MATT – Mobile Automatic Tennis Trainer

Interim Detail Design

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Overview

There is a wide range of products currently available on the market to help tennis players improve their skills or to provide an enjoyable practice session. One such product is the tennis ball launching machine, of which many different types and variations are available, each with its own advantages and disadvantages. The main problem with such tennis ball machines is the fact that they are stationary. With a stationary platform, the tennis balls are shot to the player from the same location every time, decreasing the realism of the practice session. In a game or match, the shots would be hit to the player from a variety of different locations and angles on the tennis court. The goal of the Mobile Automatic Tennis Trainer (MATT) is to provide a competitive alternative to the standard stationary tennis ball machine design. MATT will add a new element to the tennis ball machine market by being the first tennis ball machine that moves itself. The machine will change its position on the tennis court, therefore providing a wider variety of shots to the player. MATT will also include many of the same features that typical tennis ball machines exhibit. MATT will provide a more realistic training experience than a stationary tennis ball machine, while having a cost that is competitive with similar products.

Customer Needs

Several tennis players and their coaches were interviewed to determine what features are most desired or needed in a tennis ball machine. They all stated that they wanted a tennis ball machine that would behave more like a real opponent. A tennis player moves on the court and provides a wide variety of speeds and directions on shots to their opponent. The most desired features by these potential customers were variability of shot origin (the shot does not come from the same position every time), speed, angle, and height on the tennis ball. A large tennis ball capacity, a remote control, and a high percentage of shots landing within the court boundaries were also stated as customer needs. Customer needs determined by the design team were safety, ease of use, and randomization of shots. These needs were translated into seven concise customer need statements, shown here:

1. The machine itself can move and provide shots from varying locations.
2. The machine can vary speed and direction of shots.
3. The machine can launch a high percentage of shots over the net and within bounds.
4. The machine can be easily operated by either the player or coach.
5. The machine can operate for a reasonable period of time without damage or resetting.
6. The machine is safe.
7. The machine is portable.

Each of these needs was broken down into sub-categories that were related to the actual technical specifications. The needs-metrics matrix shown in Appendix A.1 shows these relationships.

Technical Requirements Specification

- **Mobility**
  - The machine will be programmed to move itself laterally and remain within 6.0 ± 0.5 meters from the center of the court at all times. This range of lateral movement will cover the entire width of the doubles lines on the tennis court. The machine will be able to operate anywhere from 10.0 ± 0.5 meters to 12.0 ± 0.5 meters from the net, with the motion of the machine intended to be parallel with the net. This range of motion can be seen in Appendix A.3.
- **Diversity**
  - The machine will launch tennis balls at an initial speed between 4 and 45 meters per second. It will launch tennis balls at vertical angles between 0^{o} and 50^{o}, and horizontal angles with a range from 40^{o} to 140^{o}. (The horizontal angles will be measured from a line parallel to the net, where rotating counter-clockwise yields positive angles.) The maximum time the machine takes to adjust its aim through the widest range of horizontal or vertical angles is 3.0 ± 1.0 seconds. The machine will travel the entire width of the court in less than 20.0 ± 1.0 seconds. Randomization of shots will be provided within user set limits, meaning that the amount of randomization will be related to what difficulty setting the user chooses.
- **Precision**
  - At least 90% of the tennis balls launched will go over the net and land within the tennis court boundaries, with the constraint that wind speeds are no greater than 5 meters per second. The tennis court will be divided into a grid of six sections for testing purposes as seen in Appendix A.2.
- **Safety**
  - The majority of moving parts of the machine will be in an encasement to protect against user injury. Moving parts such as the launch mechanism and the ball feeder may not be completely enclosed and warnings about such hazards will be posted on the machine. All electrical components will be properly covered and insulated to prevent electrocution.
- **Durability**
  - The machine will be constructed to withstand tennis ball strikes without damage. The encasement will protect tennis balls from getting under the machine and prohibiting proper operation. The machine will also resist light rain for at least 3 minutes.
- **Ease of Use**
  - Machine controls will be readable and accessible to, but not limited to, a standing user. Operational instructions will be labeled clearly on the machine. The machine can be started and stopped remotely from up to 30 meters away.
- **Operational Time**
  - The machine will operate continuously for at least 60 minutes, with the constraint that a constant supply of tennis balls is provided. The maximum storage capacity of the machine will be a minimum of 150 tennis balls. The machine will have a maximum ball

feed rate of not more than one tennis ball per 2 seconds. With this ball capacity and feed rate, the machine will be able continuously launch tennis balls for approximately 5 minutes before it must be refilled. Also, the machine will still operate with as few as one tennis ball in the hopper.

- **Portability**
  - The machine will weigh less than 60 kilograms, excluding tennis balls, and can be set up and operational within 10.0 ± 0.5 minutes. The machine will roll easily, without being turned on, for ease of transport.

Operational Description

The user will set up the tennis ball machine by first activating its power source, which could be a battery, extension cord, gasoline engine, or some other suitable power source. The user will turn on the machine and will input the desired settings. Then the device will idle on one side of the tennis court while the user goes to the other side. Upon receiving the signal to start, the machine will move, if desired, and launch tennis balls to the user's side of the court. The movement will be entirely lateral, moving no more than 6.0 ± 0.5 meters from the center line of the court, and remaining anywhere from 10.0 ± 0.5 meters to 12.0 ± 0.5 meters from the net, with the motion of the machine generally parallel with the net.

Design Deliverables

- Moving tennis ball launching machine
- User manual
- Testing and capabilities specification report
- Final system design report

<u>Not Included:</u>

- Tennis balls
- Tennis court
- Tennis racquet

Preliminary Test Plans

- A radar gun will be used to test tennis ball launch speed.
- The difference between the widest angled launch paths will be measured using a measuring tape and trigonometry.
- The time to switch between the widest range of launch angles will be timed with a stopwatch to determine if it is less than 3.0 ± 1.0 seconds.
- The time it takes the machine to traverse the entire width of the court will be measured with a stopwatch to determine if it is less than 20.0 ± 1.0 seconds.
- A randomly selected group of five tennis players will be asked to set up the machine, turn it on, and start it while being timed with a stopwatch to determine if it takes the user less than 10.0 ± 0.5 minutes to have the machine set up and operational. The selected group will be surveyed

about the ease of use and convenience of controls to determine if at least 90% find them satisfactory.

- The remote will be tested at increasing distances to determine if its maximum range is greater than 30 meters.
- The machine will operate for a set period of time while someone records the number of shots in bounds and the total number of shots.
- The machine will operate for a set period of time and the overall distribution of the shots will be measured using the grid shown in Appendix A.2. The percent distribution of the ball placement will be: 20% for sections 1 and 3, 25% for section 2, 15% for section 5, and 10% for sections 4 and 6. The margin of error will be ± 3% for all sections.
- The maximum number of tennis balls that can be placed in the hopper will be counted.
- The machine will be operated while tennis balls are allowed to strike the machine to test its durability. Using a pitching machine, 100 tennis balls will be launched at the machine with initial speed of 30 meters per second, measured by a radar gun. This test will be performed only on the front section of the machine.
- The machine will be weighed on a simple scale.
- The machine will be visually inspected to determine if all moving parts are properly encased or noted with proper warnings. All electrical components will be inspected in a similar matter to determine if they are properly covered and insulated.
- The machine will be sprinkled with water for a period of 3 minutes.

Implementation Considerations

- **Service**

The user will be able to transport the machine to the tennis court by rolling it. The user will power up the machine, and turn it on, either locally or remotely. The machine will then move sideways along the opposite backside (relative to the player) of the tennis court launching tennis balls to the player. All movement of the machine will be lateral, moving no more than 6.0 ± 0.5 meters from the center line of the court, and remaining anywhere from 10.0 ± 0.5 meters to 12.0 ± 0.5 meters from the net, with the motion of the machine intended to be parallel with the net.

- **Maintenance**

The unit will not be serviceable by customer and must be sent in to manufacturer for repairs and maintenance.

- **Manufacturability**

The machine will be manufactured mainly of pre-fabricated purchased parts for most internal mechanical and electric components. Any custom molded parts that will be needed will be produced via manufacturing options such as the 3-D printer, or the CNC machine. The frame of the machine will be constructed to custom fit the design using standard fastening methods such as glue, screws, bolts, and in some cases possibly welding. The entire design should able to be manufactured with the equipment at Harding University, except for the ordering of specific parts.

Relevant Codes and Standards

The rules and regulations of tennis can be found at *www.ITFTennis.com*.

System Design

Background

There is a wide range of products currently available on the market to help tennis players improve their skills or to provide an enjoyable practice session. One such product is the tennis ball launching machine, of which many different types and variations are available, each with its own advantages and disadvantages. The main problem with such tennis ball machines is the fact that they are stationary. With a stationary platform, the tennis balls are shot to the player from the same location every time, decreasing the realism of the practice session. In a game or match, the shots would be hit to the player from a variety of different locations and angles on the tennis court. The goal of the Mobile Automatic Tennis Trainer (MATT) is to provide a competitive alternative to the standard stationary tennis ball machine design. MATT will add a new element to the tennis ball machine market by being the first tennis ball machine that moves itself. The machine will change its position on the tennis court, thereby providing a wider variety of shots to the player. MATT will also include many of the same features that the typical tennis ball machines exhibit. Some of these features include variation of speeds, and variation of horizontal and vertical angles. All of these features will enable MATT to provide a more realistic training experience than a stationary tennis ball machine, while having a cost that is competitive with similar products.

System Overview

The MATT prototype will provide a more realistic practice experience to tennis players of any skill level with its very own unique mobility feature. MATT will be programmed to move itself laterally, parallel from the net, and remain within 6.0 ± 0.5 meters from the center of the court at all times. While moving, MATT will launch tennis balls with varying initial speeds between 4 and 45 meters per second. MATT will also provide a wide range of different angles for shots. The range of horizontal angles will be from 40° to 140° with respect to a line parallel to the net and the range of vertical angles will be from 0° to 50° with respect to the horizon. MATT will be operational anywhere from 10.0 ± 0.5 to 12.0 ± 0.5 meters from the net and will travel the entire width of the tennis court in less than 20.0 ± 1.0 seconds. The maximum time the prototype will take to adjust its aim through the widest range of horizontal or vertical angles is 3.0 ± 1.0 seconds. MATT will have adjustable settings which a user can control through a user interface system. MATT will be able to hold a minimum of 150 tennis balls, which will be launched at a maximum feed rate of one tennis ball per two seconds, allowing a continual practice of a minimum of five minutes, before needing to reload the hopper with tennis balls.

Design Concept

Figure 1 depicts a three-dimensional rendering of the general form and shape of MATT. All major physical components are modeled with simple geometries and assembled here to provide a visual representation of how the finished product will look. Overall dimensions will be shown and described in later sections.

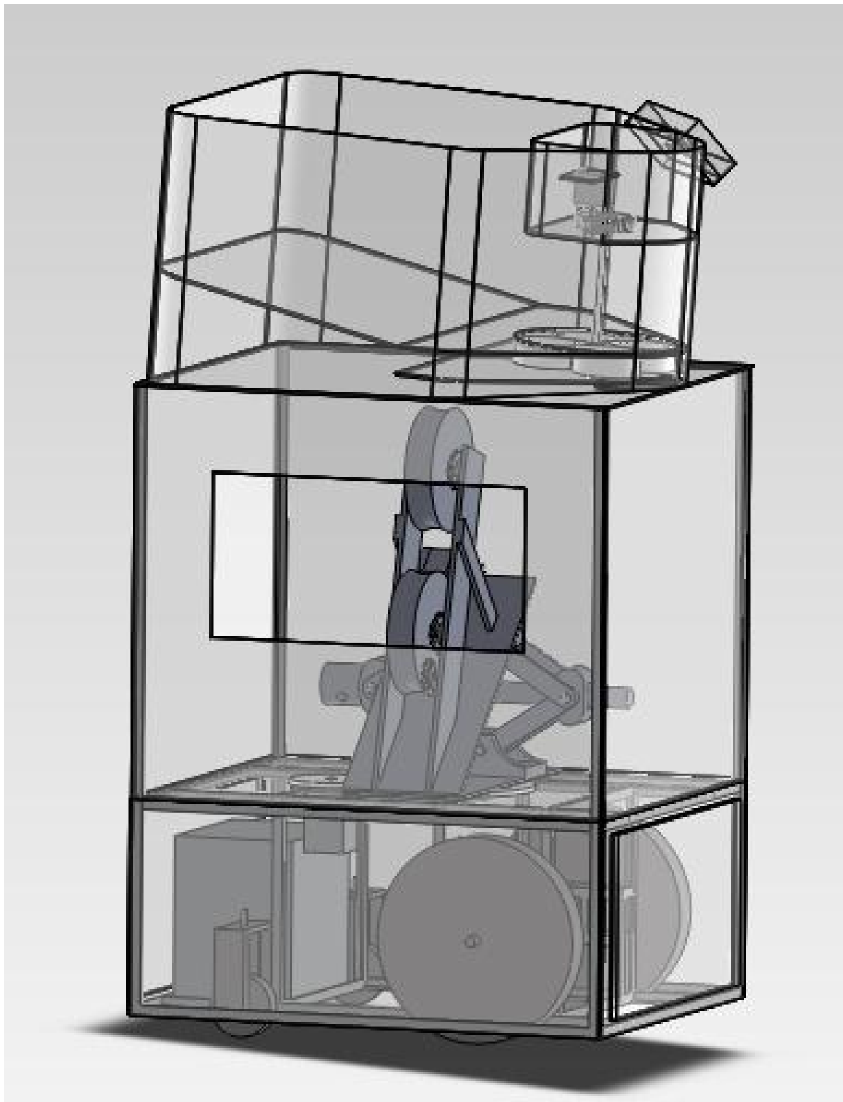


Figure 1: Design concept of MATT depicting all major components and geometries

Block Diagrams

MATT – Level 0

The block diagram shown in Fig. 2 is a representation of all the materials, energy, signals, inputs, and outputs present going into and out of MATT. The individual internal subsystems will be outlined in Level 1 and Level 2 block diagrams in the following pages. The red lines indicate energy moving into or out of the system. The green lines represent materials moving into or out of the system. The black lines represent controls moving into and out of the system. A legend is shown below Fig. 2.

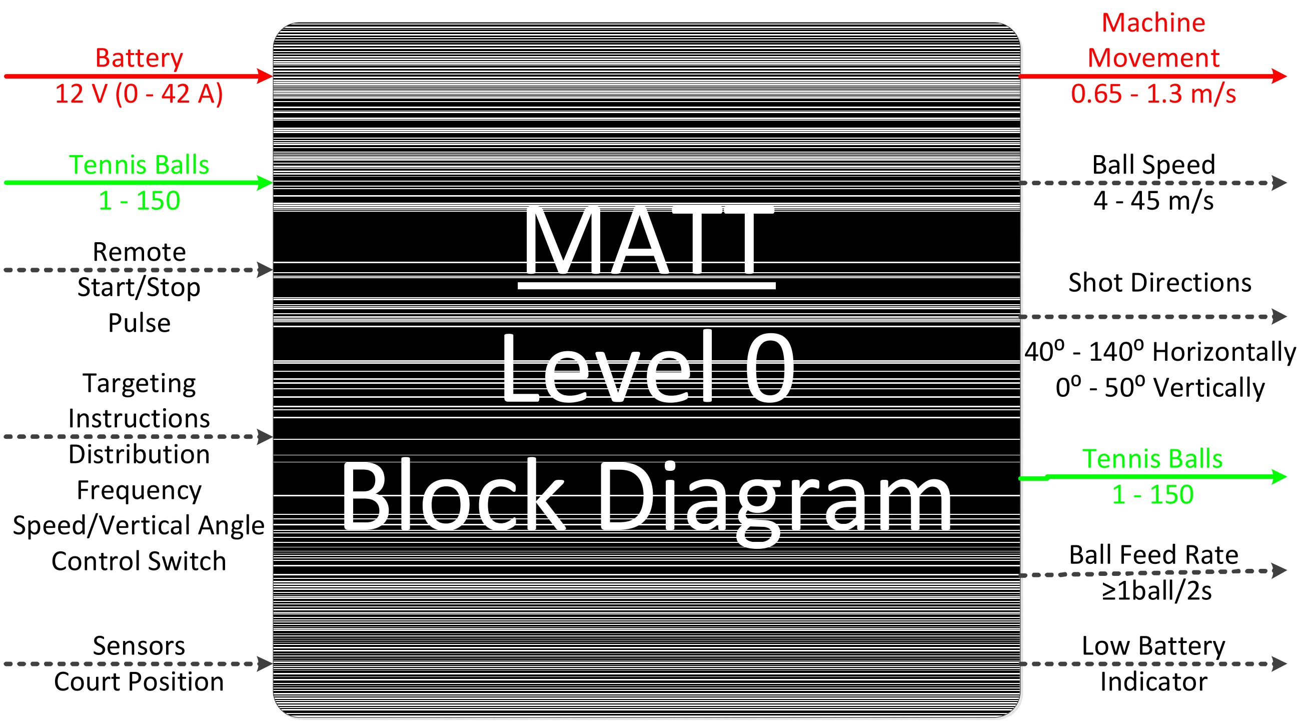
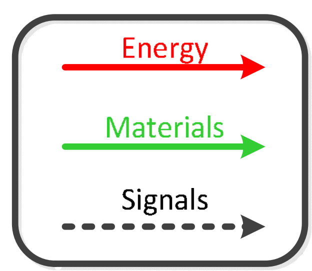


Figure 2: Level 0 block diagram of MATT with legend shown below



MATT – Level 1

The block diagram shown in Fig. 3 is a Level 1 block diagram showing all of the major systems present in MATT as well as all the of the inputs and outputs of each major system.

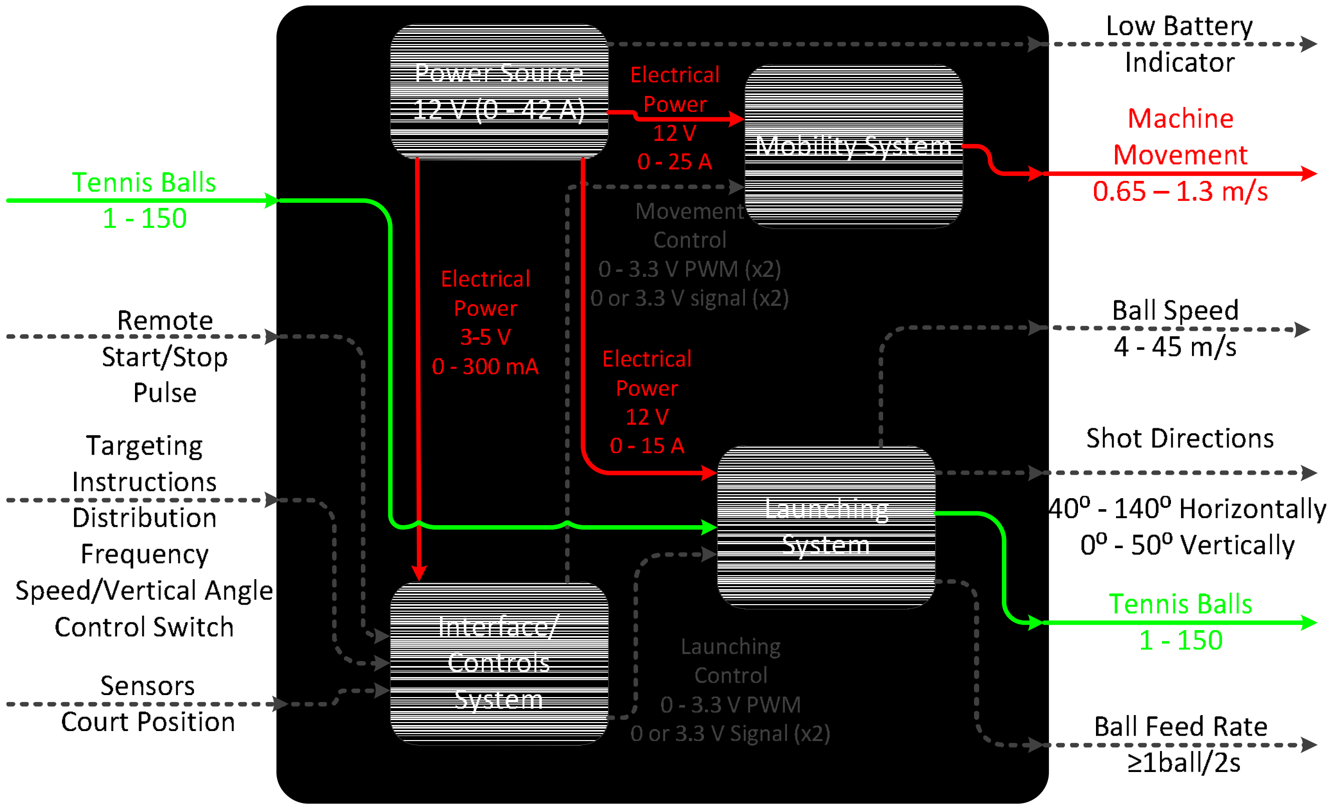


Figure 3: Level 1 block diagram of MATT showing all major subsystems

Power Source System – Level 2

The block diagram shown in Fig. 4 shows a Level 2 representation of the individual subsystems of the power source system along with all of its power outputs to the various subsystems.

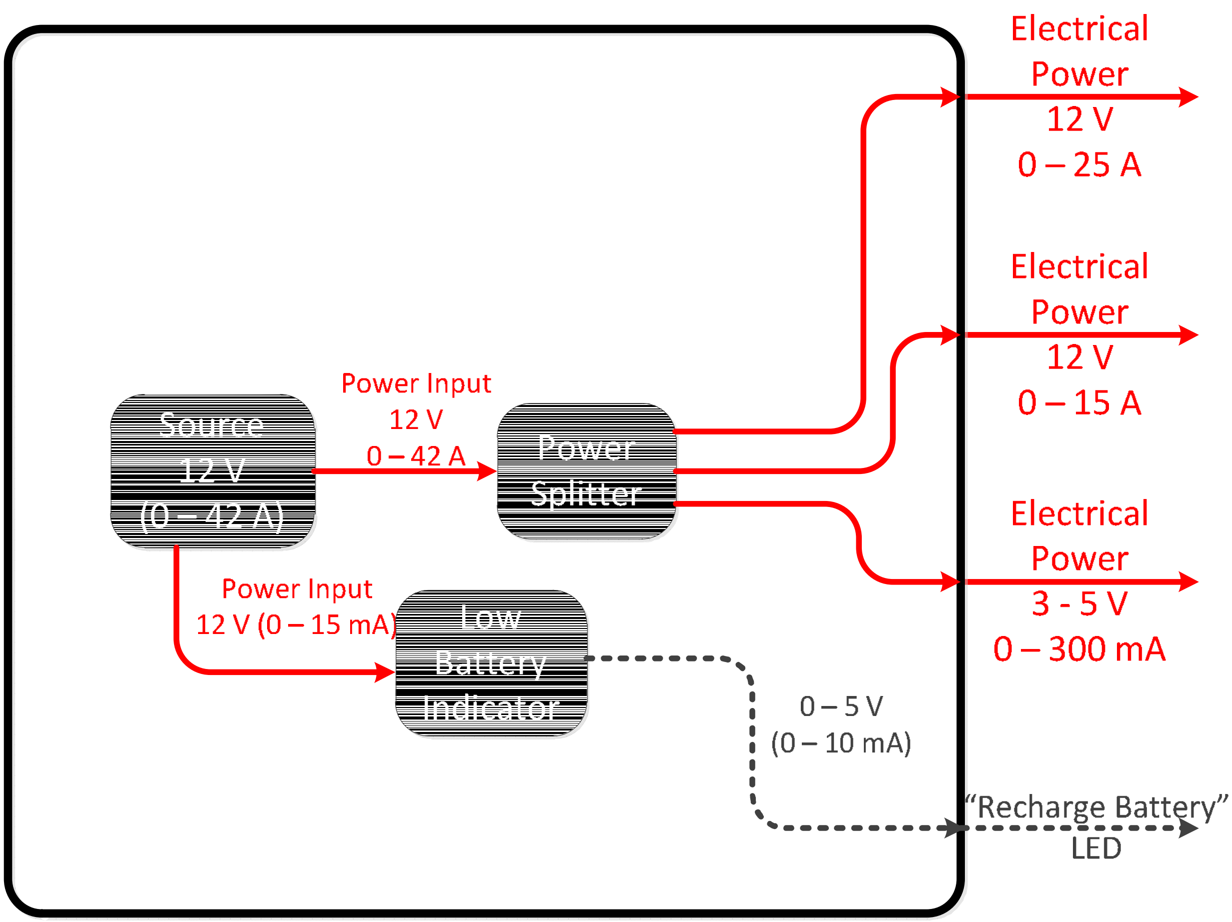


Figure 4: Level 2 block diagram of power source system showing individual subsystems

Control and Interface System – Level 2

The block diagram provided in Fig. 5 is the Level 2 representation of the control and interface system and its signal inputs and outputs as well as its power requirements.

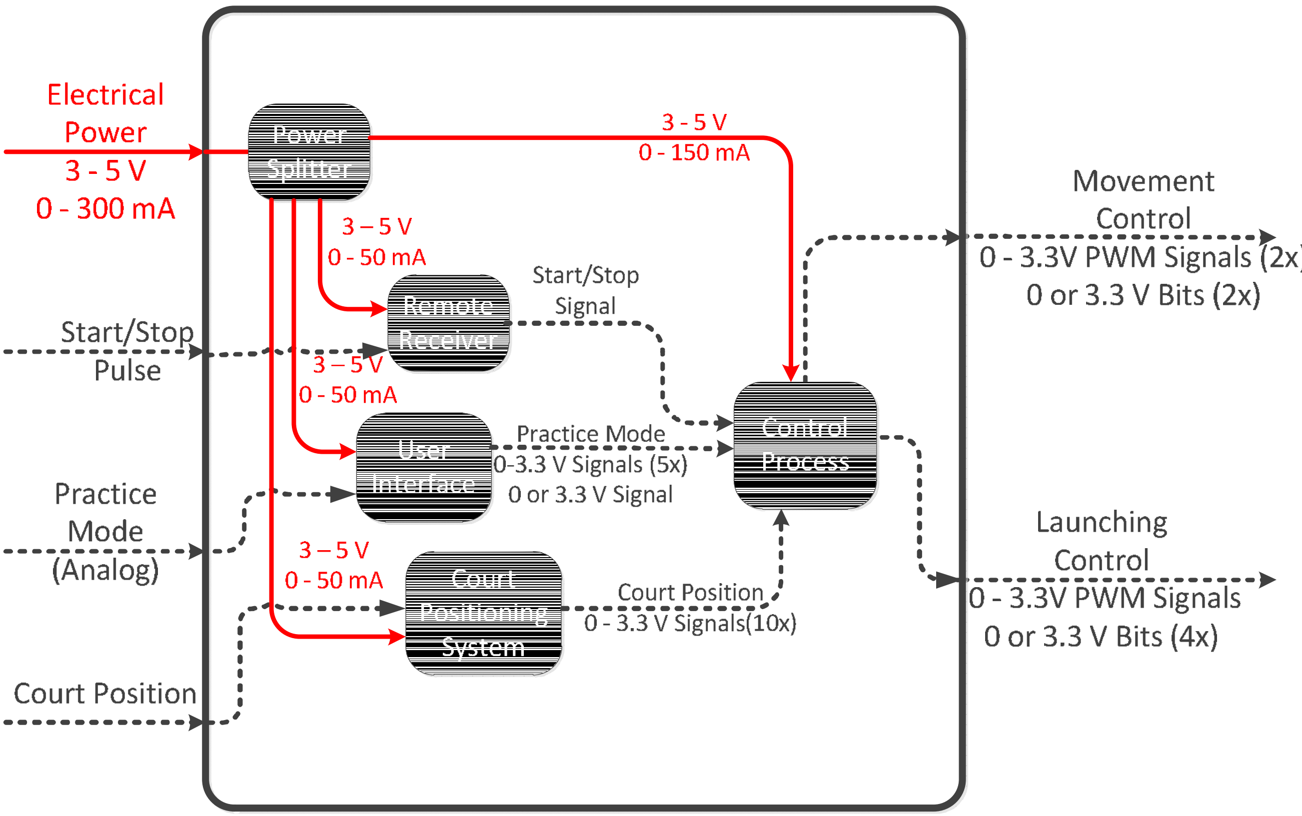


Figure 5: Level 2 block diagram of the control and interface system with its individual subsystem

Launching System – Level 2

The Level 2 block diagram shown in Fig. 6 shows the launching system and its individual subsystems with respect to its inputs and outputs as well.

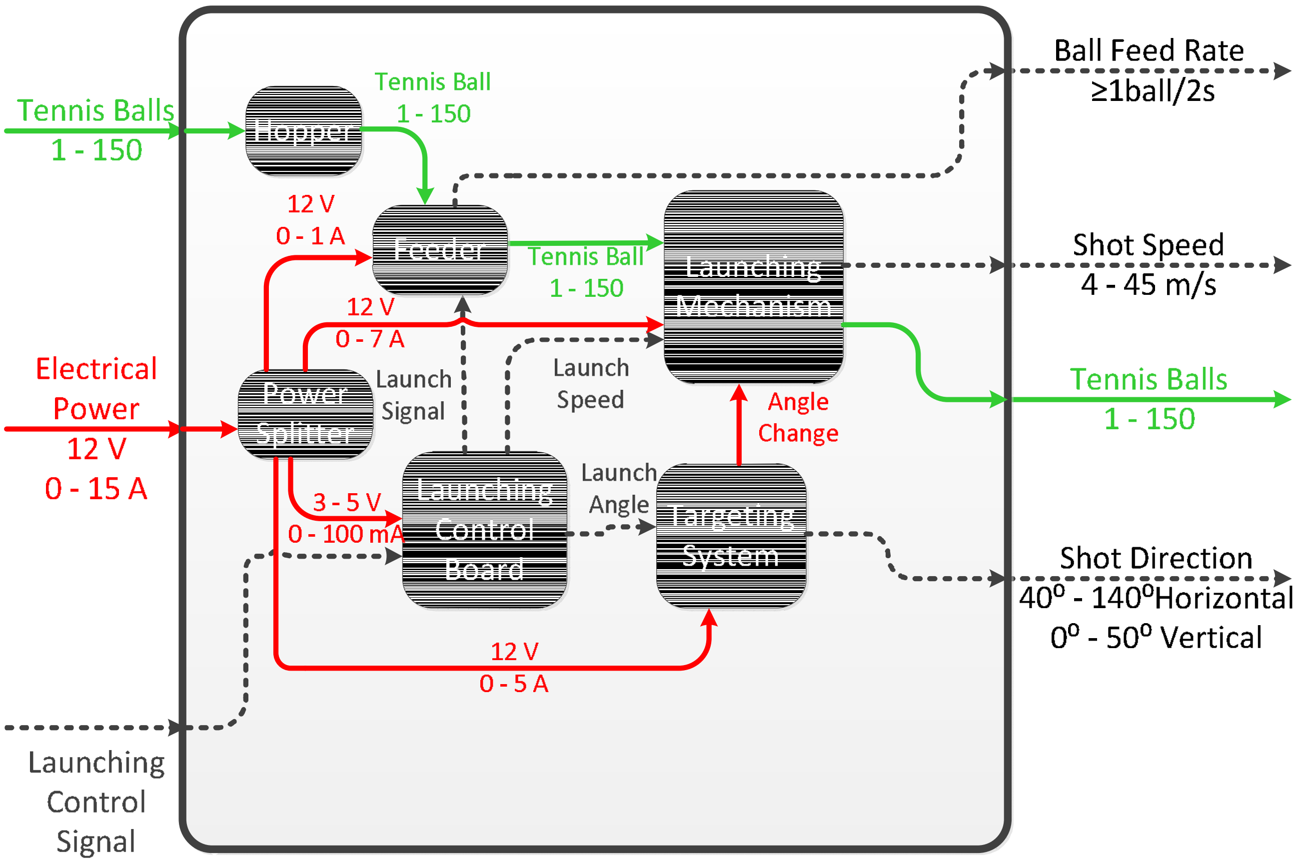


Figure 6: Level 2 block diagram of launching system and its individual subsystems

Mobility System – Level 2

The Level 2 block diagram for the mobility system and its corresponding inputs, outputs, and subsystems is shown in Fig. 7.

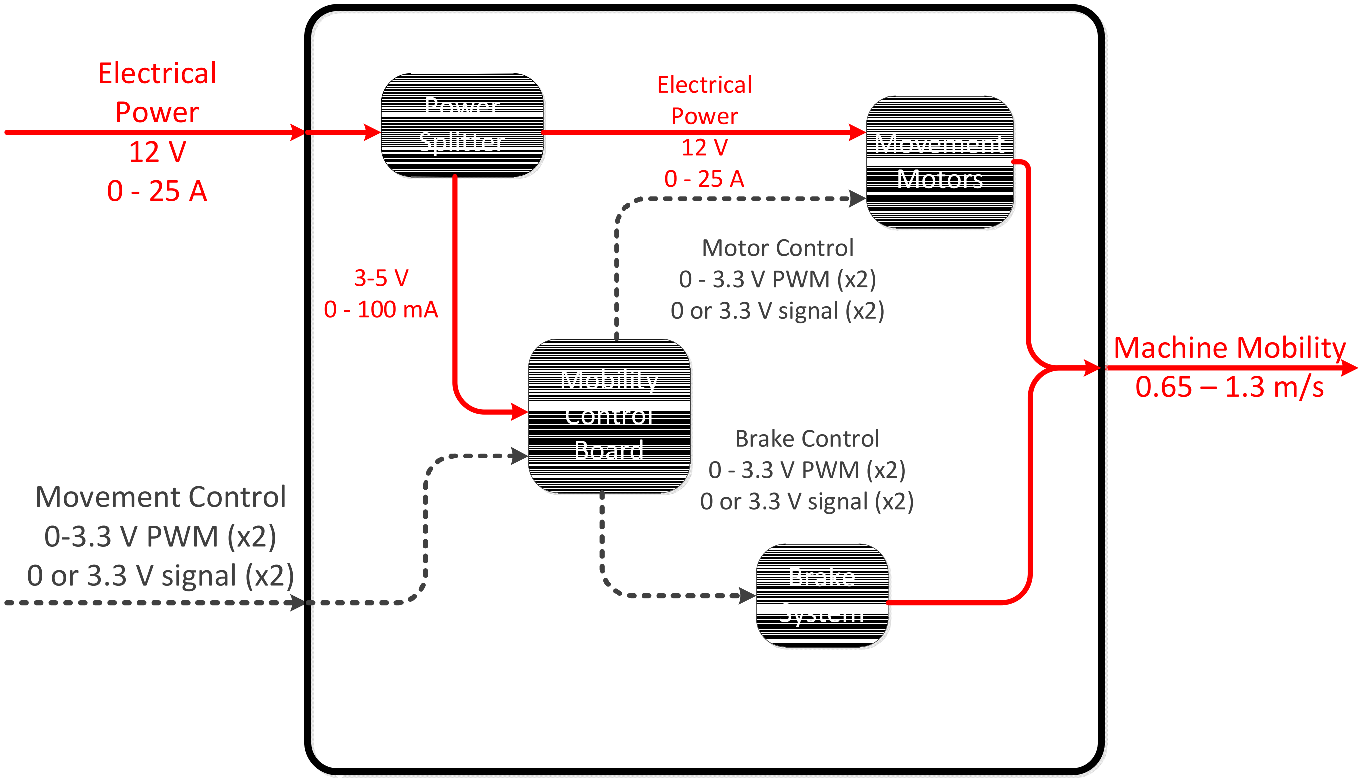


Figure 7: Level 2 block diagram for mobility system and its subsystems

Functional Description of Subsystems

Power Source

Description: The power supply will consist of one (12 VDC, 70Ah) lead acid battery. The power will then be reduced to the correct voltage and current needed by each of the other systems on the machine. There will be a low voltage indicator to indicate if the voltage drops below a certain level. There will also be a master power switch that will turn the machine on or off, which will be independent of the remote.

Inputs:

- **Power:** 12 VDC, 0-42A from battery

Outputs:

- **Control and Interface System:** 3 – 5 VDC (300 mA)
- **Launching System:** 12 VDC (0 – 15 A)
- **Mobility System:** 12 VDC (0 – 25 A)

Subsystems of Power Source:

Low Voltage Indicator

Description: The low voltage indicator is a circuit that will light an LED once the voltage of the battery drops at or below 11.5 VDC

Inputs:

- **Power Source:** Electrical power greater than 11.5 VDC (0 – 10 mA)

Outputs:

- **Light:** 75 mcd, when voltage drops at or below 11.5 VDC

Power Splitter

Description: The power splitter will distribute the required amount of voltage and current to all the various subsystems of the machine.

Inputs:

- **Power Source:** 12 VDC from battery at 0 – 42 A

Outputs:

- **Control and Interface System:** 3 – 5 VDC (300 mA)
- **Launching System:** 12 VDC (0 – 15 A)
- **Mobility System:** 12 VDC (0 – 25 A)

Interface and Control System

Description: The interface and control system receives information from the user via the user interface, the remote control, and all other external sensors. The microprocessor will process the information to determine the targeting controls, movement instructions, launching signals and parameters, and then distribute the necessary information and instructions to all of the various subsystems.

Inputs:

- **User Commands**: Instructions for operation
- **Power Source:** Electrical power at 3 – 5 VDC (300mA)
- **External Information:**
    - Court Position: Analog Coordinates
- **Launching System:**
    - Horizontal Angle Change: 0 – 5 VDC (0 – 50 mA) Encoder Signal
    - Vertical Angle Change: 0 – 5 VDC (0 – 50 mA) Encoder Signal

Outputs:

- **Launching System Control Signals**
    - Horizontal Angle: Two 0 – 5 VDC (0 – 50 mA) Direction Bits
    - Vertical Angle: Two 0 – 5 VDC (0 – 50 mA) Direction Bits
    - Launching Speed: 0 – 5 VDC (0 – 50 mA) PWM Speed Signal
    - Feeder Speed: 0 – 5 VDC (0 – 50 mA) PWM Speed Signal
- **Mobility Control Signals**
    - Movement Speed: Two 0 – 3.3 VDC (0 – 50 mA) PWM Speed Signal
    - Movement Direction: Two 0 – 3.3 VDC (0 – 50 mA) Direction Bits

Subsystems of Interface and Control System:

User Interface

Description: The user interface will provide a method for the entry of user instructions and will allow the user to determine the effective skill level of the machine. The interface will be easy to understand and use, as well as providing user control over the following factors: target distribution, speed range, height range, and launching rate.

Inputs:

- **User Commands**: Instructions for operation
- **Power Source:** 3 – 5 VDC (0 – 50 mA)

Outputs:

- **Microprocessor**
    - Target Distribution: Two 0-5 VDC(0 – 50 mA) Signals
    - Launching Speed Range: Two 0-5 VDC(0 – 50 mA) Signals
    - Height Range: One 0-5 VDC(0 – 50 mA) Signal
    - Firing Rate: One 0-5 VDC(0 – 50 mA) Signal

Remote Control Transmitter

Description: The remote control transmitter is a remote that the player can carry with them to signal MATT once they are ready for it to start launching the tennis balls. The remote will also be used to signal MATT to stop launching if the machine needs to be turned off quickly.

Inputs:

- **User Commands:** Instructions for operation
- **Power Source:** 3-12 VDC (0 – 50 mA)

Outputs:

- **Remote Receiver**
    - Start: RF Signal
        - Frequency: 315 MHz
        - Range: 30 m
        - Modulation: ASK
    - Stop: RF Signal
        - Frequency: 315 MHz
        - Range: 30 m
        - Modulation: ASK
    - Power Source: 3-12 VDC (0 – 50 mA)

Remote Control Receiver

Description: The remote control receiver subsystem receives the signal from the remote control transmitter and translates it to the start or stop instruction for the microprocessor.

Inputs:

- **Remote Transmitter**
    - Start: RF Signal
        - Frequency: 315 MHz
        - Range: 30 m
        - Modulation: ASK
    - Stop: RF Signal
        - Frequency: 315 MHz
        - Range: 30 m
        - Modulation: ASK
- Power Source: 5 VDC (0 – 50 mA)

Outputs:

- **Microprocessor**
    - Start Signal: ~5V (“High”) Pulse
    - Stop Signal: ~5V (“High”) Pulse

Sensors

Description: The sensor subsystem determines the location of the machine relative to the court, and the current targeting values. This includes both the external sensors and the code to interpret them. It then sends this information to the microprocessor main code for calculations.

Inputs:

- **External Information:**
    - Court Position: Analog Coordinates
- **Launching System:**
    - Horizontal Angle Change: 0 – 5 VDC (0 – 50 mA) Encoder Value
    - Vertical Angle Change: 0 – 5 VDC (0 – 50 mA) Encoder Value
- **Power Source:** 3 – 5 VDC (0 – 50 mA)

Outputs:

- **Microprocessor Main Code**
    - Court Position Change: 32-bit coordinate values
    - Horizontal Angle: 16-bit or 32-bit angle values

○ Vertical Angle: 16-bit or 32-bit angle values

Microprocessor Main Code
Description: The microprocessor subsystem receives data for the practice specifications, current machine conditions, and remote control signals. The microprocessor then processes the information, making the decisions and calculations necessary to set up the next shot and keep the machine from leaving the court. It translates this information into signals to send to the appropriate systems.
Inputs: • **Remote Receiver** ○ Start Signal: ~5V ("High") Pulse ○ Stop Signal: ~5V ("High") Pulse • **User Interface** ○ Target Distribution: Two 0-5 VDC (0 – 50 mA) Signals ○ Launching Speed Range: Two 0-5 VDC (0 – 50 mA) Signals ○ Height Range: One 0-5 VDC (0 – 50 mA) Signal ○ Firing Rate: One 0-5 VDC (0 – 50 mA) Signal • **Sensors** ○ Current Court Position: 32-bit coordinate values ○ Current Horizontal Angle: 16-bit or 32-bit angle values ○ Current Vertical Angle: 16-bit or 32-bit angle values • **Power Source:** 3 – 5 VDC (0 – 50 mA)
Outputs: • **Launching System Control Signals** ○ Horizontal Angle: Two 0 – 5 VDC (0 – 50 mA) Direction Bits ○ Vertical Angle: Two 0 – 5 VDC (0 – 50 mA) Direction Bits ○ Launching Speed: 0 – 5 VDC (0 – 50 mA) PWM Speed Signal ○ Launch Signal: 0 – 5 VDC (0 – 50 mA) PWM Speed Signal • **Mobility Control Signals** ○ Movement Speed: Two 0 – 3.3 VDC (0 – 50 mA) PWM Speed Signals ○ Movement Direction: Two 0 – 3.3 VDC (0 – 50 mA) Direction Bits

Launching System

Description: The launching system will consist of a launching mechanism, an aiming mechanism, a tennis ball feeding mechanism, and a motor assembly for each mechanism. The launching mechanism will launch tennis balls at speeds between 4 m/s and 45 m/s, and consists of counter-rotating wheels. The aiming mechanism will consist of both a vertical adjustment and an angular adjustment to provide for the specified angle ranges. The feeding mechanism will keep a steady flow of tennis balls to the launcher, depending on the selected setting. This system will be powered from the power source, and controlled via instructions from the microprocessor and motor controllers, based on sensor input information.

Inputs:

- **Power:** 12VDC at (0 - 15 A)
- **Launching Control Signals (Digital – from Microprocessor and Motor Controller):**
  - Horizontal Angle: Two 0 – 5 VDC (0 – 50 mA) Direction Bits
  - Vertical Angle: Two 0 – 5 VDC (0 – 50 mA) Direction Bits
  - Launching Speed: 0 – 5 VDC (0 – 50 mA) PWM Speed Signal
  - Launch Signal: 0 – 5 VDC (0 – 50 mA) PWM Speed Signal
- **Tennis Ball Feed Rate:** Delivery from hopper and feeder system at a rate less than or equal to 1 tennis ball every 2 seconds

Outputs:

- **Shot Speed:** 4 – 45 m/s
- **Shot Direction:** 0° - 50° vertical displacement, 40° - 140° angular displacement
- **Shot Feed Rate:** Less than or equal to 1 tennis ball every 2 seconds
- **Tennis Balls:** Wide variety of shots to player

Subsystems of Launching System:

Launching Mechanism

Description: The launching mechanism will provide a means of launching the tennis ball from MATT at variable speeds. The launching mechanism will most likely consist of counter-rotating wheels, attached to a single chain and a single motor, allowing both of the wheels to rotate at the same speed. With the wheels rotating at the same speed, variable ball spins will not be possible.

Inputs:

- **Power Source:** 12VDC at (0 - 15 A)
- **Launching Control Signals (Digital – from Microprocessor and Motor Controller):**
  - Launching Speed: 0 – 5 VDC at (0 – 50 mA)
  - Launch Signal: 0 – 5 VDC at (0 – 50 mA)

Outputs:

- **Tennis Balls:** Launched at speeds ranging from 4 m/s to 45 m/s

Targeting System

Description: The targeting system will control the aiming of the tennis ball launching mechanism. This system will consist of two major components, the horizontal angle adjustment mechanism and the vertical angle adjustment mechanism. The horizontal angle adjustment will provide horizontal angles from 40° to 140°, and the vertical angle adjustment will provide vertical angles from 0° - 50°. Both of these aiming mechanisms will be powered by their own motor assembly.

Inputs:

- **Power Source:** 12VDC at (0 - 5 A)
- **Launching Control Signals (Digital – from Microprocessor and Motor Controller):**

- Horizontal Angle Position: 0 – 5 VDC at (0 – 50 mA)
- Vertical Angle Position: 0 – 5 VDC at (0 – 50 mA)

Outputs:

- **Tennis Balls:** Launched at speeds ranging from 4 m/s to 45 m/s
- **Current Conditions:**
  - Horizontal Angle Change: 0 – 5 VDC (0 – 50 mA) Encoder Signal
  - Vertical Angle Change: 0 – 5 VDC (0 – 50 mA) Encoder Signal

Hopper and Feeder System
Description: The hopper will store at least 150 tennis balls in the machine when loaded to capacity. The hopper will be designed to prevent the tennis balls from spilling out during motion of the machine. The feeder will supply a steady flow of tennis balls to the launching mechanism as long as there are still tennis balls in the hopper. The feed rate will be adjustable and determined by the microprocessor and motor controller based on movement, launching, and user inputs.
Inputs: • **Power Source:** 12VDC at (0 - 15 A) • **Tennis Ball Feed Rate (Microprocessor and Motor Controller Signals):** Delivery from hopper and feeder system at a rate less than or equal to 1 tennis ball every 2 seconds
Outputs: • **Tennis Balls:** Launched at speeds ranging from 4 m/s to 45 m/s • **Shot Feed Rate:** Less than or equal to 1 tennis ball every 2 seconds

Mobility System
Description: The mobility system will consist of a motor assembly that will power wheels, and therefore allow the lateral movement of the device, generally parallel to the net. The machine will be able to traverse the court in a maximum of 20 seconds. The machine will have a braking system, which will be able to slow or stop the machine when a command to do so is provided by the microprocessor. The system will be given such a command to do this automatically, depending on sensor inputs, or by a signal provided by the user via the remote control. The braking will be performed by the motor controller, without having an actual mechanical brake system. The entire system will be powered from the power source, and controlled via instructions from the microprocessor using motor controllers. The mobility system will also have an encasement to prevent tennis balls from causing damage or prohibiting proper operation of the machine by impeding the motion of the wheels.

Inputs:
• **Power Source:** 12 VDC at (0 - 25 A)
• **Mobility Control Signals (Digital – From Microprocessor and Motor Controller):**
  ○ Movement Speed: Two 0 –3.3 VDC (0 – 50 mA) PWM Speed Signal
  ○ Movement Direction: Two 0 – 3.3 VDC (0 – 50 mA) Direction Bits

Outputs: • **Lateral Motion (Parallel to the net):** 0.65 – 1.3 m/s
Subsystems of Mobility System:

Drive System
Description: The drive system of the mobility system will consist of a motor assembly, driving the wheels of the machine. The motor assembly will have a torque reducing gearing system to reduce the size of the motor required to move the machine under the worst case scenario, which would be at a maximum mass of 70 kg. The motor assembly will consist of two separate drive motors that can be controlled individually by the motor controllers, to adjust the movement direction of the machine if necessary. For balance and stability, there will also be two pivoting caster wheels attached to the base of the machine for support and ease of direction change.

Inputs:
• **Power Source:** 12 VDC at (0 - 25 A)
• **Mobility Control Signals**
  ○ Movement Speed: Two 0 – 3.3 VDC (0 – 50 mA) PWM Speed Signal
  ○ Movement Direction: Two 0 – 3.3 VDC (0 – 50 mA) Direction Bits

Outputs: • **Lateral Motion (Parallel to the net):** 0.65 – 1.3 m/s

Braking System
Description: The braking system will slow and stop the machine automatically on command. The braking system will be controlled electronically by reversing or slowing the drive motors via instructions provided by the motor controller.
Inputs: • **Power Source:** 12 VDC at (0 - 25 A) • **Mobility Control Signals**   ○ Movement Direction: Two 0 – 5 VDC (0 – 50 mA) Direction Bits
Outputs: • The machine can stop itself once in motion

Detail Design

Mobility System

The mobility system is the system that will make MATT a unique product. Though there will be nothing revolutionary about the design of the mobility system itself, the concept of a moving tennis ball machine is new and innovative. The design team has looked through many different patents and resources and has not yet found another tennis ball launching machine that moves to provide variability of shot origin to the player.

The design of the mobility system was based on three of the explicitly stated technical requirements specified. The first two are related to the maximum mass that the mobility system must be able to support. A specification for portability was stated that the machine will weigh less than 60 kilograms, when not loaded with tennis balls. It was also stated that the machine must be able to hold a minimum of 150 tennis balls when fully loaded, which would amount to a minimum additional load of 8.91 kilograms. Therefore, the total mass that the mobility system was designed to handle was taken to be 70 kilograms for simplicity. The next design criterion that was considered was the specified speed of the machine. It was specified MATT would traverse the court in 20.0 ± 1.0 seconds. The range of operation of the MATT was also specified as well. It was specified that MATT would move laterally while remaining within 6.0 ± 0.5 meters of the center of the court at all times. Based on this movement specification it was shown that MATT would need to move a maximum of 13.0 meters in a maximum of 20.0 ± 1.0 seconds, for a velocity of 0.65 m/s. For design purposes, the velocity used was actually 1.5 times as much, meaning that MATT would traverse the maximum distance of 13.0 meters in 15 seconds, yielding a movement velocity of 0.87 m/s.

With these design criteria determined, the next step was to calculate a value for a worst case scenario torque so a motor and drive train system could be designed accordingly. To do this, a method of estimating friction in the mechanical components or a statically determinant model had to be used. It was determined that a worst case scenario would be a case when the wheel was impeded by a small object, such as a pebble, and thus requiring a much larger torque than would be required for normal operation to overcome such an object. This scenario allows for a torque estimation using only the geometry of the wheel and the load applied due to the mass of the machine. Figure 8 shows the model used to estimate the required torque for the mobility system wheel based on the design criteria previously stated.

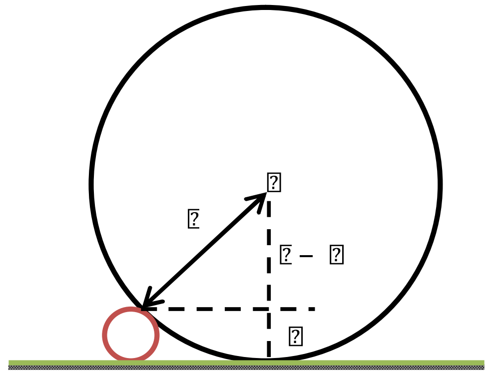


Figure 8: Depiction of geometry used in worst case scenario torque estimation model

Figure 9 shows the free body diagram of the model used to estimate the torque required by the mobility system.

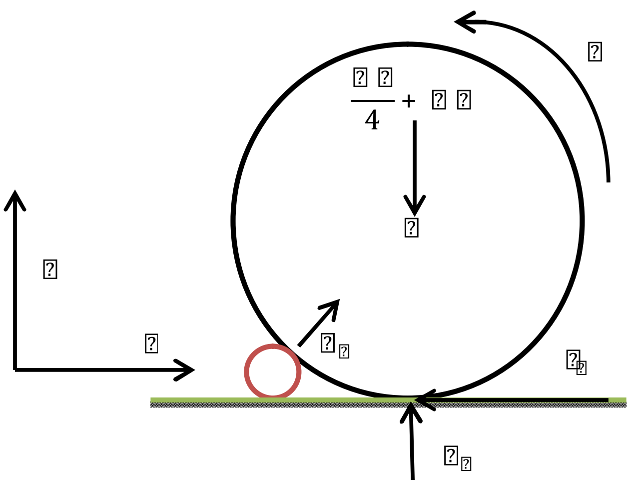


Figure 9: Free-body diagram of torque estimation model

From the geometry shown in Fig. 8 and the forces shown in Fig. 9 a relationship for torque could be derived once some values were known and some assumptions were made. Summing the forces in the x-direction and y-direction, and calculating the moments about point O, Eqn. 1 was derived.

[illegible] Eqn. (1)

The following are the definitions of the variables used:

[illegible] = [illegible] = 70 [illegible]
[illegible] = [illegible] = 1 [illegible]
[illegible] = [illegible] = 9.81 [illegible]
[illegible] = [illegible] = 0.127 [illegible] (5 [illegible])
[illegible] = [illegible] = 0.00635 [illegible] (0.25 [illegible])

Equation 1 calculates the torque required for a single wheel carrying one fourth of the total specified load, to roll over an object of 0.635 cm (0.25 in) in thickness. It was assumed that there would be four wheels to support the load and therefore each wheel would carry one fourth of the total load. Estimations were made for the radius of the wheel and the mass of the wheel as deemed necessary. From the values listed and Eqn. 1 the initial torque required for one wheel to be able to roll over an obstructing object was calculated to be approximately 7.6 N·m. Therefore, if four wheels, of the same size and weight were modeled as rolling over some impeding object all at the same time an absolute worst case scenario for the required torque was determined to be approximately 30.4 N·m. This value was therefore used as an estimation of the most torque that would ever be needed by the mobility system at any given time. With such a value known, the drive system design could be designed to meet this requirement.

Drive System

The drive system of MATT will be able to move laterally, generally remaining parallel to the net on the tennis court. It will also be able to move both forward and backward in this lateral direction. To do this the method selected was a combination of two identical motors, and associated gearing for each. Each motor will be controlled individually, which would allow for correction if MATT begins to stray off course. Having two drive motors would also exhibit the advantage of each motor carrying half of the required load. Therefore each of the drive motors would be required to be able to apply at least 15.2 N·m under the worst conditions. When searching for motors with output torques anywhere near this value it was quickly determined that such a motor would be cost prohibitive. The only plausible option was to design a smaller, less expensive motor to work with a torque increasing gear or sprocket set. After comparing many motor specifications and torque reduction scenarios it was determined that an increase of 1:64 was required at a minimum in order to decrease the cost of the motor needed. However, with this increase in torque came the additional cost of the mechanical components to gear it properly. Also with the increase in torque comes a decrease in speed by the same factor. Therefore if a high torque is required for the mobility system, a high speed at a low torque must be put into the gearing system. Based on our initial estimate of wheel radius and court traversal time, an output speed of approximately 100 rpm was needed. Therefore, an input speed of approximately 6400 rpm would be needed to increase the input torque by a factor of 64. Due to the availability of two identical 64:1 speed reduction gearboxes (1:64 torque increase), this method was selected for the mobility system. With these gearboxes selected, two identical motors that can supply at least 0.2375 N·m, (a factor of 64 less than 15.2 N·m), and operate at high speeds of greater than 6400 rpm were selected as well. More information about the selected motors and gearboxes can be found in Appendices B.1 and B.2 respectively. Figure 10 shows one motor and gearbox assembly for the mobility system.

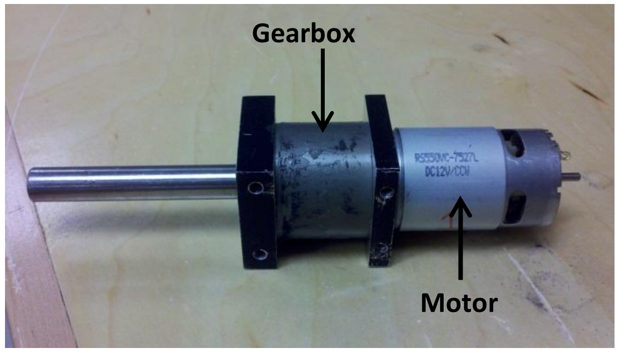


Figure 10: Mobility motor and gearbox

Since the mobility system has two drive motors there will also be two drive wheels connected to the motors. Unless a greater torque increase is needed, and therefore more gearing, the drive wheels will be mounted directly on the shaft of the gearbox. Based on the original assumption of wheel radius size and the related speed, a 25.4 cm (10 in) diameter wheel will be used for each of the drive wheels. To support the machine, and still allow for frequent direction changes, two pivoting caster wheels will be used on the mobility system as well.

To help determine the size of pivoting caster wheels to use Eqn. 1 was used to calculate the torque on wheels of various diameter. The results can be seen in Table 1.

Table 1: Relationship of diameter to required torque

Wheel Diameter (cm)	Torque Per Wheel (N·m)
5.08	4.0654
10.16	5.101
15.24	6.0293
20.32	6.8442
25.4	7.5757
30.48	8.2442

As can be seen, as the diameter decreases, the required torque does as well. Therefore, the selection of a smaller pivoting caster wheel would be beneficial, and therefore a 7.62 cm (3 in) pivoting caster will be used. With this selection, along with the 25.4 cm (10 in) drive wheel the required torque of the system is actually lower than previously estimated. The selected wheels are shown Appendix B.3.

Brake System

The mobility system of MATT will not actually have a separate mechanical system to slow down or stop the machine as required. All slowing and stopping of MATT will be controlled using instructions from the microprocessor via the motor controller. Essentially, when the machine needs to slow, stop, or even change direction, a signal will be sent to reverse the direction of the motors until the desired result occurs. Therefore the system is essentially a programmed system, and not a separate physical system.

Mobility Frame and Encasement

The frame of the mobility system and outer encasement is crucial for two reasons. The structural integrity of MATT is very dependent on the strength and support that is provided in the frame of the mobility system. Second, the encasement on the outside will prohibit tennis balls from getting under the machine and prohibiting the proper operation of the mobility system wheels. The frame must be strong enough to support the weight of the majority of the machine as well as withstand torques applied by the mobility motors and other subsystem components attached to it. The mobility frame was designed to create a sturdy base of operation, as well as providing a place to house the battery and any other bulky, stationary parts of the machine. The goal was to place as much of the total machine mass as possible in this lower section so that a low center of gravity would increase the overall machine stability. A possible frame design was assembled in SolidWorks and modeled using finite element methods in SolidWorks to determine stresses due to the expected loads. The model was 50.8 cm (20 in) wide x 60.96 cm (24 in) long x 26.67 cm (10.5 in) tall, and made from aluminum angle structural members. Figure 11 shows the finite element method simulation of the frame with a force applied to the top and a torque applied to each gearbox shaft. The analysis showed that all stresses in the frame were well below the yield strength of 6063 aluminum, which is 145 MPa. The highest stress in the simulation was located on the shaft of the gearbox, which is made from steel, and is stronger than aluminum. After several iterations and modifications to optimize strength and thickness, the frame shown in Fig. 11 was selected as the design. The frame and encasement materials can be found in Appendix B.4.

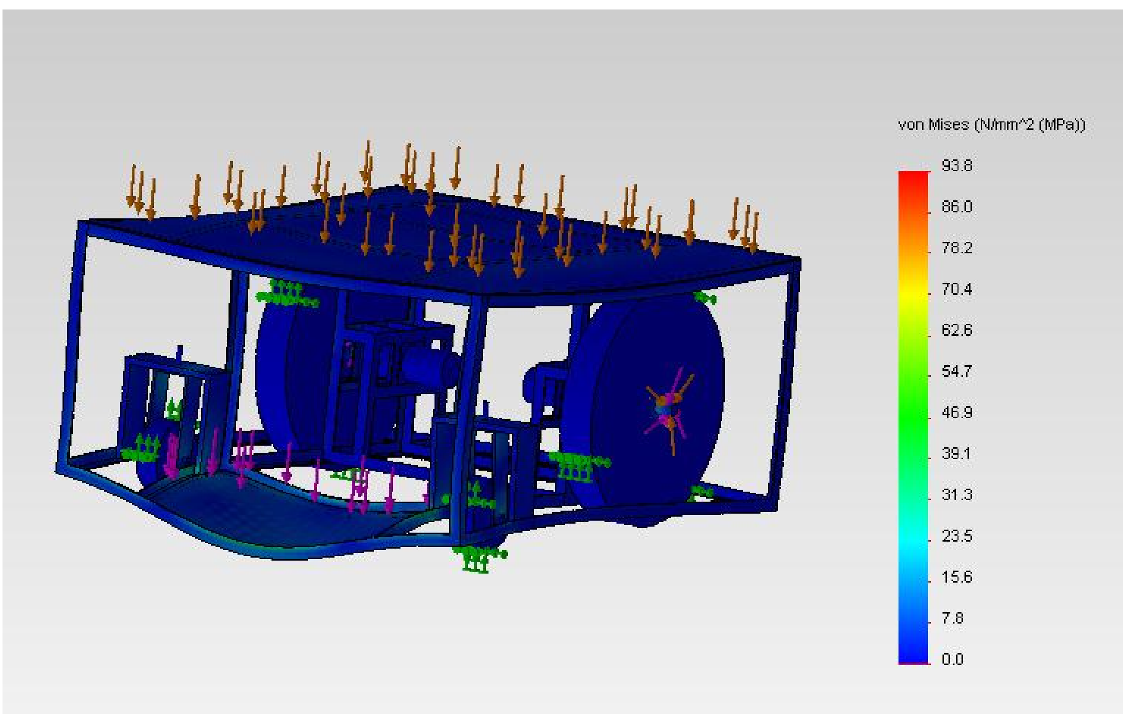


Figure 11: Mobility frame finite element analysis

Power Requirements

Based on the motor specifications provided in Appendix B.1, power calculations were performed in order to determine total power requirements under the worst-case scenario. Based on the values provided, the torque requirements, and the speed requirements, Eqn. 2 was used to calculate the required power for each motor. In Eqn. 2 T, represents the output torque in N·m, ω represents the angular velocity of the output shaft in rad/s, and P represents the power in W.

$$P = T\omega \qquad \text{Eqn. (2)}$$

Using Eqn. 2 and 15.2 N·m for torque and 6.82 rad/s (65.2 rpm) for the angular velocity, approximately 105 W of power is needed to run each motor under the worst conditions. Therefore the mobility system, which will be the system that requires the most power, will need at least 210 W of power supplied to it to ensure proper operation.

Design Drawings

Figures 12, 13 and 14 show the design of the mobility frame with placement of motors, wheels, and battery. The overall dimensions of the mobility system are labeled in the figures.

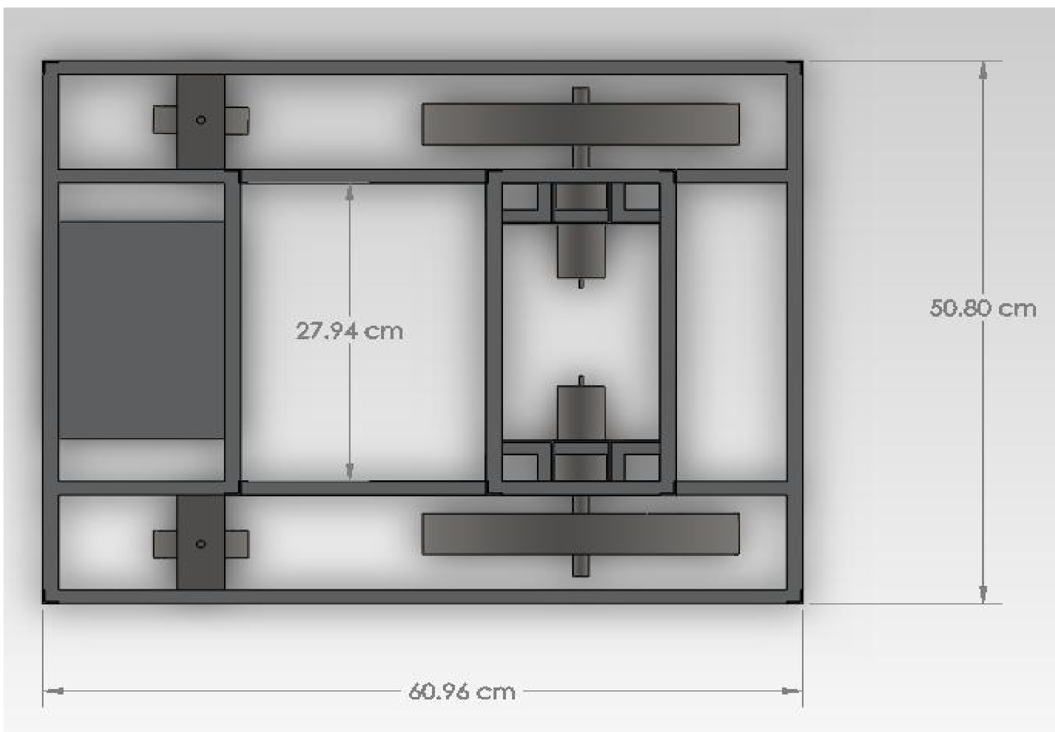


Figure 12: Top view of mobility system frame and major drive components

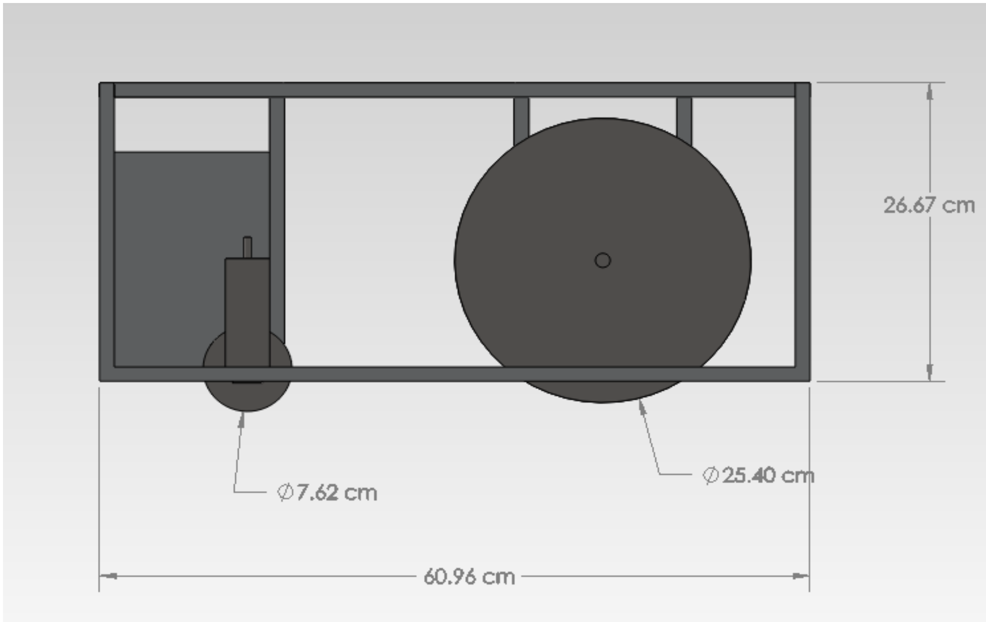


Figure 13: Side view of mobility system and frame

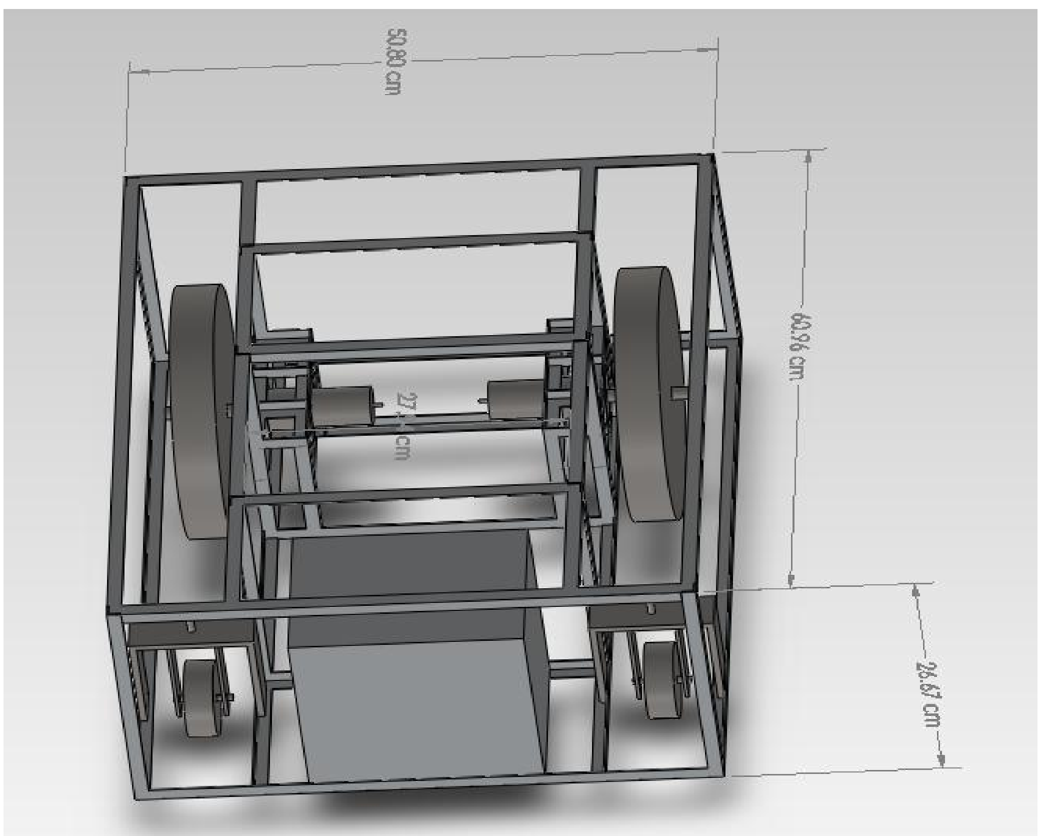


Figure 14: Angled view of mobility system frame and placement of major components

Launching System

The launching system consists of three subsystems: launching mechanism, targeting system, and the hopper and feeder system. The launching mechanism controls the initial velocity of the tennis balls, which is between 4 and 45 m/s. The targeting system controls the angular and vertical displacement of the launching mechanism for shot aiming purposes. The targeting system is then divided into angular and vertical targeting mechanisms. The hopper and feeder system controls the rate in which the tennis balls fall from the hopper into the launching mechanism. Finally, the launching system is powered from the power source, and controlled via instructions from the microprocessor and motor controllers, based on sensor input information.

Launching Mechanism

The launching mechanism consists of two launching wheels, a motor, an idler sprocket, a chain, and sprockets for the launching wheels and motor. The launching wheels are driven by the motor by means of a single chain and sprockets on each wheel, allowing them to rotate with the same angular velocity. The idler sprocket makes the wheels to counter rotate. The launching mechanism concept design is shown in Fig. 15.

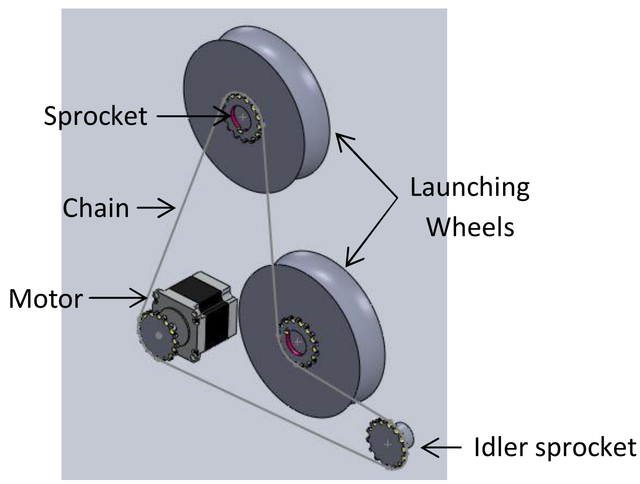


Figure 15: Launching mechanism concept design

This design was chosen because of its simplicity of one single chain and for having one adjustment point for tensioning the idler sprocket. The launching wheels are U-shaped for two reasons. First, it increases the area of contact between the wheels and the tennis ball, this way increasing friction. The higher friction helps prevent the tennis balls from slipping. Second, it prevents the tennis balls from slipping sideways out of the wheels due to the shape of the wheel.

The positioning of the launching wheels that makes the tennis balls to go just over the net with the smallest vertical angle is defined to be the default position, as shown in Fig. 16. The smallest angle was calculated when the machine is at the center of the court, furthest away from the net, launching the tennis ball straight at maximum speed. The default position was found to be where the top wheel is shifted 8° counter clockwise from bottom wheel and the distance between the wheels is approximately 6cm.

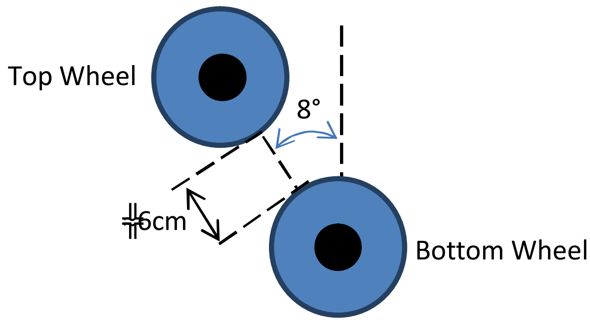


Figure 16: Default position of the wheels in launching mechanism

The motor accelerates the launching wheels until a desired angular velocity to launch the tennis ball is reached. Right after the ball is launched, the wheels slow down since some of its kinetic energy is lost to launch the tennis ball. The required motor was specified to have a torque large enough to bring the angular velocity back up within the minimum time interval between shots (2 seconds). Figure 17 shows the linear and angular velocities of the wheels and tennis ball. Although, because the tennis ball has a small mass, in reality almost no kinetic energy from the wheels is lost to launch it, so the motor is assumed to hold the speed constant.

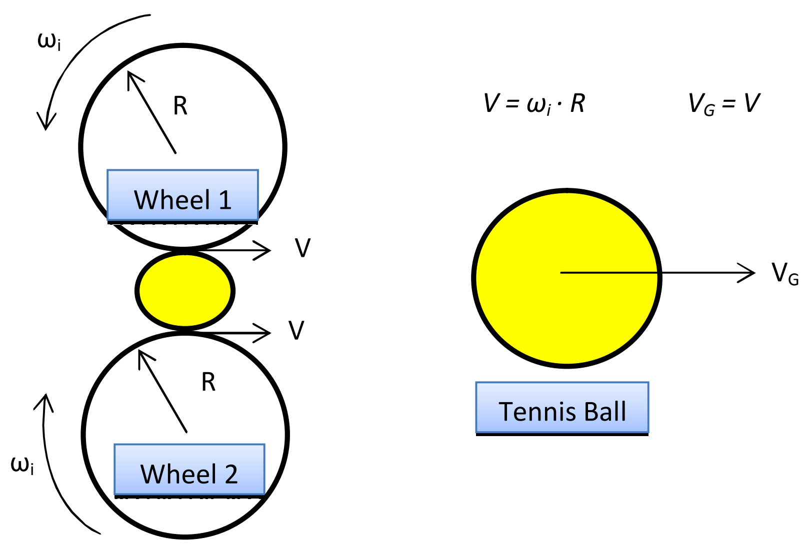


Figure 17: Free body diagram of wheels and tennis ball

The kinetic energy of the tennis ball (T_{ball}), and the kinetic energy of the wheels before ($T_{wheels,i}$) and after ($T_{wheels,f}$) the tennis ball is launched are shown next.

$$T_{ball} = 1/2 \cdot m_{ball} \cdot V_G^2 \qquad \text{Eqn. (3)}$$

$$E_{k\,ball,f} = \frac{1}{2} m_{ball} \cdot V_G^2 \qquad \text{Eqn. (4)}$$

$$E_{k\,wheel,f} = \frac{1}{2} I_{wheel} \cdot \omega_f^2 = E_{k\,wheel,i} - E_{ball} \qquad \text{Eqn. (5)}$$

where m_{ball} and V_G are the mass and velocity of the tennis ball, respectively. I_{wheel} and ω are the mass moment of inertia and angular velocity of a wheel, respectively. Subscripts i and f stand for before and after the tennis ball is launched, respectively.

The acceleration (α) to bring the angular velocity back up within the minimum time interval between shots (dt) was found to be:

$$\alpha = \frac{\omega_i - \omega_f}{dt} \qquad \text{Eqn. (6)}$$

Finally, the required torque (T) and power (P) for the launching mechanism were found to be:

$$T = I_{wheel} \cdot \alpha \qquad \text{Eqn. (7)}$$

$$P = T \cdot \omega_i \qquad \text{Eqn. (8)}$$

An Excel spreadsheet was created to easily find motor specifications based on the radius and mass of the launching wheel, and initial velocity of the tennis ball. The excel spread sheet can be found in Appendix E.1.1.1. The calculations were performed with a 7.62cm radius wheel with a mass of 0.85kg, and with the highest initial velocity of the tennis ball (45m/s). A factor of safety of 2 was used in the calculation. The motor specifications are shown in Table 2.

Table 2: Motor specifications calculated for launching system

Required Torque (mN·m)	52
Power (W)	31
Angular Velocity (RPM)	11300

Although, when buying bearings to support the shaft for the launching wheels, the viable option was to buy a 5800 maximum RPM bearing, since the one above it, 9500 maximum RPM, was too expensive for the budget.

Using no factor of safety, the angular velocity of the launching wheels to launch tennis balls at 45 m/s is 5640 RPM. To compensate the factor of safety, a motor was selected with a torque much greater than the required torque, and with a RPM close to 6000. Because of the high torque in the motor, it rotates somewhat close to no load RPM.

The no load RPM for the chosen motor was found to be 5310. The torque at stall was found to be 2425mN·m, approximately 50 times greater than the required torque using a factor of safety of 2. The current at stall and at no load was found to be 133.0 A and 2.7 A, respectively. More information can be found in Appendix E.1.1. The rest of the components can also be found in Appendix E.1.

Angular Targeting Mechanism

The horizontal angle range was specified to be between 40° and 140°, measured from a line parallel to the net on the tennis court and rotating counter clockwise. The widest horizontal angle range of similar products on the market was a total of 50°, with the range being from 65° to 115°. The wider horizontal angle range for MATT was needed because, unlike other tennis ball launching machines, MATT will move laterally on the court. It is because of this motion that MATT will need a much larger range of horizontal angles to provide a comparable set of shot angles from varying launch positions. The operating range of the machine was determined mainly based upon the horizontal angles required. The determined operating range can be seen in Fig. 18.

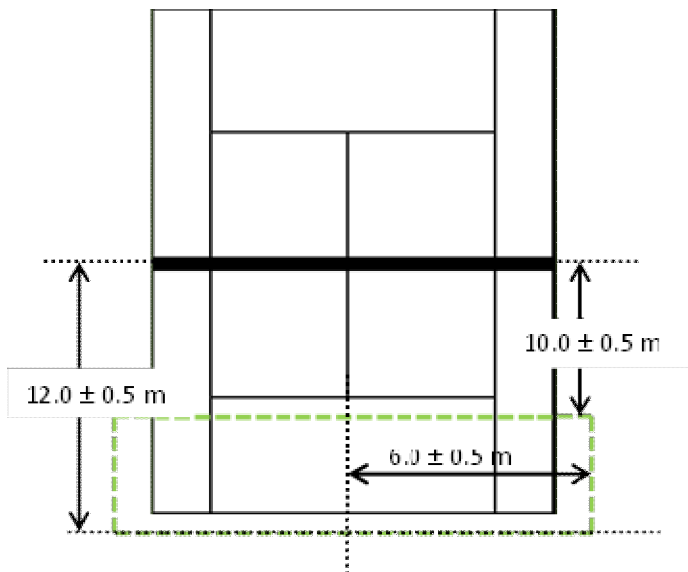


Figure 18: Operating range of MATT in regards to the tennis court

The widest range of horizontal angles required was calculated based on this operating range and the worst case scenario for shot placement. This worst case scenario would be when the machine was as close to the net as allowed, as far as possible from the center of the court and placing the shot on the opposite sideline directly behind the net. From this information, the maximum angle needed was calculated. Figure 19 shows the dimensions used to calculate the maximum angle of 50°.

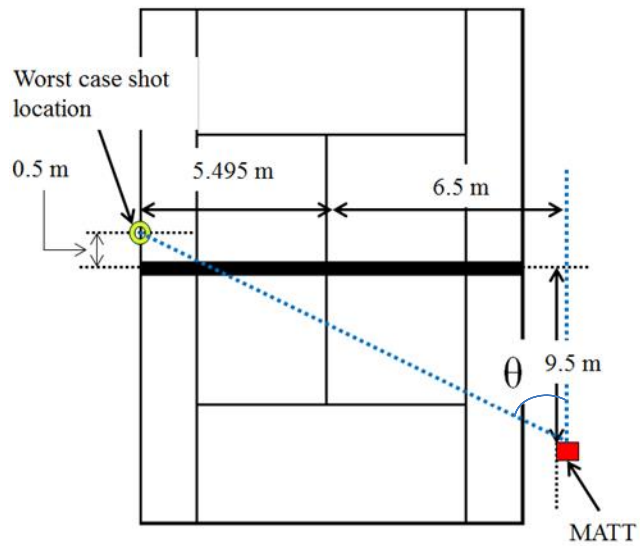


Figure 19: Dimensions for horizontal angle calculations

A few different design concepts have been considered to provide the mechanical horizontal angle adjustment. The main methods have consisted of some sort of lever system, or a rotating platform on which the launching system would rest. The lever system would be implemented with either pneumatic or hydraulic pistons or actuators, which would require a large expensive component such as an air compressor or a hydraulic pump. Due to the simplicity of the design, the rotating platform for the launching system was selected. A motor would rotate the platform through the required angular displacement. A rough diagram of this system design is shown in Fig. 20.

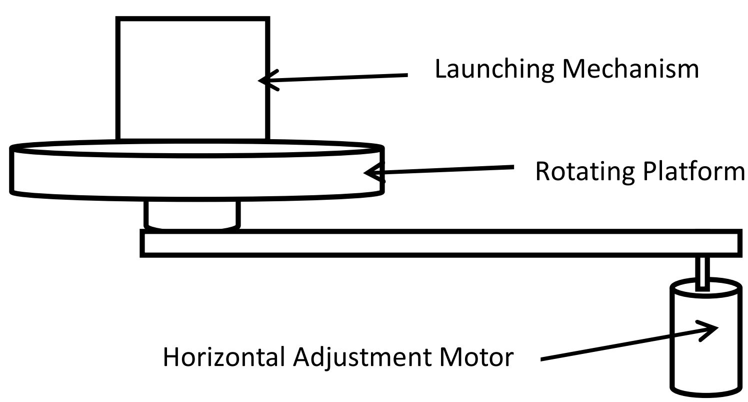


Figure 20: Horizontal angle adjustment design concept drawing

In order to determine the motor specifications for this mechanism the required speeds, accelerations, and torques of the system needed to be determined. Two different specifications affected the design here. The first was the requirement that the machine have a horizontal angular displacement totaling 100°. The second was the specification that MATT's horizontal angle adjustment be able to rotate through the widest range of angles in 3.0 ± 1.0 seconds. This means that MATT would be able to rotate through 100° in as few as 2 seconds, starting from a stopped position. To calculate the torque requirements, and therefore select a motor, the highest required angular acceleration needed to be calculated. To calculate an initial angular velocity Eqn. 9,

$$\square_{\square} = \frac{\square\square_{\square\square\square\square}}{\square_{\square\square\square}^{\square}} \qquad \text{Eqn. (9)}$$

was used, where

$\square_{\square}$ = [illegible]

$\square_{\square\square\square\square}$ = [illegible]

$\square_{\square\square\square}$ = [illegible]

The minimum required angular acceleration required was calculated to be 0.873 rad/s^2. However, if this acceleration were applied for the whole two seconds the angular targeting mechanism would speed past its desired angle. To account for this, the mechanism will need to apply an acceleration, and therefore a torque, and then apply an acceleration and stop the rotation at the desired angle, all in the given time requirements. Using only equations of motion for rotating bodies an estimated value for the required acceleration to slow and stop the machine as desired was recalculated to be approximately 2.1 rad/s^2.

The next step was to determine the mass moment of inertia of the launching mechanism that will be placed on top of the horizontal angle adjustment mechanism. It was estimated that at most the mass of the launching mechanism and all of its components would be no greater than 22.68 kg, or 50 lbs. It was also estimated that the entire apparatus would fit inside a 50.8 cm x 50.8 cm x 50.8 cm (20 in x 20 in x 20 in) box. With this information known, the mass moment of inertia was calculated as follows:

$$\square = \frac{\square}{\square}\square\,\square^{\square} \qquad \text{Eqn. (10)}$$

Equation 10 models the system as cylinder, where r is the radius of 0.254 m (10 in), and m is the mass of the load, or 22.68 kg. From Eqn. 10 the mass moment of inertia was calculated to be 0.732 kg·m^2. Then relating the angular acceleration needed for the mass moment of inertia using Eqn. 11 a torque value was calculated for the horizontal angular adjustment mechanism.

$$\square = \square \cdot \square \qquad \text{Eqn. (11)}$$

A torque value of approximately 1.5 N·m was calculated. This method of determining torque assumes no friction is present in the system. To ensure friction was accounted for, an additional factor of safety of 2 was assumed yielding a required 3.0 N·m. Equation 2 was then used to estimate the power requirements for this system, which was approximately 5.2 W.

From the torque and speed requirements a motor was selected a motor was selected that could provide the required torque and speed without any additional gearing components. The selected motor can be seen in Appendix E.2.1. The actual design of the angular targeting mechanism will consist of a turntable bearing upon which the launching system will rest. Through the middle of the bearing a shaft will connect the bottom plate of the launching mechanism directly to the motor. The shaft, as well as a mounting bracket, will be constructed from steel at the time of final fabrication.

Vertical Targeting Mechanism

The vertical targeting mechanism consists of two platforms, a hinge, and an electric car scissor jack. A concept design is shown in Fig. 21. The launching mechanism is fixed to the top platform. The platforms are hinged together so the electric car scissor jack can lift up the top platform. The vertical aiming is then controlled by adjusting the height of the scissor jack. This scissor jack design was chosen because of its simplicity and low cost compared to other possible designs.

The platforms are hinged together at the location shown in Fig. 21 so the wheels are closer to where the tennis balls leave the machine. Because of that, the space in the machine where tennis balls leave is smaller for safety purposes.

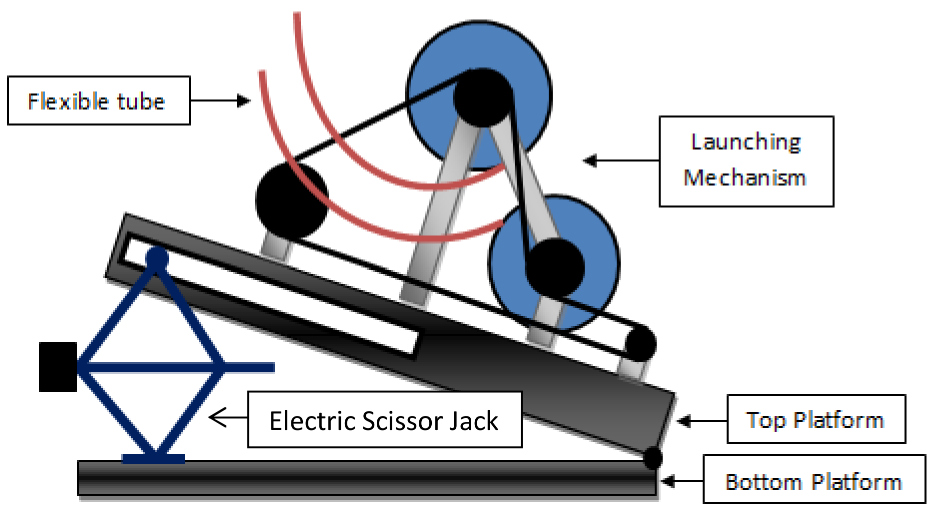


Figure 21: Vertical targeting mechanism concept design drawing

At first, a custom scissor jack was designed and analyzed in SolidWorks. The purpose for this design was to build, using the 3D-printer, a smaller and lighter scissor jack compared to car scissor jacks. This design is shown in Fig. 22.

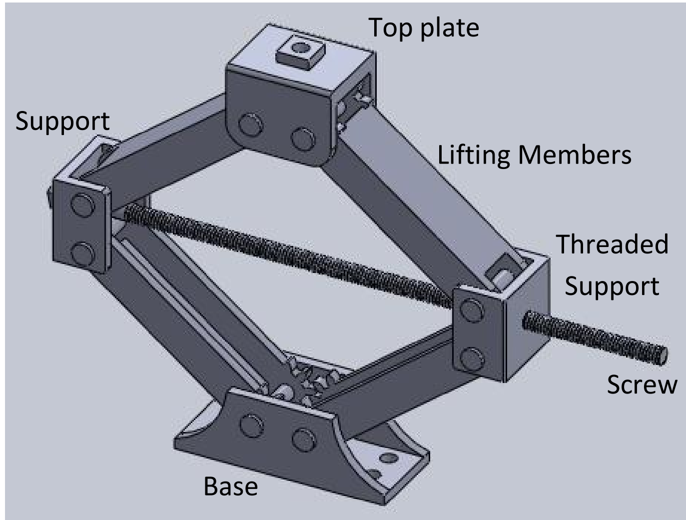


Figure 22: Custom scissor jack design in SolidWorks

The custom scissor jack had a threaded support with an additional sleeve section for reinforcement purposes, as seen in Fig. 23. Figure 24 shows the teeth on the lifting members. The teeth prevent the scissor jack from moving sideways.

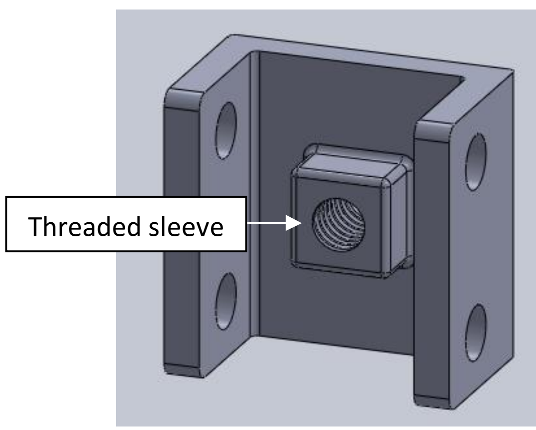


Figure 23: Threaded support with additional sleeve

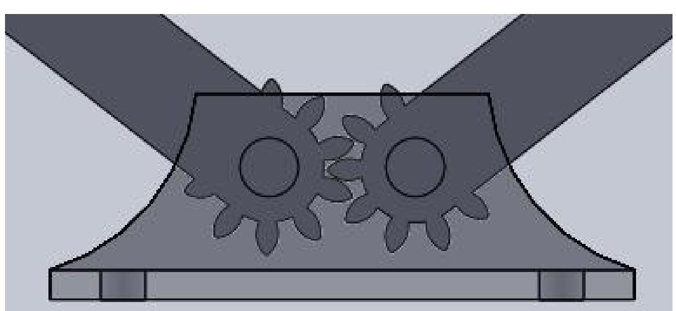


Figure 24: Teeth on lifting members to prevent side motion

Simulations were performed in SolidWorks, which showed that the design was strong enough for its purposes. Although, its volume was approximately 30 cubic inches, meaning it would cost approximately 150 dollars to have it printed. A more viable option was then found: an electric car scissor jack, shown in Fig. 25, which is nearly three times less expensive.

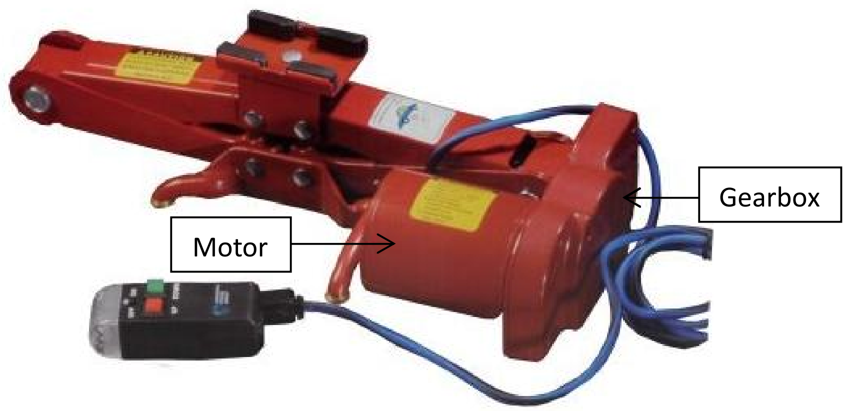


Figure 25: Electric car scissor jack

The electric car scissor jack is composed of a motor and a gearbox connected to a regular car scissor jack. Because the electric car scissor jack can support a maximum load of 2200 lbs, no stress/strength calculations were performed. More information can be found in Appendix E. 3.1. No information was found on how fast the scissor jack can go up or down, besides watching videos of similar product on the internet. Although, if the electric car scissor jack shows to be not fast enough to meet our specifications, the gear ratio in the gearbox can be easily changed so our specifications can be met.

The frame of the vertical targeting mechanism is composed of aluminum plates for the platforms, and a hinge. More information can be found in Appendix E.3.2. A SolidWorks representation of the launching mechanism and targeting system is shown in Fig. 26.

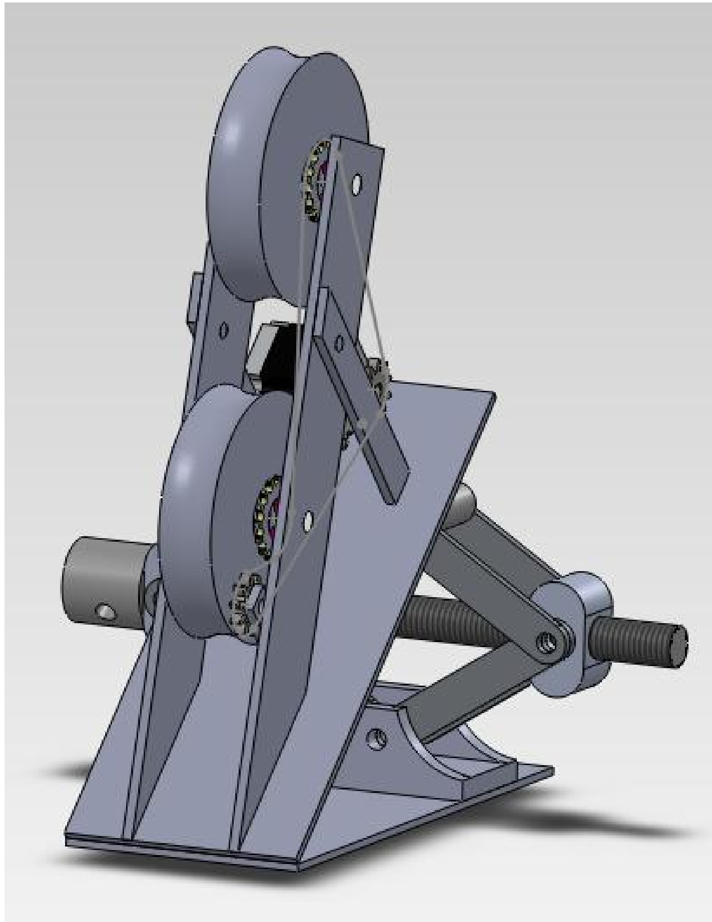


Figure 26: SolidWorks representation of launching mechanism and targeting system

Hopper and Feeder System

The hopper and feeder system consists of all of the components that deal with transporting the tennis balls from the hopper to the launching mechanism in a controlled and efficient manner. The design of this system can be broken up into smaller components. First is the hopper container itself. The only design constraint on this part is that it must be able to hold at least 150 tennis balls, and do so in a way that does not allow for spillage of the tennis balls while MATT is in operation. The next component consists of the hopper rotor mechanism. The rotor mechanism is what controls the feeding of the tennis balls for the hopper to the feed tube. The rotor will rotate at a rate specified by the microprocessor feeding the balls one at a time into the feed tube. The only constraints for the rotor is that it must be able to feed tennis balls at a rate of at most one tennis ball per two seconds and at least a minimum rate of one tennis ball per ten seconds. Obviously the rotor must be able to withstand the load of many tennis balls on top of it as it spins, as well as operating consistently without jamming. Lastly, the feed tube will transport the tennis from the rotor to the actual launching mechanism. The ball will move through the tube and into the launching wheels only under the influence of gravity.

Rotor

The first component designed from this subsystem was the rotor. The general shape and function of the rotor was borrowed from the Prince tennis ball machine that was donated to the design team. The part was designed specifically with the use of the 3-D printer for manufacturing in mind. To do this it had to be ensured that the part was no greater than 20.32 cm (8 in) wide. The rotor was designed under this constraint, yielding a four tennis ball holding rotor. To verify that the part could be manufactured in the 3-D printer finite element methods were used to test the part of failure under loading. The hopper rotor dimensions can be seen in Fig. 27. The mass of the 250 tennis balls was applied as a force of 145.7 N on top of the rotor to provide a greater load than the required minimum of 150 tennis balls. An initial value of 10 N·m for torque was applied to the rotor. Intuitively, such a torque is extremely high for the operating conditions but in order to determine if the part would fail under any circumstances this higher value was used as a baseline. The loads were applied and the results can be seen in Fig. 28. The same model used to estimate the torque requirements in the horizontal targeting mechanism was used to provide a more realistic estimate of the torque required for the rotor to operate properly. The torque calculated was 0.029 N·m. A factor of safety of 10 was used, yielding a torque of 0.29 N·m.

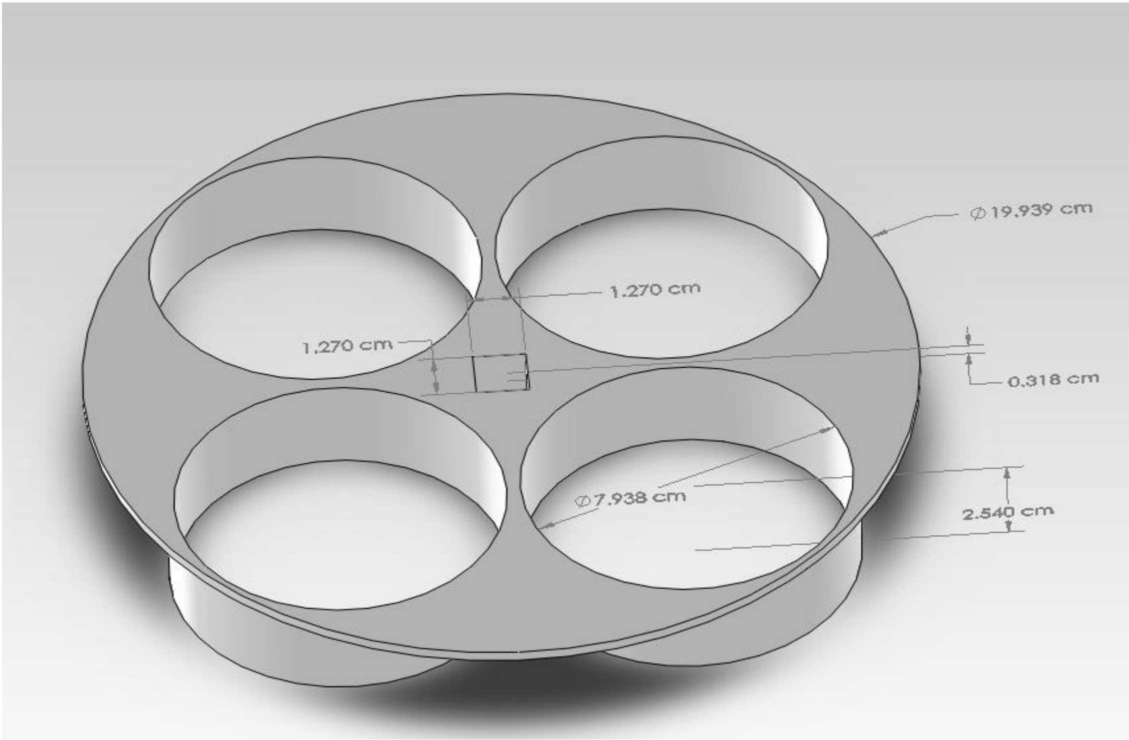


Figure 27: Hopper rotor dimensions

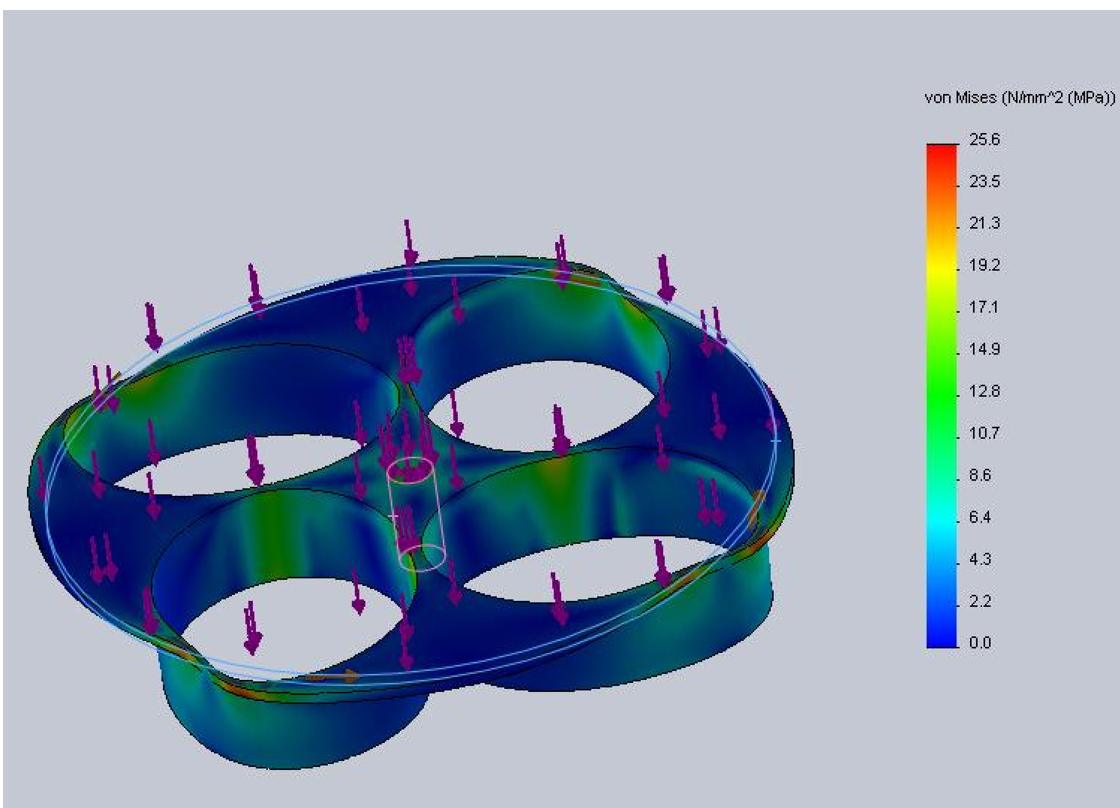


Figure 28: Finite element analysis of hopper rotor under extreme operating conditions

The material used in this simulation was the same material as the 3-D printer uses, ABS plastic. This material has a yield strength of 33 MPa. When compared to the results of the finite element analysis shown in Fig. 28, it can be seen that the maximum stress under this loading is well below the yield strength. Therefore, this design will be used for the hopper rotor part, with minor modifications to allow for the assembly of motor and gearing components.

The next step in the design of this subsystem was to determine the required power requirements for this system. Based on the specifications for minimum and maximum tennis ball feed rate the required angular velocity of the rotor was calculated. For the maximum feed rate the rotor will need to rotate at 7.5 rpm and for the minimum feed rate the rotor will need to rotate at only 1.5 rpm. Based on the previously estimated torque value of 0.29 N·m and the maximum angular velocity 0.785 rad/s (7.5 rpm), a power requirement of 0.23 W was calculated. Adding an additional factor of safety, the design team specified that a power requirement of 1.5 W would be used for selection of drive components.

The only required component from this system that will need to be purchased is the motor. With both low torque and low speed requirements an inexpensive motor has been selected to power the rotor. The motor that was selected is shown in Appendix E.4.1. The rest of the drive components for the rotor system have been constructed and analyzed on SolidWorks, and will be printed in the 3-D printer where applicable.

Based on the selected motor, which could provide a maximum torque of 0.24 N·m, a 3:1 gearing ratio was designed. The minimum pinion size of 15 teeth was chosen and designed to fit directly on the shaft of the selected motor. To achieve the desired gear ratio, a 45 tooth gear was designed as well. Both gears can be seen in Fig. 29.

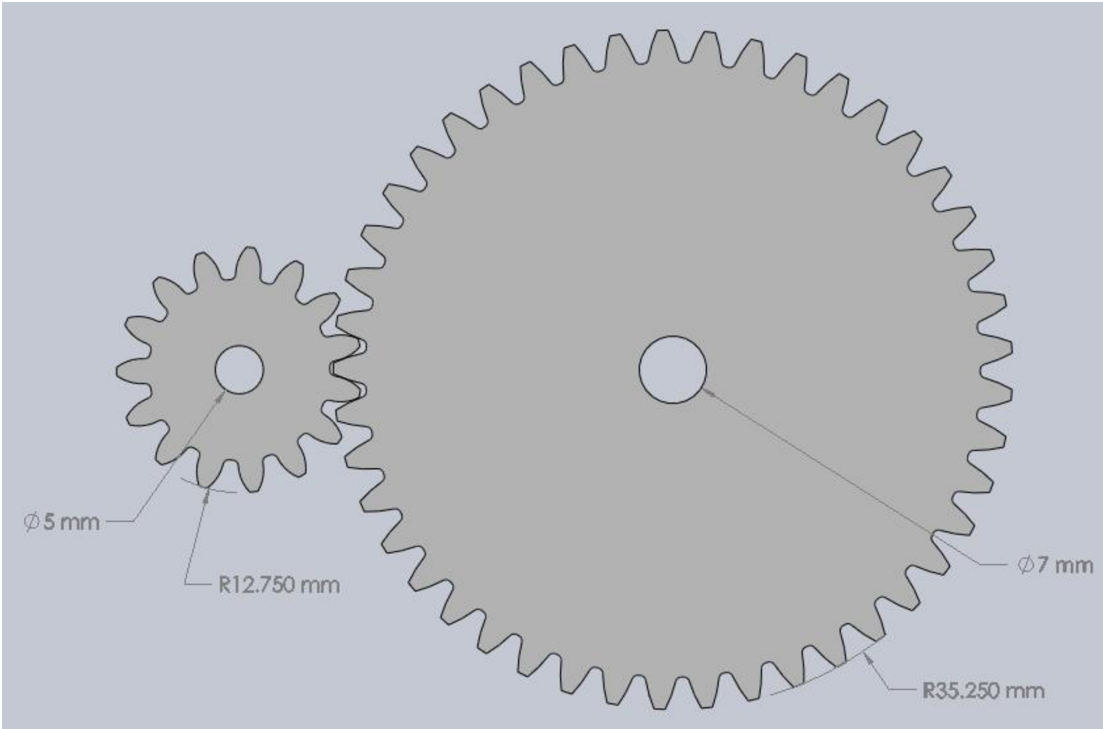


Figure 29: Hopper rotor pinion (left) and gear (right) - Both gears are 15 mm thick

Finite element analysis was performed on each gear to verify they would be able to withstand the loads under normal operating conditions. The results for the gear analysis indicated that under the normal operating conditions, with torques below 1 N·m, neither gear would fail.

The next component designed was the rotor shaft, which is shown in Fig. 30 with dimensions labeled.

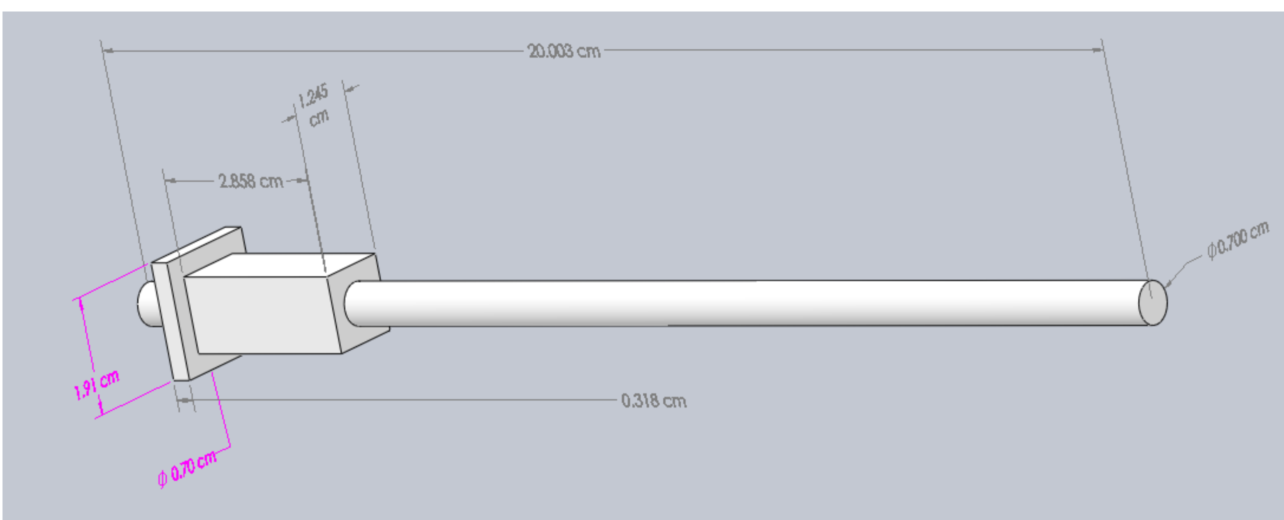


Figure 30: Rotor shaft dimensions

The rotor shaft was simulated to determine what loads it would be able to understand. A torque of 2 N·m was applied and finite element analysis was performed. The results are shown in Fig. 31. Based on these results it was determined that the shaft would suffice for normal operating conditions, and in the event of a jam, the shaft would fail long before the rotor itself. This is desired since the construction of the shaft would require much less material.

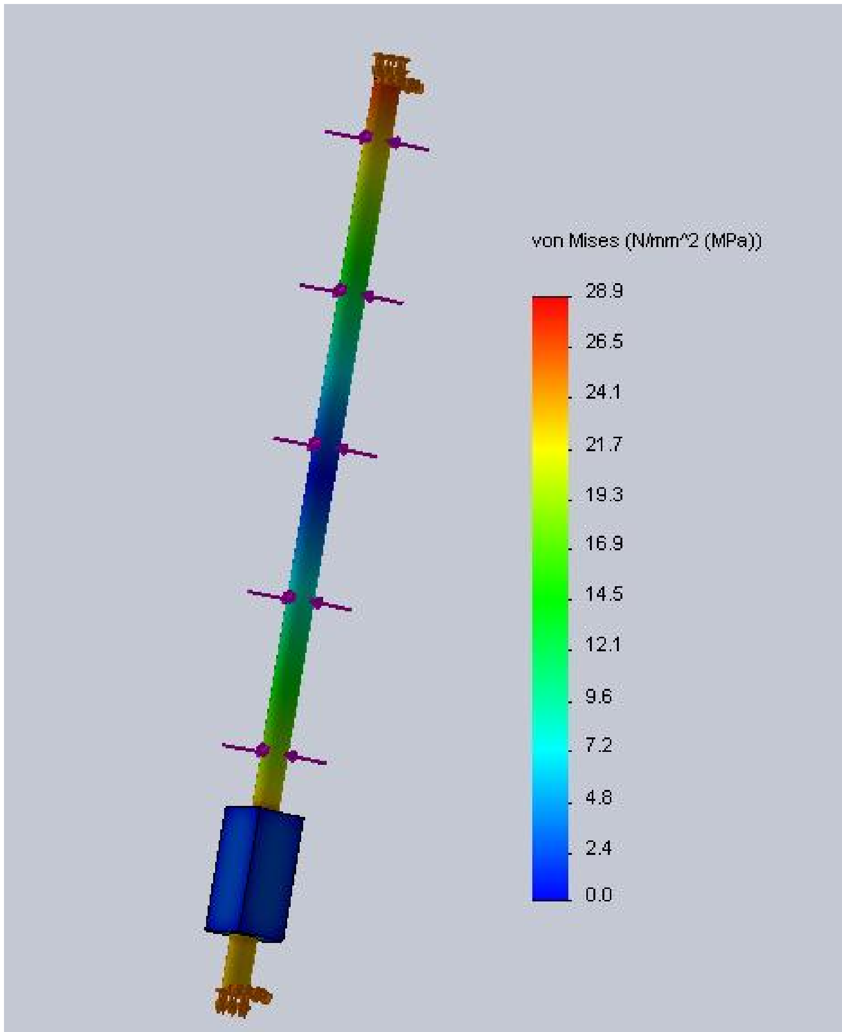


Figure 31: FEA for rotor shaft

Hopper

The next design of the overall hopper and feeder system was the hopper storage container. The only requirement here was that it be able to hold the required number of 150 tennis balls when fully loaded. The hopper will also need to be able to maintain the feed of tennis balls to the rotor as long as some still remained. Therefore, the hopper was designed to meet the minimum volume requirements as well as removing the possibility of tennis balls not automatically moving to the rotor. Figure 33 shows the hopper design from an angled view of ease of viewing mechanical components. Figure 32 shows the top view of the hopper design. The dimensions of the hopper are shown in both figures. This design is approximately 50% greater the size of the minimum required volume to store 150 tennis balls.

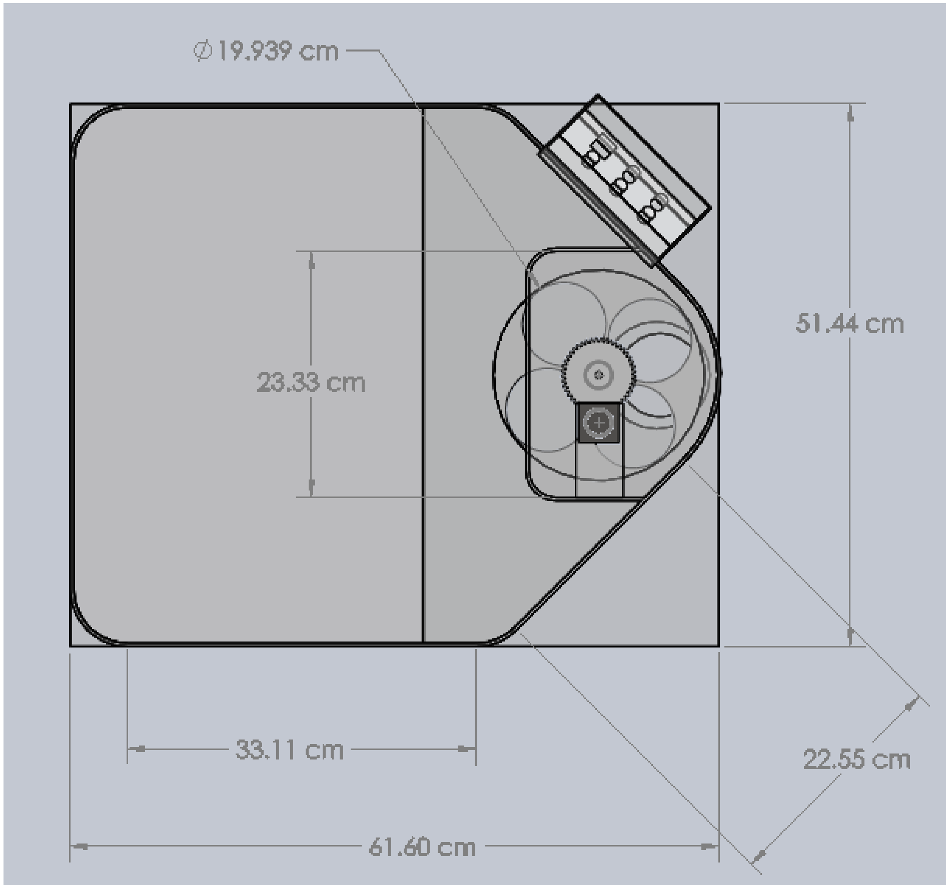


Figure 32: Hopper top view

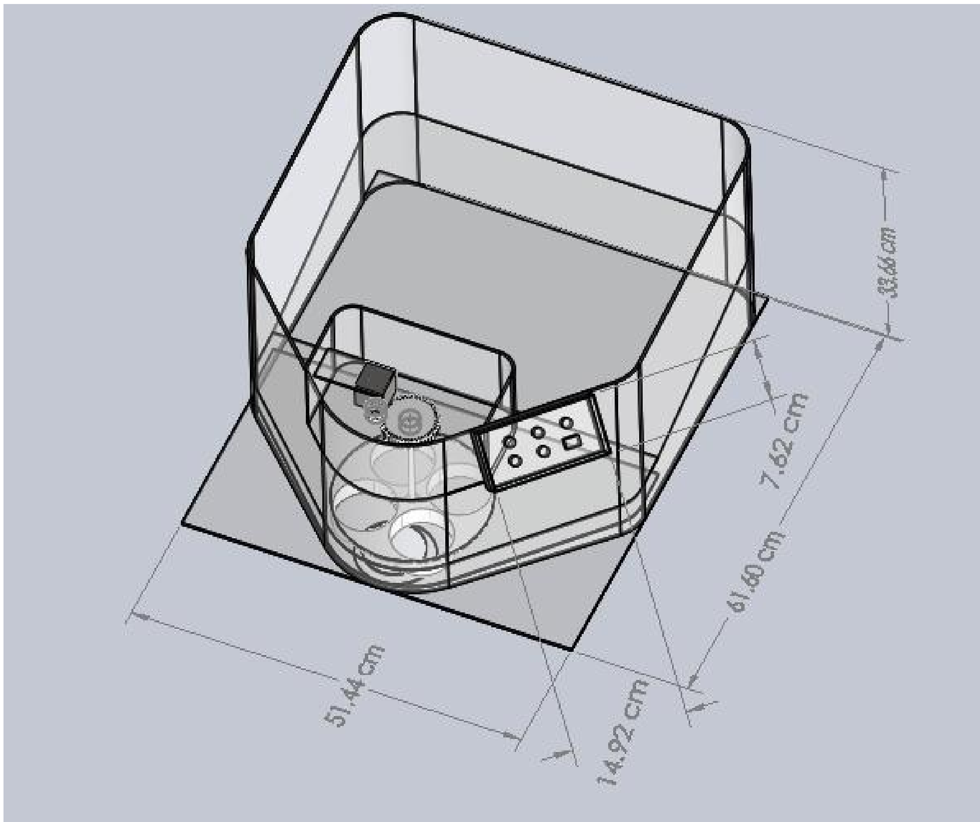


Figure 33: Hopper design showing location of rotor

The hopper will be constructed out of a material that is able to withstand tennis ball strikes. There is no need for any excessively strong material however because the hopper will not be bearing much load. Therefore, the hopper will be constructed out of welded wire mesh, which can be seen in Appendix E.4.2. The wire mesh will be bent to the desired shape and then supported with aluminum angle iron structural members where needed. The wire mesh may also be used to cover other portions of the frame of MATT where necessary.

Feed Tube

The feed tube will be the means of transporting the tennis balls from the hopper rotor, to the launching mechanism. The ball will rotate through the hopper rotor, fall into the feed tube, and then move to the launching mechanism, only under the influence of gravity. The feed tube will be constructed out of flexible plastic tubing. The tubing will be connected to the back of the launching system and will move with the launching wheels as they rotate through the total range of horizontal angles. Therefore the tube must be able to flex from side to side without causing extra loading upon the horizontal targeting mechanism. The flexible tube will be made from a semi-rigid aluminum vent, which will have enough structure for smooth rolling of the tennis ball, but will have enough flexibility to connect to the launching mechanism and provide for the entire range of motion. The materials selected for this application are shown in Appendix E.4.3.

Power Source System

The power supply is one of the most important components to this machine. It will consist of one (12 VDC, 70 Ah) lead acid battery. This battery can continuously supply 42 A for one hour. In addition to this, the battery has a maximum discharge current of 520 A for a period of 5 seconds, which could be used when needed. Because there are many subsystems on the machine that need different amounts of power, the battery power will be reduced to the correct voltage and current needed by each of these subsystems. There will be a low voltage indicator to indicate if the voltage drops at or below 11.5 VDC as illustrated in Figure 34. There will also be a master power switch that will turn the machine on or off, which will be independent of the remote. The battery unit needs a charger, but there will not be a supplied charger. The user has to supply a personal charger. Figure 35 does not show systems that will be directly attached to the battery, which are mainly all the motor controllers.

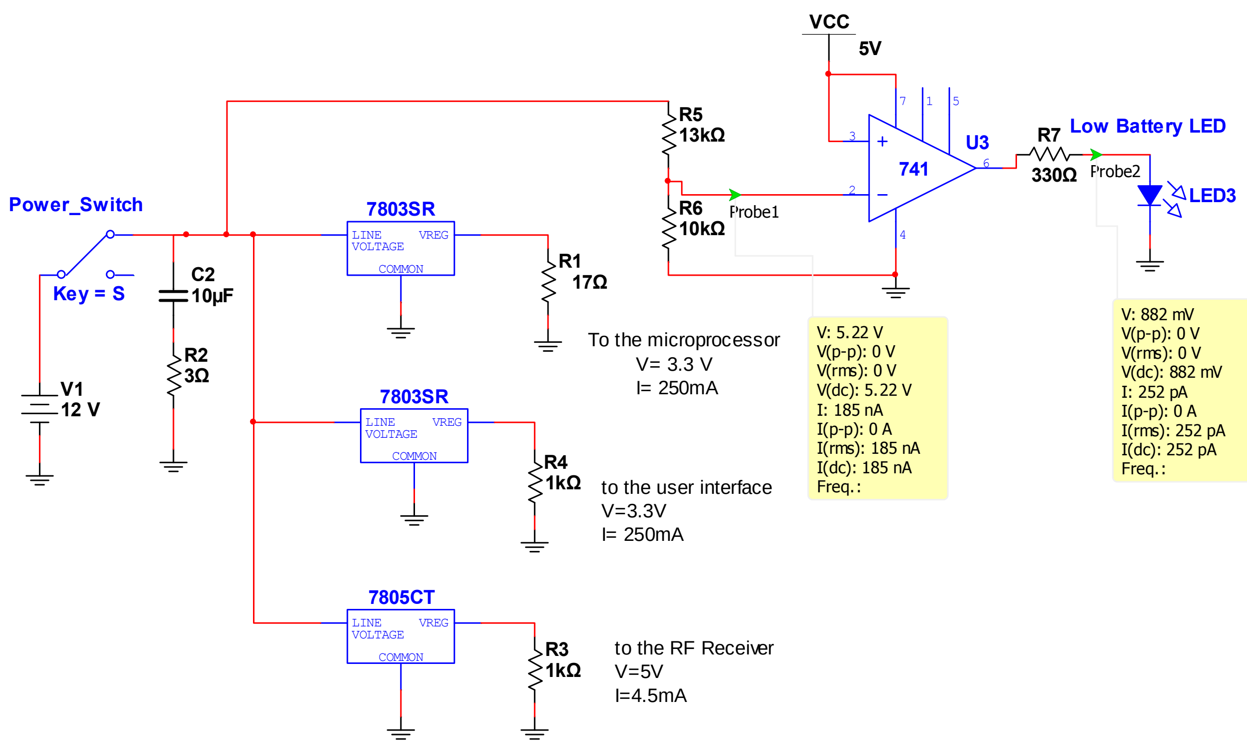


Figure 34: Power supply circuit

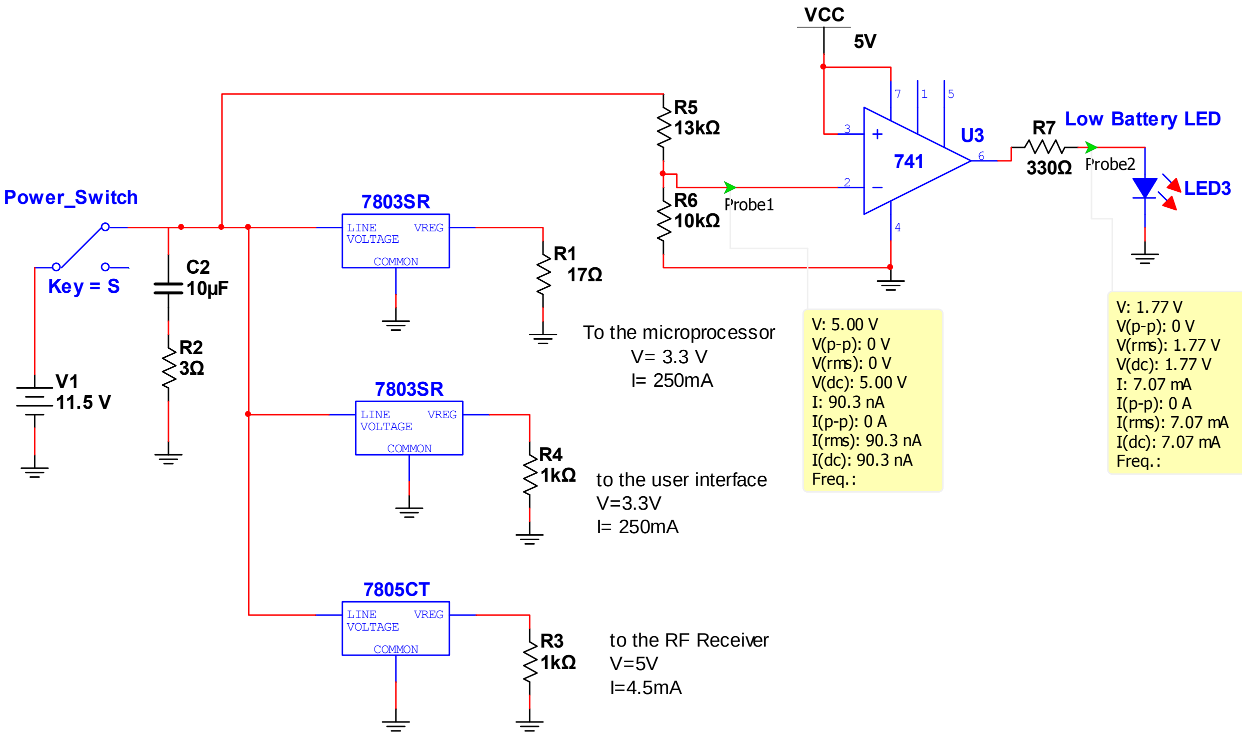


Figure 35: Low Battery Indicator

The mechanical power needed by the major systems on the machine has been calculated, and the power efficiency of the motors was estimated at 70%. The maximum electrical power was determined by dividing the mechanical power by a factor of 0.7.

1. Mobility System: 210 W /0.7= 300 W
2. Launching System: 40 W /0.7= 57 W
3. Vertical Targeting: ≈ 20 W/ 0.7= 30 W
4. Horizontal Targeting: 5.2 W/0.7=8 W
5. Hopper System: 1.5 W/0.7=3 W
6. Other miscellaneous systems (microprocessor, user interface, motor controller, sensors, etc.) were estimated to be approximately 45 W.

The total power required for this machine is then P_{total} = 443 W. Given that power, the total current required is 37 A. We can get the current value from the equation $I = \frac{P}{V}$. That is, $I = \frac{443W}{12V} = 37\ A$.

Based on this information, we will use only one battery for the entire machine. A (12V, 70Ah) lead acid battery can supply the necessary power by providing 12 V and 42 A for one hour. The maximum discharge current is 520 A for a period of 5 seconds. The current from this battery is a little higher than what the machine needs, and it weighs less than 23.0kg. More information about this battery can be found in Appendix D.1.

Interface and Control System

Most of the cheaper machines available on the open market have manually controlled targeting. This means that the user has to set the speeds and angles on their own. Sometimes even running the machine multiple times till he/she gets the settings right. However, these are also stationary machines, adding the complexity of a moving machine base requires real time adjustments to speed, horizontal angle, and vertical angle. To accomplish this we have chosen to include an electronically controlled targeting system with an onboard logic and control system. This system will also handle controlling the movement of the machine itself, and interpreting/implementing the user's instructions. We have decided to implement this in the following subsystems:

1. User Interface Board
2. Remote control
3. Sensors Systems
4. Motor Controllers
5. Microprocessor Programming

User Interface Board

In order to meet the requirement of matching the machine to the user's skill level we have chosen to give the user individual control of the following factors: Launching Distribution, Launching Rate, and Launching Speed or Vertical Angle. Figure 36 is a LabVIEW simulation of the User interface. The Physical Appearance is what the user will actually see, with the labeling made clearer. The Electrical Signal section is the electronic value of the dials. The Digital Dials is what these values will be interpreted as in the microprocessor. Figure 37 shows the circuit representation of the user interface board.

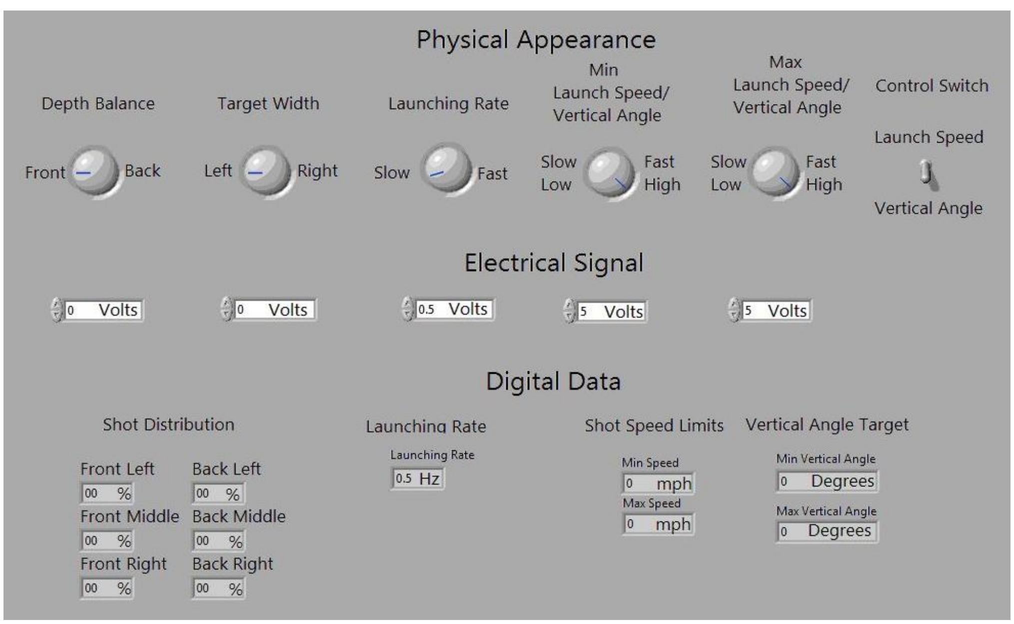


Figure 36: LabVIEW layout of user interface system

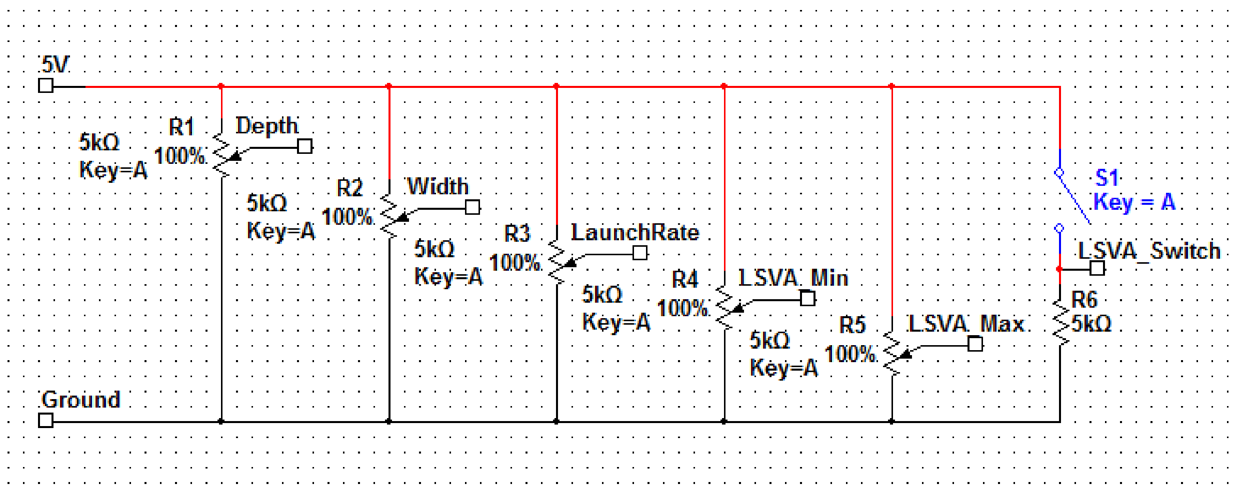


Figure 37: MultiSIM diagram of UI Board

Launching Distribution

The launching distribution describes the variety of the targetable locations. This field is controlled by the first two dials from the left in Fig. 36. To the user, the controls will be similar to the balance dials on a car stereo. Turn the depth dial left and the balls land closer to the net, turn it right and they land further from the net. Turning the width dial left, and the machine will tend to launch towards the machine's left (the player's right) more, while turning it right the machine will tend to launch towards the machine's right (the player's left) more. However, instead of an entire court of targetable positions, we have decided to split the court into six fields and specifically target an arbitrary point within each field. Figure 38 shows the fields that we have decided to split the court into. The points will be near the back middle of each field so that drag will pull the balls forward within the field. Landing point variance will be present due to air resistance and physical limitation of the machine.

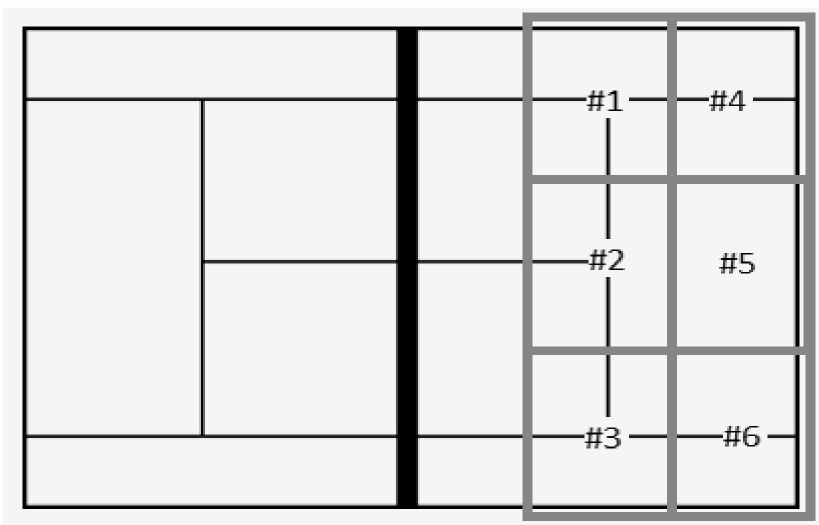


Figure 38: Tennis court with target field partitioned

The dials will be turning potentiometers that will vary the input being fed to the microprocessor from 0V to 5V (see circuit board subsection for more details on how this will be done). These voltages will be interpreted by the microprocessor using built in logic to follow the patterns set out in Fig. 39.

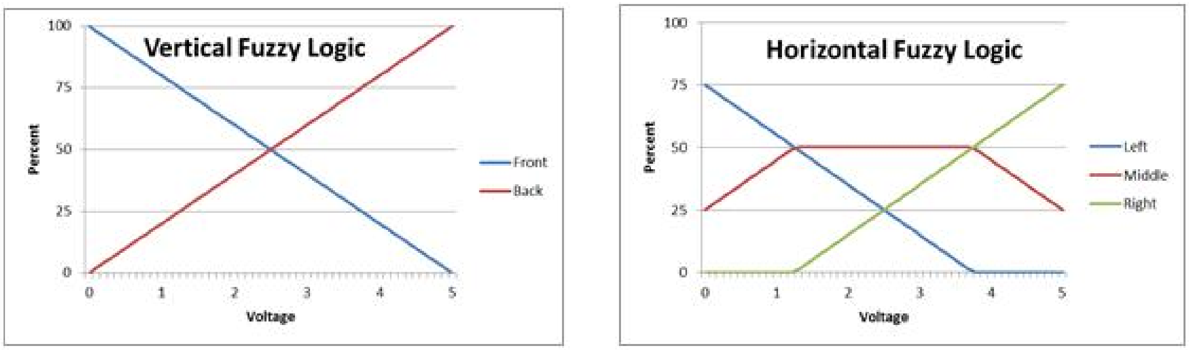


Figure 39: Fuzzy Logic Graph for Balance Dials

Both charts' X axis is the voltage received from the dial, and their Y axis is the percentage assigned to each respective block. The left chart handles the depth dial, splitting the six fields into two blocks: the front (#1, 2, and 3 from Fig. 38) and the "back" (#4, 5, and 6 from Fig. 38). The right chart handles the width dial, splitting the six fields into three blocks: the left (#1 and 4 in Fig. 38), the middle (# 2 and 5 in Fig. 38), and the right (# 3 and 6 in Fig. 38). To get the percentage for each field the percentage for the two blocks that that field falls into will be multiplied together. For example, the front percentage and the left percentage will be multiplied together to get Field # 1's overall percentage.

Launching Rate

The user has control of how frequently the balls are launched. Turning the dial to the left means the shots come less frequently, while turning right makes them come more frequently. This is a simple analog to digital converter, with the values of 0 V to 3.3 V representing 0.1 to 0.5 Hz.

Launching Speed or Vertical Angle

Since our machine calculates the trajectory necessary to hit a selected target. This means that the vertical angle and launching speed are directly related. Therefore, a user needs to only have control over one of the two factors. However, some users may wish to control speed while others wish to have control of vertical angle. In order to do this we have chosen to have a minimum and maximum dial and switch to decide if they control speed or vertical angle.

The switch will tell the microprocessor if it should interpret the analog signals on a range of 0-40° and 10-50° for minimum and maximum vertical angle, or if it should be interpreted as 10-90mph and 20-100 mph for the minimum and maximum launch speed. If the minimum is set to higher than the maximum the microprocessor will assume the lowest possible value for the minimum.

Remote Control

The radio frequency remote control will operate at 315 MHz using ASK modulation. The remote control transmitter schematic can be seen in Fig. 40. The address byte will be set with a dip switch inside the transmitter enclosure that must correspond with the address byte set by the dip switch on the receiver. The remote control receiver schematic can be seen in Fig. 41. The address byte ensures that up to 2^8 = 256 MATT machines can operate within the same local area. However, no more than one remote control can be sending data at the same time or else the transmitted signals may combine with one another to produce an invalid message that the receiver will ignore.

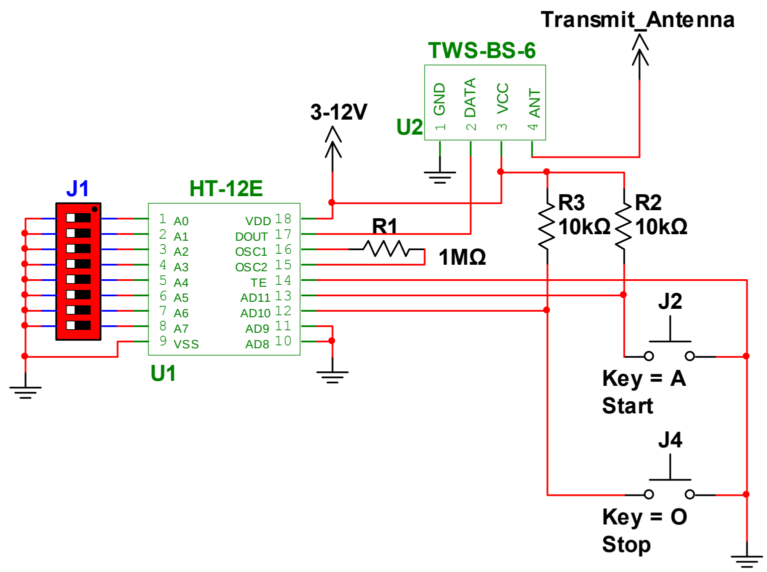


Figure 40: Remote control transmitter

The encoder and decoder are specifically mentioned in the transmitter and receiver datasheets as an example application. The mentioned datasheets can be found in Appendix RF2. Based on this information it is reasonable to conclude that the given devices will function properly in a configuration similar to the supplied example circuits.

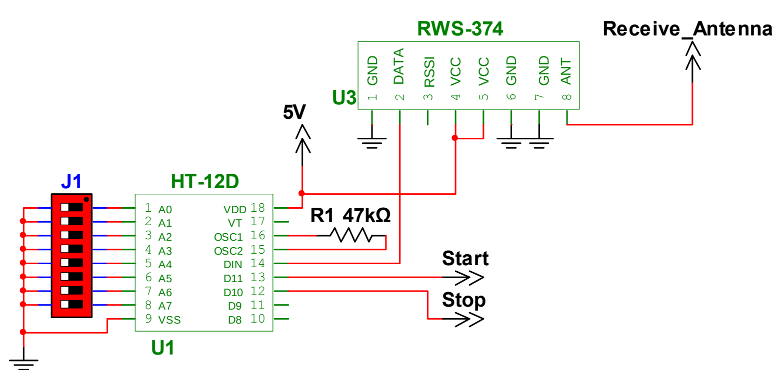


Figure 41: Remote control receiver

The remote control transmitter will have a start and a stop button. For future designs the remote control could easily support two more buttons without modifying the current design. However, the maximum number of buttons could be expanded up to $2^4 = 16$ if deemed necessary. The FCC regulations for this type of operation can be found in section 15.231 of FCC rules and regulations and can be seen in Appendix RF1. This section states that the remote control must be a periodic signal instead of a continuous signal in order to be approved for use.

The remote control will be housed in an enclosure as seen in Fig. 42. The enclosure has two buttons that will have momentary tactile switches mounted on a printed circuit board below them. The printed circuit board will also have the encoder and RF transmitter components mounted on it. The remote control will be powered with one to four CR2032 3V lithium coin cell batteries. The number of batteries required will be increased in order to achieve the desired range of at least 30 meters.

Figure 42: Remote control enclosure

Sensor Systems

Court Positioning Sensors

MATT will be able to estimate its position on the court by monitoring the baseline of the tennis court and intersecting sidelines with respect to its own position as it travels laterally along the baseline of the tennis court. The Rules of Tennis 2011 state that “all lines of the court shall be of the same color clearly contrasting with the color of the surface”. An infrared reflectivity sensor was selected in order to be able to differentiate the lines of the court from the surface based on this information. The sensor that will be used is Vishay Semiconductors’ TCRT5000L. The appropriate datasheets for this sensor can be found in Appendix H. The reflectivity sensor is composed of an infrared emitter and phototransistor that has a filter to block visible light. The test circuit seen in Fig. 43 was used to test the sensor on the Harding University tennis courts. The measured voltage will decrease as reflectivity increases.

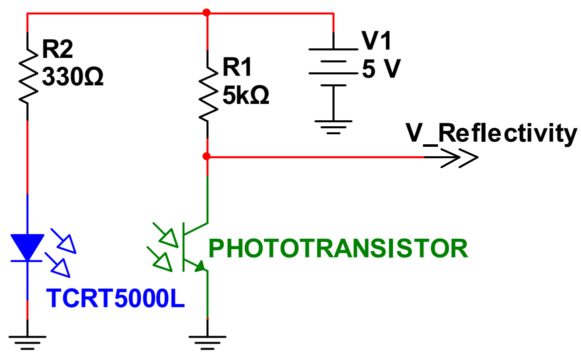


Figure 43: Reflectivity sensor circuit

Harding University's tennis courts are dark green inside the boundaries of the court and light green outside of the boundaries. The lines on the tennis court are white. Four measurements were taken of each color of the tennis court. The test sensor was placed approximately half an inch above the surface of the tennis court in a box that blocked most of the ambient light. The results of the reflectivity sensor testing can be seen in Table 3. From this data it can be observed that there is a distinct contrast between the different surfaces of the court. Not all tennis courts are the same and there will be two conditions that will limit the functionality of the sensors. First, the lines of some tennis courts may be deteriorated to a point where reliable measurements are not available. Second, the surface of the court and the lines of the court have similar infrared reflectivity values. In these circumstances the court will either need to be repainted or have a highly reflective tape placed over the lines where MATT will be operating.

Table 2: Reflectivity sensor measurements

	Dark Green	White	Light Green
Measurement 1	4.38 V	2.16 V	3.66 V
Measurement 2	4.38 V	2.10 V	3.73 V
Measurement 3	4.39 V	2.10 V	3.48 V
Measurement 4	4.36 V	2.03 V	3.46 V

The overall ball launching accuracy of MATT will be affected by its ability to stay parallel to the net. In order to achieve this accuracy multiple reflectivity sensors will be positioned in a pre-determined arrangement. The base of MATT will have fifteen total sensors. They will be positioned as can be seen in Fig. 44. The sensors will be placed one inch apart from one another along either side of MATT. The distance was experimentally chosen as the minimum distance without a significant amount of cross-contamination. The control system will use the values of the sensors to actively have the mobility system adjusting its movement in order to ensure that the baseline stays within the middle most sensors. The sensor positioned in the center of the two rows of sensors will be used as a target point for where MATT should decelerate to when the double's sideline is sensed.

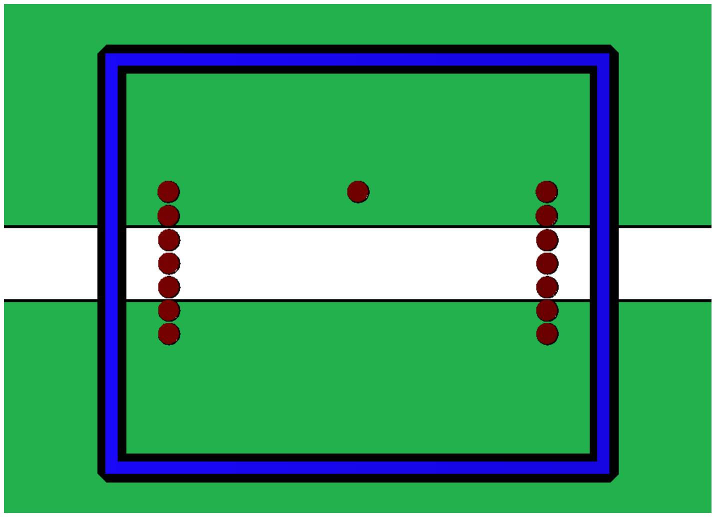


Figure 44: Reflectivity sensor configuration

Matt will require an encoder to be attached to each of the mobility motors in order to have an accurate position at any given time. The encoders will be manufactured using the Engineering Department's 3D printer. The encoders will be designed to attach to the shaft of the gearbox directly linking the mobility motors to the mobility wheels. A two dimensional version of the encoder design can be seen in Fig. 45 where the black represents printed material. An appropriate value for the resolution of the encoder wheel can be found with the use of a few calculations. Based on the information from the mobility system the circumference of the mobility wheel is 25.4 cm (10 in) and the maximum rotational speed will be 65.2 RPM. The necessary resolution of the encoder is then the circumference of the wheel divided by the desired accuracy. We will assume that the necessary accuracy is 0.2 in this yields the following result $Resolution = \frac{10\ in}{0.2\ in} = 50\ CPR$ (CPR = Counts per Revolution). The standard length of the tennis court is 10.97 m (432 in). So, using this information the total length of the court according to the encoder will be $\frac{432\ in}{0.2\ in} = 2160\ counts$. The microprocessor will then record a maximum of $\frac{50\ CPR \times 65.2\ RPM}{60\ s} = 54.33\ counts\ per\ second$. The sensor that will be used to read the encoder wheel will be Vishay Semiconductors' TCST1103. Additional information about the sensor can be found in Appendix H.

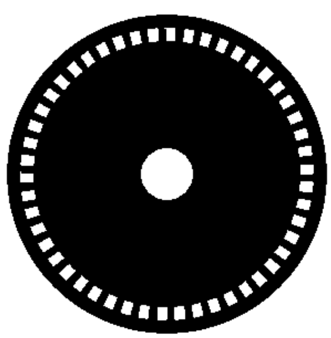


Figure 45: Mobility motor encoder wheel

Launching Sensors

The top launching wheel will have an encoder attached to it from which the microprocessor will be able to measure the rotational speed of the wheels. This will allow the microprocessor to know how to adjust the speed of the motor to achieve a desired ball exit velocity. The launching system will also have a sensor to indicate when a ball has successfully been launched. This will be incorporated in the form of a photo interrupt circuit consisting of an infrared emitter and an infrared detector. The ball exit sensor replaces the need for a feeder sensor as it supplies the rate at which balls are exiting the machine which is approximately equal to the rate at which the ball is being supplied by the feeder. If the ball exit sensor does not register a ball exit at the appropriate time then MATT will assume the hopper is empty.

The encoder wheel for the launching system will be manufactured using the Engineering Department's 3D printer. The encoder will be used with Vishay Semiconductors' TCST1103 photo-gate sensor. The two-dimensional encoder design can be seen in Fig. 46. A resolution of one count per revolution was chosen due to the high rotational speed of the launching wheel.

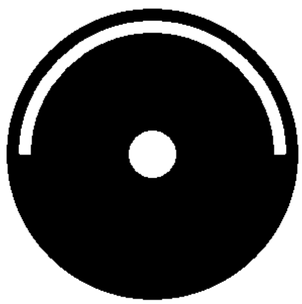


Figure 46: Launching encoder wheel

The microprocessor must accurately know where MATT's vertical and horizontal targeting systems are located. Both targeting systems have a limited range of movement so a potentiometer can be used on the pivot points of each system. The potentiometer for the vertical targeting system will be attached to the hinge of the adjustment platform. The potentiometer for the horizontal targeting system will be attached to the horizontal targeting motor.

Motor Controllers

Mobility Motor Controller

The mobility system requires the use of relatively high current motors. In order to provide variable speed for the motors at a reasonable cost the motor controllers have been designed specifically for the mobility system. The mobility system will require 150 W of electrical power for each of the two motors. The motor will be supplied with 12 VDC so the maximum continuous current that will need to be supplied to each motor is $\frac{150\ W}{12\ V}$ = 12.5 A.

To fulfill these requirements a commonly used motor controller configuration known as an H-Bridge configuration will be used for each motor. The high-level view of the motor controller can be seen in Fig. 47. The device will accept pulse width modulation, henceforth referred to as PWM, as a way to vary the power being supplied to the device. The input PWM_F will be a PWM signal from the microprocessor to control the power supplied to front motor in relation to the net of the court, while the input PWM_B will control the power supplied to back motor. The logic input from the microprocessor to the motor controller can be seen in Table 4. This enables the microprocessor to use only four pins for the entire motor controller. The schematic for this logic can be seen in Fig. 48.

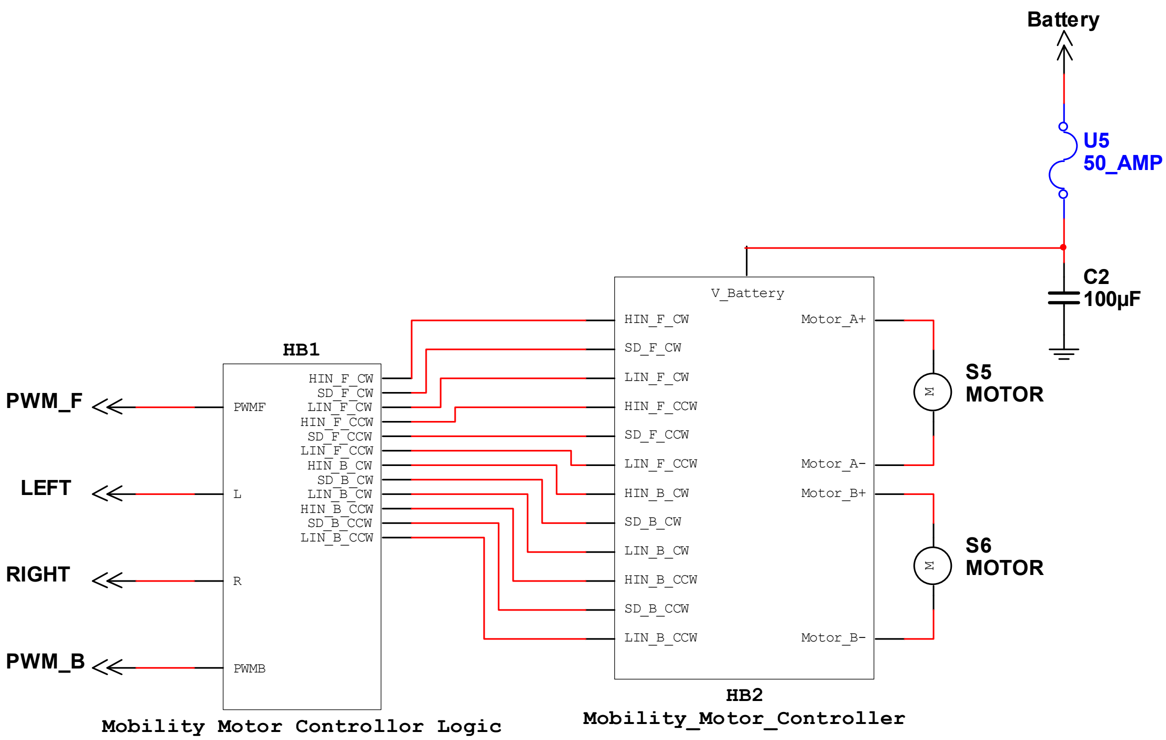


Figure 47: Mobility motor controller

Table 3: Mobility Motor Controller Logic Input

	Left	Right
Coast	LOW	LOW
Move Left	HIGH	LOW
Move Right	LOW	HIGH
Brake	HIGH	HIGH

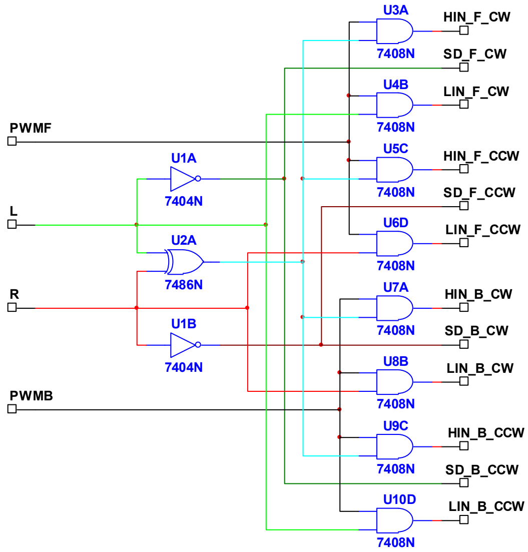


Figure 48: Mobility motor controller logic

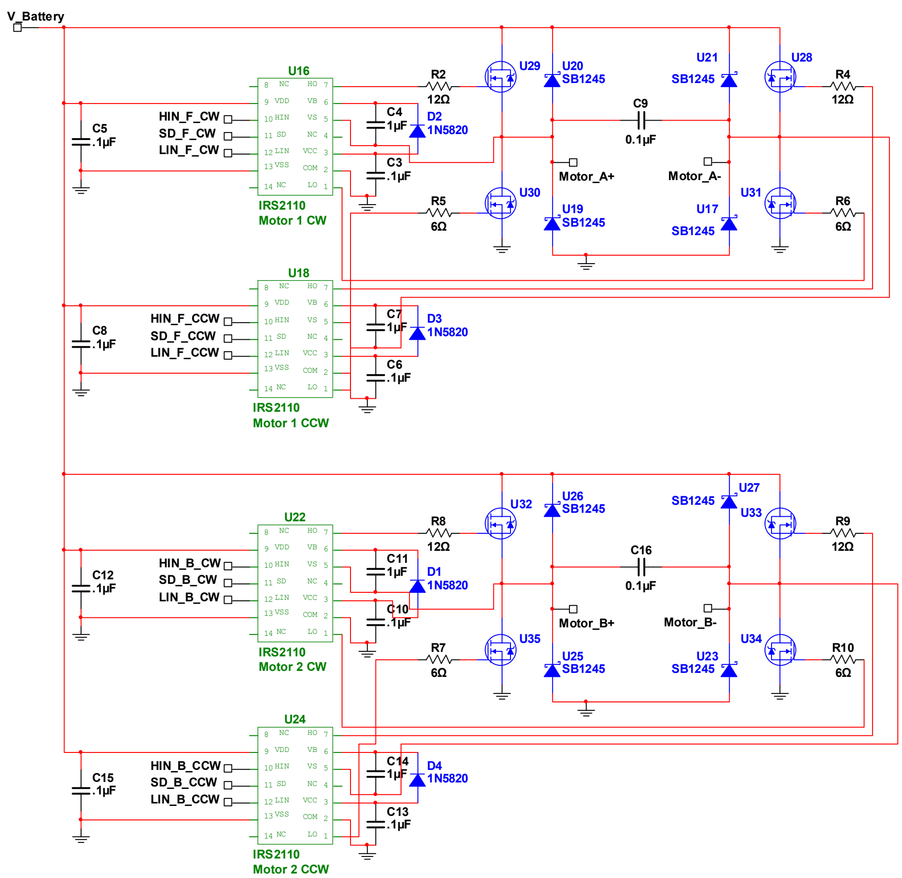


Figure 49: Mobility motor controller low-level

The MOSFET driver selected is the IRS2110 from International Rectifier. The basic functionality of these devices can be seen in Appendix I. The low-side MOSFETs are turned on by applying approximately 12V from the IRS2110. The high-side MOSFETs are turned on by applying approximately 22V from the IRS2110. This is accomplished through the use of a bootstrap capacitor circuit integrated internally in the IRS2110. The bootstrap capacitor is external connected across V_B and V_S to the IRS2110 and was chosen to be 1µF. It provides 2A of output current in order to quickly hard-switch the MOSFET while minimizing the amount of time in the linear region. The resistors on the gates of the MOSFET were chosen to limit the amount of current that the IRS2110 outputs. The calculation for the low-side MOSFET is $R_{gate} = \frac{V_{gate}}{I_{gate}} = \frac{12V}{2A} = 6\Omega$. The calculation for the high-side MOSFET is $R_{gate} = \frac{V_{gate}}{I_{gate}} = \frac{24V}{2A} = 12\Omega$. The thermal calculations for this device can be seen in Fig. 50. This is the input and resulting output when the values of the IRLB3034 N-Channel MOSFET is used with the MATLAB code in Appendix G. The ambient temperature is set to be a warm summer day temperature of 35°C (95°F). Given the results seen in Fig. 50 multiple MOSFETs will need to be connected in parallel in order to be able to handle the required current and they will also not need a heat sink.

Inputs:
Maximum Drain Current: 343 A
Ambient Operating Temperature: 35°C
Maximum Junction Temperature: 175°C
Thermal Resistance from Junction to Case: 0.4 $\frac{°C}{W}$
Thermal Resistance from Case to Sink: 0.5 $\frac{°C}{W}$
Thermal Resistance from Junction to Ambient: 62 $\frac{°C}{W}$
User Required Drain Current: 12.5 A

Results:
Minimum Number of MOSFETs Without Heatsink = 0.220560
Minimum Thermal Resistance of Heatsink Required: 280.202677 $\frac{°C}{W}$

Figure 50: Calculations for motor controller thermal properties

The time it takes the IRLB3034 to turn on (given a supplied current of 2 A) was found using the following equation $t_{turnon} = \frac{Q_{gate}}{I_{gate}} = \frac{162\,nC}{2A} = 81ns$. If this value is added to the IRS2110's maximum turn-on time of 35ns then the maximum turn-on time is 116ns. According to the maximum safe operating area figure on the datasheet, if the drain-to-source voltage is 12V and the IRLB3034 turn-on time takes 100µs then the maximum drain current is approximately 100A. The turn-on time is significantly less than 100µs and the maximum drain current is only 12.5A, so the device should have no problem switching through the linear region.

The simulation of this controller can be shown in part in Fig. 51. This is only a small part of the controller system, but it demonstrates the high current capabilities of the controller. Transistor Q4 is being controlled with PWM at 2kHz with 0 to 12V pulses. The transistor Q1 is being raised 10V above its drain voltage in order to function as a high-side switch. The current going through the motor resistance is 11.5A and the voltage drop across Q1 is shown to be 16.635 mV. This shows that the on-state resistance of the motor controller drops an almost negligible amount of voltage.

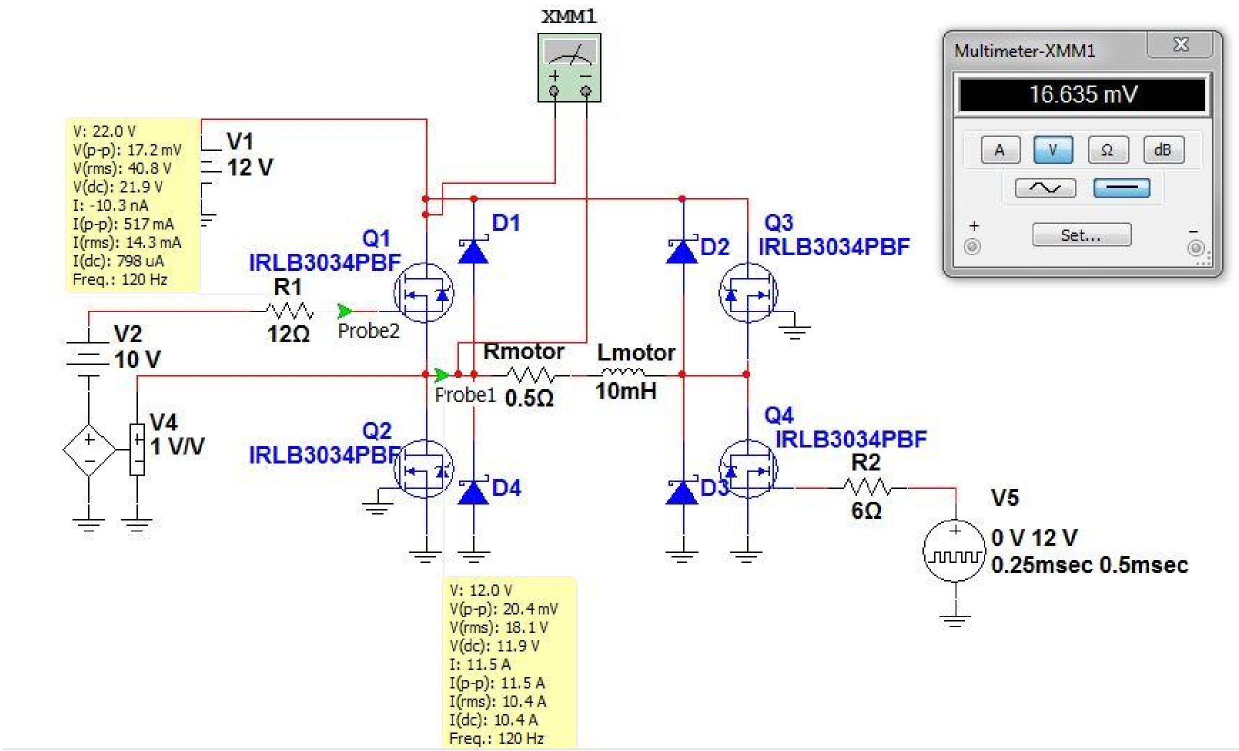


Figure 51: H-Bridge Simulation

Launching Motor Controller

The launching motor will need to spin in only one direction. The direction of current travel will never need to be reversed so the motor controller and the wheels will not need braking functionality. The motor controller will then essentially consist of a high current N-Channel MOSFET used as a low-side switch. The microprocessor will control this motor by sending a 2kHz PWM signal that will vary the amount of power being allowed to flow through the motor.

The maximum continuous current that will be drawn by the launching motor is [illegible] = 4.75A. The MOSFET driver will be Microchip's TC4432 as seen in Fig. 52 which has an output current rating of 1.5A. The gate resistor R1 has been chosen so that the maximum output current of the TC4432 cannot exceed its 1.5A limit where [illegible]1 = [illegible] = [illegible] = 8[illegible].

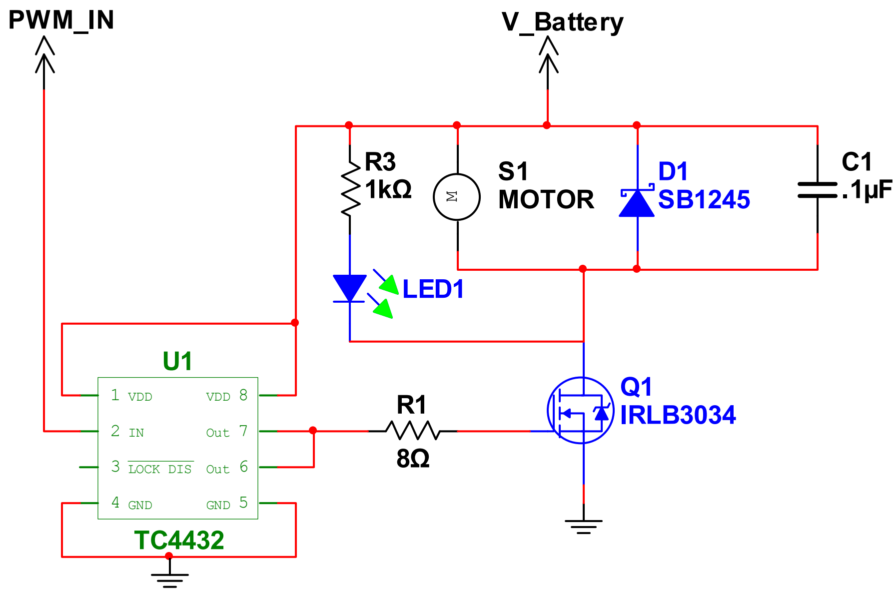


Figure 52: Launching motor controller

The thermal calculations can be seen in Fig. 53 in which no additional MOSFETs will need to be connected in parallel with Q1 in order to handle the current. The MOSFET is extremely efficient at dissipating heat even at 35°C so the calculations performed for the Mobility Motor Controller will be more than adequate for the Launching Motor Controller.

Inputs:
Maximum Drain Current: 343 A
Ambient Operating Temperature: 35°C
Maximum Junction Temperature: 175°C
Thermal Resistance from Junction to Case: .4 $\frac{°▯}{▯}$
Thermal Resistance from Case to Sink: .5 $\frac{°▯}{▯}$
Thermal Resistance from Junction to Ambient: 62 $\frac{°▯}{▯}$
User Required Drain Current: 4.75 A

Results:
Minimum Number of MOSFETs Without Heatsink = 0.031849 $\frac{°▯}{▯}$
Minimum Thermal Resistance of Heatsink Required: 1945.794441 $\frac{°▯}{▯}$

Figure 53: Mobility motor MOSFET thermal calculations

Vertical Motor Controller

The vertical targeting system's maximum electrical power requirement to be supplied to the DC motor is 30 W. The motor will be supplied with 12 VDC so the maximum current that will need to be supplied is $\frac{30\,W}{12\,V}$ = 2.5 A. The electric scissor jack that was ordered will come with a manual motor controller. There is a button for the lift to raise and another to make it lower. The buttons will be replaced with solid-state relays that will be controlled by the microprocessor.

Horizontal Motor Controller

The horizontal targeting system's maximum electrical power requirement to be supplied to the DC motor is 5.2 W. The motor will be supplied with 12 VDC so the maximum current that will need to be supplied is $\frac{8.0\,W}{12\,V}$ = 0.67 A. The horizontal targeting system will require bidirectional movement so the horizontal motor controller will use an H-Bridge configuration of motor controller. The motor controller is an H-Bridge motor controller chip that is rated at a maximum of 30A. The microprocessor will send a 2kHz PWM signal to the PWM pin and the rotational direction will be selected by INA and INB. INA and INB are logic signal inputs that inform the motor controller how to operate. More information about this functionality can be found in Appendix I. If INA is enabled then the motor will rotate clockwise. Likewise, if INB is enabled then the motor will rotate counter clockwise. If both INA and INB are disabled then the brake will resist the motor's rotation. The motor controller design can be seen in Fig. 54. STMicroelectronics' VNH3SP30-E has several onboard fault detection systems.

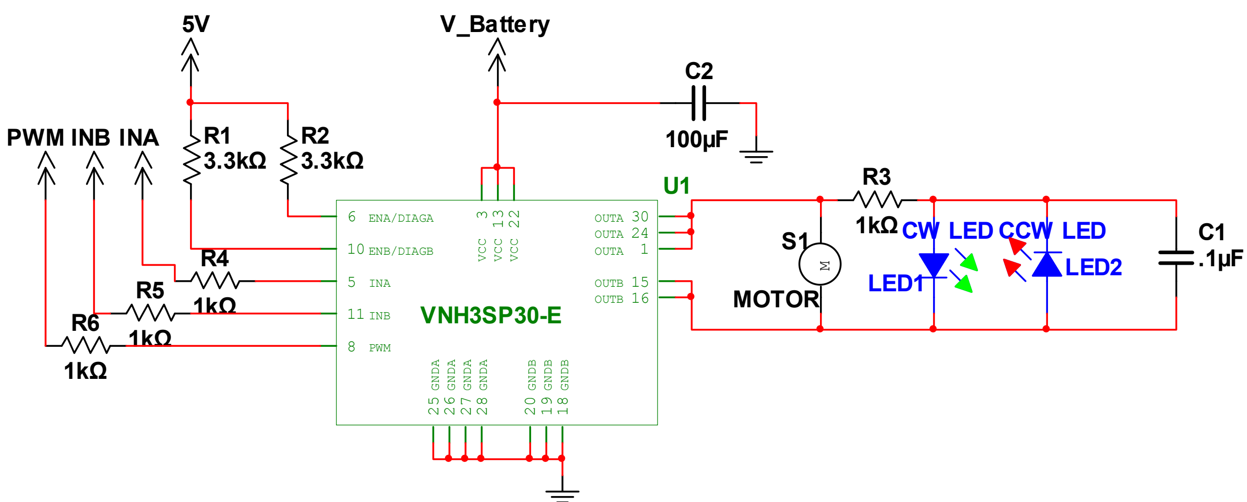


Figure 54: Horizontal targeting system motor controller

The motor controller chip can handle far higher currents than what the horizontal motor will need, but the high current rating also means the motor controller has relatively low losses. The drain-to-source resistance of each leg is approximately 45mΩ. This means the power losses while travelling in one direction can be found by $P_{loss} = (0.67\,A)^2\,(2)(45\,m\Omega) = 40.4\,mW$.

Hopper Rotor Motor Controller

The hopper rotor motor that sends balls from the hopper to the launching mechanism will be a stepper motor. The use of the L297 chip from STMicroelectronics controls the more difficult functions of controlling the signals to a stepper motor. This will be coupled with STMicroeclectronics' L298N chip to drive the stepper motor controller. Appendix I gives a brief overview of the features of this setup. The chopper circuit will be determined after testing the characteristics of hopper rotor motor. The microprocessor controls the hopper rotor motor controller by first enabling the L297 chip by setting the ENABLE pin high. Then the microprocessor can select whether to use the stepper motor in half or full mode by setting pin 19 appropriately. The direction will always be the same so pin 17 will be tied to the desired rail accordingly. To move the stepper motor the microprocessor then only has to send a clock signal to pin 18 at the desired frequency of rotation.

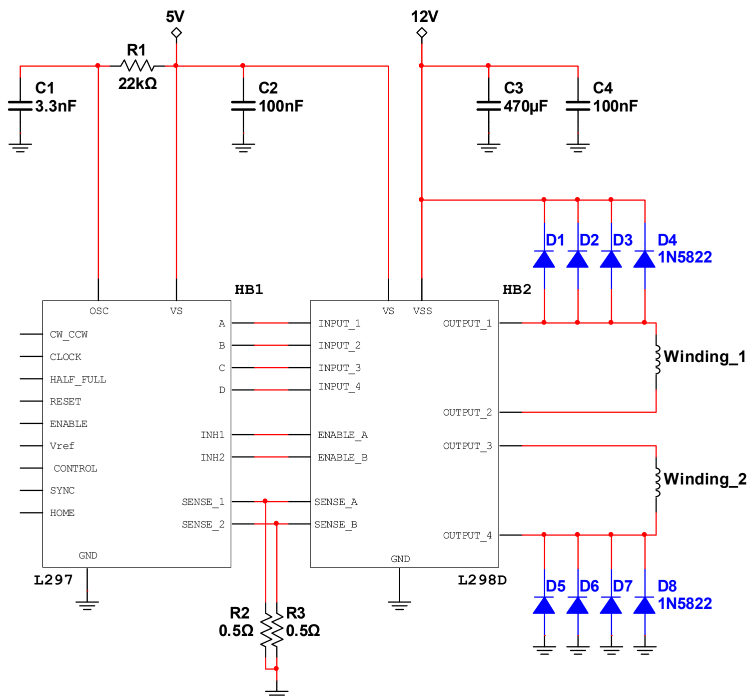


Figure 55: Hopper Rotor Motor Controller

Microprocessor Programming

The on board logic necessary to do the ball trajectory calculations is too complicated to do in a simple digital circuit design, so we have chosen to use a microprocessor system. The microprocessor that was selected is a dsPIC33FJ128MC802 made by Microchip Technology Inc. The microprocessor has the following features that made it desirable for this project:

1. 21 IO Pins
2. Up to 40 MIPS
3. 9 ADC Pins
4. 8-Channel 16-bit
5. 128 kB Flash Memory

6. 16 kB RAM
7. 4 Input Capture Pins
8. 4 Output Compare Pins
9. 1 ECAN Module

One issue arose in that this microprocessor does not have enough IO pins to handle the information flow. The calculated need for information flow is 28 (6 from UI, 2 from Remote, 10 from Sensors, 10 from motor controllers). To fix this problem we have decided to use two microprocessors with a digital information bus connecting the two. This does not cut into our spending budget because we have already received multiple free samples of this microprocessor. Also this allows for parallel processing which will help optimize the efficiency of the calculations.

The master microprocessor will handle the remote and sensor system as well as the mobility motor control. The slave will handle the user interface board as well as the launching, feeding, and targeting motor control. The master microprocessor will need to be able to tell the slave microprocessor what state the machine is in (running or waiting) and the machine's position on the court. Figure 56 is the four main program flows for the 2 microprocessors. With flow a being on the master microprocessor and flows c-d on the slave.

Master Program

The master microprocessor will stay in a busy waiting state waiting for the signal from the remote telling it to start. It will proceed to move to the right until it reaches the right most edge of the base line for calibration purposes. Then it will send the signal to the slave microprocessor to switch to running state, and begin sending the stored court position to the slave. During each timer interrupt it will determine what fine adjustments need to be made to remain on the baseline, and set the movement for the machine. Using the encoders it will determine how far it has moved and adjust the stored court position accordingly. Upon receiving the brake signal it will stop the machine movement, switch the slave into waiting state, and reset the program to the busy waiting state.

Slave Program

The slave microprocessor will continuously interpret the user interface into stored data until it receives the signal to switch to the running state. Upon switching to the running state the launching and feeding motors are set to start running. During the periods between timer interrupt the main code will determine the point to be targeted after the next launch.

The timer interrupt checks to see if a ball has been fired. If one has a flag is set to tell the main code to send the next target. Then the timer interrupt gets the stored court position from the master processor. Then the timer interrupt calculates the settings necessary to launch the ball to that target. Once these settings are calculated the motor control signals are sent to the respective motors. The position of the targeting system will be determined and the motors set to adjust them towards the calculated target.

Upon receiving the signal to switch back to waiting state, the slave processor will stop the launching and feeder motors, and set the targeting motors back to a stable state. Then the program will be reset to the user interface interpreting loop.

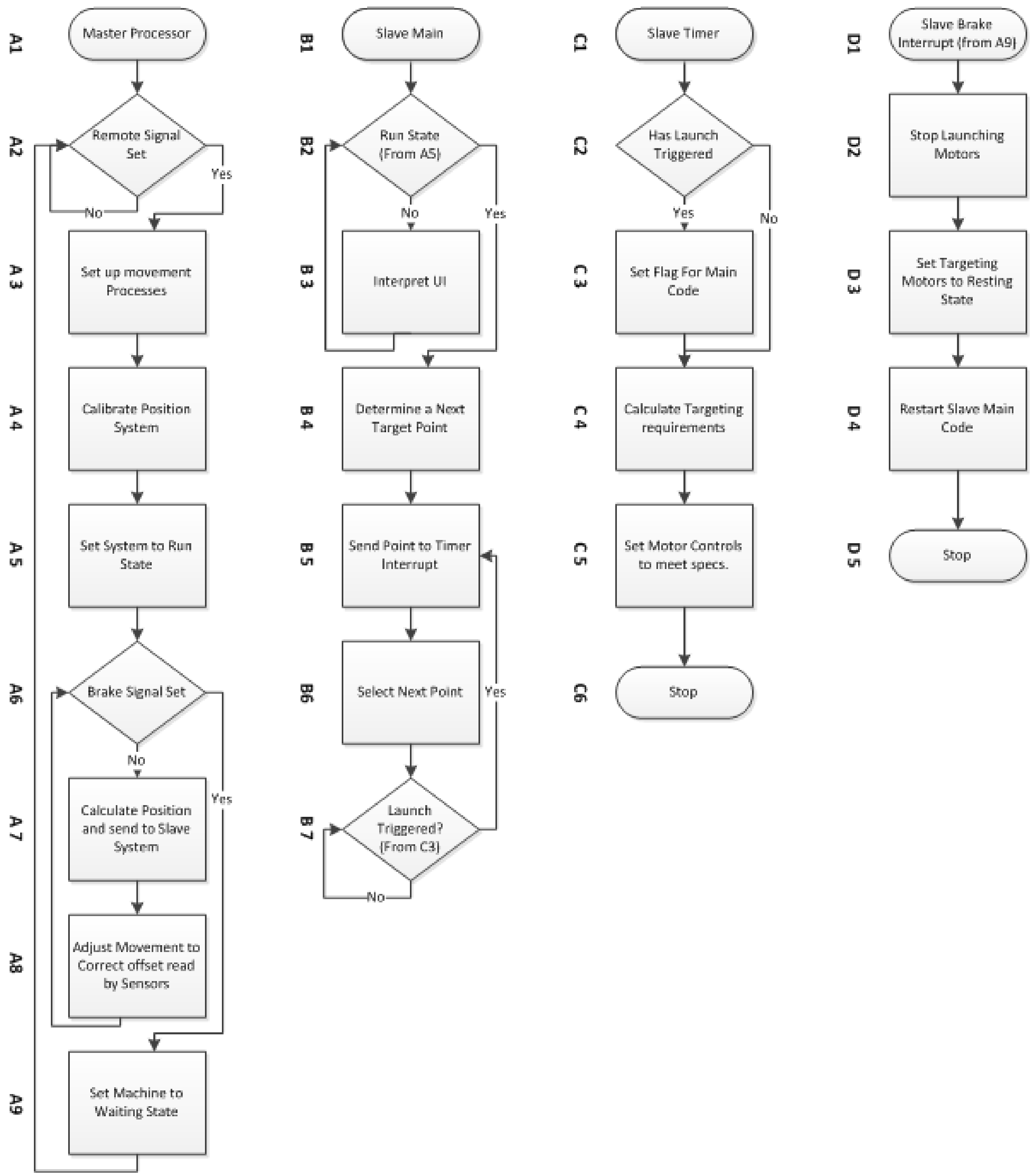


Figure 56: MATT program flow

Budget

Budget Overview

A budget overview is provided for the construction of MATT and can be seen in Table 5. The expected cost of each major system is shown here. The mobility and launching system were individually computed, while all electrical components were tallied together. The budget presented here takes into account all major components needed, but does not include miscellaneous parts such as fasteners, wiring, and small amounts of other raw materials needed for the construction and testing of MATT. Each subsystem budget will be shown in subsequent pages, where it will be broken into much greater detail, showing the cost of individual components.

Table 4: Overview of budget for MATT

System	Part Cost	Shipping/Tax Cost	Total Cost
Mobility System	$104.02	$23.93	$127.95
Launching System	$289.18	$30.74	$319.92
Power, Interface and Control System	$235.83	$9.16	$244.99
Totals:	*$629.03*	*$63.83*	*$692.86*
Remainder:			*$337.14*

Manufacturing Budget

The budget presented in Table 6 takes into account the cost of parts if MATT were to undergo full scale manufacturing at a high volume. The costs of components such as those printed on the 3-D printer, or repurposed from previous projects were factored in to determine the total expense for each MATT device if it were to be produced for the market.

Table 5: Overview of manufacturing budget for MATT

System	Part Cost	Shipping/Tax Cost	Total Cost
Mobility System	$233.02	$33.33	$266.35
Launching System	$465.78	$42.59	$508.37
Power, Interface and Control System	$235.83	$9.16	$244.99
Totals:	*$934.63*	*$85.08*	*$1019.71*

Subsystem Budgets

Mobility System Budget

Table 6: Mobility system detailed budget

Description	Vendor	Item #	Price	Quantity	Shipping/Tax	Total Cost
Mobility Motors	Bane Bots	M5-RS550-12-B	$7.50	2	$9.40	$24.40
Gearbox Screws (Incorrect)	Bane Bots	SM-CM330-4	$0.75	2	N/A	$1.50
Gearbox Screws M3-45	Coast to Coast Hardware	M3-45	$0.35	8	$0.26	$3.06
Gearbox Screws M3-50	Coast to Coast Hardware	M3-50	$0.40	1	N/A	$0.40
3-inch Casters	HU Physical Resources		$3.34	2	$0.54	$7.22
10" Drive Wheels	Amazon	490-323-0002	$10.74	2	N/A	$21.48
1/16" x 1/2" x 1/2" x 48" Angle 6063-T52 Aluminum	Speedy Metals	63a.065x.5-48	$2.01	18	$12.13	$48.31
0.25" x 4' x 8' Plywood	Lowe's	80246	$19.98	1	$1.60	$21.58
			Repurposed Parts:*			
64:1 Gearboxes	Bane Bots		$64.50	2	$9.40	$138.40
Actual Part Cost:	$104.02		**Manufacturing Part Cost:**		$233.02	
Actual Shipping/Tax Cost:	$23.93		**Manufacturing Shipping/Tax Cost:**		$33.33	
Actual Total Cost:	$127.95		**Manufacturing Total Cost:**		$266.35	

*Repurposed parts are part taken from previous projects and have no effect on actual budget.

Launching System Budget

Table 7: Launching system detailed budget

Description	Vendor	Item #	Price	Quantity	Shipping/Tax	Total Cost
Electric Scissor Jack	Amazon	UPG 86025	$56.32	1	N/A	$56.32
6" Lazy Susan Bearing	Lowe's	71060	$4.43	1	$1.14	$5.57
3" x 8' Semi-Rigid Aluminum Tubing	Lowe's	28878	$9.86	1	N/A	$9.86
Bipolar Stepper Motor	Trossen Robotics	M-200-ROB-09238	$14.95	1	$7.99	$22.94
Mounted Ball Bearings	McMaster-Carr	5913K71	$11.33	4	N/A	$45.32
Idler Sprocket	McMaster-Carr	6663K22	$22.22	1	N/A	$22.22
Motor Sprocket	McMaster-Carr	6280K331	$8.86	1	N/A	$8.86
Wheel Sprockets	McMaster-Carr	6280K332	$8.86	2	N/A	$17.72
ANSI 35 Chain	McMaster-Carr	6261K172	$12.56	1	N/A	$12.56
Steel Rod – 3' x ½" Diameter	Lowe's	44093	$5.25	1	$0.42	$5.67
8"Launching Wheels	Tractor Supply	4441143	$6.99	2	$1.12	$15.10
Hopper Wire Fence	ACE Hardware	432425	$28.99	1	$2.32	$31.31
1/4" x 2-1/2" x 48" Flat 6061-T6511 Aluminum	Speedy Metals	61f.25x2.5-48	$17.42	1	$17.75	$35.17
1/4" x 1" x 24" Flat 6061-T6511 Aluminum	Speedy Metals	61f.25x1-24	$3.29	1	N/A	$3.29
3/16" x 12" x 18" Plate 6061-T6 Aluminum	Speedy Metals	61p.190-12x18	$28.01	1	N/A	$28.01
			3-D Printer Components**			
Hopper Rotor	HU Engineering		$35.10	1	N/A	$35.10
Rotor Pinion	HU Engineering		$1.70	1	N/A	$1.70
Rotor Gear	HU Engineering		$16.15	1	N/A	$16.15
Rotor Shaft	HU Engineering		$3.85	1	N/A	$3.85
			Repurposed Parts*			
Angular Targeting Motor	Wonder Motor		$79.95	1	N/A	$79.95

Launching Motor	Bane Bots	M4-R0062-12	$28.00	1	$11.85	$39.85

Actual Part Cost:	$289.18	**Manufacturing Part Cost:**	$465.78
Actual Shipping/Tax Cost:	$30.74	**Manufacturing Shipping/Tax Cost:**	$42.59
Actual Total Cost:	$319.92	**Manufacturing Total Cost:**	$508.37

*Repurposed parts are part taken from previous projects and have no effect on actual budget.

**Price of $5/in^3 for all 3-D printed components, which is not taken from the actual budget

Power, Interface, and Control System Budget

Table 8: Electrical component detailed budget

Description	Vendor	Item #	Price	Quantity	Shipping/Tax	Total Cost
RF Transmitter	Spark Fun	WRL-10535	$3.95	1	$3.56	$7.51
RF Receiver	Spark Fun	WRL-10533	$4.95	1	N/A	$4.95
Rotary Potentiometer	Spark Fun	COM-09288	$0.95	6	N/A	$5.70
Black Knob	Spark Fun	COM-09998	$0.95	6	N/A	$5.70
Signal Encoder	Jameco	123730	$1.75	2	N/A	$3.30
Signal Decoder	Jameco	123748	$1.65	2	N/A	$3.50
Dip Switch	Jameco	139012	$0.95	2	N/A	$1.90
1/2" 4-40 Spacer	Jameco	108371	$0.45	4	N/A	$1.80
MOSFET Driver	Digikey	IRS2110PBF-ND	$4.60	4	N/A	$18.40
MOSFET N-CH	Digikey	IRLB3034PBF-ND	$2.60	10	N/A	$26.00
Schottky Diode	Digikey	SB1245CT-ND	$1.67	10	N/A	$16.70
Motor Driver	Digikey	497-3565-1-ND	$11.25	1	N/A	$11.25
0.5Ω 3W Resistor	Digikey	PPC3W.50CT-ND	$0.97	2	N/A	$1.94
Enclosure	Digikey	SRCA8-2G-ND	$7.28	1	N/A	$7.28
CR2032	Digikey	SY189-ND	$0.41	4	N/A	$1.64
10.0kΩ 1/4W 1% Resistor	Digikey	10.0KXBK-ND	$0.126	5	N/A	$0.63
13.0kΩ 1/4W 1% Resistor	Digikey	13.0KXBK-ND	$0.126	5	N/A	$0.63
Tactile Switch	Digikey	SW400-ND	$0.30	2	N/A	$0.60
Coin Cell Battery Holder	Digikey	BS-3-ND	$0.72	4	N/A	$2.88
Schottky Diode	Digikey	1N5822-TPMSCT-ND	$0.413	10	N/A	$4.13
12 V Battery	Searcy Battery Warehouse		$79.95	1	$5.60	$85.55
Printed Circuit Board	4pcb.com		$33.00	1	N/A	$33.00

Actual Part Cost:	$235.83	**Manufacturing Part Cost:**	$235.83
Actual Shipping/Tax Cost:	$9.16	**Manufacturing Shipping/Tax Cost:**	$9.16
Actual Total Cost:	$244.99	**Manufacturing Total Cost:**	$244.99

Purchases

Table 10 below gives a detailed summary of the components that have actually been purchased for the construction of MATT. Any materials or parts that are salvaged from other previous projects will be recorded in the Manufacturing Budget accordingly.

Table 9: Summary of all purchased components for MATT

Description	Vendor	Item #	Price	Quantity	Shipping/Tax	Total Cost
Mobility Motors	Bane Bots	M5-RS550-12-B	$7.50	2	$9.40	$24.40
Gearbox Screws (Incorrect)	Bane Bots	SM-CM330-4	$0.75	2	N/A	$1.50
Gearbox Screws M3-45	Coast to Coast Hardware	M3-45	$0.35	8	$0.26	$3.06
Gearbox Screws M3-50	Coast to Coast Hardware	M3-50	$0.40	1	N/A	$0.40
3" Pivoting Caster Wheels	HU Physical Resources		3.34	2	0.54	$7.22
1/16" x 1/2" x 1/2" x 48" Angle 6063-T52 Aluminum	Speedy Metals	63a.065x.5-48	$2.01	18	$12.13	$48.31
6" Lazy Susan Bearing	Lowe's	71060	$4.43	1	$1.14	$5.57
3" x 8' Semi-Rigid Aluminum Tubing	Lowe's	28878	$9.86	1	N/A	$9.86
Bipolar Stepper Motor	Trossen Robotics	M-200-ROB-09238	$14.95	1	$7.99	$22.93
10" Drive Wheels	Amazon	490-323-0002	$10.74	2	N/A	$21.48
12 V Battery	Searcy Battery Warehouse		$79.95	1	$5.60	$85.55
Electric Scissor Jack	Amazon	UPG 86025	$56.32	1	N/A	$56.32
Rotary Potentiometer	Spark Fun	COM-09288	$0.95	6	$3.56	$5.70
Black Knob	Spark Fun	COM-09998	$0.95	6	N/A	$5.70
RF Receiver	Spark Fun	WRL-10533	$4.95	1	N/A	$4.95
RF Transmitter	Spark Fun	WRL-10535	$3.95	1	N/A	$3.95
Signal Encoder	Jameco	123730	$1.75	2	N/A	$3.30
Signal Decoder	Jameco	123748	$1.65	2	N/A	$3.50
Dip Switch	Jameco	139012	$0.95	2	N/A	$1.90

1/2” 4-40 Spacer	Jameco	108371	$0.45	4	N/A	$1.80
MOSFET Driver	Digikey	IRS2110PBF-ND	$4.60	4	N/A	$18.40
MOSFET N-CH	Digikey	IRLB3034PBF-ND	$2.60	10	N/A	$26.00
Schottky Diode	Digikey	SB1245CT-ND	$1.67	10	N/A	$16.70
Motor Driver	Digikey	497-3565-1-ND	$11.25	1	N/A	$11.25
0.5Ω 3W Resistor	Digikey	PPC3W.50CT-ND	$0.97	2	N/A	$1.94
Enclosure	Digikey	SRCA8-2G-ND	$7.28	1	N/A	$7.28
CR2032	Digikey	SY189-ND	$0.41	4	N/A	$1.64
10.0kΩ 1/4W 1% Resistor	Digikey	10.0KXBK-ND	$0.126	5	N/A	$0.63
13.0kΩ 1/4W 1% Resistor	Digikey	13.0KXBK-ND	$0.126	5	N/A	$0.63
Tactile Switch	Digikey	SW400-ND	$0.30	2	N/A	$0.60
Coin Cell Battery Holder	Digikey	BS-3-ND	$0.72	4	N/A	$2.88
Schottky Diode	Digikey	1N5822-TPMSCT-ND	$0.413	10	N/A	$4.13
Mounted Ball Bearings	McMaster-Carr	5913K71	$11.33	4	N/A	$45.32
Idler Sprocket	McMaster-Carr	6663K22	$22.22	1	N/A	$22.22
Motor Sprocket	McMaster-Carr	6280K331	$8.86	1	N/A	$8.86
Wheel Sprockets	McMaster-Carr	6280K332	$8.86	2	N/A	$17.72
ANSI 35 Chain	McMaster-Carr	6261K172	$12.56	1	N/A	$12.56
1/4" x 2-1/2" x 48” Flat 6061-T6511 Aluminum	Speedy Metals	61f.25x2.5-48	$17.42	1	$17.75	$35.17
1/4" x 1" x 24” Flat 6061-T6511 Aluminum	Speedy Metals	61f.25x1-24	$3.29	1	N/A	$3.29
3/16" x 12" x 18” Plate 6061-T6 Aluminum	Speedy Metals	61p.190-12x18	$28.01	1	N/A	$28.01
			Total Part Cost:	**$527.83**		
			Total Shipping/Tax Cost:	**$58.37**		
			Total Funds Spent:	**$586.20**		
			Total Expected Budget:	**$692.86**		
			Percent of Budget Spent:	**84.6%**		

Project Plan and Management

Organization and Management

MATT's design team consists of two mechanical engineering students, two electrical engineering students, and one computer engineering student. With the design tasks complete, the next phase of the project will consist of construction, implementation, and testing. While project management responsibilities will be distributed equally among the team members, each team member will be in charge of a major subsystem of the device, with two other team members supporting him. There will be one project manager over the entire project.

- **Mark Moore (Mechanical Engineer)**
  - Mark is the project manager and is responsible for organizing the activities and tasks of the build team. He will ensure that the required documents, presentations, constructions and testing will be completed on schedule. He will also be the primary engineer responsible for the construction of the mobility system, frame and encasement, and the hopper and feeder system. He will be a secondary engineer for the both the launching system build, and the power source build.
- **Michael Gorman (Computer Engineer)**
  - Michael is the primary engineer responsible for the construction of the microprocessor, the programming, and the user interface of MATT. He will also be a secondary engineer for both the mobility system and the control and sensor systems.
- **Ivan Michelli (Mechanical Engineer)**
  - Ivan is the primary engineer responsible for the construction of the tennis ball launching system, including the targeting mechanism. He will also be a secondary engineer for both the mobility system and the control and sensor systems.
- **Prosper Majyambere (Electrical Engineer)**
  - Prosper is the primary engineer responsible for the construction of the power source for and all power distribution for the entire machine. He will also be a secondary engineer for both the microprocessor and interface system and the launching system.
- **Trevor Pringle (Electrical Engineer)**
  - Trevor is the primary engineer responsible for the construction of the control and sensor systems on MATT. This system will consist of the all motor controls, positioning and data input sensors, and the remote control. He will also be a secondary engineer for both the microprocessor and interface system, and the power source system.

Each team member will ultimately be responsible for the assigned tasks, and will be in charge of testing the components of the device they construct according to the specifications outlined. Each team member will also be expected to be familiar with all other systems on the machine, keeping in mind the total integration of all these systems in the final product at all phases in the build process. It is also important to note that though each major subsystem has a primary engineer and two secondary support engineers, the work done on each subsystem is not limited to these three team members.

Fall 2011 Schedule Analysis

Throughout the course of the semester the work breakdown structure and project plans were not followed precisely in many areas. As the semester progressed, the tasks and assignments for each of the individual subsystems and designs remained essentially the same; however the time frame in which each task was completed, or not completed for that matter, varied significantly from our original estimates. Upon discussion with the team, it seems the general consensus as to why this occurred was a result of several factors. As a general rule, the amount of time that was allotted to many of the tasks was not enough to complete the designs thoroughly. This was due to the highly iterative process that was needed for many of the designs and the different dependencies of the various subsystems. The requirements and needs of many of our subsystem designs were much more intertwined then previously assumed, and therefore as one design for a subsystem changed, another needed to be modified as well.

Another main factor that contributed our lack of schedule following was the large amount of mechanical components. A high percentage of MATT is composed of mechanical subsystems and each system had to be analyzed individually to determine motor and gearing specifications and requirements. Many of these mechanical systems became much more involved and complicated than the mechanical engineers previously assumed, and therefore each subsystem took a significantly greater amount of time to design than was expected. Due to these delays in the design for the mechanical engineers several of the electrical subsystem designs fell behind schedule as well since they were highly dependent on information provided from the mechanical engineers.

Table 11 shows the main tasks from the Fall 2011 Work Breakdown Structure which were delayed or have not yet been finalized. All of the tasks listed have been designed, but final iterations have not been completed. Therefore, though designs have been created, the main concern in all areas is the actual part selection, and preliminary testing.

Table 10: Fall 2011 Delayed Tasks

Task ID	Task Name	Description	Deliverables	Duration	Engineer(s)*
F 6.1.1	Power Source Selection	Power source design and specific components selected	Schematics, MultiSim models	Oct. 17th – Oct. 24th	P
F 6.1.2	Power Distribution & Regulation	Power regulation and design of distribution for various subsystems	Schematics, MultiSim models	Oct. 26th – Nov. 9th	M,P,T
F 6.3.1	Launching Mechanism	Launching mechanism method and controller, and ball feeding mechanism, major components selected	Schematics, SolidWorks models, datasheets	Oct. 13th – Oct. 25th	I,M
F 6.3.2	Targeting System	Design of both horizontal and vertical aiming mechanisms, major components selected	Schematics, SolidWorks models, datasheets	Oct. 13th – Oct. 30th	I,M
F 6.3.3	Hopper Design	Design of hopper size and shape to work with overall design, and feeder mechanism	SolidWorks models, miscellaneous diagrams	Oct. 25th – Nov. 2nd	M
F 6.3.4	Feeder Mechanism	Design of mechanism to feed tennis balls from hopper to launcher	SolidWorks models, diagrams, and schematics	Nov. 2nd – Nov. 11th	I,M

*I = Ivan, M = Mark, P = Prosper, T = Trevor

The first area of concern as seen in Table 11 was the with the power source system of MATT. Due to mechanical engineering delays, and therefore a lack of specific information in regards to motors and power consumptions, the power source was previously delayed. Since such delays, a power source was selected and purchased that should be able to provide the necessary power to all the subsystems. The selection was made based on worst case scenario power calculations. With the power source chosen, the design of the power distribution and regulation system has also been completed.

The rest of the delays have been largely related to mechanical systems as well. The second area of concern here is with the launching system. The launching system has been designed, but has not been finalized due uncertainties in part selection and design analysis. The main concern here is the modification of the vertical targeting mechanism, which will be customized on site. An electric scissor jack was selected for the main vertical targeting component, but in order for the part to work as desired, modifications to the gearing may be necessary. The next major concern was in regard to the design of the horizontal angular targeting mechanism. The angular targeting mechanism design has been completed, but not finalized since some custom manufacturing will be necessary.

The last major schedule deviation was related to the hopper and feeder system design. The hopper and rotor system has been designed and a large portion of the components have been manufactured on site via the 3-D printer. The rotor, the rotor shaft, the rotor gear, and the motor pinion have all been printed on the 3-D printer. The feeder system has not yet been completed since it is highly dependent on the geometry of the launching system. Once components are chosen for the entire launching system, the entire feeder system design can be finalized.

Though the design of MATT had fallen somewhat behind schedule in the previous weeks, the design team has made great strides toward meeting all deadlines and following the schedule in the last weeks of the semester. The spring work breakdown structure will not need to be modified to account for these delays, as they should all be completed before the end of the semester. Based on how the fall semester has panned out some adjustments will be made accordingly to ensure that the construction and testing of MATT proceeds according to plan. The main adjustment will be that the mechanical engineers will attempt to complete all major system constructions as early as possible to allow for maximum integration and testing time.

Spring 2012 Work Breakdown Structure

Table 11: Planned Spring 2011 Schedule Breakdown Structure

Task ID	Task Name	Description	Deliverables	Duration	Engineer(s)*
S 1.0	Project Management	Ensure that the project team is on schedule and meets budget constraints	Budget Statements, schedule	Jan. 9th – Apr. 29th	M
S 2.0	Documentation	Records of all documents, tests, design work, etc.	Design reports, schematics, flow-charts	Jan. 9th – Apr. 29th	I,M,Mi,P,T
S 3.0	Component Build	Complete assembly of subsystems	Subsystems are built as designed	Jan. 9th – Mar. 1st	I,M,Mi,P,T
S 3.1	Power System Build	Implementation and testing of the power subsystems	Working subsystem that provides the correct voltage and current values	Jan. 9th – Feb. 24th	M,P,T
S 3.1.1	Power Source	Test the power capabilities of the power source	Functioning Power Source that meets or exceeds necessary power ratings	Jan. 9th – Jan. 19th	P
S 3.1.2	Low Voltage Indicator	Build the low voltage indication system on a breadboard and test the precision of the system	Working prototype of the low voltage indication system	Jan. 20th – Jan. 25th	T
S 3.1.3	Power Distribution & Regulation	Assemble the power regulation components on a breadboard and test power distribution methods at maximum power ratings	Working prototype of regulation system and distribution methods	Jan. 20th – Jan. 30th	P
S 3.1.4	Power Switch	Test the power switch at the system's maximum power ratings	Suitable primary power switch for the overall system	Jan. 31st – Feb. 4th	P
S 3.1.5	PCB Design of Power System	Design the PCB for the power system components	Accurate PCB design of the power system	Feb. 5th – Feb. 14th	P
S 3.1.6	PCB Build of Power System	Populate the power system PCB and test the subsystems	Functioning PCB of power system components, Test Data	Feb. 17th – Feb. 24th	P
S 3.2	Control and Interface Build	Implementation and testing of the control and interface subsystems	Working control and interface subsystems	Jan. 9th – Feb. 15th	Mi,P,T
S 3.2.1	User Interface Components	Assemble and connect the user interface components	Functioning user interface system on a breadboard	Jan. 9th – Jan. 17th	Mi,P

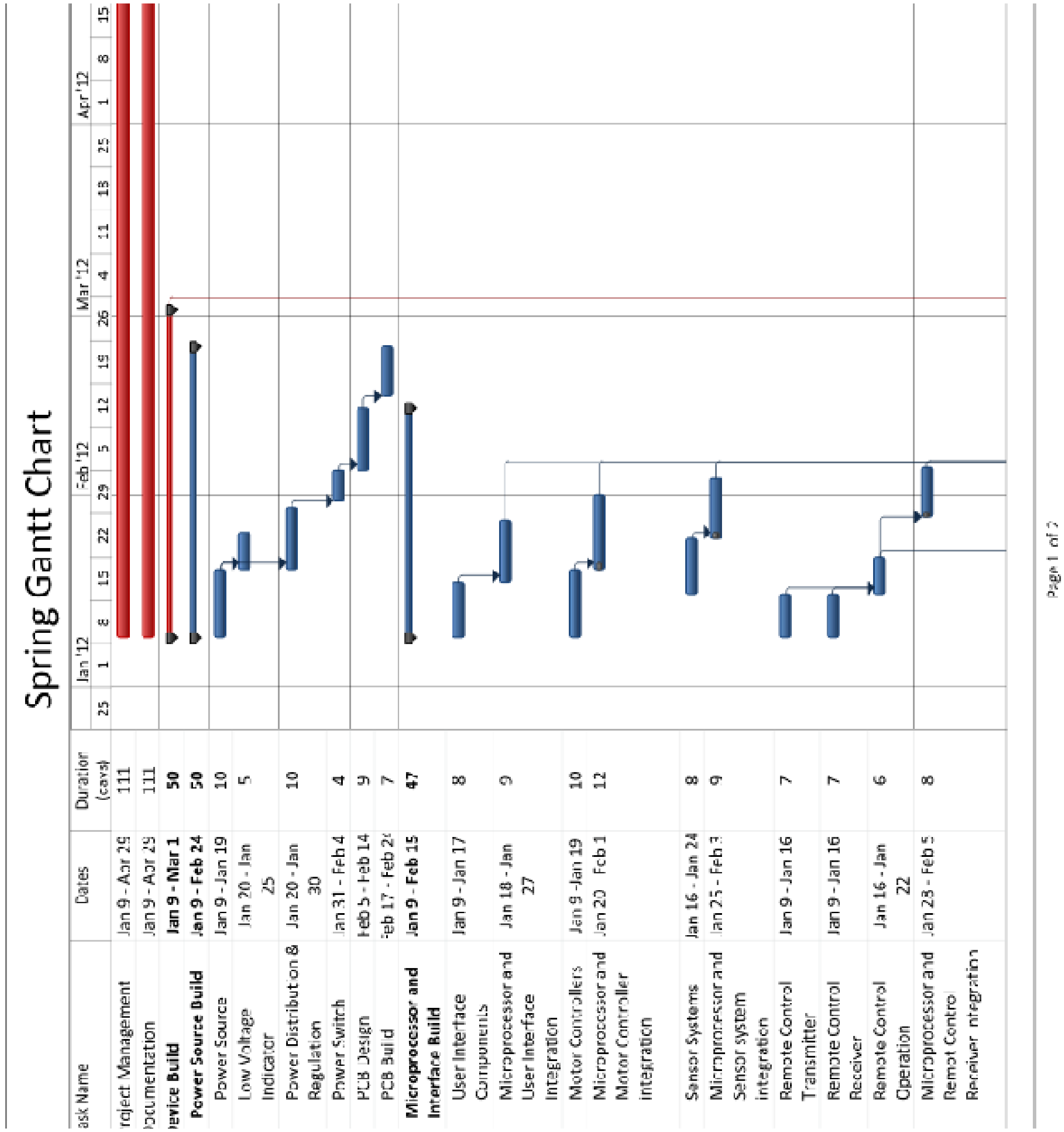
		on a breadboard			
S 3.2.2	Microprocessor and User Interface Integration	Program the Microprocessor to interact with the user interface	Functional programmed microprocessor and user interface interaction on a breadboard	Jan. 18th – Jan. 27th	Mi
S 3.2.3	Motor Controllers	Assemble and test the motor controllers on a breadboard	Functioning control of motors, Test Data	Jan. 9th – Jan. 19th	T
S 3.2.4	Microprocessor and Motor Controller Integration	Program the Microprocessor to interact with the motor controllers	Functional programmed microprocessor and motor controller interaction on a breadboard	Jan. 20th – Feb. 19th	Mi
S 3.2.5	Sensor Systems	Assemble and test the sensor systems on a breadboard	Functioning sensor system, Test Data	Jan. 16th – Jan. 24th	T
S 3.2.6	Microprocessor and Sensor System Integration	Program the Microprocessor to interact with the sensor systems	Functional programmed microprocessor and sensor interaction on a breadboard	Jan. 25th – Feb. 3rd	Mi
S 3.2.7	Remote Control Transmitter	Assemble and test the remote control transmitter system on perfboard	Properly configured remote control transmitter system, Test Data	Jan. 9th – Jan. 16th	T
S 3.2.8	Remote Control Receiver	Assemble the test remote control receiver system on perfboard	Properly configured remote control receiver system, Test Data	Jan. 9th – Jan. 16th	T
S 3.2.9	Remote Control Operation	Test the remote control transmit and receive systems	Functioning remote control system, Test Data	Jan. 16th – Jan. 22nd	T
S 3.2.10	Microprocessor and Remote Control Receiver Integration	Program the Microprocessor to interact with receiver of the remote control	Functional programmed microprocessor and remote control receiver interaction on a breadboard	Jan. 28th – Feb. 5th	Mi
S 3.2.11	PCB Design of Control and Interface System	Design the PCB for the control and interface system	Accurate PCB design of the control and interface system	Jan. 22nd – Jan. 28th	Mi,P,T
S 3.2.12	PCB Design of Remote Control Transmitter	Design the PCB for the Remote Control Transmitter System and populate the PCB	Accurate PCB design of the remote control transmitter	Feb. 6th – Feb. 15th	T
S 3.3	Launching System Build	Assemble and test the launching system	Functioning launching system assembly, Test Data	Jan. 9th – Mar. 1st	I,M,P,T
S 3.3.1	Launching Mechanism	Build and test the launching mechanism	Working launching mechanism, Test Data	Jan. 9th – Jan. 27th	I,M

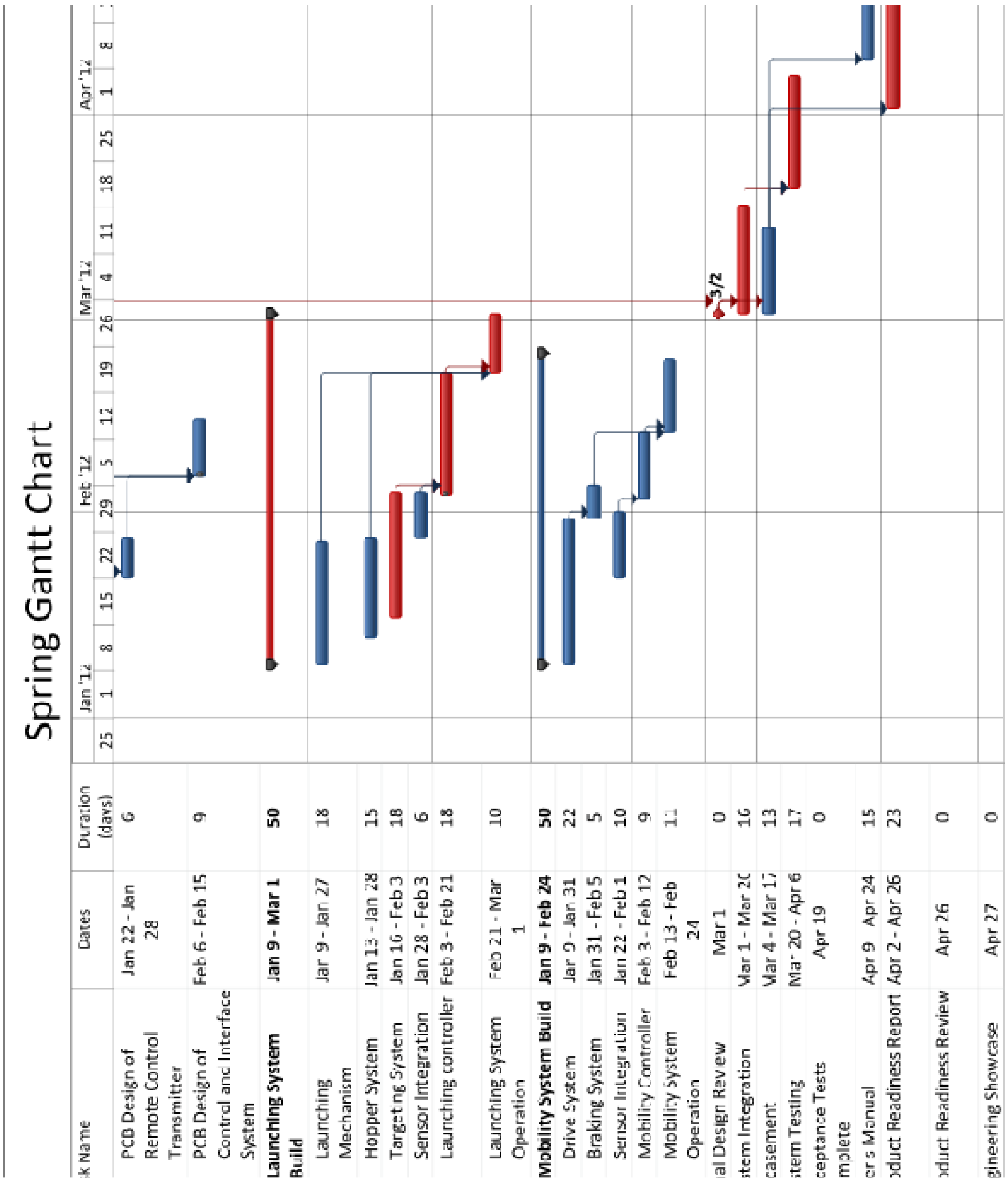
S 3.3.2	Hopper System	Build and test the hopper and feeding mechanism	Hopper that can hold required tennis balls and a functioning feeding mechanism, Test Data	Jan. 13th – Jan. 28th	I,M
S 3.3.3	Targeting System	Build and test the horizontal and vertical components of the launching system	Working horizontal and vertical components of the launching system, Test Data	Jan. 16th – Feb. 3rd	I,M
S 3.3.4	Sensor Integration	Mount the sensors to the launching system and calibrate if necessary	Functioning launching system sensors, Test Data	Jan. 28th – Feb. 3rd	P,T
S 3.3.5	Launching Controller	Interface the motor controller for the launching system to the motors	Functioning control of launching system motors, Test Data	Feb. 3rd – Feb. 21st	P,T
S 3.3.6	Launching System Operation	Test the launching system to confirm that it will meet required specifications and modify the system if necessary	Functioning launching system, Test Data	Feb. 21st – Mar. 1st	I,M,P
S 3.4	Mobility System Build	Assemble and test the mobility system	Functioning mobility system, Test Data	Jan. 9th – Feb. 24th	I,M,Mi,T
S 3.4.1	Drive System	Build and test the drive system	Working drive system, Test Data	Jan. 9th – Jan. 31st	I,M
S 3.4.2	Braking System	Test the braking method and provide alternative braking methods if necessary	Working braking method, Test Data	Jan. 31st – Feb. 5th	I,M,T
S 3.4.3	Sensor Integration	Mount the sensors to the mobility system and calibrate if necessary	Functioning mobility sensors, Test Data	Jan.22nd – Feb. 1st	Mi, T
S 3.4.4	Mobility Controller	Interface the motor controller for the mobility system to the motors	Functioning control of mobility system motors, Test Data	Feb. 3rd – Feb. 12th	Mi,T
S 3.4.5	Mobility System Operation	Test the mobility system to confirm that it will meet required specifications and modify the system if necessary	Functioning mobility system, Test Data	Feb. 13th – Feb. 24th	I,M,Mi
S M.1	Final Design Review	Present the final design to the faculty	Presentation, demonstration of functioning subsystems	Mar. 1st	I,M,Mi,P,T

S 4.0	System Integration	Integrate the subsystems together	Functioning system	Mar. 1st – Mar. 20th	I,M,Mi,P,T
S 5.0	Encasement	Construct encasement with any necessary modifications to meet acceptance tests	Protective encasement attached to the device	Mar. 4th – Mar. 17th	I,M
S 6.0	System Testing	Ensure that the device is able to complete the required specifications and modify the system if necessary	Functioning system that meets required specifications	Mar. 20th – Apr. 6th	I,M,Mi,P,T
S M.2	Acceptance Tests Complete	Complete testing of system	Fully functional device	Apr. 19th	I,M,Mi,P,T
S 7.0	User's Manual	Instructions to the user on how to operate the product	Document	Apr. 9th – Apr. 24th	I,M,Mi,P,T
S 8.0	Product Readiness Report	Final detailed report of the product's functionality	Document	Apr. 2nd – Apr. 26th	I,M,Mi,P,T
S M.3	Product Readiness Review	Present product to faculty	Presentation and demonstration of functioning system	Apr. 26th	I,M,Mi,P,T
S M.4	Engineering Showcase	Public product presentation	Complete functioning system	Apr. 27th	I,M,Mi,P,T

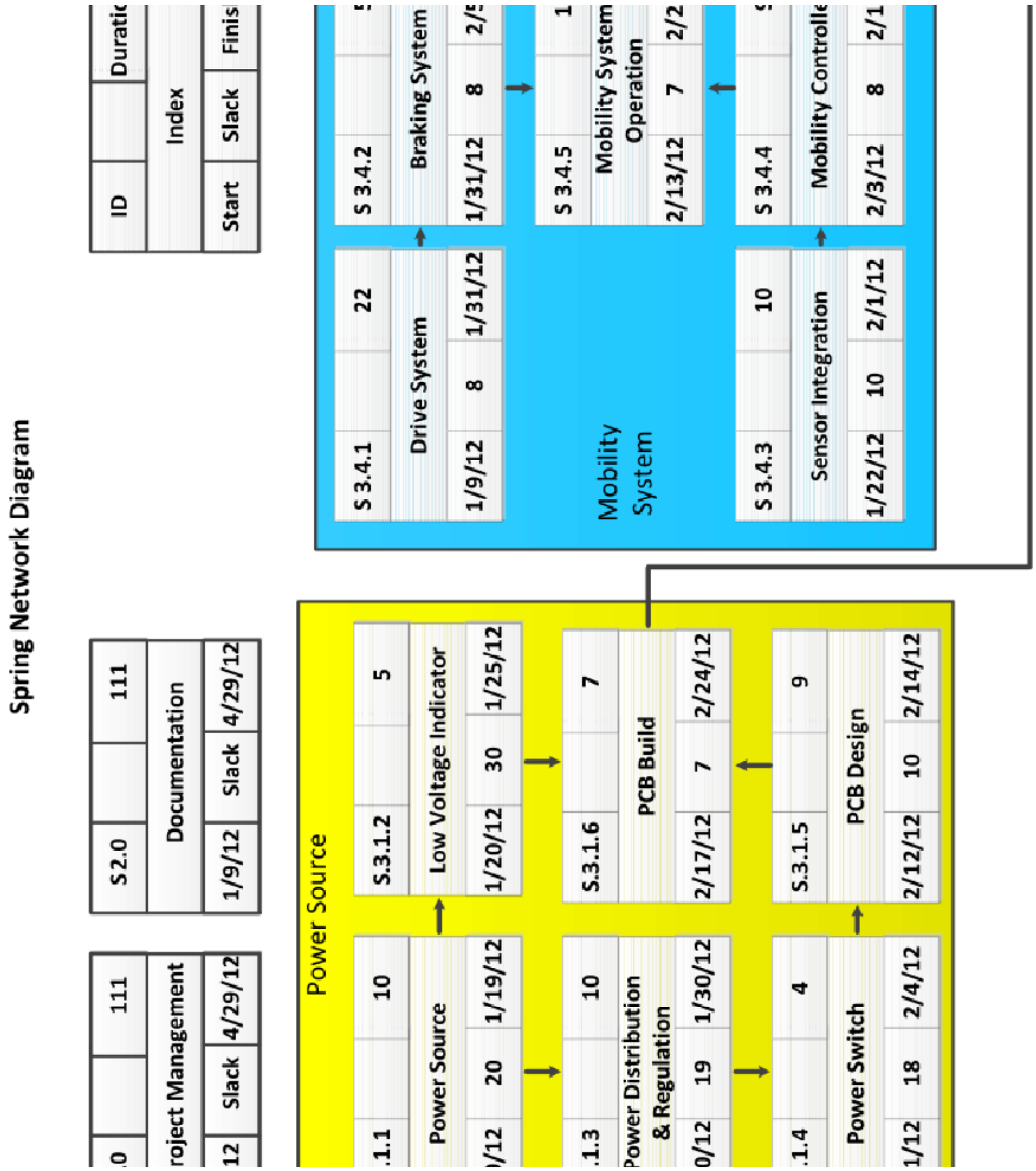
*I = Ivan, M = Mark, Mi = Michael, P = Prosper, T = Trevor

Spring 2012 Gantt Chart





Spring 2012 Network Diagram


Spring Network Diagram
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Slack
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S2.0
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Documentation
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Slack
4/29/12
Power Source
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5
Low Voltage Indicator
1/20/12
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1/25/12
Power Source
20
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1/19/12
S.3.1.6
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PCB Build
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S 3.4.5
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7
S 3.4.3
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Sensor Integration
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2/1/12
S 3.4.4
Mobility Controlle
2/3/12
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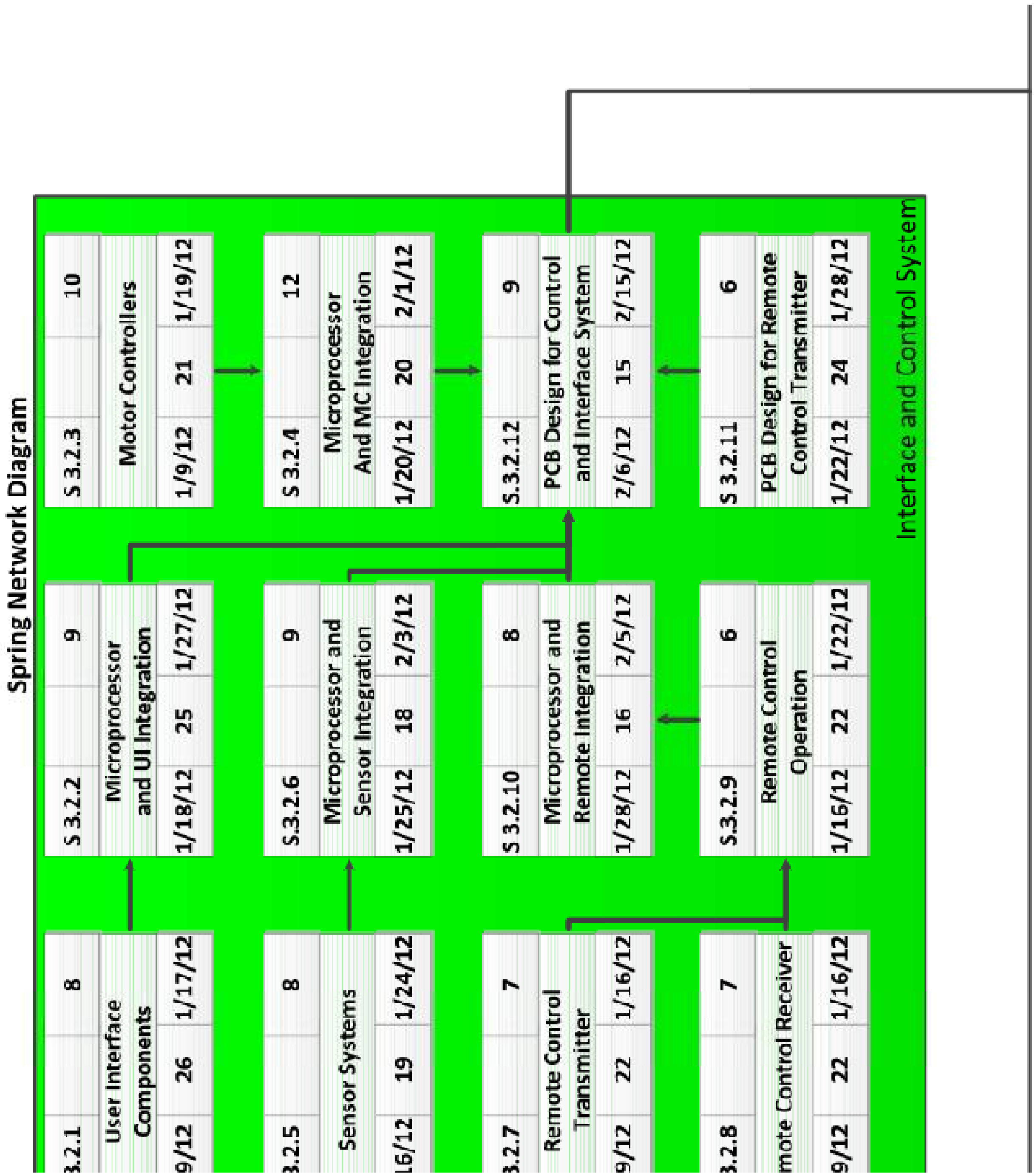
Spring Network Diagram
S 3.2.3
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S 3.2.4
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Microprocessor And MC Integration
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S 3.2.11
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PCB Design for Remote Control Transmitter
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Microprocessor and UI Integration
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S.3.2.6
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Microprocessor and Sensor Integration
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Microprocessor and Remote Integration
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User Interface Components
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Sensor Systems
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Remote Control Transmitter
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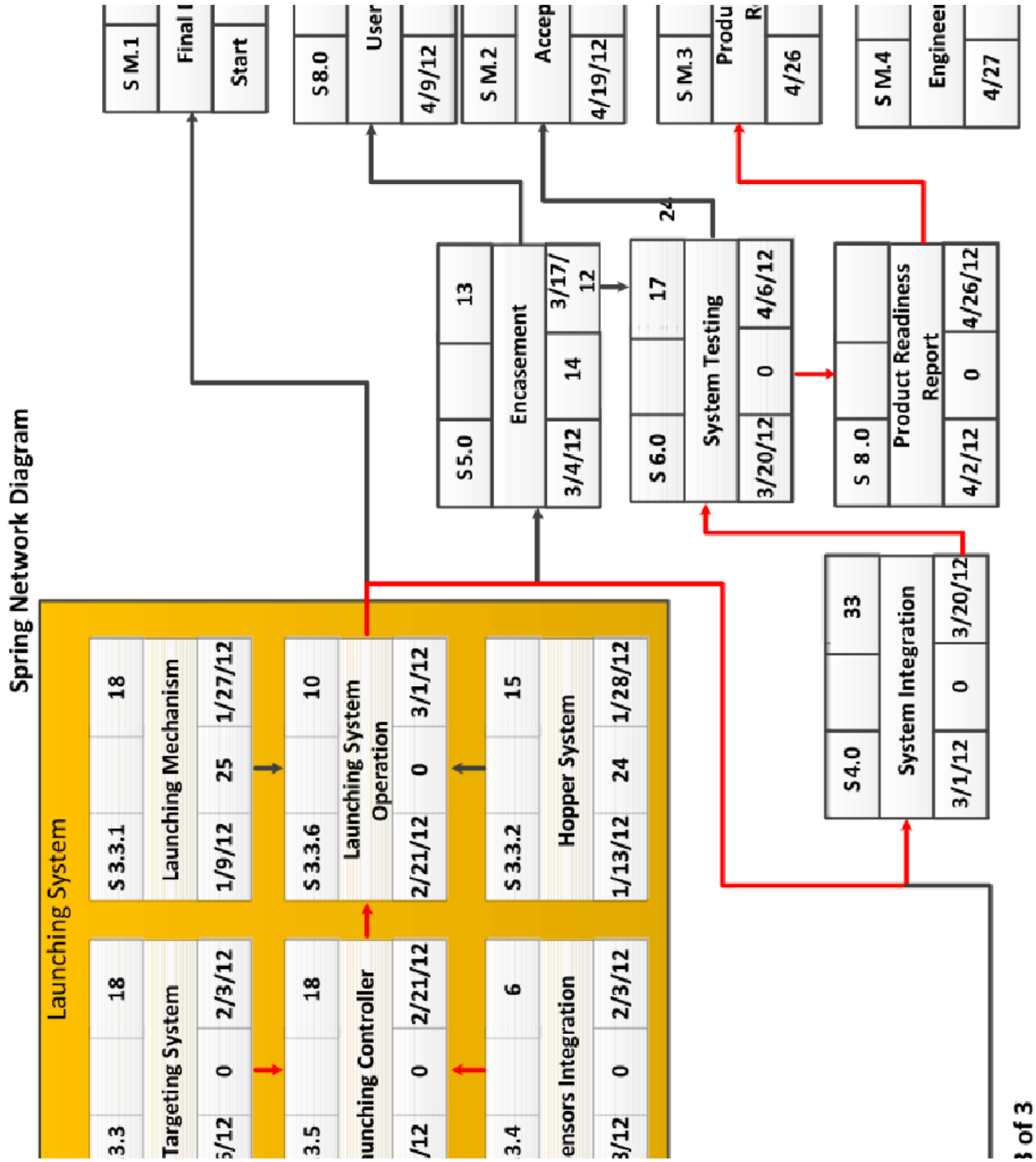
1/16/12
Interface and Control System


Spring Network Diagram
Launching System
S 3.3.1
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Launching Mechanism
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S 3.3.6
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Launching System Operation
2/21/12
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S 3.3.2
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Hopper System
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Targeting System
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Launching Controller
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Sensors Integration
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Encasement
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S 8.0
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S M.2
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S M.3
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S M.4
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Appendices

Appendix A – Requirements Specification Appendices

Appendix A.1 – Customer Needs-Metrics Matrix

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	Need / **Metric**	Stays within 6 m of center line	Launch speeds of 4 m/s - 45m/s	Horizontal angles of 40º - 140º	Vertical angles from 0º - 50º	Aim is switched in 3.0 ± 1.0 s	At least 90% accuracy	Controls in convenient location	Convenient instructions	Remote range of at least 30 m	Has power for at least an hour	Can withstand hit from returns	Minimum ball capacity of 150	Operational with only 1 ball	Operation with max capacity	Moving parts are encased	Mass is less than 60 kg	Water resistant
1	Mobility	X																
2	Various Launch Factors		X	X	X	X												
3	Precision						X											
4	Ease of Operation							X	X	X			X	X	X			
5	Long Operation Time										X		X	X	X			X
6	Safety											X				X		X
7	Portability																X	

Figure 57: Customer needs-metrics matrix

The needs listed above in Fig. 57 correspond to the seven needs listed in the Customer Needs section. The metrics are further described as following:

1. The device will not move further than 6.0 ± 0.5 meters from the center line of the court to avoid running away from the court or into another court.
2. The launching speed can vary, depending on the user input, from 4 m/s to 45 m/s.
3. The horizontal angle can vary from 40º to 140º in order to account for movement of the machine, while still making accurate shots.
4. The vertical angle can vary up to 50º to produce longer distance shots with slower speeds as well as add more variety to the shots.
5. The machine can vary its angle from one extreme to the other within 3.0 ± 1.0 seconds.
6. The machine can consistently hit the player's court without hitting the net at least 90% of the time
7. The controls for the machine are within standing reach of an average player.
8. The labels for the controls are readable for an average player.

9. The device can be started remotely from at least 30 meters away.
10. The device has enough power to run for at least 1 hour.
11. The machine can withstand being hit on over 100 returns at an initial speed of 30 meters per second.
12. The machine can hold at least 150 tennis balls.
13. The machine can shoot with only one ball left.
14. The machine can operate with the maximum capacity of tennis balls.
15. The moving parts of the machine are encased. The majority of moving parts will not be accessible without modifying the device.
16. The device will weigh less than 60 kilograms for portability.
17. The machine will resist light rain for a minimum time of 3 minutes.

Appendix A.2 – Tennis Court Dimensions and Test Grid

Figure 58 shows a diagram of the dimensions of a tennis court and the sections that will be used for testing purposes. The percent distributions of shot placements, corresponding to the grid is described in the Preliminary Test Plans section.

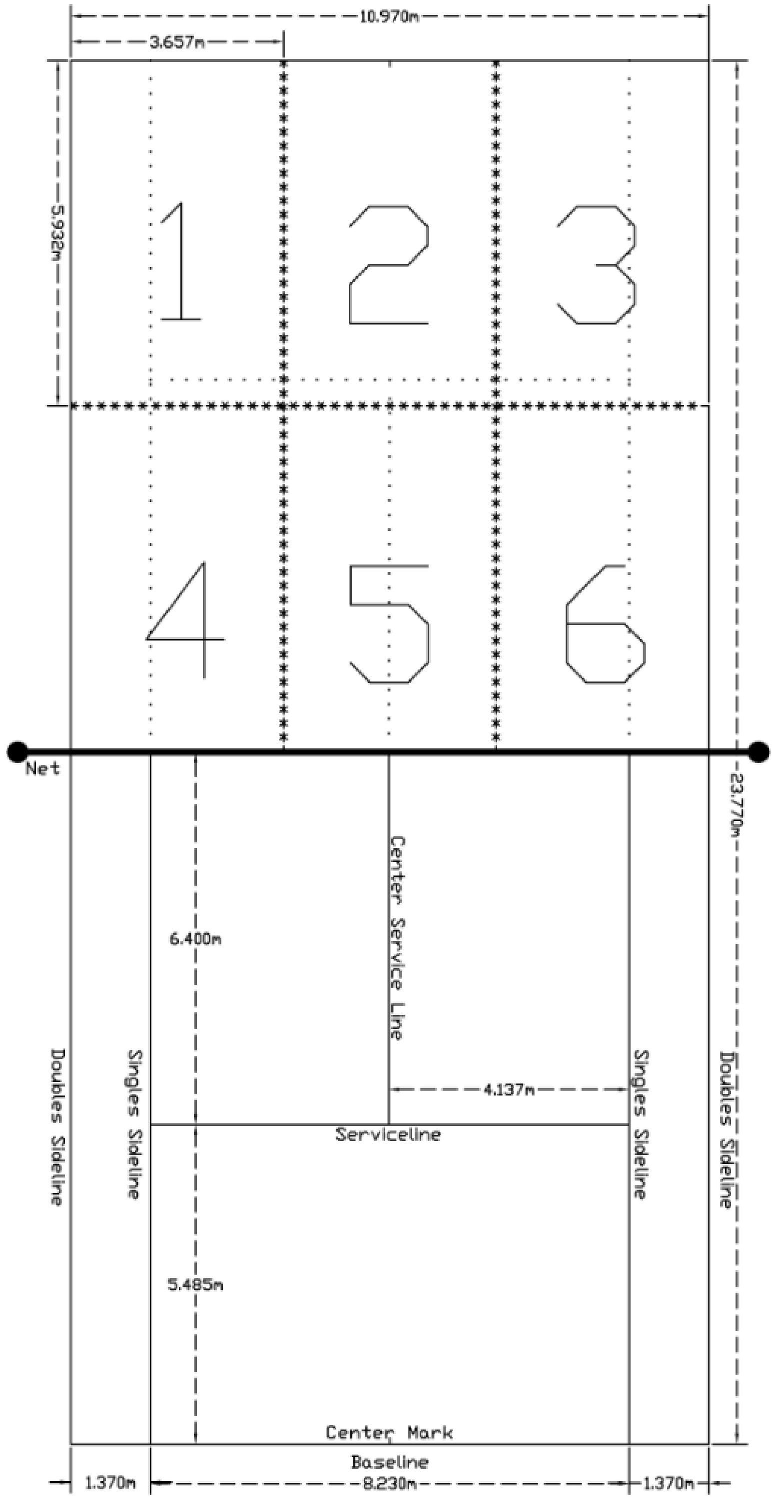


Figure 58: A diagram of the dimensions of the tennis court and the grid sections labeled 1 through 6 for testing the precision of the machine.

Appendix A.3 – Area of Operation of MATT

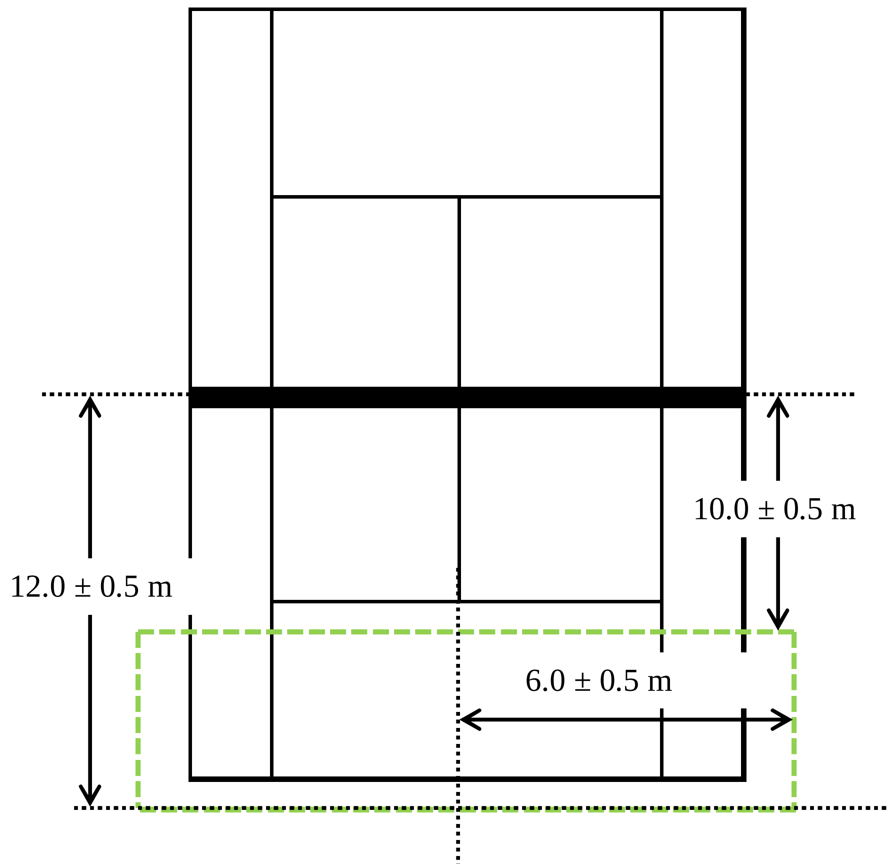


Figure 59: Diagram showing dimensions and location of acceptable area for range of motion.

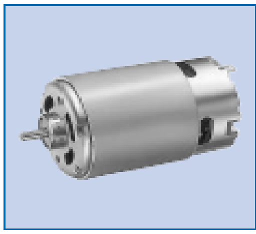
Appendix B – Mobility System Components

Appendix B.1 – Motors

M5-RS550-12-B Motors

Performance	
Model:	M5-RS550-12-B
Operating Voltage:	6 – 14.4 V
Nominal Voltage:	12 V
No Load RPM:	19300
No Load Current:	1.4 A
Stall Torque:	486.2 mN·m
Stall Current:	85 A
Kt	5.7 mN·m/A
Kv	1608 rpm/V
Efficiency	70%
RPM – Peak Efficiency:	17000
Torque – Peak Efficiency:	62.4 mN·m
Current – Peak Efficiency:	10.9 A
Physical	
Weight:	218 g
Length:	57 mm
Diameter:	38.5 mm
Shaft Diameter:	3.2 mm
Shaft Length:	7.6 mm

Price	**$7.50**
Shipping/Tax	$9.40
Quantity	2
Total Price	$24.40



RS-550PC/VC

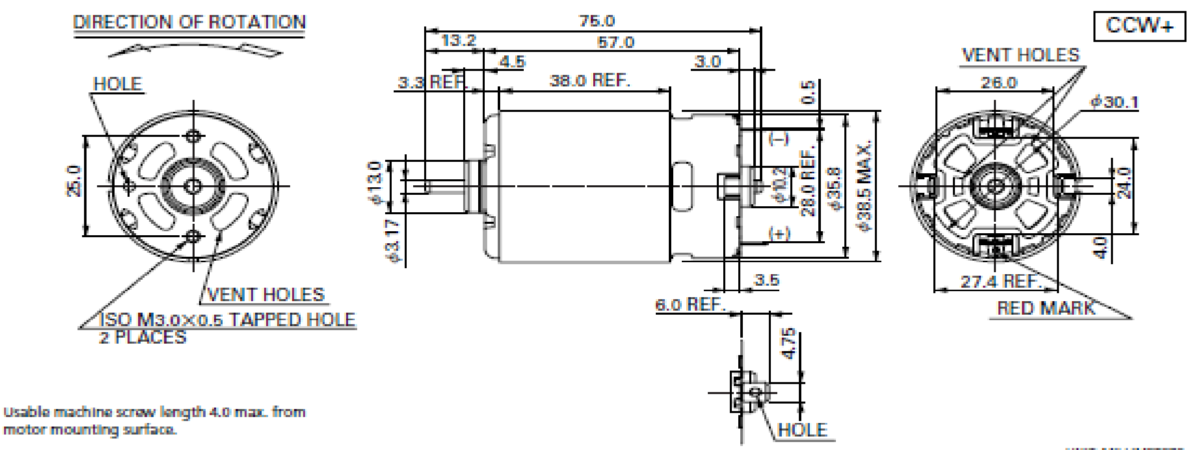
MABUCHI MOTOR
Carbon-brush motors

OUTPUT : 5.0W~100W (APPROX) WEIGHT : 255g (APPROX)

Typical Applications **Cordless Power Tools :** Drill / Cordless Garden Tool / Air Compressor
Toys and Models : Ride-on Toy

MODEL	VOLTAGE		NO LOAD		AT MAXIMUM EFFICIENCY					STALL		
	OPERATING RANGE	NOMINAL	SPEED	CURRENT	SPEED	CURRENT	TORQUE		OUTPUT	TORQUE		CURRENT
			r/min	A	r/min	A	mN·m	g·cm	W	mN·m	g·cm	A
RS-550PC-7527 (*1)	6.0~14.4	12V CONSTANT	18200	1.15	16130	8.97	47.8	488	80.7	421	4292	70.0
RS-550VC-7527 (*1)	6.0~14.4	14.4V CONSTANT	19800	1.30	17620	10.5	64.7	660	119	588	5994	85.0

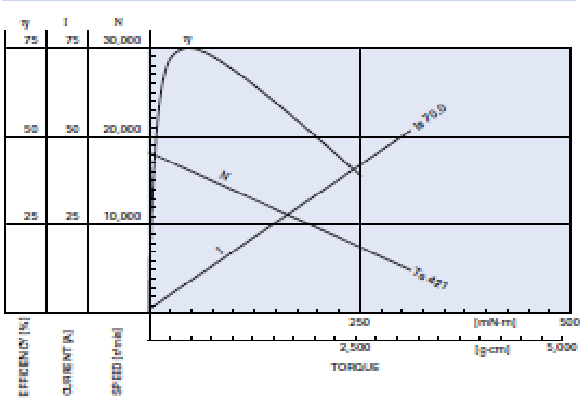
(*1) CCW shifted commutation (CCW+)



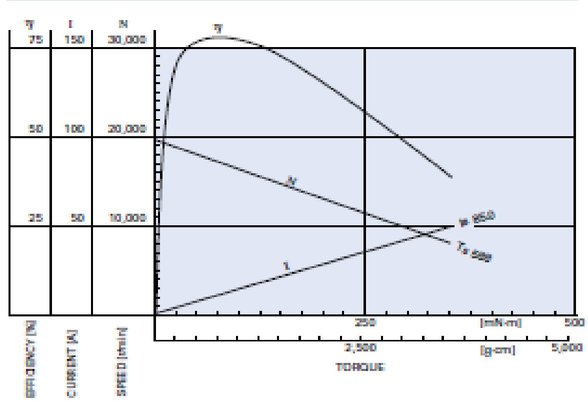
Usable machine screw length 4.0 max. from motor mounting surface.

UNIT: MILLIMETERS

RS-550PC-7527 12.0V



RS-550VC-7527 14.4V



Appendix B.2 – Gearboxes

Physical		
Type:	Planetary	
Reduction:	64:1	
Stages:	3	
Gear Material	All Metal	
Weight (Gearbox only):	7.2 oz	(205 g)
Weight (with motor):	12.6 oz	(358 g)
Length:	2.06 in	(52.4 mm)
Width (Square):	1.75 in	(45 mm)
Shaft Diameter:	0.5 in	(12.7 mm)
Shaft Length:	3.00 in	(76.2 mm)
Shaft Key:	0.125 in	(3.2 mm)
Shaft End Tap:	#8-32	
Mounting Holes (12):	#10-32	

Price	**$64.50**
Shipping/Tax	$9.40
Quantity	2
Total Price	$0.00*

*Repurposed for Harding University Engineering Department Lab

Appendix B.3 – Wheels

Arnold 10 inch Nylon Bearing Plastic Wheel

Vendor: Amazon

Specification:	Details:
Diameter:	10 inch
Tread:	Diamond tread
Hub Type:	Offset hub
Hub Length:	1.5 inch
Hub Diameter:	0.5 inch
Bearing:	Nylon bearing
Maximum Load:	80 lb

Price	$10.74
Shipping/Tax	N/A
Quantity	2
Total Price	$21.48

3-Inch Pivoting Caster Wheel

Vendor: Harding University Physical Resources

Item Description:

- Non-marking
- Quiet operation, provides low starting and rolling resistance
- Recommended for warehouse and many applications where high capacity and floor protection are required
- 3-inch swivel caster
- 210 lb. weight limit per wheel

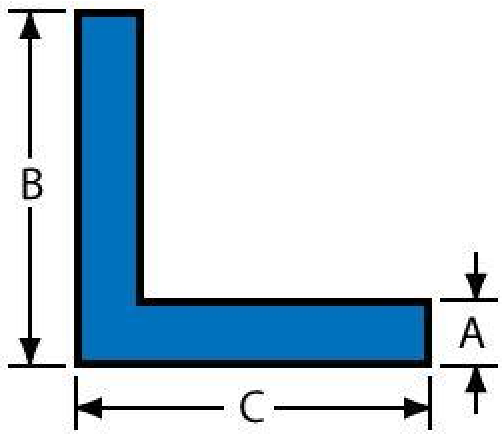
Price	$3.34
Shipping/Tax	$0.54
Quantity	2
Total Price	$7.22

Appendix B.4 –Frame and Encasement

Frame Materials

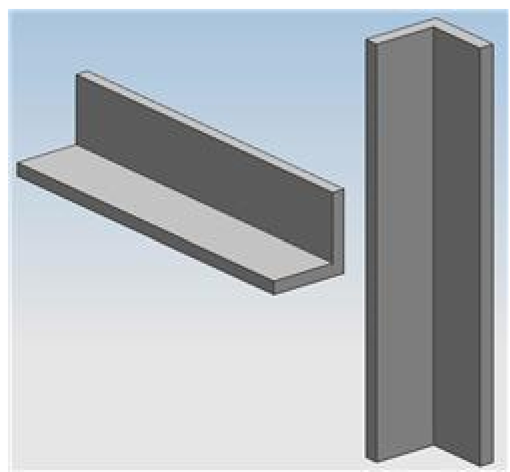
1/16" x 1/2" x 1/2" Angle 6063-T52 Aluminum

Vendor: Speedy Metals



Specification:	Details:
Dimension A:	0.0625 in
Dimension B:	0.5 in
Dimension C:	0.5 in
Length:	48 in
Manufacturing:	Extruded
Weight:	0.27 lbs
Material:	6063-T52 Aluminum

Price	$2.01
Shipping/Tax	$12.13
Quantity	18
Total Price	$48.31



Encasement Materials

0.25” x 4’ x 8’ Premium Underlayment Plywood

Vendor: Lowe’s

Price	$19.98
Shipping/Tax	$1.60
Quantity	1
Total Price	$21.58

Appendix C – Interface and Control System

Appendix C.1 –Code

Dimensional Standards

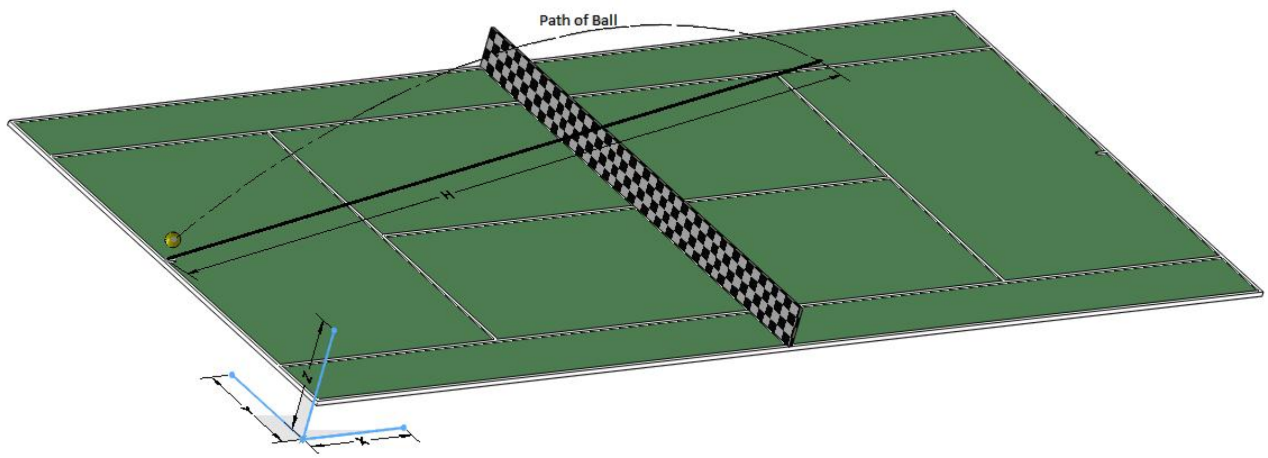


Figure 60: Dimensional representation

Figure 60 is a visual representation of the dimensions used in the physics calculations. With x being the long dimension of the court, y the short and z the vertical. H varies to be the horizontal path of the ball, allowing for 2 dimensional physics calculations instead of 3 dimensional calculations.

There are only 3 points of interest in the physics calculation; the point of launch, the net, and the point of impact. The point of launch, and the point of impact both have x, y, z, and h coordinates. The net has a constant x and z, an h coordinate and covers all y's within the court.

For the purposes of the code the points will be named as follows; M for point of origin (i.e. machine), T for point of impact (i.e. target), N for net (i.e. net).

Get Distance to Net

Finds the distance the ball has to travel before it passes the net given machine position and horizontal launching angle

$$H_n = \frac{N_x - M_x}{\cos \theta}$$

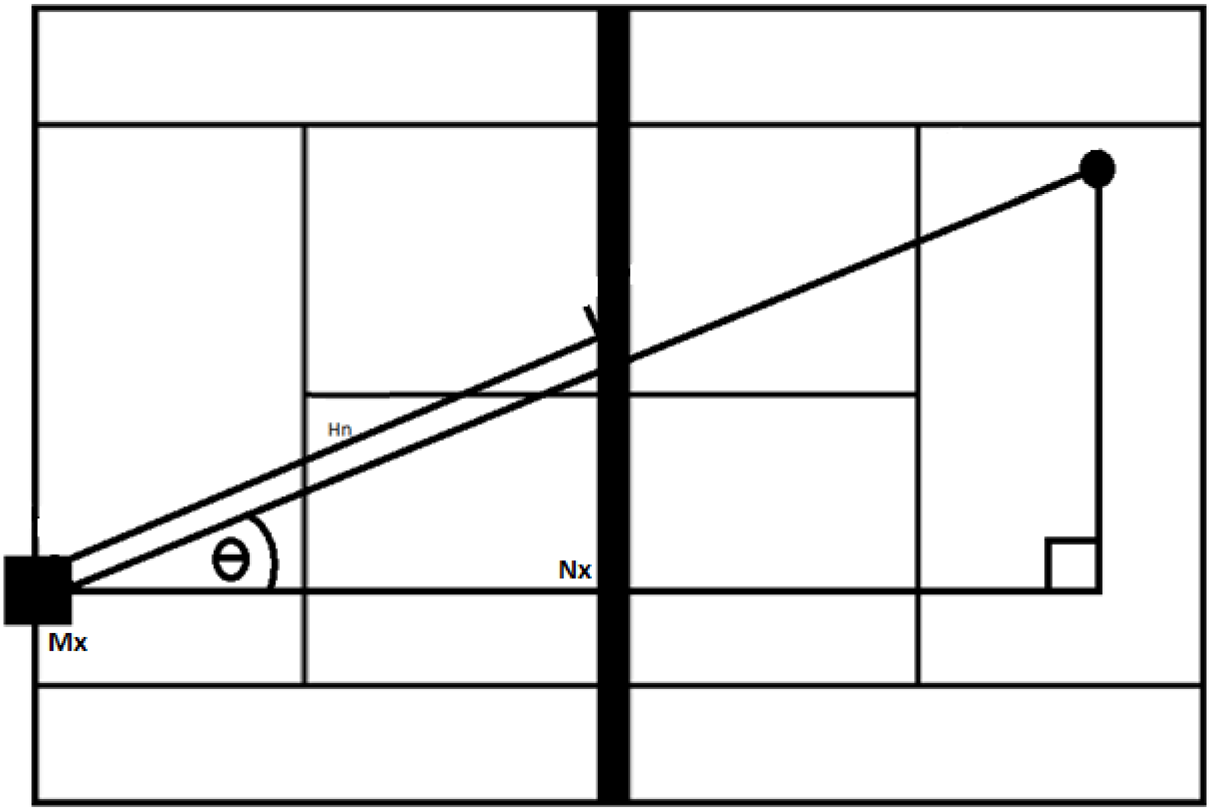


Figure 61: Trigonometry diagram for the distance to the net calculation

Hn = Distance from Machine to Net (along path of ball)
Nx = Nets X Coordinate
Mx = Machine's X Coordinate
θ (Theta) = Horizontal Launching Angle

```
int GetNetDistance(double Theta, int mx)
{
	return (nx-mx)/cos(Theta);
}
```

Get Target Distance

Finds horizontal distance the ball will travel given machine position and target position

$$H_t = \sqrt{(T_x - M_x)^2 + (T_y - M_y)^2}$$

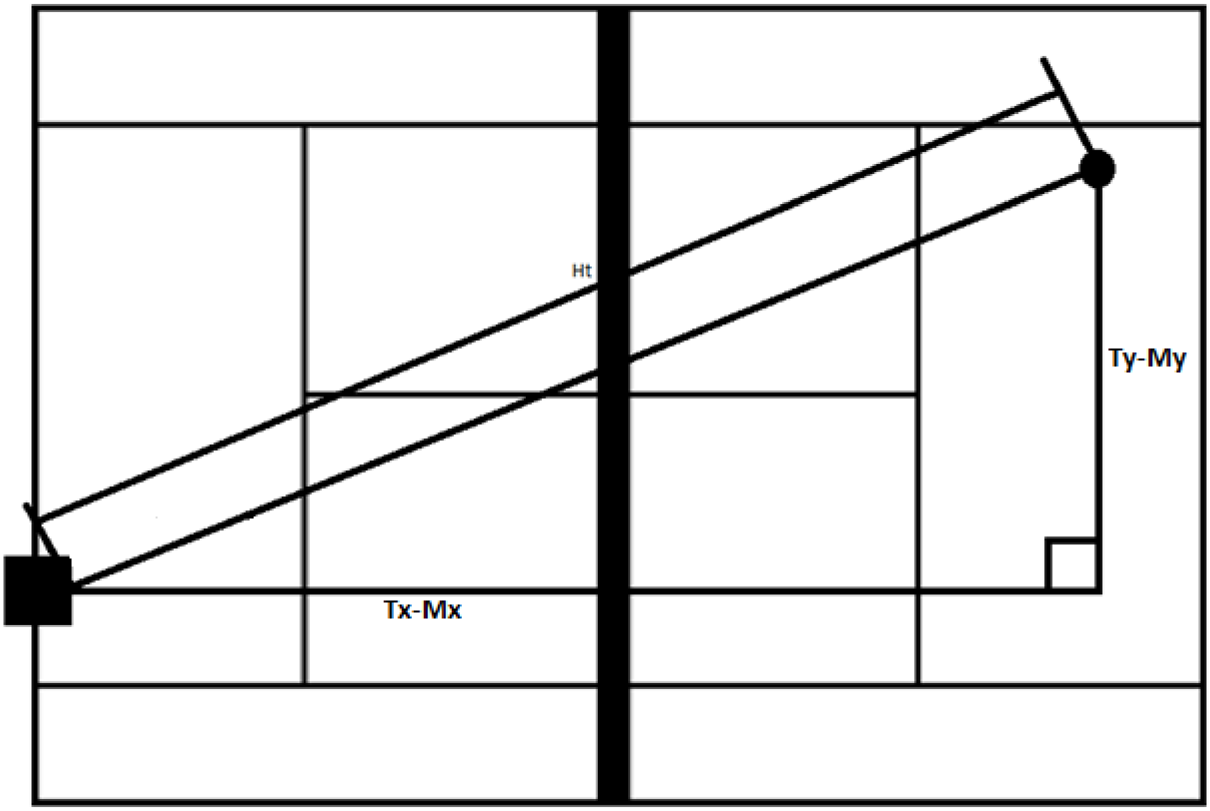


Figure 62: Trigonometry diagram for finding the distance to the target

Ht = Distance from Machine to Target

Tx = Target X Coordinate

Ty= Target Y Coordinate

Mx = Machine X Coordinate

My = Machine Y Coordinate

```
int GetTargetDistance ( int tx, int ty, int mx, int my)
{
        return sqrt( (double) (ty- my)*(ty- my) + (tx-mx)*(tx-mx) );
}
```

Get Horizontal Angle

Find horizontal launching angle given machine position and target position.

$$\theta = \arctan\left(\frac{Ty - My}{Tx - Mx}\right)$$

θ(theta) = Horizontal Launching Angle
Tx = Target’s X Coordinate
Ty = Target’s Y Coordinate
MX = Machine’s X Coordinate
My= Machine’ss Y Coordinate

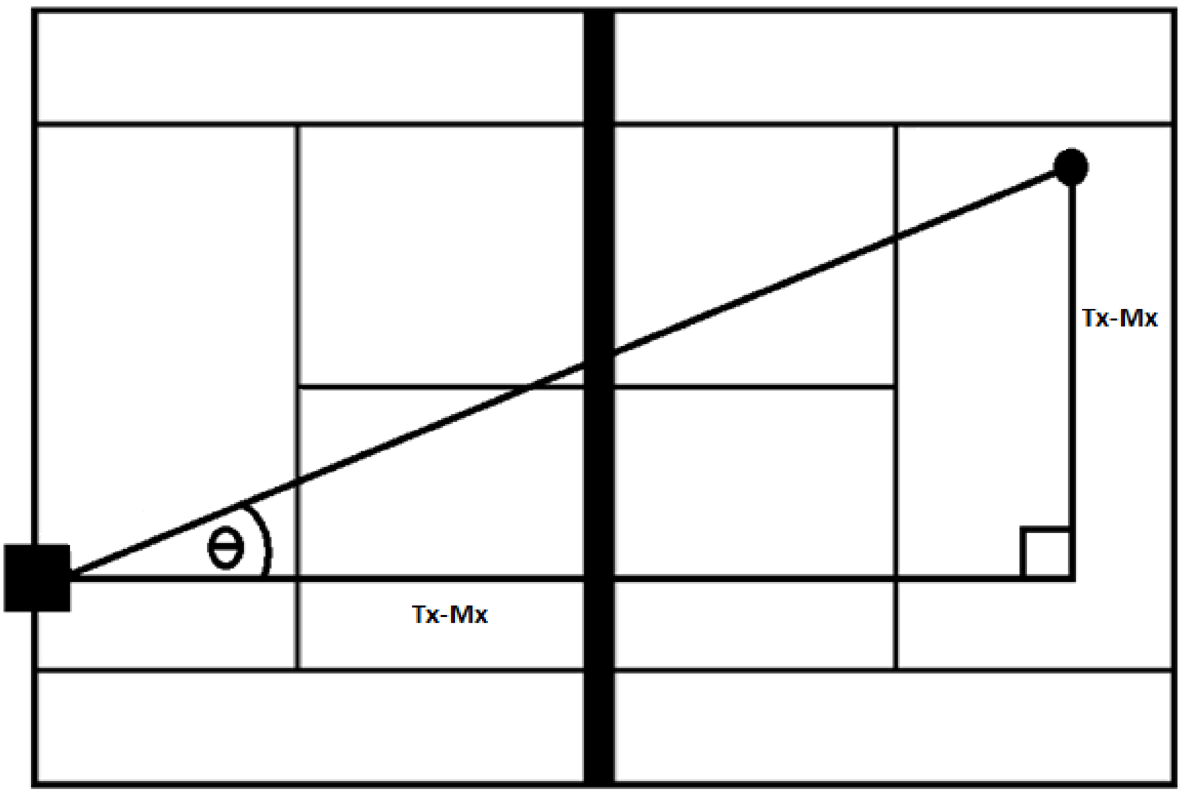


Figure 63: Trigonometry diagram for calculating horizontal angle

```
double GetAngle( int tx, int ty, int mx, int my)
{
        return atan((double) (ty- my)/(tx-mx));
}
```

Get Launch Speed

Determines the speed the ball has to travel to hit selected target at selected vertical angle (ignoring net and drag).

$$\square = \square_{\square} / \square_{\square}$$

$$\square_{\square} = \square \cos \square$$

$$\square_{\square} = \square \sin \square$$

$$\square = \frac{\square_{\square}}{\square \cos \square}$$

$$\square\square = \square_{\square}\,\square\square - \tfrac{1}{2}\square\;\square\square\;\square\square^{\square}$$

$$\square_{\square} - \square_{\square} = \square_{\square}\,\square\square - \tfrac{1}{2}\square\;\square\square\;\square\square^{\square}$$

$$\square_{\square} = \square_{\square} + \square \sin \square\;\square\frac{\square_{\square}}{\square \cos \square} - \tfrac{1}{2}\square\;\square\square\;\square\left(\frac{\square_{\square}}{\square \cos \square}\right)^{\square}$$

$$\square_{\square} = 0$$

$$0 = \square_{\square} + \square\square\;\square\tan\square\square\;\square - \frac{\square\;\square\square\square^{\square}}{2\,\square(\square\;\square\cos\square\square\;\square)^{\square}}$$

$$\frac{\square\;\square\square\square^{\square}}{2\,\square(\square\;\square\cos\square\square\;\square)^{\square}} = \square_{\square} + \square\square\;\square\tan\square\square\;\square$$

$$\frac{\square\;\square\square\square^{\square}}{\square_{\square} + \square\square\;\square\tan\square\square\;\square} = 2\,\square(\square\;\square\cos\square\square\;\square)^{\square}$$

$$\square\sqrt{\frac{\square\;\square\square\square^{\square}}{2(\square_{\square} + \square\square\;\square\tan\square\square\;\square)}} = \square\;\square\cos\square\square\;\square$$

$$\square\sqrt{\frac{\square\;\square\square\square^{\square}}{2(\square_{\square} + \square\square\;\square\tan\square\square\;\square)\cos\square\square\;\square^{\square}}} = \square$$

$$\square = \frac{\square\;\square\square\square\sqrt{2\;\square}}{2\;\square\;\square\square\square\sqrt{\sin\square\square\;\square + \square 0\;\square\cos\square\square\;\square}\;\square\square\sqrt{\cos\square\square\;\square}}$$

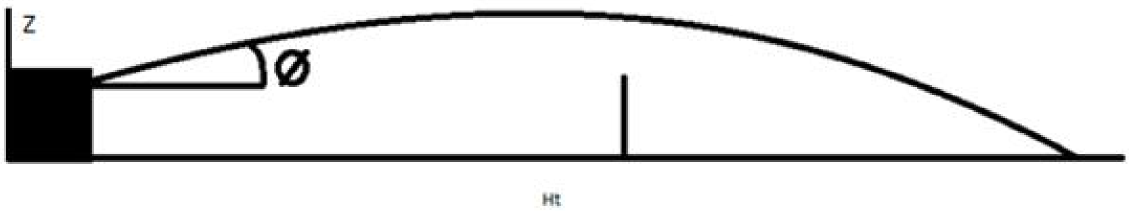


Figure 64: Ballistics trajectory of the ball

Phi(ϕ) = Vertical Angle
Ht = Distance to Selected Target
V = Launch Speed
g = Acceleration of Gravity
Z_0 = Initial Launch height

```
double GetLaunchSpeed (double Phi, int Ht)
{
        double V= (Ht * sqrt(2 * (double) g))/(2 * sqrt((double)Ht *sin(Phi) + Z0
*cos(Phi))*sqrt(cos(Phi)));
        return V;
}
```

Check if Ball Clears Net

Checks to see if Ball will clear the net with given target, vertical launch angle and launch speed (compensates for drag by assuming net is a foot taller than standard).

$$t = x_n / v_x$$

$$v_x = V \cos \phi$$

$$v_z = V \sin \phi$$

$$t = \frac{x_n}{V \cos \phi}$$

$$\Delta z = v_z t - \frac{1}{2} g t^2$$

$$z_n - z_0 = v_z t - \frac{1}{2} g t^2$$

$$z_n = z_0 + V \sin \phi \left(\frac{x_n}{V \cos \phi}\right) - \frac{1}{2} g \left(\frac{x_n}{V \cos \phi}\right)^2$$

$$z_n > h_n$$

$$h_n < z_0 + x_n \tan(\phi) - \frac{g x_n^2}{2 (V \cos(\phi))^2}$$

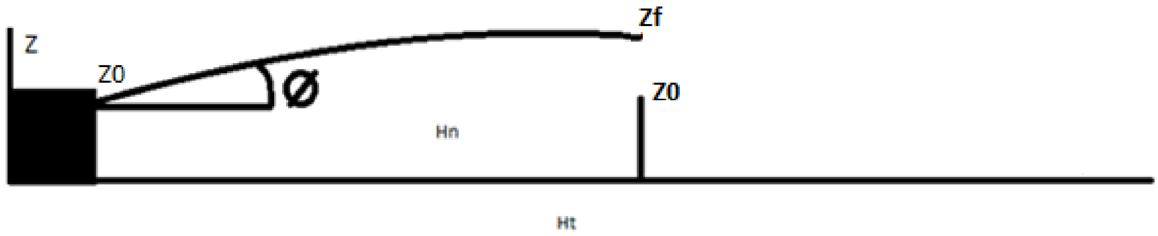


Figure 65: Ballistic trajectory for clear net check

Zn = Height of the net (+ 1 foot for drag compensation)
Z0 = Launching Height
Hn= Horizontal Distance to Net
Φ (Phi) = Vertical Launching Angle
g = Acceleration of Gravity

```
bool clearsNet ( double Phi, int Hn, double V)
        {
                int Zf = Z0 + Hn * tan(Phi) - .5 * g * (Hn * Hn)/(V * V * cos(Phi) * cos(Phi));
                if ( Zf > Zn)
                {
                        return true;
                }
                else
                {
                        return false;
                }
        }
```

Appendix D - Power Supply

Appendix D.1 – Battery Selection

☆ SPECIFICATION		☆ CHARACTERISTICS	
● NOMINAL VOLTAGE	: 12 V	● CAPACITY 25 °C / 77 °F	
● NOMINAL CAPACITY(20 hrs)	: 70.0 Ah	20 hr @ 3.5 A	: 70 Ah
● DIMENSIONS		10 hr @ 6.3 A	: 63 Ah
TOTAL HEIGHT	: 174 mm (6.85 inches)	5 hr @ 11.2 A	: 56 Ah
CONTAINER HEIGHT	: 174 mm (6.85 inches)	1 hr @ 42A	: 42 Ah
LENGTH	: 350 mm (13.78 inches)	1 C @ 70 A	: 35 Ah
WIDTH	: 166 mm (6.54 inches)	● INTERNAL RESISTANCE(25℃ , 77 ℉) : 7 mΩ	
WEIGHT	: APPROX23.0 kg (50.7 lbs)	● CHARGING VOLTAGE (25℃ , 77 ℉)	
● MAX DISCHARGE CURRENT	: 520 A (5 sec)	STANDBY USE	: 2.275±0.025 V/CELL
● MAX SHORT- DURATION DISCHARGE CURRENT	: 1300 A(0.1 sec)		: (-3.3mV / ℃ / CELL)
● STANDARD TERMINALS	: FP-28/RT-19	CYCLE USE	: 2.45±0.05 V/CELL
● CONTAINER MATERIAL	: GENERAL GRADE ABS		: (-5 mV / ℃ / CELL)
		● MAX CHARGING CURRENT	: 21 A

Appendix E – Launching System Components

Appendix E.1 – Launching Mechanism Components

Appendix E.1.1 – Motors

FIRST CIM Motor M4-R0062-12

Vendor: BaneBots

Specification:	Details:
Nominal Voltage:	12 V
RPM – Peak Eff:	4614
Torque – Peak Eff:	317.8 mN·m
Current – Peak Eff:	19.8 A
Weight:	1.3 Kg
Length:	4.32 in
Diameter:	2.6 in
Shaft Diameter:	0.31 in
Shaft Length:	1.4 in

Price	$28.00
Shipping/Tax	$11.85
Quantity	1
Total Price	$39.85

Appendix E.1.1.1 – Launching Mechanism Motor Calculation

Launching Motor Calculations			
Mass of Tennis Ball (kg)	0.06	Constant	
Radius of Tennis Ball (m)	0.03	Constant	
Mass of Wheel (kg)	0.85		
Radius of Wheel (m)	0.08		
Moment of Inertia of Tennis Ball (kg*m^2)	0.00		
Moment of Inertia of Wheel (kg*m^2)	0.00		
Top Velocity of Tennis Ball (m/s)	45.00		
Bottom Velocity of Tennis Ball (m/s)	45.00		
Top Angular Velocity (rad/s)	590.55	5639.35	rpm
Bottom Angular Velocity (rad/s)	590.55	5639.35	rpm
Total Velocity of Tennis Ball (m/s)	45.00		
Total Initial Angular Speed of Tennis Ball (rad/s)	0.00		
Kinetic Energy of Tennis Ball (J)	60.14		
Kinetic Energy of Wheels - No Load (J)	860.63		
Kinetic Energy of Wheels Right After Tennis Ball Is Launched (J)	800.48		
Assuming Final Angular Velocities Are Equal			
Initial Angular Velocity of Wheels (rad/s)	590.55		
Final Angular Velocity of Wheels (rad/s)	569.54		
Minimum Time Between Launches (s)	2.00		
Required Acceleration of Wheels After Tennis Ball Is Launched (rad/s^2)	10.50		
Required Torque (N*m)	0.03		
Required Torque (mN*m)	25.92		
Power (hp)	0.02		

Using a Factor of Safety of 1.5	
Required Torque (mN*m)	**38.88**
Power (hp)	**0.03**
Angular Velocity (rpm)	**8459.02**

Using a Factor of Safety of 2			
Required Torque (mN*m)	**51.84**		
Power (hp)	**0.04**	30.62	W
Angular Velocity (rpm)	**11278.70**		

Appendix E.1.2 –Launching Wheels

Arnold® 8 in x 1.75 in Plastic Wheel

Vendor: Tractor Supply Cº

- Maximum load capacity: 55 lb
- Tire type: Solid

Price	**$6.99**
Shipping/Tax	$1.12
Quantity	2
Total Price	$15.1

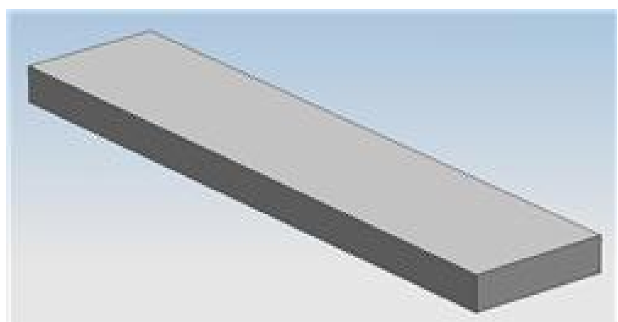
Appendix E.1.3 –Frame

1/4" (A) x 2-1/2" (B) 6061 – T6511 Aluminum, Extruded – 48"

Vendor: Speedy Metals

Item Description:

- Material: Aluminum
- Grade 6061
- Shape: Flat
- Weight: 2.96 lbs



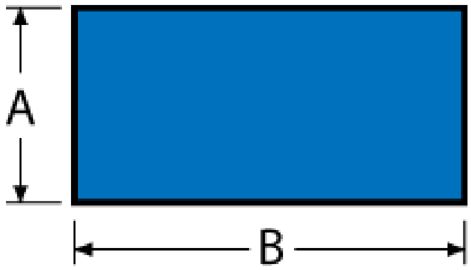
Price	**$17.42**
Shipping/Tax	$12.75
Quantity	1
Total Price	$30.17

1/4" (A) x 1” (B) 6061 – T6511 Aluminum, Extruded – 24”

Vendor: Speedy Metals

Item Description:

- Material: Aluminum
- Grade 6061
- Shape: Flat
- Weight: 0.44 lbs

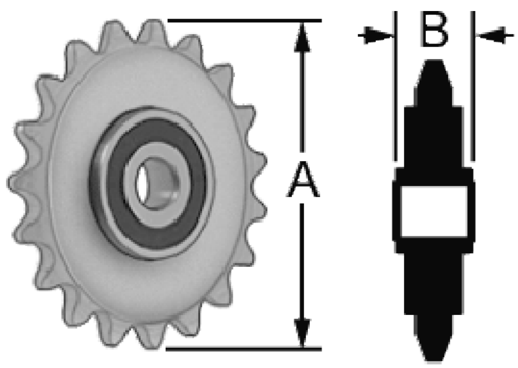


Price	$2.5
Shipping/Tax	$0
Quantity	1
Total Price	$2.5

Appendix E.1.4 –Sprockets

Idler Sprocket with Bearing – 6663K22

Vendor: McMaster-Carr



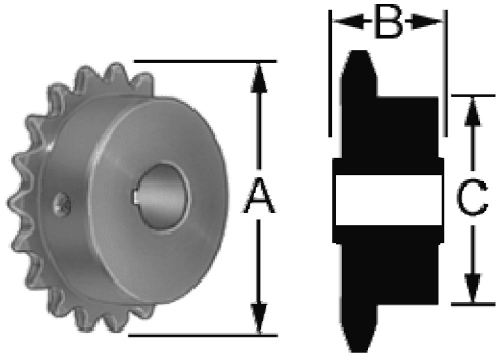
Specification:	Details:
Chain Type:	ANSI 35
Pitch:	0.375 inch
Teeth:	19
Bore Diameter:	0.5 inch
Outer Diameter (A):	2.47 inch
Width (B):	0.375 inch

Price	$22.22
Shipping/Tax	N/A
Quantity	1
Total Price	$22.22

Finished Bore Sprockets – 6280K332 (Wheel Sprockets)

Vendor: McMaster-Carr

Specification:	Details:
Chain Type:	ANSI 35
Pitch:	0.375 inch
Teeth:	11
Bore Diameter:	0.5 inch
Outer Diameter (A):	1.5 inch
Width (B):	0.75 inch
Hub Diameter (C):	1.0625 inch

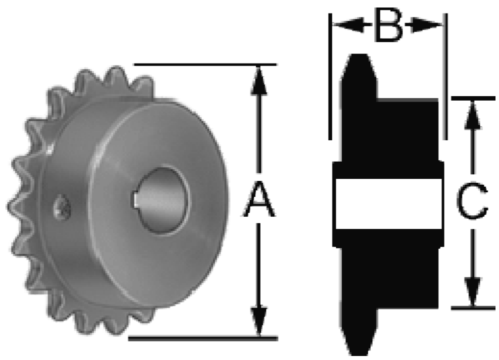


Price	$8.86
Shipping/Tax	N/A
Quantity	2
Total Price	17.72

Finished Bore Sprockets – 6280K331 (Motor Sprocket)

Vendor: McMaster-Carr

Specification:	Details:
Chain Type:	ANSI 35
Pitch:	0.375 inch
Teeth:	11
Bore Diameter:	0.375 inch
Outer Diameter (A):	1.5 inch
Width (B):	0.75 inch
Hub Diameter (C):	1.0625 inch

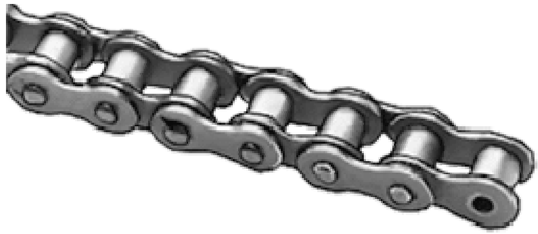


Price	$8.86
Shipping/Tax	N/A
Quantity	1
Total Price	$8.86

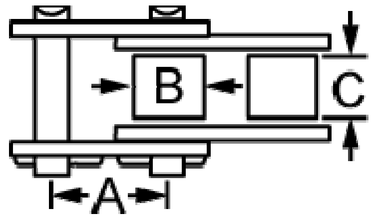
Appendix E.1.5 –Chain

ANSI 35 Roller Chain – 6261K172

Vendor: McMaster – Carr



Specification:	**Details:**
Chain Type:	ANSI 35
Pitch (A):	0.375 inch
Roller Diameter (B):	0.200 inch
Roller Width (C):	0.1875 inch
Working Load:	269 lbs



Price	**$3.14/ft**
Shipping/Tax	N/A
Quantity	4ft
Total Price	$12.56

Appendix E.1.6 –Shaft

Steel Rod – 3 ft x ½ in diameter - 44093

Vendor: Lowe's

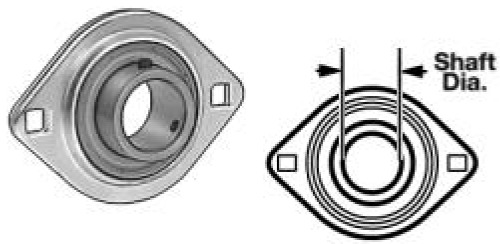
Price	**$5.25**
Shipping/Tax	$0.42
Quantity	1
Total Price	$5.67

Appendix E.1.7 –Bearings

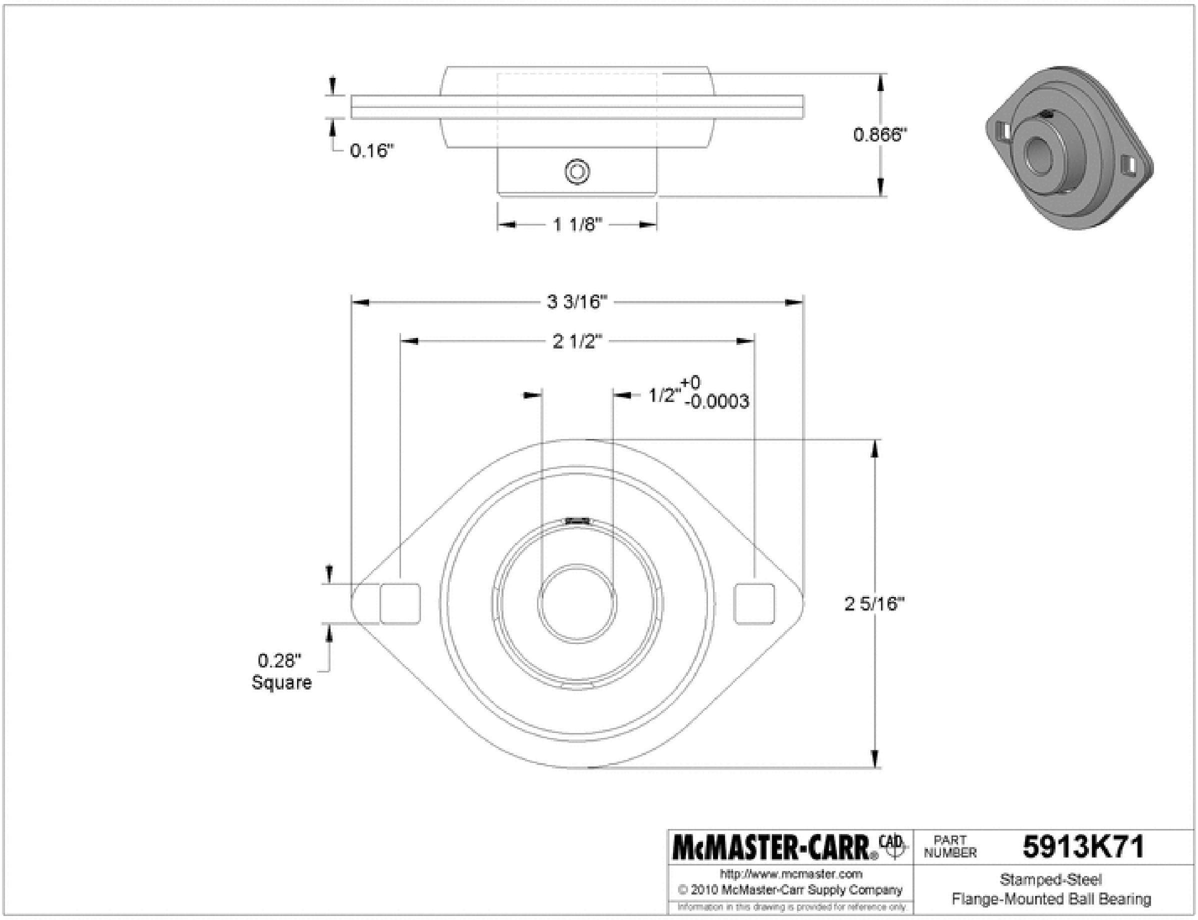
Mounted Bearings - 5913K71

Vendor: McMaster – Carr

Specification:	Details:
Mounting Style:	Flange Mount
Flange Mount Type:	Standard
Type:	General Purpose
Bearing Style:	Ball
Shaft Diameter:	0.5 inch
Radial Load Capacity:	716 lbs
Maximum RPM:	5800
ABEC Precision Bearing Rating	ABEC-1
Housing Material:	Steel
Steel Housing Material:	Stamped Steel
Bearing Material:	Steel
Temperature Range:	-4° - 212° F
Bearing Construction:	Double Sealed
Secure/Attaches With:	Double Set Screw



Price	$11.33
Shipping/Tax	N/A
Quantity	4
Total Price	$45.32


0.16"
0.866"
1 1/8"
3 3/16"
2 1/2"
1/2" +0 -0.0003
2 5/16"
0.28" Square
McMASTER-CARR CAD
PART NUMBER
5913K71
http://www.mcmaster.com
© 2010 McMaster-Carr Supply Company
Information in this drawing is provided for reference only
Stamped-Steel
Flange-Mounted Ball Bearing

Appendix E.2 – Angular Targeting Mechanism Components

Appendix E.2.1 –Motor

Vender: Wonder Motor

Item Description:

The gear motor is measured to be 7 inch long and the motor itself has a diameter of 2.5 inches. Drive shaft is 10mm in diameter with 2 flats where flat to flat is 6mm. The shaft has a threaded end that is to fit a M6 tightening nut. Rated voltage of this gear motor is 13.5 VDC and maximum speed is 50 RPM. Rated output load is 60 watts and output torque at 50 RPM is 11.5 N-m (8.5 ft-lb). Mounting is based on M6 screw mounting.

Price	$79.95
Shipping/Tax	N/A
Quantity	1
Total Price	$0.00*

*Repurposed for Harding University Engineering Department Lab

Appendix E.2.2 –Bearing

Waxman Stainless Steel 6 inch Lazy Susan Bearing

Vendor: Lowe's

Item Description:

- 6 inch square plate
- 0.25 inch ball bearings
- 300 lbs maximum load
- 12 – 25 inch turntable diameter

Price	**$4.43**
Shipping/Tax	$1.14
Quantity	1
Total Price	$5.57

Appendix E.3 – Vertical Targeting Mechanism Components

Appendix E.3.1 –Electric Car Scissor Jack

UPG 86025 12V Automotive Tire Jack

Vendor: Amazon

Item Description:

- Plugs into 12V DC power source
- Dimensions: 16 x 5 x 6.8 in
- Weight: 9 lbs
- Maximum load: 2200 lbs
- Draws maximum of 10-amp current

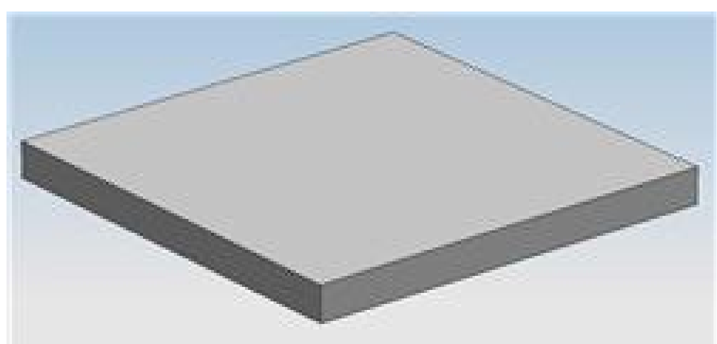
Price	**$56.32**
Shipping/Tax	$0
Quantity	1
Total Price	$56.32

Appendix E.3.2 –Frame

3/16" 6061 – T6 Aluminum Plate – 12" x 18" Plate

Vendor: Speedy Metals

Item Description:



- Material: Aluminum
- Grade 6061
- Shape: Plate
- Weight: 4.1 lbs

Price	**$28.01**
Shipping/Tax	$5
Quantity	1
Total Price	$33.01

Appendix E.4 – Hopper and Feeder System

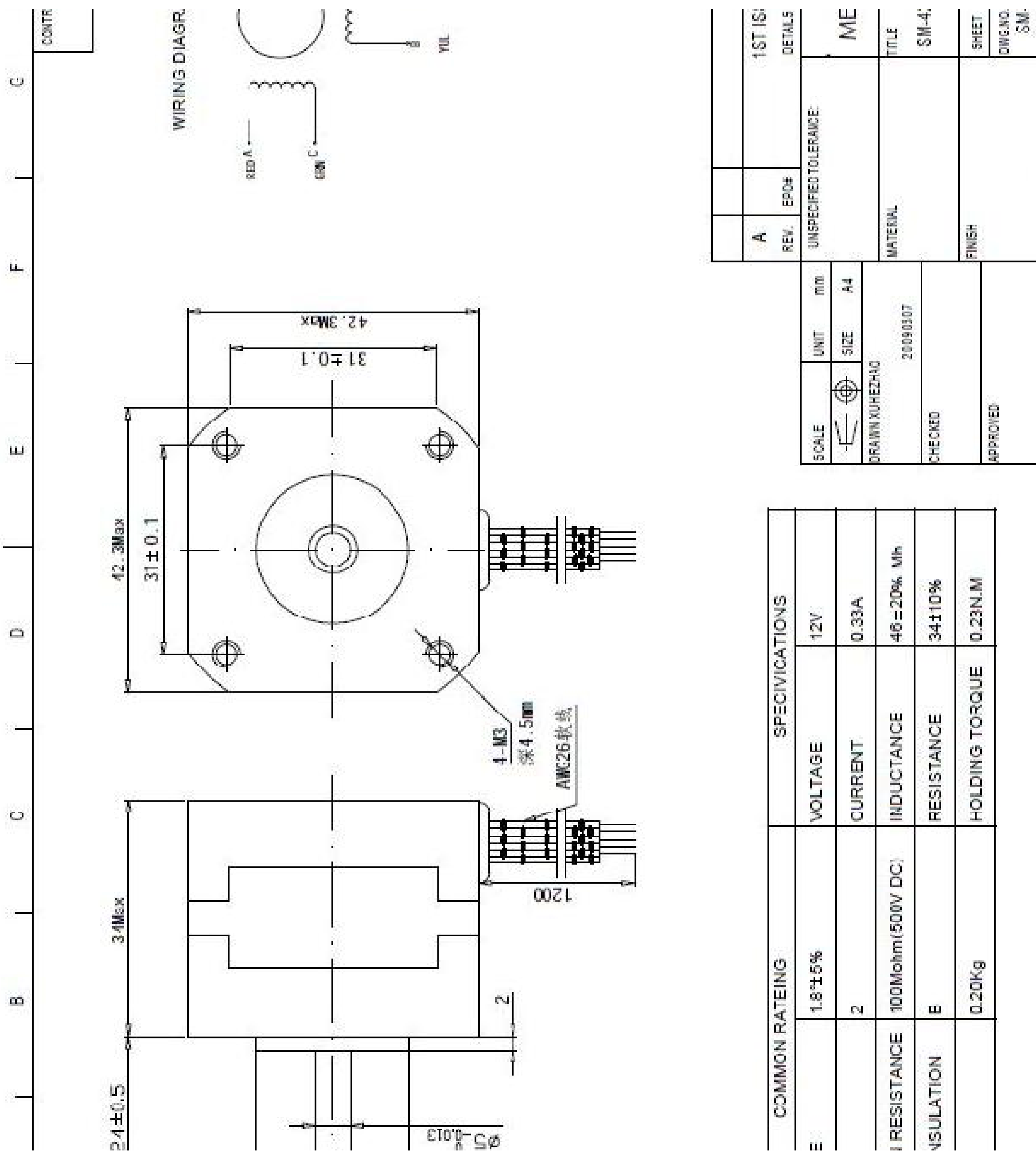
Appendix E.4.1 –Motor

Bipolar Stepper Motor - M-200-ROB-09238

Vendor: Trossen Robotics

Specification:	**Details:**
Step Angle:	1.8º
Phases:	2
Rated Voltage:	15.4 V
Rated Current:	0.28 A
Holding Torque:	2.4 kg·cm
Detent Torque:	120 g·cm

Price	**$14.95**
Shipping/Tax	$7.99
Quantity	1
Total Price	22.93


WIRING DIAGR.
RED A
GRN C
YEL
42.3Max
31±0.1
34Max
4-M3
深4.5mm
AWG26软线
1200
2
24±0.5
SPECIVICATIONS
VOLTAGE 12V
CURRENT 0.33A
INDUCTANCE 46±20% Mh
RESISTANCE 34±10%
HOLDING TORQUE 0.23N.M
COMMON RATEING
1.8°±5%
2
RESISTANCE 100Mohm(500V DC)
NSULATION E
0.20Kg
A
REV.
EPO#
1ST IS
DETAILS
UNSPECIFIED TOLERANCE:
SCALE
UNIT mm
SIZE A4
DRAWN XUHEZHAO
20090307
CHECKED
APPROVED
MATERIAL
FINISH
TITLE
SM-4
SHEET
DWG.NO.
SM.

Appendix E.4.2 –Hopper Material

Garden Zone 24" x 25' Welded Cage Wire Fence - 432425

Vendor: ACE Hardware

Item Description:

- 4" x 25 feet
- 1" x 2" mesh openings
- 14 gauge galvanized wire
- Heavy gauge utility mesh
- 25 foot rolls

Price	**$28.99**
Shipping/Tax	$2.32
Quantity	1
Total Price	$31.31

Appendix E.4.3 –Feed Tube

Imperial 3" x 8' Semi-Rigid Aluminum Duct

Vendor: Lowe's

Item Description:

- Flexible
- Semi-Rigid
- Aluminum
- 8 foot in length

Price	**$9.86**
Shipping/Tax	N/A
Quantity	1
Total Price	$9.86

Appendix F – Remote Control Components and FCC Regulations

WENSHING®© **TWS-BS** RF MODULE Series

Wireless Hi Power Transmitter Module (RF ASK)

Version History

Version	Date	Changes
V1.01	Mar. 01, 2002	1st. Edition
V1.02	Jul. 05, 2008	2nd. Edition
V1.03	Oct. 20, 2010	3rd. Edition

Model : TWS-BS-6

- Frequency Range: 315MHz
- Modulate Mode: ASK
- Circuit Shape: SAW
- Date Rate: 8Kbps
- Supply Voltage: 1.5~12V
- Output Power : 14dBm
- Working temperature: -20~+85℃
- Solder temperature: 230℃(10 seconds).
- High sensitivity is designed.

Application

● Wireless Data Transmission	● Wireless Game Pad
● Remote Control	● Wireless Toys
● Car Key	● Home Automation
● AMR- Automatic Meter Reading	● Remote Keyless Entry

Absolute Maximum Rating

Rating	Value	Unit
Power Supply and All Input/ Output Pins	-0.3~+12.0	V
Non-Operating Case Temperature	-20~+85	℃
Soldering Temperature(10 seconds)	230	℃

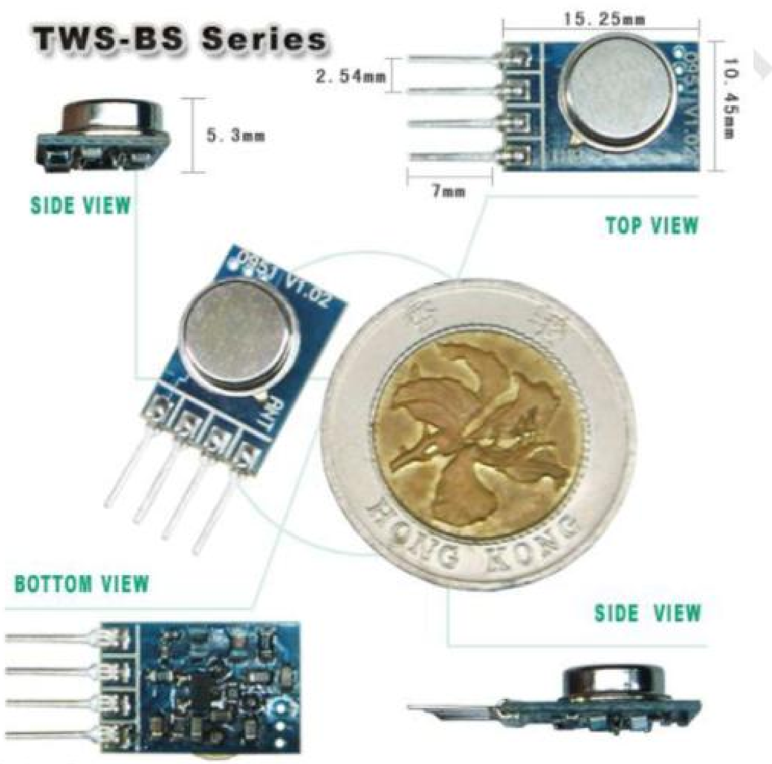
Electrical Characteristic

Characteristic	Min	Type	Max	Unit
Operating Frequency (±250KHz)	314.75	315.00	315.25	MHz
Data Rate			8	Kbps
Current Consumption			8	mA
Output Power			32	mW
Operating Voltage	3		12	VDC
Operating Ambient Temperature	-20		+85	℃

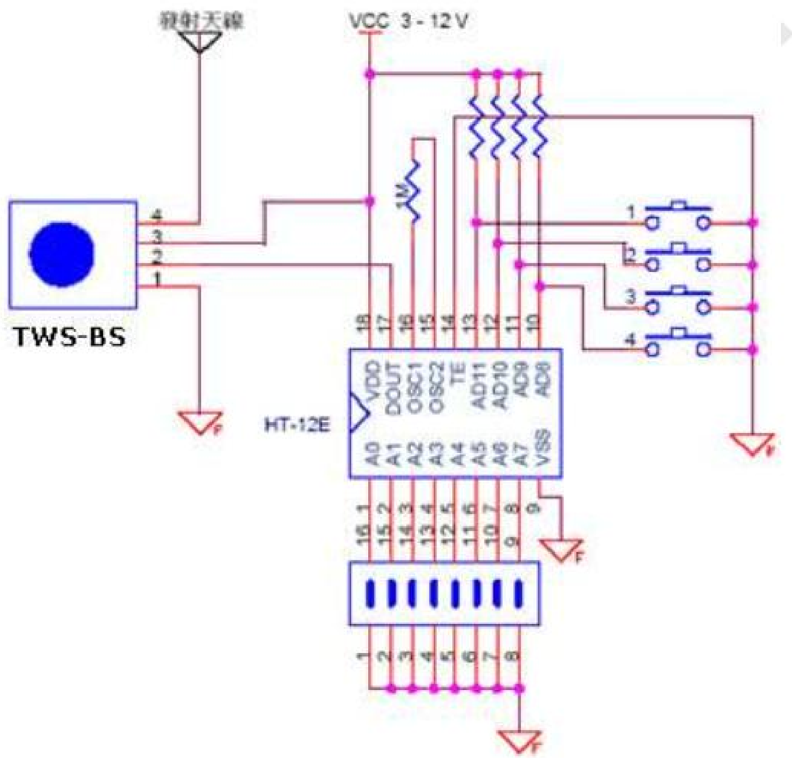
Pin Assignment

Pin	Function
1	GND
2	Data in
3	Vcc
4	ANT

Size

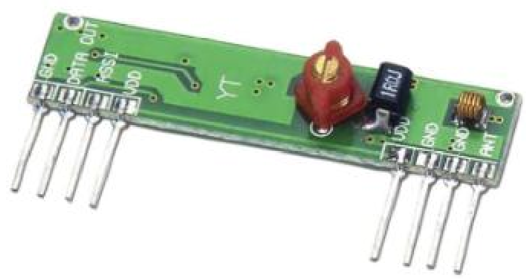

TWS-BS Series
15. 25mm
2. 54mm
10. 45mm
5. 3mm
7mm
SIDE VIEW
TOP VIEW
0853 V1.02
ANT
HONG KONG
BOTTOM VIEW
SIDE VIEW

Demo Circuit



WENSHING®© **RWS-374** RF MODULE Series

Wireless Hi Sensitivity Receiver Module (RF ASK)



Version History

Version	Date	Changes
V1.01	Mar.7, 2004	1st. Edition
V1.02	Jul.2,2008	2nd. Edition

Model: RWS-374-3

- Frequency Range: 315MHz
- Modulate Mode: ASK
- Circuit Shape: LC
- Date Rate: 4800 bps
- Selectivity: -108 dBm
- Channel Spacing: ±500KHz
- Supply Voltage: 5V
- High sensitivity passive design
- Simple to apply with low external count

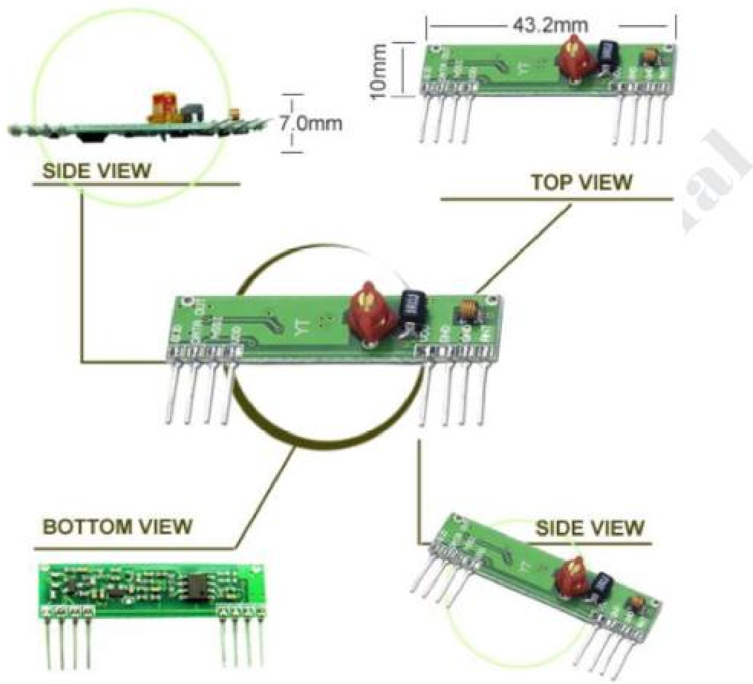
Electrical Characteristic

Characteristic	Sym	Min	Type	Max	Unit
Operating Radio Frequency	FC	314.500	315.000	315.500	MHz
Sensitivity	Pref.	-106	-108	-110	dBm
Channel Width		-500		+ 500	KHz
Noise Equivalent BW	NEB		5	4	
Baseboard Data Rate				3	KB/S
Receiver Turn On Time				3	ms

DC Characteristic

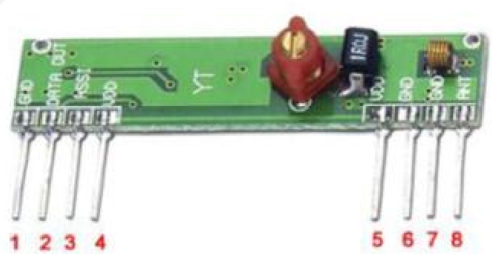
Symbol	Parameter	Condition	Min	Type	Max	Unit
Vcc	Operating Supply Voltage		4.9	5	5.1	
I Tot	Operating Supply Voltage			4.5		
V Data	Data Out	1 Data=+200uA (High)	Vcc -0.5	Vcc		V
		1 Data=-10uA (Low)			0.3	V

Size

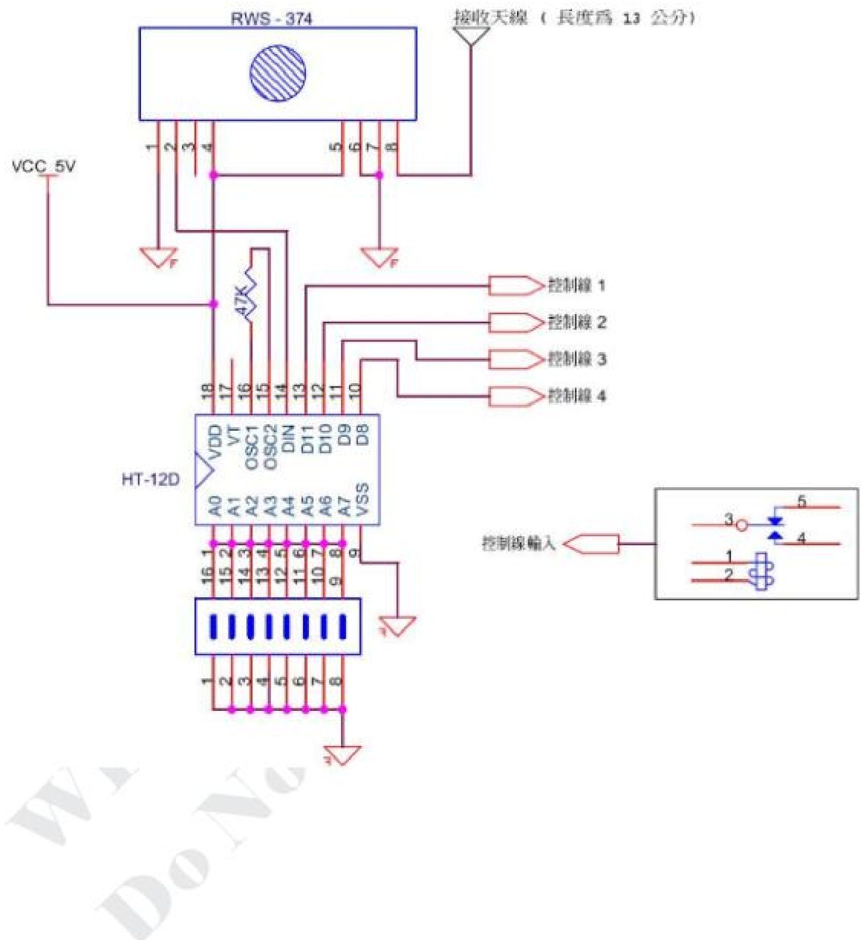


Pin Assignment

Pin	Function
1	GND
2	Digital Output
3	Linear Out
4	VCC
5	VCC
6	GND
7	GND
8	ANT(About 13cm)



Demo Circuit



HOLTEK

HT12D/HT12F
2^{12} Series of Decoders

Features

- Operating voltage: 2.4V~12V
- Low power and high noise immunity CMOS technology
- Low standby current
- Capable of decoding 12 bits of information
- Binary address setting
- Received codes are checked 3 times
- Address/Data number combination
  - HT12D: 8 address bits and 4 data bits
  - HT12F: 12 address bits only
- Built-in oscillator needs only 5% resistor
- Valid transmission indicator
- Easy interface with an RF or an infrared transmission medium
- Minimal external components
- Pair with Holtek's 2^{12} series of encoders
- 18-pin DIP, 20-pin SOP package

Applications

- Burglar alarm system
- Smoke and fire alarm system
- Garage door controllers
- Car door controllers
- Car alarm system
- Security system
- Cordless telephones
- Other remote control systems

General Description

The 2^{12} decoders are a series of CMOS LSIs for remote control system applications. They are paired with Holtek's 2^{12} series of encoders (refer to the encoder/decoder cross reference table). For proper operation, a pair of encoder/decoder with the same number of addresses and data format should be chosen.

The decoders receive serial addresses and data from a programmed 2^{12} series of encoders that are transmitted by a carrier using an RF or an IR transmission medium. They compare the serial input data three times continuously with their local addresses. If no error or unmatched codes are found, the input data codes are decoded and then transferred to the output pins. The VT pin also goes high to indicate a valid transmission.

The 2^{12} series of decoders are capable of decoding informations that consist of N bits of address and 12–N bits of data. Of this series, the HT12D is arranged to provide 8 address bits and 4 data bits, and HT12F is used to decode 12 bits of address information.

Selection Table

Function / Part No.	Address No.	Data		VT	Oscillator	Trigger	Package
		No.	Type				
HT12D	8	4	L	√	RC oscillator	DIN active "Hi"	18DIP, 20SOP
HT12F	12	0	—	√	RC oscillator	DIN active "Hi"	18DIP, 20SOP

Notes: Data type: L stands for latch type data output.

VT can be used as a momentary data output.

HOLTEK

HT12A/HT12E
2^{12} Series of Encoders

Features

- Operating voltage
  - 2.4V~5V for the HT12A
  - 2.4V~12V for the HT12E
- Low power and high noise immunity CMOS technology
- Low standby current: 0.1μA (typ.) at V_{DD}=5V
- HT12A with a 38kHz carrier for infrared transmission medium
- Minimum transmission word
  - Four words for the HT12E
  - One word for the HT12A
- Built-in oscillator needs only 5% resistor
- Data code has positive polarity
- Minimal external components
- Pair with Holtek's 2^{12} series of decoders
- 18-pin DIP, 20-pin SOP package

Applications

- Burglar alarm system
- Smoke and fire alarm system
- Garage door controllers
- Car door controllers
- Car alarm system
- Security system
- Cordless telephones
- Other remote control systems

General Description

The 2^{12} encoders are a series of CMOS LSIs for remote control system applications. They are capable of encoding information which consists of N address bits and 12–N data bits. Each address/data input can be set to one of the two logic states. The programmed addresses/data are transmitted together with the header bits via an RF or an infrared transmission medium upon receipt of a trigger signal. The capability to select a TE trigger on the HT12E or a DATA trigger on the HT12A further enhances the application flexibility of the 2^{12} series of encoders. The HT12A additionally provides a 38kHz carrier for infrared systems.

Selection Table

Function / Part No.	Address No.	Address/ Data No.	Data No.	Oscillator	Trigger	Carrier Output	Negative Polarity	Package
HT12A	8	0	4	455kHz resonator	D8~D11	38kHz	No	18DIP, 20SOP
HT12E	8	4	0	RC oscillator	$\overline{TE}$	No	No	18DIP, 20SOP

Note: Address/Data represents pins that can be either address or data according to the application requirement.

Title 47: Telecommunication
PART 15ð RADIO FREQUENCY DEVICES
Subpart Cð Intentional Radiators
Radiated Emission Limits, Additional Provisions

Browse Previous | Browse Next

§ 15.231 Periodic operation in the band 40.66–40.70 MHz and above 70 MHz.

(a) The provisions of this section are restricted to periodic operation within the band 40.66ï 40.70 MHz and above 70 MHz. Except as shown in paragraph (e) of this section, the intentional radiator is restricted to the transmission of a control signal such as those used with alarm systems, door openers, remote switches, etc. Continuous transmissions, voice, video and the radio control of toys are not permitted. Data is permitted to be sent with a control signal. The following conditions shall be met to comply with the provisions for this periodic operation:

(1) A manually operated transmitter shall employ a switch that will automatically deactivate the transmitter within not more than 5 seconds of being released.

(2) A transmitter activated automatically shall cease transmission within 5 seconds after activation.

(3) Periodic transmissions at regular predetermined intervals are not permitted. However, polling or supervision transmissions, including data, to determine system integrity of transmitters used in security or safety applications are allowed if the total duration of transmissions does not exceed more than two seconds per hour for each transmitter. There is no limit on the number of individual transmissions, provided the total transmission time does not exceed two seconds per hour.

(4) Intentional radiators which are employed for radio control purposes during emergencies involving fire, security, and safety of life, when activated to signal an alarm, may operate during the pendency of the alarm condition

(5) Transmission of set-up information for security systems may exceed the transmission duration limits in paragraphs (a)(1) and (a)(2) of this section, provided such transmissions are under the control of a professional installer and do not exceed ten seconds after a manually operated switch is released or a transmitter is activated automatically. Such set-up information may include data.

(b) In addition to the provisions of §15.205, the field strength of emissions from intentional radiators operated under this section shall not exceed the following:

Fundamental frequency (MHz)	Field strength of fundamental (microvolts/meter)	Field strength of spurious emissions (microvolts/meter)
40.66ï 40.70	2,250	225

70ï 130	1,250	125
130ï 174	[1]1,250 to 3,750	[1]125 to 375
174ï 260	3,750	375
260ï 470	[1]3,750 to 12,500	[1]375 to 1,250
Above 470	12,500	1,250

[1]Linear interpolations.

(1) The above field strength limits are specified at a distance of 3 meters. The tighter limits apply at the band edges.

(2) Intentional radiators operating under the provisions of this section shall demonstrate compliance with the limits on the field strength of emissions, as shown in the above table, based on the average value of the measured emissions. As an alternative, compliance with the limits in the above table may be based on the use of measurement instrumentation with a CISPR quasi-peak detector. The specific method of measurement employed shall be specified in the application for equipment authorization. If average emission measurements are employed, the provisions in §15.35 for averaging pulsed emissions and for limiting peak emissions apply. Further, compliance with the provisions of §15.205 shall be demonstrated using the measurement instrumentation specified in that section.

(3) The limits on the field strength of the spurious emissions in the above table are based on the fundamental frequency of the intentional radiator. Spurious emissions shall be attenuated to the average (or, alternatively, CISPR quasi-peak) limits shown in this table or to the general limits shown in §15.209, whichever limit permits a higher field strength.

(c) The bandwidth of the emission shall be no wider than 0.25% of the center frequency for devices operating above 70 MHz and below 900 MHz. For devices operating above 900 MHz, the emission shall be no wider than 0.5% of the center frequency. Bandwidth is determined at the points 20 dB down from the modulated carrier.

(d) For devices operating within the frequency band 40.66ï 40.70 MHz, the bandwidth of the emission shall be confined within the band edges and the frequency tolerance of the carrier shall be ±0.01%. This frequency tolerance shall be maintained for a temperature variation of ī 20 degrees to +50 degrees C at normal supply voltage, and for a variation in the primary supply voltage from 85% to 115% of the rated supply voltage at a temperature of 20 degrees C. For battery operated equipment, the equipment tests shall be performed using a new battery.

(e) Intentional radiators may operate at a periodic rate exceeding that specified in paragraph (a) of this section and may be employed for any type of operation, including operation prohibited in paragraph (a) of this section, provided the intentional radiator complies with the provisions of paragraphs (b) through (d) of this section, except the field strength table in paragraph (b) of this section is replaced by the following:

Fundamental frequency (MHz)	Field strength of fundamental (microvolts/meter)	Field strength of spurious emission (microvolts/meter)
40.66ï 40.70	1,000	100
70ï 130	500	50
130ï 174	500 to 1,500[1]	50 to 150[1]
174ï 260	1,500	150
260ï 470	1,500 to 5,000[1]	150 to 500[1]
Above 470	5,000	500

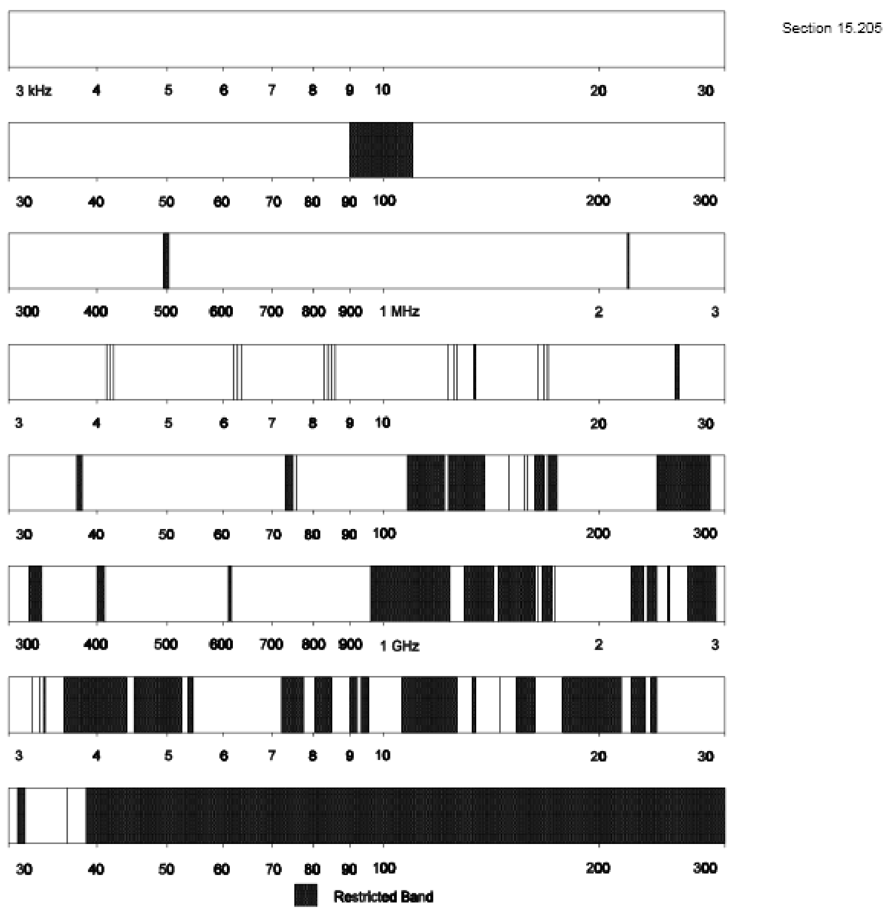
[1]Linear interpolations.

In addition, devices operated under the provisions of this paragraph shall be provided with a means for automatically limiting operation so that the duration of each transmission shall not be greater than one second and the silent period between transmissions shall be at least 30 times the duration of the transmission but in no case less than 10 seconds.

[54 FR 17714, Apr. 25, 1989; 54 FR 32340, Aug. 7, 1989, as amended at 68 FR 68546, Dec. 9, 2003; 69 FR 71383, Dec. 9, 2004]

Website Address: http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&sid=1f9d125a96a86cfbcdb02d9b6a5bc395&rgn=div8&view=text&node=47:1.0.1.1.15.3.240.21&idno=47

The Part 15 Restricted Bands - Spurious Emissions Only



the swiss power source

renata batteries

CR2032 MFR

3V Lithium Battery

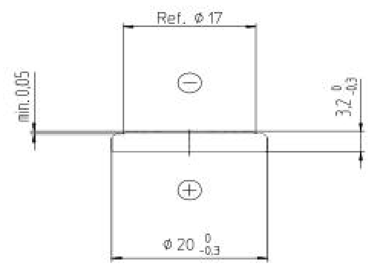
Technical Data Sheet

Specifications

Chemical System	Li / MnO_2
Nominal Voltage	3 V
Rated Capacity	225 mAh
Standard Discharge Current	0.4 mA
Max. Cont. Discharge Current	3.0 mA
Average Weight	2.8 g
Temperature Range*	-30 - +70 °C *
Self Discharge at 23°C	< 1% / year

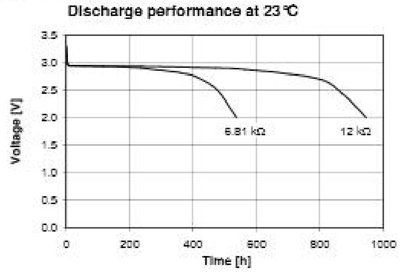
Dimensions

(According to IEC 60086)

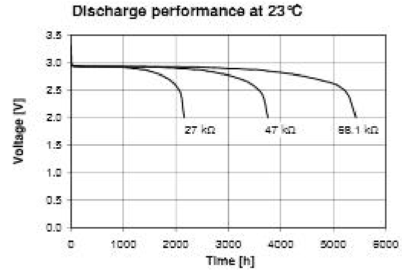


Performance

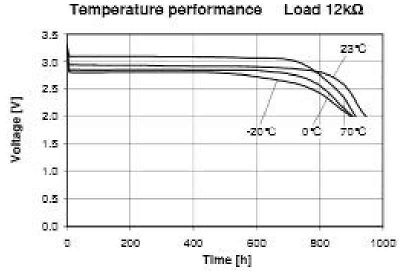
Discharge performance at 23°C



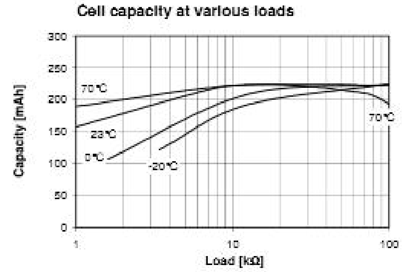
Discharge performance at 23°C



Temperature performance Load 12kΩ



Cell capacity at various loads



*In applications where the battery is exposed to temperatures above 60 °C, please contact Renata for consultancy.
Information and contents in this data sheet are for reference purpose only. They do not constitute any warranty or representation and are subject to change without notice. For most current information and further details, please contact your Renata representative.

Rev. CR2032MFR.04 / 03.2010

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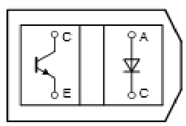
Appendix G – MATLAB MOSFET Thermal Calculation

```
% Program Name: MOSFET_Thermal_Calculations
%
% By: Trevor Pringle

fprintf('\nInputs: \n')
ID = str2num(input('Maximum Drain Current: ', 's'));
Tamb = str2num(input('Ambient Operating Temperature: ', 's'));
Tjmax = str2num(input('Maximum Junction Temperature: ', 's'));
Rthetajc = str2num(input('Thermal Resistance from Junction to Case: ', 's'));
Rthetacs = str2num(input('Thermal Resistance from Case to Sink: ', 's'));
Rthetaja = str2num(input('Thermal Resistance from Junction to Ambient: ',
's'));
ID_Desired = str2num(input('User Required Drain Current: ', 's'));

PDmax = (Tjmax - 25)/Rthetajc;
RDSon_max = PDmax/ID^2;
PDmax_without_heatsink = (Tjmax-Tamb)/Rthetaja;
IDmax_without_heatsink = sqrt(PDmax_without_heatsink/RDSon_max);
PD_Desired = ID_Desired^2*RDSon_max;
format short
fprintf('\nResults: \n')
fprintf('Minimum Number of MOSFETs Without Heatsink = %f\n',
PD_Desired/PDmax_without_heatsink);
Rthetasa = (Tjmax - Tamb)/PD_Desired - Rthetajc - Rthetacs;
fprintf('Minimum Thermal Resistance of Heatsink Required: %f\n', Rthetasa);
```

Appendix H – Sensors

Reflective Optical Sensor with Transistor Output

19156_2



Top view 19156_1

FEATURES

- Package type: leaded
- Detector type: phototransistor
- Dimensions (L x W x H in mm): 10.2 x 5.8 x 7
- Peak operating distance: 2.5 mm
- Operating range within > 20 % relative collector current: 0.2 mm to 15 mm
- Typical output current under test: I_C = 1 mA
- Daylight blocking filter
- Emitter wavelength: 950 nm
- Lead (Pb)-free soldering released
- Compliant to RoHS directive 2002/95/EC and in accordance to WEEE 2002/96/EC

Pb-free
e2
RoHS
COMPLIANT

DESCRIPTION

The TCRT5000 and TCRT5000L are reflective sensors which include an infrared emitter and phototransistor in a leaded package which blocks visible light. The package includes two mounting clips. TCRT5000L is the long lead version.

APPLICATIONS

- Position sensor for shaft encoder
- Detection of reflective material such as paper, IBM cards, magnetic tapes etc.
- Limit switch for mechanical motions in VCR
- General purpose - wherever the space is limited

PRODUCT SUMMARY

PART NUMBER	DISTANCE FOR MAXIMUM CTR_{rel} (1) (mm)	DISTANCE RANGE FOR RELATIVE I_{out} > 20 % (mm)	TYPICAL OUTPUT CURRENT UNDER TEST (2) (mA)	DAYLIGHT BLOCKING FILTER INTEGRATED
TCRT5000	2.5	0.2 to 15	1	Yes
TCRT5000L	2.5	0.2 to 15	1	Yes

Notes
(1) CTR: current transfere ratio, I_{out}/I_{in}
(2) Conditions like in table basic charactristics/sensors

ORDERING INFORMATION

ORDERING CODE	PACKAGING	VOLUME (1)	REMARKS
TCRT5000	Tube	MOQ: 4500 pcs, 50 pcs/tube	3.5 mm lead length
TCRT5000L	Tube	MOQ: 2400 pcs, 48 pcs/tube	15 mm lead length

Note
(1) MOQ: minimum order quantity

ABSOLUTE MAXIMUM RATINGS (1)

PARAMETER	TEST CONDITION	SYMBOL	VALUE	UNIT
INPUT (EMITTER)				
Reverse voltage		V_R	5	V
Forward current		I_F	60	mA
Forward surge current	$t_p \leq 10$ µs	I_{FSM}	3	A
Power dissipation	$T_{amb} \leq 25$ °C	P_V	100	mW
Junction temperature		T_j	100	°C

TCRT5000, TCRT5000L

Vishay Semiconductors

Reflective Optical Sensor with Transistor Output

ABSOLUTE MAXIMUM RATINGS [1]				
PARAMETER	TEST CONDITION	SYMBOL	VALUE	UNIT
OUTPUT (DETECTOR)				
Collector emitter voltage		V_{CEO}	70	V
Emitter collector voltage		V_{ECO}	5	V
Collector current		I_C	100	mA
Power dissipation	$T_{amb} \leq 55$ °C	P_V	100	mW
Junction temperature		T_j	100	°C
SENSOR				
Total power dissipation	$T_{amb} \leq 25$ °C	P_{tot}	200	mW
Ambient temperature range		T_{amb}	- 25 to + 85	°C
Storage temperature range		T_{stg}	- 25 to + 100	°C
Soldering temperature	2 mm from case, $t \leq 10$ s	T_{sd}	260	°C

Note

(1) T_{amb} = 25 °C, unless otherwise specified

ABSOLUTE MAXIMUM RATINGS

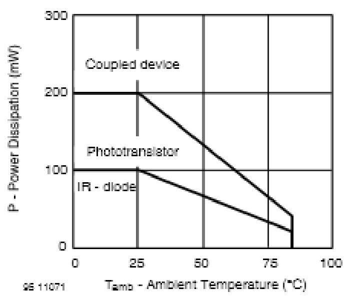


Fig. 1 - Power Dissipation Limit vs. Ambient Temperature

BASIC CHARACTERISTICS [1]						
PARAMETER	TEST CONDITION	SYMBOL	MIN.	TYP.	MAX.	UNIT
INPUT (EMITTER)						
Forward voltage	I_F = 60 mA	V_F		1.25	1.5	V
Junction capacitance	V_R = 0 V, f = 1 MHz	C_j		17		pF
Radiant intensity	I_F = 60 mA, t_p = 20 ms	I_e			21	mW/sr
Peak wavelength	I_F = 100 mA	λ_P	940			nm
Virtual source diameter	Method: 63 % encircled energy	d		2.1		mm
OUTPUT (DETECTOR)						
Collector emitter voltage	I_C = 1 mA	V_{CEO}	70			V
Emitter collector voltage	I_E = 100 μA	V_{ECO}	7			V
Collector dark current	V_{CE} = 20 V, I_F = 0 A, E = 0 lx	I_{CEO}		10	200	nA
SENSOR						
Collector current	V_{CE} = 5 V, I_F = 10 mA, D = 12 mm	I_C [2][3]	0.5	1	2.1	mA
Collector emitter saturation voltage	I_F = 10 mA, I_C = 0.1 mA, D = 12 mm	V_{CEsat} [2][3]			0.4	V

Note

(1) T_{amb} = 25 °C, unless otherwise specified

(2) See figure 3

(3) Test surface: mirror (Mfr. Spindler a. Hoyer, Part No. 340005)

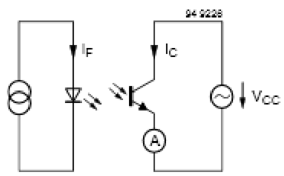


Fig. 2 - Test Circuit

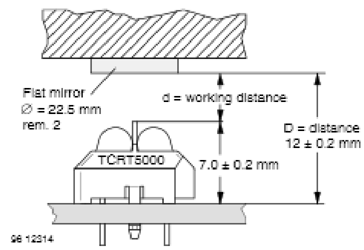


Fig. 3 - Test Circuit

BASIC CHARACTERISTICS

T_{amb} = 25 °C, unless otherwise specified

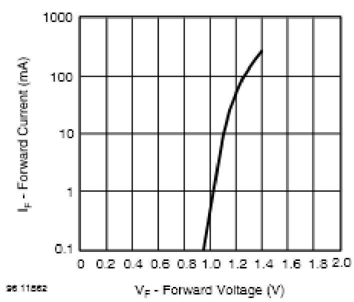


Fig. 4 - Forward Current vs. Forward Voltage

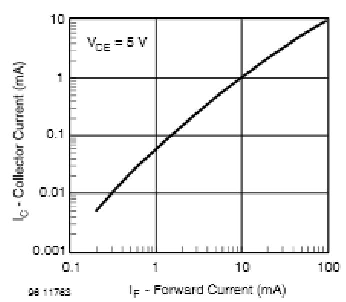


Fig. 6 - Collector Current vs. Forward Current

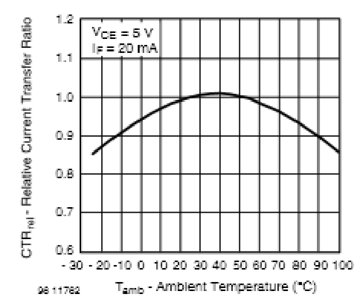


Fig. 5 - Relative Current Transfer Ratio vs. Ambient Temperature

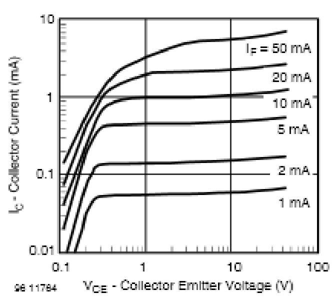


Fig. 7 - Collector Emitter Saturation Voltage vs. Collector Current

Reflective Optical Sensor with Transistor Output

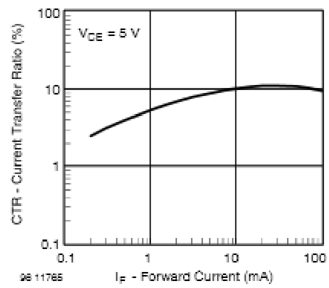


Fig. 8 - Current Transfer Ratio vs. Forward Current

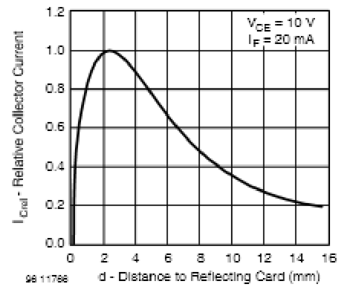
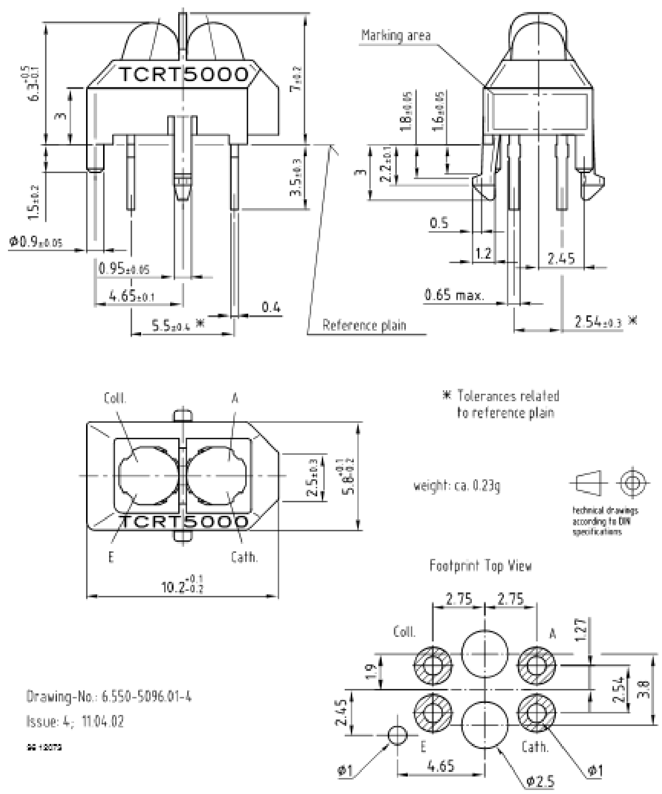
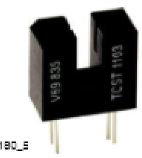


Fig. 9 - Relative Collector Current vs. Distance

PACKAGE DIMENSIONS in millimeters, **TCRT5000**

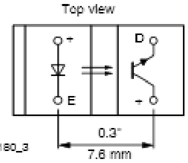


Transmissive Optical Sensor with Phototransistor Output



19180_5

Top view



19180_3

DESCRIPTION

The TCST1103, TCST1202, and TCST1300 are transmissive sensors that include an infrared emitter and phototransistor, located face-to-face on the optical axes in a leaded package which blocks visible light. These part numbers include options for aperture width.

FEATURES

- Package type: leaded
- Detector type: phototransistor
- Dimensions (L x W x H in mm): 11.9 x 6.3 x 10.8
- Gap (in mm): 3.1
- Typical output current under test: I_C = 4 mA (TCST1103)
- Typical output current under test: I_C = 2 mA (TCST1202)
- Typical output current under test: I_C = 0.5 mA (TCST1300)
- Daylight blocking filter
- Emitter wavelength: 950 nm
- Lead (Pb)-free soldering released
- Compliant to RoHS Directive 2002/95/EC and in accordance to WEEE 2002/96/EC

APPLICATIONS

- Optical switch
- Photo interrupter
- Counter
- Encoder

PRODUCT SUMMARY				
PART NUMBER	GAP WIDTH (mm)	APERTURE WIDTH (mm)	TYPICAL OUTPUT CURRENT UNDER TEST (1) (mA)	DAYLIGHT BLOCKING FILTER INTEGRATED
TCST1103	3.1	1	4	Yes
TCST1202	3.1	0.5	2	Yes
TCST1300	3.1	0.25	0.5	Yes

Note
- Conditions like in table basic characteristics/coupler

ORDERING INFORMATION			
ORDERING CODE	PACKAGING	VOLUME (1)	REMARKS
TCST1103	Tube	MOQ: 1020 pcs, 85 pcs/tube	Without mounting flange
TCST1202	Tube	MOQ: 1020 pcs, 85 pcs/tube	Without mounting flange
TCST1300	Tube	MOQ: 1020 pcs, 85 pcs/tube	Without mounting flange

Note
- MOQ: minimum order quantity

ABSOLUTE MAXIMUM RATINGS (T_{amb} = 25 °C, unless otherwise specified)				
PARAMETER	TEST CONDITION	SYMBOL	VALUE	UNIT
COUPLER				
Total power dissipation	$T_{amb} \leq 25$ °C	P_{tot}	250	mW
Ambient temperature range		T_{amb}	- 55 to + 85	°C
Storage temperature range		T_{stg}	- 55 to + 100	°C
Soldering temperature	Distance to package: 2 mm; t ≤ 5 s	T_{sd}	260	°C

Appendix I – Motor Controller Components

Data Sheet No. PD60249

International IOR Rectifier

IRS2110(-1,-2,S)PbF
IRS2113(-1,-2,S)PbF

HIGH AND LOW SIDE DRIVER

Features

- Floating channel designed for bootstrap operation
- Fully operational to +500 V or +600 V
- Tolerant to negative transient voltage, dV/dt immune
- Gate drive supply range from 10 V to 20 V
- Undervoltage lockout for both channels
- 3.3 V logic compatible
- Separate logic supply range from 3.3 V to 20 V
- Logic and power ground ±5V offset
- CMOS Schmitt-triggered inputs with pull-down
- Cycle by cycle edge-triggered shutdown logic
- Matched propagation delay for both channels
- Outputs in phase with inputs
- RoHS compliant

Description

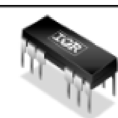
The IRS2110/IRS2113 are high voltage, high speed power MOSFET and IGBT drivers with independent high-side and low-side referenced output channels. Proprietary HVIC and latch immune CMOS technologies enable ruggedized monolithic construction. Logic inputs are compatible with standard CMOS or LSTTL output, down to 3.3 V logic. The output drivers feature a high pulse current buffer stage designed for minimum driver cross-conduction. Propagation delays are matched to simplify use in high frequency applications. The floating channel can be used to drive an N-channel power MOSFET or IGBT in the high-side configuration which operates up to 500 V or 600 V.

Product Summary

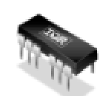
V_{OFFSET}	(IRS2110)	500 V max.
	(IRS2113)	600 V max.
I_O+/-		2 A/2 A
V_{OUT}		10 V - 20 V
$t_{on/off}$ (typ.)		130 ns & 120 ns
Delay Matching	(IRS2110)	10 ns max.
	(IRS2113)	20 ns max.

Packages

14-Lead PDIP
IRS2110 and IRS2113



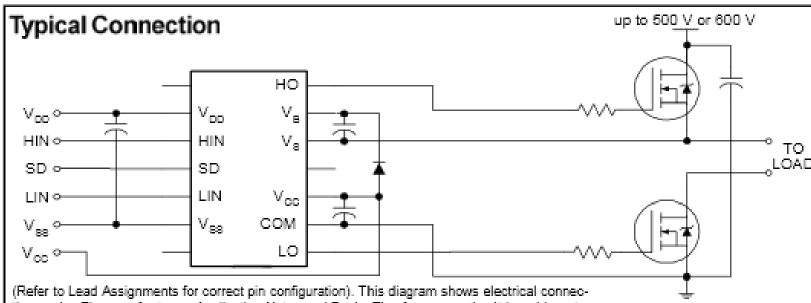
16-Lead PDIP
(w/o leads 4 & 5)
IRS2110-2 and IRS2113-2



14-Lead PDIP
(w/o lead 4)
IRS2110-1 and IRS2113-1

16-Lead SOIC
IRS2110S and
IRS2113S

Typical Connection

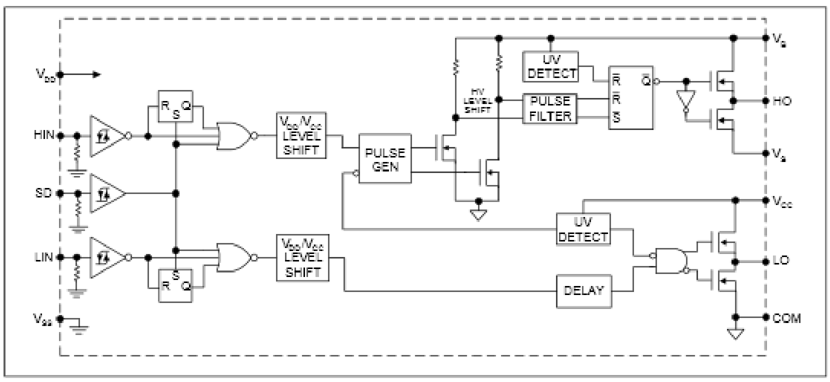


(Refer to Lead Assignments for correct pin configuration). This diagram shows electrical connections only. Please refer to our Application Notes and DesignTips for proper circuit board layout.

International IOR Rectifier

IRS2110(-1,-2,S)PbF/IRS2113(-1,-2,S)PbF

Functional Block Diagram



Lead Definitions

Symbol	Description
V_{DD}	Logic supply
HIN	Logic input for high-side gate driver output (HO), in phase
SD	Logic input for shutdown
LIN	Logic input for low-side gate driver output (LO), in phase
V_{SS}	Logic ground
V_B	High-side floating supply
HO	High-side gate drive output
V_S	High-side floating supply return
V_{CC}	Low-side supply
LO	Low-side gate drive output
COM	Low-side return

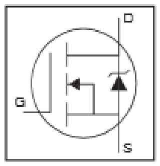
International
IOR Rectifier

PD -97363

IRLB3034PbF

HEXFET® Power MOSFET

Applications
- DC Motor Drive
- High Efficiency Synchronous Rectification in SMPS
- Uninterruptible Power Supply
- High Speed Power Switching
- Hard Switched and High Frequency Circuits



V_{DSS}		40V
$R_{DS(on)}$	typ.	1.4mΩ
	max.	1.7mΩ
$I_{D\ (Silicon\ Limited)}$		343A①
$I_{D\ (Package\ Limited)}$		195A

Benefits
- Optimized for Logic Level Drive
- Very Low $R_{DS(ON)}$ at 4.5V V_{GS}
- Superior R*Q at 4.5V V_{GS}
- Improved Gate, Avalanche and Dynamic dV/dt Ruggedness
- Fully Characterized Capacitance and Avalanche SOA
- Enhanced body diode dV/dt and dI/dt Capability
- Lead-Free

TO-220AB
IRLB3034PbF

G	D	S
Gate	Drain	Source

Absolute Maximum Ratings

Symbol	Parameter	Max.	Units
I_D @ T_C = 25°C	Continuous Drain Current, V_{GS} @ 10V (Silicon Limited)	343①	A
I_D @ T_C = 100°C	Continuous Drain Current, V_{GS} @ 10V (Silicon Limited)	243 ①	
I_D @ T_C = 25°C	Continuous Drain Current, V_{GS} @ 10V (Package Limited)	195	
I_{DM}	Pulsed Drain Current ②	1372	
P_D @T_C = 25°C	Maximum Power Dissipation	375	W
	Linear Derating Factor	2.5	W/°C
V_{GS}	Gate-to-Source Voltage	±20	V
dv/dt	Peak Diode Recovery ④	4.6	V/ns
T_J T_{STG}	Operating Junction and Storage Temperature Range	-55 to + 175	°C
	Soldering Temperature, for 10 seconds (1.6mm from case)	300	
	Mounting torque, 6-32 or M3 screw	10lbf·in (1.1N·m)	

Avalanche Characteristics

$E_{AS\ (Thermally\ limited)}$	Single Pulse Avalanche Energy ③	255	mJ
I_{AR}	Avalanche Current ②	See Fig. 14, 15, 22a, 22b,	A
E_{AR}	Repetitive Avalanche Energy ②		mJ

Thermal Resistance

Symbol	Parameter	Typ.	Max.	Units
$R_{\theta JC}$	Junction-to-Case ⑩	—	0.4	°C/W
$R_{\theta CS}$	Case-to-Sink, Flat, Greased Surface	0.5	—	
$R_{\theta JA}$	Junction-to-Ambient	—	62	

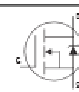
Static @ T_J = 25°C (unless otherwise specified)

Symbol	Parameter	Min.	Typ.	Max.	Units	Conditions
$V_{(BR)DSS}$	Drain-to-Source Breakdown Voltage	40	—	—	V	V_{GS} = 0V, I_D = 250μA
$\Delta V_{(BR)DSS}/\Delta T_J$	Breakdown Voltage Temp. Coefficient	—	0.04	—	V/°C	Reference to 25°C, I_D = 5mA ②
$R_{DS(on)}$	Static Drain-to-Source On-Resistance	—	1.4	1.7	mΩ	V_{GS} = 10V, I_D = 195A ⑤
		—	1.6	2.0		V_{GS} = 4.5V, I_D = 172A ⑤
$V_{GS(th)}$	Gate Threshold Voltage	1.0	—	2.5	V	$V_{DS} = V_{GS}$, I_D = 250μA
I_{DSS}	Drain-to-Source Leakage Current	—	—	20	μA	V_{DS} = 40V, V_{GS} = 0V
		—	—	250		V_{DS} = 40V, V_{GS} = 0V, T_J = 125°C
I_{GSS}	Gate-to-Source Forward Leakage	—	—	100	nA	V_{GS} = 20V
	Gate-to-Source Reverse Leakage	—	—	-100		V_{GS} = -20V
$R_{G(int)}$	Internal Gate Resistance	—	2.1	—	Ω	

Dynamic @ T_J = 25°C (unless otherwise specified)

Symbol	Parameter	Min.	Typ.	Max.	Units	Conditions
gfs	Forward Transconductance	286	—	—	S	V_{DS} = 10V, I_D = 195A
Q_g	Total Gate Charge	—	108	162	nC	I_D = 185A
Q_{gs}	Gate-to-Source Charge	—	29	—		V_{DS} = 20V
Q_{gd}	Gate-to-Drain ("Miller") Charge	—	54	—		V_{GS} = 4.5V ⑤
Q_{sync}	Total Gate Charge Sync. (Q_g - Q_{gd})	—	54	—		I_D = 185A, V_{DS} =0V, V_{GS} = 4.5V
$t_{d(on)}$	Turn-On Delay Time	—	65	—	ns	V_{DD} = 26V
t_r	Rise Time	—	827	—		I_D = 195A
$t_{d(off)}$	Turn-Off Delay Time	—	97	—		R_G = 2.1Ω
t_f	Fall Time	—	355	—		V_{GS} = 4.5V ⑤
C_{iss}	Input Capacitance	—	10315	—	pF	V_{GS} = 0V
C_{oss}	Output Capacitance	—	1980	—		V_{DS} = 25V
C_{rss}	Reverse Transfer Capacitance	—	935	—		f = 1.0MHz
C_{oss} eff. (ER)	Effective Output Capacitance (Energy Related)⑦	—	2378	—		V_{GS} = 0V, V_{DS} = 0V to 32V ⑦
C_{oss} eff. (TR)	Effective Output Capacitance (Time Related) ⑥	—	2986	—		V_{GS} = 0V, V_{DS} = 0V to 32V ⑥

Diode Characteristics

Symbol	Parameter	Min.	Typ.	Max.	Units	Conditions
I_S	Continuous Source Current (Body Diode)	—	—	343①	A	MOSFET symbol showing the integral reverse p-n junction diode. 
I_{SM}	Pulsed Source Current (Body Diode) ②	—	—	1372		
V_{SD}	Diode Forward Voltage	—	—	1.3	V	T_J = 25°C, I_S = 195A, V_{GS} = 0V ⑤
t_{rr}	Reverse Recovery Time	—	39	—	ns	T_J = 25°C V_R = 34V,
		—	41	—		T_J = 125°C I_F = 195A
Q_{rr}	Reverse Recovery Charge	—	39	—	nC	T_J = 25°C di/dt = 100A/μs ⑤
		—	46	—		T_J = 125°C
I_{RRM}	Reverse Recovery Current	—	1.7	—	A	T_J = 25°C
t_{on}	Forward Turn-On Time	Intrinsic turn-on time is negligible (turn-on is dominated by LS+LD)				

Notes:

① Calcuted continuous current based on maximum allowable junction temperature Bond wire current limit is 195A. Note that current limitation arising from heating of the device leds may occur with some lead mounting arrangements.

② Repetitive rating; pulse width limited by max. junction temperature.

③ Limited by T_{Jmax}, starting T_J = 25°C, L = 0.013mH R_G = 25Ω, I_{AS} = 195A, V_{GS} =10V. Part not recommended for use above this value .

④ I_{SD} ≤ 195A, di/dt ≤ 841A/μs, $V_{DD} \le V_{(BR)DSS}$, T_J ≤ 175°C.

⑤ Pulse width ≤ 400μs; duty cycle ≤ 2%.

⑥ C_{oss} eff. (TR) is a fixed capacitance that gives the same charging time as C_{oss} while V_{DS} is rising from 0 to 80% V_{DSS}.

⑦ C_{oss} eff. (ER) is a fixed capacitance that gives the same energy as C_{oss} while V_{DS} is rising from 0 to 80% V_{DSS}.

⑧ R_θ is measured at T_J approximately 90°C

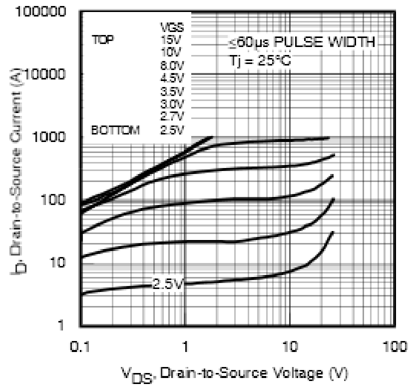


Fig 1. Typical Output Characteristics

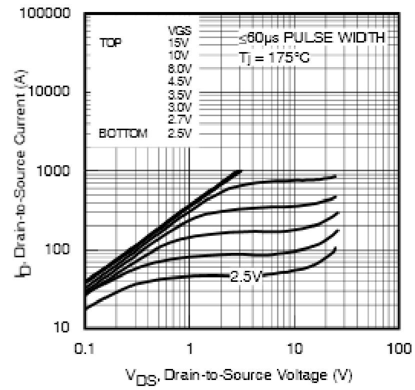


Fig 2. Typical Output Characteristics

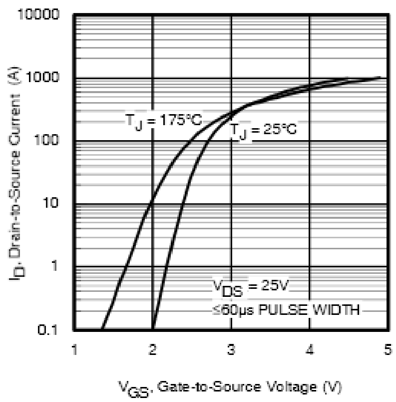


Fig 3. Typical Transfer Characteristics

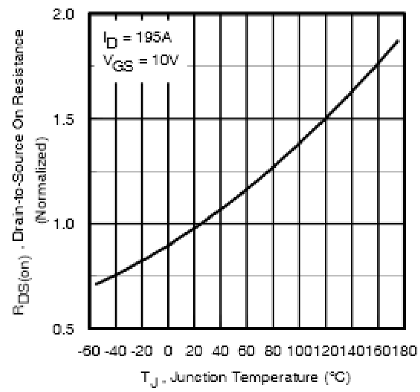


Fig 4. Normalized On-Resistance vs. Temperature

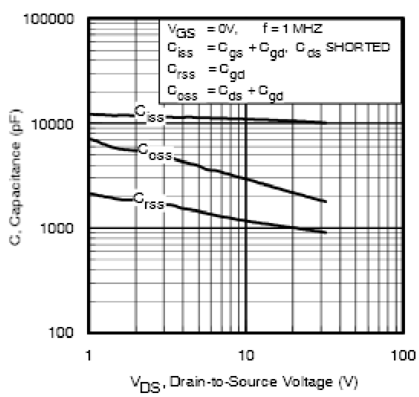


Fig 5. Typical Capacitance vs. Drain-to-Source Voltage

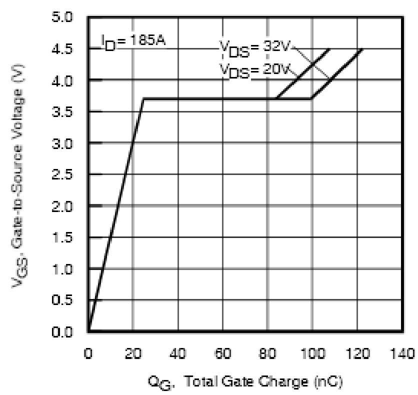


Fig 6. Typical Gate Charge vs. Gate-to-Source Voltage

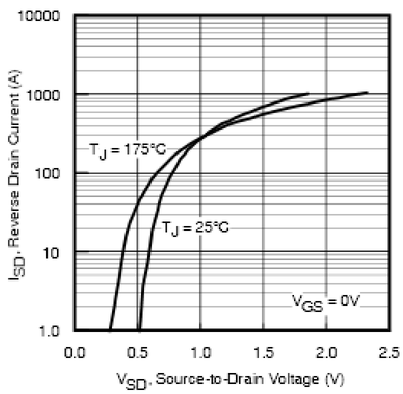


Fig 7. Typical Source-Drain Diode Forward Voltage

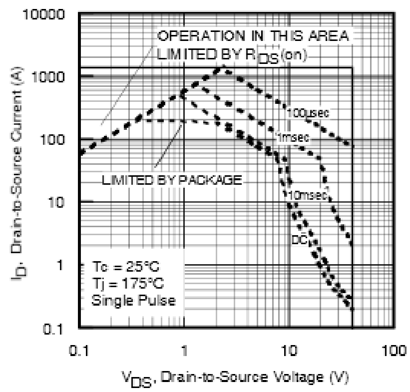


Fig 8. Maximum Safe Operating Area

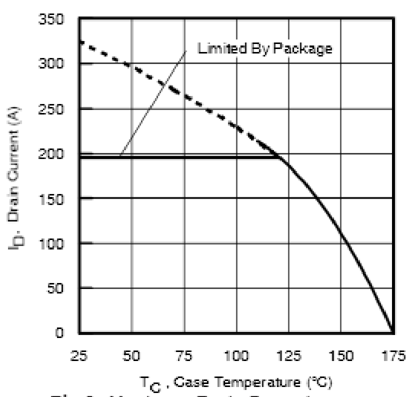


Fig 9. Maximum Drain Current vs. Case Temperature

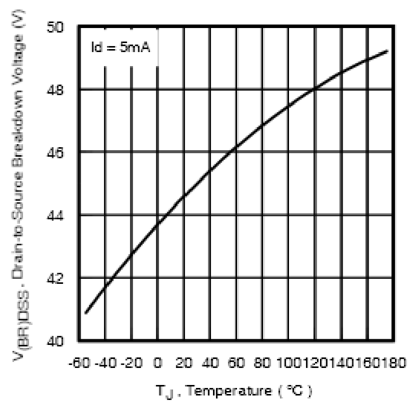


Fig 10. Drain-to-Source Breakdown Voltage

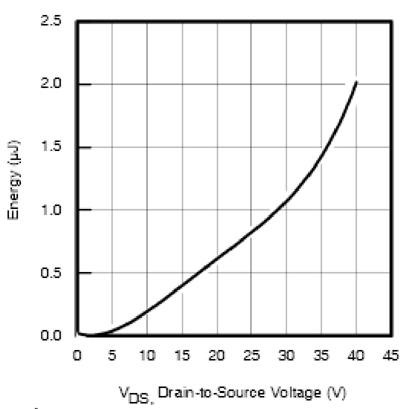


Fig 11. Typical C_{OSS} Stored Energy

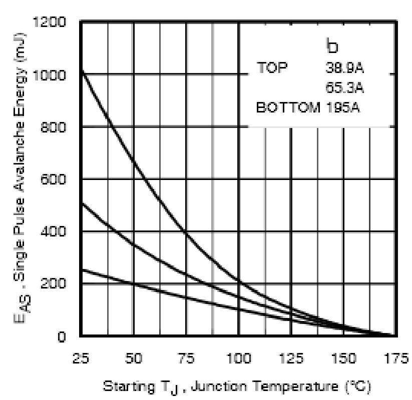


Fig 12. Maximum Avalanche Energy vs. DrainCurrent

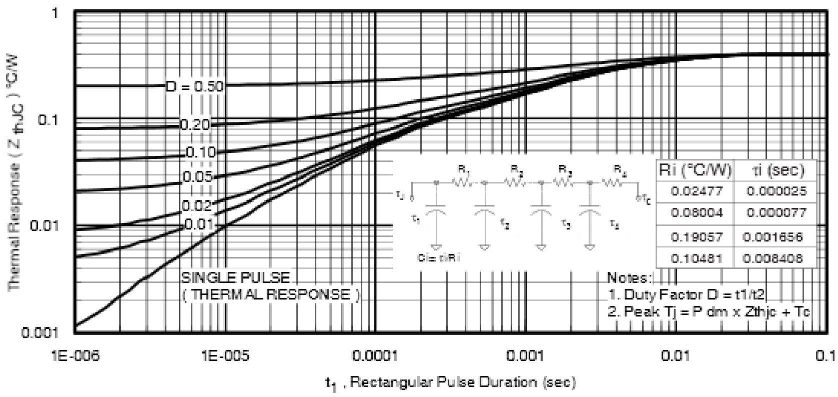


Fig 13. Maximum Effective Transient Thermal Impedance, Junction-to-Case

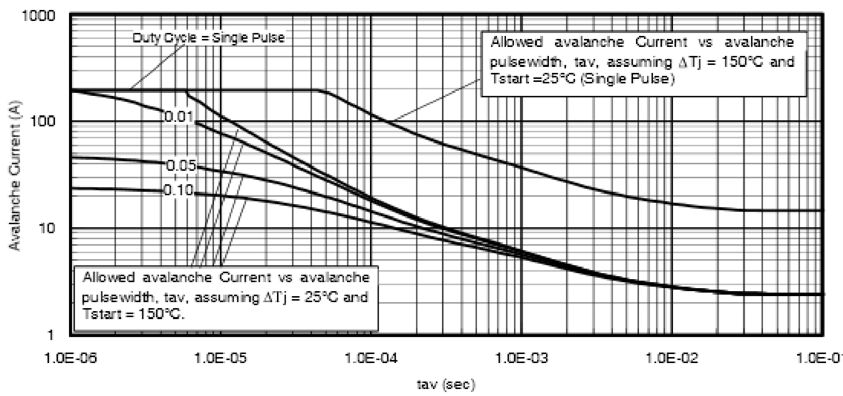


Fig 14. Typical Avalanche Current vs.Pulsewidth

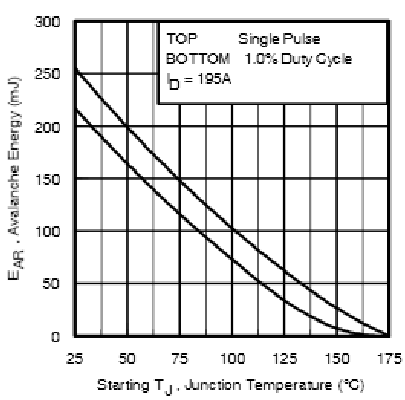


Fig 15. Maximum Avalanche Energy vs. Temperature

Notes on Repetitive Avalanche Curves , Figures 14, 15:
(For further info, see AN-1005 at www.irf.com)

1. Avalanche failures assumption:
   Purely a thermal phenomenon and failure occurs at a temperature far in excess of T_{jmax}. This is validated for every part type.
2. Safe operation in Avalanche is allowed as long as T_{jmax} is not exceeded.
3. Equation below based on circuit and waveforms shown in Figures 16a, 16b.
4. $P_{D\ (ave)}$ = Average power dissipation per single avalanche pulse.
5. BV = Rated breakdown voltage (1.3 factor accounts for voltage increase during avalanche).
6. I_{av} = Allowable avalanche current.
7. ΔT = Allowable rise in junction temperature, not to exceed T_{jmax} (assumed as 25°C in Figure 14, 15).
   t_{av} = Average time in avalanche.
   D = Duty cycle in avalanche = $t_{av} \cdot f$
   $Z_{thJC}(D, t_{av})$ = Transient thermal resistance, see Figures 13)

$$P_{D\ (ave)} = 1/2\ (1.3 \cdot BV \cdot I_{av}) = \Delta T / Z_{thJC}$$
$$I_{av} = 2\Delta T / [1.3 \cdot BV \cdot Z_{th}]$$
$$E_{AS\ (AR)} = P_{D\ (ave)} \cdot t_{av}$$

FAIRCHILD SEMICONDUCTOR®

December 2009

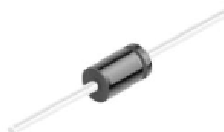
SB1245
Ultra Low VF Schottky Barrier Rectifier

Applications

- This device is designed for low voltage, high frequency inverters, free-wheeling and polarity protection applications.
- This is also designed as bypass diode for solar modules.

Features

- UL Flammability Classification 94V-O
- Environment Standards MIL-S-19500/228 Compliant
- Low Power Loss, High Efficiency
- High Surge Capacity
- Pb-free, RoHS Compliant



DO-201AD
COLOR BAND DENOTES CATHODE

Absolute Maximum Ratings * T_A = 25°C unless otherwise noted

Symbol	Parameter	Value	Units
V_{RRM}	Maximum Recurrent Peak Reverse Voltage	45	V
V_{RMS}	Maximum RMS Voltage	31	V
V_{DC}	Maximum DC Blocking Voltage	45	V
$I_{F(AV)}$	Maximum Average Forward Current	12	A
I_{FSM}	Peak Forward Surge Current 8.3ms Single Half-Sine-Wave Superimposed on Rated Load (JEDEC Method)	150	A
V_F	Maximum Forward Voltage at I_F=12A	0.55	V
I_R	Maximum DC Reverse Current at Rated V_{DC} T_J=25°C T_J=100°C	0.1 10	mA
I^2t	Rating for Fusing (t<8.3ms)	3.7	A^2sec
T_J	Operating Junction Temperature Range In DC Forward Mode	-55 to +150 -55 to +200	°C
T_{STG}	Storage Temperature Range	-55 to +175	°C

* These ratings are limiting values above which the serviceability of any semiconductor device may by impaired.

Thermal Characteristics

Symbol	Parameter	Value	Units
$R_{\theta JL}$	Typical Thermal Resistance, Junction to Lead	10.5	°C/W

* Temperature read point using thermocouple is at 10mm from case edge.

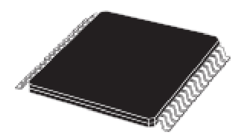
VNH3SP30

FULLY INTEGRATED H-BRIDGE MOTOR DRIVER

TYPE	$R_{DS(on)}$ (*)	I_{OUT}	V_{CCmax}
VNH3SP30	34mΩ	30 A	40 V

(*) Typical per leg at 25°C

- OUTPUT CURRENT:30 A
- 5V LOGIC LEVEL COMPATIBLE INPUTS
- UNDERVOLTAGE AND OVERVOLTAGE SHUT-DOWN
- OVERVOLTAGE CLAMP
- THERMAL SHUT DOWN
- CROSS-CONDUCTION PROTECTION
- LINEAR CURRENT LIMITER
- VERY LOW STAND-BY POWER CONSUMPTION
- PWM OPERATION UP TO 10 KHz
- PROTECTION AGAINST:
  LOSS OF GROUND AND LOSS OF V_{CC}

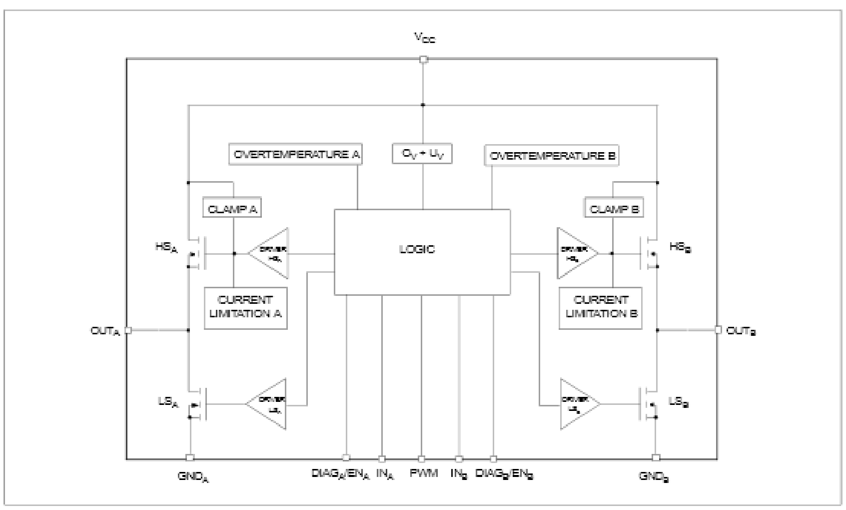


MultiPowerSO-30

DESCRIPTION

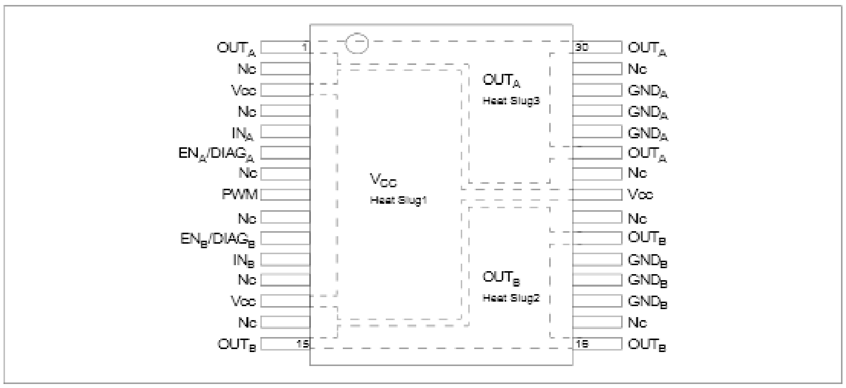
The VNH3SP30 is a full bridge motor driver intended for a wide range of automotive applications. The device incorporates a dual monolithic HSD and two Low-Side switches. The HSD switch is designed using STMicroelectronics VIPower M0-3 technology that allows to efficiently integrate on the same die a true Power MOSFET with an intelligent signal/protection circuitry. The Low-Side switches are vertical MOSFETs manufactured using STMicroelectronics proprietary EHD ("STripFET™") process.

BLOCK DIAGRAM



The three dice are assembled in MultiPowerSO-30 package on electrically isolated leadframes. This package, specifically designed for the harsh automotive environment offers improved thermal performance thanks to exposed die pads. Moreover, its fully symmetrical mechanical design allows superior manufacturability at board level. The input signals IN_A and IN_B can directly interface to the microcontroller to select the motor direction and the brake condition. The $DIAG_A/EN_A$ or $DIAG_B/EN_B$, when connected to an external pull up resistor, enable one leg of the bridge. They also provide a feedback digital diagnostic signal. The normal condition operation is explained in the truth table on page 7. The PWM, up to 10KHz, lets us to control the speed of the motor in all possible conditions. In all cases, a low level state on the PWM pin will turn off both the LS_A and LS_B switches. When PWM rises to a high level, LS_A or LS_B turn on again depending on the input pin state.

CONNECTION DIAGRAM (TOP VIEW)



PIN DEFINITIONS AND FUNCTIONS

PIN No	SYMBOL	FUNCTION
1, 25, 30	OUT_A, Heat Slug2	Source of High-Side Switch A / Drain of Low-Side Switch A
2, 4,7,9,12,14,17, 22, 24,29	NC	Not connected
3, 13, 23	VCC, Heat Slug1	Drain of High-Side Switches and Power Supply Voltage
5	IN_A	Clockwise Input
6	$EN_A/DIAG_A$	Status of High-Side and Low-Side Switches A; Open Drain Output
8	PWM	PWM Input
9	NC	Not connected
10	$EN_B/DIAG_B$	Status of High-Side and Low-Side Switches B; Open Drain Output
11	IN_B	Counter Clockwise Input
15, 16, 21	OUT_B, Heat Slug3	Source of High-Side Switch B / Drain of Low-Side Switch B
26, 27, 28	GND_A	Source of Low-Side Switch A (*)
18, 19, 20	GND_B	Source of Low-Side Switch B (*)

(*) Note: GND_A and GND_B must be externally connected together

PIN FUNCTIONS DESCRIPTION

NAME	DESCRIPTION
V_{CC}	Battery connection.
GND_A GND_B	Power grounds, must always be externally connected together.
OUT_A OUT_B	Power connections to the motor.
IN_A IN_B	Voltage controlled input pins with hysteresis, CMOS compatible. These two pins control the state of the bridge in normal operation according to the truth table (brake to V_{CC}, Brake to GND, clockwise and counterclockwise).
PWM	Voltage controlled input pin with hysteresis, CMOS compatible. Gates of Low-Side FETS get modulated by the PWM signal during their ON phase allowing speed control of the motor
$EN_A/DIAG_A$ $EN_B/DIAG_B$	Open drain bidirectional logic pins. These pins must be connected to an external pull up resistor.When externally pulled low, they disable half-bridge A or B. In case of fault detection (thermal shutdown of a High-Side FET or excessive ON state voltage drop across a Low-Side FET), these pins are pulled low by the device (see truth table in fault condition).

BLOCK DESCRIPTIONS

(see Electrical Block Diagram page 4)

NAME	DESCRIPTION
LOGIC CONTROL	Allows the turn-on and the turn-off of the High Side and the Low Side switches according to the truth table.
OVERVOLTAGE + UNDERVOLTAGE	Shut-down the device outside the range [5.5V..36V] for the battery voltage.
HIGH SIDE CLAMP VOLTAGE	Protect the High-Side switches from the high voltage on the battery line in all configuration for the motor.
HIGH SIDE AND LOW SIDE DRIVER	Drive the gate of the concerned switch to allow a good $R_{DS(on)}$ for the leg of the bridge.
LINEAR CURRENT LIMITER	In case of short circuit for the High-Side switch, limits the motor current by reducing its electrical characteristics.
OVERTEMPERATURE PROTECTION	In case of short-circuit with the increase of the junction's temperature, shuts-down the concerned High-Side to prevent its degradation and to protect the die.
FAULT DETECTION	Signalize an abnormal behavior of the switches in the half-bridge A or B by pulling low the concerned ENx/DIAGx pin.

MICROCHIP

TC4431/TC4432

1.5A High-Speed 30V MOSFET Drivers

Features

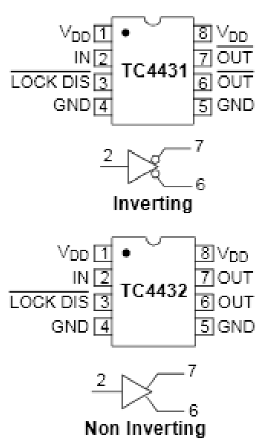
- High Peak Output Current – 1.5A
- Wide Input Supply Voltage Operating Range:
  - 4.5V to 30V
- High Capacitive Load Drive Capability:
  - 1000 pF in 25 nsec
- Short Delay Times – <78 nsec Typ.
- Low Supply Current:
  - With Logic '1' Input – 2.5 mA
  - With Logic '0' Input – 300 µA
- Low Output Impedance – 7Ω
- Latch-Up Protected: Will Withstand >300 mA Reverse Current
- ESD Protected – 4 kV

Applications

- Small Motor Drive
- Power MOSFET Driver
- Driving Bipolar Transistors

Package Types

8-Pin PDIP/SOIC/CERDIP



General Description

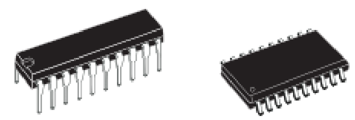
The TC4431/TC4432 are 30V CMOS buffer/drivers suitable for use in high-side driver applications. They will not latch-up under any conditions within their power and voltage ratings. They can accept, without damage or logic upset, up to 300 mA of reverse current (of either polarity) being forced back into their outputs. All terminals are fully protected against up to 4 kV of electrostatic discharge.

Undervoltage lockout circuitry forces the output to a 'low' state when the input supply voltage drops below 7V. For operation at lower voltages, disable the lockout and start-up circuit by grounding pin 3 ($\overline{\text{LOCK DIS}}$); for all other situations, pin 3 should be left floating. The under-voltage lockout and start-up circuit gives brown-out protection when driving MOSFETS.

L297

STEPPER MOTOR CONTROLLERS

- NORMAL/WAVE DRIVE
- HALF/FULL STEP MODES
- CLOCKWISE/ANTICLOCKWISE DIRECTION
- SWITCHMODE LOAD CURRENT REGULATION
- PROGRAMMABLE LOAD CURRENT
- FEW EXTERNAL COMPONENTS
- RESET INPUT & HOME OUTPUT
- ENABLE INPUT



DIP20 SO20

ORDERING NUMBERS : L297/1 (DIP20)
L297D (SO20)

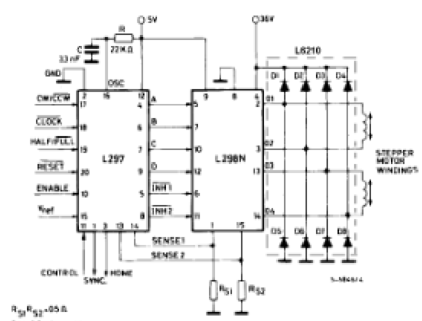
DESCRIPTION

The L297 Stepper Motor Controller IC generates four phase drive signals for two phase bipolar and four phase unipolar step motors in microcomputer-controlled applications. The motor can be driven in half step, normal and wawe drive modes and on-chip PWM chopper circuits permit switch-mode control of the current in the windings. A feature of this device is that it requires only clock, direction and mode input signals. Since the phase are generated internally the burden on the microprocessor, and the programmer, is greatly reduced. Mounted in DIP20 and SO20 packages, the L297 can be used with monolithic bridge drives such as the L298N or L293E, or with discrete transistors and darlingtons.

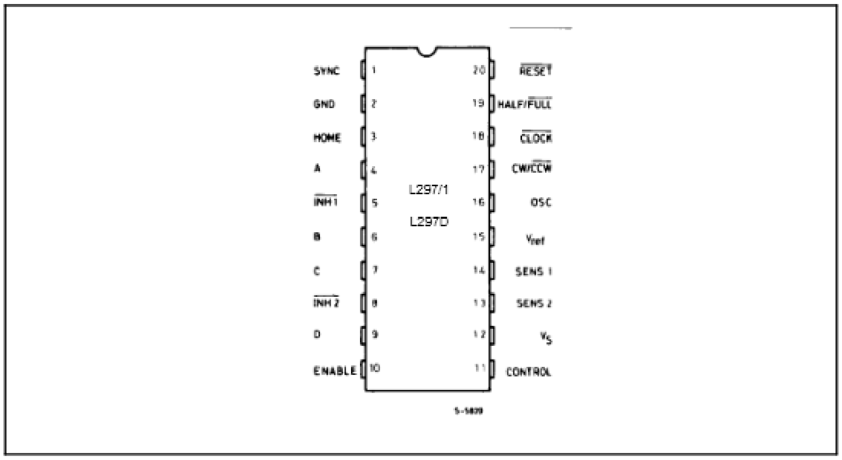
ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter	Value	Unit
V_s	Supply voltage	10	V
V_i	Input signals	7	V
P_{tot}	Total power dissipation (T_{amb} = 70°C)	1	W
T_{stg}, T_j	Storage and junction temperature	-40 to + 150	°C

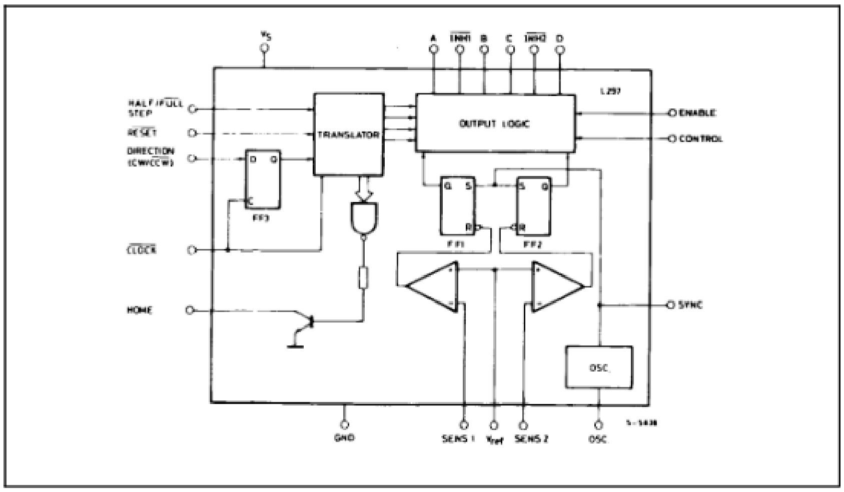
TWO PHASE BIPOLAR STEPPER MOTOR CONTROL CIRCUIT



PIN CONNECTION (Top view)



BLOCK DIAGRAM (L297/1 - L297D)



PIN FUNCTIONS - L297/1 - L297D

N°	NAME	FUNCTION
1	SYNC	Output of the on-chip chopper oscillator. The SYNC connections The SYNC connections of all L297s to be synchronized are connected together and the oscillator components are omitted on all but one. If an external clock source is used it is injected at this terminal.
2	GND	Ground connection.
3	HOME	Open collector output that indicates when the L297 is in its initial state (ABCD = 0101). The transistor is open when this signal is active.
4	A	Motor phase A drive signal for power stage.
5	$\overline{\text{INH1}}$	Active low inhibit control for driver stage of A and B phases. When a bipolar bridge is used this signal can be used to ensure fast decay of load current when a winding is de-energized. Also used by chopper to regulate load current if CONTROL input is low.
6	B	Motor phase B drive signal for power stage.
7	C	Motor phase C drive signal for power stage.
8	$\overline{\text{INH2}}$	Active low inhibit control for drive stages of C and D phases. Same functions as INH1.
9	D	Motor phase D drive signal for power stage.
10	ENABLE	Chip enable input. When low (inactive) INH1, INH2, A, B, C and D are brought low.
11	CONTROL	Control input that defines action of chopper. When low chopper acts on INH1 and INH2; when high chopper acts on phase lines ABCD.
12	V_s	5V supply input.
13	$SENS_2$	Input for load current sense voltage from power stages of phases C and D.
14	$SENS_1$	Input for load current sense voltage from power stages of phases A and B.
15	V_{ref}	Reference voltage for chopper circuit. A voltage applied to this pin determines the peak load current.
16	OSC	An RC network (R to V_{CC}, C to ground) connected to this terminal determines the chopper rate. This terminal is connected to ground on all but one device in synchronized multi - L297 configurations. f ≅ 1/0.69 RC
17	CW/$\overline{\text{CCW}}$	Clockwise/counterclockwise direction control input. Physical direction of motor rotation also depends on connection of windings. Synchronized internally therefore direction can be changed at any time.
18	$\overline{\text{CLOCK}}$	Step clock. An active low pulse on this input advances the motor one increment. The step occurs on the rising edge of this signal.

PIN FUNCTIONS - L297/1 - L297D (continued)

N°	NAME	FUNCTION
19	HALF/$\overline{\text{FULL}}$	Half/full step select input. When high selects half step operation, when low selects full step operation. One-phase-on full step mode is obtained by selecting FULL when the L297's translator is at an even-numbered state. Two-phase-on full step mode is set by selecting FULL when the translator is at an odd numbered position. (The home position is designate state 1).
20	$\overline{\text{RESET}}$	Reset input. An active low pulse on this input restores the translator to the home position (state 1, ABCD = 0101).

THERMAL DATA

Symbol	Parameter		DIP20	SO20	Unit
$R_{th\text{-}j\text{-}amb}$	Thermal resistance junction-ambient	max	80	100	°C/W

CIRCUIT OPERATION

The L297 is intended for use with a dual bridge driver, quad darlington array or discrete power devices in step motor driving applications. It receives step clock, direction and mode signals from the systems controller (usually a microcomputer chip) and generates control signals for the power stage.

The principal functions are a translator, which generates the motor phase sequences, and a dual PWM chopper circuit which regulates the current in the motor windings. The translator generates three different sequences, selected by the HALF/FULL input. These are normal (two phases energised), wave drive (one phase energised) and half-step (alternately one phase energised/two phases energised). Two inhibit signals are also generated by the L297 in half step and wave drive modes. These signals, which connect directly to the L298's enable inputs, are intended to speed current decay when a winding is de-energised. When the L297 is used to drive a unipolar motor the chopper acts on these lines.

An input called CONTROL determines whether the chopper will act on the phase lines ABCD or the inhibit lines INH1 and INH2. When the phase lines are chopped the non-active phase line of each pair (AB or CD) is activated (rather than interrupting the line then active). In L297 + L298 configurations this technique reduces dissipation in the load current sense resistors.

A common on-chip oscillator drives the dual chopper. It supplies pulses at the chopper rate which set the two flip-flops FF1 and FF2. When the current in a winding reaches the programmed peak value the voltage across the sense resistor (connected to one of the sense inputs $SENS_1$ or $SENS_2$) equals V_{ref} and the corresponding comparator resets its flip flop, interrupting the drive current until the next oscillator pulse arrives. The peak current for both windings is programmed by a voltage divider on the V_{ref} input.

Ground noise problems in multiple configurations can be avoided by synchronising the chopper oscillators. This is done by connecting all the SYNC pins together, mounting the oscillator RC network on one device only and grounding the OSC pin on all other devices.

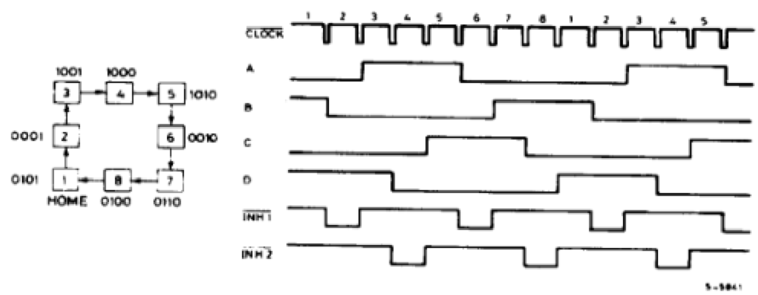
MOTOR DRIVING PHASE SEQUENCES

The L297's translator generates phase sequences for normal drive, wave drive and half step modes. The state sequences and output waveforms for these three modes are shown below. In all cases the translator advances on the low to high transition of $\overline{\text{CLOCK}}$.

Clockwise rotation is indicate; for anticlockwise rotation the sequences are simply reversed $\overline{\text{RESET}}$ restores the translator to state 1, where ABCD = 0101.

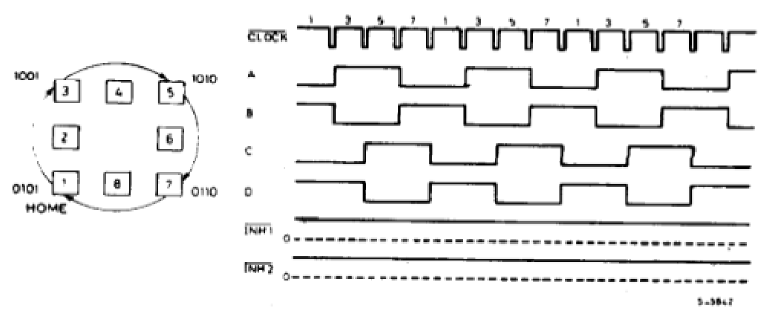
HALF STEP MODE

Half step mode is selected by a high level on the HALF/$\overline{\text{FULL}}$ input.



NORMAL DRIVE MODE

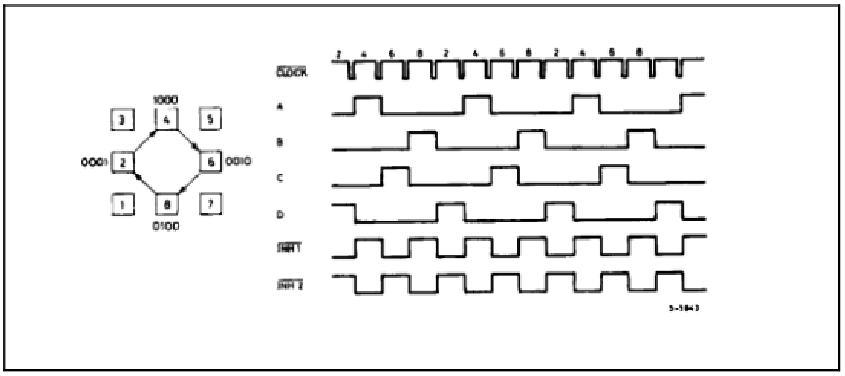
Normal drive mode (also called "two-phase-on" drive) is selected by a low level on the HALF/$\overline{\text{FULL}}$ input when the translator is at an odd numbered state (1, 3, 5 or 7). In this mode the $\overline{\text{INH1}}$ and $\overline{\text{INH2}}$ outputs remain high throughout.



MOTOR DRIVING PHASE SEQUENCES (continued)

WAVE DRIVE MODE

Wave drive mode (also called "one-phase-on" drive) is selected by a low level on the HALF/$\overline{\text{FULL}}$ input when the translator is at an even numbered state (2, 4, 6 or 8).



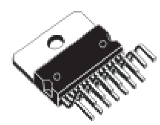
ELECTRICAL CHARACTERISTICS (Refer to the block diagram T_{amb} = 25°C, V_s = 5V unless otherwise specified)

Symbol	Parameter	Test conditions		Min.	Typ	Max.	Unit
V_s	Supply voltage (pin 12)			4.75		7	V
I_s	Quiescent supply current (pin 12)	Outputs floating			50	80	mA
V_i	Input voltage (pin 11, 17, 18, 19, 20)		Low			0.6	V
			High	2		V_s	V
I_i	Input current (pin 11, 17, 18, 19, 20)		V_i = L		100	μA	
			V_i = H			10	μA
V_{en}	Enable input voltage (pin 10)		Low			1.3	V
			High	2		V_s	V
I_{en}	Enable input current (pin 10)		V_{en} = L			100	μA
			V_{en} = H			10	μA
V_o	Phase output voltage (pins 4, 6, 7, 9)	I_o = 10mA	V_{OL}			0.4	V
		I_o = 5mA	V_{OH}	3.9			V
V_{inh}	Inhibit output voltage (pins 5, 8)	I_o = 10mA	$V_{inh\ L}$			0.4	V
		I_o = 5mA	$V_{inh\ H}$	3.9			V
V_{SYNC}	Sync Output Voltage	I_o = 5mA	$V_{SYNC\ H}$	3.3			V
		I_o = 5mA	$V_{SYNC\ V}$			0.8	

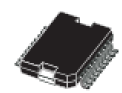
L298

DUAL FULL-BRIDGE DRIVER

- OPERATING SUPPLY VOLTAGE UP TO 46 V
- TOTAL DC CURRENT UP TO 4 A
- LOW SATURATION VOLTAGE
- OVERTEMPERATURE PROTECTION
- LOGICAL "0" INPUT VOLTAGE UP TO 1.5 V (HIGH NOISE IMMUNITY)



Multiwatt15



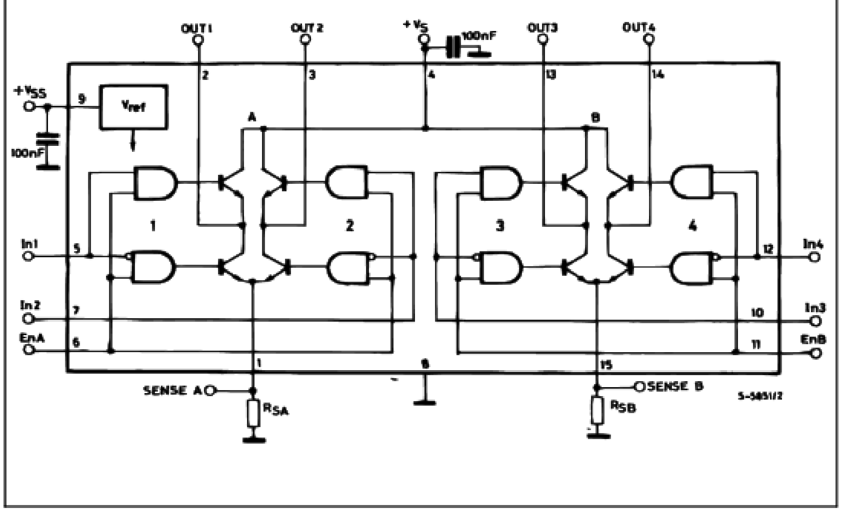
PowerSO20

ORDERING NUMBERS : L298N (Multiwatt Vert.)
L298HN (Multiwatt Horiz.)
L298P (PowerSO20)

DESCRIPTION

The L298 is an integrated monolithic circuit in a 15-lead Multiwatt and PowerSO20 packages. It is a high voltage, high current dual full-bridge driver designed to accept standard TTL logic levels and drive inductive loads such as relays, solenoids, DC and stepping motors. Two enable inputs are provided to enable or disable the device independently of the input signals. The emitters of the lower transistors of each bridge are connected together and the corresponding external terminal can be used for the connection of an external sensing resistor. An additional supply input is provided so that the logic works at a lower voltage.

BLOCK DIAGRAM



PIN FUNCTIONS (refer to the block diagram)

MW.15	PowerSO	Name	Function
1;15	2;19	Sense A; Sense B	Between this pin and ground is connected the sense resistor to control the current of the load.
2;3	4;5	Out 1; Out 2	Outputs of the Bridge A; the current that flows through the load connected between these two pins is monitored at pin 1.
4	6	V_S	Supply Voltage for the Power Output Stages. A non-inductive 100nF capacitor must be connected between this pin and ground.
5;7	7;9	Input 1; Input 2	TTL Compatible Inputs of the Bridge A.
6;11	8;14	Enable A; Enable B	TTL Compatible Enable Input: the L state disables the bridge A (enable A) and/or the bridge B (enable B).
8	1,10,11,20	GND	Ground.
9	12	VSS	Supply Voltage for the Logic Blocks. A100nF capacitor must be connected between this pin and ground.
10; 12	13;15	Input 3; Input 4	TTL Compatible Inputs of the Bridge B.
13; 14	16;17	Out 3; Out 4	Outputs of the Bridge B. The current that flows through the load connected between these two pins is monitored at pin 15.
–	3;18	N.C.	Not Connected

ELECTRICAL CHARACTERISTICS (V_S = 42V; V_{SS} = 5V, T_j = 25°C; unless otherwise specified)

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
V_S	Supply Voltage (pin 4)	Operative Condition	V_{IH} +2.5		46	V
V_{SS}	Logic Supply Voltage (pin 9)		4.5	5	7	V
I_S	Quiescent Supply Current (pin 4)	V_{en} = H; I_L = 0 V_i = L V_i = H		13 50	22 70	mA mA
		V_{en} = L V_i = X			4	mA
I_{SS}	Quiescent Current from V_{SS} (pin 9)	V_{en} = H; I_L = 0 V_i = L V_i = H		24 7	36 12	mA mA
		V_{en} = L V_i = X			6	mA
V_{iL}	Input Low Voltage (pins 5, 7, 10, 12)		–0.3		1.5	V
V_{iH}	Input High Voltage (pins 5, 7, 10, 12)		2.3		VSS	V
I_{iL}	Low Voltage Input Current (pins 5, 7, 10, 12)	V_i = L			–10	µA
I_{iH}	High Voltage Input Current (pins 5, 7, 10, 12)	Vi = H ≤ V_{SS} –0.6V		30	100	µA
V_{en} = L	Enable Low Voltage (pins 6, 11)		–0.3		1.5	V
V_{en} = H	Enable High Voltage (pins 6, 11)		2.3		V_{SS}	V
I_{en} = L	Low Voltage Enable Current (pins 6, 11)	V_{en} = L			–10	µA
I_{en} = H	High Voltage Enable Current (pins 6, 11)	V_{en} = H ≤ V_{SS} –0.6V		30	100	µA
$V_{CEsat(H)}$	Source Saturation Voltage	I_L = 1A I_L = 2A	0.95	1.35 2	1.7 2.7	V V
$V_{CEsat(L)}$	Sink Saturation Voltage	I_L = 1A (5) I_L = 2A (5)	0.85	1.2 1.7	1.6 2.3	V V
V_{CEsat}	Total Drop	I_L = 1A (5) I_L = 2A (5)	1.80		3.2 4.9	V V
V_{sens}	Sensing Voltage (pins 1, 15)		–1 (1)		2	V

AN470
APPLICATION NOTE

THE L297 STEPPER MOTOR CONTROLLER

The L297 integrates all the control circuitry required to control bipolar and unipolar stepper motors. Used with a dual bridge driver such as the L298N forms a complete microprocessor-to-bipolar stepper motor interface. Unipolar stepper motor can be driven with an L297 plus a quad darlington array. This note describes the operation of the circuit and shows how it is used.

The L297 Stepper Motor Controller is primarily intended for use with an L298N or L293E bridge driver in stepper motor driving applications.

It receives control signals from the system's controller, usually a microcomputer chip, and provides all the necessary drive signals for the power stage. Additionally, it includes two PWM chopper circuits to regulate the current in the motor windings.

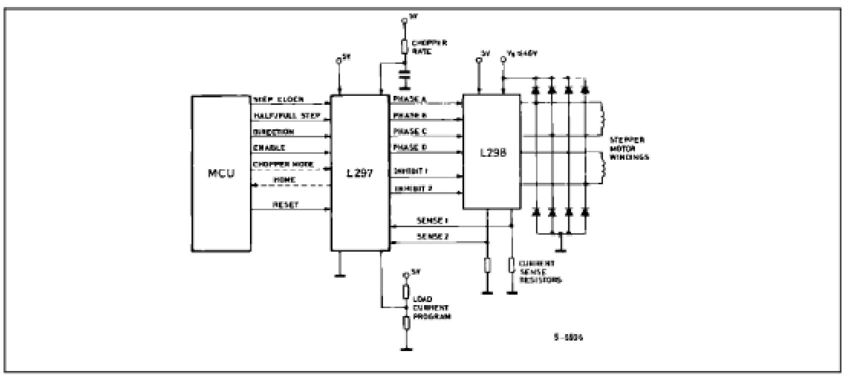
With a suitable power actuator the L297 drives two phase bipolar permanent magnet motors, four phase unipolar permanent magnet motors and four phase variable reluctance motors. Moreover, it handles normal, wave drive and half step drive modes. (This is all explained in the section "Stepper Motor Basics").

Two versions of the device are available : the regular L297 and a special version called L297A. The L297A incorporates a step pulse doubler and is designed specifically for floppy-disk head positioning applications.

ADVANTAGES

The L297 + driver combination has many advantages : very few components are required (so assembly costs are low, reliability high and little space required), software development is simplified and the burden on the micro is reduced. Further, the choice of a two-chip approach gives a high degree offlexibility-theL298NcanbeusedonitsownforDC motors and the L297 can be used with any power stage, including discrete power devices (it provides 20mA drive for this purpose).

Figure 1. In this typical configuration an L297 stepper motor controller and L298 dual bridge driver combine to form a complete microprocessor to bipolar stepper motor interface.



For bipolar motors with winding currents up to 2A the L297 should be used with the L298N ; for winding currents up to 1A the L293E is recommended (the L293 will also be useful if the chopper isn't needed). Higher currents are obtained with power transistors or darlingtons and for unipolar motors a darlington array such as the ULN2075B is suggested. The block diagram, figure 1, shows a typical system.

Applications of the L297 can be found almost everywhere ... printers (carriage position, daisy position, paper feed, ribbon feed), typewriters, plotters, numerically controlled machines, robots, floppy disk drives, electronic sewing machines, cash registers, photocopiers, telex machines, electronic carbure-tos, telecopiers, photographic equipment, paper tape readers, optical character recognisers, electric valves and so on.

The L297 is made with STMicroelectronics' analog/digital compatible I^2L technology (like Zodiac) and is assembled in a 20-pin plastic DIP. A 5V supply is used and all signal lines are TTL/CMOS compatible or open collector transistors. High density is one of the key features of the technology so the L297 die is very compact.

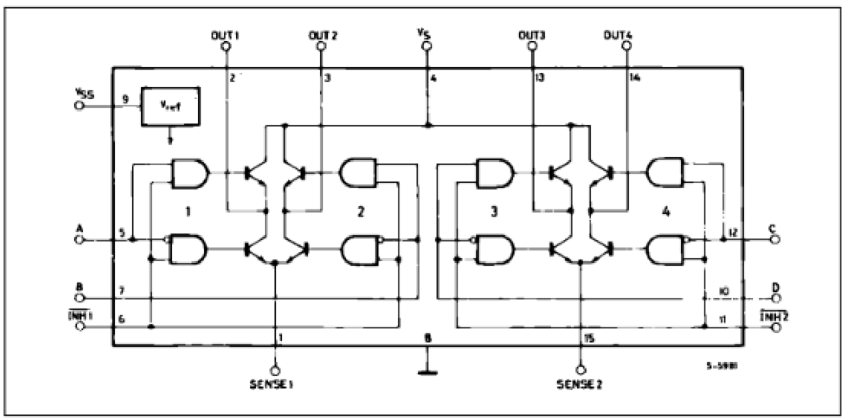
THE L298N AND L293E

Since the L297 is normally used with an L298N or L293E bridge driver a brief review of these devices will make the rest of this note easier to follow. The L298N and L293E contain two bridge driver stages, each controlled by two TTL-level logic inputs and a TTL-level enable input. In addition, the emitter connections of the lower transistors are brought out to external terminals to allow the connection of current sensing resistors (figure 2).

For the L298N STMicroelectronics' innovative ion-implanted high voltage/high current technology is used, allowing it to handle effective powers up to 160W (46V supply, 2A per bridge). A separate 5V logic supply input is provided to reduce dissipation and to allow direct connection to the L297 or other control logic. In this note the pins of the L298N are labelled with the pin names of the corresponding L297 terminals to avoid unnecessary confusion.

The L298N is supplied in a 15-lead Multiwatt plastic power package. It's smaller brother, the functionally identical L293E, is packaged in a Powerdip – a copper frame DIP that uses the four center pins to conduct heat to the circuit board copper.

Figure 2. The L298N contains two bridge drivers (four push pull stages) each controlled by two logic inputs and an enable input. External emitter connections are provided for current sense resistors. The L293E has external connections for all four emitters.



STEPPER MOTOR BASICS

There are two basic types of stepper motor in common use : permanent magnet and variable reluctance. Permanent magnet motors are divided into bipolar and unipolar types.

Appendix J – Power Components

Murata Power Solutions

Okami **OKI-78SR Series**

Fixed Output 1.5 Amp SIP DC/DC Converters

Typical unit

PRODUCT OVERVIEW

Fabricated on a 0.41 by 0.65 inch (10.4 by 16.5 mm) Single Inline Package (SIP) module, the OKI-78SR series are non-isolated switching regulator (SR) DC/DC power converters for embedded applications. The fixed single output converters offer both tight regulation and high efficiency directly at the power usage site and are a direct plug-in replacement for TO-220 package 78xx series linear regulators. Typically, no extra outside components are required.

Two nominal output voltages are offered (3.3 and 5 VDC), each with 1.5 Amp maximum output.

Based on fixed-frequency buck switching topology, the high efficiency means very low heat and little electrical noise, requiring no external components. The ultra wide input range is 7 to 36 Volts DC.

Protection features include input undervoltage and short circuit protection, overcurrent and over temperature shut down. The OKI-78SR is designed to meet all standards approvals. RoHS-6 (no lead) hazardous material compliance is specified as standard.

FEATURES

- Ultra wide 7 to 36 VDC input range
- Fixed Outputs of 3.3 or 5 VDC up to 1.5 Amps
- Vertical or horizontal SIP-mount, small footprint package
- "No heat sink" direct replacement for 3-terminal 78xx-series linear regulators
- High efficiency with no external components
- Short circuit protection
- Outstanding thermal derating performance
- UL/EN/IEC 60950-1, 2nd Edition safety approvals (pending)

Contents	Page

Connection Diagram

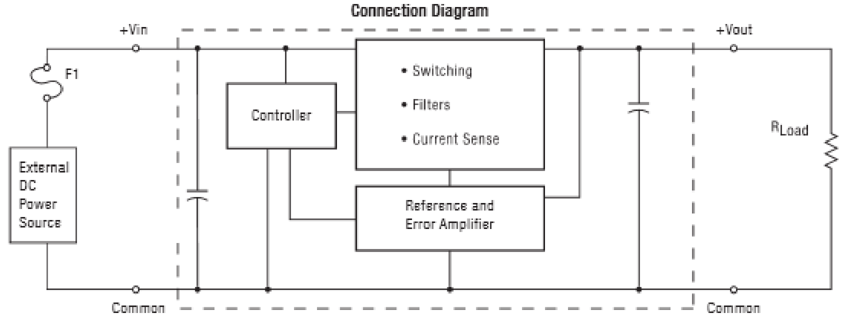


Figure 1. OKI-78SR

Note: Murata Power Solutions strongly recommends an external input fuse, F1. See specifications.

RoHS COMPLIANT 2002/95/EC

For full details go to www.murata-ps.com/rohs

c US (certification is pending)

www.murata-ps.com/support

Calculate The AMP Hour Capacity Battery You Need

In order to determine the proper amp hour rating capacity you need for your boat, simply add up the 12-volt accessories you have, multiply by 20; that should give you a very good approximation of your boat's amp hour battery requirement. Then cross reference this to the charts below. The first chart provides amp load versus minutes, the second chart provides the 20-hour rate. It is usually advised to buy a battery at least 20% over this requirement, as 12-volt capacity varies with usage and as batteries age.

AMP Load VS. Minutes

MODEL #	DISCHARGE TIME IN MINUTES					
NC-24	790	350	215	156	120	33
NG-24	920	410	254	180	140	38
NC-27	1200	500	300	211	160	40
NG-27	1270	545	335	235	182	47
NG-31	1410	615	380	270	205	54
NG-4D	2290	880	505	335	250	65
NG-8D	2700	1200	735	522	400	105
	5	10	15	20	25	75
	Load In AMPs					

220 HOUR RATE

MODEL #	AMP HOUR @ 20-HR. RATE
NC-24	70
NG-24	80
NC-27	100
NG-27	105
NG-31	115
NG-4D	160
NG-8D	200

Series Versus Parallel Installations

Batteries can be arranged differently to achieve increased capacity or increased voltage to match your specific requirements. **It is extremely important not to mix battery types (Flooded, AGM).**

Parallel Installation

Two batteries connected + to + and - to - in a parallel system that increases capacity and maintains a specific voltage. This configuration doubles the power or amp hour rating of the battery while maintaining the voltage. Thus, two 25-amp hour, 12-volt batteries in parallel will give you a 50-amp hour 12-volt system.

Series Installation

A series system increases the voltage and keeps the battery capacity the same. The same two batteries in a series arrangement will increase the voltage to 24 volts and maintain a battery capacity of 25 amp hours. To install batteries in series, one battery's positive post is connected to the second battery's negative post.

Installation And Maintenance

Exide batteries should always be installed in a ventilated area. Batteries release explosive gasses during the charging phase and should not be exposed to spark or flame. When installing a battery in your boat, it is important to use either a box or a tie-down system to keep the battery stationary once underway. This will reduce unnecessary vibration. Make sure all connections to the battery terminals are tight. Additionally, it is important to coat the terminals and connections with a corrosion inhibitor. The corrosion inhibitor should be reapplied every several months. Failure to do this will result in poor connections and wire corrosion, especially in salt water environments. Corrosion increases the resistance in the wires, requiring more amps to be drawn to run electrical equipment. When installing a new battery, be sure to remove any plastic battery terminal protectors before attaching wires.

Maintenance

All Exide marine batteries, except AGM types, have removable vent caps so that electrolyte levels can be checked regularly. You should check the electrolyte level every month. When storing a battery for the winter, check and fill with distilled water as needed, recharge the battery **fully**, and store in a cool place. When preparing the battery after winter storage, recharge the battery to its full charge state.

Leotech	UT1871-81-M1	5.0mm ROUND LED LAMP

Absolute Maximum Ratings at Ta=25℃

Parameter	Symbol	Rating	Unit
Power Dissipation	PD	66	mW
Reverse Voltage	VR	4	V
D.C. Forward Current	If	30	mA
Reverse (Leakage) Current	Ir	100	μA
Peak Current(1/10Duty Cycle,0.1ms Pulse Width.)	If(Peak)	100	mA
Operating Temperature Range	Topr.	-25 to +85	℃
Storage Temperature Range	Tstg.	-40 to +100	℃
Lead Soldering Temp.(1.6mm from body) for 5 seconds		260	℃

Electrical and Optical Characteristics:

Parameter	Symbol	Condition	Min.	Typ.	Max.	Unit
Luminous Intensity	Iv	If=20mA	42.9	75.0		mcd
Forward Voltage	Vf	If=20mA		1.8	2.2	V
Peak Wavelength	λP	If=20mA		660		nm
Dominant Wavelength	λD	If=20mA		643		nm
Reverse (Leakage) Current	Ir	Vr=4V			100	μA
Viewing Angle	$2\theta 1/2$	If=20mA		36		deg
Spectrum Line Halfwidth	Δλ	If=20mA		20		nm

NOTE: THE DATAS TESTED BY IS TESTER

Appendix K – Microprocessor

dsPIC33FJ32MC302/304, dsPIC33FJ64MCX02/X04 AND dsPIC33FJ128MCX02/X04

High-Performance, 16-bit Digital Signal Controllers

Operating Range:

- Up to 40 MIPS operation (at 3.0V-3.6V):
  - Industrial temperature range (-40°C to +85°C)
  - Extended temperature range (-40°C to +125°C)
- Up to 20 MIPS operation (at 3.0V-3.6V):
  - High temperature range (-40°C to +150°C)

High-Performance DSC CPU:

- Modified Harvard architecture
- C compiler optimized instruction set
- 16-bit wide data path
- 24-bit wide instructions
- Linear program memory addressing up to 4M instruction words
- Linear data memory addressing up to 64 Kbytes
- 83 base instructions: mostly 1 word/1 cycle
- Two 40-bit accumulators with rounding and saturation options
- Flexible and powerful addressing modes:
  - Indirect
  - Modulo
  - Bit-Reversed
- Software stack
- 16 x 16 fractional/integer multiply operations
- 32/16 and 16/16 divide operations
- Single-cycle multiply and accumulate:
  - Accumulator write back for DSP operations
  - Dual data fetch
- Up to ±16-bit shifts for up to 40-bit data

Direct Memory Access (DMA):

- 8-channel hardware DMA
- Up to 2 Kbytes dual ported DMA buffer area (DMA RAM) to store data transferred via DMA:
  - Allows data transfer between RAM and a peripheral while CPU is executing code (no cycle stealing)
- Most peripherals support DMA

Timers/Capture/Compare/PWM:

- Timer/Counters, up to five 16-bit timers:
  - Can pair up to make two 32-bit timers
  - One timer runs as a Real-Time Clock with an external 32.768 kHz oscillator
  - Programmable prescaler
- Input Capture (up to four channels):
  - Capture on up, down or both edges
  - 16-bit capture input functions
  - 4-deep FIFO on each capture
- Output Compare (up to four channels):
  - Single or Dual 16-bit Compare mode
  - 16-bit Glitchless PWM mode
- Hardware Real-Time Clock and Calendar (RTCC):
  - Provides clock, calendar and alarm functions

Interrupt Controller:

- 5-cycle latency
- Up to 53 available interrupt sources
- Up to three external interrupts
- Seven programmable priority levels
- Five processor exceptions

Digital I/O:

- Peripheral pin Select functionality
- Up to 35 programmable digital I/O pins
- Wake-up/Interrupt-on-Change for up to 31 pins
- Output pins can drive from 3.0V to 3.6V
- Up to 5.5V output with open drain configuration on 5V tolerant pins with external pull-up
- 4 mA sink on all I/O pins

On-Chip Flash and SRAM:

- Flash program memory (up to 128 Kbytes)
- Data SRAM (up to 16 Kbytes)
- Boot, Secure, and General Security for program Flash

System Management:

- Flexible clock options:
  - External, crystal, resonator, internal RC
  - Fully integrated Phase-Locked Loop (PLL)
  - Extremely low jitter PLL
- Power-up Timer
- Oscillator Start-up Timer/Stabilizer
- Watchdog Timer with its own RC oscillator
- Fail-Safe Clock Monitor (FSCM)
- Reset by multiple sources

Power Management:

- On-chip 2.5V voltage regulator
- Switch between clock sources in real time
- Idle, Sleep, and Doze modes with fast wake-up

Analog-to-Digital Converters (ADCs):

- 10-bit, 1.1 Msps or 12-bit, 500 Ksps conversion:
  - Two and four simultaneous samples (10-bit ADC)
  - Up to nine input channels with auto-scanning
  - Conversion start can be manual or synchronized with one of four trigger sources
  - Conversion possible in Sleep mode
  - ±2 LSb max integral nonlinearity
  - ±1 LSb max differential nonlinearity

Audio Digital-to-Analog Converter (DAC):

- 16-bit Dual Channel DAC module
- 100 Ksps maximum sampling rate
- Second-Order Digital Delta-Sigma Modulator

Comparator Module:

- Two analog comparators with programmable input/output configuration

CMOS Flash Technology:

- Low-power, high-speed Flash technology
- Fully static design
- 3.3V (±10%) operating voltage
- Industrial and Extended temperature
- Low power consumption

Motor Control Peripherals:

- 6-channel 16-bit Motor Control PWM:
  - Three duty cycle generators
  - Independent or Complementary mode
  - Programmable dead-time and output polarity
  - Edge-aligned or center-aligned
  - Manual output override control
  - One Fault input
  - Trigger for ADC conversions
  - PWM frequency for 16-bit resolution (@ 40 MIPS) = 1220 Hz for Edge-Aligned mode, 610 Hz for Center-Aligned mode
  - PWM frequency for 11-bit resolution (@ 40 MIPS) = 39.1 kHz for Edge-Aligned mode, 19.55 kHz for Center-Aligned mode
- 2-channel 16-bit Motor Control PWM:
  - One duty cycle generator
  - Independent or Complementary mode
  - Programmable dead time and output polarity
  - Edge-aligned or center-aligned
  - Manual output override control
  - One Fault input
  - Trigger for ADC conversions
  - PWM frequency for 16-bit resolution (@ 40 MIPS) = 1220 Hz for Edge-Aligned mode, 610 Hz for Center-Aligned mode
  - PWM frequency for 11-bit resolution (@ 40 MIPS) = 39.1 kHz for Edge-Aligned mode, 19.55 kHz for Center-Aligned mode
- 2-Quadrature Encoder Interface module:
  - Phase A, Phase B, and index pulse input
  - 16-bit up/down position counter
  - Count direction status
  - Position Measurement (x2 and x4) mode
  - Programmable digital noise filters on inputs
  - Alternate 16-bit Timer/Counter mode
  - Interrupt on position counter rollover/underflow

Communication Modules:

- 4-wire SPI (up to two modules):
  - Framing supports I/O interface to simple codecs
  - Supports 8-bit and 16-bit data
  - Supports all serial clock formats and sampling modes
- I^2C™:
  - Full Multi-Master Slave mode support
  - 7-bit and 10-bit addressing
  - Bus collision detection and arbitration
  - Integrated signal conditioning
  - Slave address masking
- UART (up to two modules):
  - Interrupt on address bit detect
  - Interrupt on UART error
  - Wake-up on Start bit from Sleep mode
  - 4-character TX and RX FIFO buffers
  - LIN 2.0 bus support
  - IrDA® encoding and decoding in hardware
  - High-Speed Baud mode
  - Hardware Flow Control with CTS and RTS
- Enhanced CAN (ECAN™ module) 2.0B active:
  - Up to eight transmit and up to 32 receive buffers
  - 16 receive filters and three masks
  - Loopback, Listen Only and Listen All
  - Messages modes for diagnostics and bus monitoring
  - Wake-up on CAN message
  - Automatic processing of Remote Transmission Requests
  - FIFO mode using DMA
  - DeviceNet™ addressing support
- Parallel Master Slave Port (PMP/EPSP):
  - Supports 8-bit or 16-bit data
  - Supports 16 address lines
- Programmable Cyclic Redundancy Check (CRC):
  - Programmable bit length for the CRC generator polynomial (up to 16-bit length)
  - 8-deep, 16-bit or 16-deep, 8-bit FIFO for data input

Packaging:

- 28-pin SPDIP/SOIC/QFN-S
- 44-pin TQFP/QFN

Note:	See Table 1 for the exact peripheral features per device.

dsPIC33FJ32MC302/304, dsPIC33FJ64MCX02/X04 AND dsPIC33FJ128MCX02/X04 PRODUCT FAMILIES

The device names, pin counts, memory sizes, and peripheral availability of each device are listed in Table 1. The pages that follow show their pinout diagrams.

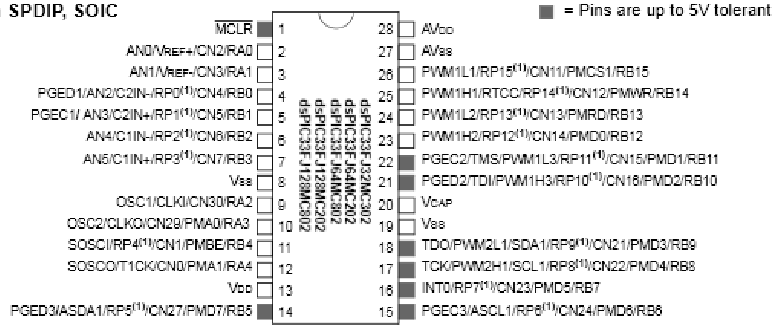
TABLE 1: dsPIC33FJ32MC302/304, dsPIC33FJ64MCX02/X04 AND dsPIC33FJ128MCX02/X04 CONTROLLER FAMILIES

Device	Pins	Program Flash Memory (Kbyte)	RAM (Kbyte)[1]	Remappable Peripheral										RTCC	I²C™	CRC Generator	10-bit/12-bit ADC (Channels)	6-pin 16-bit DAC	Analog Comparator (2 Channels/Voltage Regulator)	8-bit Parallel Master Port (Address Lines)	I/O Pins	Packages
				Remappable Pins	16-bit Timer[2]	Input Capture	Output Compare Standard PWM	Motor Control PWM (Channels)[3]	Quadrature Encoder Interface	UART	SPI	ECAN™	External Interrupts[4]									
dsPIC33FJ128MC804	44	128	16	26	5	4	4	6, 2	2	2	2	1	3	1	1	1	9	1	1/1	11	35	QFN TQFP
dsPIC33FJ128MC802	28	128	16	16	5	4	4	6, 2	2	2	2	1	3	1	1	1	6	0	1/0	2	21	SPDIP SOIC QFN-S
dsPIC33FJ128MC204	44	128	8	26	5	4	4	6, 2	2	2	2	0	3	1	1	1	9	0	1/1	11	35	QFN TQFP
dsPIC33FJ128MC202	28	128	8	16	5	4	4	6, 2	2	2	2	0	3	1	1	1	6	0	1/0	2	21	SPDIP SOIC QFN-S
dsPIC33FJ64MC804	44	64	16	26	5	4	4	6, 2	2	2	2	1	3	1	1	1	9	1	1/1	11	35	QFN TQFP
dsPIC33FJ64MC802	28	64	16	16	5	4	4	6, 2	2	2	2	1	3	1	1	1	6	0	1/0	2	21	SPDIP SOIC QFN-S
dsPIC33FJ64MC204	44	64	8	26	5	4	4	6, 2	2	2	2	0	3	1	1	1	9	0	1/1	11	35	QFN TQFP
dsPIC33FJ64MC202	28	64	8	16	5	4	4	6, 2	2	2	2	0	3	1	1	1	6	0	1/0	2	21	SPDIP SOIC QFN-S
dsPIC33FJ32MC304	44	32	4	26	5	4	4	6, 2	2	2	2	0	3	1	1	1	9	0	1/1	11	35	QFN TQFP
dsPIC33FJ32MC302	28	32	4	16	5	4	4	6, 2	2	2	2	0	3	1	1	1	6	0	1/0	2	21	SPDIP SOIC QFN-S

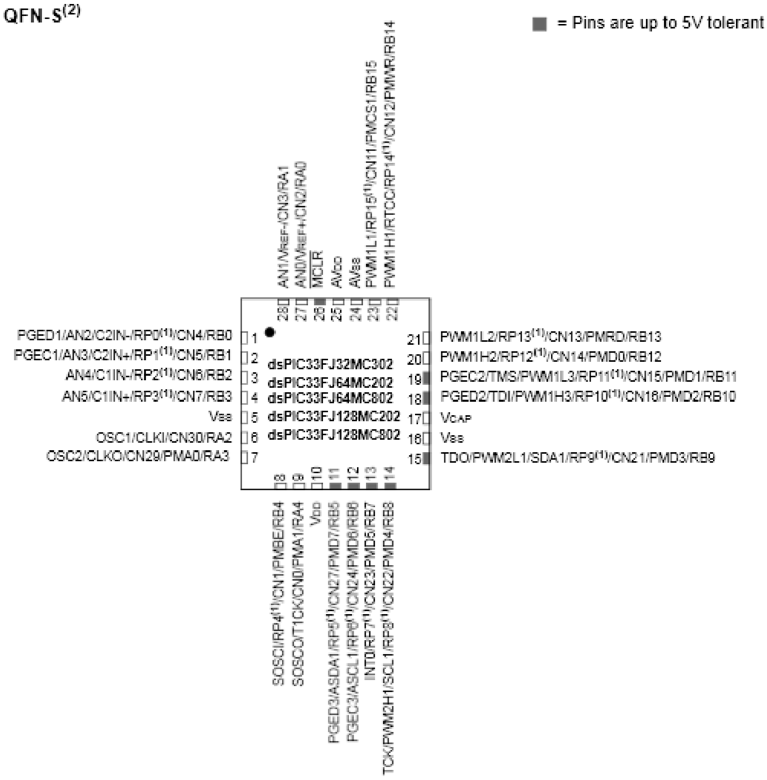
Note 1: RAM size is inclusive of 2 Kbytes of DMA RAM for all devices except dsPIC33FJ32MC302/304, which include 1 Kbyte of DMA RAM.
2: Only four out of five timers are remappable.
3: Only PWM fault pins are remappable.
4: Only two out of three interrupts are remappable.

Pin Diagrams

28-Pin SPDIP, SOIC



28-Pin QFN-S(2)



Note 1: The RPx pins can be used by any remappable peripheral. See Table 1 in this section for the list of available peripherals.

2: The metal plane at the bottom of the device is not connected to any pins and is recommended to be connected to Vss externally.

LED, PART NO.: UT1871-81-M1

Electrical and Optical Characteristics:

Parameter	Symbol	Condition	Min.	Typ.	Max.	Unit
Luminous Intensity	Iv	If=20mA	42.9	75.0		mcd
Forward Voltage	Vf	If=20mA		1.8	2.2	V
Peak Wavelength	λP	If=20mA		660		nm
Dominant Wavelength	λD	If=20mA		643		nm
Reverse (Leakage) Current	Ir	Vr=4V			100	μA
Viewing Angle	2• 1/2	If=20mA		36		deg
Spectrum Line Halfwidth	Δλ	If=20mA		20		nm