Developing an Open-Source LED Controller for FRC

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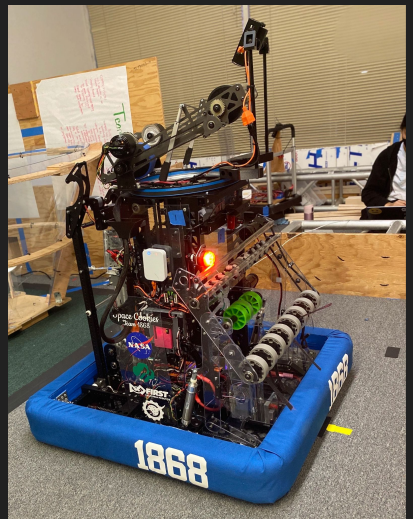
SCaLE TNG 23x

What is FRC

- First Robotics Competition
- International high-school robotics competition in which students design, build, and compete with a robot
- Robots are large, have lots of motors and moving parts, and have more EMI than most applications



What is the problem?

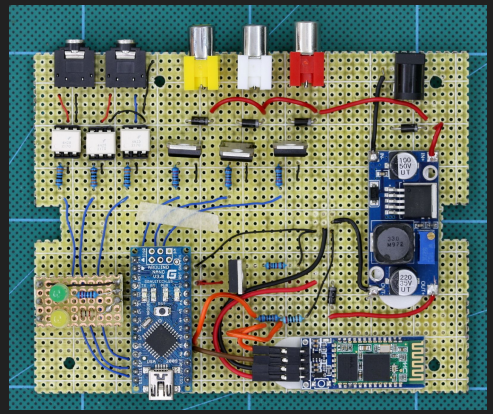
- Need for a new discrete LED controller for FRC
  - LEDs make your robot look cool, and allow for feedback to the driver
- Something that requires minimal communications bandwidth and minimal code running on the RoboRIO (main processor for the robot)
- Preferably open source and affordable with reconfigurable firmware

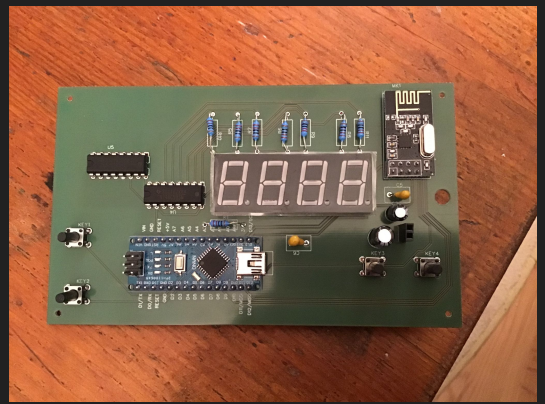
Prior LED Solutions

- Controlling off of RoboRIO DIO port
  - Takes up valuable processing time
  - More wiring complexity
- CANdle
  - Not cheap ($60), closed source, has some problems with code and firmware
- ConnectorX
  - Not cheap ($50), closed source, is relatively large, cannot use CAN

Why a PCB? Why not just an Arduino?

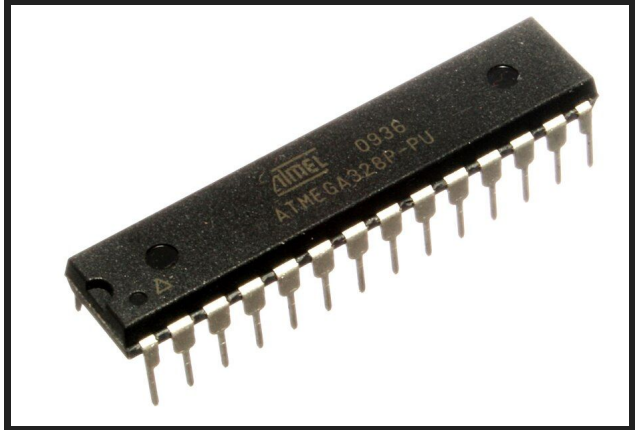
- Arduino w/ some wires and breakout boards
  - Easy, reconfigurable, quick to build, cheap
  - Wires prone to pulling out unless soldered, bulky
- Arduino on perfboard
  - Quick to build, cheap
  - Not the easiest to solder, still too large
- Arduino on a PCB
  - Easy to program, high reliability
  - Inefficient usage of space, large footprint

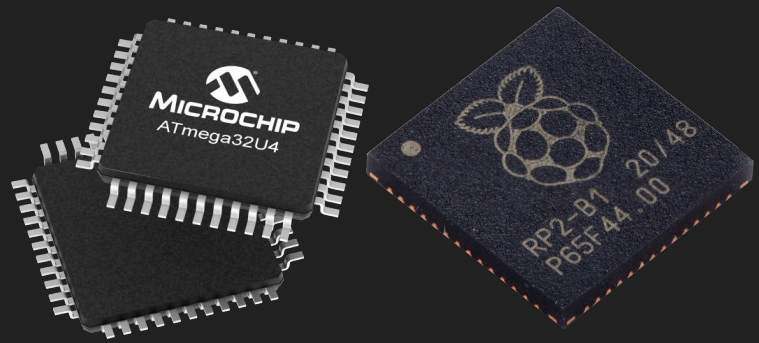




What microprocessor?

- A microprocessor is necessary to control the LED strip
- Number of options available
- What does it need to be capable of?



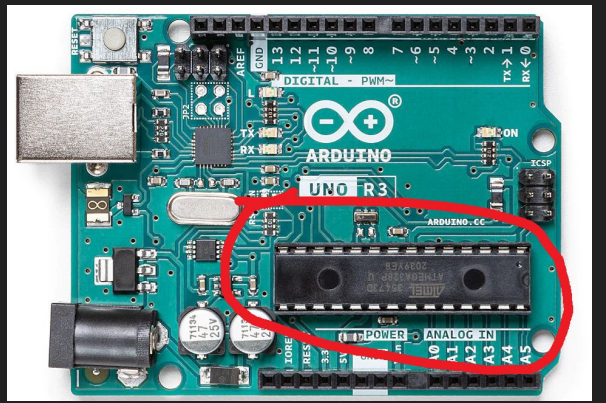


USB

- USB has a number of advantages
  - Easy to program the device
  - Easy to debug
- Hard to properly design for
  - Requires a microcontroller somewhere in the design which natively supports it (“u” series AVR)
  - Extra hardware such as 22 ohm resistors
  - Signal integrity can be a worry
- Abandoned the idea in prototyping

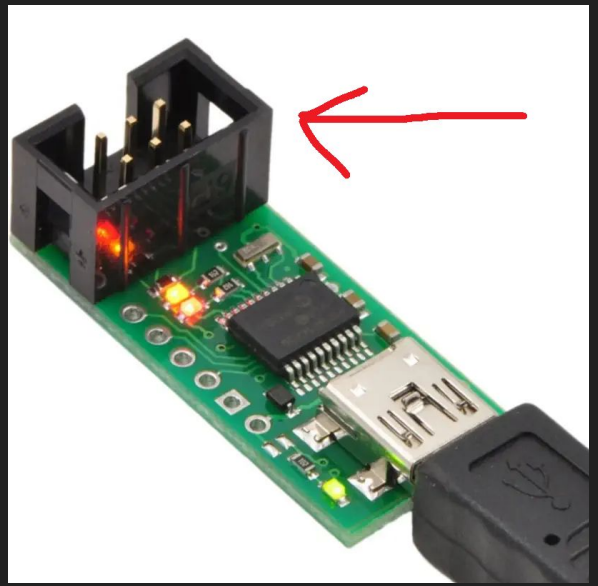
The microprocessor

- Landed on ATMega328p (best known for being the core of the Arduino UNO)
- Lots of libraries, can be programmed through Arduino Studio, powerful enough, has a DIP (through-hole) package option
- No other ICs necessary (SRAM, EEPROM, Flash all integrated into the chip)
- Drawbacks:
  - No native USB support (Arduinos use a second microprocessor)
  - Not particularly fast nor powerful (8 bit data bus)
  - Needs discrete crystal oscillator for full 16MHz clock speed
- .1 and 10 uF decoupling capacitors placed nearby



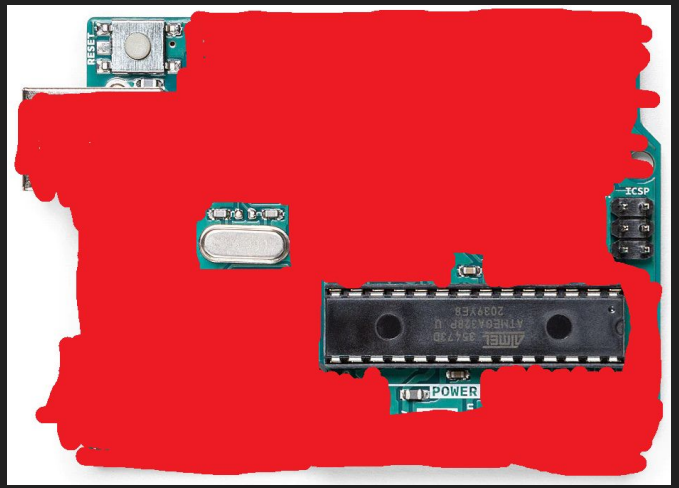
The AVR ISP Port

- AVR-architecture specific programming
- Smaller, no extra hardware needed other than an external programmer
- Extra drivers necessary, not the most reliable
- Slow, makes testing difficult



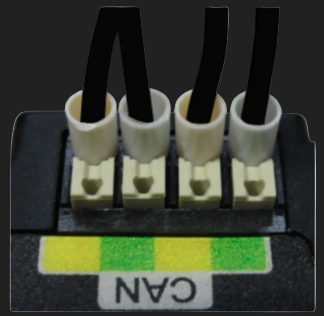
Differences from UNO

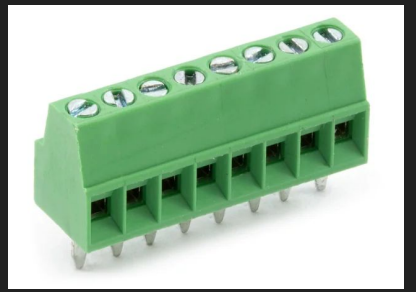
- Not everything on UNO is necessary
- No need for USB, all of the headers, etc.
  - Significant reduction in size
- ATMega328p minimal setup is outlined in documentation



Connectors

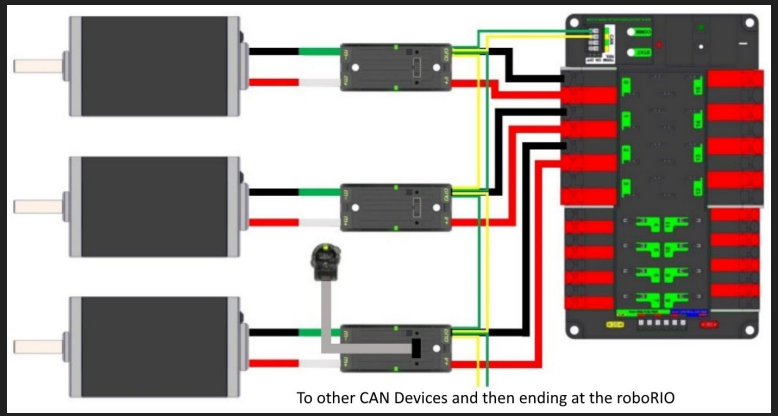
- Initial PCB had through holes which happened to be of the wrong diameter
  - Requires soldering
  - Not easily replaceable
- Went with WAGOs, which are easy to use and common in other formats in FRC
  - Little too large
- Alternatives?
  - Standard push-in Weidmuller FRC connectors
  - Screw terminals

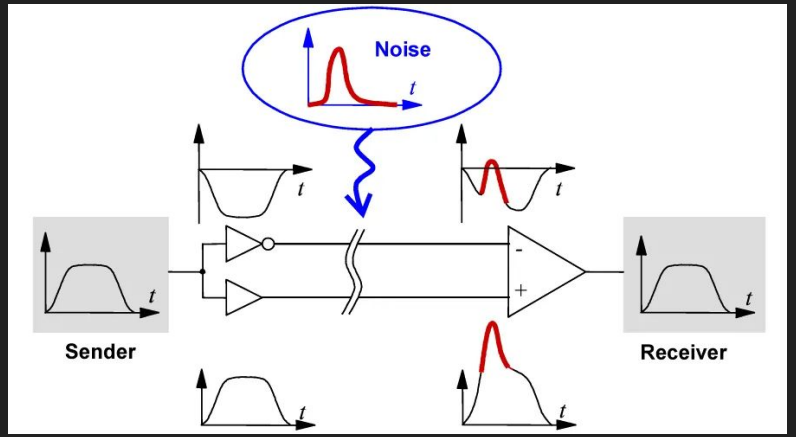




What is CAN?

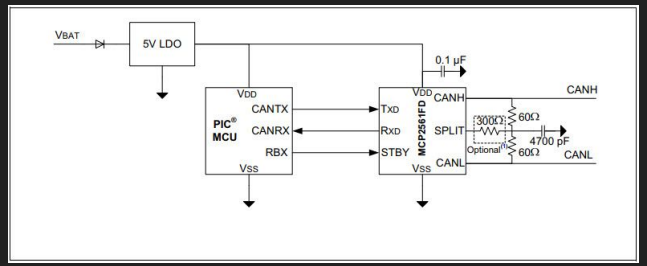
- Differential pair signaling protocol commonly used in cars
  - Extremely resilient to interference because of differential pair
- Is the most common communication protocol in FRC
- Devices are daisy-chained, so space for 2 different pairs of CAN wires necessary (unless terminating)

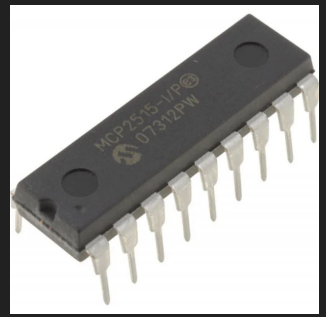




CAN ICs

- CAN is not the most common protocol
- Most common offering for the older CAN 2.0b specification is the MCP2515 CAN controller connected to some kind of transceiver
- CAN FD has the MCP2517/8, but requires another expensive closed source device to use at full speed in FRC because it uses a faster spec - CAN FD, and is only available in surface mount
- Landed on the 2515 and the MCP2561 transceiver - both are in production and are compatible





The FRC CAN standard

- FRC uses its own CAN standard
- Uses extended(29-bit) IDs and separates them into sections
  - All devices have a distinct 6-bit number at the end of their ID
- Every 20ms, a “heartbeat” packet is sent over CAN to give system time, status, etc
  - Its ID overlaps with other packets from the RoboRIO - packets we don’t care about
- Also requires devices to shut down when the robot is disabled

Example

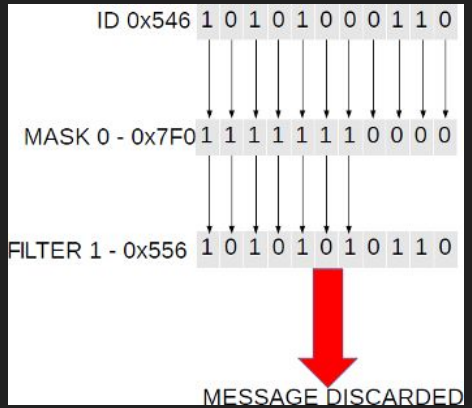
Speed Control Mode Disable from Luminary Micro Jaguar Speed Controller (dev # 4)

Field	Device Type	Manufacturer Code	API		Device Number
			API Class	Index	
Value	2	2	1	1	4

Bits	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0
Bit Position	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Programming with CAN

- The 2515 library uses “masks” and “filters”
- Masks designate which bits matter, filters specify which values of those bits matter
- Takes some testing to make sure unnecessary packets aren’t clogging your receive registers on the 2515
- Had to make it disable upon receiving the shutdown broadcast message + re-enable upon it being rescinded

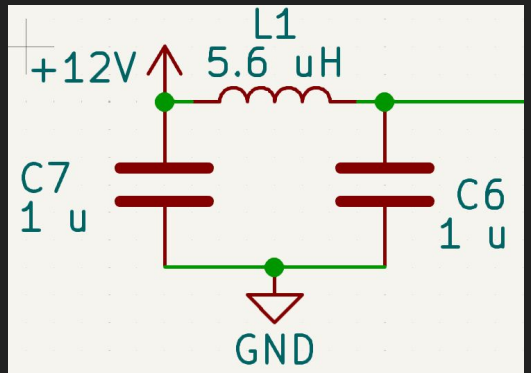


Power Supply

- Most or all power on an FRC robot is 12v
- All of the ICs used require 5v
- Conversion to 5v in FRC uses a common module - but takes up more space then necessary
- Reverse polarity protection would be nice

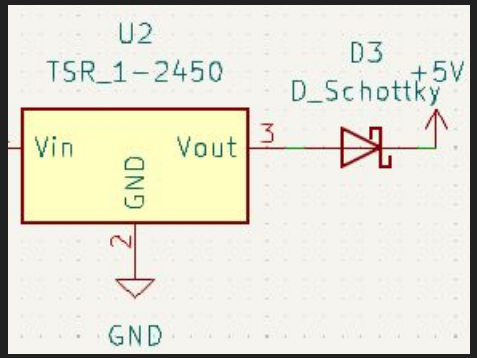
Filtering of 12v in

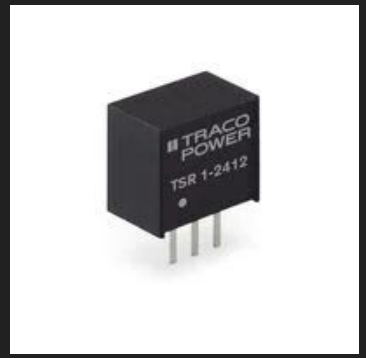
- Capacitors “pass” changes in voltage and “block” constant voltages while inductors “pass” constant voltages and “block” changes
- Capacitors placed between 12v and ground, inductor placed in series
  - Another datasheet recommendation to reduce EMI
- Downside - inductors use magnetic fields, so increased electromagnetic interference
- Slight mistake - choke was needed, not just any inductor (worse for EMI)



Power Supply IC

- Plenty of options here
- Preferably low profile with somewhere around 5 volt 1 amp output
- Needs some tolerance with the input - battery voltage in FRC can ‘droop’ all the way to 7v under high load current and is frequently >13v at full charge
- TSR 1-2450e seemed like a good idea - small (only 3 pins), high efficiency (97%) & high input tolerances (7-36v), non-isolated (common ground)
- 5v bus is connected to it through a Schottky diode for protection



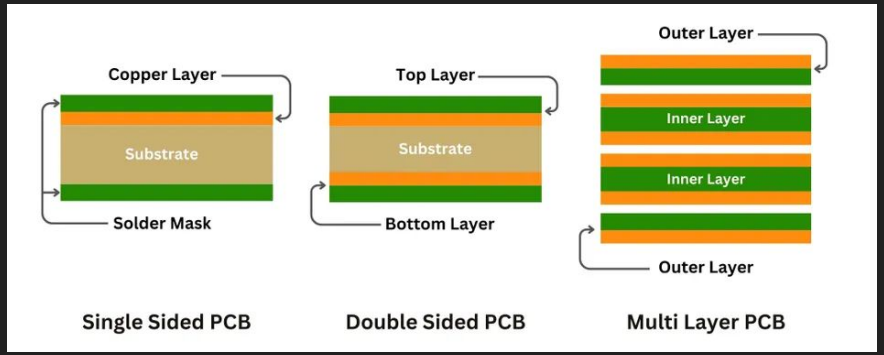


Persistent issue

- TSR likes to generate heat
- Doesn’t *seem* to hurt anything, but is definitely noticeable with a full strip of LEDs
- Could be harmful over time
- Potential solutions:
  - Higher efficiency converter
  - Passive cooling

PCB Layers

- PCBs are separated into layers - amount of layers varies
- 2 main options - 2 or 4 layer
- 4 layer is more expensive
- 2 layer can be harder to route and forgoes some advantages of 4 layer
    - Namely a separate power/ground plane for signal integrity
    - Easier separation of data lines

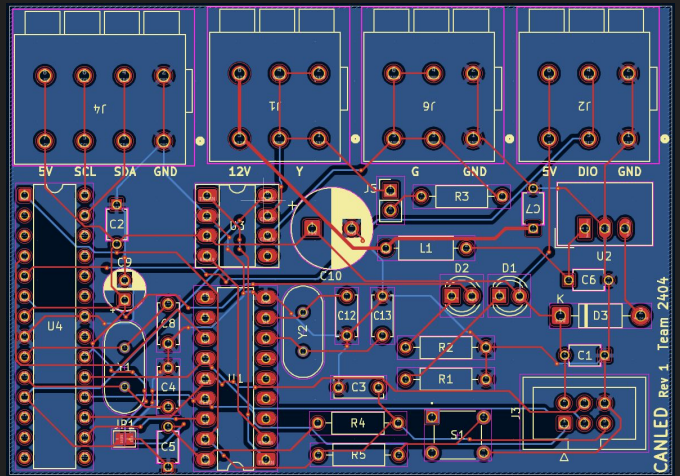


Ground Plane

- Big advantage of 4 layer PCBs - one whole layer can be dedicated to ground
  - Improves signal integrity and structural strength of board
  - Takes full advantage of your copper pour
- In the first iteration, ground was just a trace which ran throughout the board
- In the revision, I managed to make the second layer of the design (mostly) ground plane

Don’t be like me

- Gaps in the ground plane are really bad for EMI, especially if you run any high speed signals over them
- I ran the highest speed signal over one… ATMega 16MHz crystal trace
- Along with having another really big gap
- Hasn’t had a noticeable effect on performance, but its not great for signal integrity

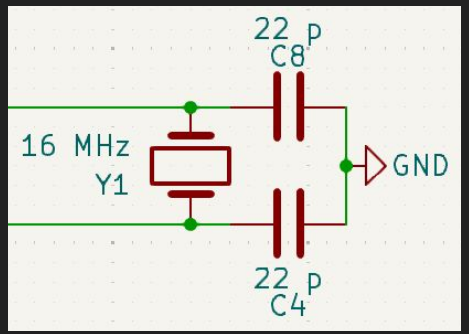


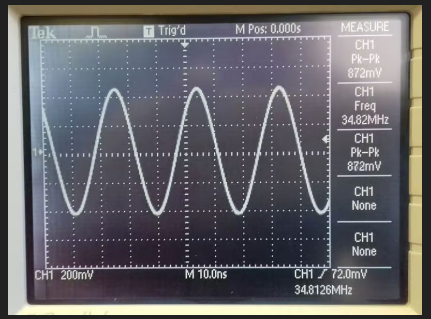
Controlling & Powering the LED strip

- Pretty simple - communication is just a single digital pin
- Lots of libraries on the software side
- Maintaining signal integrity is less of a worry than it seems - digital is pretty resilient & it’s traveling over ground plane
- Datasheet wants a 1000 uF capacitor between power and ground near it

Crystal oscillators

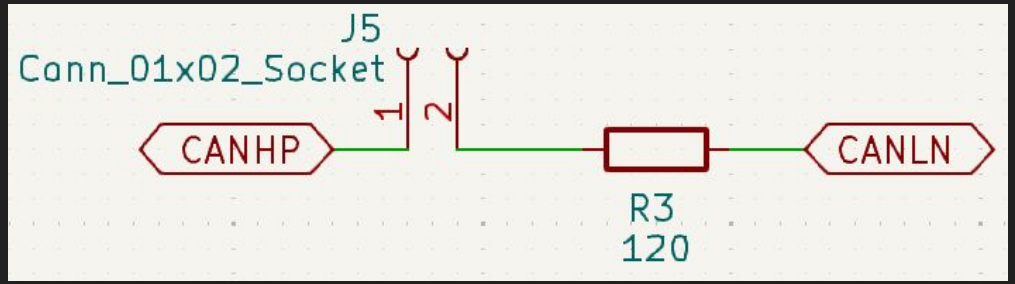
- Component which can create a sine wave with a pair of bypass capacitors and feedback
- 2 necessary - one for the 2515 and one for the 328p
- Both are placed away from 12v and over ground plane for signal integrity



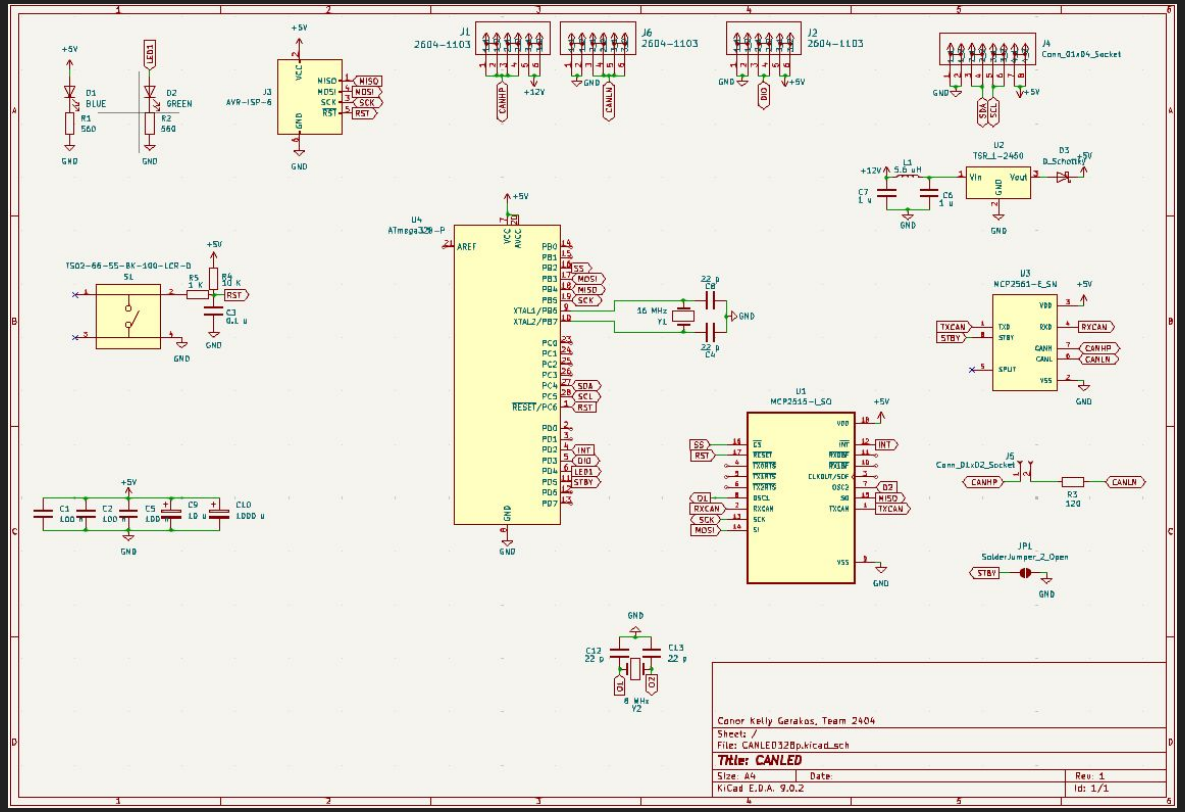


Extra features

- CAN termination optional with 2-pin header which can be shorted together to connect CANH and CANL together and to ground through a 120-ohm resistor
- I2C port for any number of devices (time of flight, IMU, etc)
- Solderable jumper to short STBY on the 2561 to ground



Schematic


Conor Kelly Gerakos, Team 2404
Sheet: /
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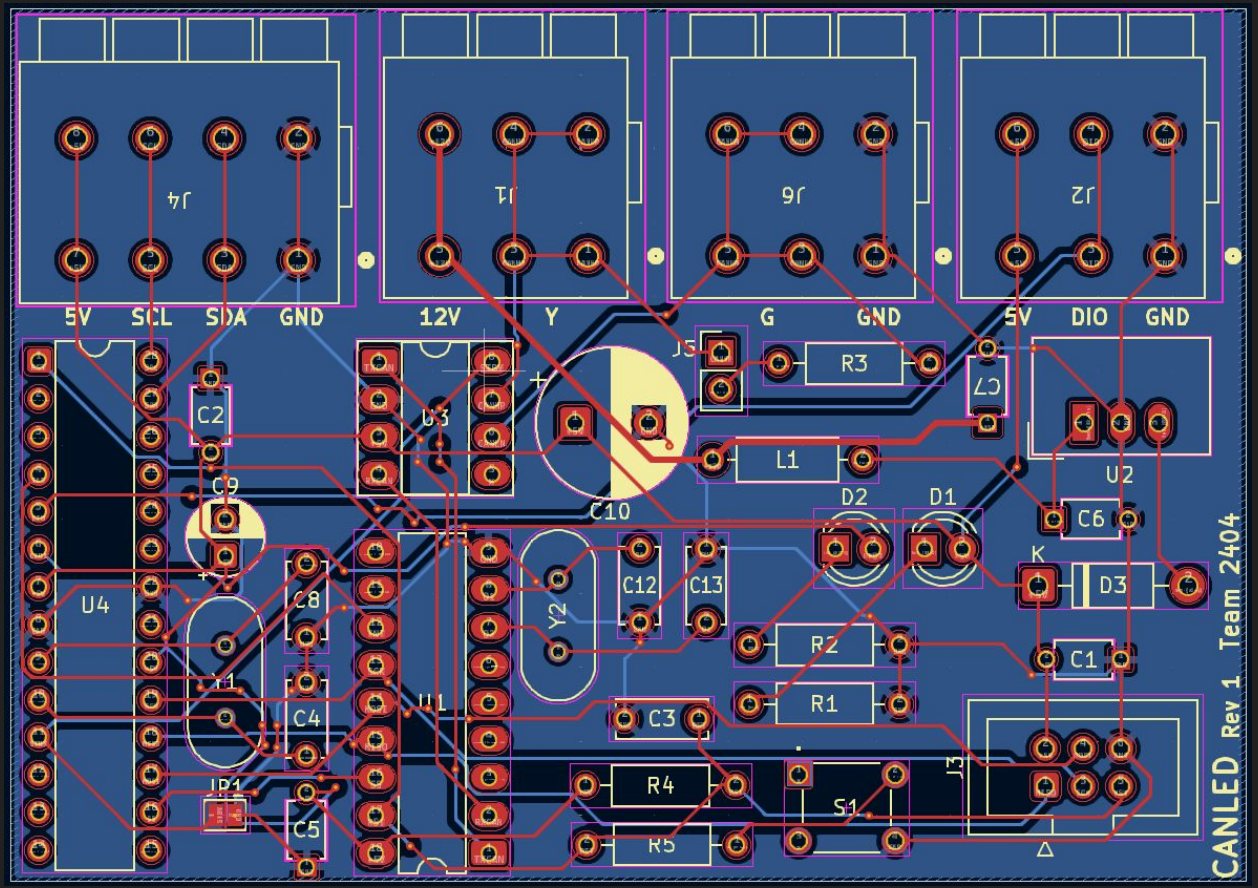
Layout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SCL
SDA
GND
12V
Y
G
GND
5V
DIO
GND
J4
J1
J6
J2
U4
U1
U2
C2
C9
C8
C4
C5
C10
C12
C13
C3
C7
C6
C1
R3
L1
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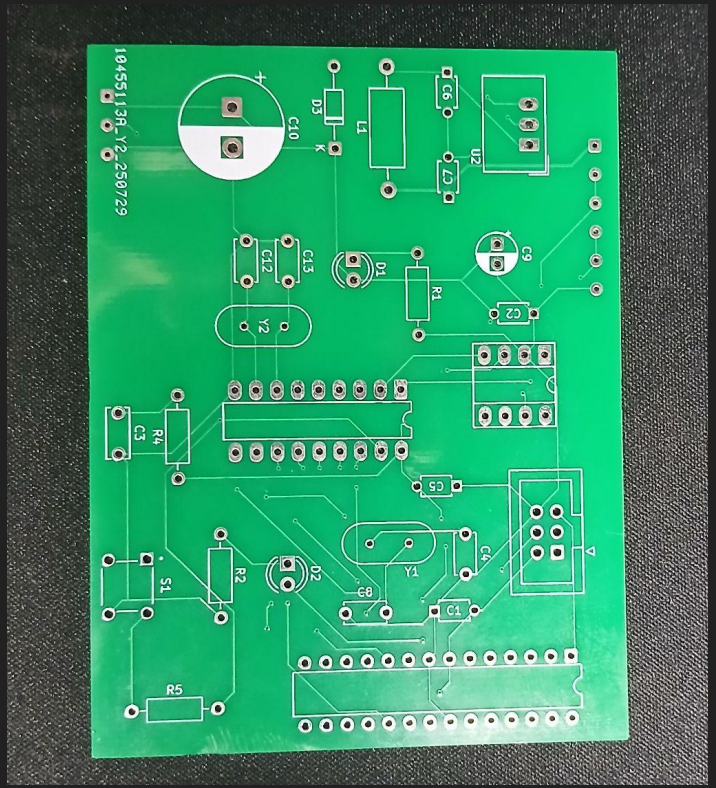
CANLED Rev 1 Team 2404

First PCB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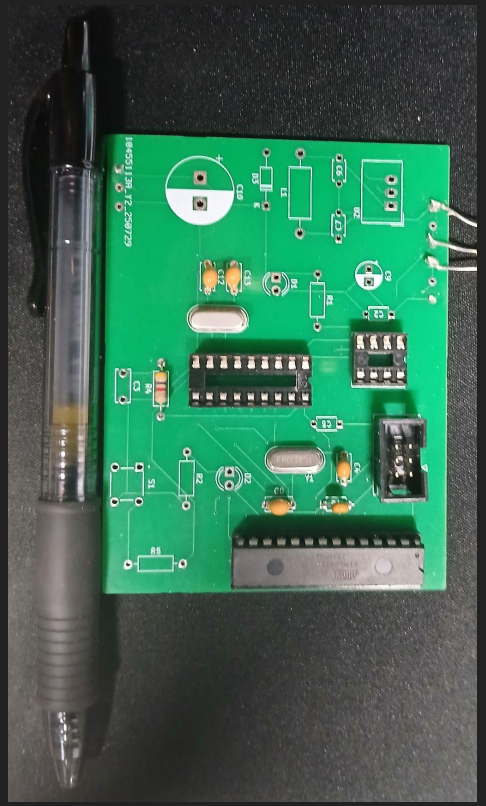
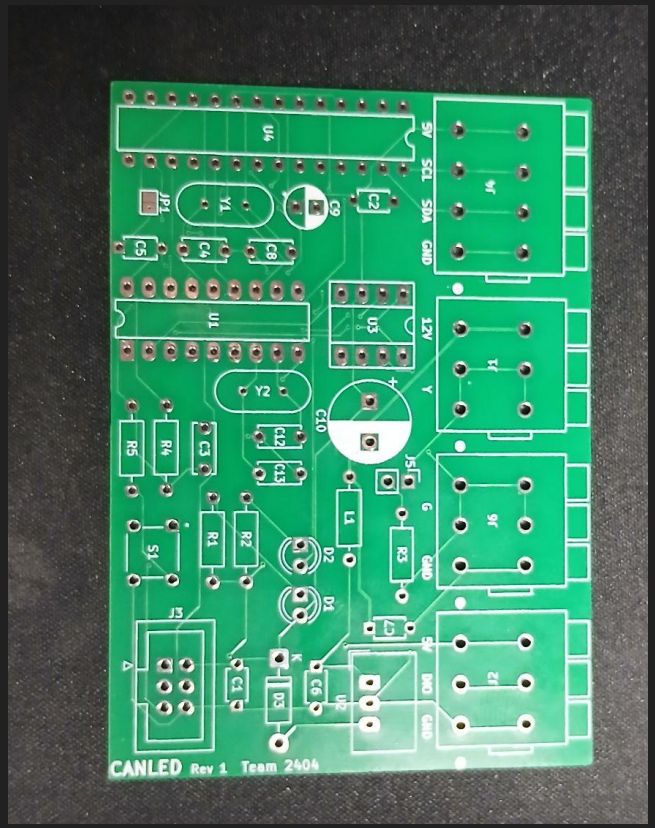


Revision

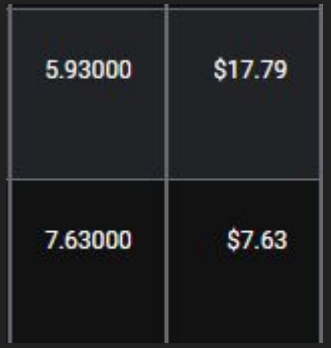


Shortcomings

- Current draw of LED strip is higher than expected - 2A converter would be much better for larger strips
- Board is overall too large (WAGOs)
- Mounting holes would be useful
- Ground plane gaps… Board should have been 4 layer

Pricing

- Using codes, PCB manufacturing cost for 5 boards from JLCPCB was $3.20
- Most expensive components were… the WAGO connectors
- All four of them increased the price by $25…
- Total price of $50.06 without shipping, so half the price was connectors
- Overall not horrible, priced similarly to the cheapest closed source competitor
- Tip: Check component prices before you design!



Potential Upgrades

- MCP2515 and 2551 could be combined into 25651 surface-mounted IC
- New controller for FRC has native support for CAN Flexible Data rate, so the 2561/2515 combo will need to be replaced with 2562/2518 for full speed performance
- WAGO connectors are too big, could be replaced with more common connectors
- Could move from through-hole to surface-mount components to further reduce size
- ATMega328p isn’t super powerful - could upgrade to use more complex LED patterns

Conclusion

- All files available on github - github.com/Team-2404/CANLED
- Project was overall successful - it can control a decently sized strip of addressable LEDs
- We plan to use it on our competition robot this year
- FRC is plagued by copious amounts of expensive closed-source hardware, despite most software being FOSS
- FRC could use more electronics design instead of just wiring - hopefully this inspires other teams to design their own custom circuits

Thank You!

Q&A