important aspect to this circuit, as this device will invert the incoming DC signal that has been rectified from the main power source back to an AC signal with very high frequency. This is what allows the design to be known as a switched mode power supply. The design is no longer dependent on the voltage level or frequency which varies from country to country across the world. Also, the oscillator will also determine what type of transformer is used in the design as it the oscillator will define the frequency at which our circuit now operates. In order to gain maximum efficiency, we will need to look at a transformer that has optimum efficiency at the frequency that our circuit is now operating. Due to the fact that there are not many Oscillators or MOSFETs that take in 120V direct current signals and convert them to an AC signal, we will need to step the DC voltage down to a lower level through the use of voltage division before we can run it through the “inversion” stage of the design. This part will likely be chosen once we have decided a few more of our design requirements as there are many different designs on the market.

The second important piece to this design is the high frequency step down transformer. This part is essential because we need it to be the most efficient at the frequency that is being put out by the oscillator. The benefit to using this method and this type of transformer is that transformers that operate at high frequency are much more efficient than traditional transformers that operate in the 50-60 Hz region. This is due to less loss in the core of the transformer due to hysteresis. The two main parts that we will consider are given in Table5 below. Both are available through Digi-Key® and can be bought as a single unit.

Manufacturer	Part Number	Cost/Unit	Specs
Wurth Electronics	750311620	$9.70	Input: 30-190V Output: dictated by turns ratio Op. Temp.: -40 - 125 °C Freq.: 53-120 KHz
	750311880	$6.65	Input: 3-6 V Output: dictated by turns ratio Op. Temp.: -40 - 125 °C Freq.: 200-600 KHz

Table 5: Part information for high frequency transformers for use in switched mode power supply

The third design consideration is a mixture of the two methods. The first stage of this design follows the transformation and rectification process that has already been outlined. We will likely use the same transformer for the main incoming power signal that has already been researched in tables givenabove. The main difference in this design is the use of a DC to DC step down converter. An incomplete schematic can be seen in Figure8 below which simply gives an overview of the AC to DC conversion and the step down DC to DC converter. Also Figure9 below gives a pin assignment for the DC to DC converter in a schematic drawing. The value of the circuit components have not yet been evaluated because we are not exactly sure what our incoming signal is going to be and what the value is after the rectification of the AC signal. If we choose to use this as our final design then the numerical values of each component must be calculated to ensure or design is functioning properly and delivering the correct power requirements to each of the devices it is driving.

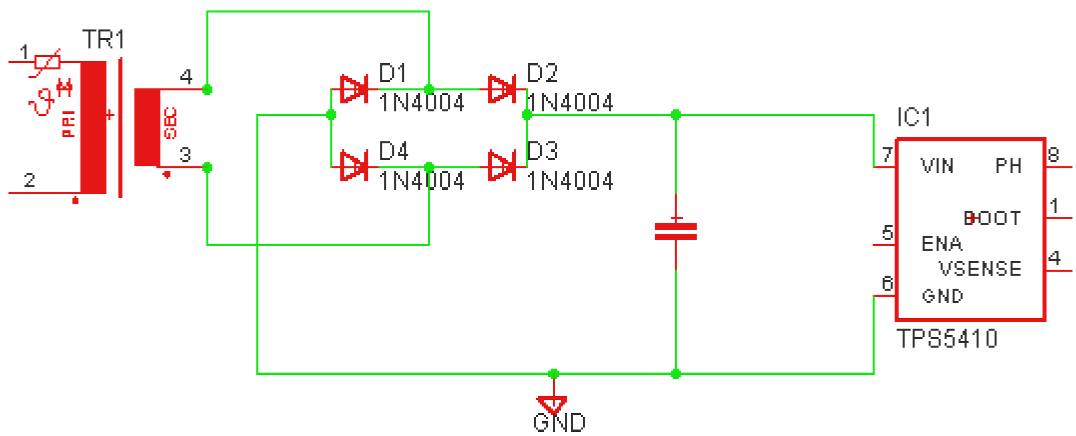

Figure 8 - Incomplete Schematic of AC to DC conversion with step down DC to DC converter

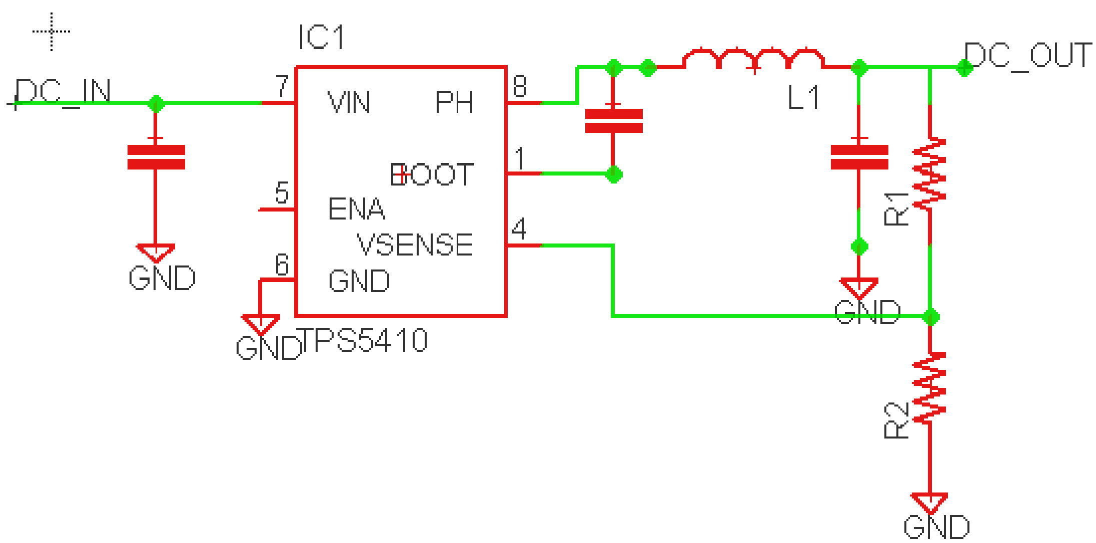

Figure 9 - Pin Assignment of the DC to DC converter

The step down DC to DC converter part will step down the DC signal coming out of the rectifier circuit to a regulated, steady level at it's output which will be used to power all of our DC devices. This device eliminates the need of voltage regulators and has built in circuit protection in the case of a power surge. Also, the device can take in a wide range of DC voltage levels and convert it to a single, steady output, much larger than the normal voltage regulator. Some of the parts in consideration are listed in Table6 below. This Table gives an overview of the operating characteristics of each device as well as the cost.

Manufacturer	Part Number	Cost/unit	Specs
Texas Instruments	PT5101A	$17.29	Input: 9-38 VDC Output: 5 VDC Efficiency: 90 % Regulation: 5 mV Power: 5 W
Texas Instruments	PT6302N	$25.42	Input: 9-38 VDC Output: 5 VDC Efficiency: 90 % Regulation: 5 mV Power: 15 W

Table 6: Technical information for step down DC to DC converter

There are many different companies that manufacture these devices, although Texas Instruments appears to make the device that will accept the widest range of inputs which increases the safety of our design as minor fluctuations will have minimal effect on our design. Also, the devices created by Texas Instruments appear very simple to use and implement into our circuit as they use a simple three prong approach similar to that of a voltage regulator.

The fourth option for the design of our power system is also a mixture of the linear power supply and the switched mode power supply. Instead of designing a circuit that will used sophisticated parts for the DC portion of the circuit like the latter design, this design will use a part that takes care of the AC to DC conversion. The part of interest must take the incoming AC signal and convert it to a low level DC signal. From there, we will use the basic voltage division and amplification techniques that have been previously discussed in our research. The AC to DC converter piece is manufactured by multiple companies and come in a variety of configurations from a simplified circuit mounted on a chip that can then be mounted on a PCB to small three prong chips that can also be mounted on a PCB. Table 7 below gives an overview of the manufacturer, cost, and specifications of the parts that we are considering for this design should we choose to use it.

Manufacturer	Part Number	Cost/Unit	Specs
CUI Inc.	VOF-6-15	$14.22	Input: 85-264 VAC Output: 15 VDC Power: 6 W Efficiency: 78%
CUI Inc.	VMS-20-5	$27.94	Input: 90-264 VAC Output: 5 VDC Power: 20 W Efficiency: 80%
TDK-Lambda Americas Inc.	KPS1515	$36.21	Input: 85-264 VAC Output: 15 VDC Power: 15 W Efficiency: 80%

Table 7: Technical information for the AC to DC converter parts

The parts researched above give us a very cost efficient advantage over many of the pervious techniques. The AC to DC converter parts allow us not only to cut our design time down by completing many of the complex tasks of our circuit design through one part, but also appears to be the most cost efficient method as well. If we decide to use one of the devices mentioned in the table above, the only circuit design left is small DC voltage division or amplification which can be achieved with resistors or small amplifiers, which are both cheap and easy to design.

3.2: Interface/Control

The Microcontroller was first invented in 1971. Since then there have been hundreds of designs and implementations of different Microcontrollers. To this day over 50% of the CPU market is still Microcontrollers. These small, efficient control modules are ideal for embedded applications where only small computations are needed. Most Microcontrollers can be purchased for under a few dollars when bought in quantity, which makes them the most common controller for inexpensive systems.

For our application we will need to utilize two separate Microcontrollers. One will be installed near our analog light sensor array. This particular controller will handle the analog to digital conversion of the signals from our light sensors. This will include sampling the light sensors analog output signal, converting this signal to the corresponding lumen representation, and then digitally transferring this information via a serial line to our projector box.Inside of our projector box we will have another Microcontroller installed to input this data from our controller mounted on the light sensor array. This controller will then process the information that came from our sensor array and output it to our host computer system via a serial cable. Seeing as these two controllers have different functionality we will need to find a solution that can hopefully satisfy both requirements. If necessary two different controllers can be implemented if a satisfactory solution for both cannot be found.

The search for a solution will begin with the investigation of multiple Microcontroller unit (MCU) development boards. Finding an existing development board with a sufficient controller unit will allow for easy development and prototyping of the system. Development boards take the messiness out of working with microcontrollers by placing them in a simple package with easy access to all of the functionality. We will begin our investigation with the Arduino family of development boards.

3.2.1: Arduino Family

The majority of the Arduino boards are designed and developed by Smart Projects in Italy. Both the hardware and software components of the board are developed and licensed under a Creative Commons Attribution Share-Alike license. This is beneficial in the development process as all the details of the board are available online and can be easily tweaked to satisfy your specific needs for a project. The Arduino family of development boards provider an excellent design and test bed for creating our control code. It can be powered via a USB cable or a 5 V DC power adapter. Code can be written and compile using software available from the Arduino website (www.arduino.cc). Once written the code can be uploaded via a USB to the boards via a USB A to Mini B cable connected to your computer. We can than attach any additional hardware to our board utilizing the breakout pins located around the edge of the board. This includes all digital I/O, analog inputs utilizing analog to digital converters, and USART ports. The two useful boards identified for use with this project are the Arduino Uno and Arduino Mega 2560.

The Arduino Uno utilizes the ATmega 328 microcontroller. The Arudino Uno is especially interesting in the fact that the microcontroller is not soldered to the board but rather is inserted into an adapter that is soldered to the board. This will allow a user to program, test, and debug their program on the Uno board and simply remove the microcontroller and move it to a board of their choosing. The datasheet from the Atmel site, the producer of the ATmega line of microcontroller, lists the following specifications in the table below

:

Microcontroller	ATmega328
Cost	$3.31
Operating Voltage	5v
Input Voltage (recommended)	1.8-5.5V
USART Ports	1
Digital I/O pins	14 (6 are PWM)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB
SRAM	2 KB
EEPROM	1 KB
Clock Speed	16 MHz

Table 8: Specifications for ATmega328

This microcontroller does have many of the features that we will need to utilize during this project. There is a lack of analog inputs for use in the D to A conversions of the light sensor array data however, this may be a satisfactory component for use within our projector box for interfacing with the host computer system. The USART port will allow for this type of interfacing via a serial cable connection to the host computer. There is also a lack of Pulse Width Modulation (PWM) ports on the digital I/O. These would be implemented to power both the light sensors as well as any servo motors we may decide to use for automation purposes. If selected this microcontroller would only be suitable for use inside the projector box.

The Arduino Mega utilizes another Atmel microcontroller, the ATmega 2560. This board does not share the simplicity in transferring the microcontroller to a different board like the Uno does. The microcontroller is soldered directly to the board, therefore requiring us to purchase another microcontroller when the time comes to build our design. The Atmel website lists the following specifications for the ATmega 2560 in the table given below:

Microcontroller	ATmega 2560
Cost	$10.75-$20 (depending on model)
Operating Voltage	5V
Input Voltage (recommended)	7-12V
USART ports	4
Digital I/O Pins	54 (15 are PWM)
Analog Input Pins	16
DC Current Per I/O pin	40mA
DC Current for 3.3V pin	50mA
Flash Memory	256 KB
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz

Table 9: Specifications for ATmega 2560

The ATmega 2560 is simply bigger and better than its 328 counterpart. This controller contains 16 analog pins which is more than we will need for the light sensor array. The controller also contains four USART ports for serial communication with either another microcontroller or a host computer system. It provides ample digital I/O pins capable of supplying PWM signals for powering our light sensors. The downfall of this controller is the cost. It is on the higher end of cost for microcontrollers but given the amount of peripherals contained in the unit, it is well worth the added cost.

3.2.2: TI Launchpad

Texas Instruments has dived into the Microcontroller Unit world as well with their Launchpad MCU. This is our most cost effective option with the entire Launchpad kit costing only $5. The kit comes with two different TI microcontrollers from the MSP430 family, MSP430G2211 and MSP430G2231. Both of these controllers differ very little from each other. A comparative specification table is given below:

Specification	MSP430G2211	MSP430G2231
Frequency (MHz)	16	16
Flash (KB)	2	2
SRAM (B)	128	128
GPIO	10	10
Timers – 16 bit	1	1
Watchdog	Yes	Yes
Comparators	Yes	Yes
ADC	Slope	10-bit SAR
ADC Channels	None	8

Table 10: Comparative Table for the MSP430 Family

Clearly, the G2211 will not work for this project due to the lack of ADC channels. The G2231 however, does come with 8 ADC Channels. This as well is insufficient for the scope of this project as we require 9 channels for use with our light sensor array. Neither chip has any sort of serial communication to allow data transfers between boards or with the host computer. While the Launchpad is an extremely cost effective development kit, the included microcontrollers simply are not robust enough for use in our project in any capacity.

3.2.3: Conclusion

Given our choices of boards already owned by this team our only choice is to go with the Atmel ATmega microcontrollers. We will implement both the ATmega 328 and the ATmega 2560 in this project. As the 2560 has sufficient ADC channels to process our light sensor array it is the obvious choice to handle the analog outputs from our light sensors. We will implement the 328 inside of our box for interfacing purposes with our host computer system. Keeping with the same brand of microcontrollers should ensure that we will not have any issues with communication between the boards as they should follow the same protocols. We will however, have to find a solution for communication with the host computer system. Both boards follow the TTL protocol for serial communication which is incompatible with most desktop computer systems. A chip such as the MAX232 will need to be implemented to invert the signals from the microcontrollers to create RS-232 compatible signals required for communication with the host system.

3.3: Analog Sensor Circuitry

In order to quantitatively see how much light the projectors in the projector array is outputting on to the BP projection screen an optical sensor, or detector, is needed to convert the light energy emitted by the projectors into a signal that can be inputted into a microcontroller for processing. On the microprocessor the signal from the photo detector will be turned into a measurement called illuminance.this allows us to identify exactly how much light is given off by a light source. Illuminance is the total luminous flux incident on a surface per unit area. It is a measure of how much the incident light illuminates the surface. In SI derived units these are measured in lux (lx) or lumens per square meter. Illuminance was formerly often called brightness; however, brightness is not a quantitative description, and only for non-quantitative references to physiological sensations and perceptions of light. See Table 11 given below to see common illuminance values.

Light Source	Illuminance (Lux)
Candle 1m distance	1
Street light	20
Office desk lighting	750
Overcast day	3,000
Overcast sunny day	20,000
Direct sunlight	100,000

Table 11: Lux measurements of everyday light sources

3.3.1: Types of Light Detectors

There are two main categories of optical detectors: photo detectors and thermal detectors. The photo detector category can be further broken down into: photodiodes, phototransistors, and ambient light sensors. As for the thermal detectors, the main type used in applications is a thermistor. Both photo and thermal detectors can be used to calculate lux, but they do this in different ways. The photo detectors react to the photons given off by light sources and generate free electrons to induce a current in the detector. This current is often very small and in the micro amp range (μA). Photo detectors output are dependent on the wavelength of light being measured. The typical spectral dependence of the output of photon detectors increases with increasing wavelength at wavelengths shorter than the cutoff wavelength. At that point, the response drops rapidly to zero. As for the thermal detectors, they respond to the heat energy delivered by a light source. The idea being, the more light given off and hitting the thermal detector mean more heat is being transferred from the light energy to the thermal detector. This heat energy causes a change in resistivity on the detector. Seeing this detector only uses the heat energy from the light the output response is independent of wavelength. Figure 10 illustrates how a typical photo and thermal detectors are affected by wavelength.

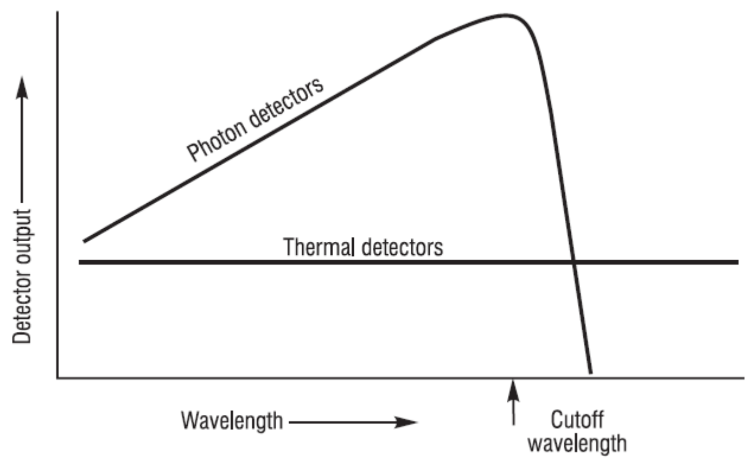

Figure 10: Comparison of photo and thermal detectors vs. wavelength

Seeing that the thermal detector is affected by thermal energy and not photons directly; it will be heavily affected by the ambient temperature of the room, and any other heat source that is close enough to the detector. For this reason this type of detector would most likely not be a good fit for this project, since the detector would constantly have to be calibrated, or a temperature sensor would also have to be added in order to keep the illuminance calculation correct. By using a photo detector we will avoid this problem.

Using a photo detector for the light detection circuit in this project would enable us to use many different configurations to fit our needs. The speeds that these components operate at are all fast operating chips. The photodiode does operate faster than the phototransistor; however, for this project both of these components will work fine speed wise. An added benefit of the phototransistor is that it is able to amplify its output with no extra component, and the average magnitude in current output on average is easily ten times greater than common photodiodes.

It may be more beneficial to use an ambient light sensor(ALS) for this project. An ALS is a special photo detector that is designed to pick up wavelengths of light only within the human eye's capability. As seen in Figure 11, the human eye's sensitivity is between 400 and 700 nm with the greatest sensitivity at around 550 nm. Also in Figure11 a standard photo detector can sense wavelengths between 350 and 1200 nm with a peak sensitivity at around 850 nm. This shows that most photo detectors pick up more light from the infrared spectrum that the human eye cannot see. An ALS is designed to shift the sensitivity more to the area of the spectrum that the human eye can perceive.

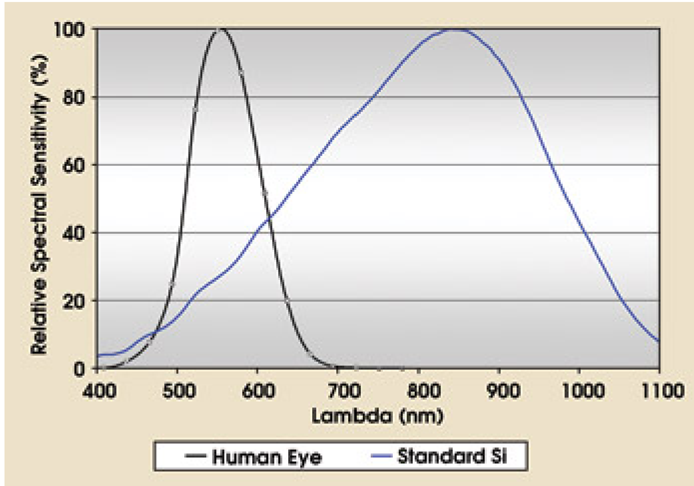

Figure 11: Human eye spectrum sensitivity vs. standard Si-detector
Reprinted with permission from OsramOpto Semiconductors Inc.

OsramOpto Semiconductors Inc. is one of the leading companies when it comes to ambient light sensors, and one of their top products is the SFH 5711. the SFH 5711 is able to mimic the human eye's sensitivity almost exactly. As seen in Figure 12, the sensitivity of most ALS is shifted toward 550 nm; however, there will still be a high amount of infrared being picked up by the sensor. The SFH 5711 is sensitive in the range of 475 to 650 nm which falls in the range of the spectrum that the human eye is sensitive to.

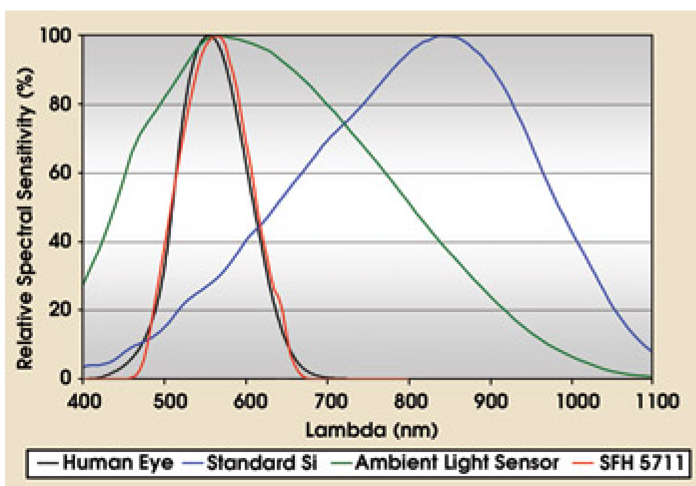

Figure 12: Relative spectral sensitivity of a standard Si-detector and the SFH 5711 compared to the human eye (V-λ).
Reprinted with permission from OsramOpto Semiconductors Inc.

3.3.2: Possible Sensors to Be Used

The SFH 5711, as seen in Figure 13, is a compact chip that is a hybrid of a photo detector and integrated circuits. It outputs a current at 27 - 32 µA, but with the aid of a load resistor the output can be converted into a voltage. This voltage can be read by a microcontroller in order to interpret the illuminance intensity. The accuracy of the 5711 can be seen in Figure 14.

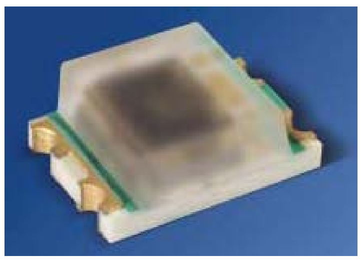

Figure 13: SFH 5711 Opto hybrid High Accuracy Ambient Light Sensor

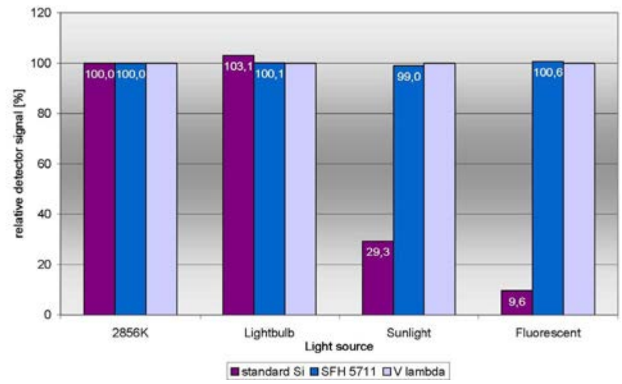

Figure 14: Detector readings for different light sources at the same brightness

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In order to represent the wide dynamic range of ambient light correctly, the SFH 5711 is equipped with an analog logarithmic current output. Figure 15 shows the output signal Iout versus illuminance

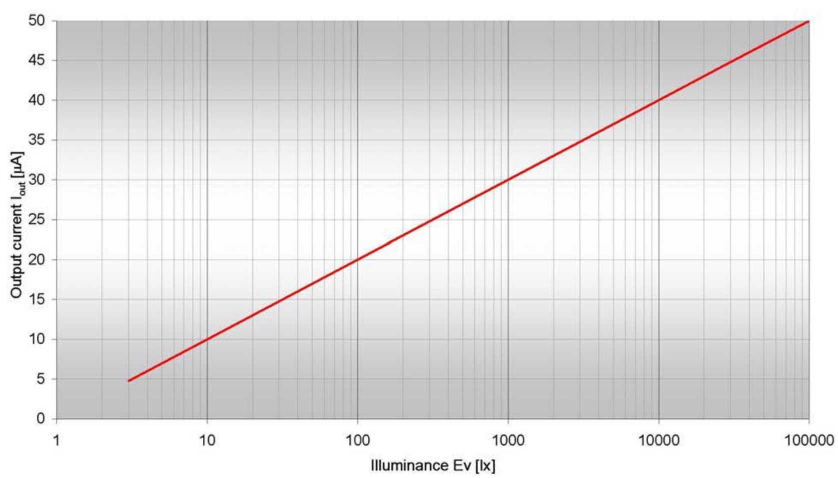

Figure 15: Output current Iout [µA] of the SFH 5711 versus illuminance

Iout = S * log(Ev/Eo) with Eo = 1 lx, Sensitivity S = 10µ A/dec

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For brightness measurements, a logarithmic output gives a good relative resolution over the entire brightness range. In other words,this is important when measuring low brightness levels.Small changes in those levels need to be detected; whereas, when high brightness levels are measured only relatively large variations are of interest.

For linear output detectors like photo transistors or photo diodes, brightness changes ΔEv result in changes ΔIout of the output current, which are proportional to ΔEv. To resolve small variations in low illumination levels it is necessary to measure in small current steps. At high brightness levels it makes little sense to collect data with such fine absolute resolution.
Source: "http://catalog.osram-os.com" from Appnote_SFH_5711_18_08_06.pdf via Osram

If the SFH 5711 is operated with an external load resistance RL, then the upper detection limit of the sensor depends on the resistor value of RL. The load resistance does not directly determine the maximum detection level, but it does determine the output voltage of the sensor, which is limited by the supply voltage Vcc. At high illuminance levels the output current Iout is high and the load resistance must be reduced in order to stay below Vcc (Vout ≤ Vcc = Iout * RL) Figure 16 shows the relationship between load resistance and maximum detecTable brightness levels. For 2.5V supply voltage, the detection limit for a 56kΩ resistor is ~9klx. To increase this level, a lower resistor value is necessary. With 47kΩ up to 60klx can be detected. For higher Vcc, the reachable detection limit increases with the same resistor values.
Source: "http://catalog.osram-os.com" from Appnote_SFH_5711_18_08_06.pdf via Osram

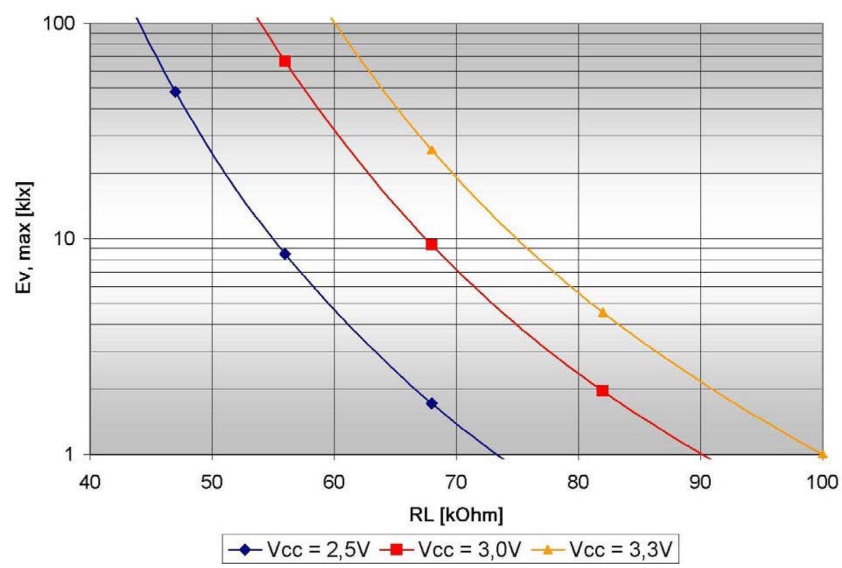

Figure 16: Maximum detectable light level vs. load resistance

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The SFH 5712 is comparable to the SFH 5711 (seen in Figure 17); however, it does have some differences. It does not mimic the human eye as well as the 5711 does and it output is digital using the I^2C digital standard. As seen in Figure 18, the 5712 has its highest sensitivity at 500 nm instead of 550 nm which is the highest sensitivity of the human eye, and the 5712 looses sensitivity very fast after 500 nm. The 5712 will also pick up light from the ultraviolet spectrum which will throw off its readings; however, the amount being picked up is practically negligible.

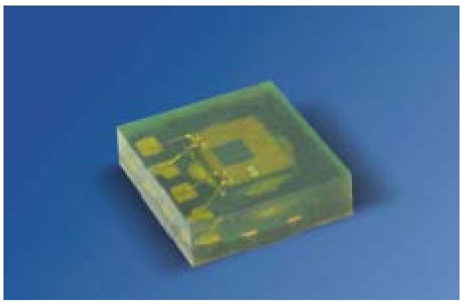

Figure 17: SFH 5712 High AccuracyAmbient Light

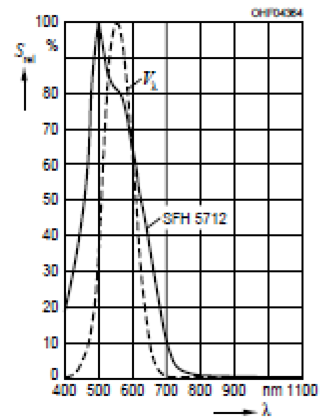

Figure 18: SFH 5712 Spectral Sensitivity

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The power being consumed by the SFH 5712 is almost three times less when it is compared to the SFH 5711, but when you consider that the current being drawn from the power supply is in the micro amp range with a low voltage draw then it is easily seen that both parts do not consume much power in order to function.

3.4: Analog Sensor Mechanics

There are a couple of ways to implement a sensor array system to which we will measure the lumens of both the projector array system and the single projector display. First and foremost is that the sensors must be either attached or mounted on a stable structure in front of the projector array. When the sensors are mounted on the array of the structure, they must be located at the specific points as described on the ANSI Lumens test. Then we must make sure that the wiring coming from each sensor and connecting to the projector box microcontroller must not intrude with each other. The sensor array system must be designed in which the wires don't tangle with each other.

Different materials can be used to implement an array system. One idea would be to place a three level shelf structure in front of the projector array system. The shelf structure must be three levels so that a 3 X 3 array can be formed using the sensors. The sensors must be mounted in such a way that they are facing the projectors. To do this, a stand structure must be placed on the shelves at the nine centers of each block. The sensor circuitry will then be mounted on each stand. The stands can be made out of plastic or acrylic. Figure19 below shows an example of what the stands would look like from a side view. It shows the how the analog sensor PCB will be placed on an acrylic stand on the shelves. The stands itself resembles a photo frame more or less. If the shelf prototype is used, the output wire form each sensor would have to be placed behind each acrylic stand so that the wires from the sensors on the top two levels don't interfere with the sensors that would be below directly below.

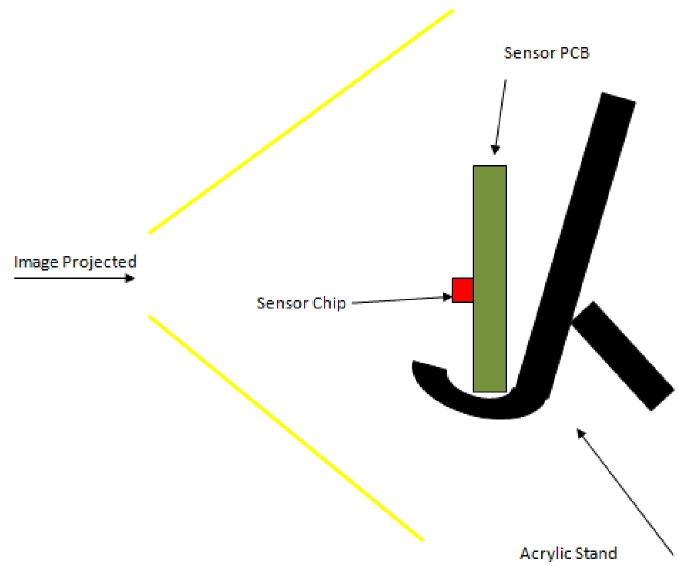


Figure 19: Acrylic Stand for Shelf Array

The potential problem that could arise from using a shelf set up though would be that the shelf itself would be difficult to move. The sensor array should be easily moveable because we want to test both the projector array and the single display system. The wires would also be all over the place if the shelf had to be moved. Also in order to for the sensors to be aligned at the correct location, the stands would have to be aligned manually. Although possible, having to manually align nine different stands at the approximate locations would not be ideal. There is also the possibility the sensor PCB would not be aligned at a 90 degree angle. If the sensor is not aligned properly facing the projector, the results of measurements when taken will be skewed. Mounting the acrylic stand on would not be possible because the trying to attach will break the acrylic stand. So even though a shelf stand is possible, it's probably not the best way to go about it.

Another approach to prototype what the sensor array should look like would be to use a multi leveled metal stand. The concept would be similar to the shelf concept. The difference though would be that we can add wheels to the bottom of the stand which will aid in moving the stand from one side of the projector to the other. Also instead of using acrylic stands to hold the analog sensor PCB we can use an enclosure to house the PCBs and leave a slight opening on the enclosure so that the actual sensor is exposed so measurements can be taken. Having an enclosure surrounding the PCB will thus allow us to stand the analog sensors upright without needing any specialized stands to hold up the PCB.

While this metal stand prototyping approach improves upon the previous, there are still limitations to this prototyping design as well. Despite the fact that this would be easy moveable by the wheels that are attached at the bottom, the output wires would still be exposed out in the open. This potential entanglements are likely to occur which would cause too many problems. Also once again even though enclosing the PCBs will allow for the sensors to be standing upright facing the projector array, it still has to be manually moved. First the position of the PCBs must be measured correctly and placed at the exact middle of the corresponding block as stated in the ANSI Lumen test. Again as stated previously while this is possible to get results, manually having to align the sensors to something that is not mounted is not an ideal approach. While better than the shelf approach, a metal steel framed stand is probably not the best prototype to execute.

A completely different way to implement a sensor array system would be to use PVC piping. We can implement a structure that uses a set of PVC pipes to build a 3 X 3 structure. We would need to have enough pipes to create sort of a checkerboard like pattern on the inner portion of the array. The parts included would be standard straight pipes, elbow joints, and standard t joints. The t joints attached to the inner portion of the structure are where the sensors should be placed. The t joints should be aligned such that the centers are placed in the same spots as the ANSI Lumen test described.

A great reason that a PVC structure would be ideal is that the output wires coming from each projector can be placed inside the hollow tubing of the price. This will take away the potential of the wires with tangling form each other. Also worth noting is that PVC piping is relatively light. This would be great in that moving the entire structure would be easy when moved from the other side of the screen. When testing occurs the position of the sensors would be fixed so that accurate measurements will be taken. The fixed position of the sensors will allow us to freely move the array from one side of the screen to the other.

After suggesting three prototypes for the possible designs for the array system, only one stood out at the best which is to create the analog sensor array using PVC piping. Unlike trying to implement a shelf array or a metal stand array, the PVC array prototype provides the mobility needed to test both our projector array configuration and the single projector display buying being lightweight enough to move from one side of the BP screen to the other. PVC piping also will provide fixed points where the sensors will be located in order to properly test the brightness of both displays. Also the fact that the PVC pipes are hollowed is great in the fact that holes can be drilled into the PVC pipes and the wires output wires from the analog sensor circuitry can be placed within the pipes to allow better ease when moving the array around for testing. All in all, the advantages of using PVC piping for the analog sensor array make it seem like it is the best prototype concept to implement.

3.5: Projectors

Due to the constraints of this project, and that today's larger more conventional projectors that are already being utilized in simulation screens are not wanted. Instead of using a single projector to display an image you can use an array of smaller projectors to display the same image, but with less pixel loss which will result in a better image. Due to a shift in the market pico projectors have been emerging in great numbers and at lower costs. Because of this market shift for the price of a large projector, or sometimes even lower, we are able to purchase multiple smaller projectors and put them in an array to get the same size image. From a business point of view this would be a logical step in order to cut costs while still maintaining the quality of the product. Figure 1 illustrates how an array of projectors can be used to produce an image just as a single projector is able to produce.

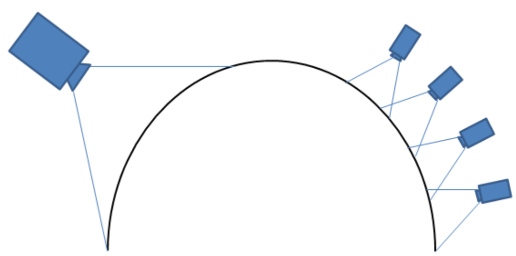


Figure 1: Advantage of using more projectors

The classification of pico projectors is in fact somewhat arbitrary. They are based on physical dimensions, weight, and price; however, they are all exceptionally small relative to traditional projectors. Actual size is not particularly critical. It is the unique features of the small projectors that offer the potential for innovation and cost-performance-functionality benefits, i.e., the black/dark level and collimating aspects of laser diodes that provide the promising benefits.

3.5.1: Lamp vs. LED vs. Laser

With new emerging technology the market is shifting away from projectors that use a lamp as their primary light source. The reason for this is simple, because for a given lifetime of a projector you will usually spend more on lamps then the projector was worth when it was bought. The lamp is very inefficient with power,

and has a relatively short lifetime. The only benefit from the lamp is that you will get a very bright image.
With projectors coming out with LEDs the pros and cons are being reversed. In the article by Colin, D. “The Pico Projectors Have Arrived!”, from the source given below, it states that “Picos use LEDs as their light source, which means the light source will outlive the projector’s useful life and provide efficient use of your battery power. The downside of using LED as the light source is that the brightness is much lower than you are able to obtain with a lamp; however, the LED projectors in the near future should be able to surpass the brightness of today’s lamps as technology progresses. Both LED and laser diode life is comparable since both types are in the tens of thousands of hours. Laser diodes do draw more power than LED’s, but both are very low in power consumption when comparing to traditional projector standards. There may be some decrease in brightness as LEDs and laser diodes age, but the color will remain highly stable over time. Laser diode color performance is actually superior to LED, and laser diode projectors will also be even easier to color match when placed in arrays. There is still some remaining concern about laser “speckle” as an unwanted image artifact caused by the laser. Due to the laser diode being small there are currently some techniques to reduce the speckle to a negligible amount.
Source: http://www.projectorcentral.com/pico_projectors.htm

Laser projectors have an even greater drop in brightness when compared to LED projectors, but they also have a greater depth of color and black levels which help laser projectors produce an image that appears brighter than it is. In addition to superior black/dark level and color performance, laser diode light is also fully collimated. This means it does not need to be focused and lends itself far more readily to image forming on irregular, non-flat, projection screens or other surfaces. The etendue, “spread”, of laser light is close to zero, which means that lasers can be ganged together to increase the brightness level of a single projector. On the other hand, the etendue of LED light is high and it is therefore extremely difficult, to produce a brighter projector by ganging LED light sources.

The primary barrier for laser diode projectors has been the green laser. In the past these projectors relied on an infrared laser, at 1064 nm, whose wavelength was frequency doubled requiring additional components to produce a nearly optimal 532 nm (1064 / 2) green wavelength. These green lasers were more bulky than the red and blue lasers, and complicated the optical design for pico-projectors even further. The direct green laser diodes remove the need of frequency doubling by producing a wavelength of 531nm directly, hence direct green laser. These lasers are now in production and being integrated into pico-projectors by a number of companies.
Source: www.picoprojector-info.com/tags/laser/green-laser

3.5.2: Reliability, maintainability, low cost

Although an array of pico projectors needed to fill up a large screen is more than needed using traditional projectors, the new projectors will be less expensive on a unit basis and essentially maintenance-free. Pico projectors have low heat output and will not require any special cooling systems.

LED and laser diode life is comparable since both types are in the 10's of thousands of hours. Laser diodes draw more power than LEDs; however, both are very low in power consumption when compared to current projectors being used today. There may be some decrease in brightness as LED's and laser diodes age, but the color will remain highly stable over time and brightness can be adjusted by an auto-alignment system if necessary.

Even the most expensive pico-projectors are well under $1000. There is no long-term reliability data for pico-projectors, and there is at least some concern that a $500 projector can be run 18 hours a day on a motion platform for years without failures. However, reliability of the more expensive ($20K) DLP/LED projectors has so far been excellent with no major problems.

3.5.3: Projector types

There are two main types of pico-projectors found in today's market. The fist type and most widely used is the DLP (Digital Light Processing) projector. A DLP chip uses an array of millions of tiny mirrors on a silicon chip to reflect light on to a projection screen to form an image. Each mirror acts as one or more pixels, and is controlled by an electrically driven hinge to adjust the amount of light reflected. Projectors use one to three DLP chips to create an image; however, pico-projectors typically use a single DLP chip with an LED as its light source. DLP offers a cost effective solution for projectors which also produces smooth, high resolution, and jitter free images. This technology does not suffer any color decay, and allows great contrast. The main downfall of DLP projectors, which is only a minor problem, is that after the projector has been on for about a half hour to forty five minutes the image tends to shift. The image shifts up and to the left about an inch to an inch and a quarter. The good thing about the shift is that the image moves as a whole so there is no distortion of the image, so only the position of the entire image is changing and not just certain portions.
Source: http://en.wikipedia.org/wiki/Digital_Light_Processing

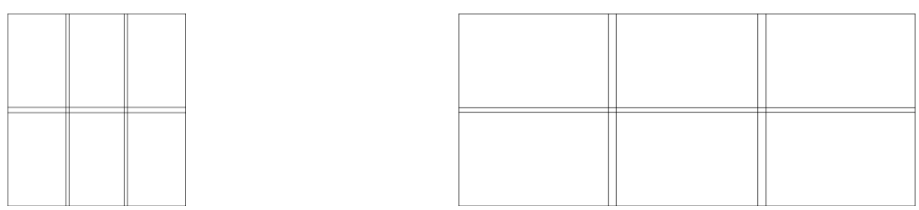
The second type of pico-projector is a hybrid of DLP and LCD technology known as LCoS (Liquid Crystal on Silicon). In the article by Evan Powell, "What's so Hot about LCOS Technology?".he states the LCoS technology is similar to DLP projectors, but instead of mirrors LCoS uses liquid crystals, one per pixel, to control the light for the image. The liquid crystals are located on a reflective mirror substrate, and as the liquid crystals open and close, the light is either reflected from the mirror below or blocked. All colors are sent at the same time using three separate chips. This prevents image distortion known as the rainbow affect. The downside to LCoS is that it does not have as high of a contrast ratio as DLP projectors.

Source: http://www.projectorcentral.com/lcos.htm

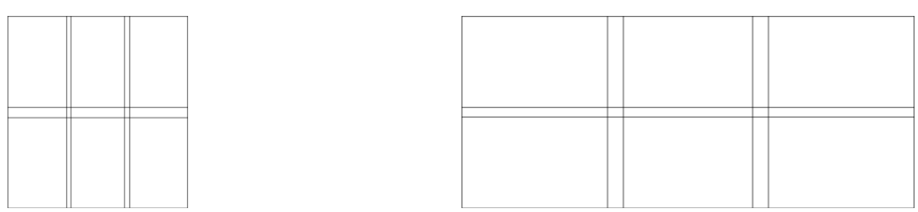
3.5.4: Aspect ratio and Screen Orientation

There is currently no set standard for pico projector aspect ratios; however, most companies do use the same aspect ratios for their projectors. All of the projector candidates being tested all have a native aspect ratio of 16:10, but they all also support 16:9 and 4:3. By using the native resolution of 16:10 we will be able to get the most pixels possible out of the projector; however, if this aspect ratio does not fill the screen well then using one of the supported aspect ratios of 16:9 or 4:3 can also be used. Our main goal is to get as many pixels possible out of the projectors in order to get the best image possible. In order to blend the edges of the images coming from each projector we will lose pixels. To maintain a perfect image and keep the best image quality you want to have the least overlap possible. Normally an overlap of five to fifteen percent of the image is used, but without prototyping the setup of the projectors it is very hard to know the sweet spot that will give us an image which will satisfy or specifications.

For the screen orientation we can keep the projector orientated in is default position to obtain a widescreen aspect ratio, or we can turn the projectors by ninety degrees to get a normal aspect ratio. An example is given below in Figure20 depicting the projectors using a 16:10 aspect ratio in each orientation that we will explore. Also shown is how the images can be blended together by using a five percent overlap or a ten percent overlap.



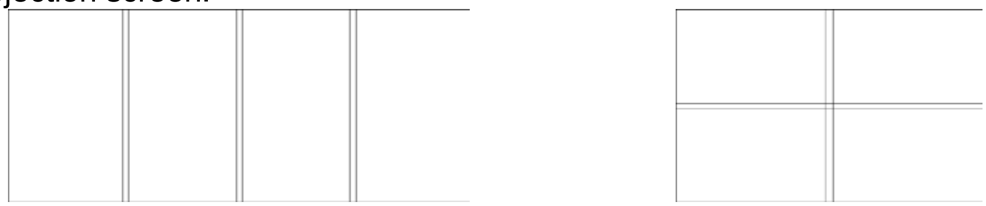
5% overlap



10% overlap

Figure 20: Six Projector array Orientations at 5% and 10% image blending Reprinted with permission from OsramOpto Semiconductors Inc.

The above Figure depicts the orientation of the projector images by using a total of six projectors. If four projectors are used the then Figure 21 gives a good example of how the projectors could be orientated to make the best use of the projection screen.



5% overlap

10% overlap

Figure 21: Four Projector array Orientations at 5% and 10% image blending Reprinted with permission from OsramOpto Semiconductors Inc.

3.5.5: Projector candidates

Projectors being considered to be used in this project are the Aaxa M2, Acer K11, AcerK130, Acer K330, Asus P1, BenQJoybee GP2, ViewSonic PLED-W200, and the VivitekQumi Q2. All of these projectors have a brightness level which we believe to be sufficient enough to provide a clear image, and they really only differ on paper by their contrast ratios. However, we expect the brightness levels listed on paper to be lower than what is listed as the ANSI lumen output for all of these projectors, and it is quite possible that the contrast ratios could be all about the same due to there not being a standard way to test contrast.

Since there is no standard way to test contrast, all manufactures have different ways of accomplishing this task. This means that different contrast ratios may be very similar when looking at different manufactures, but when looking at products from the same manufacturer, such as Acer with their K series, you can trust that their contrast ratios can be compared to one another. It is also of note that all of these projectors use LEDs as their light source.

A laser projector would be a top candidate to be used due to its ability to increase the light output by ganging the projectors together, and laser projectors also never have to be focused. The main problem is that there are not many on the market right now, and what is on the market is simply not anywhere near bright enough to be viable for this project. The Aaxa L1v2 is one of the brightest laser pico-projectors on the market and it outputs a measly 20 lumens. The Aaxa L1v2 could be ganged together to increase the brightness; however, if you want a brightness of 100 lumens you would need five projectors to get the required lumen output. That would only be for a single image in the array, so if you had an array of four projectors then you would have a total of twenty projectors to complete the array. This would not be cost effective and goes against what we are trying to accomplish.

Given below are Tables, Table 12 and Table 13, portraying the specifications of each projector that may be used for our design. We are going to eliminate some of the projectors, and then we will get one of each of the remaining projectors on a thirty day loan. During this time we will test each projector. After we have rigorously tested each projector we will make a decision on a single model that will be used in our projector design.

	Aaxa M2	Acer K11	Acer K130	Acer K330
Device Type	LCoS	DLP	DLP	DLP
Native Resolution	XGA (1024x768)	SVGA (858x600)	WGXA (1280x800)	WGXA (1280x800)
Maximum Resolution	1600x1200	1440x900	1600x1200 (UXGA) 1920x1080 (1080p)	1600x1200
Projector Distance	NA	25in – 11.17ft	23.62in – 10.5ft	35.43in – 9.83ft
Throw Ratio	NA	.597	.794	.85
Display Size	10in – 8.33ft	14.9in – 6.67ft	18.75in – 8.34ft	30in – 8.33ft
ANSI Lumens	110	200	300	500
Contrast	2000:1	2000:1	10000:1	4000:1
Lamp	LED	LED	LED	LED
Aspect Ratio	4:3	4:3	Native: 16:10 Supported: 16:9, 4:3	Native: 16:10 Supported: 16:9, 4:3
Power supply	19V DC via 100-240V AC 50/60 Hz adaptor	19V DC via 100-240V AC 50/60 Hz adaptor	19V DC via 100-240V AC 50/60 Hz adaptor	100-240V AC 50/60 Hz
Power Consumption	50w	81w	65w	120w
Video Inputs	HDMI, mini-VGA, Composite	D-Sub, HDMI, Composite, Component	Component, Composite, HDMI	D-Sub, HDMI, Composite
Dimensions	5.2x4.9x1.9 in	4.8x4.6x1.7 in	5.5x4.6x1.6 in	8.6x6.6x1.8 in
Weight	1 lbs	1.30 lbs	.95 lbs	2.73 lbs

Table 12: pico-projector comparison

	Asus P1	BenQJoybee GP2	ViewSonic PLED-w200	Vivitek Qumi Q2
Device Type	DLP	DLP	DLP	DLP
Native Resolution	WGXA (1280x800)	WXGA (1280x800)	WXGA (1280x800)	WXGA (1280x800)
Maximum Resolution	1600x1200	1600x1200	1680x1050 1920x1080 (WXGA+)	1600x1200
Projector Distance	19.69in – 9.8ft	17.7in – 11.8ft	24in – 6.5ft	39.36in – 9.84 ft
Throw Ratio	1.16	1.13	1.16	1.55
Display Size	20 in – 10 ft	20 in – 13.33 ft	24 in – 6.67 ft	30 in – 7.5 ft
ANSI Lumens	200	200	250	300
Contrast	2000:1	2400	2000	2500
Lamp	RGB LED	LED	DLP LED	LED
Aspect Ratio	Native: 16:10 Supported: 16:9, 4:3	Native: 16:10	Native: 16:10 Supported: 16:9, 4:3	Native: 16:10 Supported: 16:9, 4:3
Power supply	19V DC via 100-240V AC 50/60 Hz adaptor	19V DC via 100-240V AC 50/60 Hz adaptor	19V DC via 100-240V AC 50/60 Hz adaptor	19V DC via 100-240V AC 50/60 Hz adaptor
Power Consumption	50w	45w	50w	85w
Video Inputs	D-Sub, Composite	D-Sub, Composite, HDMI	D-Sub, Composite, Component	Mini-HDMI, VGA, Component
Dimensions	4.94x5.12x1.32in	5.52x2.07x5.11 in without battery 5.52x3.69x5.11 in with battery	5.1x5x1.3 in	6.3x4x1.3 in
Weight	.92 lbs	1.23 lbs without battery 2.31 lbs with battery	.9 lbs	1.4 lbs

Table 13: pico-projector comparison cont.

Out of the eight projectors we have chosen to test the projectors detailed in

Table14 given below. The main specifications we looked at in order to narrow down the list were lumen output, high definition connectivity, throw ration, and contrast. Upon receipt of the projectors, we performed an initial test focusing on contrast, focus control, brightness, noise, and overall image quality. We have discovered the following:

Projector	Contrast	Focus Control	Brightness	Noise	Overall image
Acer K11	6.5	8	7	4	6
Acer K130	NA	NA	NA	NA	NA
Acer K330	8	8	10	7	8
ViewSonic PLED	4	8	5	3	4
VivitekQumi Q2	8	3	7	7	7.5

Table 14: Projector Comparisons
***Scale 1-10 with 10 being the best**

The ViewSonic PLED-w200 only uses an analog input through a proprietary connector. This limits the overall image quality due to the limitations of analog inputs compared to digital ones. The ViewSonic was mainly tested to show the drawback of analog inputs when compared to a projector with a digital input, and we will not continue to test this projector due to the ViewSonic's limitation in video quality.

The Acer K11 has a lower resolution then the other projectors being tested. The lower resolution introduces an abundance of "halo" and "rainbow" effects during darker scenes. Bright spots such as light posts produce a halo like aura around the central light spot. Contrasting dark images such as clouds at night produce an unwanted, pixilated transition which is unsuitable in simulation applications.

The VivitekQumi Q2 and Acer K330 are the clear front runners so far. Both provide excellent image quality in both clarity and contrast. They provide a smooth transition between dark and light scenes of any nature. The K330's 500 lumen light source provides a slight advantage over the Qumi Q2 in overall image quality.

The K130 is currently back ordered with many local vendors but should be here for evaluation in the coming days.

3.6: Rear Projection Films and Screen Coating

Rear projection screens are frequently being used in many different markets. These markets include television, movie theaters, and simulations. The film used to "coat" theses screens are called rear projection film or RPF for short. RPF is a paper thin projection screen material used on glass so that video from a projector can be displayed to it. This technique will be useful to our project in that the collimated BP dome is made of glass.

The types of RPF available are dark RPF, white RPF, and holographic RPF. The dark RPF is designed to add depth and color to the image that is being projected by the projector. Dark RPF is usually used in areas and environments where there is bright ambient light. The dark film counteracts this ambient light to give as much color as possible. White RPF is used to add brightness to the image projected to the screen. White is the most standard used RPF in the market. Holographic RPF is designed to have a transparent look so that the image that is being projected is "see through." This type of film is used for showy displays in stores and malls to attract customers to walk inside. For the purpose of this project however the holographic RPF will not be used because we want to show that the projector array can give a better quality image than using a single projector. Having a transparent display will defeat the purpose of the intent of this project. Investigation is needed however to determine whether white or dark RPF is the best "screen coating" for the BP dome.

One RPF that will be looked at for the BP dome is 3M's Vikuiti Rear Projection film. It is a dark RPF that is adhesive and according to 3M; "easy to remove with little or no adhesive residue. The film comes in available pre-cut sizes and roll sizes. An outline of the features for the Vikuiti RPF from 3M's website is listed below, the rest can be found in the appendix.

- Film is easy to cut and shape
- Self-adhesive and flexible properties make film easy to apply to glass or acrylic surfaces
- Patented properties that focus projected light and absorb ambient light - Provides high-contrast, high-resolution images with superior color
- High resolution across wide range of viewing angles (180°)
- Thickness - 0.3 mm w/o liner. 0.5mm with liner
- Weight - 38grams/ft (4kg/M)
- Liner Type - Polyethylene-coated

All these features make it seem like 3M's Vikuiti RPF is the ideal film to use for this project but there are some drawbacks to using this film. One such drawback is the price. 3M lists the price points of Vikuiti RPF in 45 and 60 inch diagonal screen each in either 4:3 or 16:9 aspect ratio. Considering that for this project we want to maintain a 16:9 to 16:10 ratio because it is the ratio used for HDTV format we will therefore only look at the screens at this ratio. The price for the 45 inch diagonal screen (39 in X 22 in) is listed as $655.42 and the price for the 60 inch diagonal screen (52 in X 29 in) is $1,151.94. The price is the Vikuiti film is a major disadvantage as we want to keep the overall cost of the project to be as small as possible. Another drawback to this film is that on 3M's website it states the film will not work with short throw projectors. For projectors throw is the distance from the lens of the projector to the screen. A related measurement is throw ratio, which is the ratio of the distance of the lens to the screen to the width of the screen. Throw ratio is used to determine how far back the projector must be placed in order to project how large of image you want. Being that the

VikuitiRPF does not allow short throw projectors, it will force us to narrow our choices of pico projectors.
Vutec is another company that specializes in projector screens. Vutec has several lines of RPF that could be considered for use on the BP dome. Their line of RPF included the Fusion-HD, Prisma Tec, Twin-VU, and Rear-Vu. Each screen surface have different characteristics that differentiate them between each other most notably the gain of each surface. Screen gain is the measurement of reflectivity of a projection screen. It is the ratio of light reflected from the screen as compared to the light that is reflected from a standard magnesium oxide white board. So a screen of 1.0 will reflect the same light as the white board while a gain of 2.0 will reflect twice as much light and so on. A higher screen gain essentially equates to a higher screen brightness but the higher the screen gain, the lower the viewing angle of the screen. A high gain means that the screen will be bright when viewed from the center but will noticeably drop off in brightness when viewed at an angle from the center of the screen.

The Fusion-HD features are that it is a rigid acrylic rear screen with a 2.0 screen gain and a high contrast ratio designed for High Definition movies and digital image files. The Prisma Tec is a RPF with high contrast, high gain (5.0) rigid rear projection surface. The Twin-Vu is a self supported surface with a rear projection gain of .85. Lastly the Rear-Vu is a screen surface with ambient light rejection and a screen gain of 2.5. All Vutec rear projection screen surfaces will need to be investigated further to determine if they are suitable for the BP dome in this project.

Draper has a line of screen coating they dubbed Cinescreen™ which is used to coat rear projection screens to create optimum viewing performance. According to their website, Draper claims that it Cinescreen™ brand of optical coatings "have been formulated to provide inherent abrasion resistance. No other manufacturer offers you this protection." The Cinescreen™ screen coating has six different variations which include the Cine 10, Cine 13, Cine 15, Cine 18, Cine 20, and the Cine 25. The differences, as described on Draper's website, of each variation are shown below:

- Cine 10 - Ultra-wide angle coating for maximum center-to-corner uniformity of projected image. Gain of 1.0 Suitable for higher luminance projectors.
- Cine 13 - Gain of 1.3, with extremely broad viewing cone and uniform distribution of projected light. Use with all projection formats, including higher-luminance video and data-graphics projection.
- Cine 15 - Benchmark wide-angle coating. Gain of 1.5, with uniform distribution of projected light. For all formats and higher luminance video projectors.
- Cine 18 - For medium to wide-angle viewing, with on-axis gain of 1.8. Suitable for all projection formats, including video.

- Cine 20 - Peak gain 2.0, with a somewhat broader viewing cone that Cine 25. Suitable for relatively high ambient light conditions. For all projection formats, including data, graphics and video.
- Cine 25 - Suitable for narrow viewing cones and lower output projection formats. On-axis gain of 2.5. Good image resolution and color reproduction.

It is worth nothing that Cine 18, Cine 20, and the Cine 25 are only for projectors with long throw lenses meaning no short throw. That will have to be taken under consideration. Below are the gain charts for all the Cine variations that were provided by Draper on their website. It can be seen from the charts that brightness deviations for the Cine 18, Cine 20, and Cine 25 are the largest as the viewing angles increased when compared to the Cine 10, Cine 13, and Cine 15.

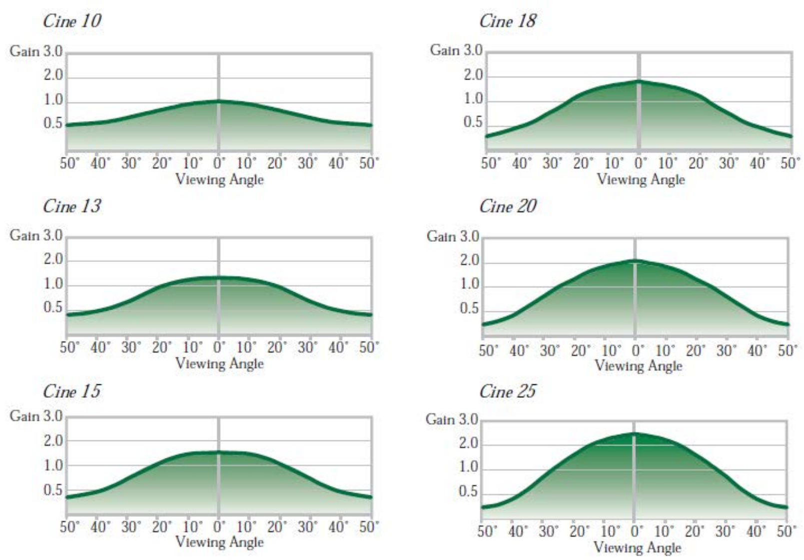


Figure 22: Rear Projection Film Gain Charts

Also worth nothing that Draper also has what they call ArmorKote™ which is an extra invisible layer of coat available for Cinescreen™ that serves as an "insurance policy." The ArmorKote™ coating is used to protect the rear projection screen as it is highly resistant to scratches and abrasions. It also will not reduce the image quality of the image being projected onto the screen. According to Draper it is "by far the toughest rear screen protective coating available." Further investigation is needed to confirm this.

UK based company ClearJekt provides four different lines of projections films in their product line. The films are called Aura HC, Aura Ice, Clarity Film, and Ultra XC. The Aura HC line comes in normal and extra dark film variations. The normal Aura HC provides a brighter image while Aura HC darks has slightly higher contrast. Both are made with polyvinyl chloride (PVC) material which ClearJekt touts as "very hard to tear without scissors or a knife, it's tough properties make it very versatile." Aura HC is non-adhesive which means it must be affixed to glass using adhesive spray. Aura HC can be ordered in any size needed up to the size of a full roll (2.2m X 10m). Specifications of the Aura HC are as followed:

- Thickness: 0.5 mm
- Maximum Width: 10 meters
- Maximum Height: 2.2 meters
- Transmittance: 90%
- Gain: 2.0
- Contrast: 200:1

Aura Ice is a frosted white colored RPF that is non adhesive and works best in areas that bright meaning that ambient light will have little effect on the overall brightness of the projected image. Aura Ice can be ordered in cut sizes and full rolls of 10m X 1.524m. Specifications are listed below.

- Gain: 6.0
- Viewing angle: 180 degrees
- Contrast: 200:1
- Short throw projector compatible
- Maximum Width: 1.52 meters
- Maximum Height: 10 meters

Clarity film is a self-adhesive holographic RPF with a transparency of 88 percent. It is meant to use for glass and windows where you want to project an image but still be able to see through the glass or window. As with all the other ClearJekt film, Clarity can be ordered in any size up to the full roll size of 10m X 1.52m. The high transparency of the Clarity film will probably deter us from using this film for the BP dome. Specifications are listed below.

- Thickness: 0.1mm
- Maximum Width: 10 meters
- Maximum Height: 1.52 meters
- Transmissance: 88%
- Gain: 6.0
- Viewing Angle: 150 degrees
- Contrast: 200:1

The final film in ClearJekt's product line is the Ultra XC in which ClearJekt touts as a high contrast rear projection film and "a flag-ship product and one of our leading, ultra professional, rear projection screen solutions. Ultra XC is a dark charcoal colored film and is dual sided in that in can perform both front and rear projection. Also promised is that the film will not hotspot. This means the brightness projected on the Ultra XC is evenly distributed along the film no matter what angle it image being projected is being view at. Clearjekt has a ten year UVA warranty on the Ultra XC. Specifications are listed below.

- Thickness: 0.1mm
- Maximum Width: 10 meters
- Maximum Height: 1.52 meters
- Contrast: 300:1
- Projection Angle: 180 degrees
- Gain: 4.0

3.7: Graphics Post Processing/Host Computer

Nvidia and AMD: There are few rivalries in the tech world that can compare to the graphics card battle between Nvidia and AMD. Both are constantly switching places with the title of the “best” graphics card. While both companies produce outstanding top of the line cards each has its own subtle flaws and advantages.

Technologies: To truly understand the differences in each company’s cards you must look beyond what is in the spec sheet. For the sake of comparison we will use AMD’s Radeon 7970 and Nvidia’s GTX 680, both being the respected top cards from each company. AMD’s 7970 utilizes the Graphics Core Next architecture that optimizes parallel processing and scalability. Nvidia’s GTX 680 is based on the Kepler architecture, a variation of the Fermi architecture. Both offer excellent graphics abilities with most of their pros and cons going unnoticed to the average user. For 3D gaming the 7970 uses the open HD3D platform, while Nvidia continues to perfect their proprietary 3D vision in the 680. AMD also includes their proprietary Eyefinity technology for easy setup of multiple monitor display. This is crucial to this project as we are attempting to drive an array of many projectors. Both cards support other necessary technologies such as DirectX and OpenGL, so neither is advantageous in these categories.

Computational and Graphics Performance: Most people don’t think about a GPU when talking about a computers computational performance, however in recent years raw data computation by the GPU has become a serious part of the market. There are a number of tests on the market for measuring computational performance of a GPU; One such test being the 64-bit LuxMark 2.0 benchmark. The 7970 scored a 1,591 on the medium test and 987 on the Complex test, while the 680 scored 622 and 281 respectively. This test gives a significant advantage to the 7970 in raw data computation. Graphics performance also has similar benchmark tests. Using the SiSoftware Sandra GP Processor test the 7970 pulled off a rate of 2.2 gigapixels per second to the 680’s 756.4 megapixels per second. This is an understandable loss for the 680 as Nvidia removed some of the GPU computational abilities in order to lower the power usage of the card. While both of these tests would lead you to believe that the 7970 outperforms the 680, we find a different results while running graphics intensive video games. The figure below shows average frames per second while playing Battlefield 3.

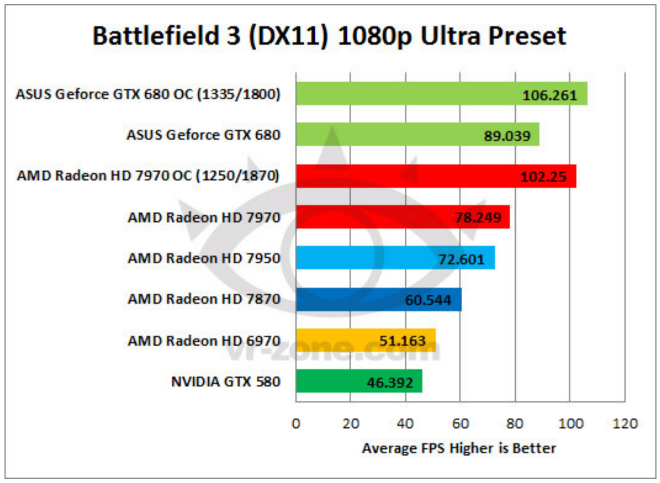


Figure 23: Average frames per second (FPS) during game play
Reprinted with permission from VR Media Pte, Ltd.

During game play both the stock and over-clocked 680's outperformed the respected stock and over-clocked 7970's in FPS. Though the theoretical simulations give the 7970 a significant advantage, real world usage seems to allude to a slight advantage for the 680.

Multi-monitor Support: When it comes to multi-monitor support we have a more clear cut winner. AMD began offering support for up to 6 simultaneous displays from one card in 2009 and continues to offer this in the 7970. Using display port outputs AMD has been able to squeeze in six ports on their higher end cards. Nvidia has been lagging in this category for quite some time now. It's 400 and 500 series cards required two cards to drive a mere three monitors. The 680 steps this up a bit and is the first card from Nvidia to offer support to four monitors from a single card. While this is a major improvement, AMD's six display port outputs coupled with their Eyefinity technology is by far the winner in this category.

Our project requires the ability to drive extremely high graphics to multiple projectors simultaneously. With these requirements in mind AMD graphics cards are the clear choice. Nvidia offers only a very slight advantage in graphics rendering which is easily surpassed by AMD's support and ease of use in multi-monitor setups.

AMD cards: Now that we have identified AMD as our brand of choice for graphics cards we need to compare some of their cards on the market. We will need to have a top of the line card to handle the amount of graphics processing we wish to accomplish. Ideally we would like a card that is designed with projectors in mind, more specifically multi-projector setups. With this in mind we have identified the Radeon 7000 series and the AMD FirePro line for display walls.

7000 Series: The 7000 series is AMD's leading line of graphics cards, with the Radeon 7970 being the forerunner. These card's utilize the best of the best in AMD's graphics technology. Included is advanced support of DirectX11 gaming, the newest version of AMD's Eyefinity technology, and full support for the highest resolution monitors allowing for resolutions up to 4096x2160. The 7000 series also keeps with AMD's domination in multi-monitor setups allowing for up to 6 displays to be connected to a single card, allowing for fully immersive gaming set ups. The 7970 is truly a graphics powerhouse.

FirePro line for display walls: Along with a focus on extreme gaming setups, AMD also offers a professional line of cards. The FirePro line for display walls offers interesting newer technologies from AMD for use with multi-monitor setups. The FirePro w600 is an excellent example of these newer advances. The w600 is designed for use with display walls offering 6 display port outputs and is capable of placing one single image across 12 different displays (in a two graphics card configuration). The most useful advancement for us is their use with multi-projector setups. The driver suite for the w600 allows for projector overlap when using multiple. Allowing for projector overlap gives the end user the ability to produce a single seamless image from multiple projectors, with the use of some sort of edge blending technology. The figure below gives an example of projector overlap in a 3 projector configuration:

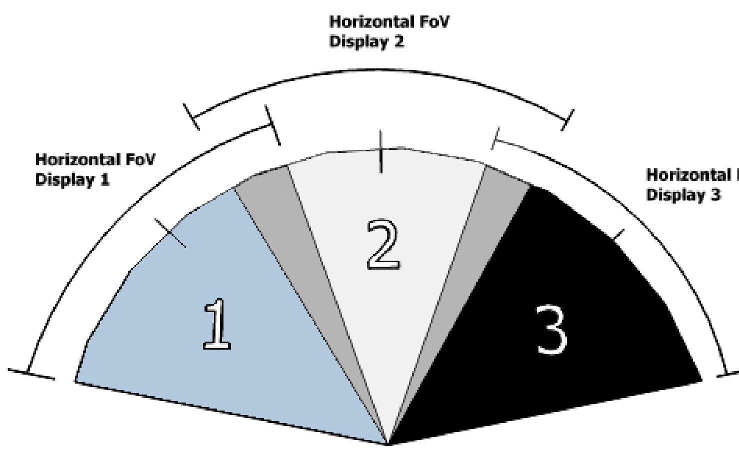


Figure 24: Field of View (FOV) diagram showing projector overlap
Gray area shows the overlapping of projector images
Reprinted with permission from Q4 Services

AMD plans to go even a step further in multi-projector setups by adding both warping and edge blending capabilities to the w600 sometime in Q4 of 2012.

The 7000 series cards are the clear graphics intensive winner however, the Firepro line and specifically the w600 card offer the ideal parameters for multi-projector setups. Given the advantage with projectors the w600 is the clear choice for use in our project.

3.8: Alignment system

One of the biggest issues facing simulators with dome, cylindrical, or spherical displays is the need to correct images projected onto the surfaces. Projectors are designed to project images onto flat surfaces. Projecting those same images onto curved surfaces creates distortion near the edges of the picture. The figures below show the difference between a planar projection and a curved one:

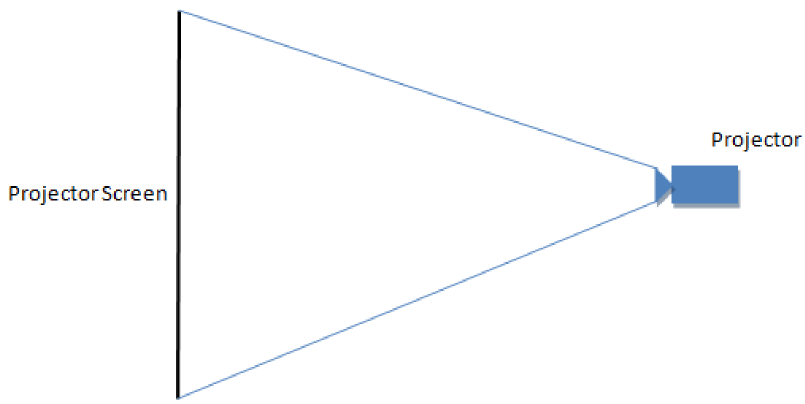


Figure25 : Pixel Spread of Single Projector

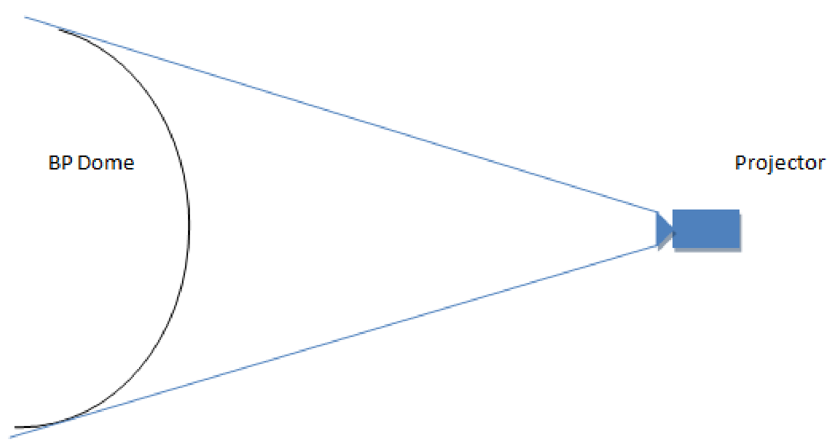


Figure 26: Warping of Single Projector and BP dome

This of course needs to be corrected to ensure a clear and accurate picture. We can correct this distortion through a method none as image warping. Image warping gives the user the ability to essentially point and drag any part of the image to a new spot on your projection surface. The warping hardware or software then runs any number of image processing algorithms to correct the rest of the image to coincide with the user changes. The figures below show a 3 projector setup before and after warping:

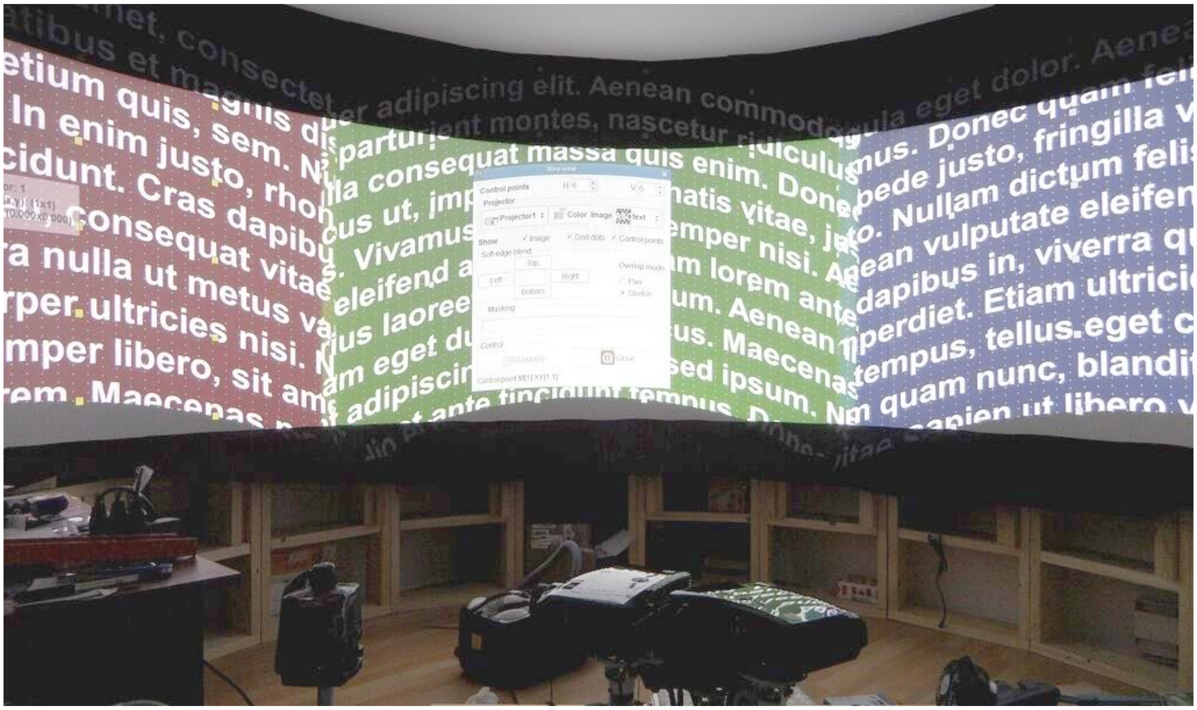


Figure 27: Three Channel setup before warping
Reprinted with permission from Q4 Services

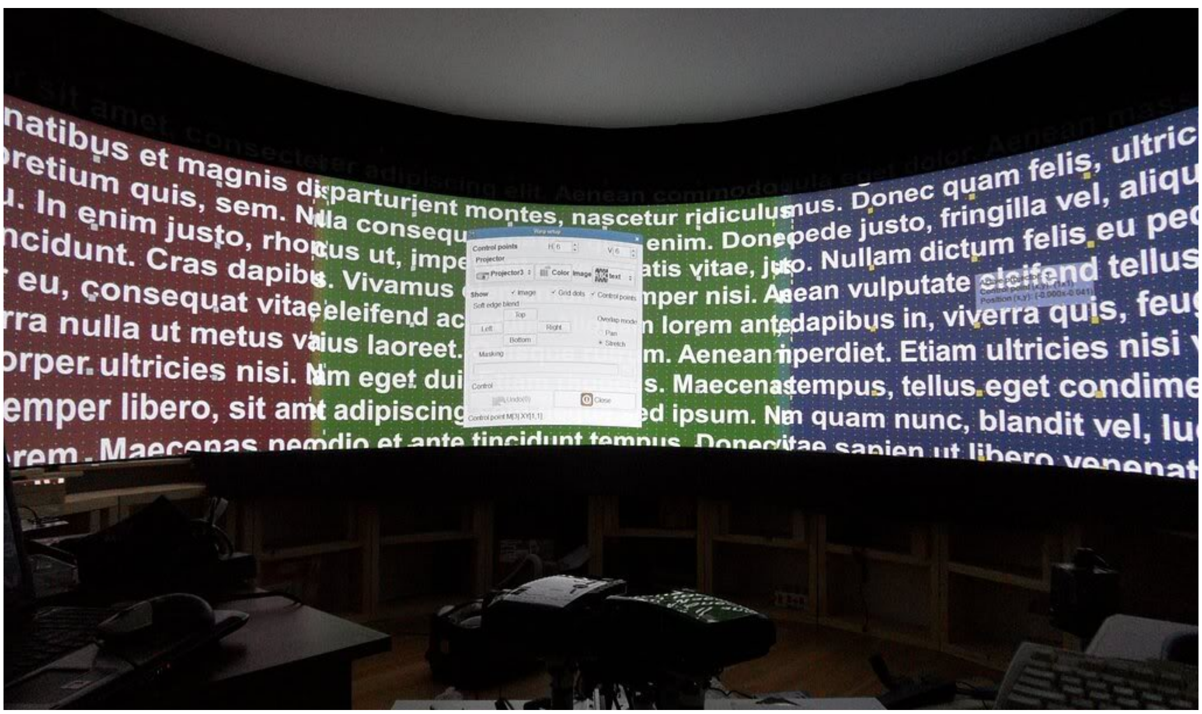


Figure 28: Three Channel Setup after Warping
Reprinted with permission from Q4 Services

As you can see warping is a crucial part of any multi-projector setup, especiallyon military grade systems where accuracy and perfection are critical to pilot training

There is also the need to create a single seamless image using the images projected by multiple projectors. You can see in the pictures above a small overlapping area on either side of the center (Green) channel, where the projector light paths cross. The image below shows the typical overlap of a three channel system:

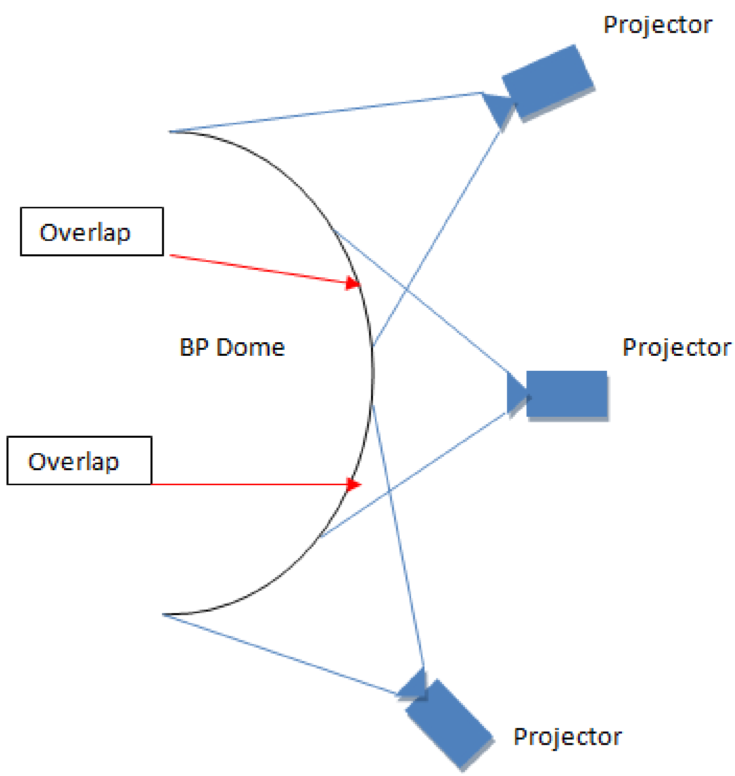


Figure29 : Projector Array With Overlaps

To create a more accurate picture a technique known as edge blending is required. Edge blending takes the edge of the image and decreases the light intensity as you approach the edge. The figure below gives a visual representation of the overlap and differing light intensities:

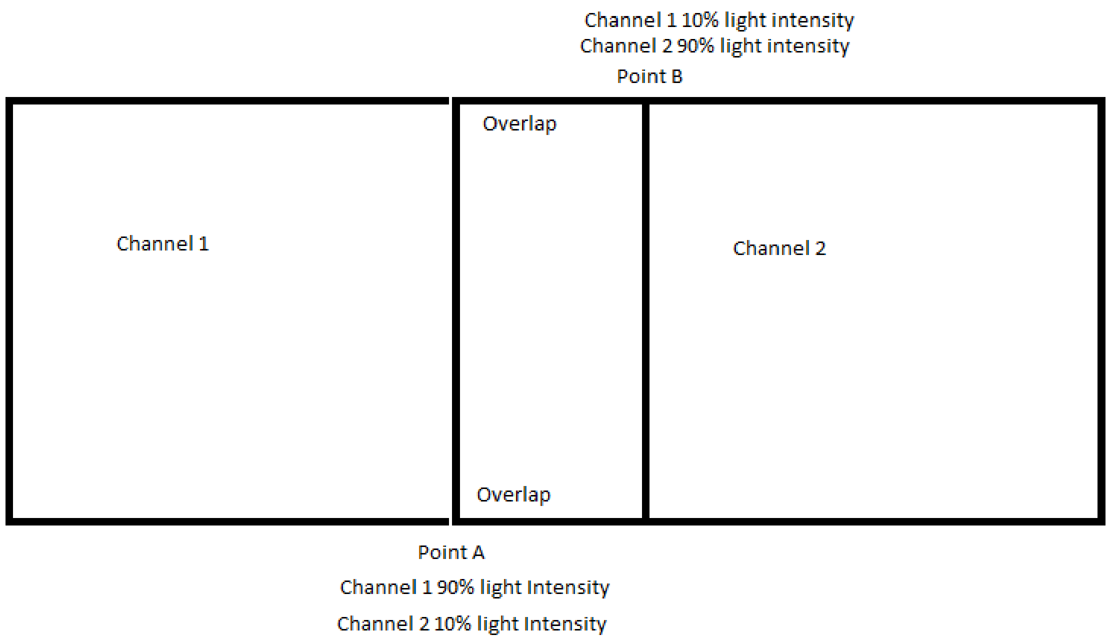


Figure 30: Visual Representation of varying light intensities due to edge blending

The light intensities generally will vary following a linear equation, though sometimes it is necessary to adjust this equation to more adequately suit the application. The figure below shows a before and after comparison of the edge blending technique:

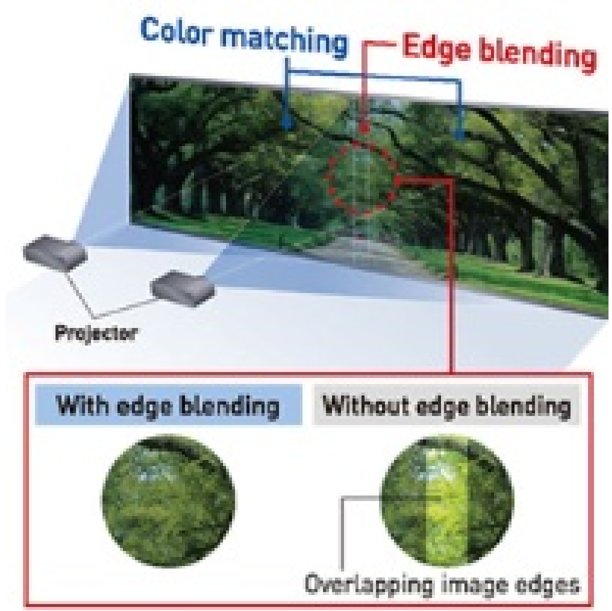


Figure 31: Before and After comparison of Edge Blending techniques Reprinted with permission from Q4 Services

In the past both warping and edge blending needed to be adjusted by the user. Warping was done using a point and drag with an array of control points on the image. Edge blending was generally done by measuring the degree placements of overlapping images and the user entering these into the edge blending software or hardware. A newer technique is emerging to simplify this process, Auto-alignment. Auto-alignment is a technique where either camera systems or specially designed images are used to implement both warping and edge blending techniques. This can save a simulation companies hundreds if not thousands of man hours a year that were normally wasted due to the tedious nature of warping and edge blending.

Most auto-alignment systems are still solely research based and done at major universities. We have identified four different systems of auto alignment outside of university research teams: Dome Projection, BSM Auto Alignment, Scalable Easyblend, and Warpalizer. All of these systems have the exact same functionality, with the biggest difference being cost. Before exploring any of the system capabilities we identified an immediate issue with the cost of each system. Dome Projection, BSM Auto Alignment, and Scalable Easy blend are all $15,000+ systems. While these may prove useful in a later phase of this project, cost restraints immediately eliminate all of these systems. After contacting the UniVisual Technologies, the creators of Warpalizer, it was identified as the only system cost effective for use in this project. We were able to negotiate a proof of concept fee of 150 Euro or approximately $180 per channel.

Warpalizer will handle both the edge blending and warping of our image onto our spherical BP screen. The edge blending is handled by way of a configuration file where the user can input the degree measurements that each projector occupies in the horizontal field of view (FOV). The warping is does similarly with the addition of user entered dimensions of the screen. Once the values are entered by the user the software can automatically warp, edge blend, and align our image onto the screen.

UniVisual'sWarpalizer supports all types of simulators and trainers that include a seamless multi-projector based projection system, projecting onto flat, cylindrical or spherical screens. Being able to align in a multitude of different screen variations, especially spherical, is ideal as we would want to display our image on a collimated mirror display. The Warpalizer also supports any number of channels in 1, 2 or 3 rows configuration, in addition to the polar cap. The Warpalizer is the only product in the market that supports overlap generation and warp and blend of up to 6 channels from 1 single graphic card. Warpalizer should allow the implementation of up to 6 pico projectors then. Further investigation is needed.

The Warpalizer has already been used in various simulation and video game applications. Some notable applications include the Presagis Vega Prime 5.0, a 360 degree display with treadmill and gun mounted motion detection, and a cylindrical screen projected with four to six FullHD projectors at the Digital Art

Center in Sweden. Vega Prime 5.0 is used in many real time 3D simulations. Battlefield 3, one of the most processor-intensive video games available, was used in the 360 degree display to demonstrate the Warpalizer. In the demonstration a single power full PC was connected with six super short throw projectors.

Hardware solutions for auto-alignment are also available to use. One such solution that exists would be so that each projector in our array would be able to be automatically adjusted through a GUI from the host computer so that each projector would be made to perfectly aligned at specific points on the projector screen to create a seamless image. In order for this solution to work, each projector would have to be able to tilt in an XY plane (up, down, left, right) automatically. To do this each projector would have to be attached to what's called a pan tilt tray which is a device that uses two servomotors to tilt an object up and down in the Y direction and also pans the object left and right in the X direction. An additional microprocessor would be needed to control the servos to direct the motion of the pan tilt tray.

Several servos from different companies will be considered to use for the pan tilt tray. Hitec features both analog and digital servos. For the sake of this project, only digital servos will be considered because we would want to control the input signals going to the servo. Hitec'sline of digital servos include Digital Micro & Mini, Digital Sport, Premium Digital, Gyro & Tail Rotor, Ultra Premium Digital, Robtics, Waterproof Servos. The ideal servo would be one that does not have much torque because we want the movements of the pan and tilt to be controlled and accurate and not fast and jerky. So for this we will only include the servos in the Digital Micro & Mini line and from the Digital Sport line because the other lines would have too much power for the purpose of this project.

Table 15 shows all the specs for all of Hitec'sDigital Micro & Mini line.Table16shows all the specs for Hitec's Digital Sport line. The Tables compares and contrasts each mini servomotor. The information for all of the servos are found in the specs page of each servo from the Hitec's website. Each of the servos in Table A have an operating voltage between 4.8V - 6.0V. This should be taken under consideration for power design.

Servo Part Number	Motor Type	Bearing Type	Speed	Torque oz./in.	Size (in.)	Weight (oz.)
HS-5035HD	3 Pole	None	0.10 / NA	11 / NA	0.73 X 0.30 X 0.61	0.16
HS-5045HB	3 Pole	Top Ball Bearing	0.12 / 0.10	14 / 17	0.92 X 0.38 X 0.88	0.29
HS-5055MG	Coreless	None	0.17 / 0.14	17 / 21	0.89 X 0.45 X 0.94	0.33
HS-5056MG	3 Pole	Top Ball Bearing	0.11 / 0.09	21 / 25	0.88 X 0.45 X 0.94	0.45
HS-5065MG	3 Pole	Top Ball Bearing	0.14 / 0.11	25 / 31	0.92 X 0.45 X 0.94	0.42
HS-5085MG	3 Pole	Top Ball Bearing	0.17 / 0.13	50 / 60	1.14 X 0.51 X 1.18	0.77
HS-5125MG	3 Pole Ferrite	Dual Ball Bearing	0.17 / 0.13	42 / 49	1.18 X 0.39 X 1.33	0.84
HS-5245MG	3 Pole	Dual Ball Bearing	0.15 / 0.12	61 / 76	1.27 X 0.66 X 1.21	1.12

Table 15: Hitec Digital Micro & Mini Servos

Servo Part Number	Motor Type	Bearing Type	Speed	Torque oz./in.	Size (in.)	Weight (oz.)
HS-5485HB	3 Pole	Top Ball Bearing	0.20 / 0.17	72 / 89	1.57 X 0.78 X 1.49	1.59
HS-5495BH	3 Pole Ferrite	Top Ball Bearing	0.17 / 0.15	89 / 104	1.57 X 0.78 X 1.50	1.59
HS-5496MH	3 Pole Ferrite	Top Ball Bearing	0.17 / 0.15	83 / 100	1.57 X 0.78 X 1.50	1.59
HS-5565MH	Coreless Metal Brush	Dual Ball Bearing	0.11 / 0.09	153 / 194	1.57 X 0.78 X 1.49	2.1
HS-5585MH	Coreless Metal Brush	Dual Ball Bearing	0.17 / 0.14	194 / 236	1.57 X 0.78 X 1.49	2.1
HS-5625MG	3 Pole Ferrite	Dual Ball Bearing	0.17 / 0.14	110 / 131	1.59 X 0.77 X 1.48	2.11
HS-5645MG	3 Pole	Dual Ball Bearing	0.23 / 0.18	143 / 168	1.59 X 0.77 X 1.48	2.11
HS-5665MH	3 Pole Ferrite	Dual Ball Bearing	0.16 / 0.14	122 / 139	1.6 X 0.8 X 1.5	2.1
HS-5685MH	3 Pole Ferrite	Dual Ball Bearing	0.2 / 0.17	157 / 179	1.6 X 0.8 X 1.5	2.1
HS-5755MG	3 Pole Ferrite	Triple Ball Bearing	0.18 / 0.15	278 / 347	2.32 X 1.14 X 2.04	5.68
HS-5765MH	3 Pole Ferrite	Triple Ball Bearing	0.16 / 0.13	278 / 348	2.32 X 1.14 X 2.04	6.07
HS-5805MG	3 Pole Ferrite	Dual Ball Bearing	0.19 / 0.14	275 / 343	2.59 X 1.18 X 2.26	6.95

Table 16: Hitec Digital Sport Servos

After comparing the specifications of all Hitec's servers mentioned, it seems that the HS-5665MH is the best servo to use because it is small enough so that there won't be too much size added to the overall array but powerful enough to be able to pan and tilt each projector. The HS-5665MH was designed to run on a 2-cell 7.4N LiPo battery. The bulleted list below shows the features of the HS-5665MH as provided from Hitec's website.

- Programmable Digital Circuit
- Heavy Duty Metal Gear Train (MK first gear)
- 7.4V Optimized Motor
- Programmable Features Include:
    - Dead Band Width
    - Direction of Rotation
    - Speed of Rotation
    - End Points Neutral Points
    - Fail Safe On/Off
    - Fail Safe Point

The most important feature listed above is the HS-5665MH ability to be able to control the speed of rotation of the motor. As stated previously the plan is to get the projectors to move but we do not want to the projectors to move jerkily in any direction. Precise adjustment is needed for each projector in order to blend the images correctly so being able to slow the servo down to accurately place each projector is essential.

The servo motors must be controlled by a motor driver which is connected to the microcontroller and code must be written in order to manipulate the movement of the pan-tilt tray. There are several microcontrollers that are specifically designed to handle the operations of servos. The microcontrollers in question use a configuration called an H-Bridge Driver circuit. The H-bridge main function is to enable a voltage to be applied across a load in either direction. This function allows DC motors to be able to run forwards and backward which is essential for our potential design in that it enables us to control panning and tilting in either direction. Figure 32shown below shows a simple circuit diagram for an H-bridge circuit. The servo (M) is connected to the four switches. Depending on the digital input to the circuit, the switches will open and close to allow the servo to rotate clockwise, counterclockwise, stop instantly, or stop slowly.Figure 33shows this explanation of the simple operation of the H-bridge circuit**.** Table 17shows the truth for the inputs and which operation the servo will conduct. Both the circuit diagrams and the truth Table can be found on the Wikipedia page for H-bridge circuits.

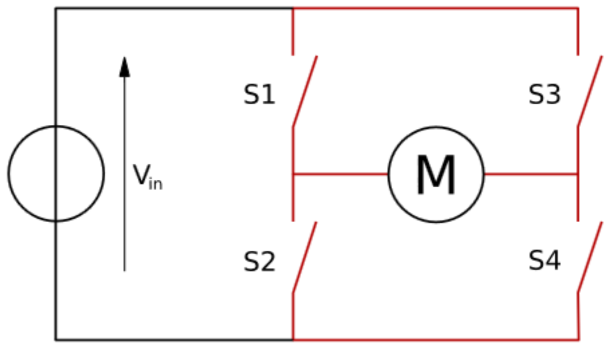


Figure 32: Simple H-bridge Circuit Diagram

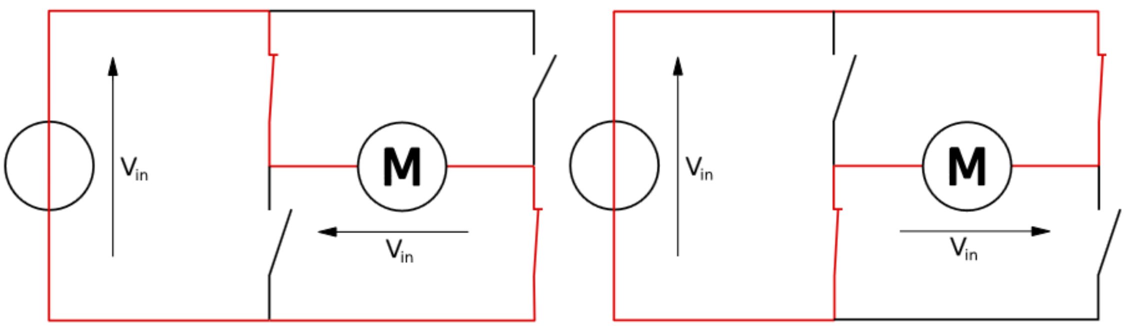


Figure33: Simple Operation of H-bridge Circuit

S1	S2	S3	S4	Results
1	0	0	1	Motor Moves Right
0	1	1	0	Motor Moves Left
0	0	0	0	Motor Free Runs
0	1	0	1	Motor Brakes
1	0	1	0	Motor Brakes
1	1	0	0	Shoot-through
0	0	1	1	Shoot-through

Table17: H-bridge Truth Table

There are potential motor drivers that are available for use for our projectors. They include the SN754410 by Texas Instruments, the L293D by Texas Instruments, and the Atmel ATA6823.Both the SN754410 and the L293D have the same pin layout so one diagram will suffice for both drivers. Figure34 below shows the pin layout of both the SN754410 and the L293D. The diagram of the pin layout can be found on the datasheet of both the SN754410 and the L293D provided by Texas Instruments.

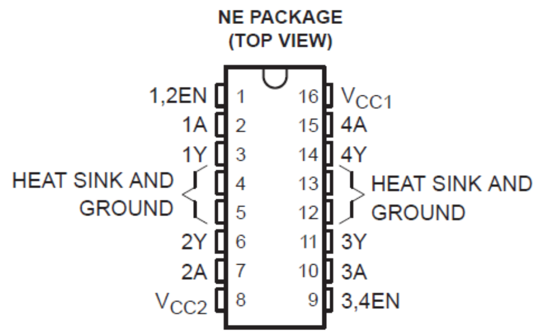


Figure34: SN754410 & L293D Motor Driver Pin Layouts
Courtesy of Texas Instruments

The advantage of using either the SN754410 and the L293D motor drivers are that very few additional circuitry is needed for operation. One advantage that the L293D has over the SN754410 is that it has internal diodes within to direct the current between the transistors that act as the switches to drive the motor in either direction. The SN754410 do not have these diodes internally and must be added outside of the chip in order to produce the same effect. Figure 35 and Figure36 below shows this comparing the application of both chips. From the Figures it is seen that buffers must be added circuit components to operate the inputs. Both Figures were obtained under the application information section of the datasheets by Texas Instruments.

While both the SN754410 and the L293D have the same pin layout, both have different operating conditions. Both motor drivers at V_{CC1} have a minimum operating voltage at 4.5V. The max input voltage for the SN754410 is 5.5 while the L293D operates at a max of 7V. These both have to be taken under power considerations. Below in Table 18 and Table19 show the rest of the operating conditions for both motor drivers. The Tables are referenced from the datasheet of both motor drivers.

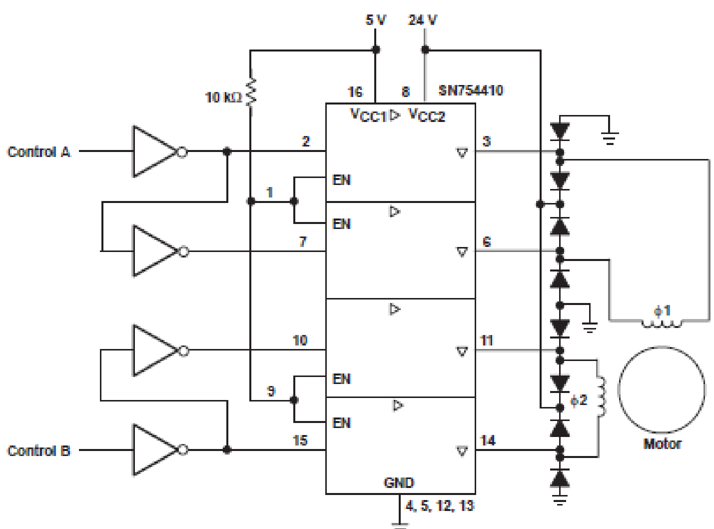


Figure35: SN754410 Application
Courtesy of Texas Instruments

Parameter	MIN	MAX	Unit
Output Supply Voltage, V_{CC1}	4.5	5.5	V
Output Supply Voltage V_{CC2}	4.5	36	V
High-level Input Voltage, V_{IH}	2	5.5	V
Low-level Input Voltage, V_{IL}	-0.3	0.8	V
Operating Virtual Junction Temperature, T_J	-40	125	^oC
Operating Free-air Temperature, T_A	-40	85	^oC

Table18: SN754410 Operating Conditions

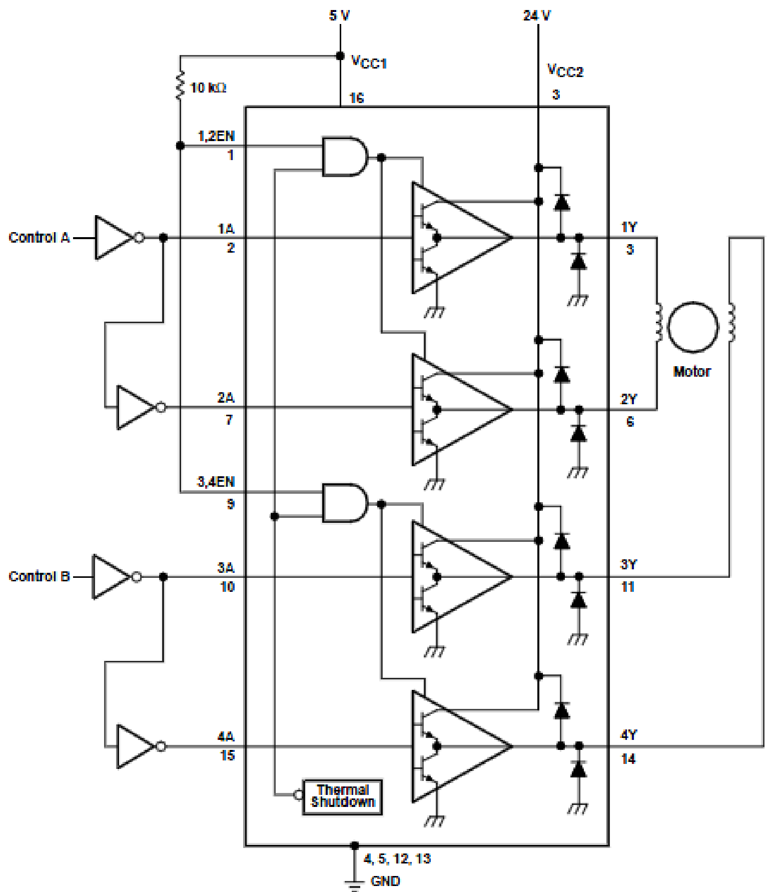


Figure36: L293D Application
Courtesy of Texas Instruments

Parameter		MIN	MAX	UNIT
Supply Voltage	V_{CC1}	4.5	7	V
	V_{CC2}	V_{CC1}	36	
High-level Input Voltage, V_{IH}	$V_{CC1} \leq 7$ V	2.3	V_{CC1}	V
	$V_{CC1} \leq 7$ V	2.3	7	
Low-level Input Voltage, V_{IL}		-0.3	1.5	V
Operating Free-air Temperature, T_A		0	70	^oC

Table19: L293D Operating Conditions

After comparison it seems that the L293D should be the better of the two Texas Instruments motor drivers. While it may be necessary to have a higher supply voltage than the SN754410, the fact that the diodes already internally installed saves the hassle of trying to add diodes to the driver externally through a breadboard for testing and eventually to a PCB which in turns saves crucial space. Now it is time to compare the L293D to the ATA6823.

Figure37 below shows the pin configuration of the ATA6823. As seen from the Figure, the Atmel ATA6823 is a 32 pin motor driver. The 32 pins on the ATA6823 show that it has much more functions than the L293D motor driver. Table20 below shows the what each pin shows the function of each pin. The Table below is found from the ATA6823 datasheet.

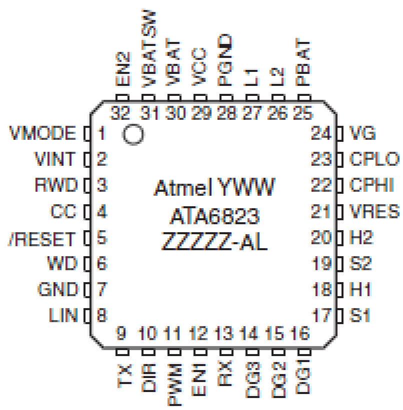


Figure37: ATA6823 Pin Layout
Reprinted with permission from Atmel

Pin	Symbol	I/O	Function
1	VMODE	I	Selector for V_{CC} and interface logic voltage level
2	VINT	I/O	Blocking capacitor 220nF/10V/X7R
3	RWD	I	Resistor defining the watchdog interval
4	CC	I/O	RC combination to adjust cross conduction time
5	RESTET	O	Reset signal for microcontroller
6	WD	I	Watchdog trigger signal
7	GND	I	Ground for chip core
8	LIN	I/O	LIN-bus terminal
9	TX	I	Transmit signal to LIN bus from microcontroller
10	DIR	I	Defines the rotation direction for themotor
11	PWM	I	PWM input controls motor speed
12	EN1	I	Microcontroller output to keep the chip in Active mode
13	RX	O	Receive signal from LIN bus for microcontroller
14	DG3	O	Diagnostic output 3
15	DG2	O	Diagnostic output 2
16	DG1	O	Diagnostic output 1

17	S1	I/O	Source voltage H-bridge, high-side 1
18	H1	O	Gate voltage H-bridge, high-side 1
19	S2	I/O	Source voltage H-bridge, high-side 2
20	H2	O	Gate voltage H-bridge, high-side 2
21	VRES	I/O	Gate voltage for reverse protection NMOS, blocking capacitor 470nF/25V/X7R
22	CPHI	I	Charge Pump Capacitor 220nF/25V/X7R
23	CPLO	O	
24	VG	I/O	Blocking capacitor 470nF/25V/X7R
25	PBAT	I	Power supple (after reverse protection) for charge pump and H-Bridge
26	L2	O	Gate voltage H-Bridge, low-side 2
27	L1	O	Gate voltage H-Bridge, low-side 1
28	PGND	I	Power ground for H-Bridge and charge pump
29	VCC	O	5V/100mA supply for microcontroller, blocking capacitor 2 2µF/10V/X7R
30	VBAT	I	Supply voltage for IC core (after reverse protection)
31	VBATSW	O	100Ω PMOS switch from V_{VBAT}
32	EN2	I	Enable input

Table20: ATA6823 Pin Description

When compared to the L293D, the ATA6823 is a full H-bridge configuration while the L293D is configured using a half H-bridge. The difference between a full H-bridge and a half H-bridge is that the full H-bridge uses 4 diodes for each output pin to allow current flow while a half H-bridge uses 2 diodes. The increase in the number of diodes translates to better current flow and less noise from PWM signal and less noise from output.

In addition to having a full H-bridge configuration, the ATA6823 also provides an additional pins not found in the L239D. Pins 14-16 on the ATA6823 are labeled "diagnostic" pins. The output of these pins allows us to see potential problems with the motor driver which will help us in debugging any potential error entered in the code we write. Below is Table21 shows the diagnostic pin outputs and the error that is associated with it. The X's in the Table represents don't cares. The Table is found in the ATA6823 datasheet.

Device Status					**Diagnostic Outputs**			**Comments**
CPOK	**OT1**	**OV**	**UV**	**SC**	**DG1**	**DG2**	**DG3**	
0	X	X	X	X	-	1	-	Charge pump failure
X	1	X	X	X	-	-	1	Overtemperature warning
X	X	1	X	X	-	1	-	Overvoltage
X	X	X	1	X	-	1	-	Undervoltage
X	X	X	X	1	1	-	-	Short circuit

Table 21: ATA6823 Diagnostic Outputs

Another unique pin found on the ATA6823 and not on the L293D Pin 10 which is the DIR pin. According to Table F above, the DIR controls the direction of the motor which it can either go clockwise or counter-clockwise. The DIR pin will allow for more precise control while coding for precise movement of the projectors when attached to the pan-tilt tray. Table 22 below shows the truth Table of the DIR pin with the high side (H1) and low side (H2) PWM inputs from a microcontroller. This Table is found in the ATA68233 datasheet.

Control Inputs			**Driver Stage for External Power MOS**				**Comments**
ON	**DIR**	**PWM**	**H1**	**L1**	**H2**	**L2**	
0	X	X	OFF	OFF	OFF	OFF	Standby mode
1	0	PWM	ON	OFF	PWM	PWM	Motor PWM forward
1	1	PWM	PWM	PWM	ON	OFF	Motor PWM reverse

Table 22: Motor Direction based on DIR Pin

After comparing both the ATA6823 and the L293D, the clear choice is the ATA6823. The ATA6823's ability to provide IC status' for potential problems (charge pump failure, over temperature warning, overvoltage, under voltage, short circuit) as well as its ability to provide more control of the direction of current flow with the DIR Pins as well as the high and low pins gives the ATA6823 a clear advantage over the L293D. If a hardware auto-alignment solution is decided upon in the final design for our projectors, the ATA6823 is the motor driver that will be used.

Section 4: Design

4.1: Overall Design

Our complete system will show a comparison between existing simulation setups and our new projector array design. The figures below show an overview of our system setup.

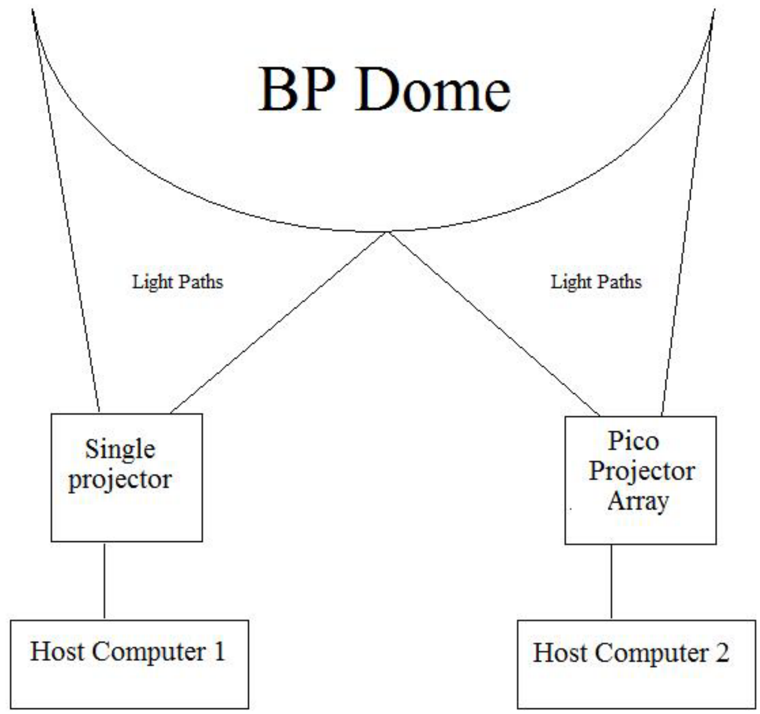


Figure 38: Basic System Setup

The goal of this design is to compare and contrast the existing setup in simulators to our newly developed solution. The ideal outcome is to have a higher quality image coming from our projector array; however,a equivalent image is more than sufficient.The images below show the comparison between existing setups and our new setup:

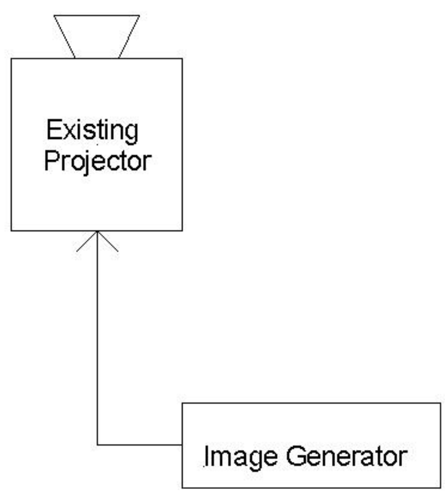


Figure 39: Existing Projector IG setups used for current systems

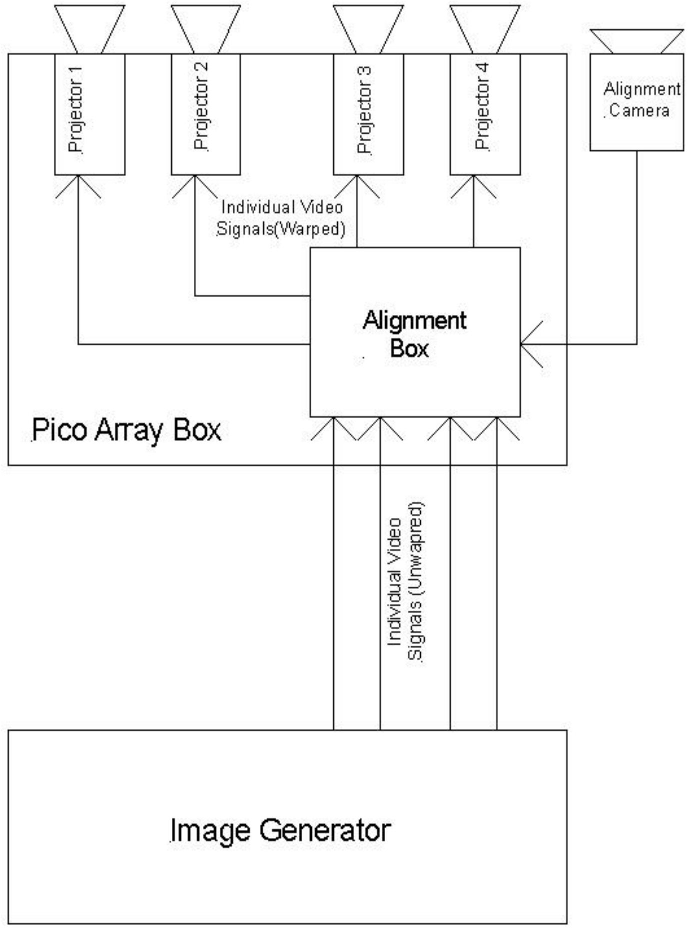


Figure 40: Our Pico Array Setup

4.2: Host Computer System

Our host computer system will be designed as a graphics workhorse. The ideal setup will have the ability to drive a large number of projectors with extremely high quality graphics. This computer will handle all of the graphical processing including the warping and alignment of the image, which will require an immense amount of graphics processing. We have identified the AMD FirePro W600 graphics card for use with our system. This gives us an ideal mixture of high quality graphics, a large number of output ports, and native compatibility with multi-projector display setups. This will be placed into our host computer system to drive our projector array via a PCI express bus.

The host computer system will be a Windows based desktop computer. It will be powered by an Intel i7 processor to ensure maximum computational abilities and to remove any system bottlenecks that could limit the graphical output of the system. We will install the Warpalizer alignment software onto this computer. The Warpalizer software requires Windows 7 to operate correctly, as it utilizes

Windows proprietary AeroGlass technology. Many simulators run on customized Linux operating systems, however due to cost restrictions in the alignment technology a Windows based solution was necessary for this project. The AMD graphics card will require the latest drivers to be installed to ensure maximum compatibility with multi-projector setups, as new updates are expected in Q4 of this year. A quality video player will also be required for testing purposes. Windows Media Player, which is factory installed on all Windows based systems, should provide sufficient video capabilities for this purpose.

Video Signals: From our host computer system we will run four video cables to our box to supply imagery to the projectors. The AMD FirePro W600 supplies us with 6 mini display ports, which follow the DisplayPort1.2 formatting, for this purpose. We will acquire mini display port to HDMI conversion cables, to convert the formatting of the signals to a format accepted by our projectors. These cables will plug into the back of our projector box and additional HDMI cables, contained within our box, will then supply the signal to our projectors.

The video signals will be warped and aligned using the Warpilizer alignment software. Warpilizer allows the user to save any configuration once aligned. This will allow us to warp and edge blend our image before any presentation of the system. Once a configuration is saved, the user can easily upload this configuration with one button press. This gives us the ability to show both our warped and un-warped images for the purposes of comparison, without any lengthy setups.

A serial communication interface will be used to transmit data to and from our PCB within our box. Our microcontrollers will supply TTL serial data that will be converted to RS-232 data which can be accepted by our host system. After conversion, the signal will be routed to a Db9 connector on the back of our projector box. If a standard 9 pin serial port is available on our host system, we will use this port for the interfacing. Serial ports of this nature are becoming a rarity in modern computer systems, so a RS-232 to USB converter may be required for this interfacing. This will not be determined until a host computer system is acquired.

To ensure user friendliness, a simple Graphical User Interface (GUI) will be created to display information to the screen. This will be created using the GUI toolkit, Fox. A toolkit such as fox takes out the lengthy programming required to make simple GUI’s, with a simple API to create windows, buttons, texts, and other elements required in GUI’s.

Our GUI will ensure maximum user friendliness. There will be only one window with two buttons placed within it. One button will be used to get light levels measured by our light sensor array, while another button will be used to exit the program. When the user presses the button to acquire light levels, a command will be sent from our host computer via RS-232 serial data to our microcontroller inside of our projector box. This data will be converter to TTL serial data which is accepted by our microcontrollers. The microcontroller inside of the box will then retrieve the data from our light sensor array PCB and transmit this data back to our host computer system. The GUI will then display this data onto the screen for the user. The data will be displayed in an array showing the light intensity (in lumens) measured by each sensor, as well as the total lumen measurement of the image as a whole. This total measurement is calculated by averaging the measurement from each sensor and will be calculated by the host computer system, as the computers computational abilities will greatly outweigh the microcontrollers computational abilities.

The GUI will be designed using Microsoft Visual Studio. Once a solution file (.sln) is created via Visual studio, we will create a Windows installer using the NSIS program. An installer allows any user to easily install the program onto their system. It also ensures that the program, and all of its dependencies, is correctly installed and used by the Windows operating system. The installer will also create a executable file to uninstall the program, ensuring accurate and correct removal of the program from the system.

4.3: Interface/Controls

The interfacing and control of our system will require synchronization of 3 separate components. A PCB with a microcontroller will be used on our light sensor array to input the analog data from our light sensors and transfer that data to our box. A PCB with a microcontroller will be used inside of our projector box to input the serial data from the light sensor array PCB and transmit this data to the computer. The user interface will be implemented on the host computer system. Each component will be independent and require independent circuit design and/or programming to work properly.

4.4: Light Sensor PCB

The light sensor PCB will be controlled by the ATmega 2560 microcontroller. Once a command via the TTL serial data link to the projector box is received the microcontroller will then poll the light sensors for data regarding the light intensity of our projector’s image. The microcontroller will then convert the analog signals data to the corresponding lumen values and transmit this data via the TTL serial data link back to the projector box. No conversion of the serial data will be needed as both microcontrollers accept and transmit TTL serial data.

Programming: The programming for this microcontroller will be developed using the Arduino development environment available via Arduino’s website. This environment accepts high level languages such as C and C++, as well as object oriented design. There are some proprietary API’s that will also be implemented.

The program will utilize four custom functions and one main function outside of the proprietary API. The four functions will include:

- TTL Serial data receive (Serial_receive())
- TTL Serial data transmit (Serial_transmit())
- Analog signal receive (Analog_receive())
- Data conversion (Data_Convert())

Serial_receive() and Serial_transmit() will be used to send and receive the TTL serial data to and from the projector box. Analog_receive() will be used to poll the light sensors and input it's corresponding analog signal. Data_Convert() will be used to convert the analog signals to their corresponding lumen values.

The program will sit in a loop waiting for a digital signal to come from the projector box requesting data. Once this signal is received, the program will we use the analog_receive function to poll the light sensors and receive their corresponding analog signals. Once it has received these signals it will call data_convert to convert the signals to the respected lumen values. Once all the conversion is completed the microcontroller will use Serial_transmit to send the data down to the box. The following flow chart shows the logical flow of the program:

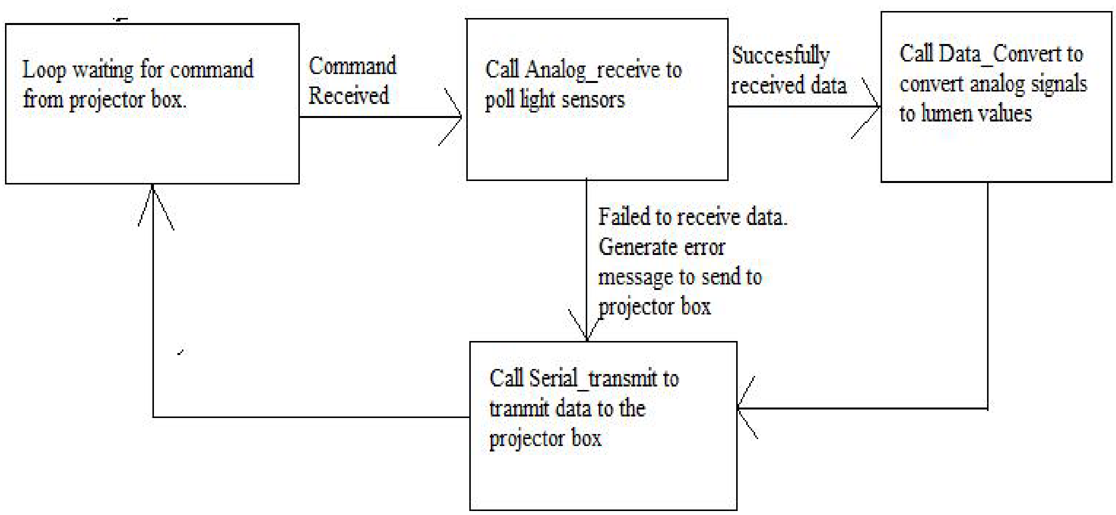


Figure 41: Light Sensor Microcontroller Program Flow Chart

Circuitry: A PCB will be designed to hold all of the circuitry for our Light Sensor Array. A 9 pin header will be used to attach the individual light sensors to our PCB. A Db9 connector will be used to send power to the board from our projector box, to transmit the TTL serial data to and from our projector box, and carry a single control signal from our box to initiate the program. A low pass filter will be designed to filter out any noise that may come through from our light sensors before the signal reaches our microcontroller. All 9 different light sensor signals will need to pass through this filter before being sent to the microcontroller for processing. Instead of building 9 filters we will implement a 9 to 1 multiplexer to switch between each of our signals and allowing them to pass through our single low pass filter. The multiplexer will be controlled via our digital outputs from our microcontroller. The output from the multiplexer will be attached to one of the analog inputs on our microcontroller. The circuitry for our light sensor PCB is given below:

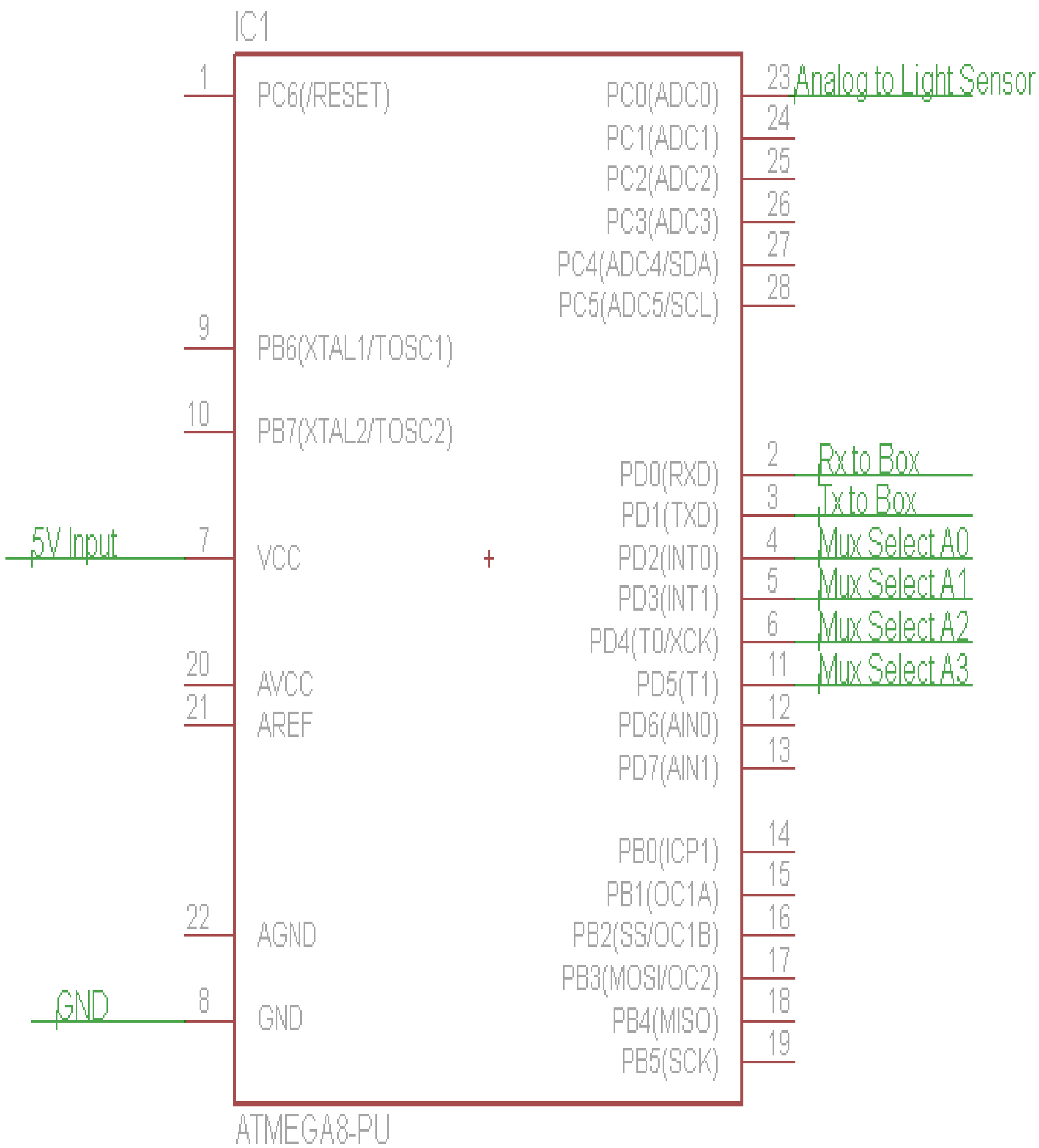


Figure 42: Light Sensor Microcontroller Schematic

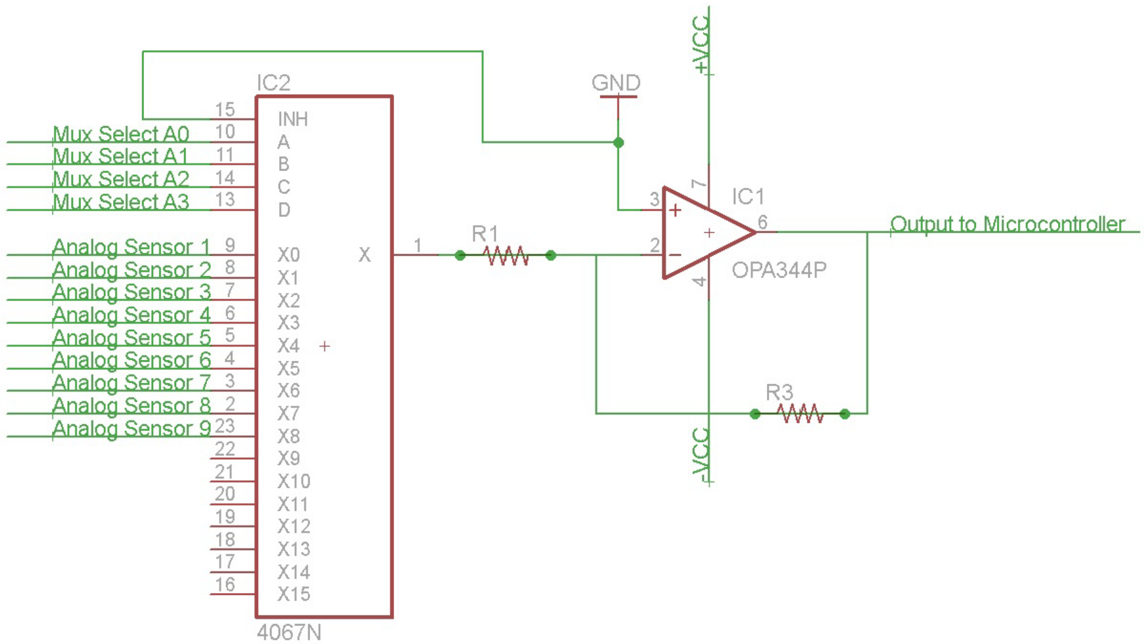


Figure 43: Light Sensor Filter and Mux Schematic

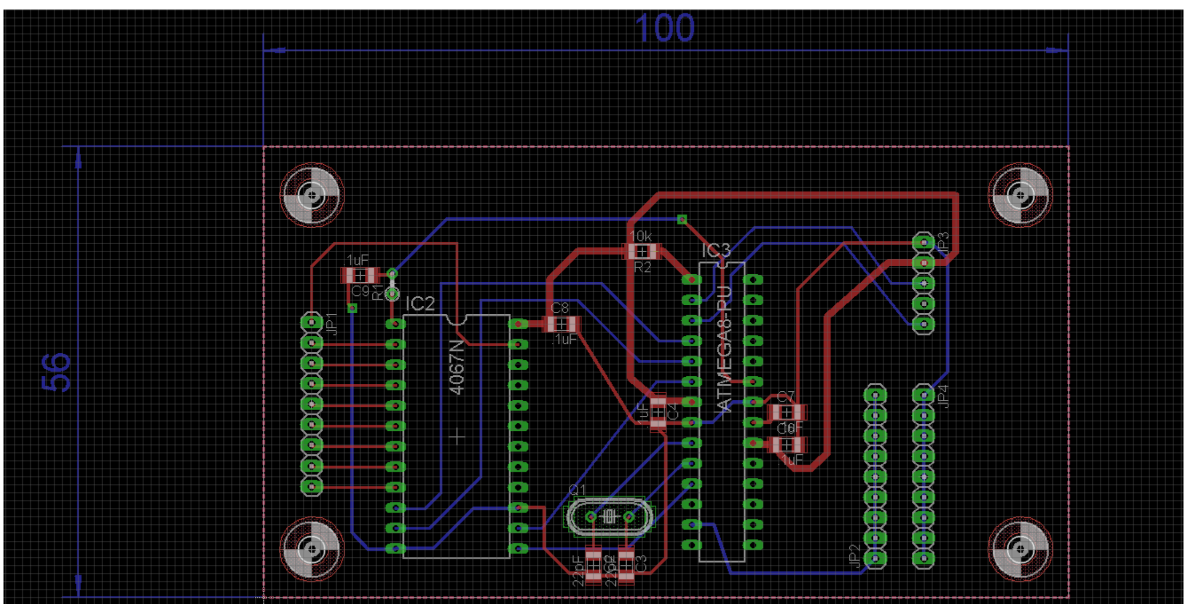


Figure 44: Light Sensor PCB Layout

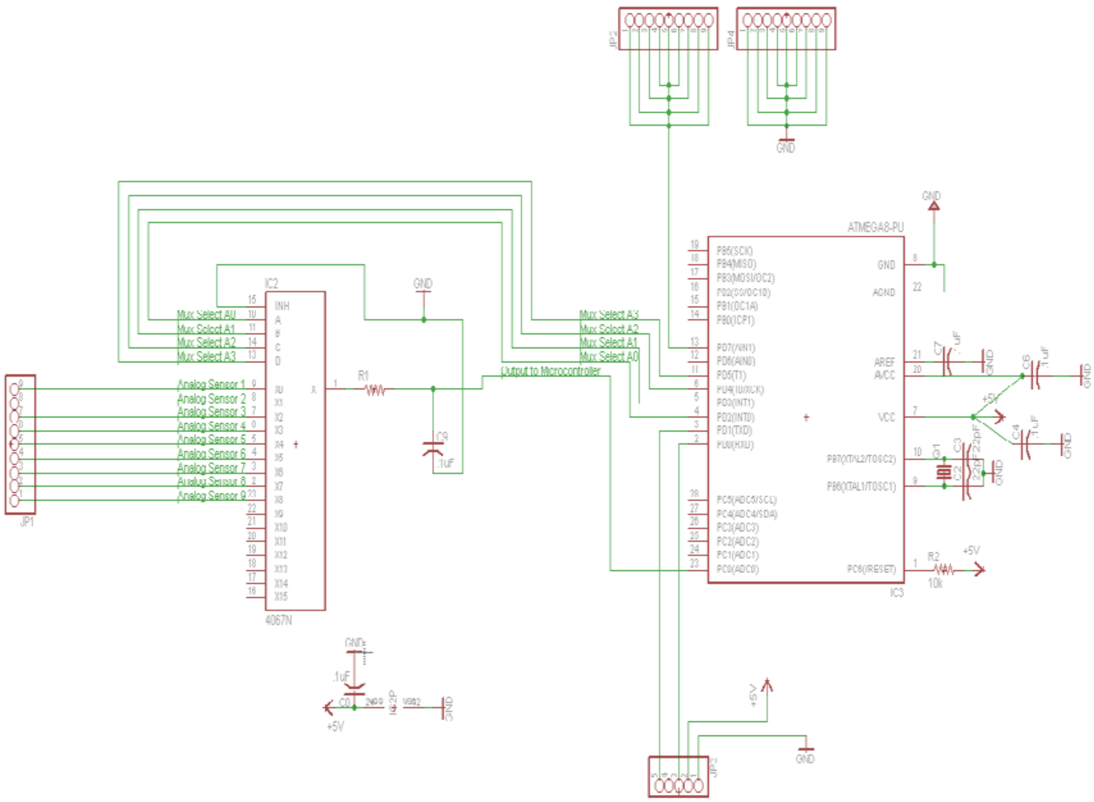


Figure 45: Light Sensor Controller Full Schematic

4.5: Projector Box PCB

The projector Box PCB will include an ATmega 328 microcontroller for control and interfacing purposes. This PCB will also contain the power source for our entire system but that will be covered in another section of this report. This controller will be connected to our host computer system via a RS-232 serial data link for displaying information to the end user. Our host computer will send a command to this controller asking for data. The controller will interpret this command and then poll the light sensor array for information via a TTL serial data link. It will then receive this data via the same serial data link and then transmit this information out to the host computer system.

Programming: The programming for this microcontroller will be developed using the Arduino development environment available via Arduino's website. This environment accepts high level languages such as C and C++, as well as object oriented design. There are some proprietary API's that will also be implemented.

This program will implement two custom functions and one main function outside of the proprietary API's. The functions will include:

- RS-232 Data Receive   Serial_receive()
- TTL Data Transmit   Serial_transmit()

Serial_receieve will input the RS-232 Serial data from the Host computer system. Serial_transmit will output TTL serial data up to the Light Sensor Array. Our microcontroller can only receive and transmit TTL serial data but our circuitry will invert the RS-232 signals from our host computer to TTL signals that can be accepted by our microcontrollers.

The program will sit in a loop waiting for a digital signal from the host computer system requesting data. A digital signal will then be sent out to a multiplexer to switch the path of the serial data away from the computer system to the light sensor array. It will then send a digital signal up to our microcontroller on our light sensor array requesting the data needed by the host system. Once the light sensor array sends the data the program will receive the data, change the digital signal to the multiplexer rerouting the signal to the host computer system, and then send that data on to the host computer system. The following flow chart shows the logical flow of the microcontrollers program:

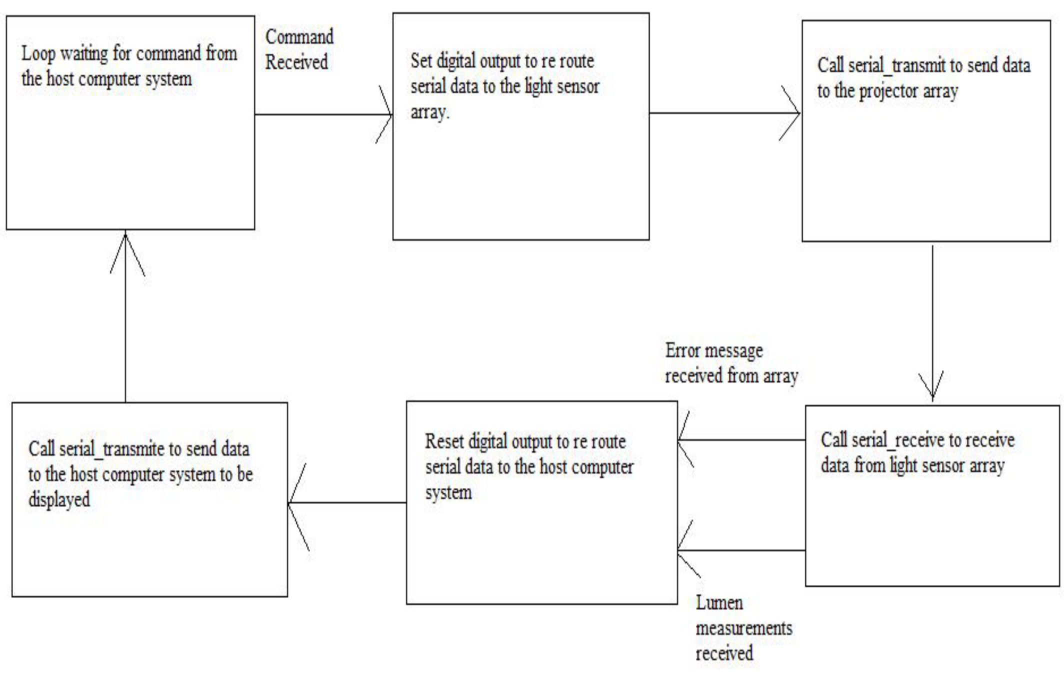


Figure46: Flow Chart for Projector Box Microcontroller Program

Circuitry: A PCB will be design to hold all of the circuitry for the interface will the host computer system as well as the Power source. A two pin header will take the RS-232 serial data from the back of our box to the PCB. A 4 pin header will take TTL serial data, power, and a control signal to a Db9 connector to route up to the light sensor array PCB. The RS-232 serial data will need to be inverted to TTL signals that are accepted by our microcontroller. This inverting will be done by a MAX 232 chip. Both the serial data links will be connected to a 2 to 1 multiplexer that will be controlled by a digital output from our microcontroller. Power will be supplied to the controller from the power source circuitry on this board. Theschematics for the Controllers circuitry only is given below:

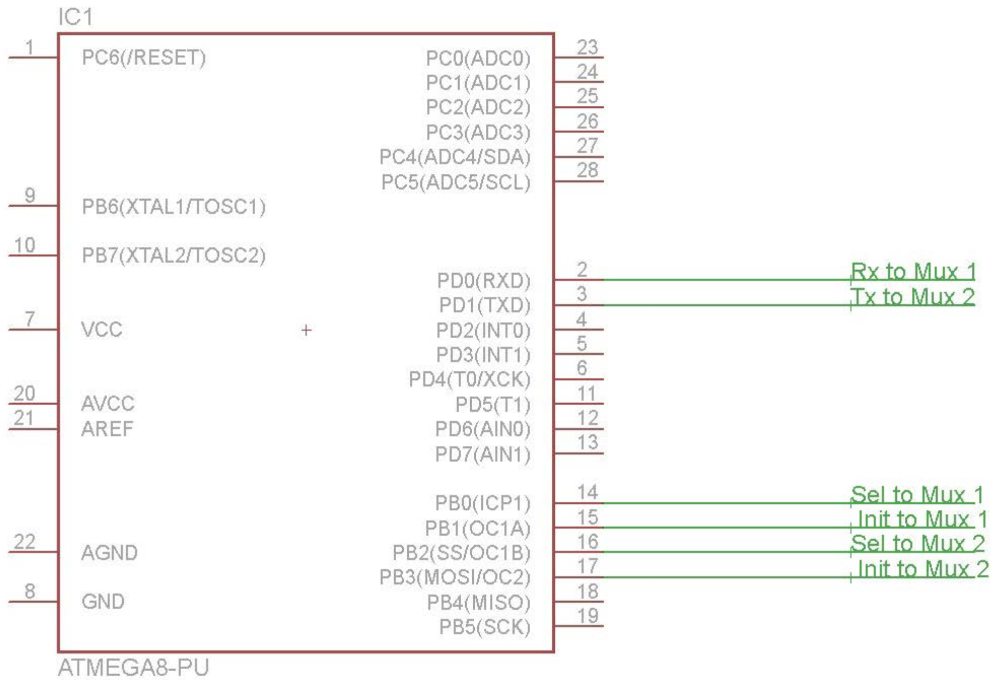


Figure 47: Projector Box Microcontroller Schematic

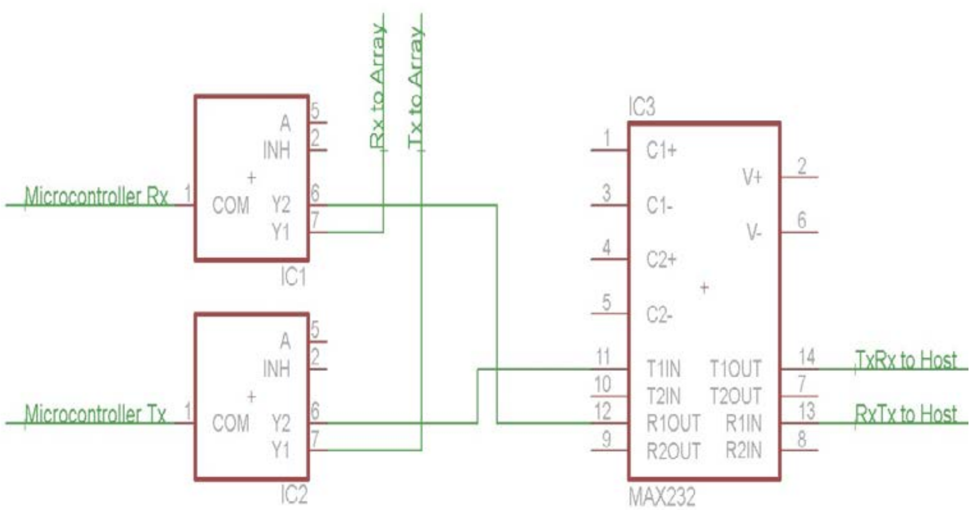


Figure 48: Projector Box Mux and Max232 Schematic

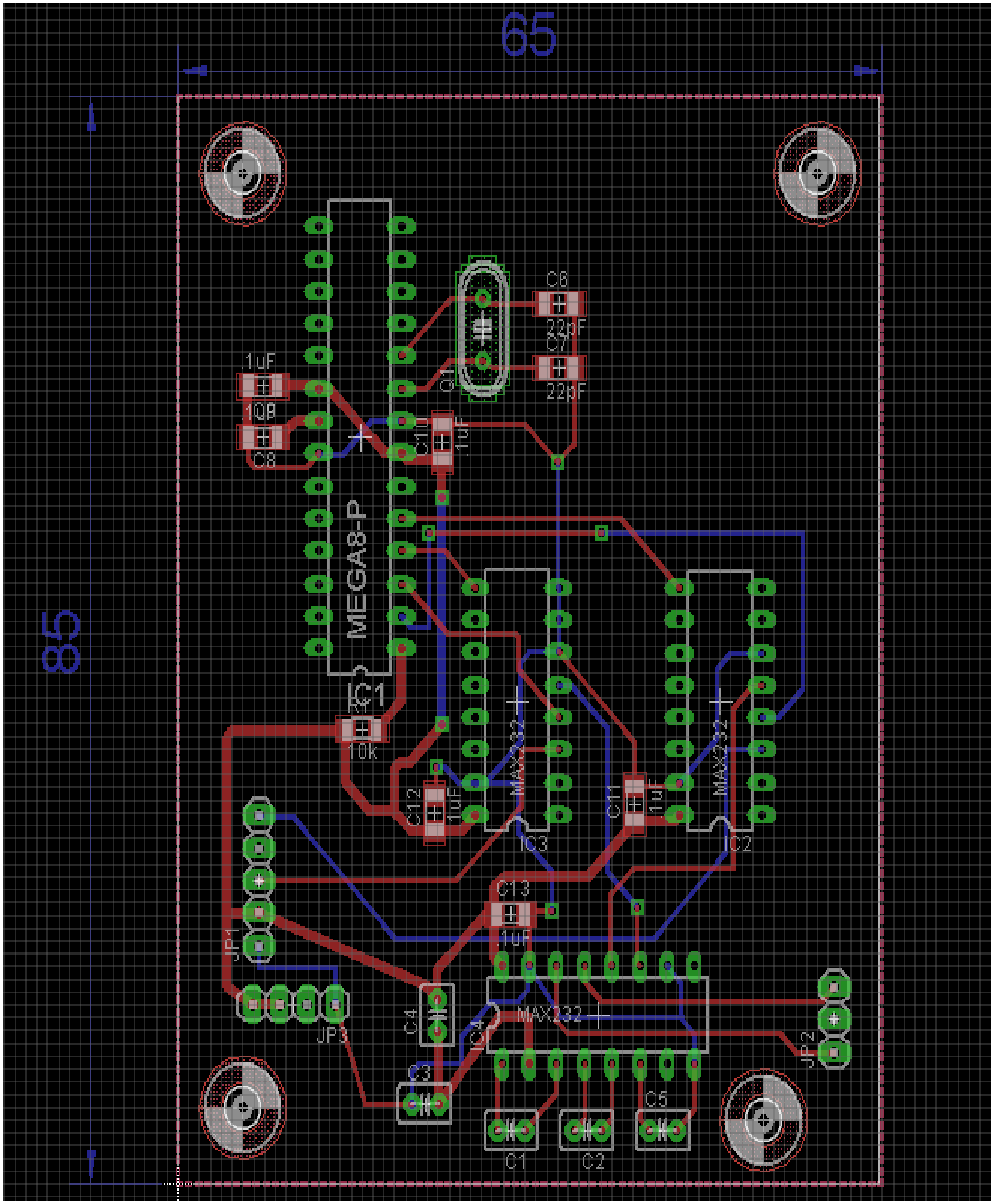


Figure 49: Projector Box PCB Layout

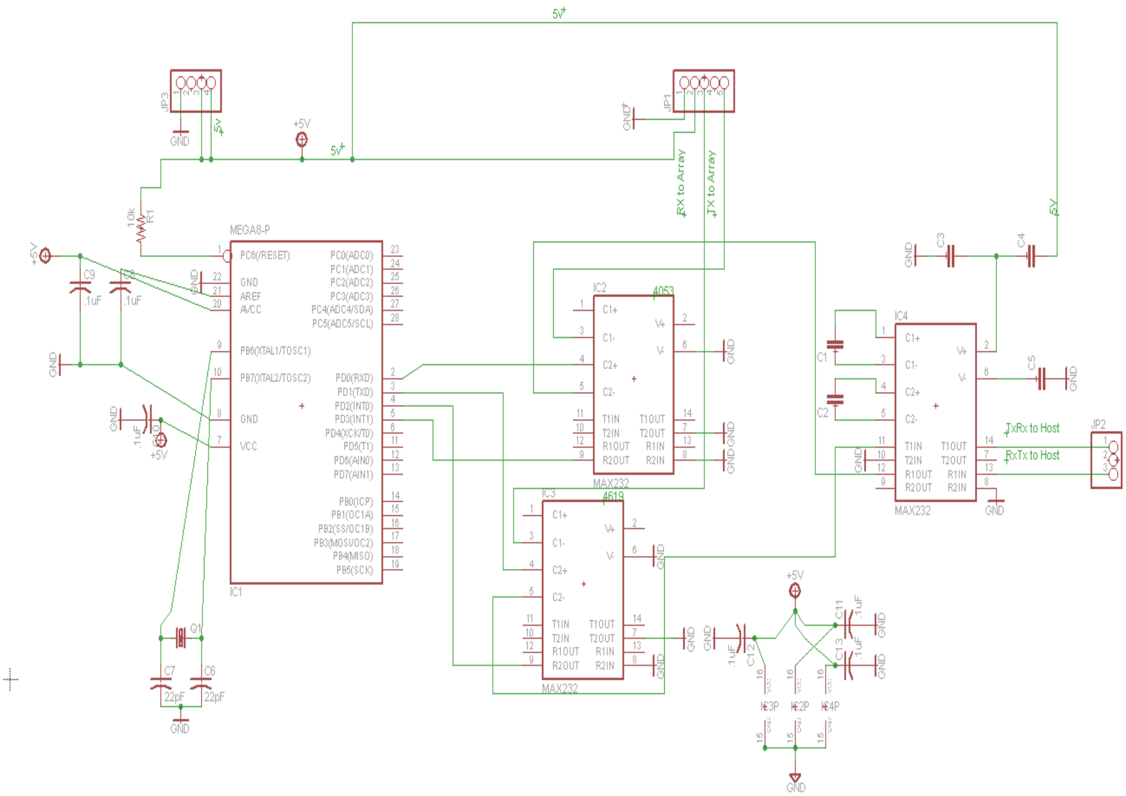


Figure 50: Projector Box Full Schematic

4.6: Power

In order to make the best design decision, we must first analyze the different reference designs discussed in the research section of this document. Each of the designs have pros and cons and all things including efficiency, simplicity, cost, functionality, feasibility, performance, and many other factors need to be considered before the design process can begin. The information below gives an overview of the comparisons and tradeoffs between the switched mode power supply and the linear power supply. This information will be used to help determine which design is best suited for our design specifications which will allow us to proceed with the design phase of the project. The first design we will take a look out will be the linear power supply.

Linear Power Supply

Size and Weight:

- Heatsinks for high power linear regulators add size and weight. Transformers, if used, are large due to low operating frequency (mains power frequency is at 50 or 60 Hz); otherwise can be compact due to low component count.

Output Voltage:

- If a transformer is used, any output voltage is available; if transformer is not used, no output voltage available exceeding input. If unregulated, voltage varies significantly with load.

Efficiency, Heat, and Power Dissipation:

- If regulated: efficiency largely depends on voltage difference between input and output; output voltage is regulated by dissipating excess power as heat resulting in a typical efficiency of 30–40%.[13] If unregulated, transformer iron and copper losses may be the only significant sources of inefficiency.

Complexity:

- Unregulated may be simply a diode and capacitor; regulated has a voltage-regulating circuit and a noise-filtering capacitor; usually a simpler circuit (and simpler feedback loop stability criteria) than switched-mode circuits.

Radio Frequency Interference:

- Mild high-frequency interference may be generated by AC rectifier diodes under heavy current loading, while most other supply types produce no high-frequency interference. Some mains hum induction into unshielded cables, problematical for low-signal audio.

Electronic Noise at Output Terminals:

- Unregulated PSUs may have a little AC ripple superimposed upon the DC component at twice mains frequency (100–120 Hz). It can cause audible mains hum in audio equipment, brightness ripples or banded distortions in analog security cameras.

Electronic Noise at Input Terminals:

- Causes harmonic distortion to the input AC, but relatively little or no high frequency noise.

Acoustic Noise:

- Faint, usually inaudible mains hum, usually due to vibration of windings in the transformer or magnetostriction.

Power Factor:

- Low for a regulated supply because current is drawn from the mains at the peaks of the voltage sinusoid, unless a choke-input or resistor-input circuit follows the rectifier (now rare).

Inrush Current:

- Large current when mains-powered linear power supply equipment is switched on until magnetic flux of transformer stabilizes and capacitors charge completely, unless a slow-start circuit is used.

Risk of Electronic Shock:

- Supplies with transformers isolate the incoming power supply from the powered device and so allow metalwork of the enclosure to be grounded safely. Dangerous if primary/secondary insulation breaks down, unlikely with reasonable design. Transformer less mains-operated supply dangerous. In both linear and switch-mode the mains, and possibly the output voltages, are hazardous and must be well-isolated.

Risk of Equipment Damage:

- Very low, unless a short occurs between the primary and secondary windings or the regulator fails by shorting internally.

Switching Power Supply

Size and Weight:

- Smaller transformer (if used; else inductor) due to higher operating frequency (typically 50 kHz – 1 MHz). Size and weight of adequate RF shielding may be significant.

Output Voltage:

- Any voltages available, limited only by transistor breakdown voltages in many circuits. Voltage varies little with load.

Efficiency, Heat, and Power Dissipation:

- Output is regulated using duty cycle control; the transistors are switched fully on or fully off, so very little resistive losses between input and the load. The only heat generated is in the non-ideal aspects of the components and quiescent current in the control circuitry.

Complexity:

- Consists of a controller IC, one or several power transistors and diodes as well as a power transformer, inductors, and filter capacitors. Some design complexities present (reducing noise/interference; extra limitations on maximum ratings of transistors at high switching speeds) not found in linear regulator circuits.

Radio Frequency Interference:

- EMI/RFI produced due to the current being switched on and off sharply. Therefore, EMI filters and RF shielding are needed to reduce the disruptive interference.

Electronic Noise at Output Terminals:

- Noisier due to the switching frequency of the SMPS. An unfiltered output may cause glitches in digital circuits or noise in audio circuits.

Electronic Noise at Input Terminals:

- Very low cost SMPS may couple electrical switching noise back onto the mains power line, causing interference with A/V equipment connected to the same phase. Non power-factor-corrected SMPSs also cause harmonic distortion.

Acoustic Noise:

- Usually inaudible to most humans, unless they have a fan or are unloaded/malfunctioning, or use a switching frequency within the audio range, or the laminations of the coil vibrate at a sub harmonic of the operating frequency.

Power Factor:

- Ranging from very low to medium since a simple SMPS without PFC draws current spikes at the peaks of the AC sinusoid.

Inrush Current:

- Extremely large peak "in-rush" surge current limited only by the impedance of the input supply and any series resistance to the filter capacitors.

Risk of Electronic Shock:

- Common rail of equipment (including casing) is energized to half the mains voltage, but at high impedance, unless equipment is earthed/grounded or doesn't contain EMI/RFI filtering at the input terminals.

Risk of Equipment Damage:

- Can fail so as to make output voltage very high. Stress on capacitors may cause them to explode. Can in some cases destroy input stages in amplifiers if floating voltage exceeds transistor base-emitter breakdown voltage, causing the transistor's gain to drop and noise levels to increase. Mitigated by good failsafe design. Failure of a component in the SMPS itself can cause further damage to other PSU components; can be difficult to troubleshoot.

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Using the information on the previous pages as well as the information contained in the research section of this document, a design decision based on multiple considerations must be made in order to begin the design process.

The linear regulator design is the most simplistic solution to our design requirements. There is no need for complex parts in this design other than possibly the transformer. The other circuit elements to this design include:

- Step down transformer to decrease the amplitude of the incoming AC signal
- 4 diodes for the full wave rectifier
- Multiple Capacitors that will be used for smoothing and filtering
- Multiple Resistors for voltage divider circuits and circuit stability
- Multiple Operational amplifiers to amplify DC signal levels
- Multiple voltage regulators to regulate DC voltage to specific parts

At this point, the linear regulator is a viable option, but will not be used as the final design for our project. Although the circuit is the most basic in design nature, it is the least electrically efficient design, and not the most cost efficient option for our design specifications.
The switched mode power supply is by far the most complex design we are considering for our design. This design requires many high frequency components that enable us to achieve a very high efficiency through the transformation process of our design. The main components included in this design include:

- 8 diodes for full wave rectification (rectification done twice in this design)
- Power Oscillator for the "inversion" stage to convert high level DC voltage into high level AC voltage at very high frequency
- High frequency step down transformer to step down AC signal from oscillator
- Capacitors for smoothing of DC signal and filtering
- Resistors for voltage division and circuit stability
- Voltage regulators to regulate voltage at a steady level to electronic devices

Although the switched mode power supply provides us with probably the most efficient design, it is the most complex design and introduces the highest level of electronic noise into our circuit. The electronic noise is a byproduct of the multiple high frequency components that are used in this design and thus would require further design stages to properly filter and shield the noise from the other electronics in our circuit. Due to the fact that the circuit will be located in a box in close proximity to other electronic devices, such as the pico projectors, the noise generated from the design could have an adverse affect on the picture quality of the projectors. Also, the switched mode power supply is also the most expensive solution for our design specifications. All of these reasons have led us to consider our other options in choosing our final design.

The third option for our design solution uses methods from the linear power supply as well as the switched mode power supply. In this design the transformation and rectification will be done via methods similar to those of the linear power supply, thus requiring many of the same parts as that specific design. However, the DC circuitry will consist of a step down DC to DC converter similar to the designs of the switched mode power supply. The DC to DC converter will also act as a regulator as the part accepts a wide range of DC inputs and regulates at a constant DC output. This alleviates the need of multiple voltage regulators on the DC side of the design and as long as we design the output from the converter to be high enough, simple voltage division techniques can be used to supply steady power to all of the electronics. The main parts included in this design are:

- Step down transformer to step the incoming AC signal down
- 4 diodes for rectifier circuit
- Multiple Capacitors for smoothing and filtering
- Step down DC to DC converter to regulates steady DC signal
- Multiple resistors for voltage division and circuit stability

This design has an increased efficiency when compared to that of the pure linear power supply due to the high efficient DC to DC converter chip, but not as efficient as the switched mode power supply due to the losses incurred during the transformation stage as this design does not utilize the high frequency transformer as the switched mode supply does. The circuitry for this circuit is not very complex although the use of the DC to DC converter will take some additional requirements that need to be addressed before the design phase can actually begin. The cost of this design is slightly more than the linear regulator but much less than that of the switched mode power supply. All things considered, this is definitely a viable option to satisfy our design requirements, but will not be the design we use for our project.

The fourth option is also a mixture of linear power supply and switched mode power supply. This design utilizes a commercially available part for the transformation and rectification phase of the design which utilizes switched mode technology. The part is capable of accepting any incoming signal from a power outlet anywhere in the world and producing a steady DC output. This all in one part delivers a cost efficient solution for multiple requirements in the design of our power system. Also, since the output of this part is regulated through a vast range of inputs, there is no need for additional voltage regulators in our circuit as the output will remain constant at all times. We can further simplify our design from the use of operation amplifiers as long as the output of the part we use outputs a DC voltage level higher than what any of our electronic devices require, we can use simple voltage division techniques to deliver the required power to the parts in our circuit. The parts that we will need to build this design are:

- AC to DC conversion part
- Resistors for voltage division and circuit stability
- Capacitors for circuit stability
- Inductor to control current flow to DC circuit

This design has similar efficiency to the third design option we explored, which is lower than the switched mode design and higher than the linear power supply. This design has by far the easiest design implementation with regards to building the circuitry, and is about as cost efficient as any other solution as well. Another benefit of using this part to achieve our design solution is the fact that this part also has built in circuit protection for the AC to DC conversion. This too alleviates the problem of having to design multiple circuit protections systems for issues that may arise, and can also be very difficult to do as well. Due to all of these factors and the fact that what we are giving up in efficiency to the switched mode power supply is not very significant when considered with the cost savings of this design and implementation, this is the design we will go with for our solution to our design specifications. Table 23below gives an overview of each design and it's rating with regards to many fundamental concepts and considerations that were used in making this decision.

Design	Efficiency	Design Difficulty	Cost	Electronic Noise
Linear Power Supply	~ 58 – 70%	Moderate	~ $60	Low
Switched Mode Power Supply	~ 78 – 84%	High	~ $80-95	High
Step Down DC to DC Converter	~ 70 – 78%	Moderate	~ $65	Low
AC to DC Converter	~ 72 – 79%	Low	~ $55-75	Low

Table 23: Design Decision Matrix

The “Design Difficulty” column is based on a low, moderate and high scale and describes how complex the actual circuit design will be based on what components are required for the build.

The “Cost” column gives an overview on how much the design will cost to build and actually implement on to a PCB. These are just rough estimates based on the parts that were researched in the preceding sections as well as cost to develop a printed circuit board with all parts soldered onto the board, so basically the completed product.

The “Electronic Noise” column is rated on the same low, moderate, high scale and gives us insight into the amount of electronic noise introduced by each design. We felt this was valuable information due to the fact that our power system design will be placed inside a box that will be in close proximity to other electronic devices such as the pico projectors and the analog light sensors and could introduce interference to these parts. This could ultimately compromise the performance of our design and circuits with high noise levels would also required “shielding” techniques, thus requiring further design and funding that at this point is unnecessary for our requirements.

4.6.1: Design Implementation

Since we now understand all of our design requirements and have adequately researched all of our potential solutions and made a design decision, we must focus on how our design is going to be implemented. Throughout the process of our design there have been a few changes as to what all will need to be addressed from the power end of the project. The following changes have been made to the design, and thus have created changes within the power requirements which need to be considered for our implementation:

- Decision to go with software auto alignment over hardware so servo motors will not be used and do not need to be accounted for
- Pico Projectors run on AC power as they contain their own AC to DC conversion circuitry, so power block will be set up in conjunction with PCB
- Microcontroller requires 5 VDC input and can consume up to 15 W of power so AC to DC converter must be capable of supplying this to the DC circuit

Although there have been multiple changes since the initial design specifications were created, none of the above changes affect our decision on the design that we have chosen. The elimination of the servo motors actually greatly reduces the complexity of our design as these motors generally consume a lot of power in comparison with the other small devices. The decision to use the AC to DC conversion circuitry that comes with the pico projectors also greatly reduces our design efforts with regards to designing the printed circuit board. We will still have to take into consideration the power requirements of the pico projectors, but this allows us to take the pico projectors off of our printed circuit board and find another means of supplying the correct power to these devices. The power flow block diagram is given in Figure48 below. In this diagram the power flow is laid out on a printed circuit board giving the names of the blocks that are responsible for different functions in our design. The parts that will be included in this design can all be found in the power system research section of this document.

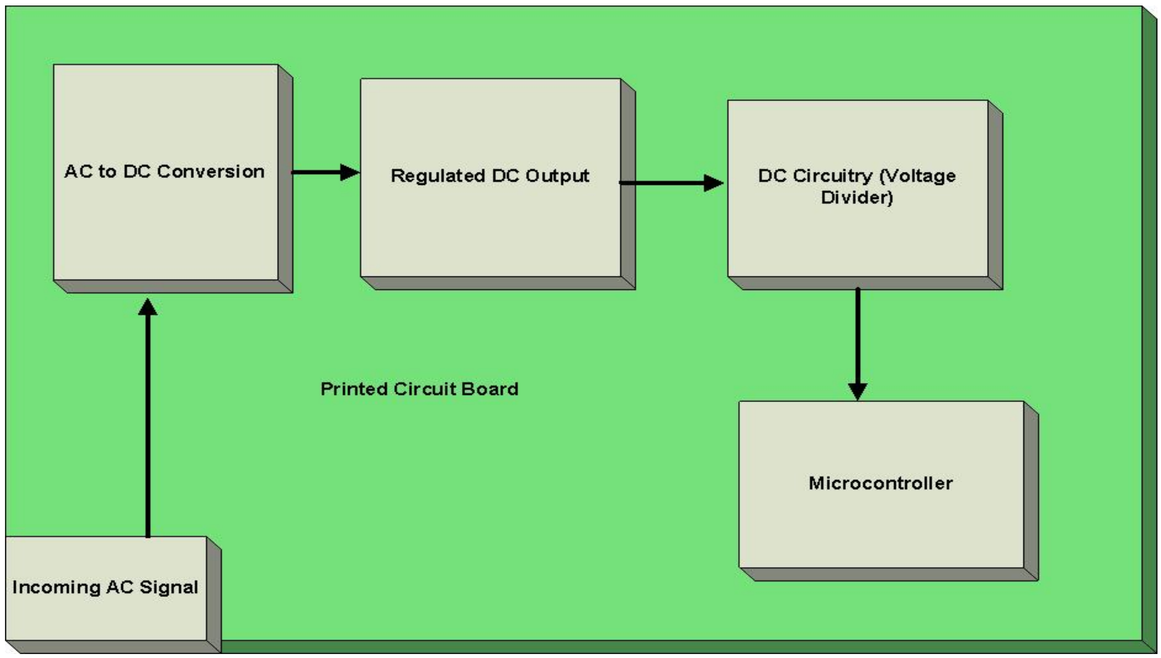

Figure 51: Power Flow Block Diagram on PCB

Also, as stated above, the microcontroller used in our design consumes 10 watts of power at 5 volts DC. Using the information that we acquired in the "Power System Research" and specifically the "Parts Research" section, only one of the devices we were interested in are capable of this power requirement. Thus, the VMS-20-5 by CUI Inc. will be the part that we choose to use in our design. If we find that this part is not capable of supplying the correct power requirements then there are multiple devices that provide more power than this specific part and are implemented in a similar fashion. The cost of these parts does increase as the power input increases however. Although this does give some rise for concern, the power system is relatively inexpensive in comparison to the rest of our design, which includes graphics cards that cost hundreds of dollars and projectors that can total over five hundred dollars apiece. The power system will still be developed for less than one hundred dollars even if we do discover that we need a power supply with a larger output power. Some additional research has led us to find a part that is similar to the same input and output ranges as stated in the parts research section and manufactured by Volgen America® and is capable of higher power outputs than any of the parts we previously quoted.

Going back to the fact that the pico projectors contain their own AC to DC conversion circuitry, this greatly reduces the design complication of the power system. This allows us to create a power block that can be placed off of the printed circuit board but close in proximity within the box. We can take the incoming power line into the box, which will house the projectors, the power system and the circuitry containing the microcontrollers and the light sensors, and split the power line to go to the power block as well as the input to the printed circuit board. At this point the incoming power signal will be applied to the power block and the printed circuit board.

The printed circuit board will then take that incoming power and create the steady DC signal that it is designed to do and power all of the small electronics, such as the microcontroller and the light sensors.

The power block will act as a power hub for the pico projectors and is in essence just a parallel connected outlet port. This will provide the unchanged incoming AC signal to the pico projectors which contain their own AC to DC conversion circuitry to ensure they are properly powered.

All of the previously mentioned devices will be contained inside a single unit, “power box”, which will be hidden from view. At this time, there are multiple configurations on how to use the power block in conjunction with the printed circuit board, but Figure49 below is the design that we intend to use as of right now.

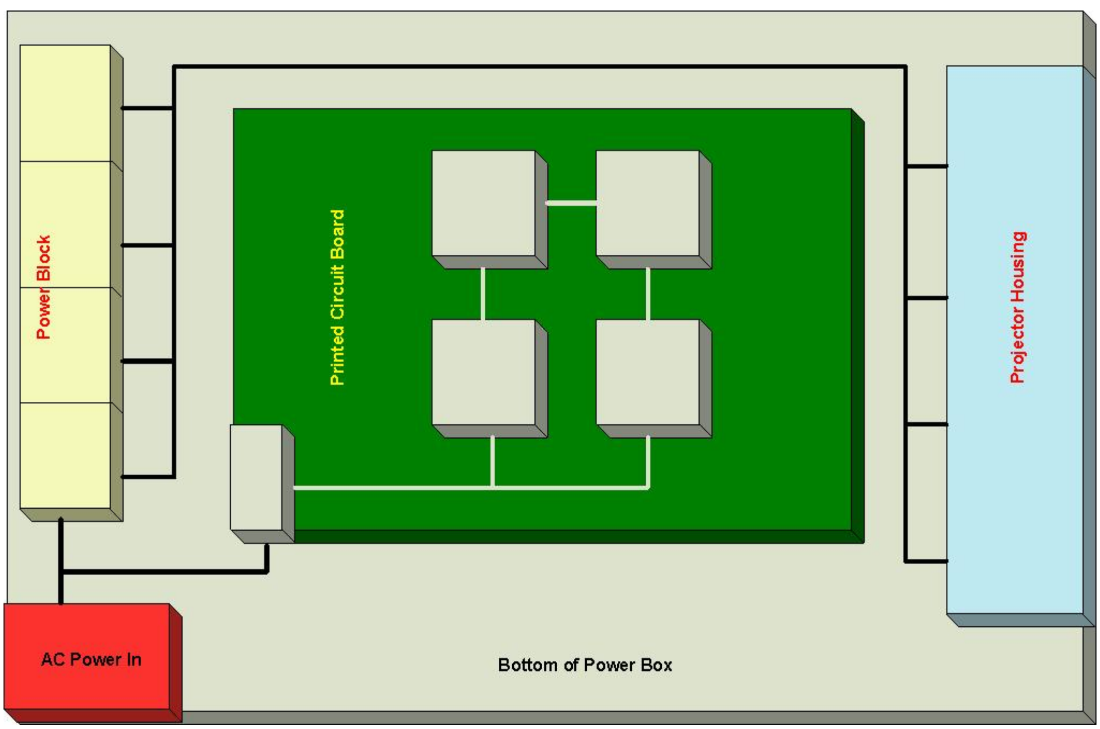

Figure52: Top view, looking down, of “Power Box” Design

Using the Figure above, there are many obstacles concerning the power box design outside of the circuitry itself. The “AC Power In” will be the power coming from a traditional wall outlet. The cord will plug into a wall outlet and run into the side of the power box. On the inside, the cord will be connected to a mounted adapter. From there the signal will be routed to the power block as well as the printed circuit board. At the power block there will be 4 traditional outlets that will provide the required power to each of the four projectors that will also be mounted inside the power box.
At the printed circuit board terminal, the same signal will be connected to the board via a terminal block connector and the signal will be routed directly to the AC to DC conversion area of the circuit. This signal will then be transformed to a DC signal and manipulated to supply the correct amount of power to the microcontroller.

The last item that needs to be taken into consideration as far as the power system of our project is concerned is power to the host computer system that will contain the user interfaces for all of modules associated with our simulator system. Since we have chosen to go with the use of a power block to power the AC projectors which we now know can run off of AC power, we will utilize the power block to provide the proper power requirements to our host computer system as well. Figure50 below gives a block diagram of how the power requirements will be satisfied in our design implementation. This design has changed from the beginning of our project as we have decided to go with some different approaches to satisfy our design specifications.

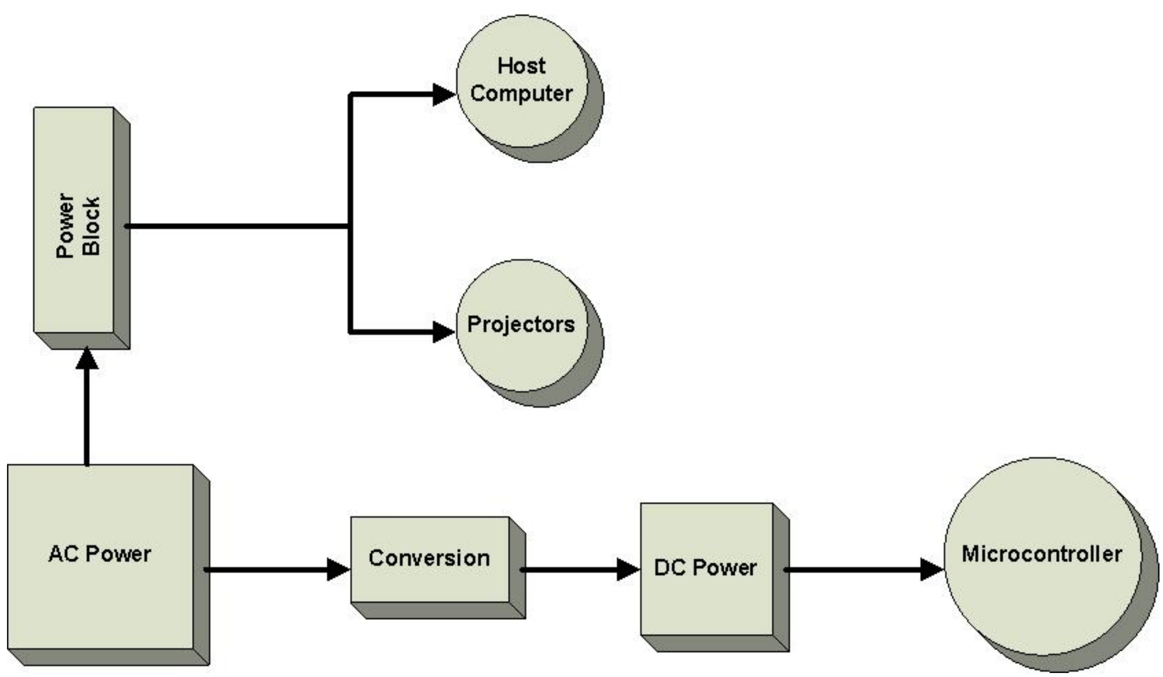

Figure53: Final Power Flow Diagram

4.7: Analog Sensor Circuitry

In order to get the best results we can from the analog light sensor array we will be using the Osram SFH 5711 ambient light sensor. Due to its unique characteristics, the SFH 5711 is able to almost perfectly mimic how the human eye detects light. The human eye is most sensitive to the 550 nm wavelength, and the SFH 5711 is most sensitive at 555 nm. This is only a tiny deviation, which should not have much effect, if any, at all. With the range of the sensor, 475 – 650 nm, within the range of the human eye's sensitivity, 400 – 700 nm, we will be sure to get an accurate reading that is easily compared to our own vision. This is the main reason the SFH 5711 was chosen over the other light sensors. The SFH 5712 would have been another great candidate; however, this chip did not mimic the eye's spectral sensitivity very well. It was within the eye's sensitivity area, but the SFH 5712 just does not compare to the SFH 5711 capabilities. As for other photodiodes, phototransistors, and thermal detectors; these parts pick up way too much infrared light and are also heavily affected by temperature changes. It is because of the downfalls of the other candidates that we chose to use the SFH 5711 for our design.Table 24 depicts the most important operating parameters from the data sheet for the SFH 5711.

Parameter	**Symbol**	**Value**			**Unit**
		Minimum	**Typical**	**Maximum**	
Supply Voltage	V_{CC}	2.5		5.5	V
Illuminance T_A= -30°C to 70°C T_A= -40°C to 100°C	E_V		3 to 80k 10 to 80k		lx
SpectralRange Sensitivity	$\lambda_{10\%}$	475		650	nm
Wavelength of Max Photosensitivity	$\lambda_{s\ max}$	540	555	570	nm
Output Current @ E_V= 1000 lx	I_{out}	27		32	μA
Current Consumption V_{CC}= 2.5 V V_{CC}= 5.0 V @ E_V= 0 lx	I_{CC}		410 420	500	μA
Current Consumption V_{CC}= 2.5 V V_{CC}= 5.0 V @ E_V= 1000 lx	I_{CC}		460 470	550	μA

Table24: Recommended Operating Conditions for SFH 5711

As seen from Table 24 the SFH 5711 is a very low power consuming part; therefore, we will not have to worry about this part taxing the power supply or micro controller which will give power to the SFH 5711. A general schematic diagram for the SFH 5711 is shown below in Figure 51. This design does not offer any control of the maximum illuminance that can be detected, and the output will be a current. By using a load resistor connected from the I_{out} output to ground we are able to fix both problems. The load resistor can be seen in Figure 52 given below. This load resistor allows the current to be transformed into a voltage that can easily be processed later, and the load resistor also sets a maximum for the illuminance that can be detected.

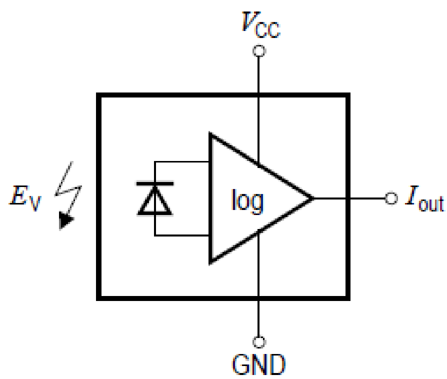

Figure 54: Typical Circuit Diagram for SFH 5711

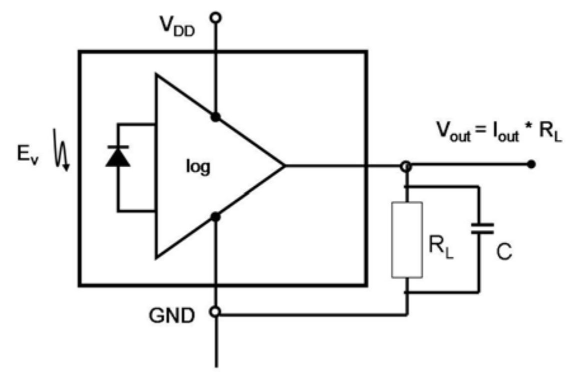

Figure 55: Modified Circuit Diagram for SFH 5711

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Due to the projectors not putting out a great deal of light, meaning around 10k lx and above, we do not have to necessarily have the sensor setup to detect an illuminance above 10k lx. If we select our peak illuminance to be 10k lx then we can then solve for the output current. The equation as well as solution is provided below.

$$I_{out} = S * \log\left(\frac{E_V}{E_0}\right) whereS = sensitivity = 10\mu A;\ E_0 = 1\ lx; andE_V = 10{,}000\ lx$$

Therefore

$$I_{out} = 10\mu A * \log\left(\frac{10{,}000lx}{1lx}\right) = 10\mu A * \log(10{,}000) = 10\mu A * 4 = 40\mu A$$

As seen from the above equations I_{out} is equal to 40 μA for a value of 10,000 lx. If use an input voltage of V_{CC}= 3.3V, and V_{out}can not be greater than V_{CC} then we must select a resistance value for the load resistor that will not violate this rule.By using Figure 52 we can get an idea for the resistance value we should choose for the load resistor. By looking at the far right curve for V_{CC}= 3.3V in Figure 53 we can see that for a peak value of 10,000 lx of illumination we should use a load resistor equal to about 75k Ω.

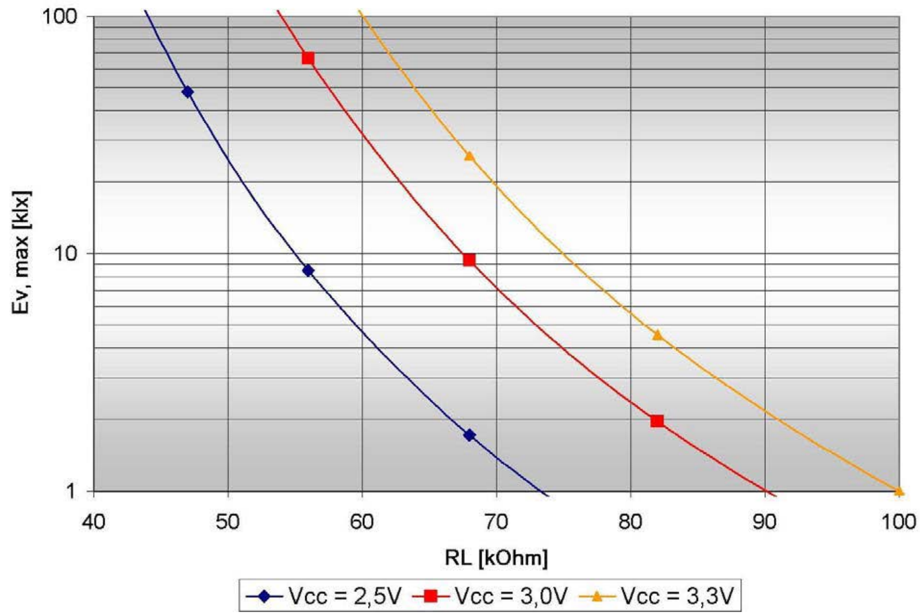

Figure 56: Maximum detectable light level vs. load resistance
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We can now solve for V_{out} to make sure the resistance value of 75k Ω will be sufficient for this design or not.

$$V_{out} = I_{out} * R_L = 40\ \mu A * 75k\ \Omega = 3\ V$$

Since V_{out}= 3.0 V and V_{CC}= 3.3 V we can see that V_{out} is indeed less than V_{CC}. Therefore this would be a viable solution for this design; however, once we obtain the SFH 5711 chip we will have to test and verify that our design remains within our specifications for this project. If any adjustments are needed we can adjust our detection range of the circuit shown in Figure 54 by adjusting the value of the load resistor, or the value of V_{CC}.

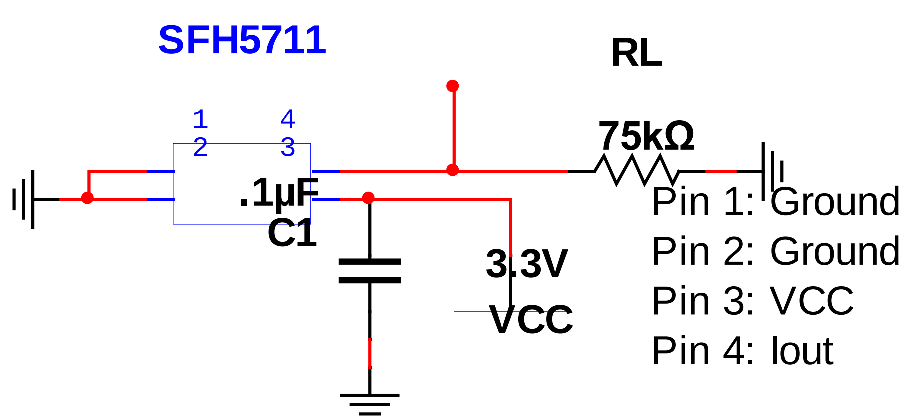

Figure 57: SFH 5711 Light Detection Circuit

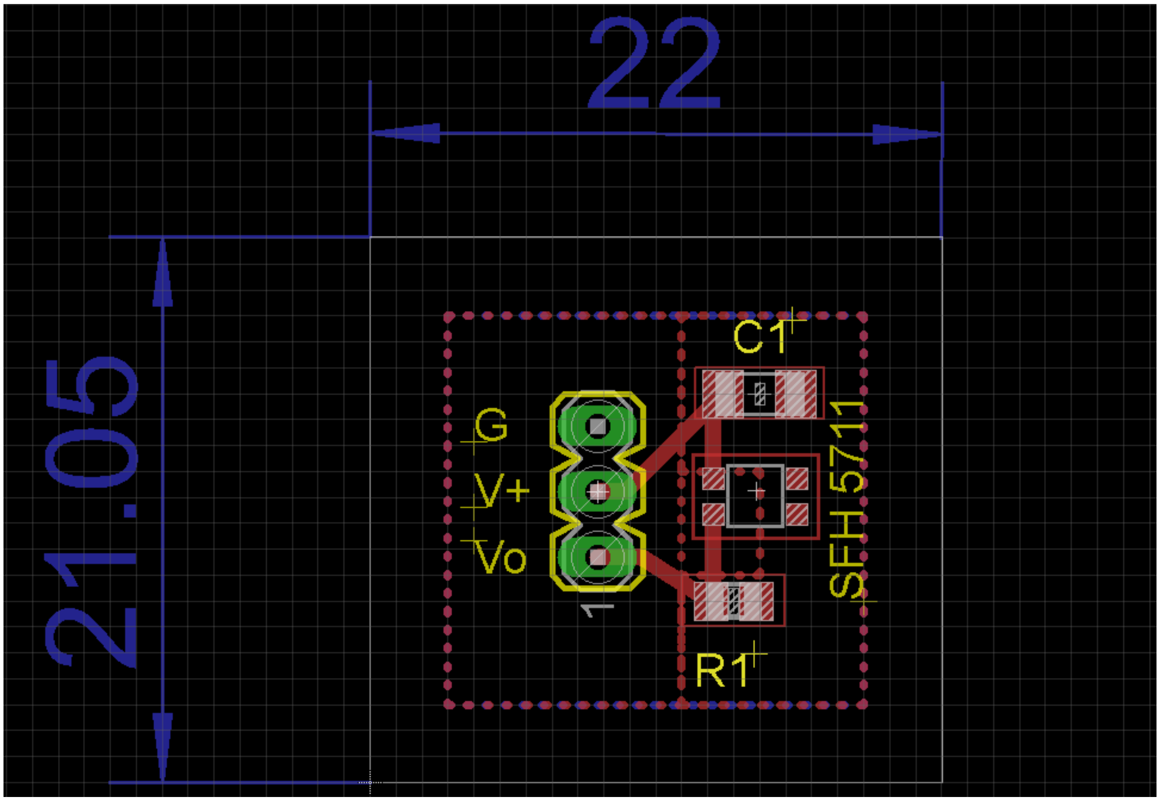

Figure 58: Light Sensor PCB Layout

It is important to note that a bypass capacitor is being used in order to remove any noise that may come through with the supply voltage. This can be seen in the above Figure 13*, and it has a value of C1= .1 µF. In order to get the maximum effect of the bypass capacitor it will be placed as close as possible to the SFH 5711, but we will make sure there is enough room so that soldering of the components will not be hindered in any way. Any noise coming in from the supply voltage would make it almost impossible to get any viable data from the light detection circuit. If the noise caused the supply voltage to rise then we would get a higher than actual reading for the illuminance of the projector array. If the noise was constant it would not be much of a problem; however, noise usually fluctuates which makes it nearly impossible to receive accurate data in any situation. Also, a capacitor could be added in parallel with the load resistor in order to adjust the reaction time of the light detection circuit, but we do not believe this will be necessary for this design.

The capacitor selected to be used for the bypass capacitor is a monolithic ceramic capacitor produced by Murata Electronics North America, and Table 25 gives a general breakdown of the specifications for this capacitor. We selected a capacitor with a tolerance of ±5% in order to receive a capacitor that will fit our needs. This ensures that even if the capacitor is not exactly .1 µF that it will be extremely close. Being that a slight fluctuation in the capacitance of the bypass capacitor will not harm the design the 5% tolerance should work very well.

Parameter	Value
Manufacturer Part Number	GRM31C5C1E104JA01L
Capacitance	0.1µF
Voltage – Rated	25V
Tolerance	±5%
Temperature Coefficient	C0G, NP0
Mounting Type	Surface Mount, MLCC
Operating Temperature	-55°C ~ 125°C
Size / Dimension	0.126" L x 0.063" W (3.20mm x 1.60mm)
Thickness (Max)	0.071" (1.80mm)

Table25: Bypass Capacitor Specifications

The load resistor will be a thin film surface mounted resistor manufactured by Panasonic Electronic Components. By viewing Table 26, which gives the general specifications for this part, you can see that this is a high reliability product with a tolerance of ±0.1%. The high tolerance was necessary due to the resistance being so high. Since this resistor is 75k Ω with a tolerance of ±0.1% we can expect the value of these resistors to be anywhere from74.925k to 75075k Ω. The equations shown below show that if the output voltage remains the same as we found in our prior equations, V_{out}= 3 V and only the resistance is changed. Then the resultant output current will have virtually no change.

$$\frac{3\,V}{74925\;\Omega} = 40.04\;\mu A \qquad \frac{3\,V}{75000\;\Omega} = 40\;\mu A \qquad \frac{3\,V}{75075\;\Omega} = 39.96\;\mu A$$

Parameter	Value
Manufacturer Part Number	ERA-6AEB753V
Resistance (Ohms)	75k
Power (Watts)	0.125W, 1/8W
Tolerance	±0.1%
Temperature Coefficient	±25ppm/°C
Mounting Type	Surface Mount
Composition	Thin Film
Size / Dimension	0.079" L x 0.049" W (2.00mm x 1.25mm)
Thickness (Max)	0.024" (0.60mm)

Table 26: Load Resistor Specifications

Seeing there is such a small current being generated by the SFH 5711 the power flowing through the resistor will be very small. With an output voltage of V_{out}= 3 V and an output current of I_{out}= 40 µA we will have a massive power output of 120 µW. This resistor is rated at 1/8 W, .125 W, or to give an even greater perspective it is equal to125, 000 µW. We will not be taxing this resistor at all in terms of what it is able to handle.

4.8: Projectors

After testing the Acer K330 and the VivitekQumi Q2, we have decided to utilize the Acer K330 for our projector array design. The Acer K330 and the VivitekQumi Q2 were both very similar in many aspects; however, the Acer K330 was superior in focus control, brightness, and overall image quality. The main aspect of the Acer K330 that won us over was that it is capable of outputting 500 lumens which added to the image quality greatly.

Based on the 16:10 aspect ratio of Acer K330 selected, we plan to place two projectors together, one on top of the other to create a square format image (1:1 ratio) that will be easily scalable.

The 2 projector layout (projector 1 and 2 = 1:1) in Figure 55 would have a format of 1600x1600 pixels for a total of 2.5M usable pixels. Two 2 projector layouts will then be combined side by side to create a 4 projector layout.

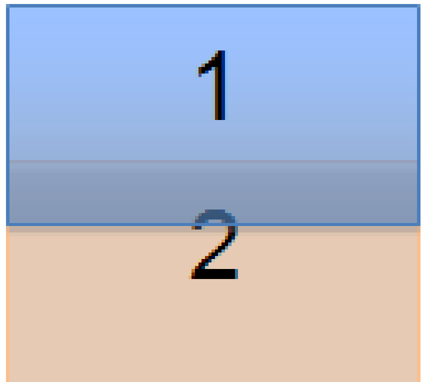

Figure 59: Two Projector Screen Format

The 4 projector layout (projector 1 , 2, 3 and 4 = 1:1) in Figure 56, given below, would give a format of 2600x1600 for a total of over 4.5M pixels and almost identical to the latest WQXGA format at a fraction of the cost. The 4 projector layout with an aspect ratio of 1:1 will make the most use out of the usable area of the screen that our projector array will be projecting onto.

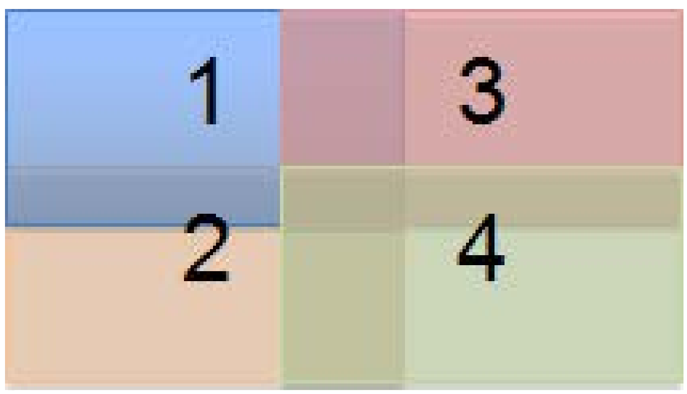

Figure 60: Four Projector Screen Format

We will place the projector array into a “projector box” which will house the projectors as well as essential microcontrollers used for this project. The box will be made out of aluminum and silk screened red where the box will be visible. Figure 57 given below shows the overall layout that will be used for the projectors when placed into the projector box.

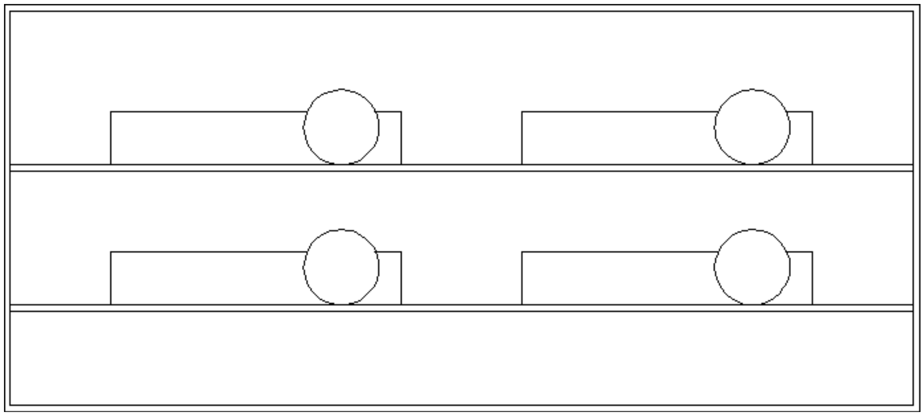

Figure 61: Example Projector Box

4.9: Auto-Alignment

It was decided that the best solution for our project would be to use a software solution for the auto-alignment process specifically the Warpalizer. The Warpalizer will be used because we decided to align the pico projectors in a 2X2 array inside of our "projector box." The fact that the projectors will be inside of the projector box, it would be extremely difficult to attach the extra components that a hardware solution would require. These extra components include the servo motors, the motor driver, and the pan-tilt trays. Each projector would require two servos to move the projector in the XY direction. This means that even if we used the AXA6823 motor driver was used for our design, we would have to use one AXA6823 motor driver for each projector. The coding for one of the projectors would be difficult enough. When three more motor drivers are introduced, the amount of coding would increase the difficultly immensely. Also the pan-tilt trays would not be feasible if the it was contained in a box. In case of an alignment error due to the trays, it would not be possible to correct if the trays were inside a box.

Aside from sheer coding difficulties that would naturally arise from implementing this hardware solution, power considerations must also be mentioned. It was already decided that an Analog to Digital design was to be used to power all of the components inside the projector box which will convert the 120V AC coming from a standard outlet be transformed to 12V DC. This 12V will then be stepped down to power the microcontroller, the analog sensors, and the projectors. That alone is already a lot of power demand. Add in the 4 AXA6823 motor drivers and the 8 HS-5665MH servos that would be needed for the hardware design and we are talking about enormous power necessity. Naturally supply power to the pico projectors and the microcontrollers should already cause some heat generation. If the 4 AXA6823 motor drivers and the 8 HS-5665MH servos were in the box, there's no telling how much heat would be generated because all the components would be closed off within the projector box. Overheating of the internal circuitry would likely occur which is something that should be completely avoided.

4.10: Analog Sensor Mechanics

The specifications of the ANSI Lumens test will be the basis of the design of the analog sensor array. The test describes that measurements must be taken at the 9 specific points on the screen in which we divide the screen into 9 equal blocks and take the data from the center of these 9 blocks. Our analog sensor array will mimic this. Since 9 measurements are needed obviously 9 analog sensors are needed in the array. The only difference in which we will change the ANSI Lumens test for brightness is that instead of testing one projector at a time, we will test the entire warped image of the projector array. The result of this will be compared to the single projector display on the opposite side of the BP dome.

A viable way to design the analog sensor array would be to use a PVC piping structure to house the sensors. PVC pipes would be lightweight so that the sensor array could be easily moved. This is essential when we compare the projector array to the single projector. The sensors must be moved from one side of the BP dome to the other. PVC piping would allow this to happen. Also the use of PVC piping will allows us to house and hide the sensor circuitry all the signal wires coming from the sensor away from the outside world. There would be less loose wiring which will provide us with ease.

In order to comply with the ANSI Lumens testing regulations, we will build the array using PVC piping with the dimension being 3ft by 3ft. The outside of the array use 6 PVC pipes with the corners being attached together by an elbow joint and the center of the structure attached by a two standard T joints. The intersection of pipes within our PVC piping setup is where the sensors will be located. The points where the analog sensors are located will be where the center of all these intersections on the inner portion of the sensor array setup. Figure58 below roughly shows how the array structure will look like and how the wires from the analog sensors will go to the microcontrollers in the projector box

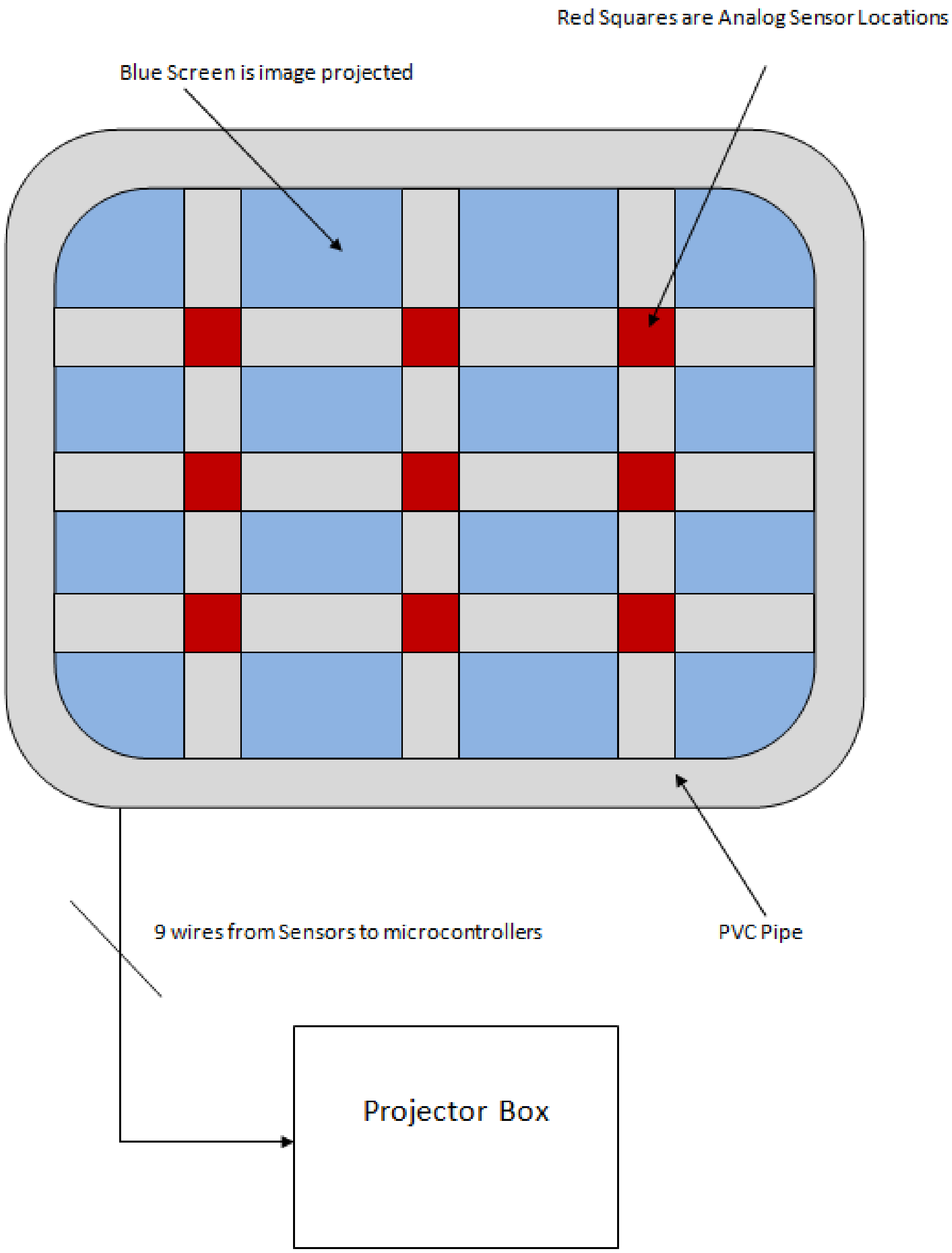

Figure62: Analog Sensor Array

With the image being projected in front of the array the measurements will be able to take place. The signals measured from each sensor will be displayed on the GUI on the host computer system.

Section 5: Prototype

5.1: Projector Box

5.1.1: PCB Power

Once all of the parts required for our power system arrive, the initial prototype of our design will begin. The prototype for the printed circuit board will be built on a bread board until a working design is created. From this design, a schematic will be generated and then sent off to create a printed circuit board designed specifically for out parts. In order to ensure that we have developed a properly functioning prototype, the following steps will be followed:

1. Receive all parts from suppliers

2. Measure all resistors to ensure that they are within .1% tolerance of quoted value

3. Measure all capacitors to also ensure that they are within .1%tolerance of quoted value

4. Measure all inductors to ensure that they are within .1% tolerance of quoted value

5. Create a wall mounted plug that can adapt to the bread board

6. Wire the wall mounted power to the power terminals of the bread board (Be sure that the plug in not yet plugged into the outlet!!)

7. Locate the AC to DC conversion chip and place part on the bread board.

8. Run wires from the power terminals from the bread board to the input terminals on the AC to DC conversion chip. Be sure to use the documents provided from the supplier as improper placement of hot wires could burn the chip immediately. Also be sure that the DC output of the AC to DC conversion chip has a path to return to ground.

9. When everything is properly wired, double check one more time, and then plug the AC power cord into the wall socket.

10. Allow the unit to operate for a few minutes to ensure that there is no burning smells or parts that are now faulty under power.

11. Using an oscilloscope, obtain a measurement at the power terminals to the breadboard. This should include the amplitude of the voltage as well as the frequency of the signal.

12. Now obtain an oscilloscope measurement on the secondary side of the transformer. The frequency should be identical to the incoming signal, but the voltage level should be reduced by ratio on the transformer rating. If this is not the occurring then transformer should be inspected for issues, replaced if needed and the above process will be repeated

13. The next measurement that will be taken is on the output side of the rectifier circuit. The incoming signal to the rectifier circuit is the signal obtained on the secondary side of the transformer. Using an oscilloscope obtain the signal on the output of the rectifier circuit, this should be a DC signal with a ripple voltage.

14. If you are not obtaining a DC signal on the output of the rectifier circuit, check that the diodes are properly oriented and have solid connections.

15. Next obtain a measurement on the output side of the smoothing capacitor. Using the oscilloscope zoom in to make sure that there is virtually no ripple voltage. A ripple voltage of 20-30 mV is acceptable in this stage of the design as it will have no adverse affects on any of the electronics.

16. The next measurement will be taken using the oscilloscope on the output of the AC to DC conversion device. Using a digital multi meter, place the prongs on the output terminals of the device and hold them there for a few seconds. Be sure that the output is regulating at the rated voltage for the device.

17. The final measurement to ensure that the AC to DC conversion device is functioning properly will be performed to ensure that the output voltage is maintained through a variety of input signals. This is taken as a safety precaution as there will be minor fluctuations in the main incoming signal over a long duration of time.

18. Using a signal generator, create an AC signal with a 60 Hz frequency that has a voltage level than that of the main incoming signal. However, be sure that the signal is within the acceptable ranges of the AC to DC conversion part.

19. Apply the signal to the input terminals of the breadboard that still contains the AC to DC conversion device.

20. Using the digital multi meter, measure the steady DC signal at the output terminals of the AC to DC conversion part to ensure the voltage is being regulated.

21. With the digital multi meter still being held to the output of the part, vary the amplitude of the signal generator.

22. Be sure that there are no variances in the steady DC voltage level. If all of

these requirements are met, then the device can be considered to be properly functioning.

23. Remove all power from the system and allow capacitors to fully discharge before placing under power again.

24. Using the output voltage of the AC to DC conversion part and the known input voltage to the microcontroller to determine what type of voltage divider circuit will need to be built in order to deliver the proper power requirements.

25. Build a voltage divider circuit and wire the circuit to the output terminals of the AC to DC conversion part.

26. Once the circuit has been wired correctly to the part and everything has been properly grounded, apply the power from the wall outlet to the input terminals of the bread board.

27. Using the digital multi meter, measure the voltage at the output of the voltage divider circuit and verify that this is correct voltage level for the microcontroller to operate safely.

28. Also using the multi meter, measure the current running through the output of the voltage divider circuit into the microcontroller.

29. Using the proper equation for power calculation, P=V*I, calculate the power being delivered to the microcontroller.

30. Verify that the power being delivered is sufficient for proper operation of the microcontroller.

31. If all of the calculations and measurements are with acceptable operating tolerances, unhook all the power from the circuit.

32. Obtain a schematic drawing to be used in the creation of the printed circuit board for the design

33. The next part to test for the power system is the power block that will power the host computer system as well as the projectors.

34. Using the same wall socket power supply, apply the power to the power block via the terminal connections.

35. Using an oscilloscope, measure the output signal at each terminal of the power block

36. Be sure to verify that the output signals of each terminal is identical to the input signal to the power block to ensure there is no shorting or grounding

occurring inside the terminal blocks.

If the signal at each of the terminals matches the input signal to the power block, the device is functioning properly and the power can be unhooked.

5.1.2: PCB Analog Circuitry

After all parts to complete the circuit for the light sensor circuits have arrived, we will start by prototyping each of the circuits on a breadboard. By using a bread board we will be able to easily take measurements from each circuit component, and we will be able to change out components as needed during the prototyping process. We will be performing the prototyping the circuits in a lab environment, either at UCF or at Q4, where we will have access to quality testing equipment. We could use simple multimeters and power supplies, but it would be more beneficial to use proper testing equipment that is lab grade.

Before starting the prototyping process we must first measure the resistors and capacitors. By measuring each component by itself and not connected to any circuit we will be able to accurately measure the value of the component. We will record the value for each resistor and capacitor in order to make sure that they are within the tolerances for each component. If a component is not within its range it will not be used if it does not allow the circuit to act as it should.

Once all resistor and capacitor values have been recorded, the components will be wired together onto a breadboard where measurements can easily be taken. We will want to especially test for noise from the power supply to see if the bypass capacitor is sufficiently reducing any noise from the supply voltage. If the capacitor is inadequate then adjustments and more testing will be completed until the noise can be reduced to a reasonable amount.

We will want to focus on input versus output power in order to see how much power is being consumed by the SFH 5711 as well as how much power is being sent through the output of the SFH 5711. We will take measurements at various input voltages from zero to five volts, and since this is an ambient light sensor we must also take each measurement with varying levels of light being exposed to the SFH 5711. The other major data collected will be the actual voltage coming out from the output of the sensor and sent to the microcontroller. We will need to use light sources with a known lumen output to get accurate data for the output of the SFH 5711, and it may be necessary to adjust the resistance of the load resistor in order to get the best light detection range of the SFH 5711 sensor.

The importance of any data collected is not only important in order to optimize and make sure the circuits are working correctly, but this data will also be very important when these sensors are integrated with the microcontroller that will be interfacing with the sensors. The data will allow us to modify the code running on the microcontroller to get accurate results from the SFH 5711 light sensors.

We plan to have nine different light sensor circuits, so while we are testing the circuits we will want to be able to compare the output voltage of all the sensors at a given light intensity. This is important to see if all the sensors are getting the same output voltage, or if they are all giving many different read outs. It would be more beneficial to have sensors that are all pretty well matched with one another. This will make it easier to get an accurate average lumen output from the projector array. We will be buying an excess amount of SFH5 711 light sensors to ensure that we will get at least nine sensors that are closely matched with one another.

After we are happy with our results we will integrate the light sensor circuits with our own power supply. We will test for noise going into the circuit, and re-test the circuits with the same tests performed above. We want to make sure that the power supplies do not cause the light sensor circuits to act differently than they should. If excess noise is going through then the output from our light sensors will be off. The worst thing that could happen is that we get a noise that fluctuates which will cause our output from the light sensors to also fluctuate.

After prototyping on the breadboard and compiling all data needed to satisfy our expectations, we will make a PCB board for the components to be soldered onto. We will get extra PCBs in case of soldering mishaps, and also to have extra light sensor circuits in case a circuit fails later on. The PCB will first be used as a prototype also. We will perform test, and if a change needs to be made to the circuit we will complete the change and then re-test. we also want to make sure that the PCB we will design will be adequate for our circuit. If the components are too close, or there is something else that we notice that would make for a better PCB design we will do a re-design and order the new PCBs.

5.1.3: PCB Interface/Control

Microcontrollers and Related Circuitry: The prototyping for the microcontrollers will be done on the Arduino Uno and Arduino Mega development boards. These boards allow for rapid prototyping testing of the programs. They also give you easy access to the I/O architecture of the microcontrollers through various breakout pins allowing for simple connections to various other parts.

We will begin by writing the entire program and then testing each part of the system individually. This will allow us to easily identify any small errors or discrepancies in the individual parts of the system.

Light Sensor Array PCB: The light sensor array will require use of the Arduino Mega board, as it utilizes the ATmega 2560 microcontroller which will be used in our final PCB design. Once the initial program has been written, we will begin with only one light sensor and no multiplexer connected to one of the analog inputs on the Mega. This will ensure that we are accurately reading in the analog signal from the light sensor. Once it has been confirmed that the reading function of the program is working correctly we will start increasing the number of sensors being read until we have reached our full amount of 9 sensors. Once additional sensors are introduced it will be necessary to run the signals through our multiplexer. The multiplexers select lines will need to also be connected to 4 of our digital outputs on the Mega board for control purposes.

The multiplexer and light sensor circuitry will be placed on a bread board during the prototyping phase. This will allow us to quickly make any changes to the circuitry, while also giving us a convenient place to make connections. Power will be supplied from a desktop power supply to ensure accurate and sufficient power is supply to the circuitry. Once the circuitry is confirmed to be working correctly, we will make a finalized schematic of the connections being used for production of the PCB.

Projector Box PCB: The projector box will require use of the Arduino Uno board, as it utilizes the ATmega 328 microcontroller which will be used in our final PCB design. Once the initial program has been written, we will begin integrating the communication with the light sensor array as it does not require any signal conversion. We will connect the Uno’s serial outputs to the serial outputs of the Mega board. We can ensure communication is correct by sending various characters from the Uno board and then see if they are received by the Mega board. Once communication is confirmed, we will start sending the data acquired from the light sensors to ensure it can be properly sent from the Mega to be received by the Uno.

Now that we have correct TTL serial communication we can try converting it for integration will the host computer. We will place a Max232 chip onto a bread board and connect the Uno’s serial communication pins to the corresponding input pins of the 232 chip. We will begin by sending various characters from the Uno board and will measure the voltage levels of the output signal of the Max232 chip via an Oscilloscope. The signals should be inverted and amplified from the 0 (logic 0) to 5V (logic 1) TTL signals to -13V (logic 1) to +13v (logic 0) RS-232 signals. Once the conversion is confirmed we will connect this output to a computer. The signal will need to be routed via a Db9 connector with the transfer and receive lines connected to pins 2 and 3. A serial monitoring program such as minicom or PuTTY can be used to ensure that accurate information is being received by the computer.

Once both forms of communication are confirmed to be working we can integrate the multiplexers to switch between the two forms. Two multiplexers will be placed on a bread board and the transfer and receive lines will be connected to their outputs. One input will be connected to the ATmega’s serial lines will the other input will be connected to the Max232 chip. One digital output will be connected to each of the multiplexers to switch between the two lines of communication. We can then test the communication.

We will receive light sensor data from the Mega and then switch the multiplexer and send this data on to the computer. Once it is confirmed accurate data is being received by the computer the system can be declared working. Finalized schematics will be taken from the setups and used to build the PCB.

The following Figures are the open sourced schematics for both the Arduino Mega and Arduino Uno. Both will be essential during the prototyping phase of our project, as they will need to be referenced for accurate design of our PCBs:

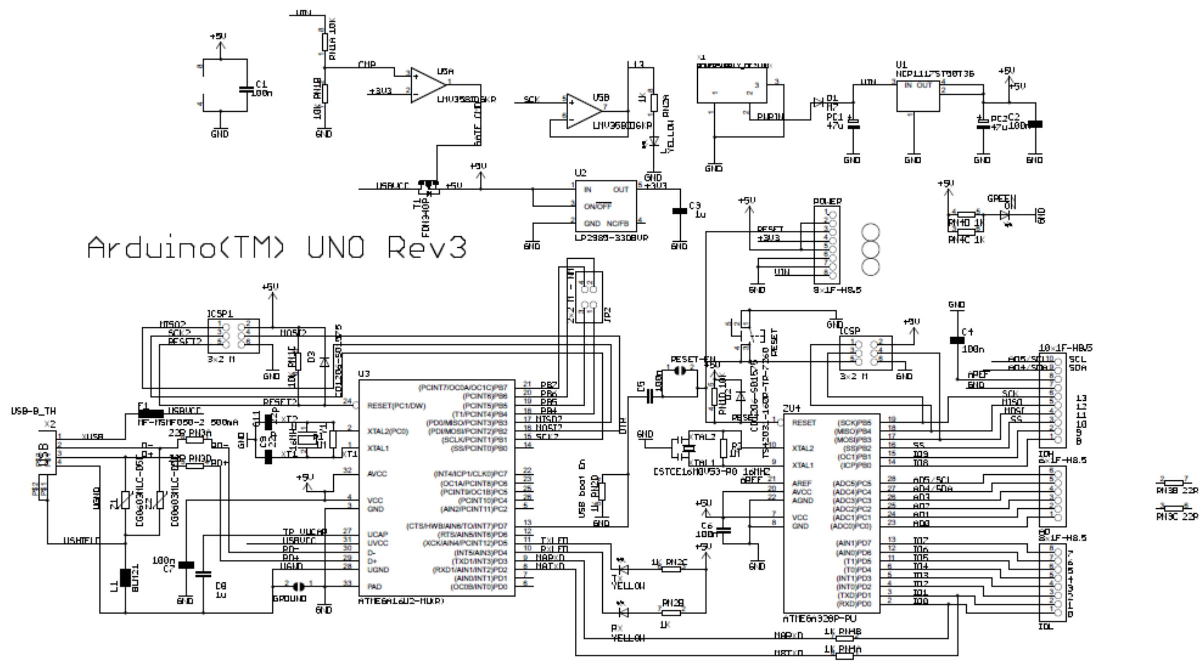

Figure 63: Schematic for the Arduino Uno

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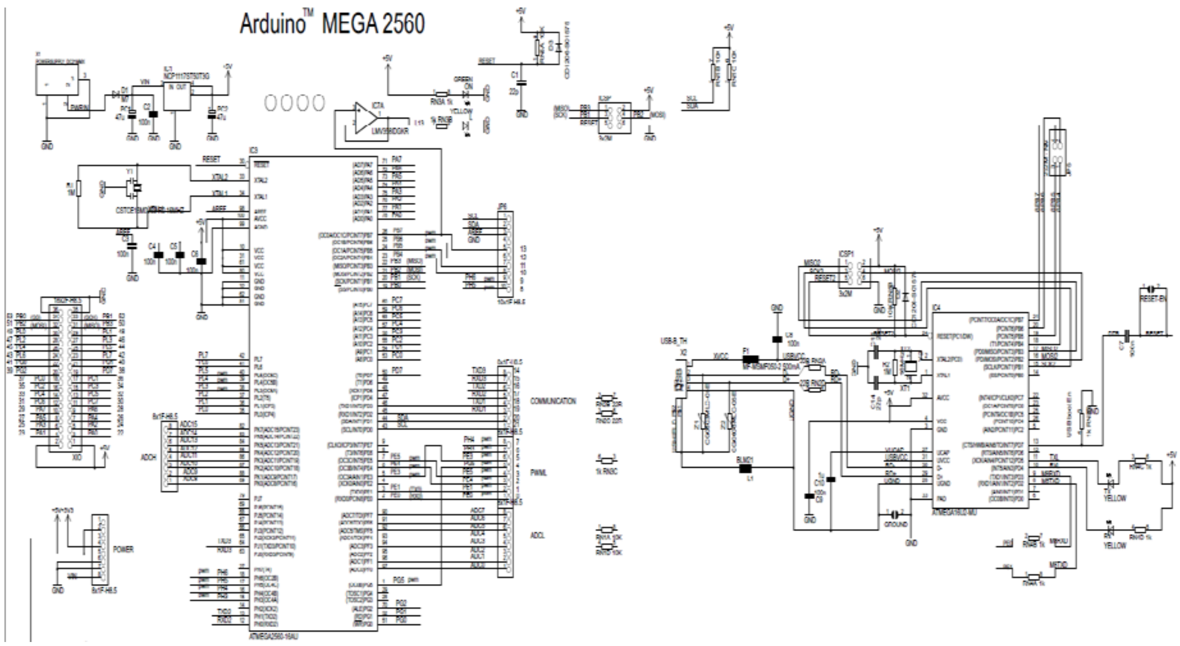

Figure 64: Schematic for the Arduino Mega

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5.2: Setup

5.2.1: Projectors

In order to ensure that the projectors are operating the way that we want them to, and also to find out if there is anything that we will have to account for we will prototype the projectors outside of the system first to ensure quality insurance. We will start off by performing a soak test of each projector separately. The soak test will be done by essentially leaving the projectors on for an extended amount of time where measurements can be taken periodically. Since we have already performed basic image quality tests on the Acer K330 we will not be focusing on this aspect; therefore, we will focus more on image drift, due to the DLP chips in the projector, and power consumption.

The DLP chips in the Acer K330 have a tendency to cause the projected image to drift up and to the left as the projectors warm up. The amount of time can vary, but it is usually anywhere between thirty to forty-five minutes. This is different for different brands of projectors, but can also be true for projectors in the same brand. This is due to the fact that it is not the projectors that cause this problem, but the DLP chip that is used to generate the image. In order to see the extent of the drift we will setup each projector on its own screen, and display an image with a grid of Xs. The screen will be a normal flat screen, and the Xs will be used to identify how much drift has occurred. A mark will have to be placed at the beginning of the test to serve as a reference point in order to accurately measure the exact drift, if any, that have occurred. Figure 61 shows what the setup would look like.

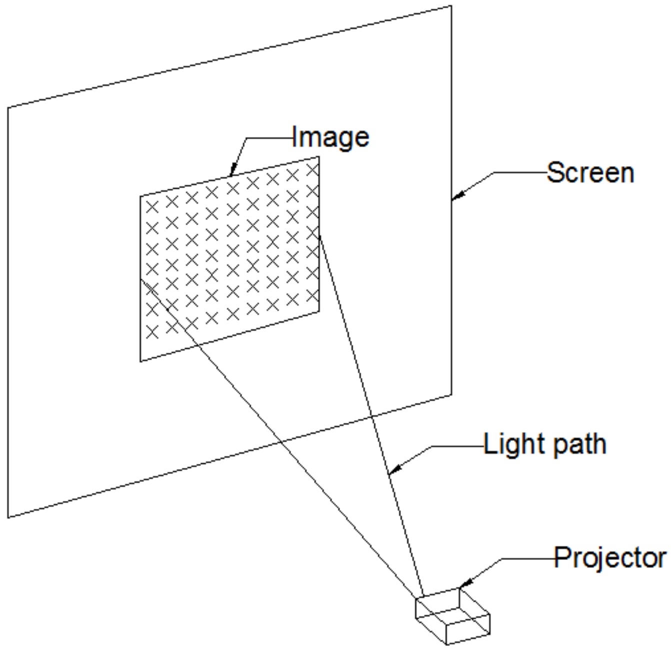

Figure 65: Drift Detection Setup

To make sure that the whole image drifts in unison, we will use multiple reference points, around ten should be fine, spread over the image where a measurement can be taken for each point and compared. If the image does not drift in unison then each point will drift at different rates, or some points may just not drift at all. If this happens we will also notice some image distortion; however, we do not think the points will drift at different rates, but they will drift in unison. The best spot to mark the reference point will be right at the middle of the Xs being projected onto the screen. There are many ways to make a mark, we can use a sticker, draw a mark, or be destructive and punch a whole right into the screen. By using the middle of the X we will have an exact and easy spot to measure in respect to our reference point. Figure 62 shown below gives an example of what the image drift may look like.

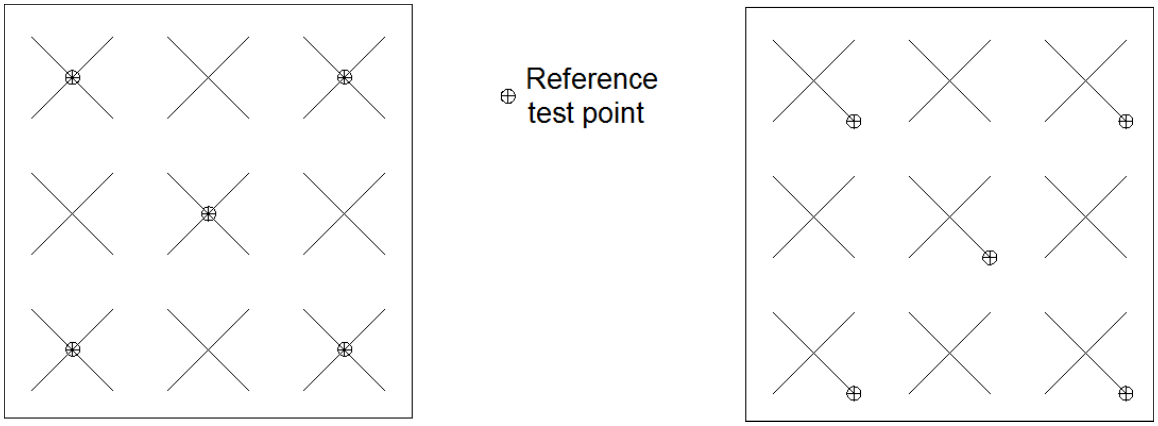

Figure 66: Reference Test Point Example

We will also be monitoring how much power is being while the drift test is being preformed. This will let us know that the projectors are consuming the amount of power that the Acer K330's data sheet says they will. We suspect that if anything the projectors will consume less power than what is in the data sheet, but we feel this is something that should be checked.

As the prototyping progresses we will slowly integrate the projectors together to make sure they play nice together. We will also switch from still images to a video feed sent from the host computer and begin simple warping. This will allow us to begin the long process of tweaking the projectors by physically getting them into positions relative with one another that will work well with the auto alignment system to produce the best image that we are capable of producing from our projector array. This will also allow us to catch any problems associated with the auto alignment system and the projectors when they have been integrated with one another.

During the phase of looking at the image quality being produced by the projectors we will be adjusting all of the projectors various settings. This will be done to find the most optimal setting combination to give the best image possible. The other reason for doing this is due to the fact that these projectors will be blended together. We not only want to make sure we are getting a good image out of each single projector, but we also want to make sure that the image being formed by all of the projectors combined into one entity will also look its very best. Even if each projector looks amazing by itself, it will look very bad if when all of the projectors are in the array that one projector is dark, another is too bright, another has bad looking contrast, and the list goes on. Our end goal is to have all of the projectors in the best sync possible so when all of the projected images are combined a person will not be able to tell where one projected portion starts and another begins. We all have seen bad examples with LCD screens put together, and the giveaway is the black lines produced between the screens.

5.2.2: Host Computer System

The most important aspect of the host computer system is the graphics cards in that it must be powerful enough to relay our projector array with high quality images to each projector. The AMD FirePro W600 that will be used has the capability to output multiple channels. This will be examined when our whole project is setup. First from our host computer, we will try to display an image that is not overly graphics intensive. This is to see if the signals are being properly sent to each projector before alignment.

The Warpalizer will then be open and run to warp the image. Using the grid array system supplied by the Warpalizer software, we can drag each projectors image to fill the area desired. Once the image is where we want it, we can compress or stretch the edges of the image to correct any image distortion caused by the curvature of the screen. We will then need to measure the field of view for each projector in degrees and input these values into a configuration file. Once confirmed that the Warpalizer correctly aligns the image onto the screen we will then increase the image output. The next step would be to see if a video can be displayed from the host system. Any video file should suffice. The video will be displayed both warped and unwarped. When confirmed that both versions of the video are able to be displayed we will then move on to a graphics intensive video. Either a graphics heavy game like Battlefield 3 or a high resolution 4K video will be sent from the to the projector box. The video will be shown playing in the native Windows Media Player on the computer. We will see if the projector array can display both the unwarped and warped video. If confirmed that the video can be displayed then we know the AMD FirePro W600 is a powerful enough graphics card to use for the host computer system.

When confirmed that the graphics card is sufficient for use we will then see if the GUI is both displaying information from each sensor and to see if the total lumens for the whole screen. First we will place our sensor array front of the projector screen. We will then display an image from our projector box. From the host computer we will open the GUI. The light sensor button from the GUI will be pressed. The lumens measured from all the sensors as well as the total lumen for the whole screen should then be shown on the host system. These measurements will be compared to the measurements taken from a lux meter that we will use to measure the 9 points individually. Then we will calculate the total lumen output we be calculated from the lux meter measurements. If the values taken from both the analog sensor and the lux meter are close enough in value then we know that our array is sending the information correctly and being converted properly in the GUI. If not then the code from either the microcontroller or the code written from the GUI must be checked. When codes are debugged then we will retake measurements to confirm that the values seen on the GUI match that on the lux meter. When confirmed we will know that the GUI and both sending the signal correctly to the microcontroller and receiving and displaying the correct values.

5.2.3: Analog Sensor Mechanics

In order to decide which analog sensor array that will be used for the final design for the project we will have to build and test all researched concepts under certain guidelines so that the array meets our approval. We will first build and test the shelf array concept. First we will examine the shelf array concept. The projector box will power up and display our image. When the image is projected we will then divide the screen area into the 9 blocks as described in the ANSI Lumens test and then determine the center points of these 9 blocks. With the points noted for we will then move the shelf in front of the projector screen. We place the 9 acrylic stands needed for each sensor in the middle of the 9 blocks of the screen area. Then place the sensor circuitry standing up on these acrylic stands. The output wires coming from each sensor that must not interfere with the other sensors so they will have to be placed behind the shelf array and on the floor to the projector box. Once all of the sensors are in place we then run the GUI from the host computer and see if the measurements are taken. If confirmed that measurements are being taken we will then pick up and move the shelf structure to the other side of the screen to test the single projector display. While moving we will take note of how easy or difficult it is to move the shelf. The sensors would have to be taken off while moving since the acrylic stands cannot be mounted. Once moved, we will follow the same procedure as before when taken measurements on the opposite side of the screen.

After testing for the shelf array concept is done we will then try out the metal stand array concept. Testing for the metal stand array is similar to the shelf in that the stand must be placed in front of the projector screen after locating and dividing the screen area into the 9 blocks needed for taking measurements. The sensors this time will be inside an enclosure of some type and made to stand on the metal racks of the stand at the 9 measurement points. The wires once again have to be placed behind the metal structure in order to not interfere with the other sensors. The “measure brightness button” will be pressed in the GUI and see if measurements are being taken. Once confirmed the metal stand array will be moved to the other side of the screen. This should be easier to do than the shelf array system in that the metal stand can just roll across to the single display system screen area because of the wheels attached at the bottom. We will take note of this while moving the metal stand.

The last prototype we will check is the PVC piping array. Before testing can occur the structure will have to be built based on the screen area we are using. With a predetermined screen area we build the array and surface mount the sensors onto the PVC pipes at the center points of each of the 9 blocks. The wiring for the sensors is placed inside the PVC pipes for ease. After the array is built we then follow the same procedure as before for testing. Once confirm we then move the array while taking note of the ease of moving the array for testing the single projector display. Once all three prototypes are tested we then will decide which one meets our demands for the final design.

Section 6: Design Test

6.1: PCB

6.1.1: Power

During the final design testing of our design, the power system will be subjected to multiple tests and measurements to ensure that the proper requirements are being delivered. There are many different methods of testing electronic equipment and many different measurements that the results can be taken in. The main concepts we will focus on in the testing of our system is the type of signal, the voltage level at certain stages in the circuit, the current running into certain elements, and the measured circuit resistance of certain elements.

The following steps are a guide to ensure that the final design is functioning properly and all devices have been integrated properly.

1. Locate the power box of the design which includes the PCB power system as well as the power block. These devices are responsible for supplying power to the entire system.

2. Open the power box and locate the PCB and the power block and ensure that no power is being supplied to the system.

3. Plug the system into the wall and monitor the devices to ensure there are no clear disruptions occurring anywhere in the system.

4. Using an oscilloscope obtain images of the incoming signal to the PCB at the terminal contacts located on the edge of the circuit board.

5. Next, still using the oscilloscope measure the incoming signal to the power block at the terminal contacts located on the side of the of the power block.

6. Next, using the multi meter, place the contacts at the output terminals of the AC to DC conversion chip to ensure that a steady DC signal is being supplied to the DC circuitry.

7. Still using the multi meter, measure the output voltage on the output side of the voltage divider circuit. This should be the voltage that is being sent into the microcontroller.

8. If all measurements agree with the measurements obtained during the prototype stage of the design then the power system is functioning properly.

9. In order to make sure that the power supplied to the microcontroller is sufficient, perform a task that requires the microcontroller and measure the response time. If this occurs within the time that is acceptable then the power supplied is efficient.

If the system is functioning according to design specifications then the power system is properly functioning.

6.1.2: Sensors

To begin with, we will test each light sensor circuit separately; however, we will leave the sensor in its intended spot within the project setup. We have already tested the parts in a lab setting, but now we will be testing the circuits while they are integrated with the rest of the project. The purpose of this testing is to make sure that the sensors will work as they should. They may work well in a lab setting, but we may find that once the light sensors are removed from the lab setting and placed into the project setting they may not work right at all.

We do not expect the part to completely fail, but it is possible that we will encounter a few problems that will have to be addressed to make the sensors work the way we intend them to work. So, we will start by testing each circuit separately, and then begin testing them as a whole. It is possible that only one sensor has a problem, but the problem is so small that it is not seen with the setup as a whole.

For this testing phase we are not really interested in specific values of the resistors and such; however, we are interested in the input and output of the sensors. The list below will show how we will progress through the testing of the projectors in the array. If any part of the test does not meet our specifications we will perform any needed modifications to the system and re-test the system to ensure the problem has been corrected to our satisfaction.

1. Check that the sensors are all placed in their required locations and are positioned the correct way.

2. Check each PCB light sensor to make sure that the solder joints look good and that all components are making good contact to all of the PCB solder pads.

3. Make sure that each sensor has its wires placed into its correct location on the sensor, and that it is tightly connected. A loose wire not only will cause the sensor to not work properly, but it could also very well cause a heat buildup. This heat buildup can cause the sensor to fail prematurely, or give false intermittent results.

4. We will now make sure that the wire from the sensor is going to the correct power supply and microcontroller port. The wires must also be secure just as in the above step to avoid any unplanned mishaps caused by carelessness.

5. If all of the wires are correct make sure that the power supply is plugged in and turned on.

6. Measure the input voltage going to each sensor to make sure there is correct voltage going to each sensor. If the voltage is not correct check that the wire is tight on the sensor PCB and the power supply. Recheck the voltage, and if the voltage is still not right check that the power supply is operating correctly.

7. Either by turning off the lights, or by using some object, such as tape, to block the light out completely from the sensor.

8. With no light going to the sensor measure the output voltage coming from the sensor output. Compare this data to what was found in the lab, and also verify that the read out in lumens is zero or very close to the value. Repeat this process with all light sensors.

9. Now get a light source with a known lumen output. Place this light source about three feet away from the sensor. For best results have the light source directly in front of the sensor, but three feet away. Record the results for each sensor. Leave the sensor and light source on for about ten minutes and recheck the voltage output of all sensors. Make sure that there is no major change in any output.

10. Repeat the above step; however, use a brighter light source.

11. Once all measurements have been taken switch the projectors on and allow the projectors to fully warm up.

12. We will now test all of the sensors with the projector array. Set the projectors to their lowest brightness, and record the data from the host computer. This data will be in lumens. Again let the system run and come back ten minutes later and record the data. Compare the data and look for any major deviations.

13. Repeat the above step and increase the brightness by ten percent each time.

14. After all data has been collected, for each level of projector brightness, plot the data. If the sensors are working correctly, and they were calibrated correctly then the plot should appear linear.

15. If the plot does not look correct then more calibration may be needed. Recheck each sensor, and if they all appear fine check the code on the microcontroller that receives the data from the light sensors.

6.1.3: Interface

The following procedure is a simple test to ensure the setup is working prior to demonstration:

1. Ensure power is being supplied to the projector box, light sensor array, and host computer system.
2. Check that the light sensor array is connected to the projector box.
3. Check that the projector box is connected to the host computer system.
4. Open the GUI program on the Host computer system.
5. On the GUI system click the "Display Light Measurements" button.
6. A new screen should appear with the lumen measurements displayed in a grid.

Once the lumen measurements are displayed on the screen you have correctly tested the system for accuracy. If the information is not displayed an error message and description will be displayed instead. The description will inform you of any issue within the system for debugging purposes. If any error should occur, follow the instructions displayed in the error message and then restart the test procedure.

6.2: Setup

6.2.1: Projector Testing

The Acer K330s will undergo rigorous testing to see that the completed design is working as they should be. That being said, this testing will be done when we have finished prototyping everything, being all parts with this projector array project, and we have combined all our work into a single hopefully working entity. This testing is done as a sort of quality insurance type of way. Our team's goal is to work out all, if any, problems during prototyping, so this testing will weed out any bugs that have yet to be determined. For the projectors we will do testing from making sure they are connected correctly all the way to the quality of the image being produced. The projectors will be connected to the system as they are intended to be when the project is completed. This will make sure that the projectors are working correctly in the final system. What we will be focusing on is mostly the quality of the image. The list below will show how we will progress through the testing of the projectors in the array. If any part of the test does not meet our specifications we will perform any needed modifications to the system and re-test the system to ensure the problem has been corrected to our satisfaction.

1. Ensure that all projectors are plugged in correctly and securely. All power cables should be secure and not loose, and all video cables should be checked so that each cable goes to the intended projector, the correct port on the computer, and that the cables are not loose and secure.

2. Make sure each projector is secure and set into its intended position in the projector box. Also make sure that the projector box is also in its intended position.

3. Boot up all projectors, and allow them to fully power up. Projectors should be completely warmed up to the point that they will be used in the system.

4. Look at the image position on the screen, and make adjustments as necessary to make sure image is being projected onto the intended position.

5. Use the ambient light sensor array to record the average image brightness.

6. Perform quality checks on the overall image quality. Look at how clear the image is by looking for distortions, pixilation, hot spots, and that the image looks well blended.

7. Mark reference points, and begin a soak test. this will be done by leaving the projectors on for an hour, and measurements will be taken at set intervals. Look for image drift by checking for image deviation from the reference points. This will be easier to do with a still image. Also at each interval a image quality check should be performed, and the results should be recorded and compared with the original image quality test as well as with each test at every interval. This will allow us to see if the is any change in image quality as the projectors are on for an extended amount of time.

8. Use the ambient light sensor array to record the average image brightness.

9. Look at the image position on the screen, compare with original screen position and reference point data to see if there is any drift that will be of concern.

10. Perform another soak test by changing the projected image from a still image to a video stream, preferably something graphics intensive, to check the image quality. To get the best feel for the image quality multiple type of videos should be used, and at least three videos. This test should be performed for at least an hour, and checked periodically for the image quality. The results should be recorded and compared with the original image quality test as well as with each test at every interval.

11. Use the ambient light sensor array to record the average image brightness. Compare all light sensor data to see how the brightness has changed over the testing period.

12. If happy with all above results, shutdown the system.

This test should be performed at least one more time by a group member, and all data should be compared with the previous test. It will also be necessary to have people who are not in the group to comment on the image quality from the projector array. This will get more opinions and reveal and problems that may not have been caught from previous testing.

6.2.2: Analog Sensor Testing

Before testing can test place on the brightness of the projector, it needs to be mentioned the way to go about testing for projector illumination. The American National Standards Institute or ANSI for short, has issued a standardized way for measuring the brightness of a projector. This method is called the ANSI Lumen Method. In 1992 ANSI developed this method in the document ANSI IT7.215 which describes the nature of the testing. Before describing the method we must know the units we are measuring. Lumens is the SI unit for measuring light that is being emitted by a source. It is related to the candela, which is the unit used to measure the light emitted from a lit candle. In relation 1 lumen = 1 cd * sr. Lumens is derived from the unit lux which measures the light illuminated over a given area. In relation 1 lumen = 1 lm/m^2.

The ANSI Lumen Method is the most accurate way to test the brightness of a projector. In order to perform the method, the first thing that must be done is to allow the projector to stabilize for 15 minutes before any measurements are taken. The projector should be in a completely dark room to avoid causing the light sensor to read any fluctuations due to ambient light. The room where the projector is being tested should have an ambient temperature of 25 degrees Celsius. The aspect ratio tested should be 4:3 unless the projector is designed for another ratio. Since most modern HD projectors have either a 16:9 or 16:10 ratio, 16:10 is the ratio that will be tested. The brightness of the projector should be adjusted at 0%, 5%, and 10% brightness, each level is easily distinguishable. The contrast level of the projector should be adjusted so that at 90%, 95%, and 100% brightness, each level is easily distinguishable from the other. When both the brightness and the contrast are adjusted to the conditions, the projector is ready to be tested.

The image being projected should be a blank white field that is projected on a white board. Then the area of the image needs to be divided into nine equal blocks as shown in the figure below. Then measurements must be taken at the center of each of the nine blocks. When all the measurements are taken, they are all added to together and divided by 9 to get an average reading. Then this average is multiplied by the total area of the image to give the lumens reading in ANSI Lumens.

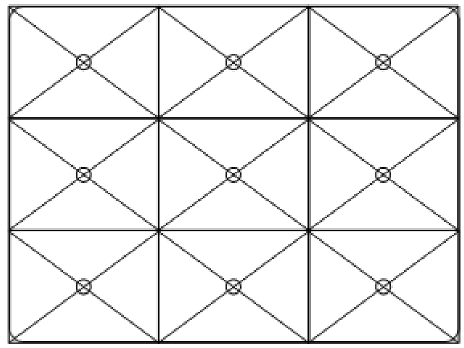

Figure 67: Light Sensor Array for ANSI Lumen Test

We will follow this exact method in order to get the best possible lumen reading for our projector. The easiest way of testing is to test just of our projectors and then the values we get for the test projector we can use as somewhat of a baseline when the rest of the projectors are tested. The projector will be set up as described in the ANSI Lumen method in that it will be in a dark room with no other light source present. After the fifteen minute start up and the after both the brightness and the contrast has been adjusted according to the specifications required, we can begin testing. With the OSRAM SFH 5711 analog sensor, each block will be measured to get the output reading. In order to get the output reading, we must measure the voltage drop across the load resistor. This voltage will then be passed through the A/D converter in the microcontroller in our Projector Box and will display the value in our host computer. With this value we compute the current by simply using ohm law $V = IR$ to obtain the current value. We then check Figure 64, given below, to determine the lumen value that is associated with the current we calculated. This value is the lumen value of the first reading of the first block of the projector. This process is done eight more times for the remaining sensors and each lumen reading should be recorded.

When all the blocks are tested we add all the values together to get the average lumen value of the entire screen. Then this lumen value is converted into lumens by multiplying it by the total area of the projected screen. This value will equal the total lumen output of the projector. This value will be compared with lumen value that was listed for the projector to see if they closely match. This testing will be required for each of the remaining 5 projectors.

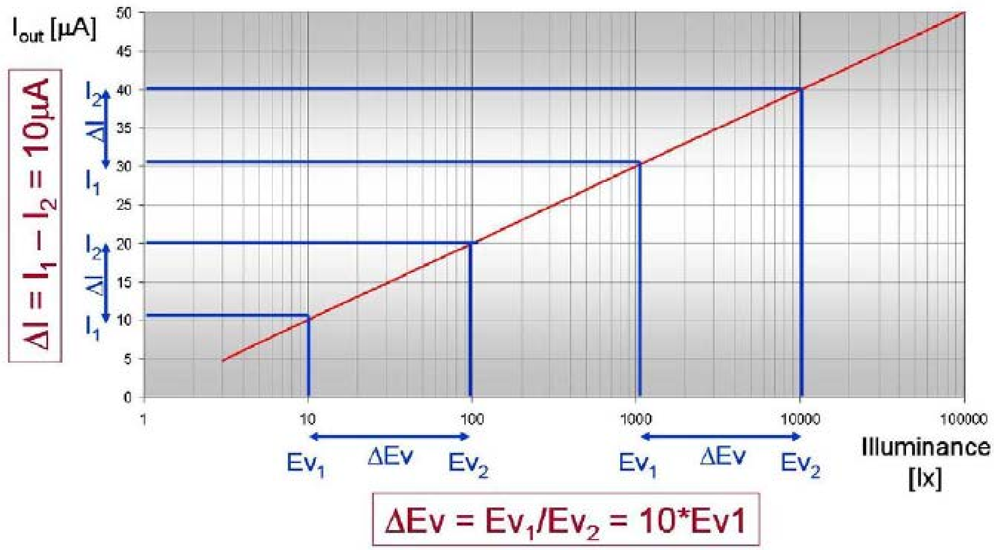

Figure 68: Logarithmic Output for SFH 5711 Light Sensor
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The ANSI Lumen Method must also be done to the standalone projector that we are comparing our pico-projector array system to. Comparing the values of the standalone projector to our array system should yield that the lumen output of the array systems is larger than that of the lone projector. This is because the image create will yield a greater lumen output because a single projector in our array will concentrate it's pixel allotment on a portion of the image and the total combination should outperform the single projector.

Before any testing can be done we must make sure the SFH 5711 is calibrated correctly so that we are getting accurate readings for our ANSI Lumens test. One simple way of testing the sensor is to first see if there is any readings in a completely unlit room. We test to see if there is any current flowing into the load resistor on the Iout pin of the SFH 5711 in a dark room. First have to output voltage from the load resistor pass the A/D converter in the projector box and have the host computer display the value. The voltage value should be close to zero. If not, it means that there is current going to the load resistor which means the sensor is not properly reading the right measurements. If there is no voltage value it means that no current is flowing through the resistor which should mean that the sensor is getting correct information.

1. Place the PVC piping array structure in front of BP dome

2. Make sure wiring coming out of the array is attached properly to the microcontrollers in the projector box

3. Power up host computer system and projector array and single projector. Allow 15 minutes for the projectors to stabilize.

4. Send image from host computer to the projector array.

5. Run the Warpalizer software to correct warping and edge blending.

6. Open the GUI program on the host computer that displays the lumen output of each sensor.

7. Through the GUI program check to make sure that an output is being shown for each sensor.

8. If the output is shown for each sensor, get the average of the lumen values and multiply by the screen width. This value will give the ANSI Lumen value.

9. Move the array system to the other side of the BP Dome.

10. Repeat steps 1-8 for the single projector system.

This testing procedure is what will be used to compare our projector box array to the single projector display. The results of this testing should confirm that the array system will produce a brighter image then the single projector display.

Section 7: User Manual

7.1 General Use

This manual assumes that all connectors have been properly connected to their according headers.

1. Place the Screen in the desired location.
2. Place the projector Box approximately 3 feet away from the screen and centered about the screen.
3. Place the host computer system behind the box and connect the 4 Mini DisplayPort connectors to the FirePRO W600.
4. Connect the laptop containing the GUI system to the projector box's open Serial Port using a straight through serial cable. **NOTE**: A USB to Serial Port converter box may be needed in this step if no Serial Port is available on the laptop.
5. Plug in the AC Power cord for both the Projector Box and the Host computer system.
6. Turn on all the projectors using the ACER K330 remote provided. **NOTE**: This must be done prior to host computer system booting to ensure a proper visual is displayed.
7. Turn the host computer on and wait for the system to boot.
8. Once the computer has finished booting you should see a warped image on the screen.
9. Adjust the warping if necessary. **See Warpalizer manual for instructions**

on how to adjust the warping.

10. Place the Light sensor array in front of the screen making sure that each sensor is within the light paths of the projector. **NOTE:** There is a small dead zone approximately 1 foot from the screen in between the top and bottom channels. Ensure the light is hitting the middle row of sensors before continuing.
11. Turn on the laptop containing the GUI.
12. Open the GUI.
13. In the lower left hand corner press the “Get light sensor values” button.
14. Wait approximately 10 seconds for the light sensor data to be displayed.
15. Check that accurate values are displayed. **NOTE**: You can use a calibrated lumen measurement device to ensure that these values are accurate.
16. Once the lumens have been measured you may display any image, movie, or game you wish through the projector system via the host computer system.

7.2 Troubleshooting

Error Message stating:

Error Opening the Serial Port
Please check the port and wiring and try again

This generally refers to an incorrect port being used. Ensure that you are using a standard 9 pin serial port and that the port is named “COM1” in the control panels device manager. If needed change the com port to “COM1” via the device manager.

Error Message stating:

Error Reading the Serial Port
Please check the port and wiring and try again

This generally refers to either a disconnected serial port or a loose ground wire. Ensure that a straight through serial cable is being used. Ensure that the serial cable is properly connected between the computer and the projector box; Tighten the screws if necessary to ensure a good connection. Ensure that the ground wire between the projector box and light sensor has not come loose on either end. Ensure that the ground wire between the host computer system and the terminal box has not come loose on either end.

Section 8: Group Members and Responsibilities

Each member of our group will have a specific element of this project to accomplish. This will include researching, testing, and ultimately (with some group input) make a final decision on each aspect of this project.

Since Nicholas Futch is a current employee of Q4 Services and has the greatest knowledge of simulator design and implementation, he will assume to role of project manager and assist in all aspects of the project. With 12 years of programming experience, Nicholas will also assume the role of microcontroller and interface programmer within the team. With projects ranging from robotics, GUI design, embedded controls, and graphics processing his experience will prove essential to the implementation of our design He has spent the last 2 years gaining extensive experience with a variety of microcontrollers and their implementation into simulation systems. This makes him the ideal candidate to handle this aspect of our design.

Ryan Gallo is currently, and has been an employee, of Siemens Energy Inc. for over 2 years and has developed a good working knowledge of power systems and power system design. Throughout his time with the company he has contributed to multiple projects, but not limited to power system design of control systems both analog and digital, commercial power systems, industrial power systems, and many other power system related projects. He has also spent time with the transmission and distribution division of Siemens and has accumulated a diverse working knowledge on transformer design and operation. Since the power system for our project will include AC to DC conversion, DC signal smoothing, power electronics, DC voltage amplification and modification as well as voltage regulation, we feel that Ryan has the most exposure to these topics and will be best suited to deliver a working solution to our design specifications.

Chris Rowe has worked at Walt Disney World where he worked at Architectural and Facilities Engineering department (A&FE). While in this position he worked in power system, distribution simulation, architectural / electrical / mechanical drafting, and also power control systems. These control systems included power management for backup generators and ride control systems. Chris has also focused his tech electives in power systems, but also is an avid hobbyist in circuit design. This design includes experience the Arduino Uno and Mega 2560. He also has experience working the light sensors when integrating them into designs. Chris also has over two years experience in AutoCAD design.

Gilbert is a RC hobbyist in his spare time. So he's worked on projects with servo applications including a robotic moving turtle that used four servos for movement. With having small projects the past couple of years, Gilbert has enough knowledge to pick the right servo for a potential design solution which is a good reason why he's handling hardware solutions for auto-alignment.

While all members will play a crucial role in the research, testing, and final design of this project we have chosen to divide the elements to each member as follows:

Nicholas Futch – Project Manager/Software Development
Ryan Gallo – Power System Design
Chris Rowe – Pico Projectors, Sensors
Gilbert Duverglas – Auto Alignment, BP Screen Sensor Mechanics

Section 9: Facilities and Equipment

During this project, research and development activities will be conducted at the Q4 facility in Orlando and the system will be supported by highly experienced Q4 personnel. Q4 Services currently owns a number of projectors and other simulator hardware and software relevant to this effort.

The Q4 facility in Orlando, Florida has large engineering and mechanical construction spaces. There is a permanent test bed at the Q4 facility, which includes a generic cockpit and collimated display system for evaluating internally developed components as well as other commercial-off-the-shelf (COTS) products. The Figure below shows one of the test setups of one of Q4's full motion simulator. Q4 is continually evaluating new products and has existing relationships with all the major vendors, including the major projector manufacturers. It will not be necessary to spend program funds until a component has been fully tested (as a "loaner") and proven cost-effective for the particular application.

Figure 69: Q4's Full Motion Simulator
Reprinted with permission from Q4 Services

Q4 has recently acquired a surplus MH-60S cockpit, pilot seats, display bowl and back projection screen, which will be available to this SBIR project for NVG evaluations at no additional cost to the program.

It will be possible to perform all demonstrations, prototyping and testing at the Q4 location, which is also within 20 minutes drive of UCF.

This facility meets all federal, state (FL), and local Government environmental laws and regulations pertaining to the work to be carried out.

Section 10: Consultants and Suppliers

Located in Orlando, Florida, Q4 Services is a *Women-Owned Small Business*, specializing in manufacture, service, and support of visual display systems in the global military and commercial flight simulator industries. Q4 Services has a full manufacturing shop and avionics refurbishment capability that will meet the needs of this research program.

Q4 Services is currently under contract to supply a number of its collimated mirrors to different programs in both the commercial and military simulation market. Recent contracts include United Parcel Service (UPS), CAE (FalconJet and Westwind), USAF B2 Bomber, and the KC-135 SOAR. The applied mirror technology is Q4's own high-fidelity, cost-effective, branded product called Supra-Vue™, which is also leveraged in the Williams Formula 1 Racing Simulator discussed further below. Standard features of the Supra-Vue™ display system include a single point of control for all display hardware assets through a dedicated maintenance Tablet computer and software GUI. The Q4 display methodology has been deployed world-wide and has been thoroughly field-tested to ensure easy set-up and consistent and reliable performance. The Supra-Vue™ approach insulates the user/maintainer from technology obsolescence and prevents the user from getting "locked" into a given supplier or "make and model" for life. The Supra-Vue™ product allows efficient technology insertion in later years, whether it is for fidelity improvement or even due to accidental damage. Q4 works with many vendors and can determine the best-value hardware component available to meet the specific need or desire.

The senior members of our engineering team are former employees of Rediffusion Simulation, Hughes Training Inc., Thomson Training and Simulation, Evans & Sutherland and/or Rockwell Collins and have accomplished a wide variety of Visual Installations and Integrations. Past buyers include most major airlines, including American Airlines and British Airways.

Q4 has an extensive history in the simulation industry. This makes them an ideal candidate to deploy such an innovative design into the industry. Between their years of experience and our fresh ideas there is no doubt we can successfully design, implement, and deploy this projector array.

For suppliers we will be purchasing mostly all of our circuit components from Digi-Key®. This supplier allows us to buy single parts instead of bulk purchases, and we can also receive sample parts. This allows us to test the part before we buy them to make sure the part is up to our specifications. If a cheaper supplier is found some parts may be ordered, but this will be on a part by part basis.

Section 11: Financing

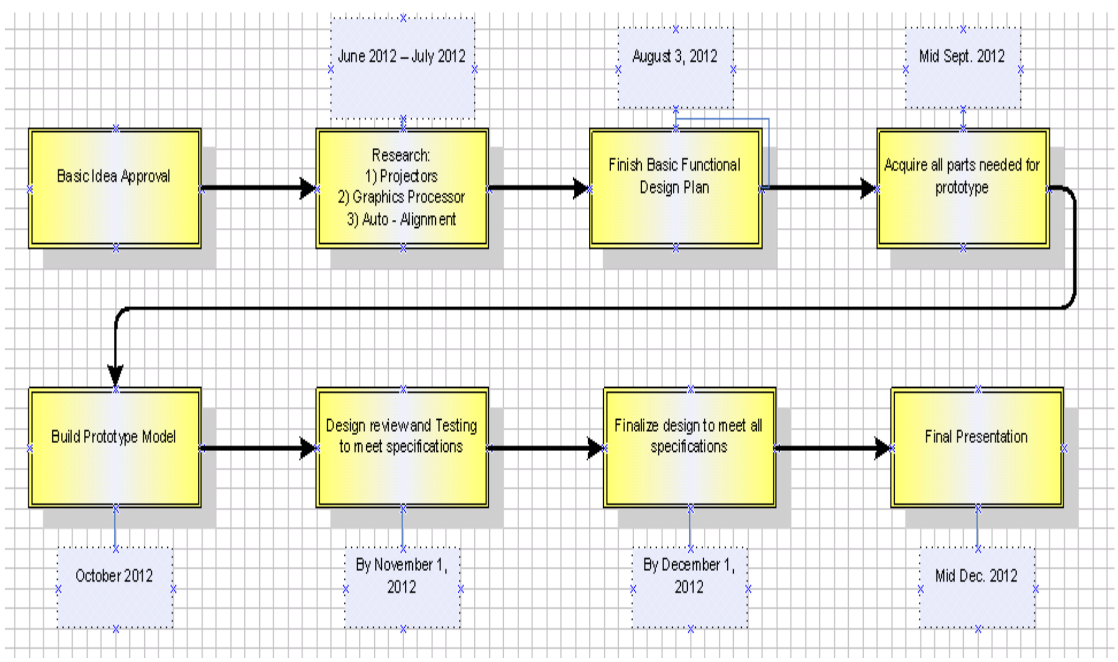
This project will be funded by Q4 Services LLC. Q4 specializes in the production of collimated display systems for flight simulators, their control systems, and CRT display system repairs. Our sponsor and contact there will be Martyn Rolls, Vice President of Business Development, and Tiffany German, Project Manager. All parts will be either purchased or donated by Q4. These materials, shown in Table 27, include but are not limited to:

BP System List			
Item	**Cost per Unit**	**Quantity**	**Total Cost**
Projectors	$500	4	$2000
Computer Host System	$2500	1	$2500
Auto Alignment	Donated	1	Donated
Array Frame	Donated	1	Donated
BP Dome	Donated	1	Donated
Dinrail Terminal Blocks	Donated	1	Donated
Miscellaneous Parts	N/A	N/A	$600
TOTAL			**$4100**

PCB Cost List			
Item	**Cost Per Unit**	**Quantity**	**Total cost**
ATmega 328	$7.54	1	$7.54
ATmega 2560	$14.78	1	$14.78
16 to 1 Mux	$5.68	2	$11.36
2 to 1 mux	$2.45	4	$9.80
MAX232	$4.55	2	$9.10
Transformer	$12.45	2	$24.90
Voltage Regulators	$0.17	6	$1.02
DC to DC Converter	$17.29	2	$34.58
AC to DC Conversion	$14.22	2	$28.44
Light Sensors	$1.87	20	$37.40
Total			**$178.92**

Table 27: Project Item List and Cost

Section 12: Project Milestones



Summer 2012

Decide on pico projector:	June 11, 2012
Decide on video post-processor technology (software/hardware):	July 2, 2012
Decide on auto-alignment software:	July 16, 2012
Begin final documentation:	July 18, 2012
Finish final documentation:	August 3, 2012

Fall 2012

Order all parts needed	August 15, 2012
Begin Prototype build (pending parts arrivals)	August 15, 2012 and later
Acquire all parts (Planning for any lead time)	Mid September 2012
Completed Prototype Build	October 15 2012
Completed Testing	November 15 2012
Sponsor Review	November 202012
Presentation:	December 5-11, 2012

Section 13: Project Summary

Current simulator systems today face an enormous challenge creating highly realistic images for training purposes. Current projects can cost tens of thousands of dollars and require immense amounts of adjustments in order to create a realistic image. We chose to investigate a solution to this problem by introducing a high quantity of low cost projectors used to produce a higher quality, self adjusting image.

By implementing an array of 4 pico-projectors we are capable of producing an image that supplies more pixels and higher resolutions at a fraction of the cost of standard simulation projectors. We are able to confirm these results through an automated light sensor array that can calculate the brightness of out images.

Future development of this project will look to implement the image splitting and alignment components of the system inside the box. This will help move the small projector array box to be easily implemented to existing systems.

The simulation industry could benefit greatly from the deisgn in our project. Removing the alignment labor would allow the alignment system to be free of countless man hours during installation. A low cost projector system will cut the cost of multiple projector setups down to and industry all time low.

Section 14: Appendicies

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3.3 Upon registration the User will be provided with an access code, comprising a User ID and a password ("User Data"). On first access, the User shall change the password provided by OSRAM into a password known only to the User. User Data allows the User to view of change his or her own data or to withdraw or grant consent to processing of his or her data.

3.4 The User shall ensure that User Data is not accessible to third parties and is liable for all transactions and other activities carried out under his or her User Data. At the end of each online session, the User shall log-off from the password protected area. If, and to the extent, the User becomes aware that third parties are misusing his or her User Data, the User shall notify OSRAM thereof without undue delay in writing, as well as by immediate e-mail where applicable.

3.5 After receipt of the notification in section 3.4, OSRAM will deny access to the password-protected area under such User Data. Access by the User will only be possible again upon the User´s application to OSRAM or upon new registration.

3.6 The User may at any time request termination of his or her registration in writing, provided that the deletion will not violate the proper performance of contractual relationships. In such an event, OSRAM will delete all User Data and any other personal data related to the User as soon as this data is no longer needed.

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> Hello Mr. Hewes,
>
> I am contacting you to request persmission to use one of diagrams for a
> power supply contained on your website at the link listed below. I am a
> senior Electrical Engineering student at the University of Central Florida
> and we are currently doing research for our senior design project. My
>responsibilites include desiging a power supply system for a flight
> simulator and would like to use your diagram in our 120 page design paper.
>
> Best Regards,
> Ryan Gallo
>
>http://www.kpsec.freeuk.com/powersup.htm
>

14.2 Figures

14.3 Tables

14.4 Abbreviations

lux, lx Lumens

PCB	Printed Circuit Board
MCU	Multiple Microcontroller Unit
USB	Universal Serial Bus
PWM	Pulse Width Modulation
ADC	Analog to Digital Converter
ALS	Ambient Light Sensor
PVC	Polyvinyl Chloride
LED	Light Emitting Diode
DLP	Digital Light Processing
LCoS	Liquid Crystal on Silicon
RPF	Rear Projection Film
FOV	Field of View
LiPo	Lithium-ion Polymer Battery