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March 9, 1999

Dr. Andrew Rawicz
School of Engineering Science
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Re: ENSC 370 Project – *SpotU Design Specifications*

Dear Dr. Rawicz,

The attached document, *SpotU Design Specifications*, describes the detailed design of our system. Our project is an automatic stage spotlight that will constantly maintain its focus on a particular performer by determining the location of this performer through transmitters and receivers.

This document explains our design and integration associated with a prototype SpotU's three subsystems: signal acquisition and conditioning, signal processing, and mechanical control system; as well as the component selected for implementation.

InnoDimension Enterprise is set up by five highly motivated Engineering Undergraduate students from Simon Fraser University: Ada Pang, Joyce Wong, Mei Chan, Sherla Cheung, and Victoria Chen. If you have any questions or concerns about the project, please feel free to contact us through e-mail at inno-d@sfu.ca or contact Mei Chan at (604) 436-2349.

Sincerely,

Victoria Chen, President
InnoDimension Enterprise

Enclosure: ENSC 370 Project – *SpotU Design Specifications*

InnoDimension Enterprise

SpotU Design Specifications

Submitted to	Andrew Rawicz School of Engineering Science Simon Fraser University Steve Whitmore School of Engineering Science Simon Fraser University
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Abstract

SpotU is an automatic follow-spot that tracks the location of a performer on the stage and follows the performer with a light beam to allow the audience to see the performer clearly and to create special effects. Our SpotU prototype will track the performer's location by having two sensors detecting ultrasound signal transmitted from the locator unit on the performer. Three RF modules are used for ultrasound triggering and data communication. The FPGA times the ultrasound signal and store the timing in a register. The microcontroller reads the timing value and translate the data into output for motor control. The mechanical control system then positions the light according to the microcontroller output.

This Design Specifications details the design decisions and processes of the SpotU and its subsystems: signal acquisition and conditioning, signal processing, data communication, and mechanical control system.

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1. Introduction

A tracking system is a system that follows a specified target by sensing the direction of this target's movement and carrying out the corresponding procedures to reposition. In everyday life, this system has a wide range of applications, one of which is in the entertainment industry. When a performer is giving a performance on stage either in a theater or in a concert, a **spotlight**[1] will constantly keep its focus on this performer and will follow the performer around the stage. This type of spotlight is called **follow-spot**. Almost all of the follow-spots in use today are controlled manually by light operators. SpotU, from InnoDimension Enterprise, is an automatic follow-spot that uses the tracking concept to locate a performer, who is wearing a locator unit, on the stage and adjust its focus and orientation accordingly.

This Design Specifications details the design decisions and processes of our prototype SpotU and its subsystems: signal acquisition and conditioning, signal processing, data communication, and mechanical control system.

[1] Bold terms are defined in the glossary

2. System Overview

2.1 Prototype System Overview

The SpotU prototype for ENSC370 will be able to track the performer in one dimension. Figure 2.1 illustrates the basic system composition.

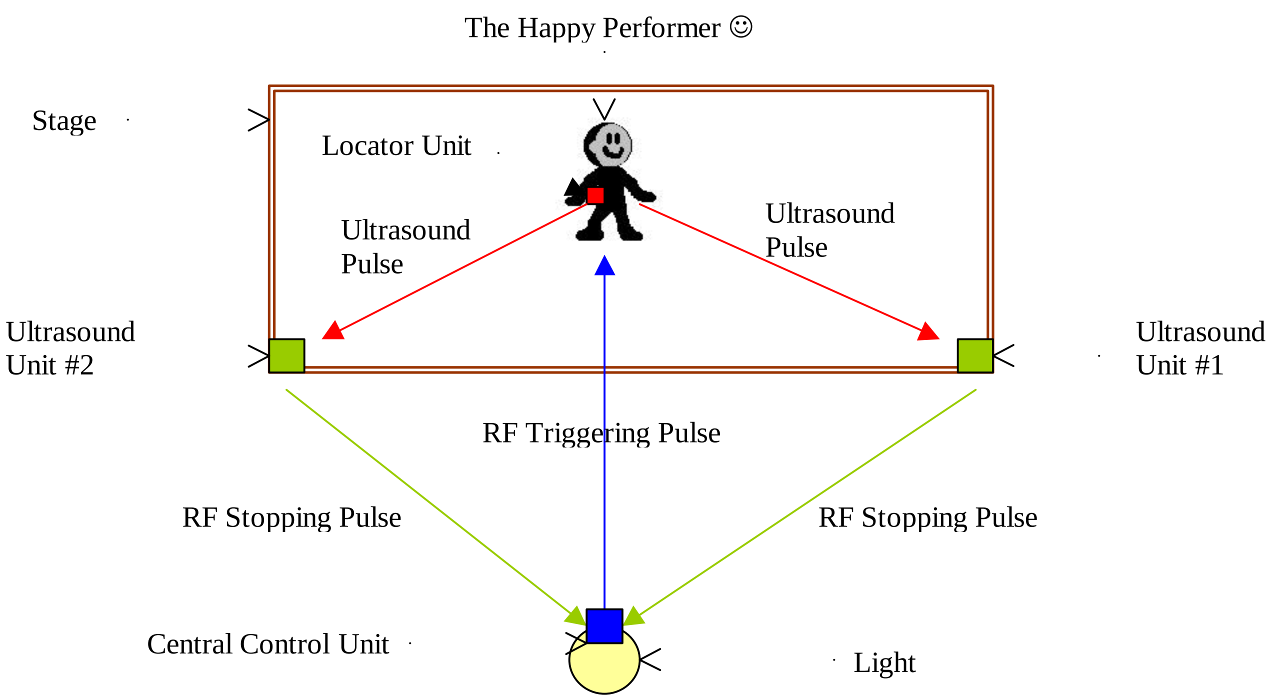

Figure 2.1: SpotU System Overview

The central control unit, shown in blue in figure 2.1, contains a triggering unit composed of a FPGA and two clocks. The FPGA operates on one of the clock cycles and the other clock starts the counter in FPGA and generates a **triggering pulse**. The triggering pulse is sent to the locator unit, shown in red, through a RF module and it triggers the ultrasound transmitters. Two ultrasound transmitters emit two ultrasound pulses and the pulses will be picked up by two ultrasound units located at the corners of the stage. The ultrasound units then transmit **stopping pulses**, through two other RF modules, to FPGA to stop the counter. The times take for the ultrasound pulses to travel is then recorded in registers. The microcontroller in the central control unit reads the values in the registers and translates the data into output for motor control. The motor rotates the light to the desired position.

2.2 Prototype Functional Specifications

The SpotU prototype developed for ENSC 370 will be able to track a performer's movements in one dimension. The signal acquisition, conditioning, and processing subsystem is capable of dealing with movements in two dimensions; however, the mechanical control system will only support horizontal movements for demonstration purposes. The requirements for each subsystem are outlined in the following paragraph.

2.2.1 Signal Acquisition and Conditioning System Requirements

General Requirements:
- must receive signals regardless of the position and orientation of the performer
- be able to receive signals within a 30 to 40 feet range
- external interference produces no significant effect on the signal
- customized for theatre size of 30 by 30 feet and stage size of 30 by 10 feet

Timing Unit:
- transmits trigging pulse to trigger the ultrasound transmitter in the locator unit
- capable of timing ultrasound signals
- provides data to the processing unit

Locator Unit:
- transmits ultrasound pulses to ultrasound units when triggered by the triggering pulse
- able to amplify the signal to the desired level
- weights less than 100g and smaller than 5cm $\times$ 5cm $\times$ 1 cm
- attaches easily but firmly on a performer's clothing
- possesses minimal interference to the performer

Ultrasound Units:
- receives ultrasound pulse from locator unit
- transmits pulse to stop timing unit from counting when receives ultrasound pulse

2.2.2 Signal Processing System Requirements

- ability to perform accurate mathematical analysis
- ability to map timing data to voltage for motor control
- filter out movements of performer within the spot
- generate output signal to the mechanical control system
- fast processing time

2.2.3 Mechanical Control System Requirements

- receive controlling signals from the processing unit
- smooth movements
- fast response time
- maximum angular velocity of 5°/sec
- maximum target object velocity of 2.5m/sec
- controls horizontal movement of the light
- ability to span 53° in horizontally
- support precise and fine movements

3. Signal Acquisition and Conditioning

3.1 Overview

The block diagram of the signal acquisition and conditioning system is shown in Figure 3.1. The timing unit starts the two counters once it generates a triggering pulse to the locator unit. The pulse triggers the ultrasound transmitter in the locator unit to emit ultrasound pulse to the two receivers in the ultrasound units. Each ultrasound unit sends a stopping pulse to the timing unit once it receives the ultrasound pulse. Each of the time, the counter value, is then stored in a register for the microcontroller to read. 500µs later, a **flag** is set to indicate to the microcontroller that a valid data is been stored. The next triggering pulse then resets the counter and the flag; and the procedure repeats.

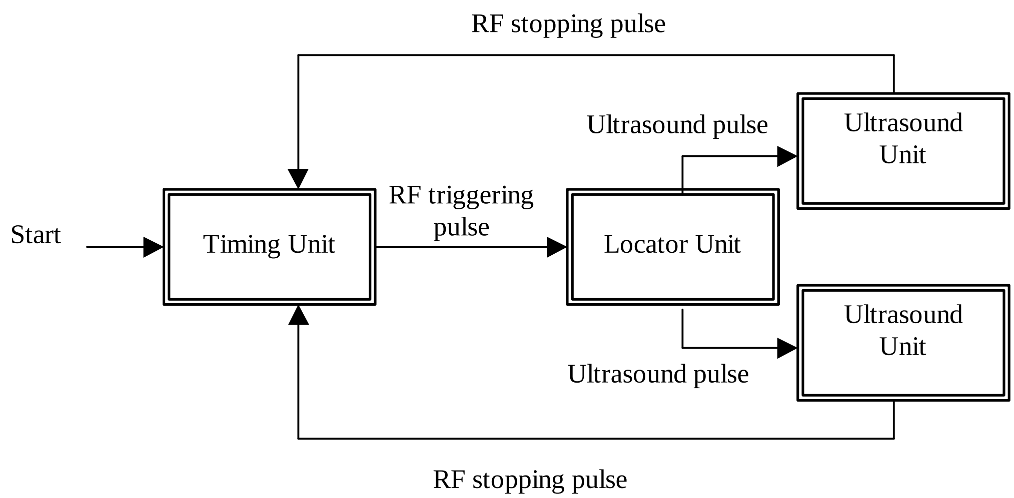

Figure 3.1: Block Diagram of the Signal Acquisition and Conditioning System

Thus, the signal acquisition and conditioning system is responsible for the following tasks:

1. Every 0.5 seconds, the timing unit generates a triggering pulse to the locator unit through a 433MHz RF transmitter-receiver set.
2. The locator unit generates an ultrasound pulse when the triggering pulse is at **logic high**.
3. The ultrasound units picks up the ultrasound pulse through two receivers located at the front corners of the stage.
4. The ultrasound unit generate a stopping pulse once detect the ultrasound pulse.
5. The timing unit stores each counter value into register once receiving the corresponding stopping pulse.
6. 500µs after storing a value, the timing unit sets the corresponding flag to indicate that new data is ready.
7. The next triggering pulse resets the counter and the flag.

Figure 3.2 shows the detailed block diagram of the locator and the ultrasound unit of the SpotU.

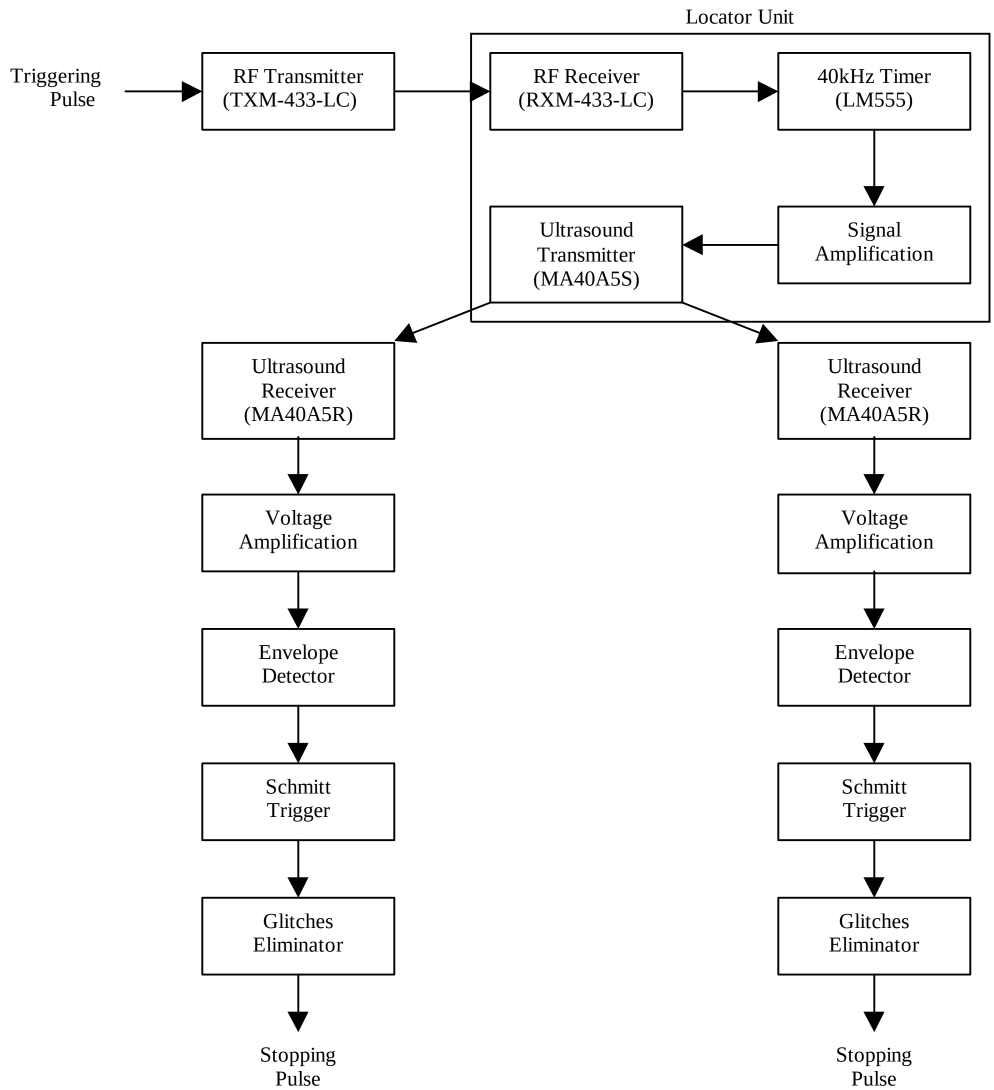

Figure 3.2: Detailed Block Diagram of the Locator and Ultrasound Unit

The input is the triggering pulse generated by the **control clock**. This pulse is used to trigger the ultrasound transmitter inside the locator unit to generate an ultrasonic signal, which will be timed in order to determine the performer's location. The output of this stage is the stopping pulse. The stopping pulse is a digital pulse which is used to indicate to the control clock that a particular ultrasound receiver has seen an ultrasound signal, therefore, the control clock should stop the timing procedure for this particular ultrasound link (hence, called "the stopping pulse").

3.2 The Timing Unit

3.2.1 The Control Clock

The first part of the system is essentially a control clock, which generates a digital pulse train (called a triggering pulse) for controlling the data acquisition unit. It is implemented using the LM555 Timer and Figure 3.3 shows the clock schematic.

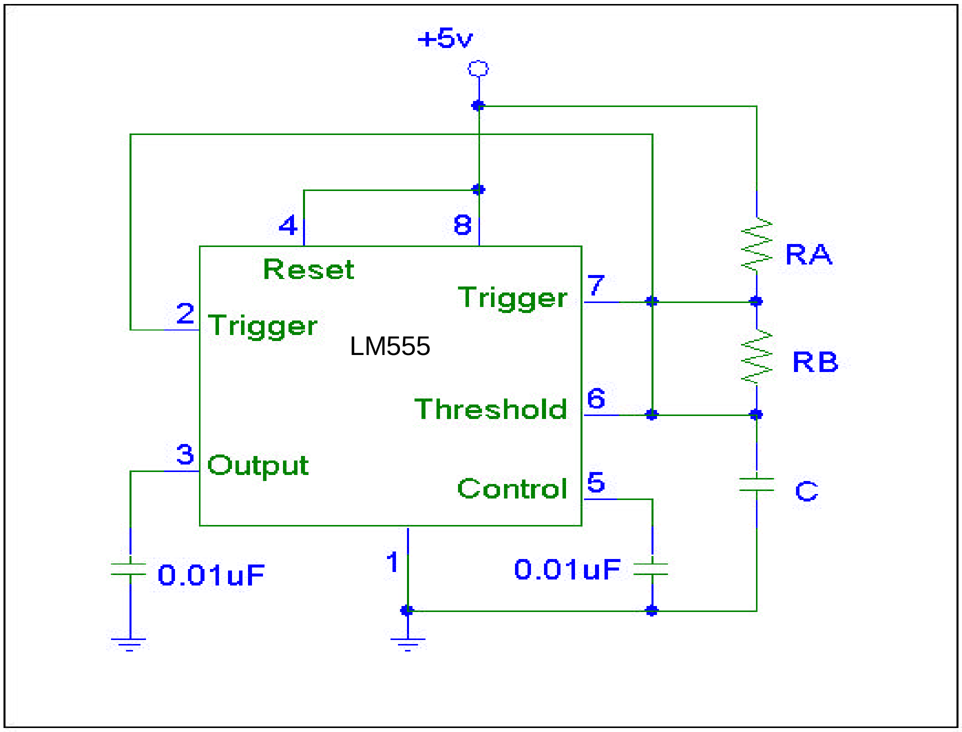

Figure 3.3: Schematic of the Control Clock

The timer is operating in **astable mode**, which means that the characteristics of the pulse train depend on the choices of resistors R_A, R_B and capacitor C.

$$\text{pulse width} = 0.693\ (R_A + R_B)\ C \qquad (1)$$
$$\text{total period} = 0.693\ (R_A + 2R_B)\ C \qquad (2)$$

The LM555 Timer is used because it is a highly stable device, it provides accurate timing in microseconds and the output pulse is adjustable to suit design needs.

Our system requires a **pulse train** that has a total period of 0.5s and a **pulse width** of 500 µs. The pulse width is the time that the output stays at logic high in a cycle and a 5V amplitude is interpreted as a logic high. Figure 3.4 shows the waveform of the pulse train.

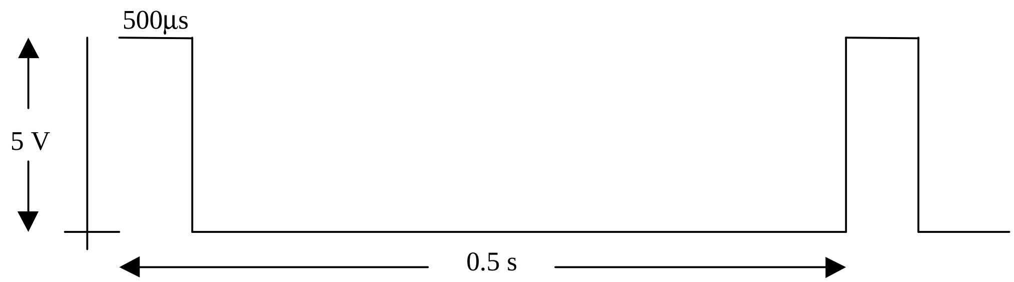

Figure 3.4: Pulse Train Generated by the Control Clock

Applying equations (1) and (2), the ratio of the two resistors can be found which is independent of the capacitor value.

$$5 \times 10^{-4} = 0.639\ (R_A + R_B)\ C \qquad (3)$$

$$0.5 = 0.639\ (R_A + 2R_B)\ C \qquad (4)$$

Dividing (3) by (4) and simplifying,

$$1 \times 10^{-3} = \frac{R_A + R_B}{R_A + 2R_B}$$

$$R_A + 2R_B = 1000R_A + R_B$$

$$-0.999\ R_A = 0.998\ R_B$$

Therefore, $R_A \approx R_B$

The output train is used to drive the data acquisition unit. On the rising edge of the clock signal, RF transmitter at the timing unit is triggered and emits a RF triggering pulse to the stage. At the same time, some necessary initializations such as clearing of counters and flags are performed. Then on the falling edge of the control clock signal, the counter starts incrementing by 1 for every 500µs. The counter is used to keep track of the number of counts that an ultrasound signal takes to travel from the performer to the sensors on the stage. The next sections give a detailed explanation on the design of the counter.

3.2.2 The Counter

The counter starts counting once the timing unit sends out a triggering pulse. When one of the RF receivers on the spotlight gets the stopping pulse from the corresponding transmitter on the stage, the counter value is stored in a register. The data is an 8-bit binary value, with the most significant bit (MSB) used as the **valid data flag** to indicate to the microcontroller that the data is available. Seven bits are left to store counter value; therefore, the counter value is limited to a maximum of $2^7 = 128$ counts. With 128 counts, the ultrasound pulse has to arrive its receiver within 64ms, assuming it takes 0 second for the RF signals to travel. Since the speed of ultrasound is approximately 300m/s, the performer must stay within 19m from the sensors. This limitation does not pose a problem to our prototype development since our prototype stage size is approximately 9m by 3m.

500ms after the counter value is stored into the register, the valid data flag is set to 1 – indicating to the microcontroller that the data is available for loading. Storing data and setting the flag occur at two consecutive rising edges of the counter clock; in other words, the data is transferred from the counter to the register within 1ms. The counter keeps incrementing until the second RF receiver receives its stopping pusle. Then the new counter value is stored a second register, the valid data flag is set and data is transferred to the microcontroller.

We make an assumption that all the processes – from clearing the counter to transferring the second counter value to the microcontroller – is completed within 0.5s, which is the period of the control clock signal. Finally, the counters are cleared and the valid data flags are reset to 0 on the rising edge of the new control clock pulse, which indicates the beginning of a new cycle.

The counter will be implemented using a FPGA chip. The control process will be developed in VHDL and simulated using the MAX+PLUS II software. The Altera EPM7128SLC84-7 device will be used as the platform. Table 3.1 below lists the features of EPM7128SLC84-7.

Table 3.1: Features of EPM7128SLC84-7

Speed Grade	7.5ns
Density	2500 logic gates
Operating Voltage	3.3V – 5.0V
# of Pins	84

The EPM7128SLC84-7 belongs to the Altera MAX7000 series. It is fast and is able to operate at multiple voltages. It is compatible with multiple I/O voltages and is supported by an easy-to-use design software.

3.2.3 The RF Modules

Most of the time, a spotlight is located far away from the stage, at the other end of the theatre and behind the audience. The SpotU follow sport relies on certain form of communication between the locator unit on the stage and the microcontroller on the light. RF is an ideal choice since it is long range, fast and it support multiple channels using different frequencies with little interference.

TXM - XXX - LC RF transmitters

The LC Series transmitters by Linx Technologies Inc. provide three modules of different **carrier frequencies**, as indicated by the numbers in the middle of the part names. The three frequencies are 315MHz, 418 MHz and 433 MHz, which are all employed by the SpotU system. TXM-433-LC transmitter is used by the timing unit to send the triggering pulse to the locator unit. TXM-315-LC and TXM-418-LC are used by the ultrasound units to transmit the stopping pulses back to the timing unit. Except for the carrier frequencies, they display the same features and those that are of concern to the project are listed in Table 3.2 below.

Table 3.2: Features of Linx LC RF Transmitters

Features	TXM – XXX - LC
Size	9.5mm x 13mm x 3.8mm
Supply Voltage	2.7 – 5.2 VDC
Supply Current	1.5 mA
Range	300 feet minimum

The transmitters are 8-pin devices. They take a serial **bitstream** as input and send out an identical signal in RF. Therefore, referring back to the block diagram in figure 3.2, the transmitter TXM-433-LC actually reproduces the control clock signal in RF.

RXM - XXX - LC RF Receivers

Each member of the LC series transmitters has a corresponding partner in the Linx LC Series receivers. The receivers get the RF input and recover the original digital signal that drives the transmitters. Table 3.3 lists some of the features common to all three types of receivers.

Table 3.3: Features of Linx LC Series RF Receivers

Features	**RXM – XXX - LC**
Size	14.7mm x 21.2mm x 6.4mm
Supply Voltage	2.7 – 5.2 VDC
Supply Current	4.0 – 8.0 mA
Data Out Voltage for Logic High	0 – 0.2 V
Data Out Voltage for Logic Low	3.5 – 3.7 V

Each type of receiver has a **frequency pickup range** centered around the **nominal carrier frequency**. The values are given in Table 3.4.

Table 3.4: Frequency Pickup Range

Receiver Part No.	**Receive Frequency**
RXM-315-LC	314.83 – 315.07 MHz
RXM-418-LC	417.96 – 418.08 MHz
RXM-433-LC	433.86 – 433.97 MHz

RXM-315-LC and RXM-418-LC are located at the timing unit to receive stopping pulses from their corresponding transmitters at the ultrasound units. RXM-433-LC is located at the locator unit to receive triggering pulses transmitted from its corresponding transmitter at the timing unit.

As seen from Table 3.4, the three frequency ranges do not overlap; therefore interference should not occur between the three RF modules used in our implementation. However, if other RF signals present in the theatre falls into any of the three ranges and are of significant magnitude, interference could pose a problem. In that case, different RF module with non-conflicting frequencies can be chosen to avoid interference with RF signals from other theatre equipment.

Antenna

Antennas are needed at the output pin of each transmitter and at the input pin of each receiver. Choices of antennas include **whip style**, **helical style** and **loop style**. We have chosen the whip style antenna because it provides exceptional performance and can be easily made from a length of conducting wire. Generally, the higher the carrier frequency, the shorter the antenna. Table 3.5 summarizes the 1/4-wave wire length for each frequency.

Table 3.5: 1/4-Antenna Length

Frequency	Antenna Length
315 MHz	8.9"
418 MHz	6.7"
433 MHz	6.5"

Since the presence of an antenna poses certain inconvenience to the performer, the antenna length should be reduced as much as possible without affecting signal reception. Therefore, the 433 MHz RF module is used to transmit pulses from the timing unit to the locator unit to minimize the size of the locator.

3.2.4 TXM-433-LC RF Transmitter

The TXM-433-LCtransmitter is used to send the triggering pulse to the locator unit on the stage. The triggering pulse is generated by the control clock. This pulse is fed directly to the TXM-433-LC, which converts this pulse into RF signals over a 433MHz carrier. Figure 3.5 shows the schematic of the TXM-433-LC. The characteristics of TXM-433-LC are provided in table 3.2 in section 3.2.2 The RF Modules.

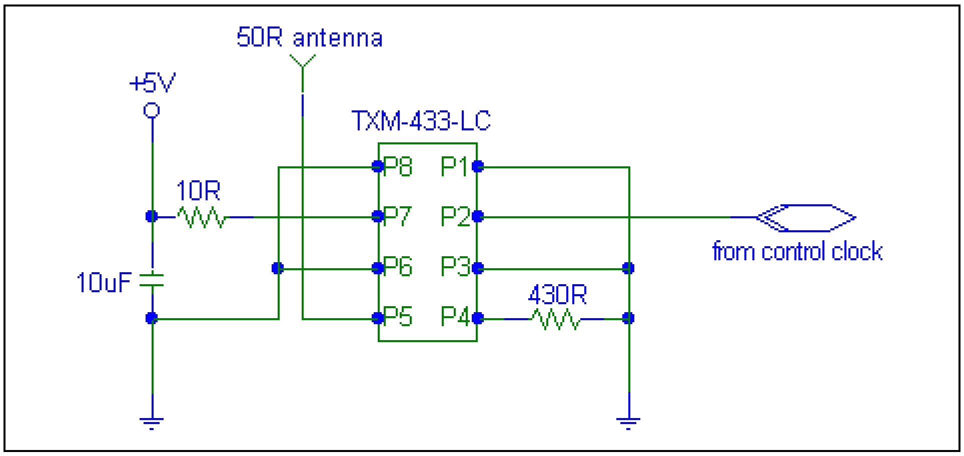

Figure 3.5: Schematic of TXM-433-LC

The TXM-433-LC transmitter is used for sending the triggering pulse because it has a small dimension; it does not require additional RF components; it is easy to use; and it has a low cost. A **supply filter** that consists of a 10Ω resister and a 10µF capacitor is used to ensure the transmitter gets a clean, well-regulated power source. The 430Ω resister connected to pin 4 (P4) is an operational requirement of the module since V_{cc} is +5V. The triggering pulse output of the control clock is connected directly to pin 2 (P2) while pin 5 (P5) is connected to a 50Ω antenna.

3.3 Locator Unit

3.3.1 RXM-433-LC RF Receiver

The RF signals sent out by TXM-433-LC are picked up by the RXM-433-LC receiver inside the locator unit. The RXM-433-LC regenerates this RF signal into the original triggering pulse. Figure 3.6 shows the schematics of the RXM-433-LC. The characteristics of RXM-433-LC are provided in table 3.3 in section 3.2.2 The RF Modules.

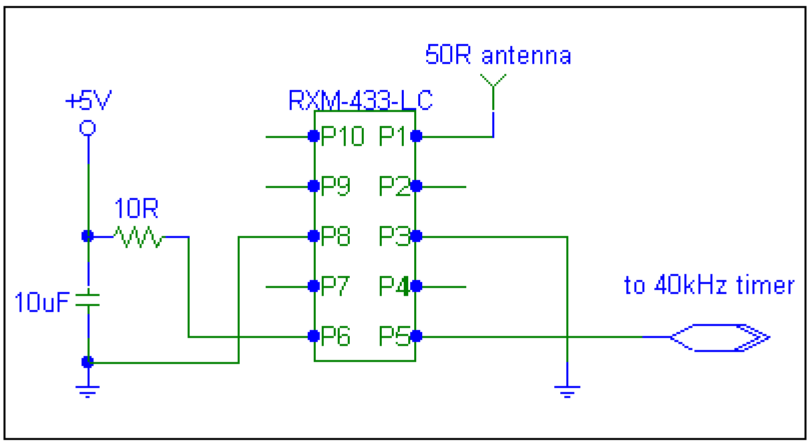

Figure 3.6: Schematic of RXM-433-LC

A supply filter is used again to ensure the RXM-433-LC receives a clean power supply. Pin 1 (P1) of the module is connected to an antenna that matches the antenna used by TXM-433-LC at the timing unit. The RXM-433-LC regenerates the RF signal, transmitted by the TXM-433-LC, into the triggering pulse. This regenerated pulse is fed into the 40kHz timer; therefore, the output of the RXM-433-LC, which is pin 5 (P5), is connected to the 40kHz timer directly. Pins 2, 4, 7, 9, and 10 are left floating.

3.3.2 LM555 40kHz Timer

When transmitting a digital signal using ultrasound wave, a 40kHz signal will be generated to represent a logic high and no signal will be produced for a **logic low**. Therefore, in order for the locator unit to send out a pulse using ultrasound wave, the LM555 timer is enabled and will generate a 40kHz signal whenever the triggering pulse is at logic high. In other words, the duration of the triggering pulse determines the duration of the 40kHz signal and the amount of time the LM555 is enabled. When the triggering pulse is at logic low, no signal is generated. The schematic of the LM555 is shown in Figure 3.7.

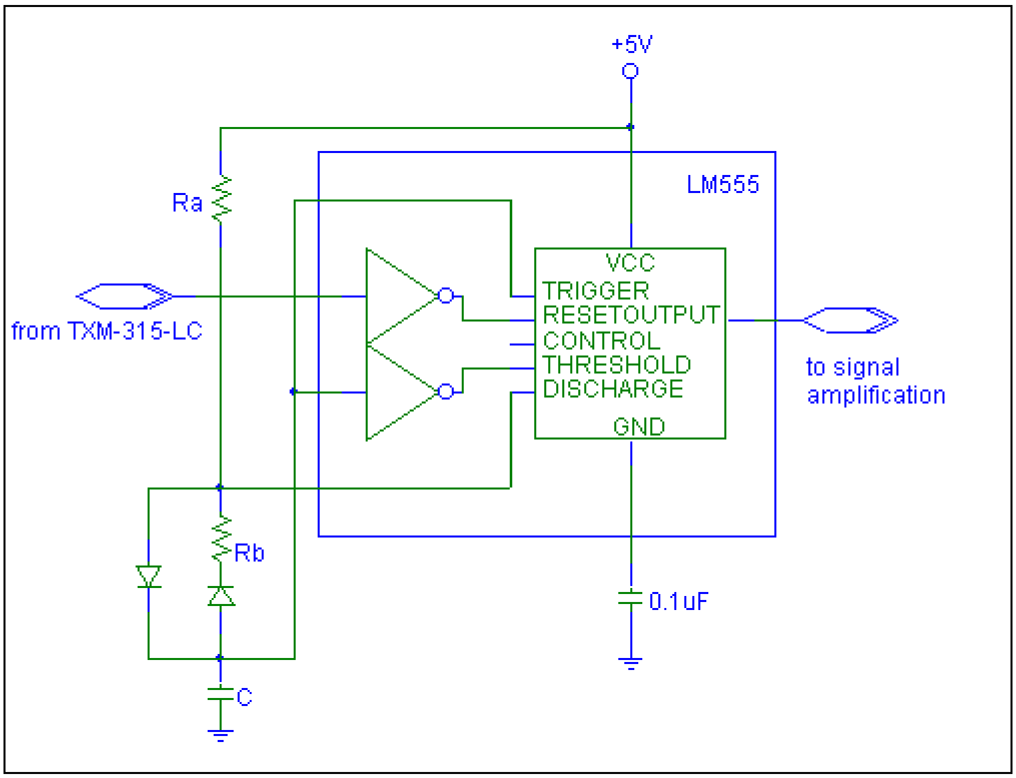

Figure 3.7: Schematic of the LM555 40kHz Timer

The main reason for using the LM555 is because it is a very common electronics component that can be found in most electronics stores. The frequency of the LM555 is determined by equation (5)

$$f = \frac{1}{T} = \frac{1.44}{(R_A + 2R_B)C} \tag{5}$$

In order to obtain a 40kHz timer, R_A and R_B are set to 3.9kΩ and C is set to 3nF.

3.3.3 Signal Amplification

The output of the LM555 is a 40kHz signal that swings between 0 and 5V. In order for the ultrasound transmitter to generate a stronger ultrasonic signal, the magnitude of the signal should be amplified to -12 to 12V. This is achieved by feeding the signal coming out of the LM555 into a MAX232 **signal amplifier**. The MAX232 signal amplifier is capable of converting a +5V signal into a ±12V signal. Although the MAX232 is able to amplify the magnitude of the signal, it does not provide power amplification. Therefore, the ±12V signal coming out of the MAX232 is fed into a **unity-gain op-amp** that is powered by ±12V power supply. The ±12V power supply is obtained by the MAX742 chip which is capable of delivering ±12V power from a +5V source. The signal coming out of this stage will be strong enough to drive the ultrasound transmitter.

3.3.4 MA40A5S Ultrasound Transmitter

The MA40A5S ultrasound transmitter is the final component inside the locator unit and it generates ultrasound signals using the 40kHz ±12V signal coming out of the signal amplification stage of the locator unit. The reasons for using the MA40A5S are because of its high sensitivity and its small dimensions. The characteristics of the MA40A5S transmitter are listed on Table 3.6.

Table 3.6: MA40A5S Characteristics

Parameter	**MA40A5S**
Nominal Frequency	40kHz
Maximum Sensitivity	112dB
Directivity	50°
Capacitance	2000pF
Resolution	9mm

3.4 The Ultrasound Unit

Two ultrasound units will be installed at the front corner of the stage. Please refer to figure 2.1 for an general overview. Each ultrasound unit is consisted of a ultrasound receiver, voltage amplifier, envelop detector, schimitt trigger, glitches eliminator, and a RF transmitter.

3.4.1 MA40A5R Ultrasound Receiver

A MA40A5R ultrasound receiver is placed at each front corner of the stage in the ultrasound unit. These MA40A5R receivers pick up the ultrasound wave generated by MA40A5S at the locator unit. Table 3.6 lists the characteristics of the MA40A5R component.

Table 3.6: MA40A5R Characteristics

Parameter	MA40A5R
Nominal Frequency	40kHz
Maximum Sensitivity	-67dB
Directivity	50°
Capacitance	2000pF
Resolution	9mm

3.4.2 Voltage Amplification

The signal that the MA40A5R receives may be too small and weak for processing; therefore, the signal needs to be amplified. The amplification is done by connecting two inverting op-amps in **cascade configuration**. The schematic for the voltage amplification stage is shown in Figure 3.8.

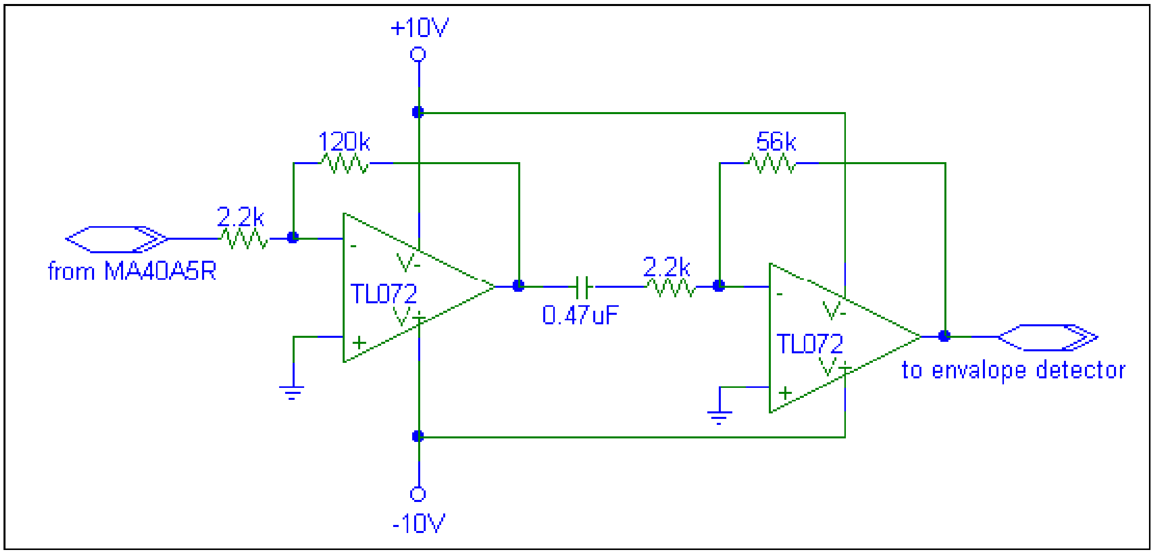

Figure 3.8: Schematic of the Voltage Amplifier Stage

The gain of one single **inverting op-amp** is given by equation (6)

$$A_v = -\frac{R_{out}}{R_{in}} \tag{6}$$

where R_{out} is the resister connected between the output and the inverting input of the op-amp and R_{in} is the resister connected between the signal source and the inverting input of the op-amp. The overall gain of the cascade configuration is the product of the two inverting op-amp gains. Therefore, the gain of the first inverting op-amp is about -55V/V while the second one has a gain of approximately -25V/V. Therefore the overall gain is approximately 1375V/V. The reason for using two inverting op-amps instead of one op-amp with a larger gain is because in order to have a higher gain, R_{out} needs to be very large. However, if R_{out} is in the MΩ range, non-ideal situation will occur. Some of the non-ideal situations include input offset voltage is also amplified by the op-amp, input bias current can be large, output offset voltage is introduced into the signal. Connecting two op-amps together can also eliminate the **loading effect** on the op-amps; therefore the gain will not be driven down if a large load is connected to the op-amps. In order to eliminate DC offset from the first op-amp, a coupling capacitor is placed between the output of the first op-amp and the input of the second op-amp.

3.4.3 Envelope Detector

The signal that the MA40A5S receives is made up of bursts of 40kHz wave whose amplitude varies with time. It is necessary to covert this 40kHz signal into a digital signal for the control clock. An envelope detector reduces the variation in the magnitude of the signal and "traces out" the logic high and low of the signal. Figure 3.9 compares the waveform of the signal before and after going through the envelope detector.

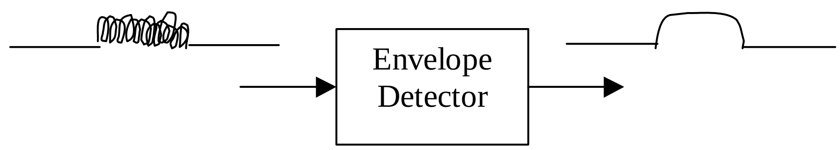

Figure 3.9: Signal Before and After Envelope Detector

The schematic for the envelope detector is given by Figure 3.10.

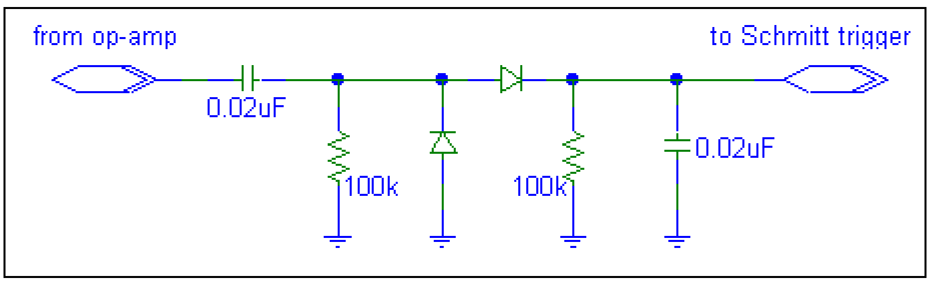

Figure 3.10: Schematic for the Envelope Detector

After the MA40A5S receives the ultrasound signal, the signal will be amplified by the two op-amps as mentioned previously. Then the amplified signal goes through the above envelope detector so the magnitude of the signal is more constant than before. The envelope detector can be thought of as outlining the pulse from the 40kHz signal that the MA40A5S receives.

3.4.4 Schmitt Trigger

Even though the envelope detector has stabilized the magnitude of the signal, this signal still does not have a very clean raising and falling edge. Therefore, the signal is not good enough to be used as the digital stopping pulse. The purpose of the Schmitt trigger is to reshape the "outline" of the pulse into a digital signal whose edge is more defined and visible. Figure 3.11 compares the waveform of the signal before and after going through the Schmitt trigger. Schematic for the Schmitt trigger is shown in Figure 3.12.

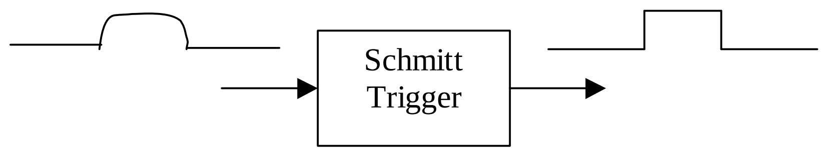

Figure 3.11: Signal Before and After Schmitt Trigger

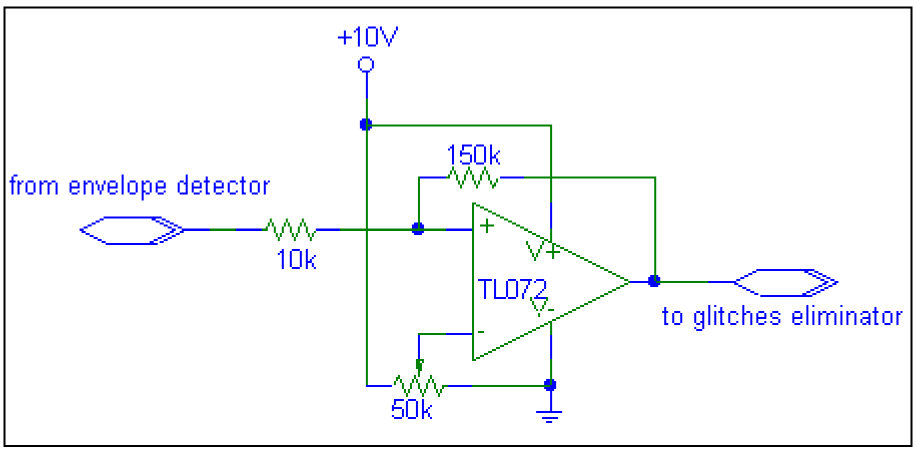

Figure 3.12: Schematic for the Schmitt Trigger

3.4.5 Glitches Eliminator

The signal the envelope detector traces out may contain ripples caused by disturbances. These ripples may be large enough to cause the Schmitt trigger to regard it as a possible digital signal edge and, therefore, to add an undesirable logic transition to the final digital output. Figure 3.13 indicates this situation.

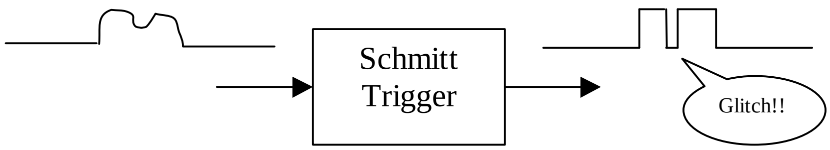

Figure 3.13: Glitches in Digital Signal

Glitches are dangerous to the system, since the counter in the control clock operates according to the raising and the falling edges of the stopping pulse. The combination of digital and analog circuit in Figure 3.14 is used to eliminate any possible glitches. After this stage, the stopping pulse is ready to be transmitted to the timing unit through a RF transmitter.

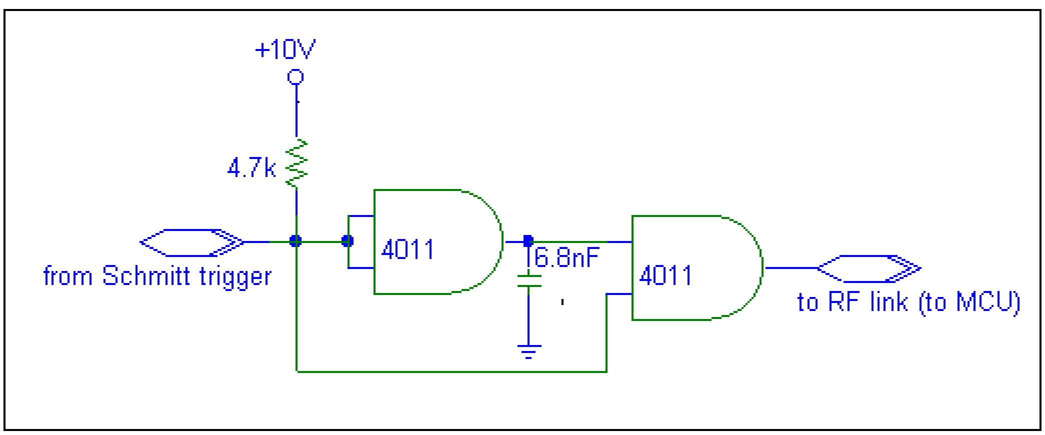

Figure 3.14: Schematic for Glitches Eliminator

3.4.6 RF Transmitter

Two ultrasound units are placed at the two front corners of the stage; each has its own signal conditioning circuit described above. Two stopping pulses are generated and conditioned. Each stopping pulse is used to drive a RF transmitter in each of the ultrasound units. Each transmitter sends out a stopping pulse to the corresponding RF receiver on the spotlight. The RF modules used are the Linx LC Series with carrier frequency of 315MHz and 418 MHz. Please refer to section 3.2.2 The RF Modules for details on these two transmitters selected.

4. Signal Processing

4.1 Overview

Signal processing subsystem, more commonly known as the “brain” of the system, is the central controller that controls and interacts between different subsystems.

The signal processing subsystem of the SpotU system is responsible for interpreting the received signals. This interpretation involves deriving the location of the performer and then determining how much the spotlight should move correspondingly. In addition, the signal processing subsystem must generate correct output signals to the mechanical control system to rotate the head of the light to the desired position.

The signal processing unit must be capable of processing two major tasks: signal analysis and output generation. The following figure provides a brief overview of the methods involved:

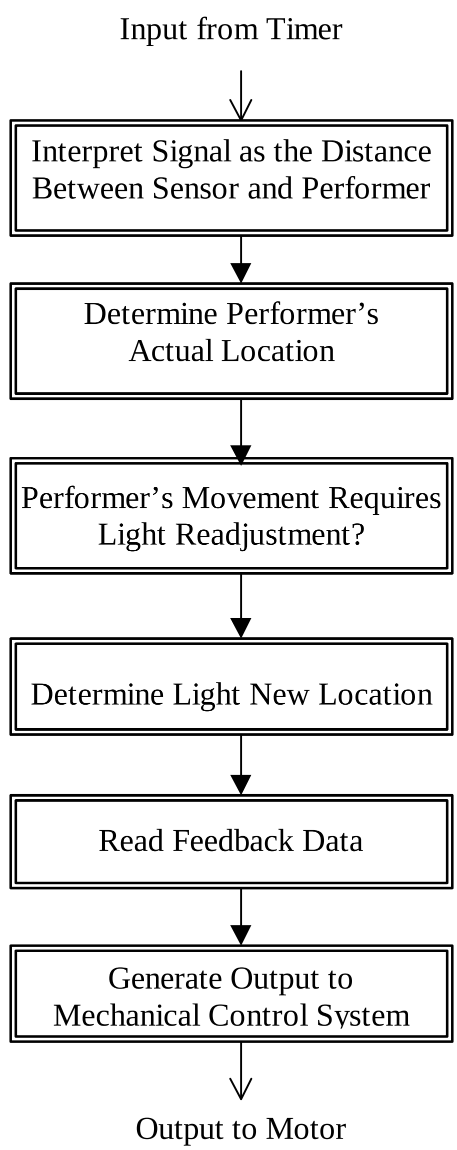

Figure 4.1: FlowChart for Signal Processing Unit

4.2 The Microcontroller

The microcontroller performs and controls the procedures described in section 4.3. Intel, Motorola, MicroChip are just a few of the major names in the market for microcontrollers. Although microcontrollers from different manufactures all have the basic functionality, care must be taken when selecting a microcontroller that provides the optimum set of development tools.

In comparison with other industrial systems, SpotU system does not require complicated calculations. Thus, a microcontroller that is capable of doing simple calculations and comparison is adequate. The microcontrollers that are best suited for SpotU applications is MicroChip's PICs and Motorola's HC11s. Since large amount of power is not readily available in theaters, the selected microcontroller must have low power consumption. The HC11 has an approximation of 20 mA current consumption while the PIC only consumes less than 5mA. Since no complicated calculations and comparison are required for the SpotU system, the PIC microcontroller is capable of processing the required tasks. Consequently, the PIC microcontroller will be used at the central signal processing system of the SpotU system.

Within the PIC microcontroller class, the PIC17C4X family is chosen for a number of reasons. First and foremost, the PIC17C4X family has a relatively large instruction set. While other families only have 35 single word instruction sets, the PIC17C4X family supports 58 instructions. Within the additional 23 instructions is the hardware multiplier, which facilitates the multiply algorithm by reducing the code length immensely. Implementing multiplication using other PIC microcontroller families requires approximately 13 word-size of program memory and a maximum of 69 clock cycles. In contrast, the PIC17C4X family only requires 1 word-size from program memory and 1 clock cycle to perform multiplication. The hardware multiplier calculates the product of two 8-bit numbers, and places the result in a 16-bit register. The PIC17C4X is the only PIC microcontroller family that is capable of handling 16-bit numbers. Additional instructions to perform operations on 16-bit numbers are also available with the PIC17C4X family.

Apart from the above reasons, the PIC17C4X family has a larger register set to allow high performance. Comparing to other families, PIC17C4X provides a 2:1 code compression and a 4:1 speed improvement; thus, the PIC17C4X is best suited for precise motor control required by our system.

Inside the PIC17C4X family, 2K, 4K, and 8K program memory is available. The PIC17C43 is chosen because it provides a 4K program memory, which will be sufficient for our system. During development, the code may need to modified frequently; thus, the UV-erasable CERDIP-package version of PIC17C43 is used. When manufacturing the final SpotU product, One-Time Programmable (OTP) version of the microcontroller can be used instead.

Figure 4.2 shows the pin diagram for the PIC17C43. Considering future expandability, a 33 I/O pin device is used. For one dimension, only one sensor is required to detect the performer's location. For our prototype, two input pin is used for two input signals from two ultrasound sensors. However, as the dimension increases, the number of sensors increases, and consequently, the number of input ports to the microcontroller will increase correspondingly.

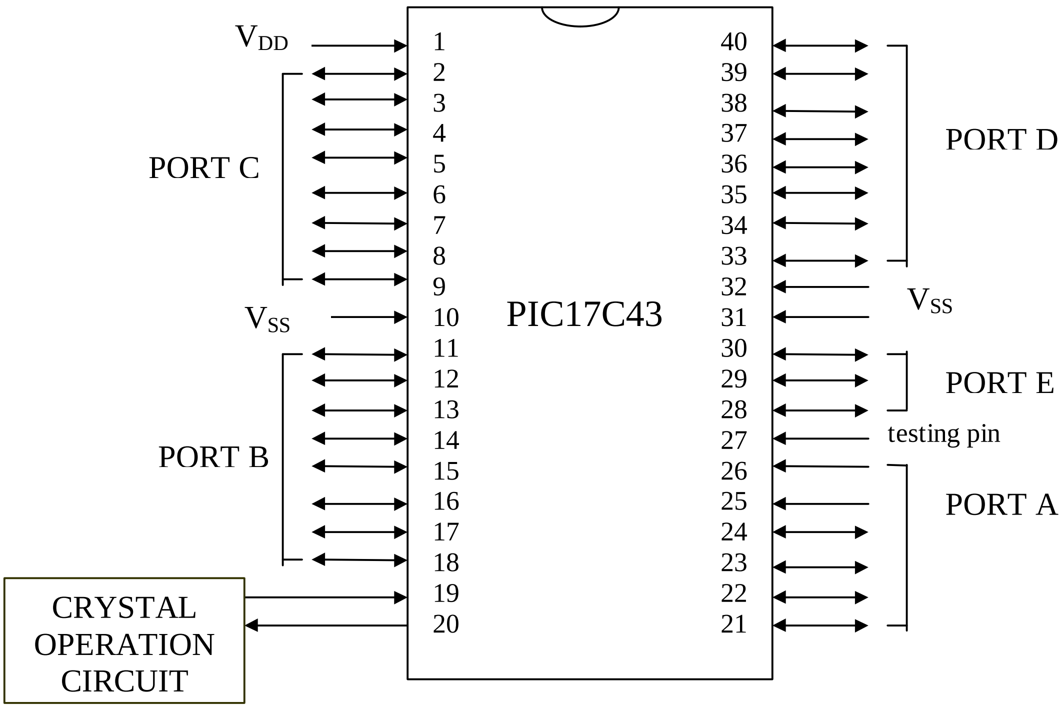

Figure 4.2: Pin Diagram for PIC17C43

Pin 1 is V_{DD}, which is the supply voltage. The operating range of the microcontroller is 4.5V to 6.0V with a 24mA maximum input current. Pins 10 and 31 are V_{SS}, which are the ground terminals. The pins marked with Port B, Port C, and Port D are 8-bit bi-directional ports. By setting the corresponding data direction registers, the ports can switch between input mode and output mode. Port A has two input pins and four bi-directional pins. Port E is a 3-bit bi-directional port.

Pin 19 and Pin 20 are connected to Crystal Operation Circuit, which serve as the oscillator's input and output terminals. A parallel cut crystal is preferred over a series cut crystal; since a series cut crystal may emit a frequency that is beyond the crystal manufactures specifications. Figure 4.3 illustrates the basic schematic of the Crystal Operation Circuit.

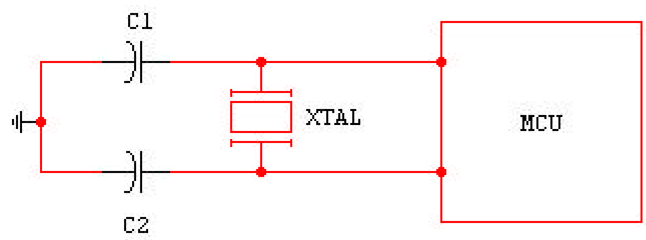

Figure 4.3: Crystal Operation Circuit

The capacitors in the above circuit are used to increase the stability of the oscillator. This tends to increase the start-up time for the system; however, the tradeoffs between stability and start-up time can not be avoided in an non-ideal environment. If the oscillator is operating at 16.0 MHz, the capacitor values are in the 33 pF to 100 pF range.

4.3 The Algorithm

Figure 4.4 is the detailed microcontroller algorithm. The microcontroller has to determine the location of the performer from the two input data, which is the number of clock cycles that ultrasound requires to travel from the performer to the sensors. The microcontroller calculations the location of the performer with respect to the reference point, say the leftmost side of the stage.

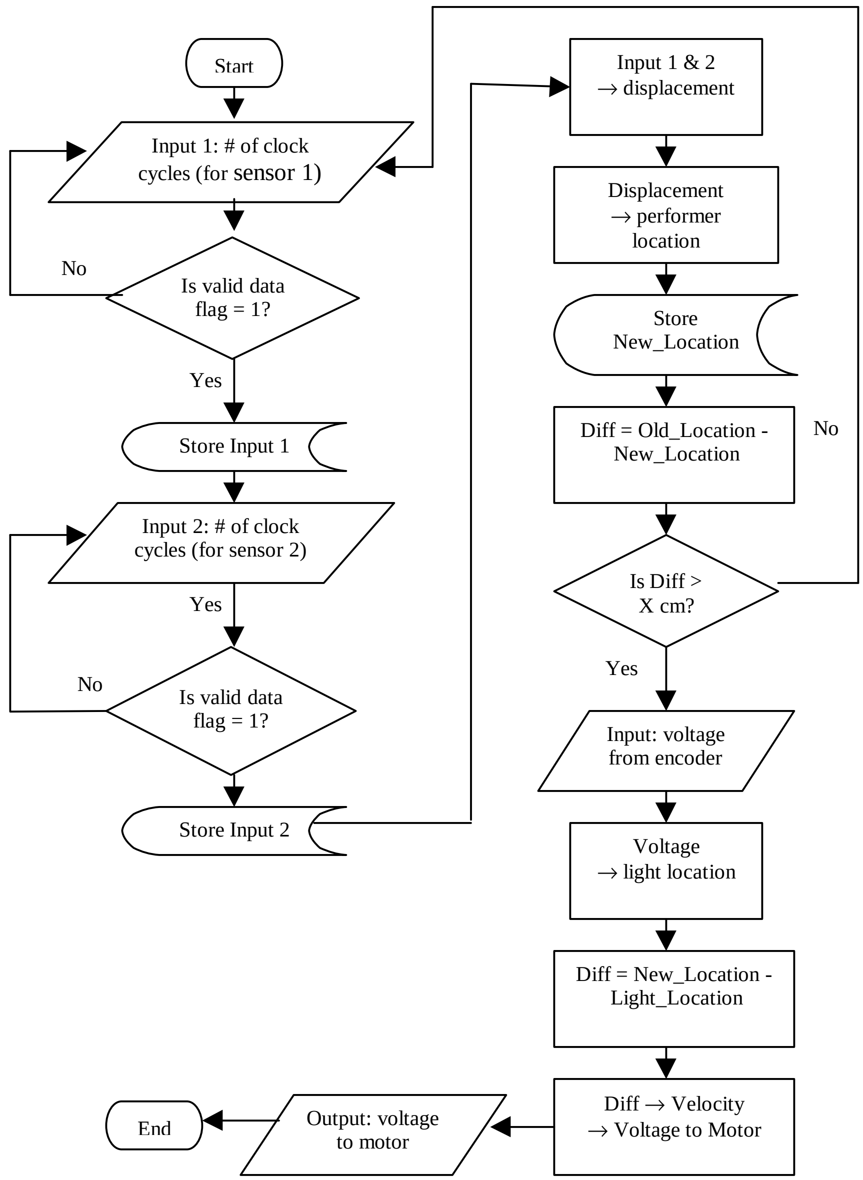

Figure 4.4: The Algorithm

The microcontroller gets input data is through a method called polling. The input received from the signal acquisition and conditioning system is an 8-bit data. The most significant bit of the data is the valid data flag. The microcontroller carries out data manipulation operations only when the valid data flag is at logic 1.

To calculate the direct distance between each sensor and the performer, the following formula is used:

$$D = \text{\# of clock cycles} \times T \times V \quad (7)$$

where D is the distance between each sensor and the target, T is the period of the clock cycle and V is the speed of ultrasound. Since the period is 500 μs and ultrasound travels at approximately 300 m/s, the value of $T \times V$ is a constant and the formula can be simplified to

$$D = \text{\# of clock cycles} \times 15\text{ cm} \quad (8)$$

Equation 8 shows that the calculation can introduce an absolute error of 15 cm to both left and right of the exact location. A smaller clock period can be used to reduce the absolute error and to increase accuracy. However, for the prototype, 500 μs is used.

As shown in Figure 4.5, if the distances between the performer and the ultrasound sensors are A and B respectively and the distance between the two sensors is fixed known value, C; then, the location of the performer on stage can be calculated.

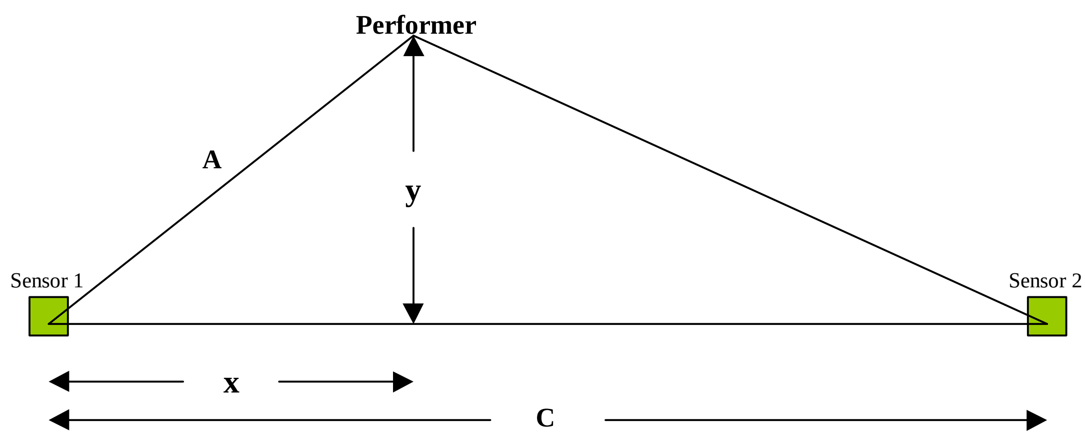

Figure 4.5: Performer's Location with Respect to the Sensors

Let x be the distance from Sensor A to the projection of the performer on the line joined by the two sensors and let y be the distance between that line and the performer. Using the Pythagorus Theorem, two equations can be obtained.

$$y^2 = A^2 - x^2 \qquad (9)$$

$$y^2 = B^2 - (C - x)^2 \qquad (10)$$

Equating (9) and (10),

$$\begin{aligned} A^2 - x^2 &= B^2 - (C - x)^2 \\ A^2 - x^2 &= B^2 - C^2 + 2Cx - x^2 \\ A^2 &= B^2 - C^2 + 2Cx \end{aligned}$$

Therefore,

$$x = \frac{A^2 - B^2 + C^2}{2C} \qquad (11)$$

Equation 11 gives the x coordinates of the performer on the stage with respect to the reference point, which is the location of sensor 1. Similar calculations can be applied to find the performer's location in two dimensions and in three dimensions with additional sensors.

Since the mechanical control system is controlled by varying input voltage to regulate the angular velocity of the motor, displacement has to be calculated from the current location and the previous location of the performer to determine the angular velocity of the motor. A variable is designated to store the previous location of the performer in the memory of the microcontroller. For each incoming current location data, the microcontroller compares the new location with the previous location. If the displacement is greater than a certain preset range, for example, 30cm, then the new location replaces the old location and this displacement translated into voltage for motor control.

By comparing the displacement with the preset range, light will not oscillate when the performer moves within light spot. This concept is illustrated in Figure 4.6. If the performer is at location A, and he moved to location B, which is d cm away from A; the performer is still in the light spot and the spotlight should not reposition. If the performer moves from A to B and then from B to C, each displacement is less than the radius of the light, but the total displacement is greater than the radius of the light spot and thus the performer is outside the light spot. Therefore, when a displacement less than the radius of the spot size is made, say from location A to B, the microcontroller does not update location variable from A to B so that the next displacement, say to C, is compared to location A. Future improvements can be made with a feedback system that detects if the light is shinning on the performer. Since this feedback system will not be implemented for the SpotU prototype, minor movements will be filtered out by comparing to the preset range.

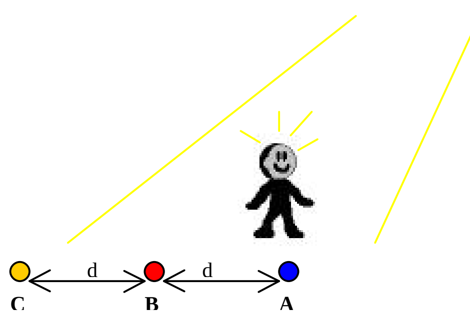

Figure 4.6: Movements Within the Light Spot

Before the microcontroller generates an output to the mechanical control system, it reads in the voltage input from the **encoder** of the motor. The voltage input is translated into position of the light on stage. Please refer to section 5. The Mechanical Control System for more details. The displacement of the light spot is the new performer location – the light spot location. This displacement is then translated into voltage require to drive the motor at the desired angular velocity and is output to the mechanical control system.

5. Mechanical Control System

5.1 Overview

The mechanical control system is responsible for moving the follow-spot; for the prototype, it is responsible for moving the lamp. The system responds to the output voltage from the microcontroller. The criteria we consider when designing the mechanical control system are as follow:

- Torque requirement
- Speed requirement
- Accuracy in control
- Precision in control
- Cost
- Complexity

The overall structure of the mechanical system is described in Figure 5.1. The desired position is feed into the compensator. The amplifier amplifies the signal to sufficient level to drive the motor. The motor rotates the load, which is the prototype lamp. A encoder is used to measure the position of the light and the data is used for feedback control. An analog-to-digital converter is required to digitalize the encoder signal before it can be processed by the microcontroller. Similarly, a digital-to-analog converter is needed in order for the amplifier to understand the digital signal sent out by the microcontroller.

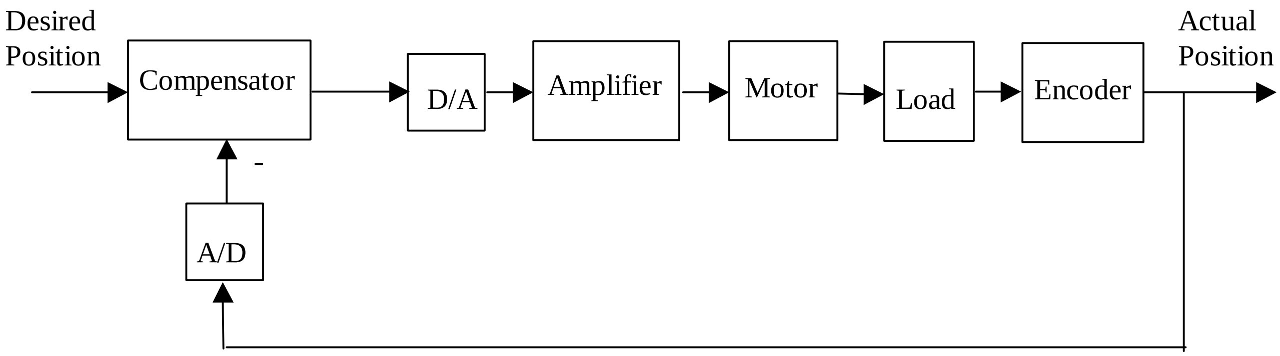

Figure 5.1: Mechanical Control System Block Diagram

We have chosen to implement a servo system to control spotlight movement for SpotU. A servo system, by definition, is a system with feedback control. In other words, a closed loop system is considered a servo system. Our decision is based on the fact that by measuring the output, the position of the light, and feeding it back into the input, the performance of our system will improve substantially. Our trade off to this improvement in performance is the increase in the complexity of the system since a closed loop system requires a compensator and sensors. However, steady-state error can be eliminated, or at least minimized, with a closed loop system.

5.2 The Compensator

The compensator is the brain of the mechanical control system. It takes in the desired position that the motor system needs to move to, and by comparing it to the actual movement measured by the sensors, it calculates the input voltage for the amplifier. Compensators are divided into two main categories: analog and digital. A digital compensator, even though more complex, has advantage over analog ones because they are easier to modify and are capable of more sophisticated control strategies. To leave room for future development such as feedback control by sensing if the performer is in the light spot, we decided use a digital compensator. Our compensator is combined with the brain of our overall SpotU system, the microcontroller. The microcontroller incorporates signal processing and compensation into one unit. For a more detailed description on the microcontroller, please refer to section 4. Signal Processing.

The microcontroller first compares the desired location, which is the location of the performer, and the actual position of the light, which is measured by the encoder. The difference generates an error; this error is than compensated into the next output, the next desired location. This output is feed to the amplifier instead of open loop desired location to reduced the steady-state error. This concept is outlines in Figure 5.2 below.

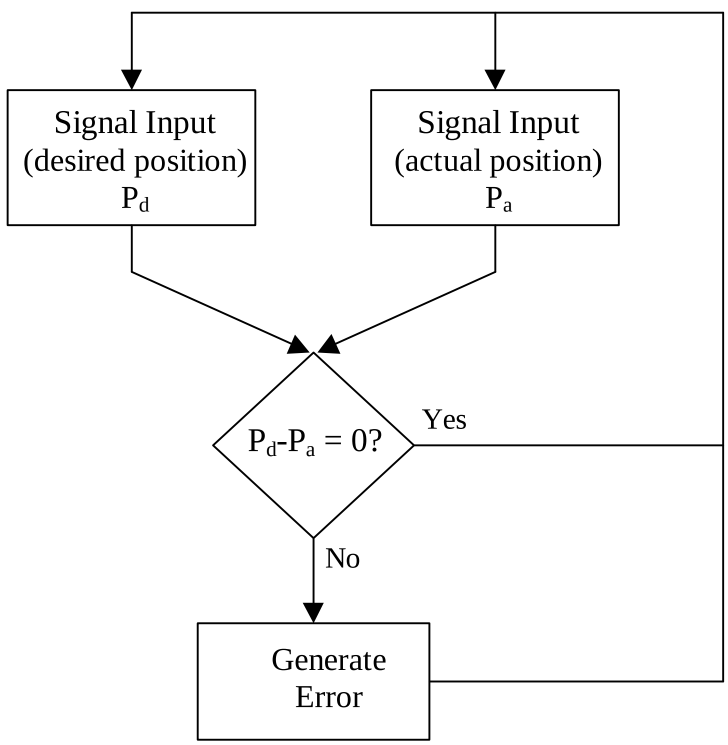

Figure 5.2: Flowchart for Compensator

5.3 The Amplifier

Amplifiers are often called drives. The purpose of an amplifier is to supply power to a motor, enabling it to produce motion with certain levels of control. Different types of motors require a different amplifier. The motor used for this SpotU protoype is a **DC brushed motor**. Please refer to 5.4 The Motor for more details. A DC brushed motor is driven by applying a voltage across its terminals. The current generated by the voltage is directly related to the torque output of the motor. The brushed motor's speed and torque can be controlled by varying the mean voltage applied. This type of control drivers is commonly known as **PWM**, pulse width modulation, drives. We choose the Advanced Motion Controls PWM servo amplifier, model 5A5, primarily because it is available to us at no cost. Also, the Advanced Motion Controls produce good quality amplifiers that provide us the necessary requirements. The amplifier is mounted on a matching mounting card, model MC1X5A5, with connections shown in Figure 5.3. Only the used ports are labeled in this diagram.

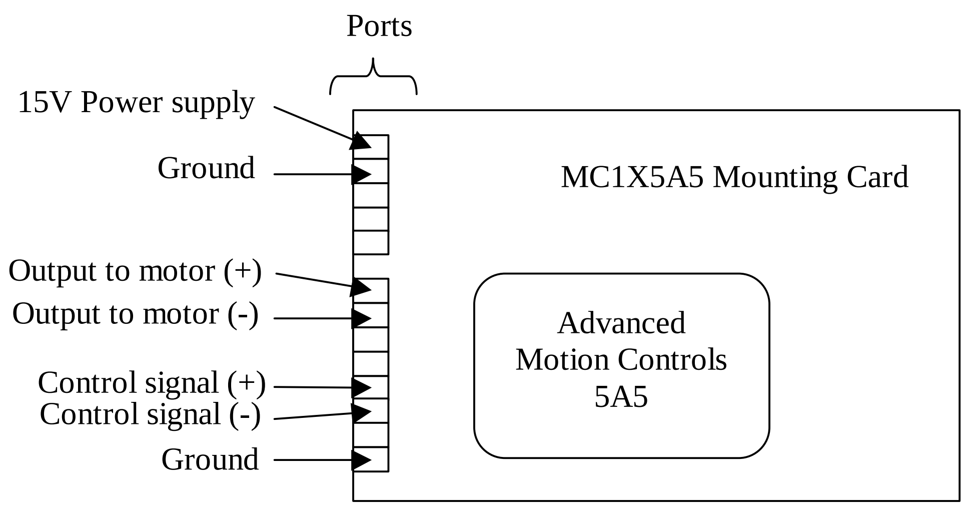

Figure 5.3: Port Connection of Advanced Motion Control 5A5 Servo Amplifier

5.4 The Motor

5.4.1 Motor Selection

The SpotU requires a high torque, low speed motor to control the motion of the spotlight. This is because the spotlight needs fine movements within 53°. Many types of motor exist in the market. Some examples are DC brushed, DC brushless, servo and stepper motors. A **servo motor**, as its name indicates, is made for a servo system and thus it best suits our needs. Servo motors are specially designed so that they respond rapidly to changes in speed and position; and are able to handle high acceleration and deceleration rates. Another key characteristic of the servo motor is its high torque to inertia ratio, which is important in determining motor responsiveness. Servo motors are also designed to react to small voltage variations, so they are able to respond to small changes in the control signal. All these special features of the servo motor make it an excellent choice for our system, which requires precise speed and position control. However, with increased design demands, servo motors are very expensive. Due to our limited funding, we do not wish to spend $300-500 on a good servo motor for prototyping.

We obtained some good DC motors from friends and professors. Their major disadvantage is that they are made to run at high speeds. The motor we chose to use, unfortunately, has lost its label. Through applying a voltage difference across its terminals, we found that it runs at a much lower speed as compare to the other motors we have because it has a build-in gear box. By experimenting with the motor, we gathered the following set of data:

Table 5.1: Motor Input Voltage vs. Motor Speed

Voltage	Speed (rpm)
5	10.9
5.5	12.32
6	13.92
7	16.74
8	19.63
9	22.41
10	24.97
11	28.24
12	31.02

The speed varies linearly with the voltage supplied to the motor. A plot of the above data in Figure 5.4.

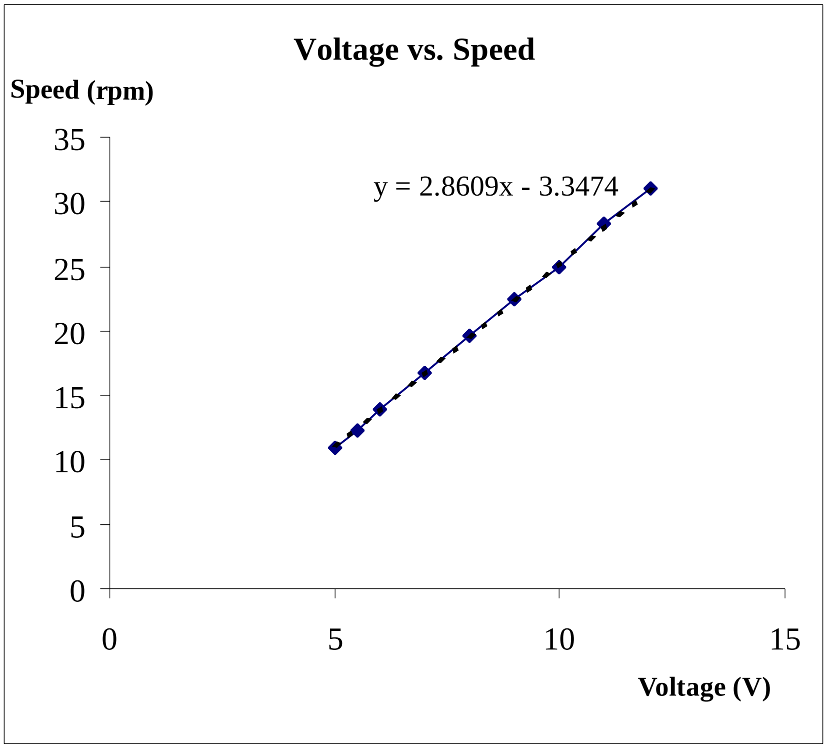

Figure 5.4: Motor Voltage vs. Motor Speed

Due to the stage size we specified for our prototype, the light rotates within an angle of 53°. The speed the motor required is approximately 0-5rpm. The motor we chose is safe to run at the voltage range of 5-10V. At this range, the motor runs faster than this required speed. To compensate for this difference, a 5:1 reduction in speed is needed. Pulleys and belts will help achieve our “high torque and low speed” requirement.

5.4.2 Mapping Displacement to Velocity

To realize how fast the motor needs to turn in order to track motion, we must first find out how fast can a person move on stage. An experiment has been repeated several times with our group members. Each group member walks as fast as possible across a 30 feet distance and is timed. The average time is 6 seconds. Since position sampling is done approximately every 0.5 seconds, a person can move approximately 2.5 feet in-between 2 sampling times.

When deciding how motor velocity corresponds to displacement of the performer, the delay time, processing time, and the motor response time have to be taken into consideration. A signal is detected 0.5 seconds after the performer has moved. Also, a finite time is required for the signal to be processed be and passed on to the amplifier and motor. On top of that, the motor needs an acceleration time and cannot reach its required speed instantaneously. With all the reasons stated above, we want to push the motor to a speed such that the light can track the performer and not follow him/her behind. A table of velocity vs. displacement is shown in Table 5.2. The entries are tentative, when we actually test out the mechanical system the values may need to be adjusted slightly. The amplifier has a potentiometer built in for gain adjustment.

Table 5.2 Mapping Displacement to Velocity

Displacement (feet)	Velocity (rpm)
0.5	1
1.0	2
1.5	3
2.0	4
2.5	5
3.0	6
3.5	7

5.5 The Encoder

An **encoder** is another name for sensors that determine position or the velocity of a motor. The measurement of an encoder reflects the actual movement of the light and this information is fed back to the compensator. Two different types of encoders have been investigated: **optical encoder** and potentiometer.

An optical encoder uses a light source, such as an LED, to track position. Light projects through slits in a rotary disc and two photo receptors on the opposite side of the disc detect the light and convert it to electrical outputs. The phase difference in the two electrical signals gives information on the position and the velocity of the motor. Optical encoders offer the higher resolution and accuracy compare to other encoders. However, since our motor does not have a build-in encoder, and due to its cost and relatively complexity, we choose to sense position of our prototype spotlight with the a potentiometer.

A rotary potentiometer provides an output voltage proportional to angular position. Figure 5.5 below shows a schematic of the rotary potentiometer.

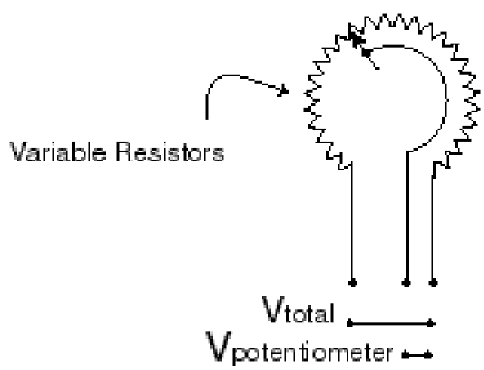

Figure 5.5: Rotary Potentiometer

The output voltage varies according to the location of the sliding contact on the resistor; the angle of the sliding contact is proportional to the output voltage. The microcontroller is capable of translating the measure potentiometer voltage to the position of light spot on stage for feedback control. Even though a potentiometer does not provide accurate position monitoring like an encoder, it is an affordable and adequate position sensor suitable for our system. It gives a much simpler and cheaper solution.

5.6 Mechanical Assembly

The load of our system is our spotlight. For our prototype, a lamp is used instead. It is connected to the motor through a belt drive configuration. When assembling the motor and the light together, fiction and load effects are considered. Also, as mentioned in section 5.4 The Motor, the speed of the motor is faster than the speed required; therefore, a reduction mechanism is needed. With these requirements in mind, the light will be mounted on a table and will be connected to the motor through coupling, bearing, and a belt-driven configuration. This way, the weight of the load is supported by the bearing and the table instead of the motor. Please refer to Appendix B for the basic mechanical assembly drawing and the detailed dimensions of the parts. The belt and pulleys reduces the rotation speed. Figure 5.6 outlines the belt drive configuration.

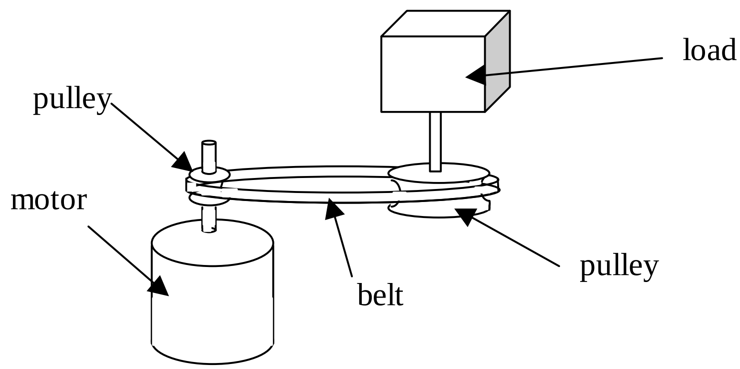

Figure 5.6: Belt Drive Configuration

The belt drive configuration uses pulleys and belts to convert rotary motion of a motor to a more suitable form. It decreases the motor speed and increases torque output. Two pulleys are needed for the reduction of speed. One is mounted on the motor and the other is mounted on the load. The ratio of the diameters of the two pulleys determines the speed reduction ratio. Figure 5.7 shows how the motor shaft is connected to the pulley.

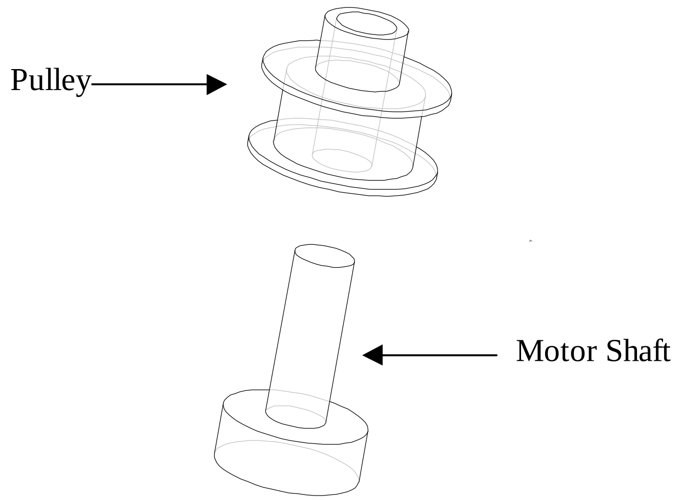

Figure 5.7: Motor Shaft and Pulley Assembly

A bearing plays a very important role in mounting the light to the pulley. Since the light has a finite weight it needs to be supported by a table. A bearing would be embedded in this table and acts as an interconnection between the light and the pulley. Figure 5.8 illustrates this idea. The actual connection is then done through a device called coupling. While it fits through the middle of the bearing, one end of it attaches to the light while the other end of it connects to the pulley. With the bearing and coupling intact, the light is supported fully by the bearing and table. Therefore, the torque exerted from the motor is not affected by the weight of the light. Also, the effect of friction is reduced with the light firmly connected to the bearing through the coupling. When it turns the surface of the table will not rub against the light.

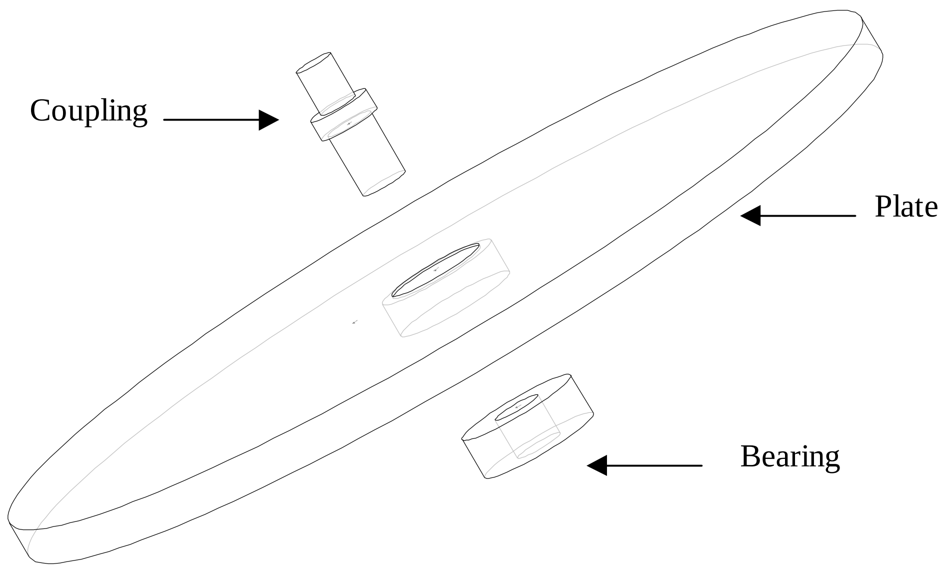

Figure 5.8: Plate Assembly Diagram

6. Packaging

6.1 Locator Unit

Some of the main components in the locator unit include a RXM-433-LC RF receiver, a MA40A5S ultrasonic transmitter, a LM555 timer, a MAX232 signal amplifier, a MAX742 power supply converter, and a TL072 op-amp. The dimension of the locator unit is 2" x 2" x 0.75". The top of the locator unit has a circular hole of diameter 0.625". This opening is for ultrasound signals to come out of the MA40A5S ultrasound transmitter. One of the sides of the locator unit has an opening of 0.25" in diameter for the antenna of the RF receiver. Figure 6.1 is the top view of the locator unit and Figure 6.2 is the side view of the locator unit with the antenna opening.

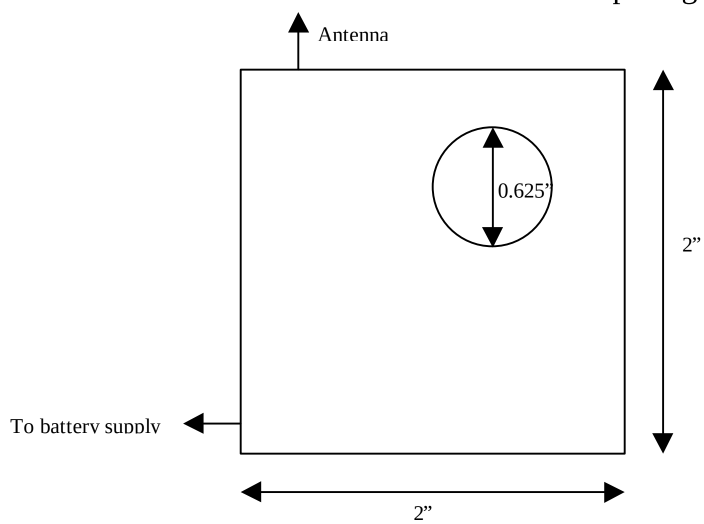

Figure 6.1: Top View of Locator Unit

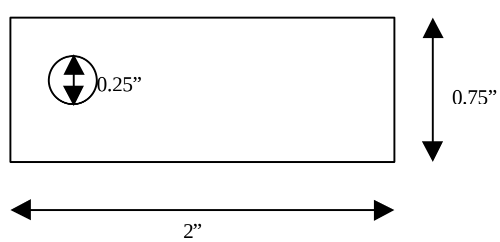

Figure 6.2: Side View of Locator Unit

6.2 Ultrasound Units

Some of the main components that needs at be placed at each of the two front corners of the state include a MA40A5R ultrasound receiver, three TL072 op-amps, and a TXM-XXX-LC RF transmitter. All these components are to be packaged into a box with dimensions of 2” x 3” x 0.75”. The top of this box has a circular hole of diameter 0.625”. This opening is for ultrasound signals to come into the MA40A5R ultrasound receiver. One of the sides of the locator unit has an opening of 0.25” in diameter for the antenna of the RF transmitter. Figure 6.3 is the top view of this box and Figure 6.4 is the side view with the antenna opening.

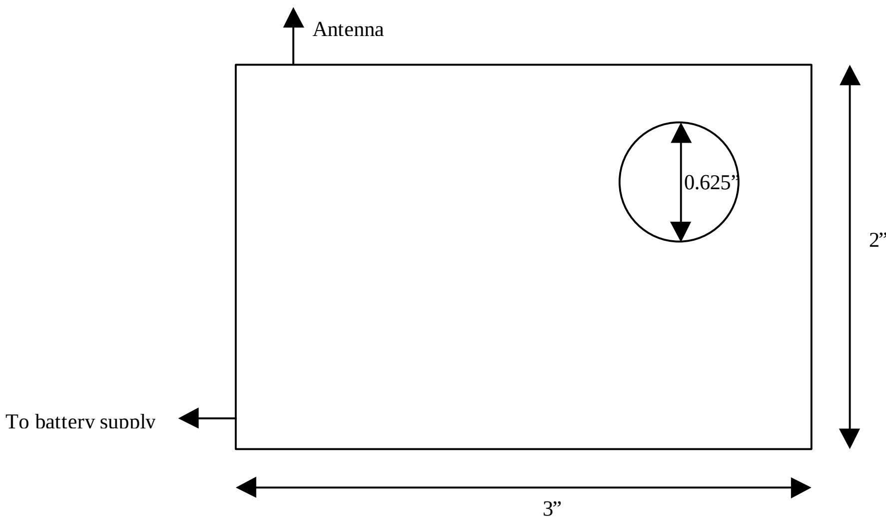

Figure 6.3: Top View of the Ultrasound Units

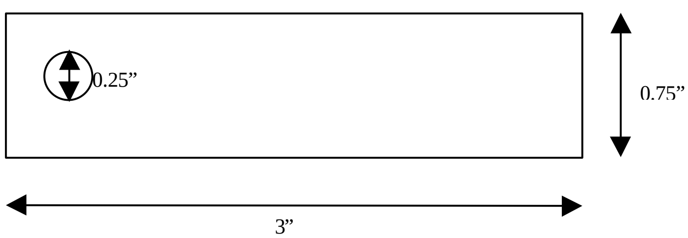

Figure 6.4: Side View of the Ultrasound Units

6.3 Central Control Unit

All other electronic components such as the RF receivers, RF transmitter, microcontroller, amplifier, etc. are packaged into this central control unit and will be mounted on the table with the lamp. Figure 6.5 shows the top view of this unit.

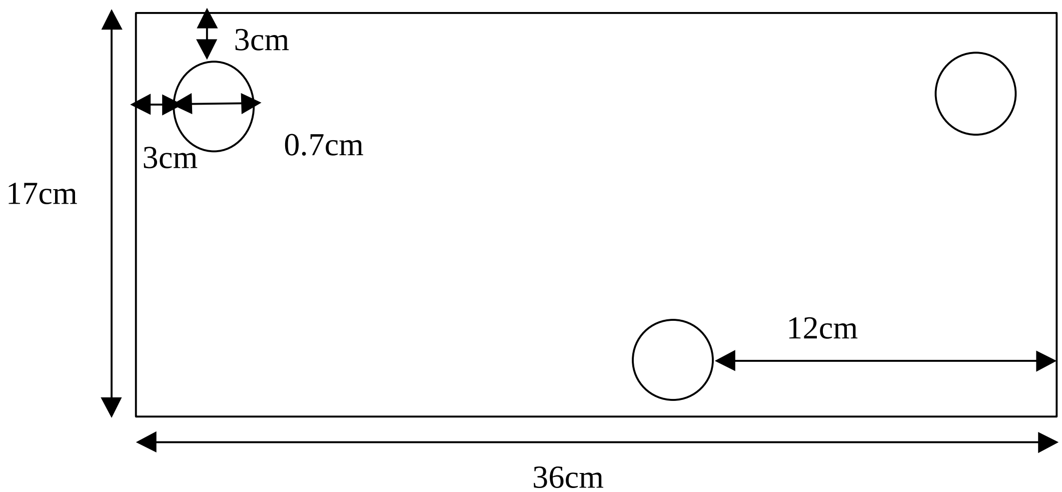

Figure 6.5: Top View of the Central Control Unit

7. Testing

7.1 Signal Acquisition and Conditioning

The following procedure will be used to test the signal acquisition stage:

1. Place the two MA40A5R ultrasonic receivers 30 feet apart from each other.
2. Place the TXM-315-LC RF transmitter at midpoint between the two MA40A5R modules.
3. Generate a 2Hz 0 to 5V peak-to-peak square wave using a function generator and apply this signal to the TXM-315-LC RF transmitter.
4. Display the square wave in step 3. on the oscilloscope.
5. Display the signals coming out of the two glitches eliminators on the oscilloscope. (Since the MA40A5R modules are so far apart, each glitches eliminator will have to be connected to a different oscilloscope.).

7.2 Signal Processing

The signal processing stage can be tested simulation; as well as by the connecting diodes to the output pins. An example of testing using LED is giving below:

Displacement Calculations Verifications:

1. Connect Pin 1 to a 5-V power supply.
2. Ground Pins 1, 27 and 31.
3. Add LEDs to pin 4 down to 9 for displaying output.
4. Apply signals of 1010011 to Pins 17 down to Pins 11. This generates a valid input time of 19 from sensor #1.
5. Apply signal of 1 to Pin 18, then 111011 for Pins 21 to 26. This generates a valid input time of 59 from sensor #2.
6. Apply 00101000 to Pins 33 to 40. In addition, apply 00 to pins 2 and 3. This sets the absolute position from the feedback system to be 40.
7. Should see that the LEDs that are connected to pins 5 and 7 are light up.
8. Repeat the same steps for different input valuesand observe the corresponding output.

Validation Bit Verifications:

1. This part is executed right after the Displacement Calculations Verifications testing
2. Apply 00111100 to Pins 33 to 40. In addition, apply 00 to pins 2 and 3. This sets the absolute position from feedback to be 60.
3. Apply signals of 0111011 to Pins 17 down to Pins 11. This generates an invalid input time of 59 from sensor #1.
4. Apply signal of 0 to Pin 18, then 010011 for Pins 21 to 26. This generates an invalid input time of 19 from sensor #2.
5. You should see that none of the LEDs are light up. (Since inputs are not accepted because the MSB of the input time from the two sensors are set to 0).
6. Repeat the same steps for different input values and observe the corresponding output.

7.3 Mechanical Control System

The mechanical system will be tested with the following procedures:

1. Connect power supplies to all components.
2. Connect components together.
3. Generate a signal using the function generator.
4. Vary the amplitude of signal. The light should move at different speeds.
5. Measure the angle the light rotated with respect to a signal. Deduce the angle to the actual position moved on stage and check if it corresponds to the desired position as indicated by the signal.

7.4 SpotU

1. Find an area cleared with the actual theatre dimension. Figure 7.1 shows the dimension chosen for our prototype implementation.
2. Set up equipment with power supplies all connected.
3. Put the locator unit on a test subject.
4. Draw angles of rotations on a piece of cardboard and calculate the respective position on stage. Put the spotlight on top of this cardboard.
5. Have a 30-feet long piece of cardboard calibrated. The subject will move on this long piece of cardboard and his/her position can be read off directly.
6. As the test subject move freely, the light will follow the angle of movement as required.
7. Repeat with different test subjects.

Note: Or a laser pen can be attached to the lamp to show if the light is pointing at the test subject. The lamp used for our SpotU prototype does not emit a focused light beam.

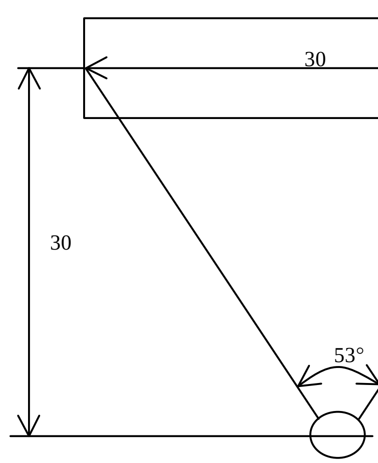

Figure 7.1: Theatre Dimension

8. Power for the Three Subsystems

The power supplies required for all components are summarized in the Table 8.1 below:

Table 8.1: Power Requirements

Component	**Voltage required**	**Location**
A/D converter	5V DC	Spotlight
Advanced Motion Controls 5A5	15V DC	Spotlight
D/A converter	5V DC	Spotlight
PIC Microcontroller	5V DC	Spotlight
RF Receiver (×2)	5V DC	Spotlight
RF Transmitter	5V DC	Spotlight
Timer	5V DC	Spotlight
Spotlight	120V AC	Spotlight
Ultrasonic Receiver (Left)	± 10V DC	Stage Left
Ultrasonic Receiver (Right)	± 10V DC	Stage Right
Locator Unit	5V battery	Locator

For SpotU, as declared in the functional specification, powered is supplied through plugging in a wall socket. To achieve this requirement, the AC 120V (rms) has to be transformed to a DC voltage. The following block diagram, Figure 8.1, describes a DC power supply circuit built from an AC voltage input:

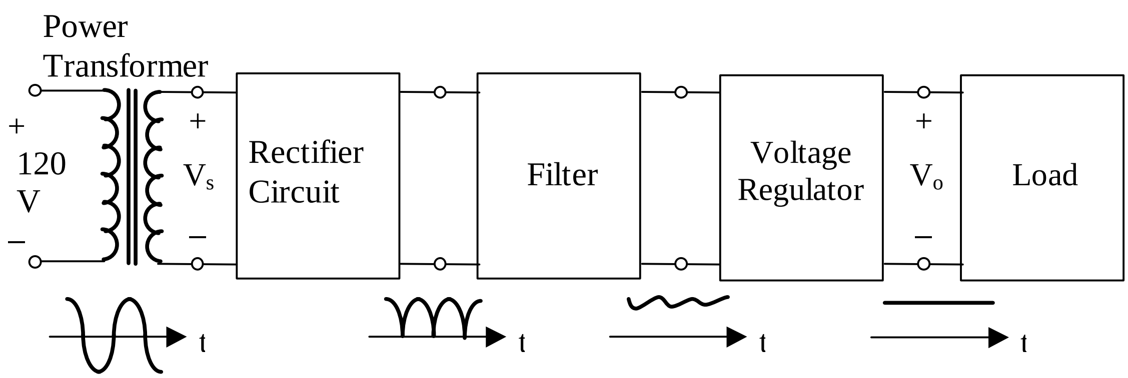

Figure 8.1: Block Diagram of a DC Power Supply

To build a DC power supply from an AC source, several stages need to be implemented. The first stage is the power transformation stage, for determining the DC voltage level. Different V_s can be set by altering the ratio between the number of turns in the two windings of the transformer. The second block, the rectifier circuit block, is responsible for converting the input sinusoid V_s to a unipolar output, as indicated in the waveform diagram in figure 8.1. After this signal passes through the third stage, the filter stage, the variations in the magnitude of the rectifier output are reduced and a ripple is generated. To reduce this ripple and to stabilize the magnitude of the DC output voltage of the supply, a voltage regulator is needed as the last block of the circuit. As our components lie in three separate locations, three DC power supplies are needed. In the location of the spotlight, 2 parallel supplies are to be built to provide the 5V and 15V.

For our prototype, this power unit will not be implemented. This is due to the time constraints we have to face and also the limited funding we acquired. Power supplies in the engineering lab will be used to provide the required voltage to the various components. At the location of the spotlight, even though 6 components need power, only 2 different DC voltage is required. Since one DC power supply unit can provide two independent DC voltage levels, one of such power supplies would be sufficient to power all the components on the spotlight. 2 more power supplies would be needed on both the left and right side of the stage to power the 2 ultrasonic receivers.

Glossary

Amplifier
Also known as driver. Its purpose is to provide power to a motor and allow motion with control.

Astable mode
An operation mode of the LM555 Timer in which the output digital pulse waveform can be customized by external circuitry.

Bit stream
A digital data stream containing only 1's and 0's.

Carrier frequency
The frequency of the radio wave that carries the essential information for communication.

Cascade configuration
The configuration in which two components are connected together one after the other.

Compensator
A device for controlling motions. Generates appropriate input to an amplifier through comparing desired and actual movement.

Control clock
The part of the system that generates a periodic pulse to trigger off the RF transmitter on the spotlight and to starts the timing of the ultrasound signal. It is implemented by the LM555 Timer.

DC brushed motor
A motor that runs on a DC voltage supply. DC brushed motors rotates through commutation, a switching sequence applied to the motor armature.

Encoder
A sensory device that tracks position and/or velocity.

Flag
A digital signal which indicates the status of the accompanying data.

Follow-spot
A light directed at an actor which follows his or her movements around the stage.

Frequency pickup range
The range of frequencies that a particular RF receiver can collect without much attenuation

Glitch
A situation in which the digital signal has yet to reach its steady-state value.

Helical style antenna
A type of antenna that is made from a wire coil of steel, copper or brass.

Input bias current
Input DC current.

Inverting op-amp
An op-amp configuration in which the output of the op-amp is fed back to the inverting input of the op-amp.

Loading effect
The effect of the output voltage and current caused by the addition of a load.

Logic high
A digital signal is at logic high if it has a value of '1' represented by a relatively high voltage.

Logic low
A digital signal is at logic low if it has a value of '0' represented by a relatively low voltage.

Loop style Antenna
A type of antenna that can be printed directly on the PCB as a plane of spirals or rectangles.

Nominal carrier frequency
The manufacturer-specified carrier frequency at which an RF transmitter or receiver is working optimally.

Optical encoder
A device that uses light to track position.

Potentiometer
A variable resistor that can be used to track position.

Pulse train
A series of digital pulses

Pulse width
The time for which a digital pulse remains at logic high during a single cycle.

PWM
Pulse-Width-Modulation – a method that utilize pulses with different width to control the amplitude of a signal.

Servo motor
A motor specially designed for a servo system. It reacts to small variations in voltage and also responds rapidly to changes in speed or position.

Servo system
A system that has feedback, or, a closed loop system.

Signal amplifier
An amplifier which increases the strength of a signal by increasing its magnitude.

Spotlight
An instrument giving control of the angle of the emerging light beam and therefore of the size of area lit.

Steady-state error
The difference between the desired position and the actual position at steady-state.

Stopping Pulse
A pulse that signals the recording of counter value.

Supply filter
A filter whose purpose is to eliminate any noise from the power supply.

Triggering Pulse
A pulse that triggers the counter of the timing unit and the ultrasound transmitter on the locator unit. It also resets the counter and the valid data flag.

Unity-gain op-amp
An op-amp which is configured to have a gain of one.

Valid data flag
A flag which indicates the validity of the output data.

Whip style Antenna
A type of antenna made from a straight length of conducting wire

References

Books

Jerry C. Whitaker, *The Electronics Handbook*, U.S.A.: IEEE Press, 1996.

Mike James, *Microcontroller Cookbook*, U.S.A: Newnes, 1997

Websites

Automation control discussion group: http://www.control.com/alist/index.asp

FLEX10K Device Family: http://www.altera.com/html/products/110k.html

J R Kerr—motion control specialists: http://www.jrkerr.com/

Linx Technologies – RF Modules: http://www.linxtechnologies/f_modules.htm

LM555 Timer IC: http://www.radioshack.com/sw/swb/parts/linics/lm555.htm

Maxim Homepage: http://www.maxim-ic.com/

Motion control products distributor: http://www.servosystems.com/

Motor manufacturer: http://www.pittmannet.com/

Motorola: http://www.mot.com/

Murata Electronics North America: http://www.murata.com/

National Semiconductor: http://www.national.com/

Texas Instruments: http://www.ti.com/

The Product Finder Homepage: http://www.motioncontrolsolutions.com/index.shtml

Appendix A: Parts List

Signal Acquisition and Conditioning System			
Item	**Manufacturer**	**Part Number**	**Quantity**
AND gate		4011	1
Antenna	Linx Technologies Inc.	ANT-315-PW-RH	2
	Linx Technologies Inc.	ANT-418-PW-RH	2
	Linx Technologies Inc.	ANT-433-PW-RH	2
BJT transistor		QN2222	1
Capacitor		3 nF	1
		6.8 nF	1
		0.01 µF	3
		0.02 µF	2
		0.1 µF	1
		0.47 µF	1
		10 µF	2
Diode		IN4148	4
FPGA	Altera	EPF10K20	1
Power chips	(from old project)	MAX232	1
	(from old project)	MAX742	1
Op-amp		TL072	4
Potentiometer		50 kΩ	1
Resistor		10 Ω	2
		430 Ω	1
		5 kΩ	2
		2 kΩ	1
		2.2 kΩ	2
		4.7 kΩ	1
		3.9 kΩ	2
		10 kΩ	2
		56 kΩ	1
		100 kΩ	2
		120 kΩ	1
		150 k	1

RF receiver	Linx Technologies Inc.	RXM-315-LC	1
	Linx Technologies Inc.	RXM-418-LC	1
	Linx Technologies Inc.	RXM-433-LC	1
RF transmitter	Linx Technologies Inc.	TXM-315-LC	1
	Linx Technologies Inc.	TXM-418-LC	1
	Linx Technologies Inc.	TXM-433-LC	1
Timer	National Semiconductor	LM555	1
Ultrasonic transmitter		MA40A5S	1
Ultrasonic receiver		MA40A5R	2

Signal Processing System			
Item	**Manufacturer**	**Part Number**	**Quantity**
Capacitor			3
Crystal		33 MHz	1
Diode			N
Microcontroller	MicoChip	PIC17C43	2
PC Circuit Board			1
Resistor		50 – 100 Ω	1
		100 Ω – 1 kΩ	1

Mechanical Control System			
Item	**Manufacturer**	**Part Number**	**Quantity**
A/D, D/A converters			2
Ball bearing	(from old projects)		1
Belt	(from old projects)		1
Coupling	(from old projects)		1
DC Motor	(from old projects)		1
Lamp			1
Laser Pen			1
Mounting Card	Advanced Motion Controls	MC1X5A5	1
Mounting Table	(from old projects)		1
Potentiometer			1
Pulley	(from old projects)		2
PWM Servo amplifier	Advanced Motion Controls	5A5	1
Screw		0.075 inch	1

Appendix B: Mechanical Assembly Sketch

Please see attached photocopy.

Appendix C: Revised Schedules

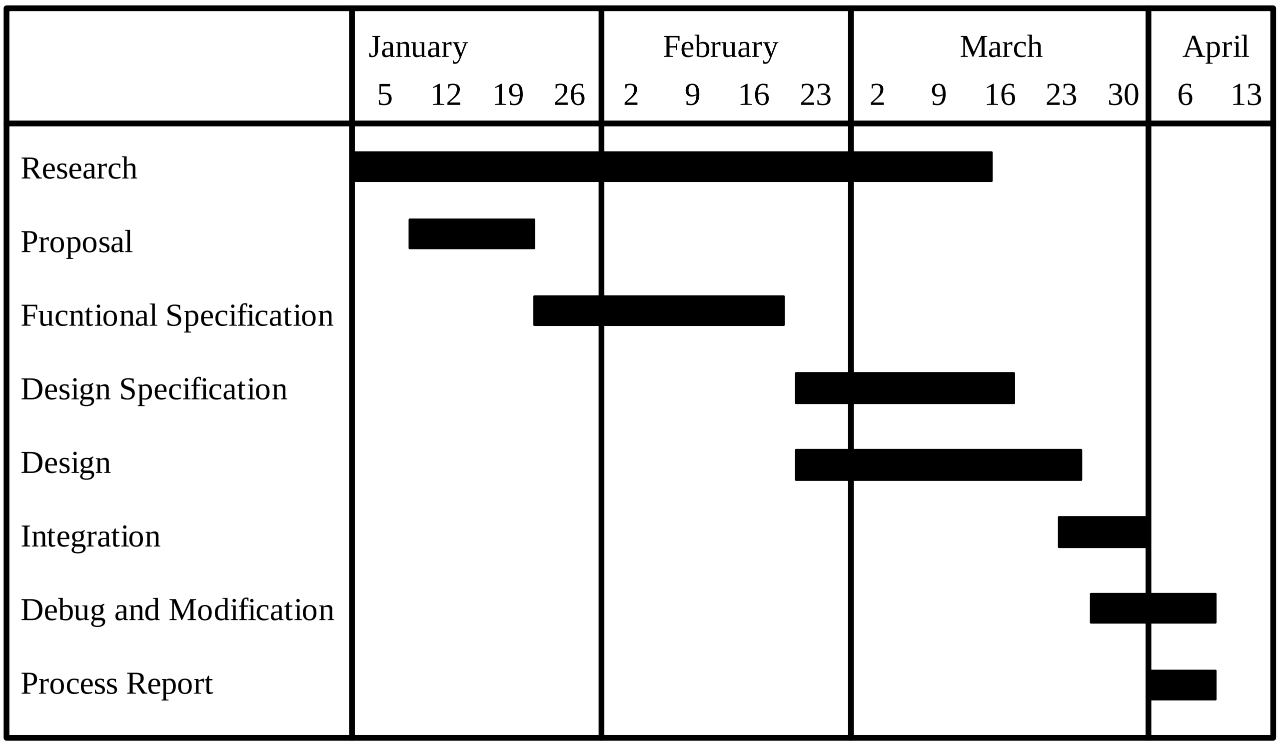

Figure C.1: Gantt Chart

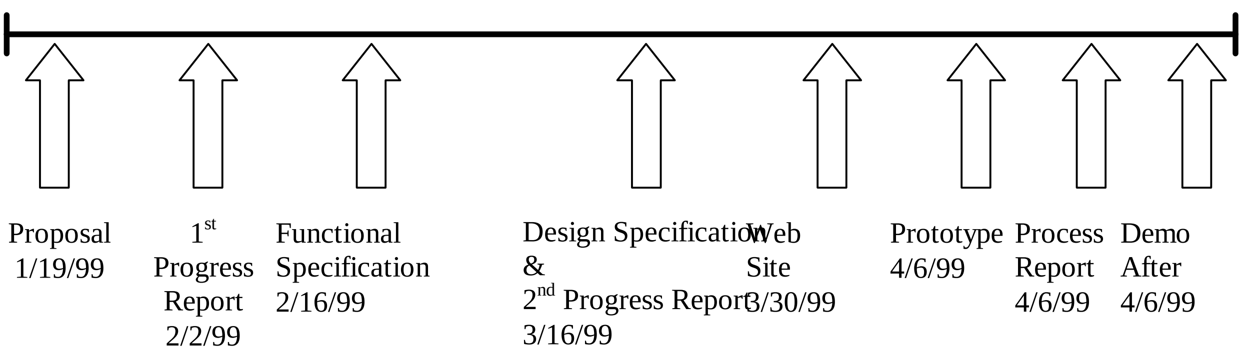

Figure C.2: Milestone Chart