

# PINBALL MACHINE DEVELOPMENT NOTES

EPIC Robotz, Fall 2022 Project

# AC Wiring

Otherwise known as “Mains” Wiring

# 110 Volt AC Line Items

- Power to the main 20-48 Adjustable Supply for Magnets and Coils
- Power to 12 Volt Supply for high powered LEDs
- Power to 5 Volt Supply for Raspberry, Logic, and NeoPixel LEDs
- Power to 17" Monitor used as the Score Board

# Questions to Resolve

## Requirements:

- One ON/OFF switch for entire machine.
- One AC power cord to outlet on a wall to power entire machine.

## Questions:

- Where should the On/Off switch be mounted?
- Do we need a fuse? If so, where should it be mounted?
- How should the power be routed to various components?
  - Use Power Strip and Multiple AC cords inside of machine?
  - Or use terminal screw strip and route AC power over custom wires?

# Controlling Magnets and Coils

# List of High Voltage Magnets and Coils

Feature	Number	Coil Resistance	Coil Windings	Amps @ 48v
Flippers	3	3.3 / 350	25-500 / 34-4500	14.5
Bumpers	3	11.2	26-1200	4.2
Kickers	3	4	023-800	12
New Ball Kicker	1	4	023-800	12
Dropped Ball Kicker	1	4	023-800	12
Replacement	0	14.25	26-1500	3.4
<b>Total Circuits</b>	<b>11</b>			

# Direct Control vs Computer Control

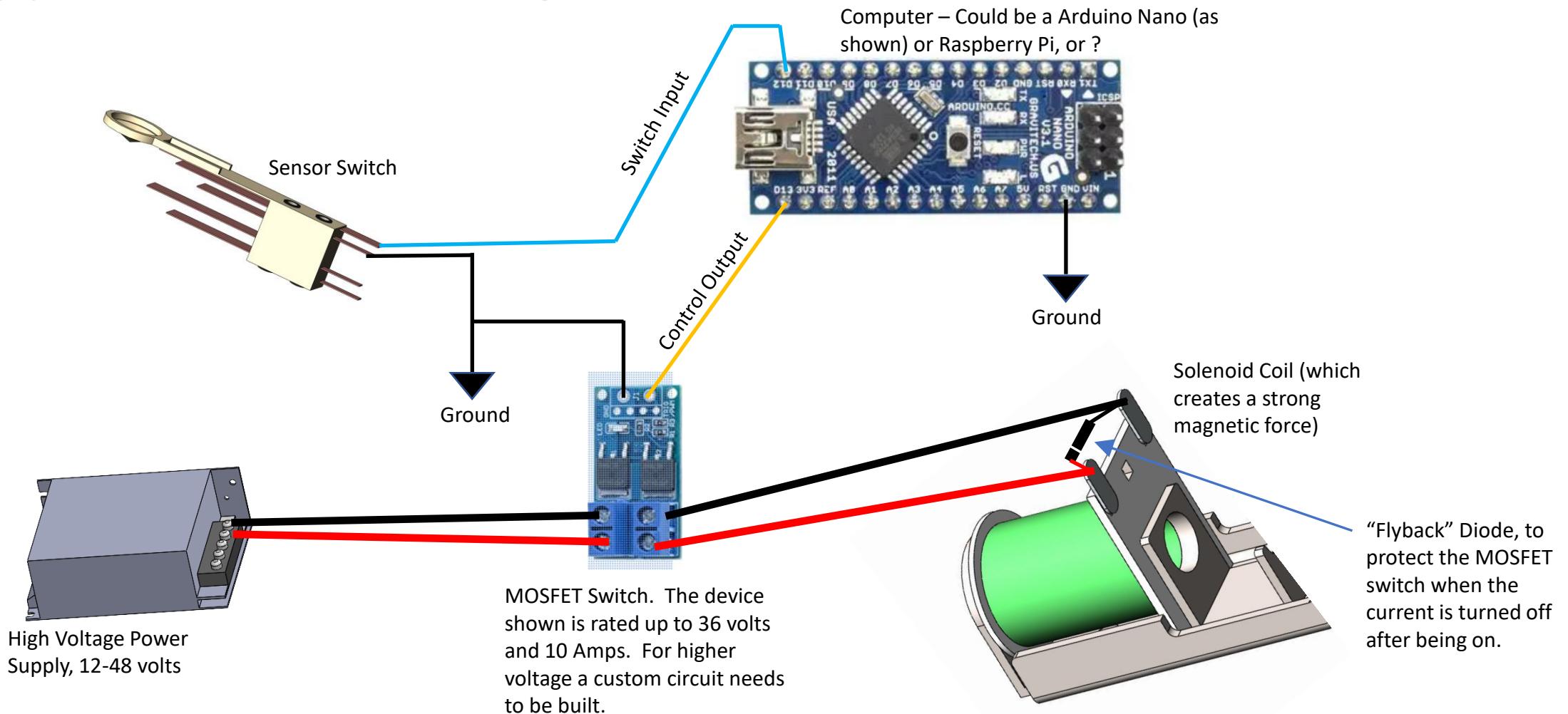
## Direct Control:

- Current runs though “switch” directly to Coil.
- Switch is physically closed by human or pinball
- Switch must be rated for high current
- By itself, computer does not know about switch closure, and therefore cannot score or make sounds
- High current must be limited by circuit design
- In old pinball machines, this design was only choice since there were no computers.

## Computer Control:

- The computer has ability to fire the coil anytime it wants
- The computer reads switch inputs and decides when the coil should be fired.
- Using PWM, the computer can change the strength of the coil magnet, and limit current.
- The sensing switches can be driven with very low current and voltage, so they can be much smaller.
- Scoring is easy, just becomes a software issue
- Downsides:
  - The computer must respond fast enough so that any delay in coil activation does not change gameplay. (Flippers, Kickers, Bumpers, etc)
  - A special computer-controlled switch is needed for each coil. (We use MOSFET switches)

# Typical Coil Wiring



# MOSFET for Coil Switch: FQP30N06L

## Important Parameters:

- 60 Volts
- 32 Amps
- .045 ohm On State Resistance
- About \$1.00 each

**FAIRCHILD SEMICONDUCTOR**

**FQP30N06L**

**N-Channel QFET® MOSFET**  
60 V, 32 A, 35 mΩ

**Description**

This N-Channel enhancement mode power MOSFET is produced using Fairchild Semiconductor's proprietary planar stripe and DMOS technology. This advanced MOSFET technology has been especially tailored to reduce on-state resistance, and to provide superior switching performance and high avalanche energy strength. These devices are suitable for switched mode power supplies, audio amplifier, DC motor control, and variable switching power applications.

**Features**

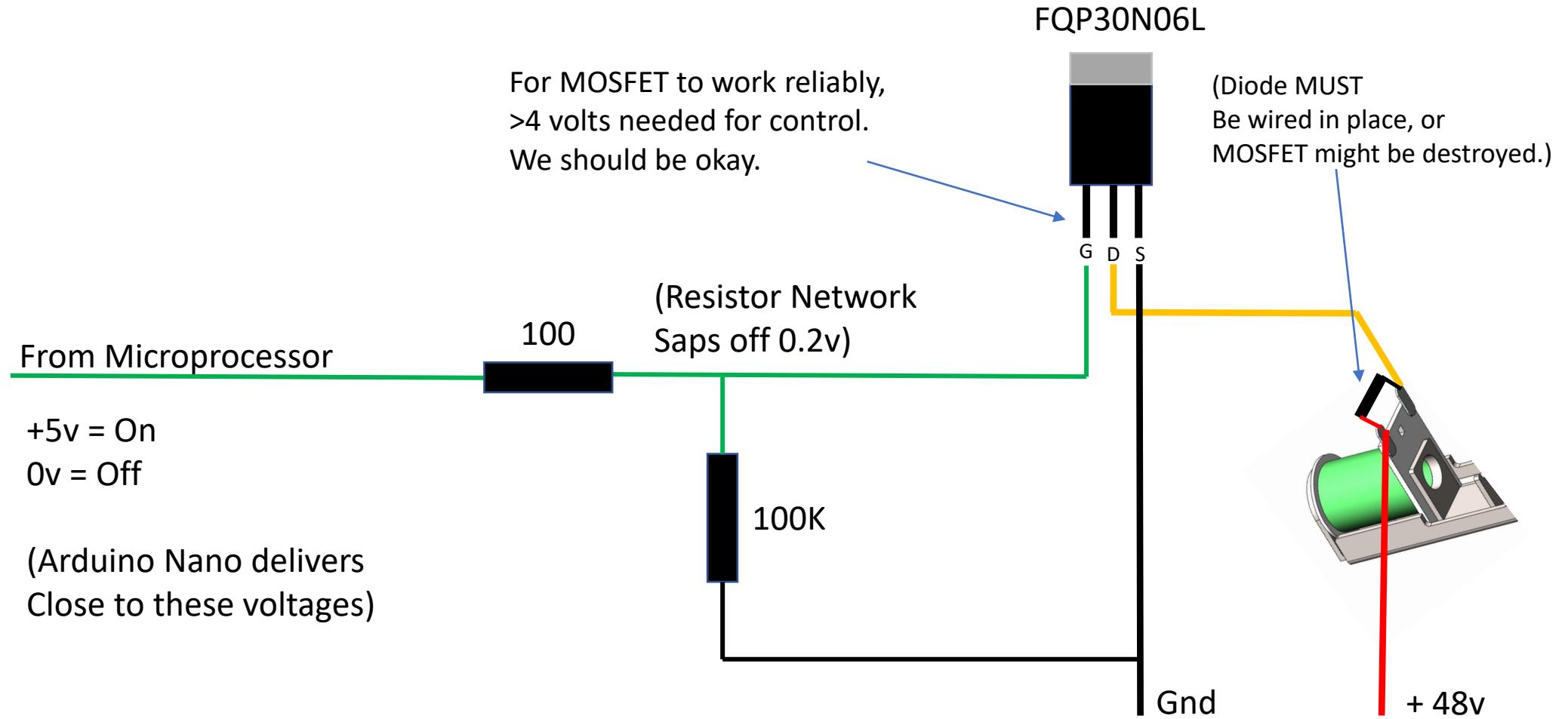
- 32 A, 60 V,  $R_{DS(on)} = 35 \text{ m}\Omega$  (Max.) @  $V_{GS} = 10 \text{ V}$ ,  $I_D = 16 \text{ A}$
- Low Gate Charge (Typ. 15 nC)
- Low Crss (Typ. 50 pF)
- 100% Avalanche Tested
- 175°C Maximum Junction Temperature Rating

**Absolute Maximum Ratings**  $T_C = 25^\circ\text{C}$  unless otherwise noted.

Symbol	Parameter	FQP30N06L	Unit
$V_{DSS}$	Drain-Source Voltage	60	V
$I_D$	Drain Current - Continuous ( $T_C = 25^\circ\text{C}$ )	32	A
	- Continuous ( $T_C = 100^\circ\text{C}$ )	22.6	A
$I_{DM}$	Drain Current - Pulsed	(Note 1)	A
$V_{GSS}$	Gate-Source Voltage	$\pm 20$	V
$EAS$	Single Pulsed Avalanche Energy	(Note 2)	mJ
$I_{AR}$	Avalanche Current	(Note 1)	A
$EAR$	Repetitive Avalanche Energy	(Note 1)	mJ
$dV/dt$	Peak Diode Recovery dv/dt	(Note 3)	V/ns
$P_D$	Power Dissipation ( $T_C = 25^\circ\text{C}$ )	79	W
	- Derate above $25^\circ\text{C}$	0.53	W/°C
$T_J, T_{STG}$	Operating and Storage Temperature Range	-55 to +175	°C
$T_L$	Maximum Lead Temperature for Soldering, 1/8" from Case for 5 seconds	300	°C

Package Marking and Ordering Information									
Part Number	Top Mark	Package	Packing Method	Reel Size	Tape Width	Quantity			
FQP30N06L FQP30N06L TO-220 Tube N/A N/A 50 units									
Electrical Characteristics $T_C = 25^\circ\text{C}$ unless otherwise noted.									
Symbol	Parameter	Test Conditions		Min	Typ	Max	Unit		
<b>Off Characteristics</b>									
$V_{DSS}$	Drain-Source Breakdown Voltage	$V_{GS} = 0 \text{ V}, I_D = 250 \mu\text{A}$		60	--	--	V		
$\Delta V_{DSS} / \Delta T_J$	Breakdown Voltage Temperature Coefficient	$I_D = 250 \mu\text{A}$ , Referenced to $25^\circ\text{C}$		--	0.06	--	V/°C		
$I_{DSS}$	Zero Gate Voltage Drain Current	$V_{DS} = 60 \text{ V}, V_{GS} = 0 \text{ V}$		--	--	1	μA		
		$V_{DS} = 48 \text{ V}, T_J = 150^\circ\text{C}$		--	--	10	μA		
$I_{GSSF}$	Gate-Body Leakage Current, Forward	$V_{GS} = 20 \text{ V}, V_{DS} = 0 \text{ V}$		--	--	100	nA		
$I_{GSSR}$	Gate-Body Leakage Current, Reverse	$V_{GS} = -20 \text{ V}, V_{DS} = 0 \text{ V}$		--	--	-100	nA		
<b>On Characteristics</b>									
$V_{GS(th)}$	Gate Threshold Voltage	$V_{DS} = V_{GS}, I_D = 250 \mu\text{A}$		1.0	--	2.5	V		
$R_{DS(on)}$	Static Drain-Source On-Resistance	$V_{GS} = 10 \text{ V}, I_D = 16 \text{ A}$		--	0.027	0.035	Ω		
$g_{FS}$	Forward Transconductance	$V_{DS} = 25 \text{ V}, I_D = 16 \text{ A}$		--	24	--	S		
<b>Dynamic Characteristics</b>									
$C_{iss}$	Input Capacitance	$V_{DS} = 25 \text{ V}, V_{GS} = 0 \text{ V}$		--	800	1040	pF		
$C_{oss}$	Output Capacitance	$f = 1.0 \text{ MHz}$		--	270	350	pF		
$C_{rss}$	Reverse Transfer Capacitance			--	50	65	pF		
<b>Switching Characteristics</b>									
$t_{d(on)}$	Turn-On Delay Time	$V_{DD} = 30 \text{ V}, I_D = 16 \text{ A}, R_G = 25 \Omega$		--	15	40	ns		
$t_r$	Turn-On Rise Time			--	210	430	ns		
$t_{d(off)}$	Turn-Off Delay Time			--	60	130	ns		
$t_f$	Turn-Off Fall Time			--	110	230	ns		
$Q_g$	Total Gate Charge	$V_{DS} = 48 \text{ V}, I_D = 32 \text{ A}, V_{GS} = 5 \text{ V}$		--	15	20	nC		
$Q_{gs}$	Gate-Source Charge			--	3.5	--	nC		
$Q_{gd}$	Gate-Drain Charge			--	8.5	--	nC		
<b>Drain-Source Diode Characteristics and Maximum Ratings</b>									
$I_S$	Maximum Continuous Drain-Source Diode Forward Current			--	--	32	A		
$I_{SM}$	Maximum Pulsed Drain-Source Diode Forward Current			--	--	128	A		
$V_{SD}$	Drain-Source Diode Forward Voltage	$V_{GS} = 0 \text{ V}, I_S = 32 \text{ A}$		--	--	1.5	V		
$t_{rr}$	Reverse Recovery Time	$V_{GS} = 0 \text{ V}, I_S = 32 \text{ A}, dI_F / dt = 100 \text{ A}/\mu\text{s}$		--	60	--	ns		
$Q_{rr}$	Reverse Recovery Charge			--	90	--	nC		
<b>Notes:</b>									
1. Repetitive Rating : Pulse width limited by maximum junction temperature.									
2. L = 400 μH, $I_{GS} = 32 \text{ A}$ , $V_{GS} = 25 \text{ V}$ , $R_G = 25 \Omega$ , starting $T_J = 25^\circ\text{C}$ .									
3. $I_{GS} \leq 32 \text{ A}$ , $dI_F / dt \leq 300 \text{ A}/\mu\text{s}$ , $V_{GS} \leq BV_{DSS}$ , starting $T_J = 25^\circ\text{C}$ .									
4. Essentially independent of operating temperature.									

# Building a MOSFET Switch



# Experiments for Computer Control

# Control Questions

- What Electrical Architecture should be used to respond quickly to sensor inputs?
- Is a cheap Arduino Nano (\$2.00 each) fast enough for our needs?

# Computerized Control Test

- Testing ability of microprocessor to be in full control of solenoid
- Wrote NanoMagTest
- Had following states:
  - READY – fires the solenoid on switch closure
  - FIRING – Holds the solenoid down for 100 msec
  - STUCK – Comes here after FIRING if switch is still closed. Waits for switch to open.
  - RESTING – comes here after FIRING or STUCK to “rest” before allowing another cycle... Rest time was 80ms
- Observations:
  - Seems to work.
  - Sometimes gets untriggered double strikes
  - Shaking and vibration of table causes fires... Solve that with sturdy table?

# Response Time Test

- Measure time to respond to interrupt on Pin 3 of NANO
- Looks like about 9 uses.



```
3 #define PIN_SQ 3 // Input Square Wave
4 #define PIN_OUT 4 // Output flasher
5
6 // the setup function runs once when you press reset or power the board
7 void setup() {
8     // initialize digital pin LED_BUILTIN as an output.
9     pinMode(PIN_SQ, INPUT_PULLUP);
10    pinMode(PIN_OUT, OUTPUT);
11    attachInterrupt(digitalPinToInterrupt(PIN_SQ), sq_ISR, FALLING);
12    Serial.begin(115200);
13 }
14 long volatile counter = 0;
15 long last_counter = 0;
16 int volatile iled = 0;
17
18 void sq_ISR() {
19     counter++;
20     iled++;
21     if (iled > 1) iled = 0;
22     if (iled == 0) digitalWrite(PIN_OUT, LOW);
23     else digitalWrite(PIN_OUT, HIGH);
24 }
```

# Notes on Arduunio NANO @ 16 MHz

- Max out square wave: 113 Khz, 8.8us
  - Two Digital Write Calls in a while(true) loop.
  - A NANO should execute 16 instructions every 1us.
  - The argues that the C loop generated about  $8.8 \times 16 = 140$  Instructions!
  - (Same code should be about 10 instructions in assembly language, or over 1MHz square wave).

# Slot Switches



Senses when ball rolls  
through a slot

# Force Calculation

Assume Best Case: weight of entire ball presses down at right angle to flat, horizontal surface where the switch is located.

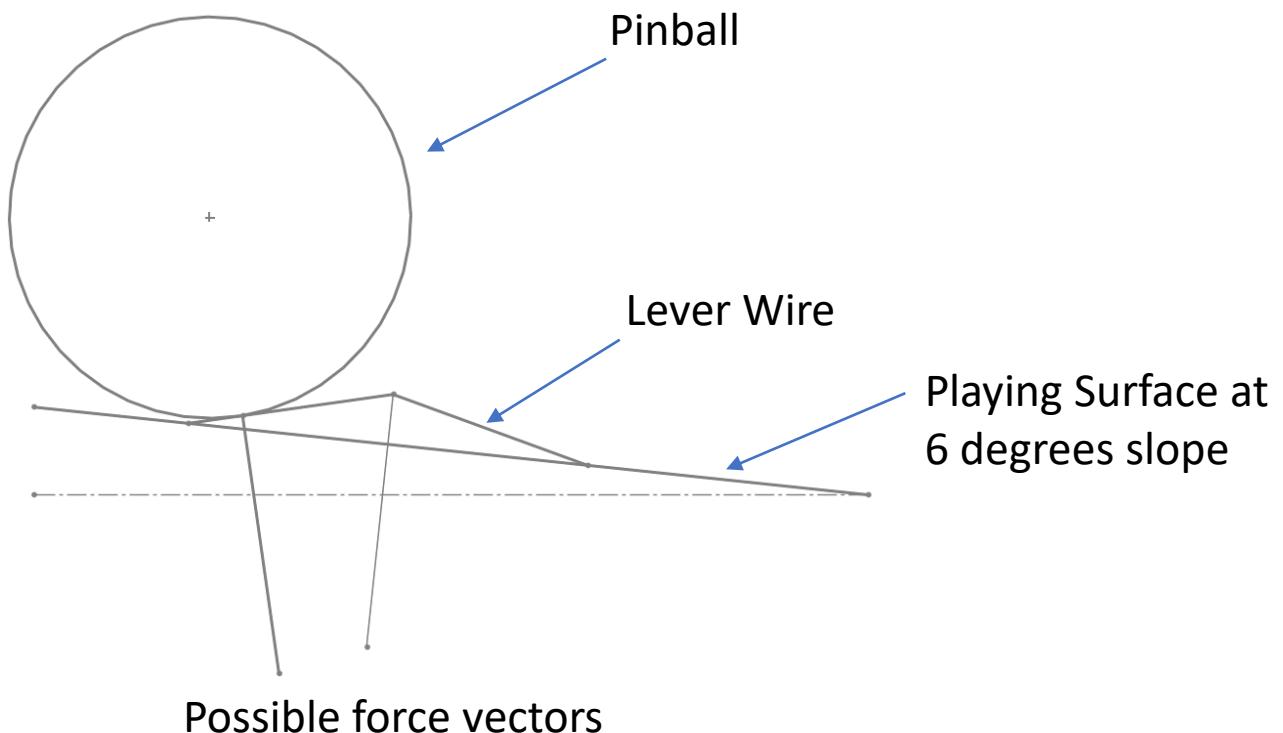
Weight of ball is about 0.15 pounds, or about 2.4 oz, or about 68 grams

Therefore, to account for misalignment, slope of table, and angle to where the force will be applied, assume we want an activating force of about half the weight of the ball, or about 34 grams, or 0.034 kg.

1 Newton of Force is 9.8 kg of mass.

$$\text{Our Max Force} = 0.034 * 9.8 = 0.33 \text{ Newtons}$$

Note, also, we don't want to slow the ball down or change its direction to activate the switch.



# Old Machines, How They Did It

Williams/Bally Sub-Microswitch

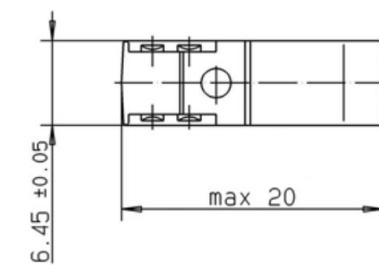
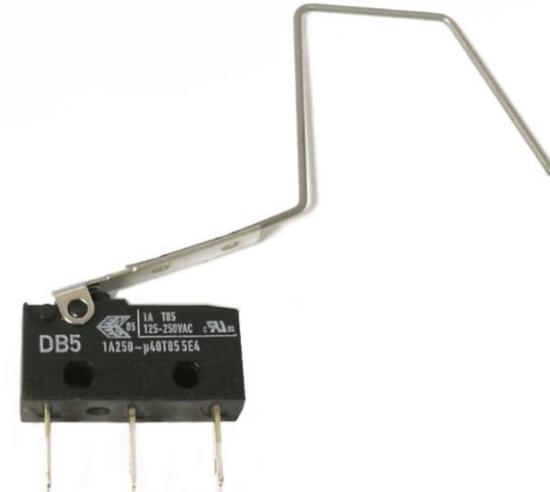
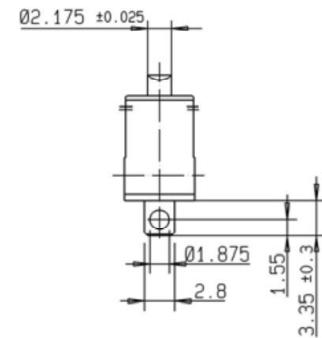
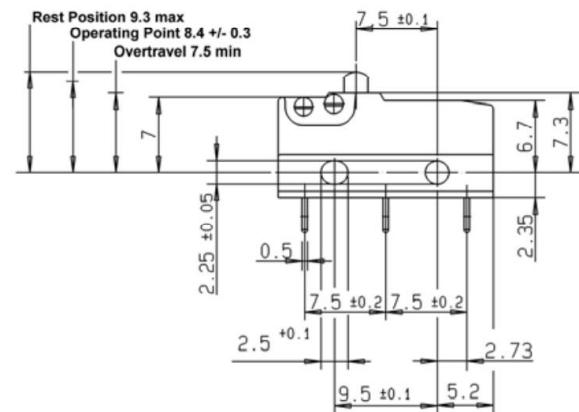
About \$5.00 each

Appears to have spot welded paper clip wire

More Info on DB5 Switch

- Made by CHERRY
- Datasheet: <https://www.farnell.com/datasheets/1641341.pdf>
- Hard to Tell, but Operating Force seems to be about 0.50 N

Dimensions - millimeter



# Possible Substitute Switches

 MUZHI SPDT 1NO 1NC Hinge Lever Momentary Push Button  
Micro Limit Switch AC 5A 125V 250V 3 Pins 12 Pcs

Brand: MXRS  
★★★★★ 785 ratings | 30 answered questions  
#1 Best Seller in Limit Switches

-33% \$6.69 (\$0.56 / Count)  
List Price: \$9.99 ⓘ  
prime  
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Save 5% at checkout Terms ⓘ

Style: 4

1 \$6.99 (\$0.58 / Count) prime	2 \$6.99 (\$0.58 / Count) prime	3 \$6.99 (\$0.58 / Count) prime	4 \$6.69 (\$0.56 / Count) prime
--	--	--	--



★★★★★  
4 out of 5  
Rated By 12 Customers

CHERRY SUB-MINIATURE SWITCH 1 AMP 125/ 250V  
.110" TERMINAL DB5G-B1AA 70 GRAM

Part # 95-1807-00

\$4.00 ea.  
\$2.58 ea. L/100

Out of Stock, please contact your sales rep for updated ETA information

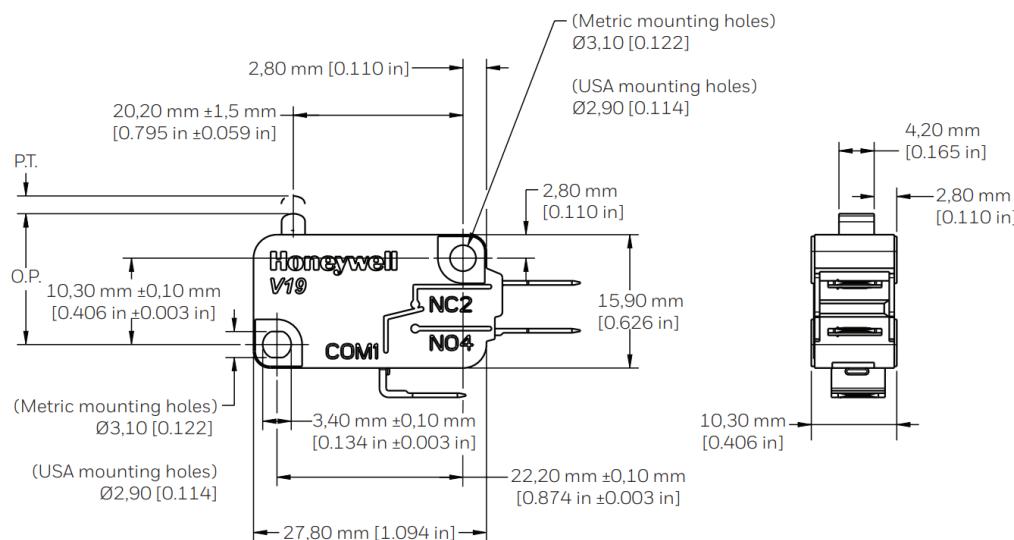
QTY: 1 

I believe that this is the present-day raw switch that the original pinball machines used.

# DigiKey Switches

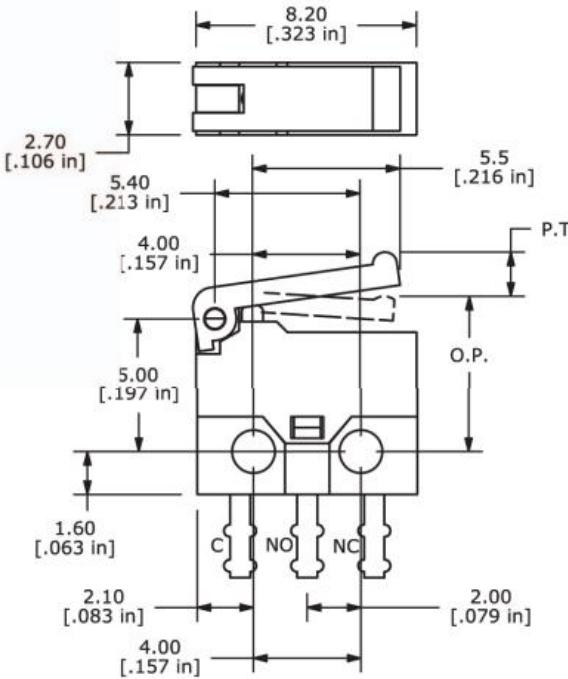
## V19S05-HZ015A03

- 0.15 Netwons of force, or 15 grams of force
- Lever Far from Plunger
- 3.1mm Mounting Holes
- \$1.93 each
- Plunger Travel: 9 + 3.8 + 2.0 mm

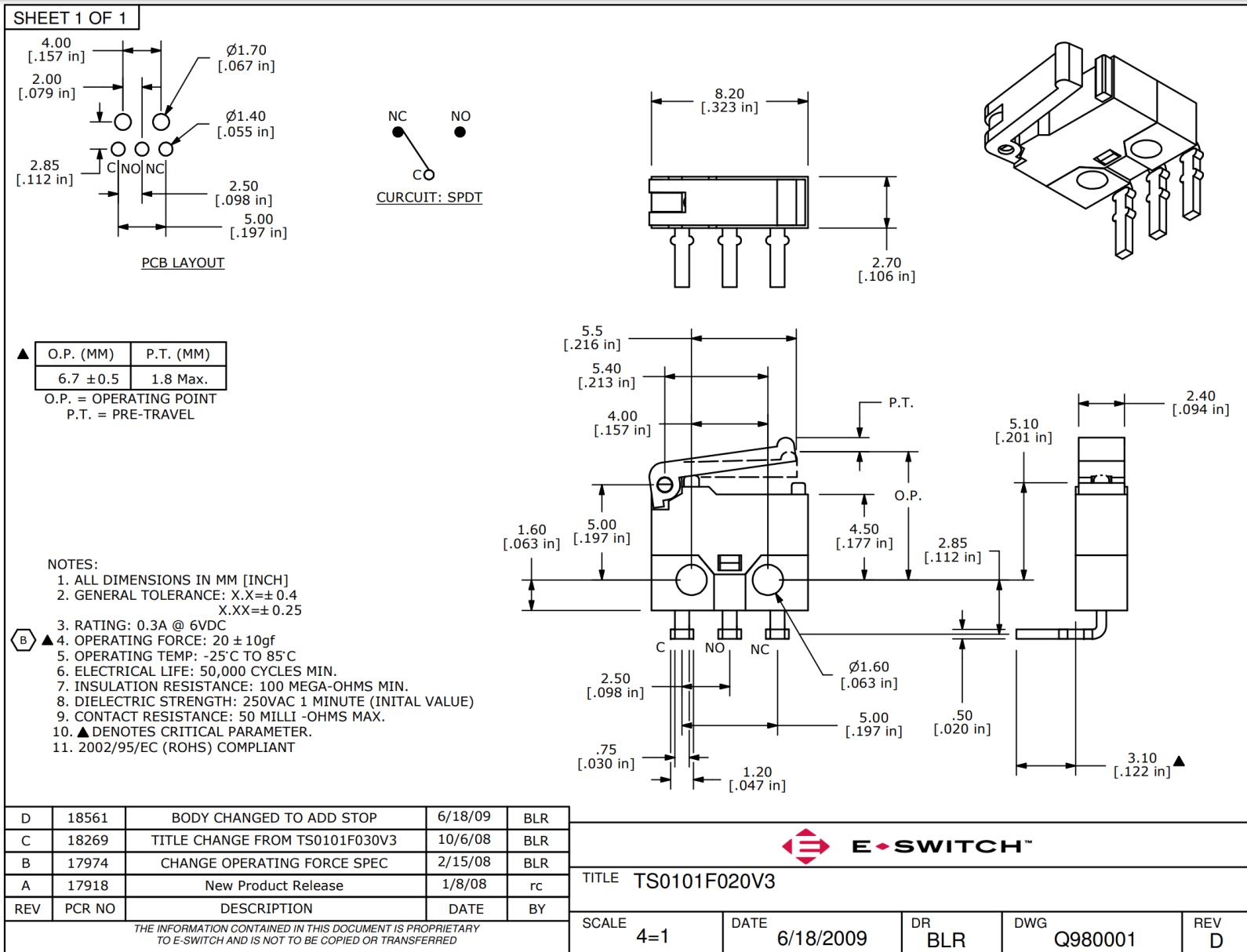


## TS0101F020V3

- Made by E-Switch
- Only rated for 6v @ 0.3 amps
- 20 grams (+/- 10g) operating force
- PCB terminals – must be soldered
- About \$1.00 each



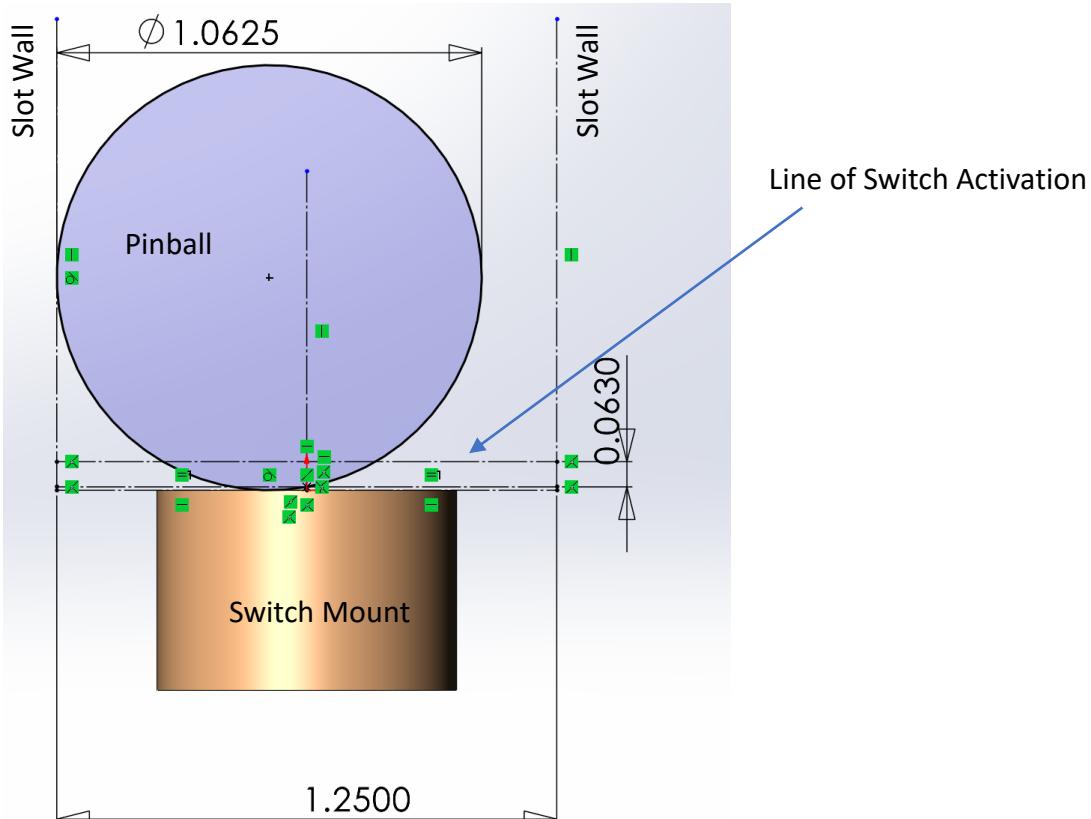
# Micro Switch: TS0101F020V3



Most Promising

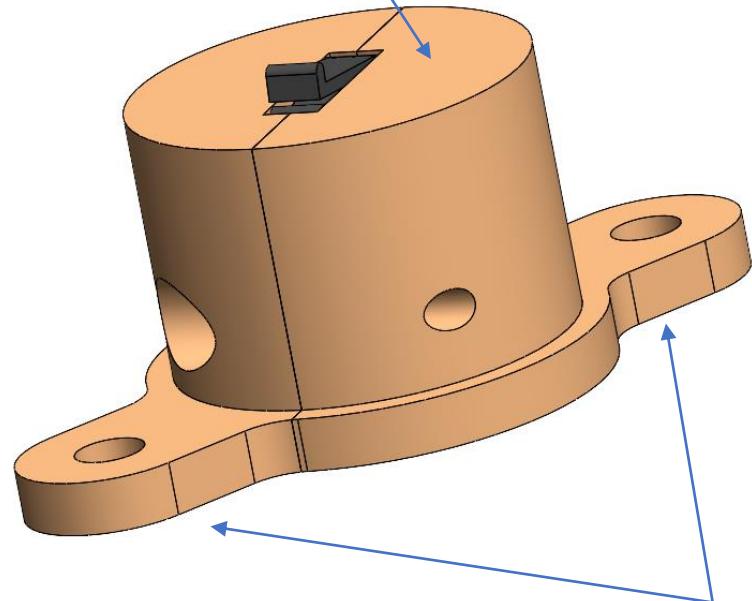
# Drawing Showing that TS Micro Switch can Work

This shows that the switch should be activated even when the pinball is traveling against the slot side wall.



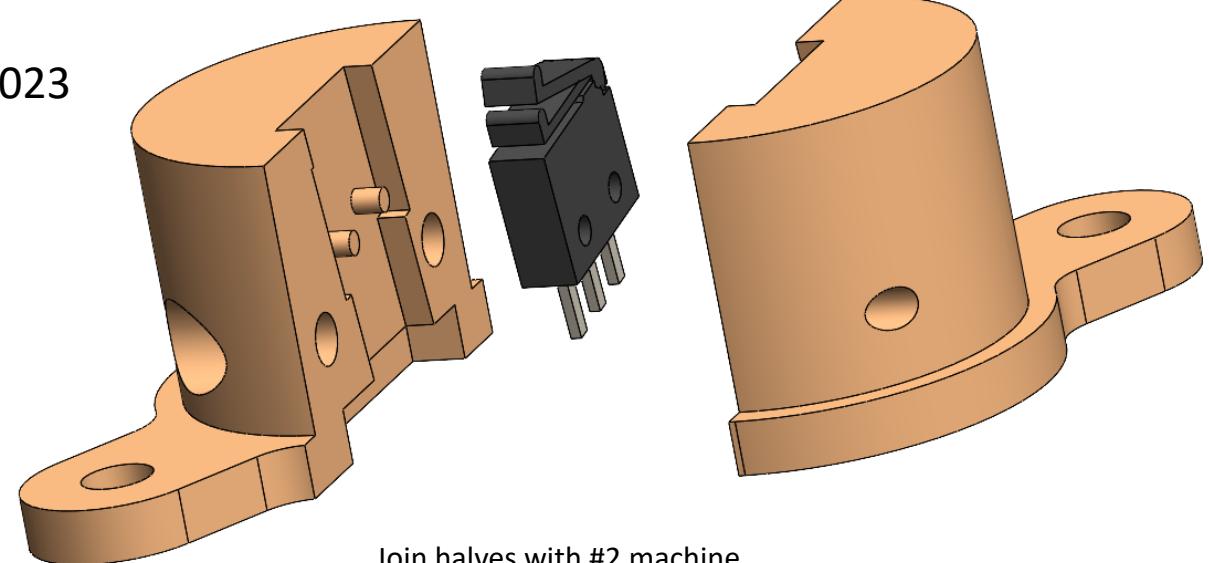
# Micro-switch Mount for Slot Switches

Drill 0.75 inch hole in playing surface. Insert Part, making this surface flush with playing surface



Mount with 2 #4 Pan Head  
Wood Screws, 0.5 inches long

F22-PM-3023



Join halves with #2 machine  
screws, 0.25 inches long

# Score Board

# Requirements and Ideas

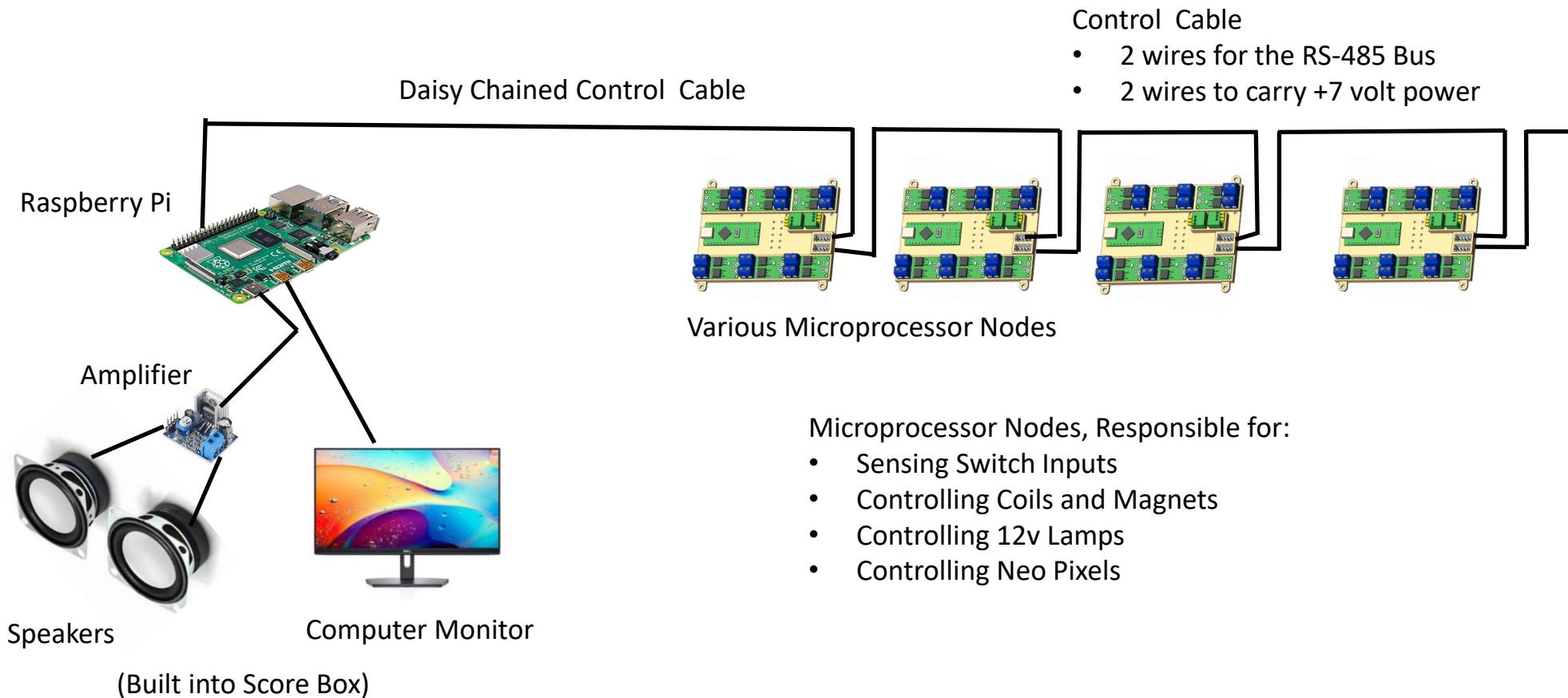
- Scoreboard Attached to rear of machine on pivots for transport
- Scoreboard houses Monitor and Speakers
- Scoreboard may house AC system, on/off switch, computers?
- Scoreboard has bright lights and Neo Pixels
- Must provide Disconnect of wires between scoreboard and rest of machine

# Wires in Scoreboard Disconnect

Purpose	Conductor	Max Current	Plug Type
48 Volt Supply	12 AWG	20 Amps	Anderson
12 Volt Supply	12 AWG	15 Amps	Anderson
5 Volt Supply	12 AWG	15 Amps	Anderson
Ground	12 AWG x 3	50 Amps	Anderson
Computer Control	24 AWG Stranded, x4	I2C + Logic Power	MicroFit-4Pin



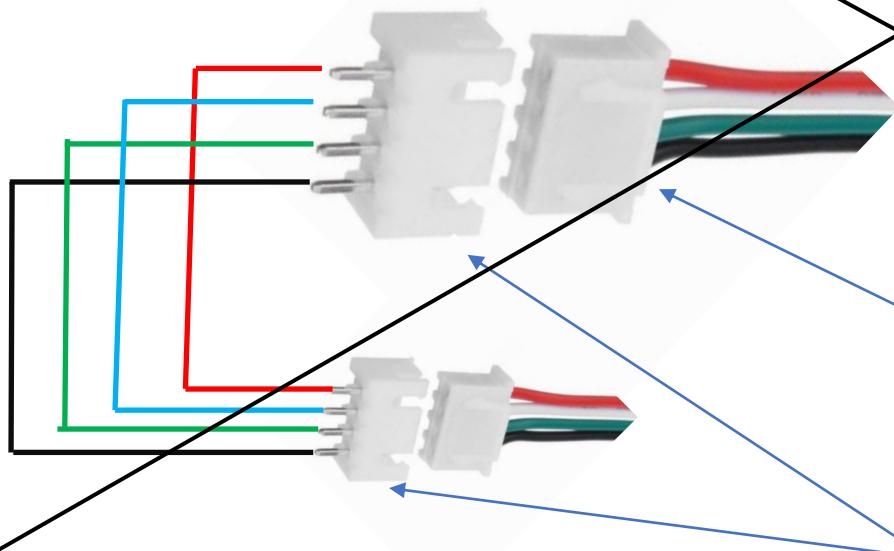
# Block Diagram of Control Circuitry



# Control Signal Wiring to all Microprocessor Nodes

- Use I2C bus -- Later can use CAN physical layer for increased robustness
- Send Logic Power (+7 volts) with Data Signals
- Use JST connectors...
- Each Node does a pass through for all signals and power

Superseded cause I2C Sucks!



+7v Power  
SDA  
SCL  
Logic Ground

These wires should be stranded, 18-24 gauge

Cables between nodes made with Female JST connectors

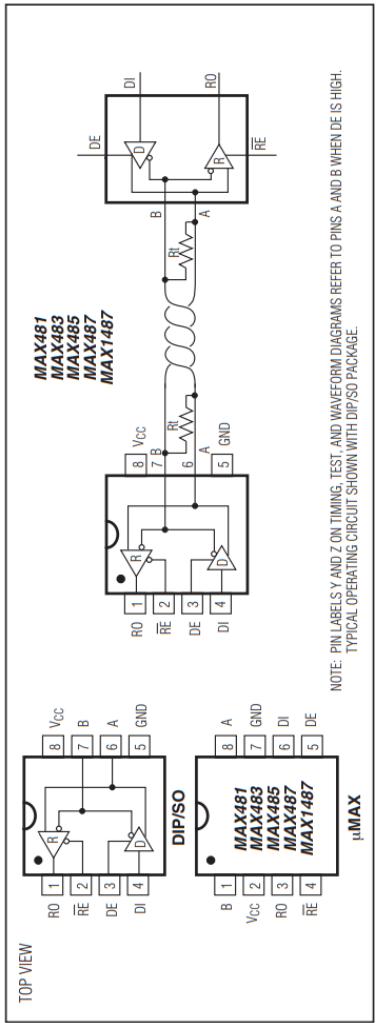
Each Node has daisy chained in/out Male JST connectors

# Implementing a Robust Comm Bus

- Use RS-485
  - According to Wikipedia, good to 50 meters at 2 Mbits/s, and up to 10 Mbits/s at shorter distances, such as 2 meters in the pinball machine. We only need about 100 KHz.
  - Uses differential signaling over twisted pair
  - One twisted pair means half duplex communication.
  - Can be implemented with the MAX485 chip for less than \$1/node

# Data on MAX485 chip

**MAX481/MAX483/MAX485/  
MAX487-MAX491/MAX1487  
Low-Power, Slew-Rate-Limited  
RS-485/RS-422 Transceivers**



## Pin Description

PIN					NAME	FUNCTION
MAX481/MAX483/ MAX485/MAX487/ MAX1487		MAX488/ MAX490		MAX489/ MAX491		
DIP/SO	µMAX	DIP/SO	µMAX	DIP/SO		
1	3	2	4	2	RO	Receiver Output: If A > B by 200mV, RO will be high; If A < B by 200mV, RO will be low.
2	4	—	—	3	RE	Receiver Output Enable. RO is enabled when RE is low; RO is high impedance when RE is high.
3	5	—	—	4	DE	Driver Output Enable. The driver outputs, Y and Z, are enabled by bringing DE high. They are high impedance when DE is low. If the driver outputs are enabled, the parts function as line drivers. While they are high impedance, they function as line receivers if RE is low.
4	6	3	5	5	DI	Driver Input. A low on DI forces output Y low and output Z high. Similarly, a high on DI forces output Y high and output Z low.
5	7	4	6	6, 7	GND	Ground
—	—	5	7	9	Y	Noninverting Driver Output
—	—	6	8	10	Z	Inverting Driver Output
6	8	—	—	—	A	Noninverting Receiver Input and Noninverting Driver Output
—	—	8	2	12	A	Noninverting Receiver Input
7	1	—	—	—	B	Inverting Receiver Input and Inverting Driver Output
—	—	7	1	11	B	Inverting Receiver Input
8	2	1	3	14	Vcc	Positive Supply: $4.75V \leq VCC \leq 5.25V$
—	—	—	—	1, 8, 13	N.C.	No Connect—not internally connected

# Data on MAX485 chip

Vcc is 5v

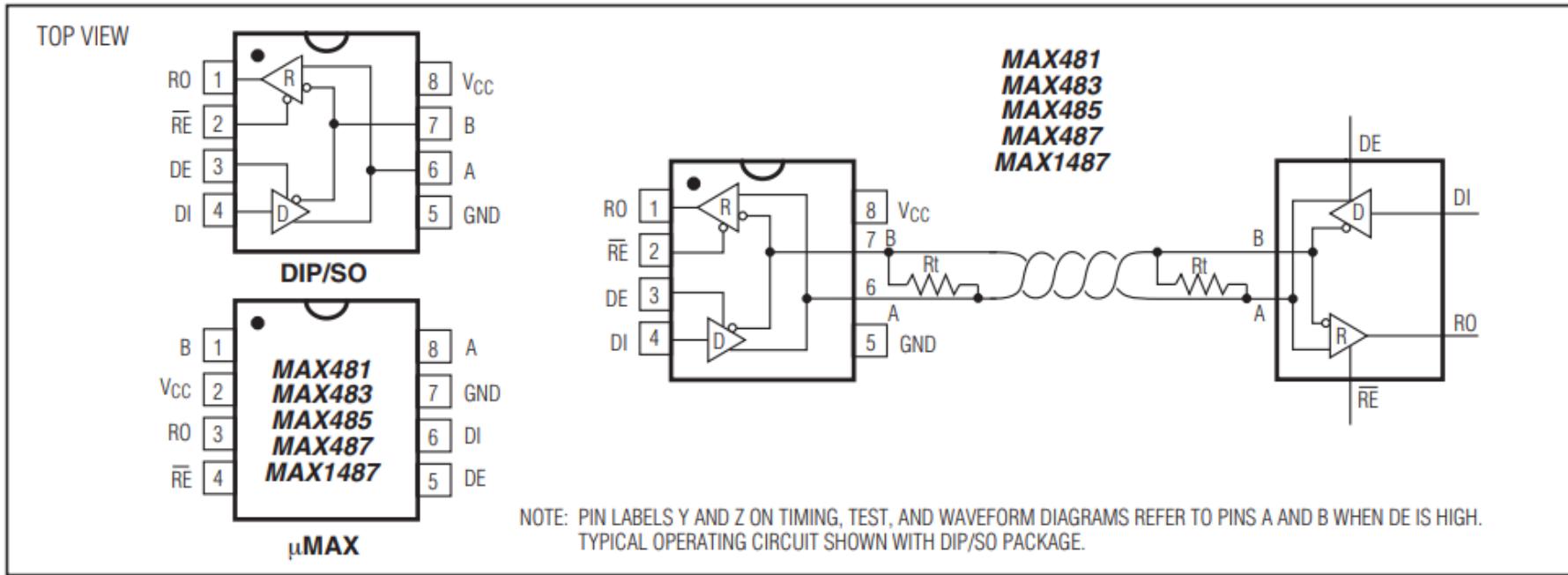


Figure 1. MAX481/MAX483/MAX485/MAX487/MAX1487 Pin Configuration and Typical Operating Circuit

We need to terminal the twisted pair at each end with a 120 ohm resistor.

Vcc is 5 volts, so we need to level shift for Raspberry Pi on R0.

However, V-high is 2 volts, so Pi can drive DI direct.

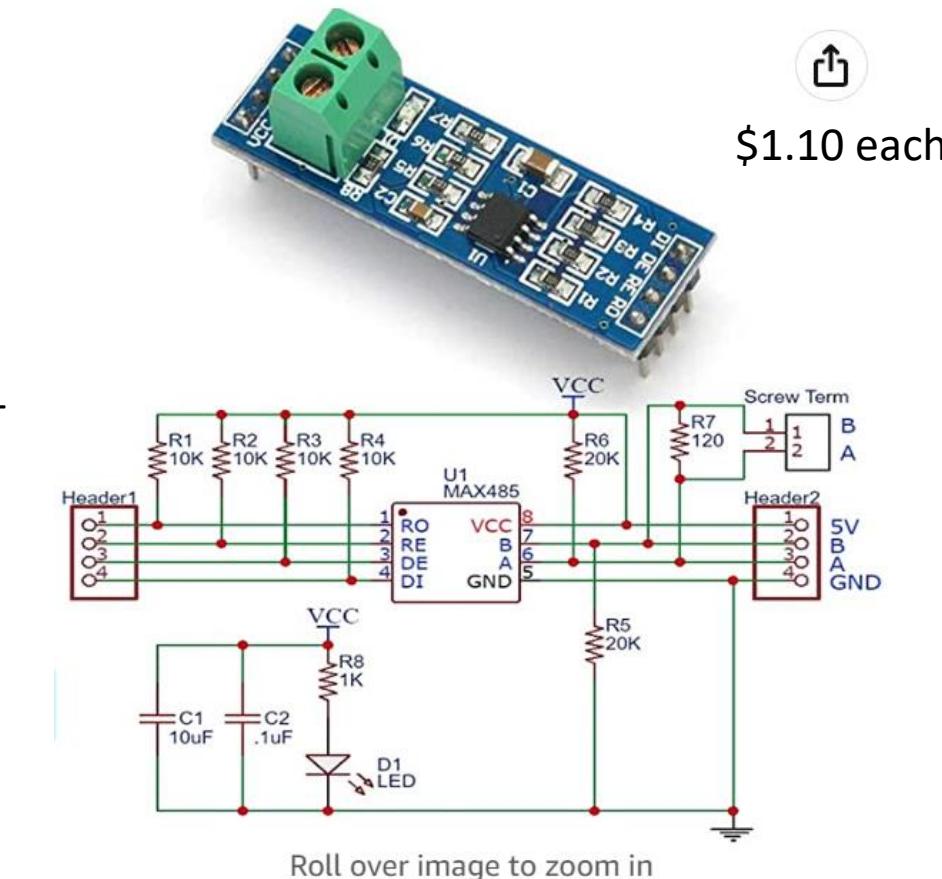
# MAX485 Module from Amazon

Vcc = 5 volts

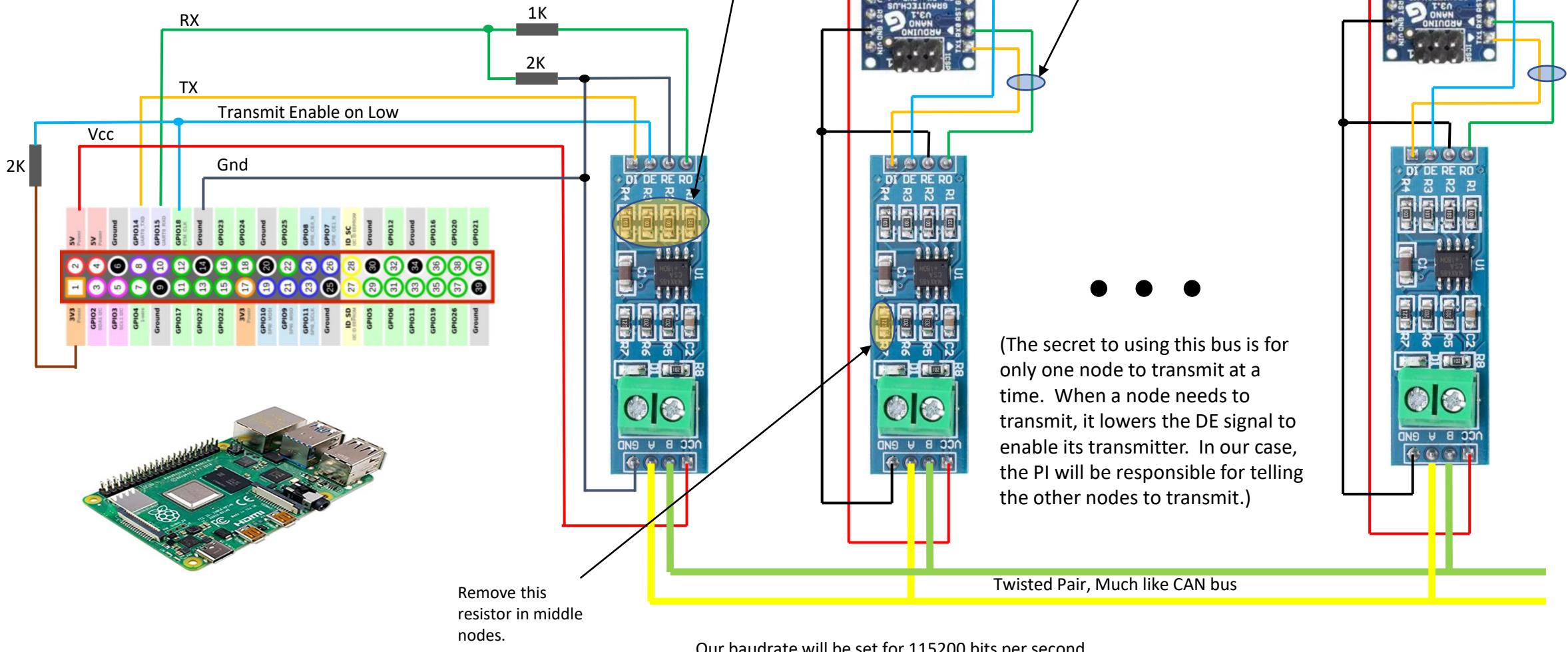
V-high on DI, DE, and RE  $\geq 2.0$  so Pi Logic levels will be okay.

Possible Modifications:

- Note there is a 120 ohm resistor already across the A and B lines. This resistor should be removed on all nodes except the Pi and the last node.
- For the Pi Node, the pullups may interfere with the level shifting needed. Therefore, remove them all (R1-R4).



# A Communications Bus for the Pinball Machine



# Estimate of Nodes Needed

Node Name	Inputs	Outputs	Comments
Light Control Unit	None	NeoPixels, 6x Lamps	To be used in the Scoring Box for Lights
Light Control Unit	None	NeoPixels, 6x Lamps	To be used under playfield to control all NeoPixels, Panic Light, And Other Decorative Lights
Bumper Control Unit	Bumper Contacts (x3)	Bumper Coils (x3) Bumper Lamps (x3)	Controls all aspects of the three round bumpers in the center of the board
Flipper Control Unit	Flipper Switches (x2) Game Start Button (x1)	Flipper Coils (x3)	Controls all aspects of the flippers
Kicker Control Unit	Kicker Switches (x3) Hole Senser Switch (x1) Ball Ready for Load (x1)	Kicker Coils (x3) Drop Hole Coil (x1) Ball Load Coil (x1)	Controls Kickers, Drop Ball and Coils for returning the ball into play
Switch Input Unit	Micro Switches (Approx x20)	None	Senses all remaining micro switches.

# Heart of Control System: Raspberry Pi



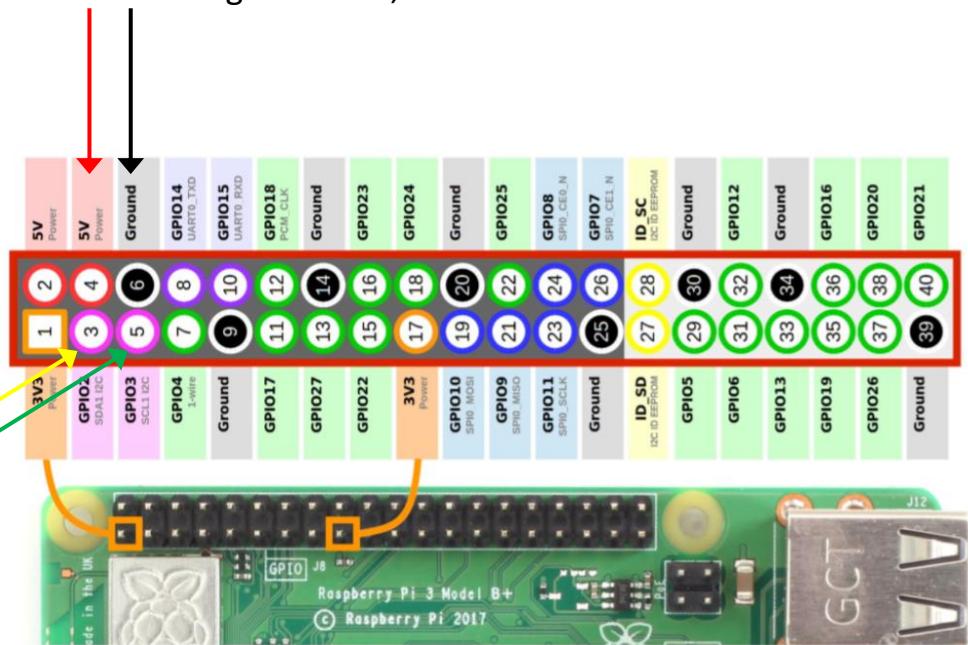
SDA = Pin 3 = Yellow or White  
SCL = Pin 5 = Green or Blue

Power with these two pins.

Be sure to get polarity correct!

Pin 4 = + 5 Volts, Regulated, at least > 2 Amps

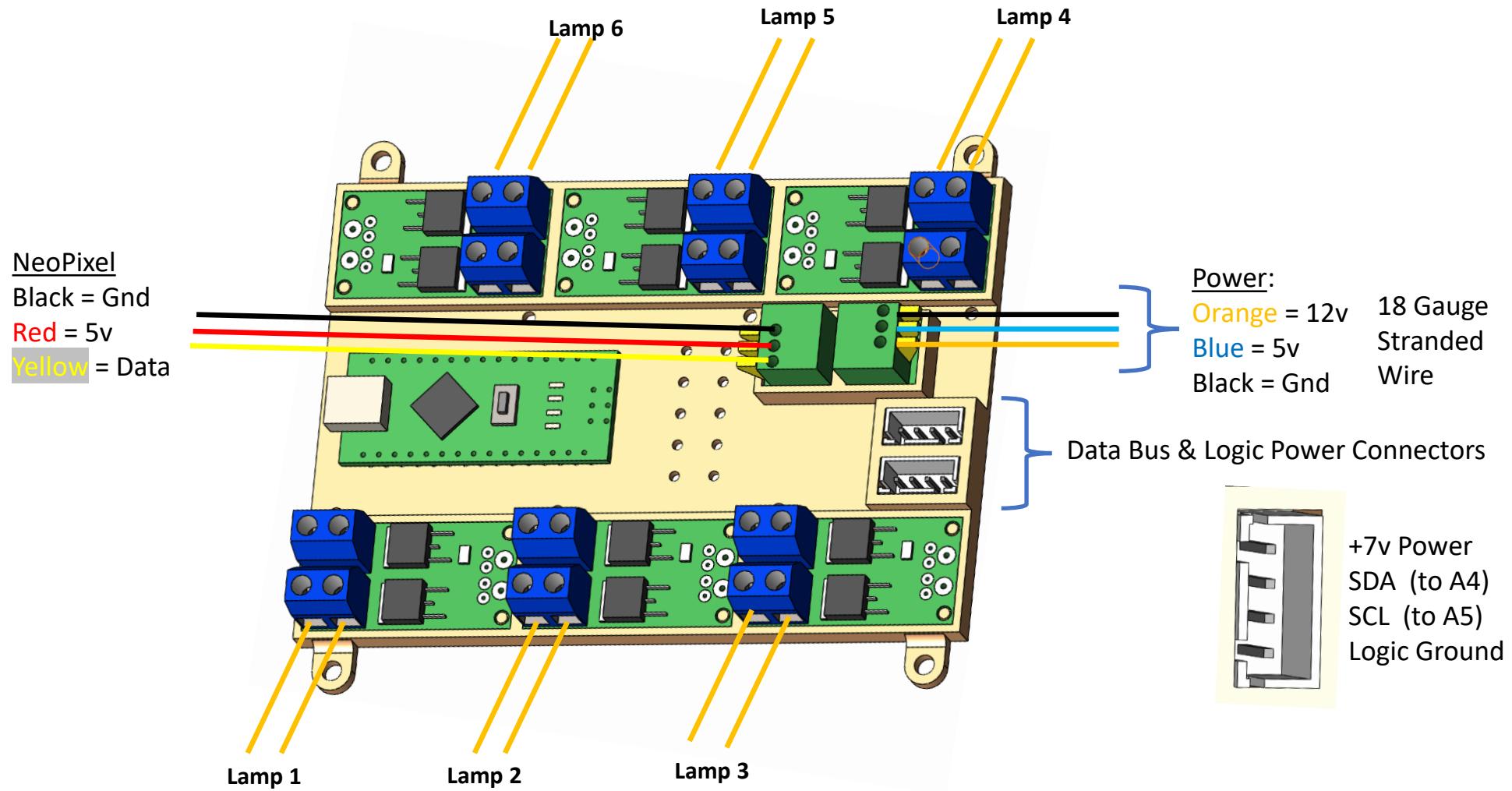
Pin 6 = Logic Ground, 0 volts



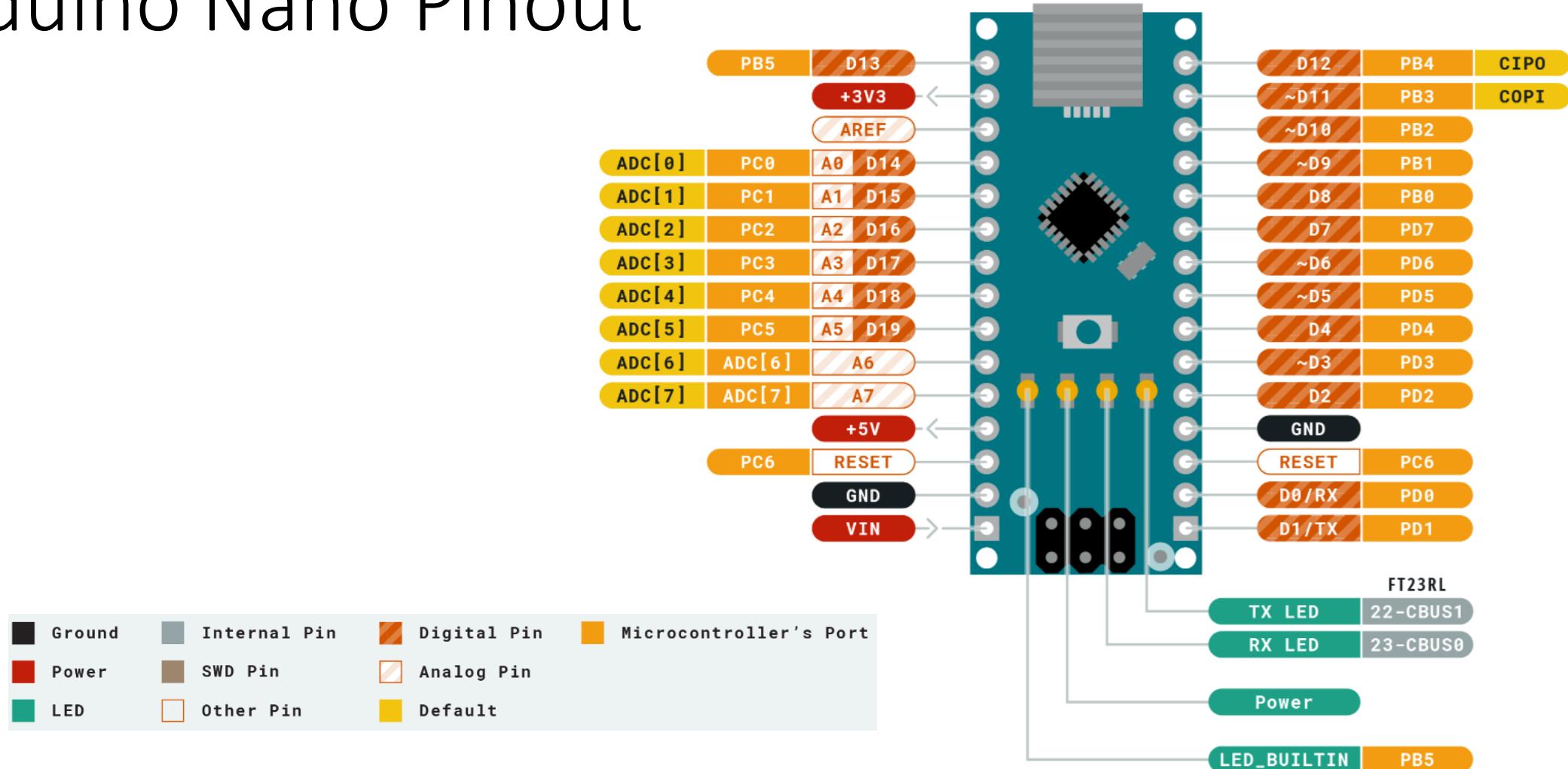
# Light Controller Unit -- Requirements

- Two similar units needed: Scoreboard and Playfield
- Features: Controls 6x 12v LED lamps, and one Neo-Pixel Strand
- Inputs:
  - 12v, 5v, GND -- Spring Terminals
  - I2C in (4 Conductors) JST
- Outputs:
  - I2C out (4 conductors) JST
  - Pos, Neg x6 for Lamps – Screw Terminals
  - Neo Out (3 conductors) – Spring Terminals

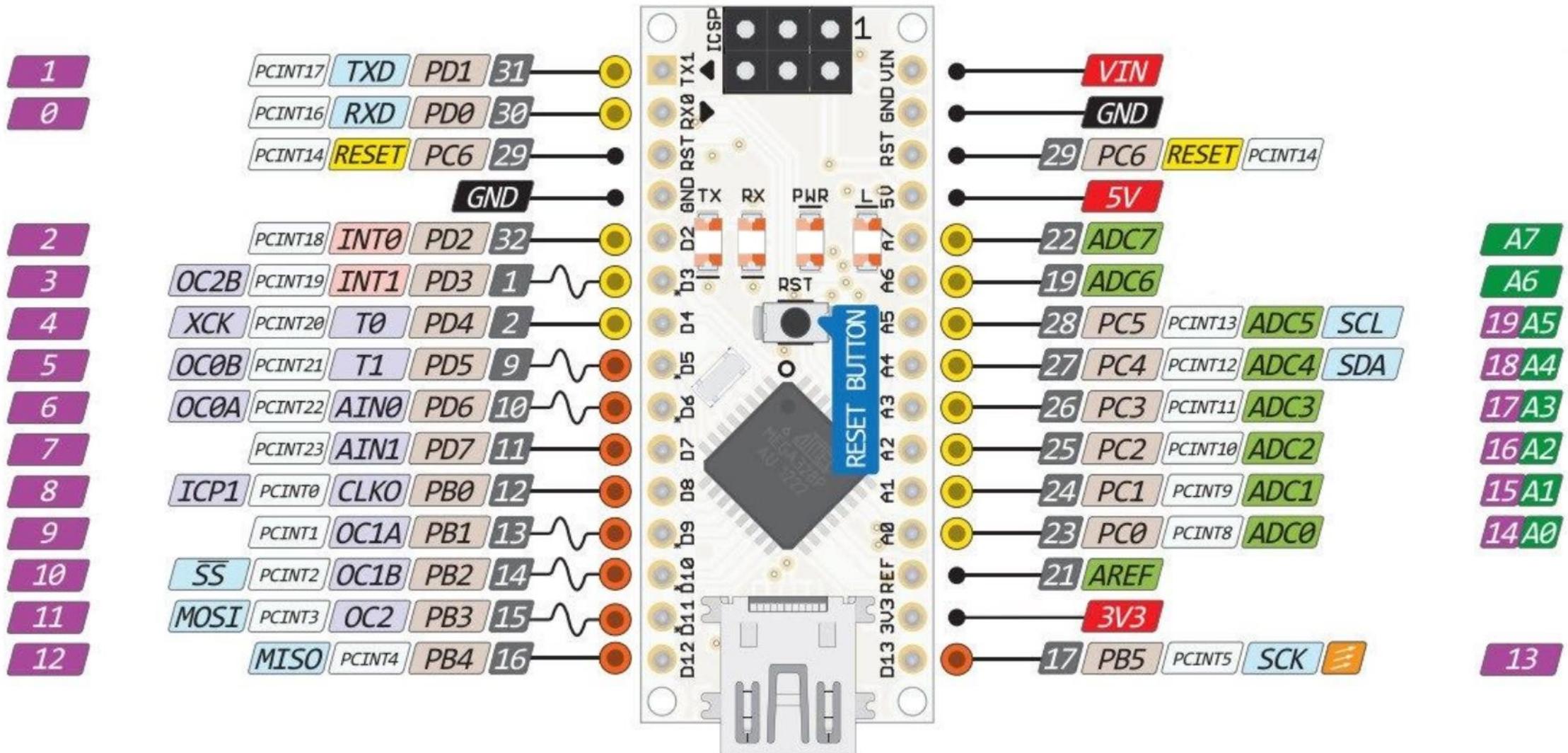
# Light Controller Unit (LCU)



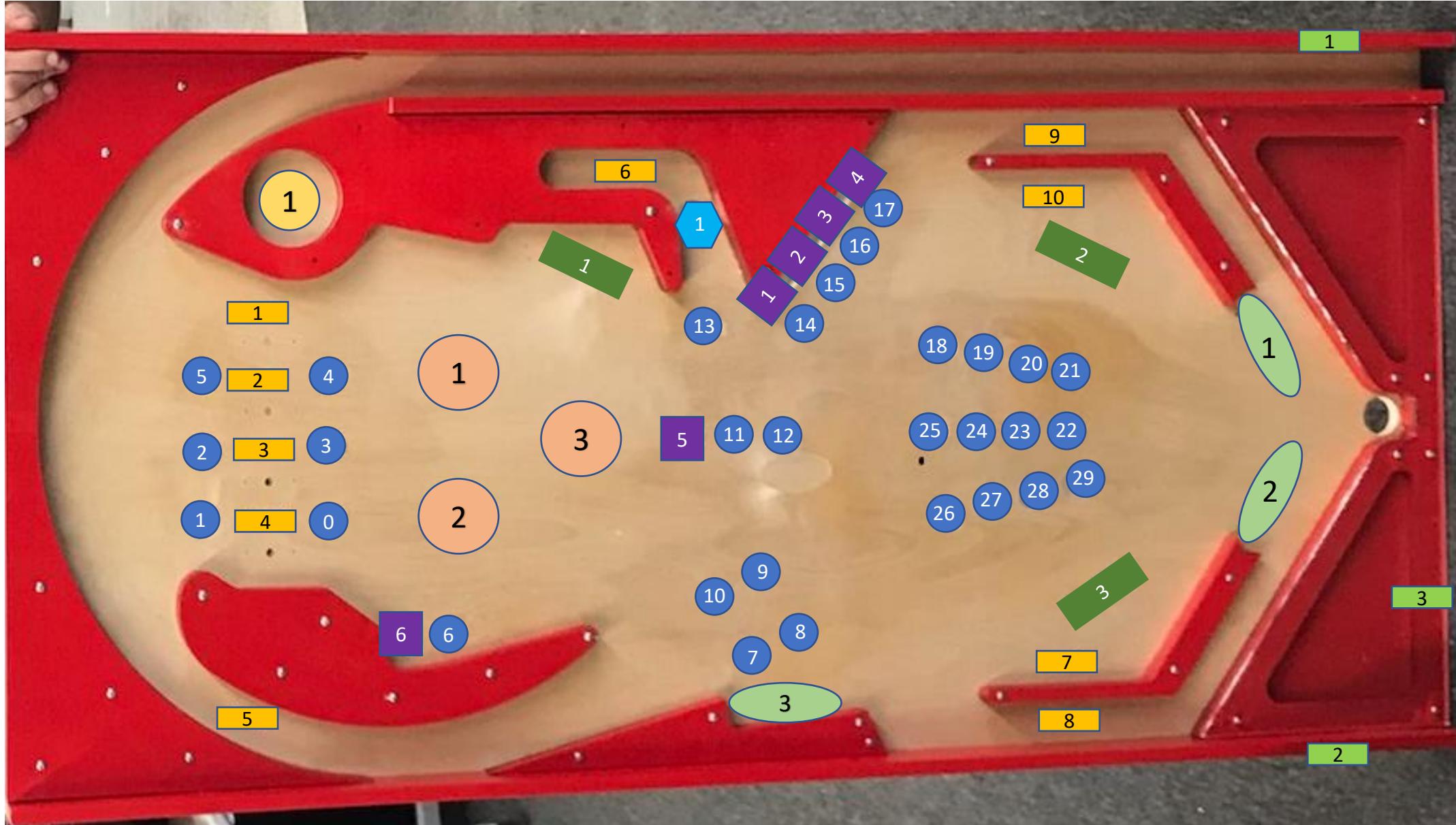
# Arduino Nano Pinout



# Arduino Nano Pinout



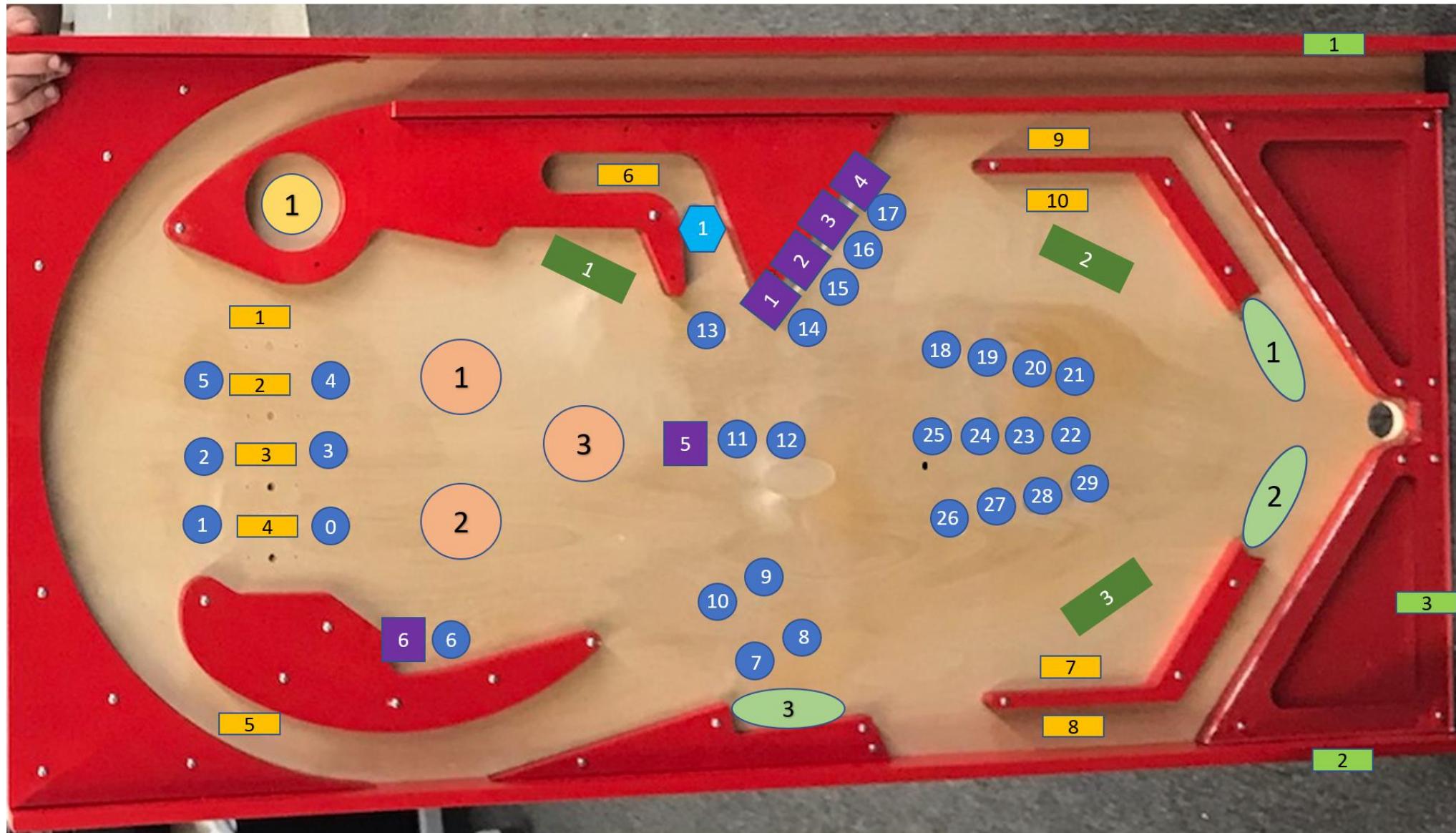
# Feature Layout and Designations



-  Neo Pixel
  -  Lane Switch
  -  External Button
  -  Target
  -  Kicker
  -  Flipper
  -  Jet Bumper
  -  Panic Light
  -  Drop Hole

(Editable Version)

# Feature Layout and Designations



(Fixed Version)

# Game Play Sounds

Welcome to the Game Debut – Study the Game with the Jet Bumpers  
Build Season Starts! -- You have 6 Weeks!  
Hit all the EPIC targets to make a better robot  
Don't Hit the Panic Button!  
5 Weeks to Go. Hit the Targets in Order for the Best Robot  
4 Weeks to GO! Hurry, Hurry. Hit more targets!  
3 Weeks to GO! Hurry, Hurry Hurry! Hit More targets!  
2 Weeks to GO! HURRY! MORE, MORE, MORE,  
1 Week to GO! You're almost out of TIME. HURRY! But Don't Panic!  
It's TIME TO PANIC – Parts are out-of-stock!  
It's TIME TO PANIC – CNC isn't finished!  
It's TIME TO PANIC – CAD is not ready!  
It's TIME TO PANIC – Programmers are sick!  
It's TIME TO PANIC – Your robot is trash!  
Welcome to Competition! Cash in with your Robot!  
Hit the Targets to get ranked.  
Climb the Ramp for more ranking points!  
You Made it to PLAYOFFS!  
Get selected with the Jet Bumpers.  
You are seeded #47 – Hit the PANIC or go home!  
Too bad, you didn't get selected.  
You are seeded #8 – good luck!  
You are seeded NUMBER ONE!

Use your scouting data at the Jet Bumpers to select your team!  
FOUL! – Frame Out of Bounds  
FOUL! – Illegal Contact  
FOUL! – Human Player Violation  
FOUL! – Overweight  
RED CARD! -- (For no discernable reason!)

# Nodes

Node Name	Node Function	Address	Inputs	Outputs
Lights – Score Box	Lights in Score Box	2	None	Neo Pixels 6 Lamps
Lights – Playfield	Lights in the Playfield	3	None	Neo Pixels 2 Lamps
Flippers	Flippers	4	6 Switches	6 Coils
Bumpers	Jet Bumpers	5	3 Switches	3 Coils 3 Lamps
Kicker	Sling Shot Kickers	6	3 Switches	3 Coils
Lane Sensors	Lane Switches	7	15 Switches	None
Targets	Target Switches	8	8 Switches	None
Test	Debugging Comm Bus	9	NA	NA

# Node Pins VS Outputs

For the “Lights” Node

Function	IO Pin
Neo Pixels	D12
Panic Light	D6
Spare Light	D5

For the “Target” Node

Function	IO Pin
S1	D4
S2	D7
S3	D8
S4	A0
S5	A1
S6	A2
S7	A3
S8	A4

For the “Kickers” Node

Function	IO Pin
K1	D6
K2	D5
K3	D3
SW 1	D4
SW 2	D7
SW 3	D8

For the “Lane Sensor” Node

Function	IO Pin
S1	A0
S2	D11
S3	D10
S4	D9
S5	D8
S6	D7
S7	D6
S8	D5
S9	D4
S10	D3
S11	A1
S12	A2
S13	A3
S14	A4
S15	A5

# Node Pins VS Outputs

For the “Jet Bumpers” Node

Function	IO Pin
B1	D6
B2	D5
B3	D3
SW 1	D4
SW 2	D7
SW 3	D8
L1	D11
L2	D10
L3	D9

For the “Flippers” Node

Function	IO Pin	Expected Usage
F1	D6	Right Flipper Coil
F2	D5	Left Flipper Coil
F3	D3	Third Flipper Coil
X1	D11	Lift Motor
X2	D10	
X3	D9	
EX Button 1	D8	Right Flipper Button
EX Button 2	D7	Left Flipper Button
EX Button 3	D4	Start Button
Ball 1	A0	First ball to play, next to lift gate
Ball 2	A1	Second ball position
Ball 3	A2	Third ball position
Ball 4	A3	Lost ball entry position
Extra Input	A4	
Ball Cycle	D12	Controls Ball Servo



# Animation and Score Board

# 000160

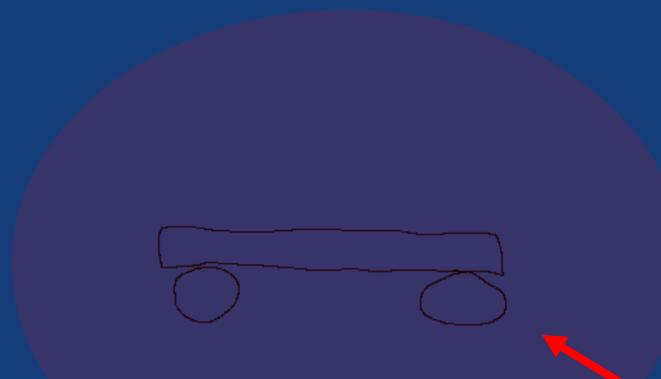
High Score

012043

## Build Week 1

Balls

07



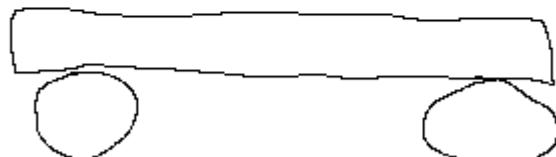
Design your robot  
at the Jet Bumpers!  
Try Hard!

Node 5 (kickers) not responding.

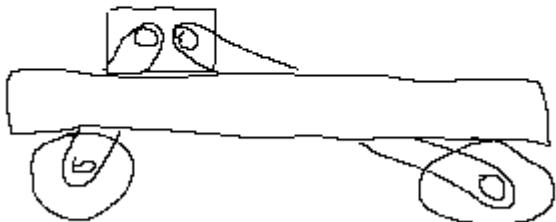
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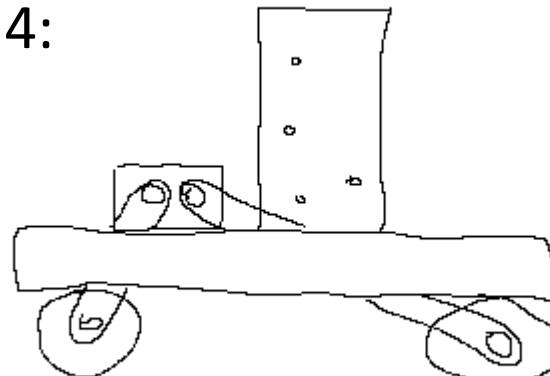
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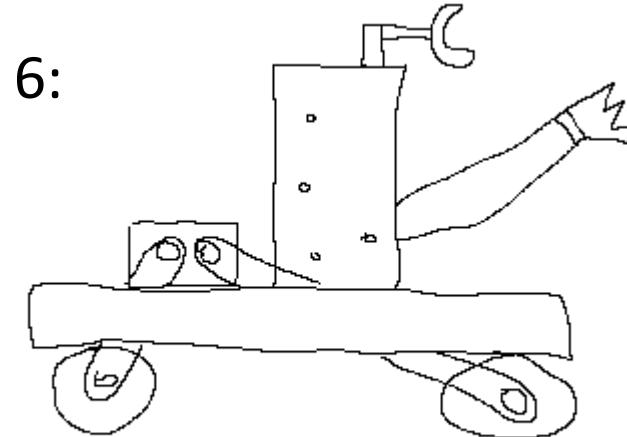
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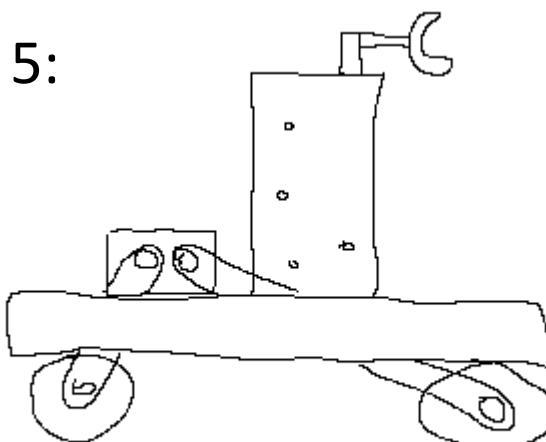
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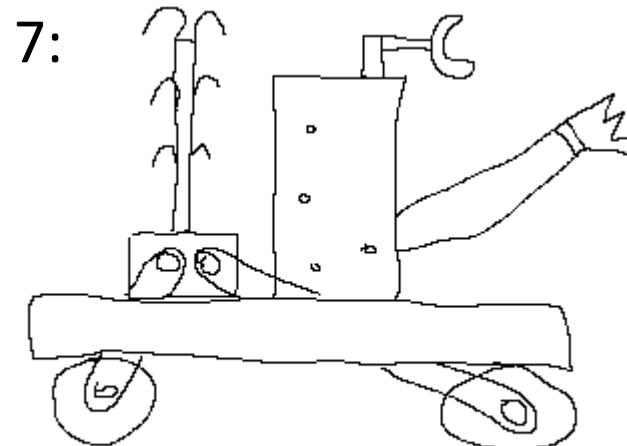
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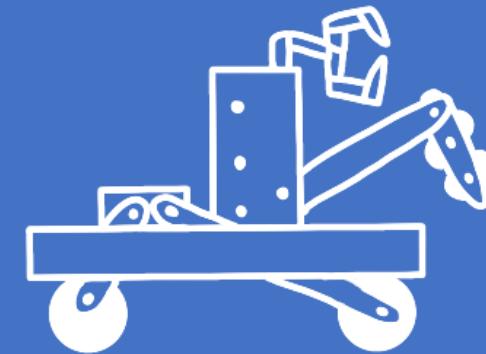
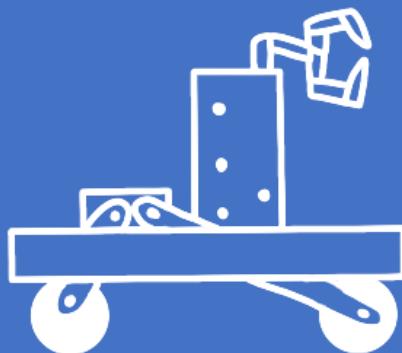
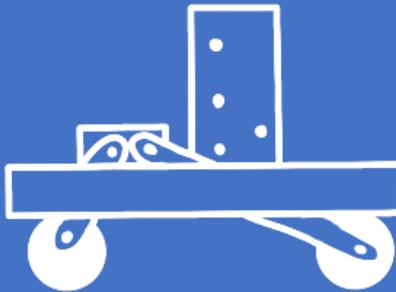


5:



7:

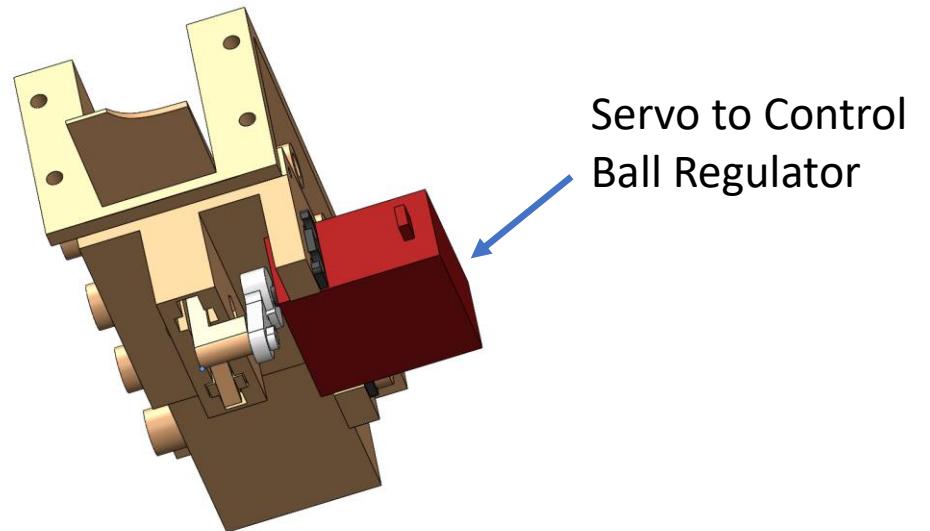
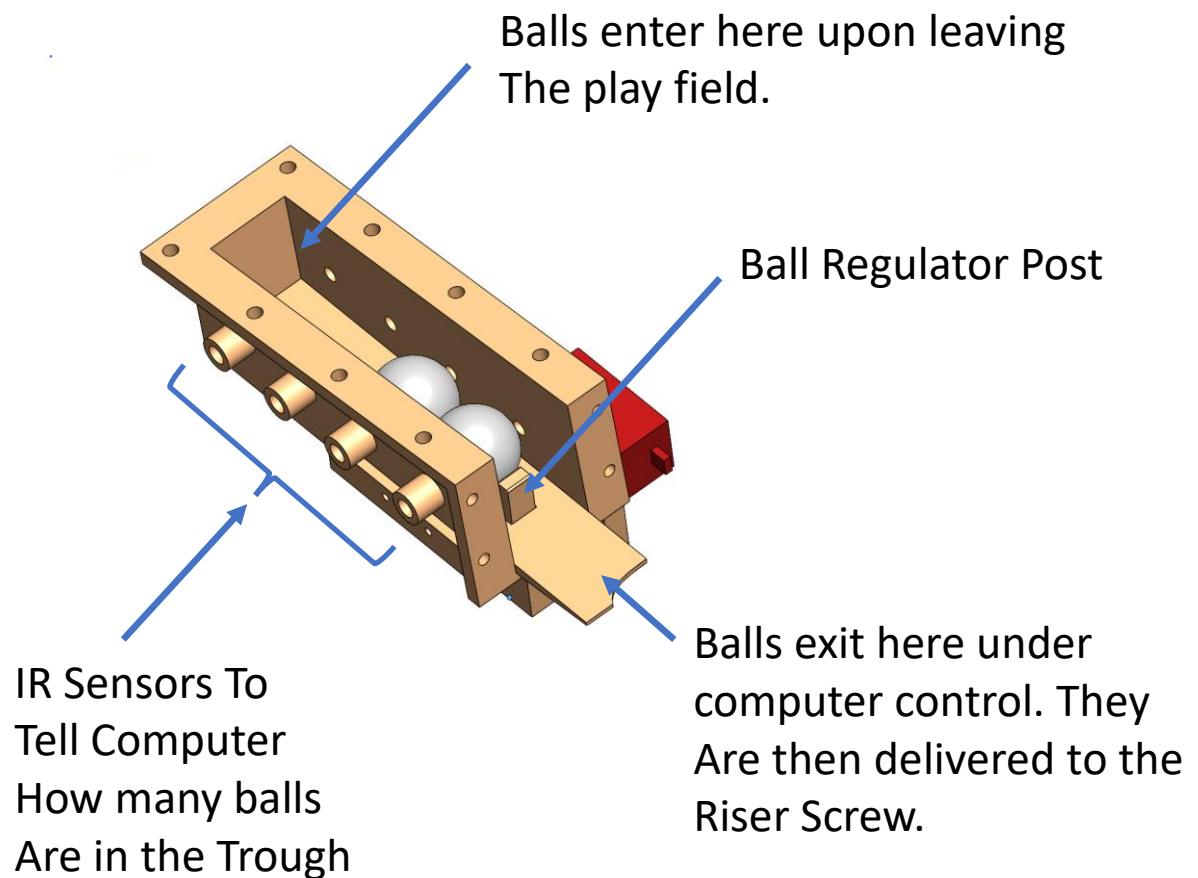




# Ball Trough

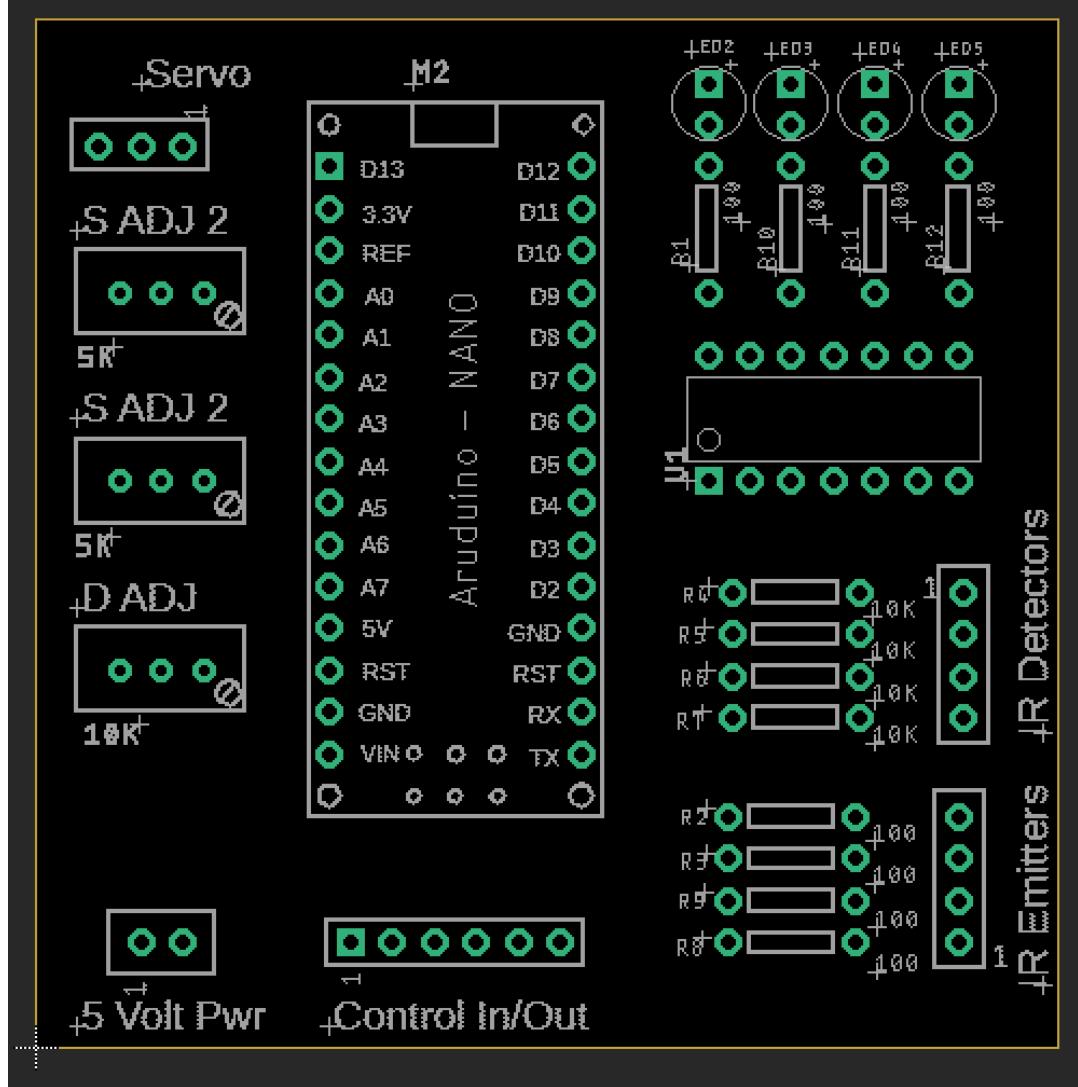
Sensors and Control to Deliver Ball into Game

# Ball Trough Mechanics

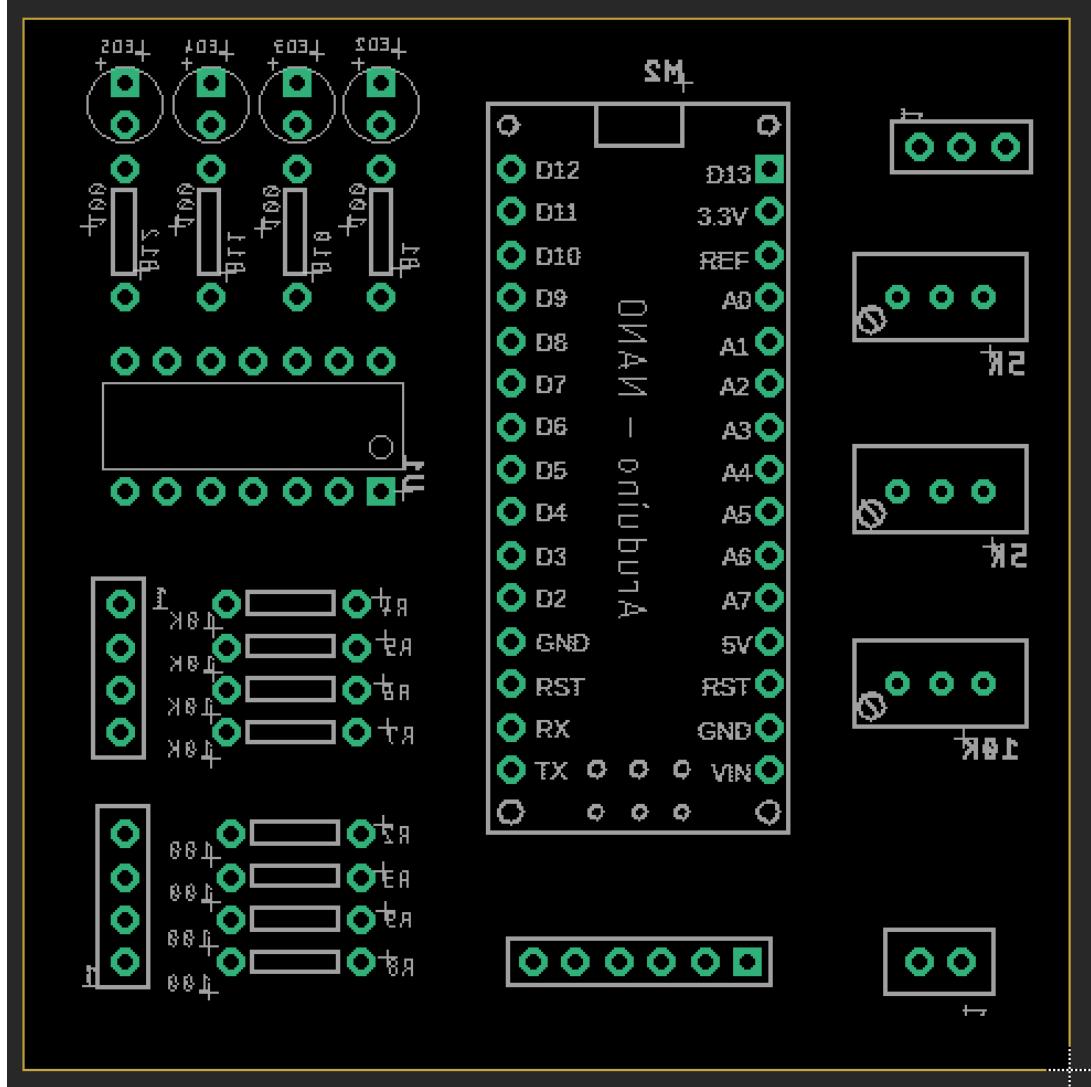


# Circuit for Ball Trough, PCB LAYOUT

Top Side View

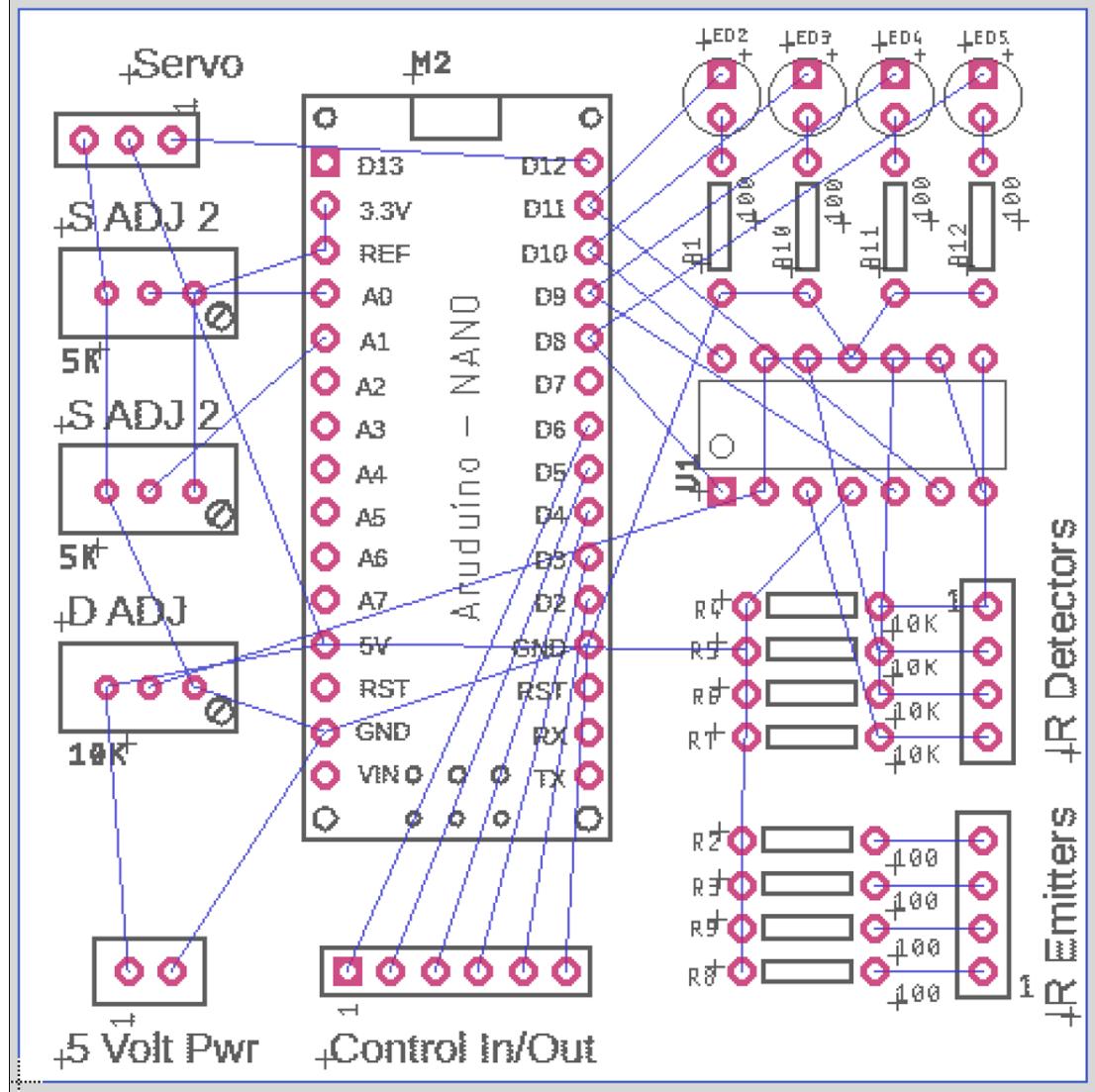


Under Side View

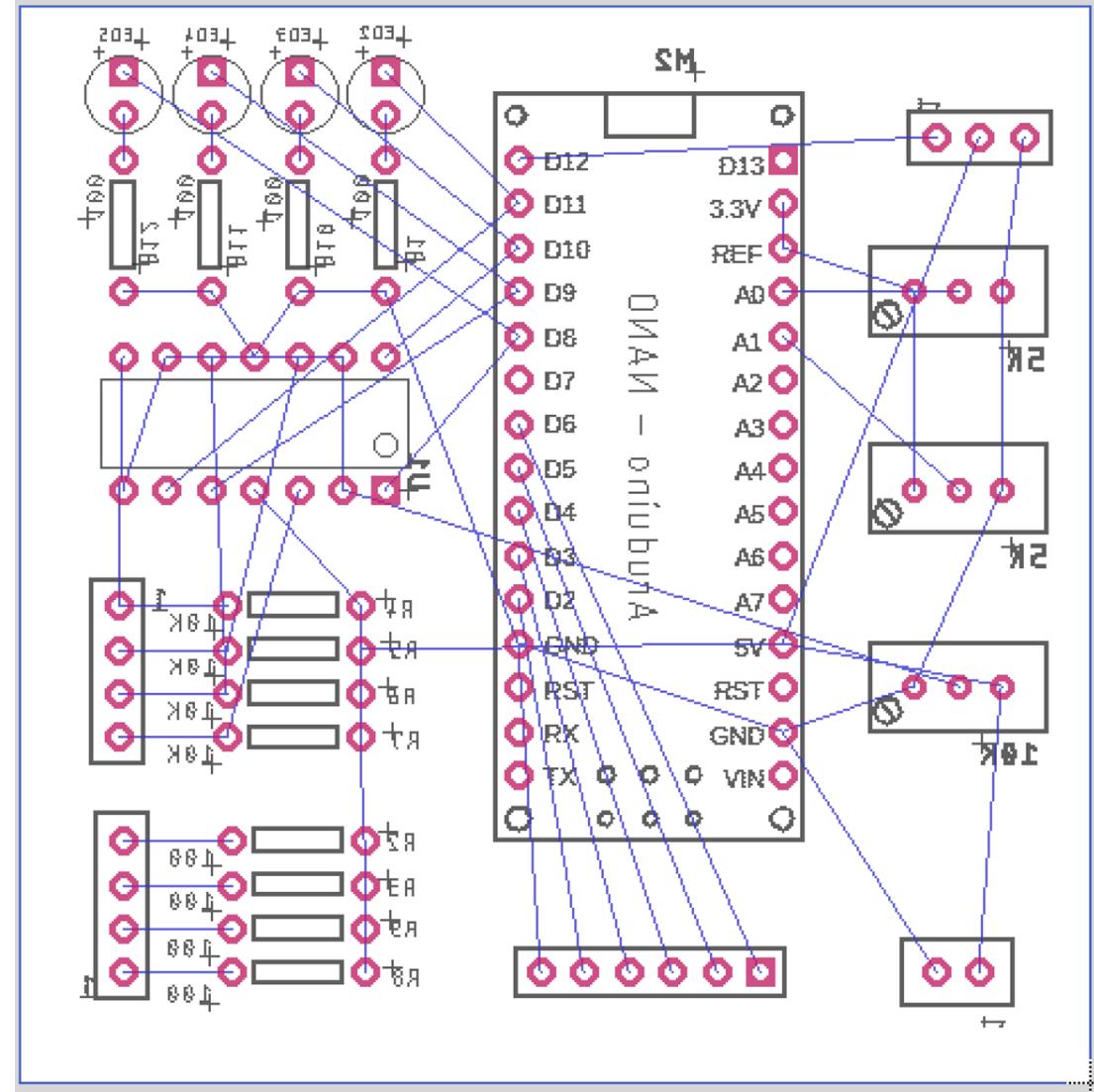


# Circuit for Ball Trough, PCB LAYOUT (With Airwires)

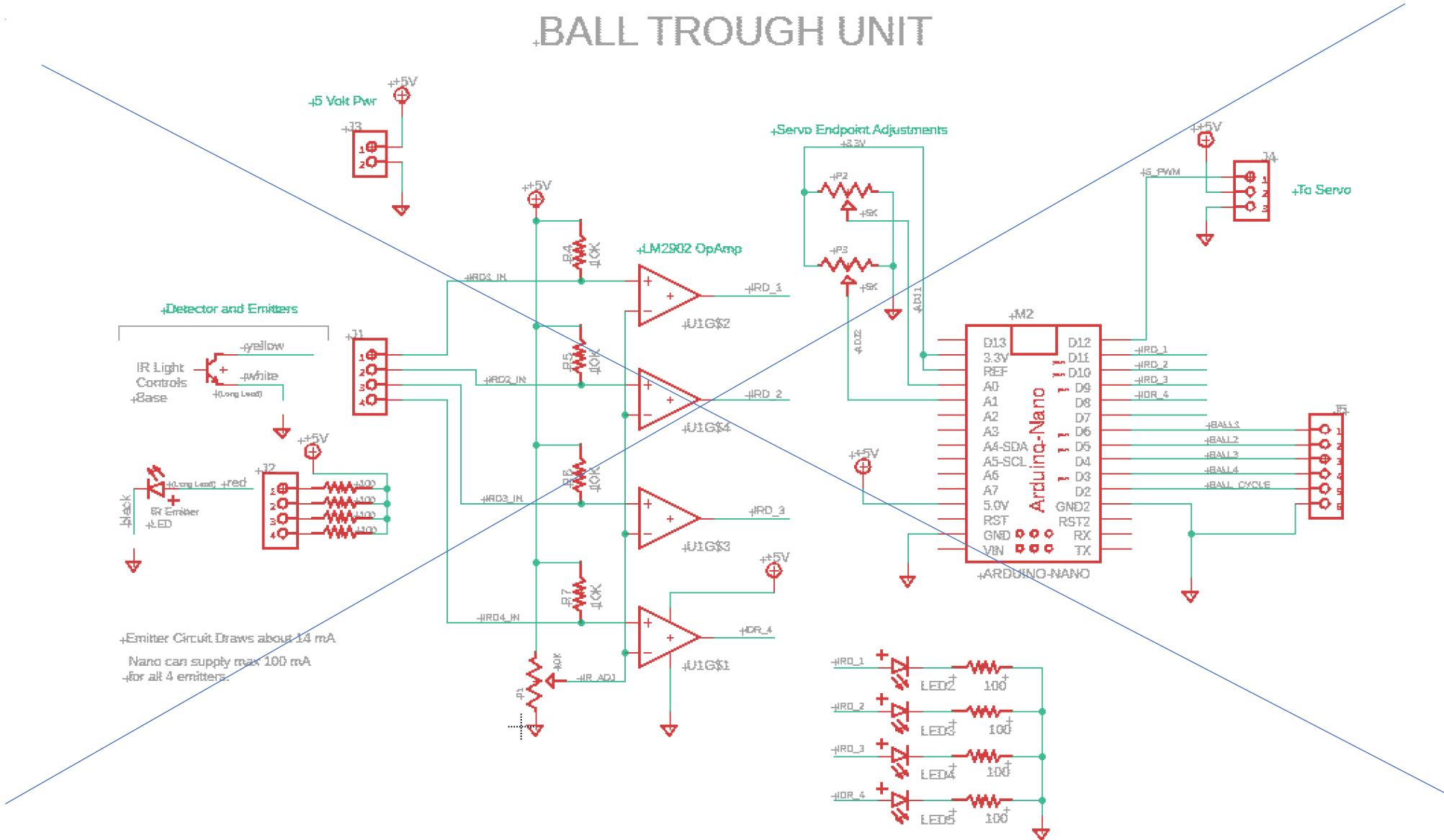
Top Side View



Under Side View

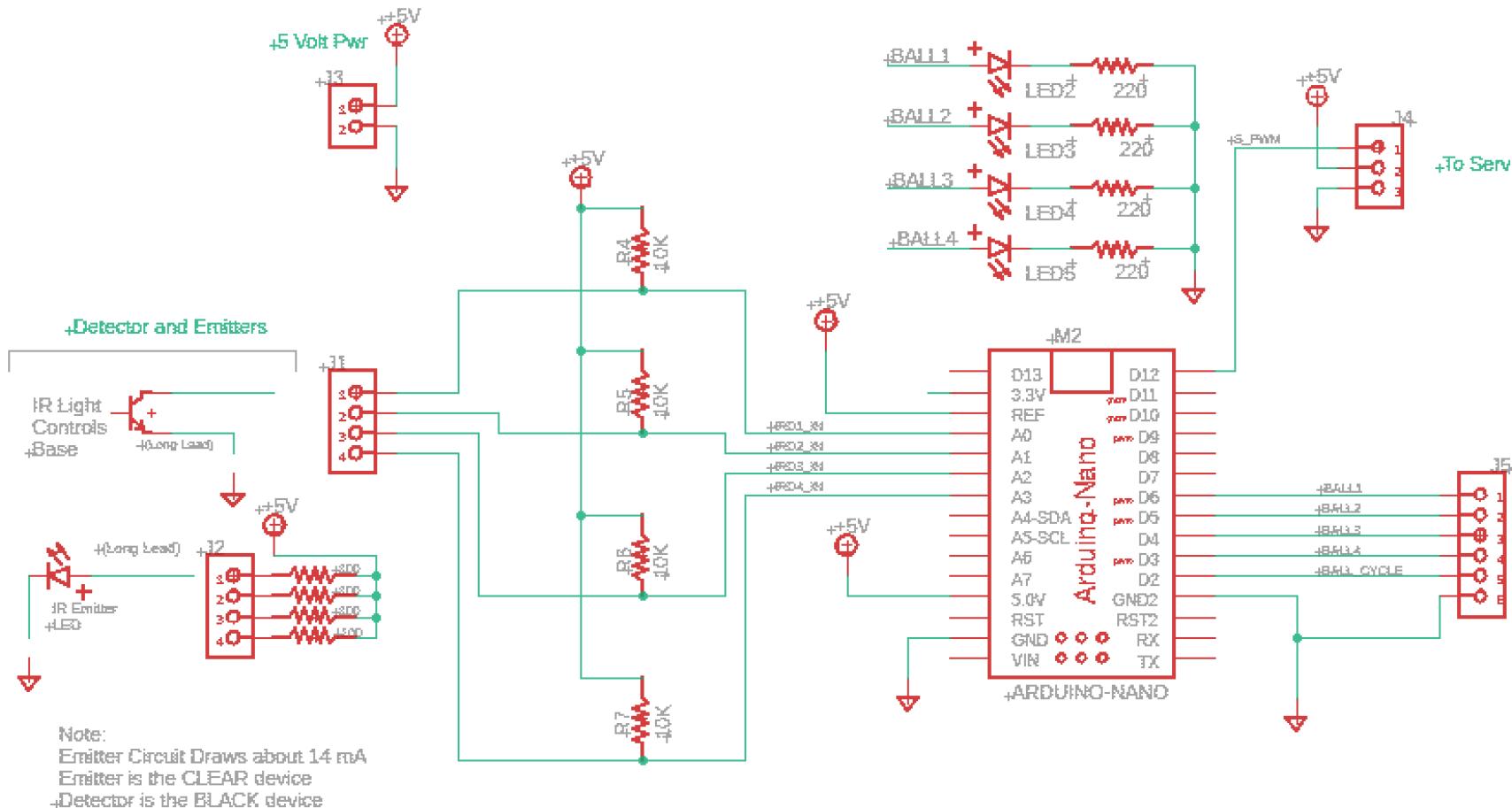


# Circuit for Ball Trough, V1



# Circuit for Ball Trough, V2

## BALL TROUGH UNIT



Note: Much simpler to build. The V1 Circuit didn't work well cause the Inputs to the ADCs were unstable which Lead to jittering on the servo.

Instead, we hard-wired the servo limits into The code.

Also, instead of using a op-amp to do threshold compare, just use the ADC on the nano. It was found that the input swing is very wide for a break in the IR beam.