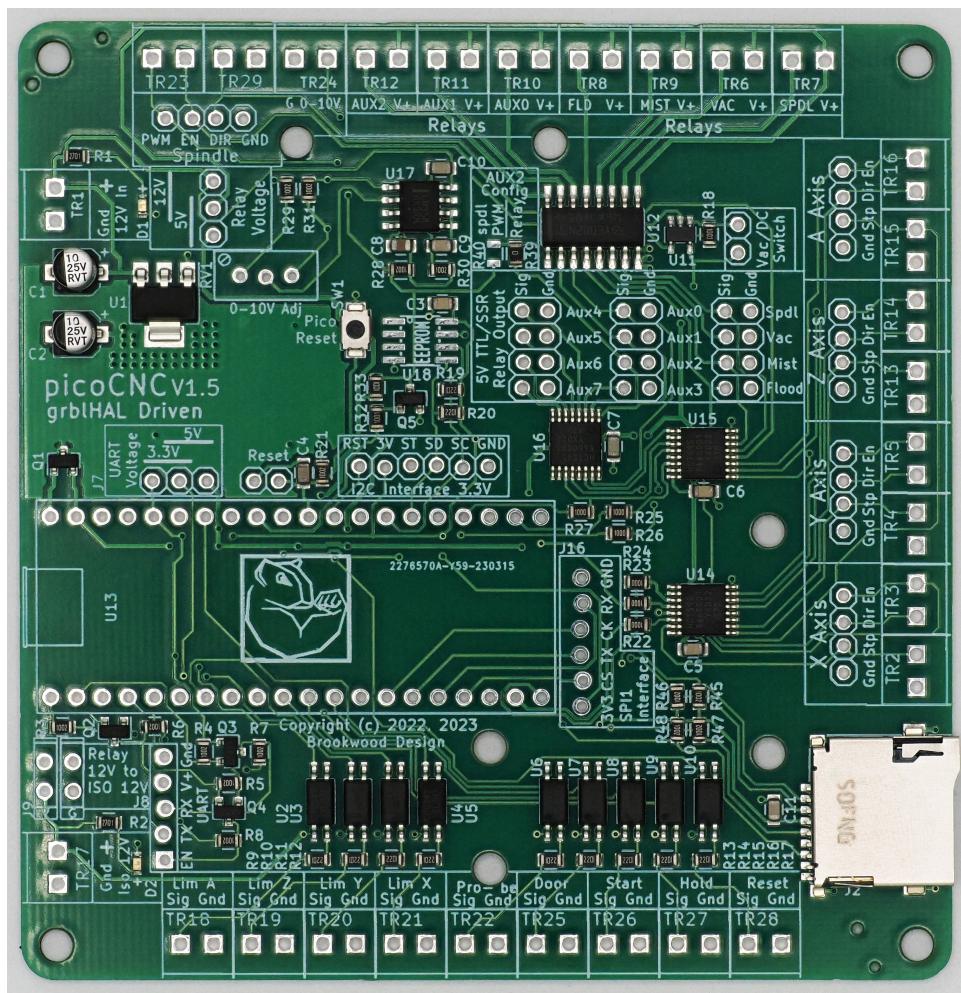


grblHAL PicoCNC Motion Controller Breakout Board User Manual

Document Version 0.95

Applicable PCB Revisions: 1.5, 1.51



The PicoCNC PCB is a CNC controller board designed to run grblHAL.

Features:

- Compatible with Raspberry PI Pico and Pico W.
- 4 Axis control outputs – 5V compatible.
- Independent enables for each axis.
- 9 Opto-isolated inputs including standard Grbl controls and limits switches for all axes.
- Isolated 12V limit switch input on all 4 axes.
- 7 Relay Outputs – Spindle, Mist Coolant, Flood Coolant, Dust Extraction and 3 auxiliary relays. Each output can directly control a relay coil or 5V TTL (SSR compatible) devices.
- 5 additional 5V TTL/SSR outputs.
- Dust Extraction relay support. Activated by spindle enable.
- Separate control of Dust Extraction relay via pin header.
- Relay coil voltage switchable between 5V and 12V.
- Standard Grbl spindle control outputs – 5V compatible.
- 0-10V spindle control output.
- Screw Terminals for reliable connections available for most I/O.
- I2C header.
- SPI header
- microSD Card socket
- UART header with 3.3/5V translation.
- EEPROM footprint for SOIC8 devices.
- Requires 12V supply.
- On-board 5V regulator.
- Flexible 12V power for isolated inputs. May be powered separately for isolation or off main board 12V.
- LED indicators for 12V input.
- USB interface (via Pico).
- WiFi interface (via Pico W).
- EEPROM footprint. Supports EEPROM or FRAM.
- I2C header with daughter card mounting holes.
- SPI header with daughter card mounting holes.
- UART header with daughter card mounting holes. Supports 5V or 3.3V.

Stepper Driver outputs.

There are 4 sets of standard Grbl stepper driver outputs: X, Y, Z and B axes. Each has 4 pins: step, direction, enable and Gnd. Each are 5V compatible and capable of driving opto-isolated stepper driver inputs. Each axis has a set of screw terminals as well as pin headers (0.1"/2.54 mm spacing).

Limit Pins.

There are 4 limit inputs: X, Y, Z and A. All are opto-isolated and available via screw terminals. Powered by 12V and compatible with numerous limit sensors and switches. Fully compatible with mechanical switches or 12V powered proximity switches. When powered via an isolated 12VDC supply, they are fully isolated from the main processor and associated logic.

Control Input Pins.

Standard Grbl control input pins are supported via screw terminals: Feed/Hold, Cycle/Start, Halt/Stop and Safety Door open. These are opto-isolated. When powered via an isolated 12VDC supply, they are fully isolated from the main processor and associated logic.

Probe Input

Probe input is opto-isolated and available via screw terminals. When powered via a separate 12VDC supply, it is fully isolated from the main processor and associated logic.

Spindle Control.

Outputs for Spindle Enable, Spindle Direction and PWM signals available via screw terminal and pin header. These are 5V TTL logic compatible. There are relay outputs for the spindle (direct relay coil and 5V TTL). See Relay section for more details. Standard 0-10V output for spindle control is provided via a screw terminal. One auxiliary output can be set up to support 12V PWM output, open collector.

Relay outputs.

Standard Grbl Flood and Mist relay outputs are supported via screw terminals. Spindle relay output via a screw terminal is supported and controlled by Spindle Enable. In addition, a separate screw terminal relay output for Dust Collection is activated by either the Spindle Enable output or a separate pin header.

3 auxiliary relay outputs are supported via screw terminals and used via M62-M65 grblHAL pin control.

All relay coil outputs configured as open collector drivers and capable of directly driving relay coils. Each relay driver is capable of up to 100 mA. All 7 are limited to 500 mA in total. Above 250 mA, forced air cooling is recommended.

All relay coil drivers have open collector outputs.

Each relay also has a 5V TTL output that can be used to drive solid state relays, separate relay boards or other low voltage activated devices. In addition, there are 5 TTL/SSR outputs.

Relay coil voltage is selectable between 5 and 12V/24V via the pinheader labeled Relay Voltage in the upper left corner of the PCB or, alternatively, via a solder jumper on the bottom the PCB.

One auxillary output (Aux 2) may be connected to the spindle PWM signal to drive 12V devices. It can be used as an open collector driver or with an optional pull up resistor.

All relay coil outputs have an optional pull up resistor pad.

Digital Outputs

Name	Open Collector Screw Terminal	TTL/SSR Pin Header	Notes
Spindle	✓	✓	TTL signal available via Screw Terminal
Dust Extraction/Vacuum	✓	✗	Triggered via Spindle or Pin Header
Mist	✓	✓	
Flood	✓	✓	
Aux 0	✓	✓	
Aux 1	✓	✓	
Aux 2	✓	✓	Assignable as 5V or 12V spindle PWM
Aux 3	✗	✓	
Aux 4	✗	✓	
Aux 5	✗	✓	
Aux 6	✗	✓	
Aux 7	✗	✓	

I2C Header

An I2C header is provided. 3.3V only, there is no translation to/from 5V and the inputs are not 5V tolerant. A strobe line is provided on the header. In addition, a line for an E-Stop signal is routed directly to the Grbl Halt input. Currently, only a limited number of devices are supported. Check the [grblHAL](#) github site for more details.

SPI Header

An SPI header is provided. 3.3V only, there is no translation to/from 5V and the inputs are not 5V tolerant. The header pins are also connected to a microSD socket. It is not recommended that the header is used when a microSD card is inserted in the socket.

UART Header

A UART header is provided. RX, TX and an enable pin are available. Supports 3.3V/5V translation, output voltage selectable via the UART Voltage pin header.

External Connections

Power

12V, Input, main power.

Supply for relays, 0-10V output amplifier and 5V regulator.

12V, Input, isolated input.

Supply for isolated input switches.

Stepper motor, Output

5V Logic Signals.

Pin	Signal
G	Ground
Stp	Step Pulse. Positive.
Dir	Direction
En	Enable

Limit Switches, Input

One input for each axis. Opto-isolated, 12V.

Halt, Door, Cycle/Start and Feed/Hold, Input

Opto-isolated, 12V.

Probe

Opto-isolated, 12V.

Spindle Group, Output.

PWM, Direction, Enable, Ground. 5V compatible.

0-10V.

Relay Coil Group, Output

These are open collector sinks. They run at the selected relay voltage.

Flood, Mist, Spindle, Vac/Dust Collector, Aux0, Aux1, Aux2

Relay TTL Group, Output.

These are 5V, TTL compatible outputs suitable for SSR, powered relay modules or any 5V compatible logic.

Flood, Mist, Vac/Dust Collector, Aux0, Aux1, Aux2, Aux3, Aux4, Aux5, Aux6, Aux7.

Note: Enable in the Spindle Group is capable of driving an SSR, powered relay modules or 5V compatible logic.

Vac/DC trigger.

External Switch to activate a vacuum or dust collector.

I2C Header, Input/Output.

Pin	Signal
G	Ground
SC	I2C SCL
SD	I2C SDA
St	Strobe, used for signaling outside of I2C
3V	3.3VDC, sourced by Pico
Hlt	Halt Signal. Connected to the Halt input Pico pin.

SPI Header Input/Output

Pin	Signal
Gnd	Ground
RX	SPI Device output, MISO
CK	SPI Clock
TX	SPI Device input, MOSI
CS	Component (Device) Select
3V3	3.3VDC, sourced by Pico

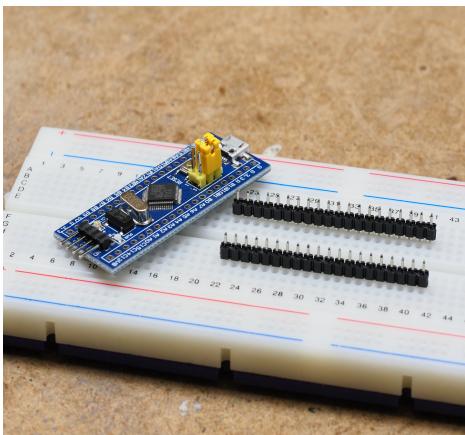
UART Header Input/Output

Pin	Signal
Gnd	Ground
V+	3.3V or 5V, selected via UART Voltage header
RX	Receive, 3.3V or 5V
TX	Transmit, 3.3V or 5V
EN	Enable, 3.3V or 5V can be used for signaling or switching half duplex logic

PCB Assembly

The PicoCNC board is provided with all standard surface mount components soldered in place. You are responsible for installing the through-hole components, either from the option assembly kit or sourced yourself (See BOM section). Assemble the PCB in the following order:

1. Install 1x2 and 1x3 pin headers: Vac/DC Trigger, 5/12V selection and Ser1. Carefully snap each one off the longer pin-header strip. Use tape (painter's tape works well) to hold them in place. Solder 1 pin and then verify the alignment. The header should be perpendicular to the board. If it is not, reheat the soldered pin and gently press it into place (watch the heat on the short headers!). Be sure to be gentle with heating headers as the plastic spacer softens quickly.
2. Install longer 1x headers : Spindle (1x4), I2C (1x6), SPI (1x6) and 4 Axis Headers (1x4). Use same technique as in 1).
3. Install 2X headers: TTL Relay 3X 2x4 headers. Isolated 12V header 2x2. Use same technique as in 1).
4. If you bought a Pico or Pico W without headers, install pin headers. A solderless breadboard makes a great way to stabilize the pin headers while soldering the 0.1" header strips. (The photo below is just for illustration, that is not a Pico.)



5. Install the 3 pin potentiometer. You can bend the leads to ensure it stays in place. But, also follow the the above approach of soldering 1 pin first, verifying alignment and then finishing.
6. Install the Pico. Place the sockets on the pin headers you just soldered onto the Pico. The photo shows a Teensy but the Pico will look similar.



Now, gently insert the socketed Pico assembly into the indicated holes on the breakout board. Verify that all socket pins are correctly in place. Secure the entire assembly with tape on the component side of the board and then solder one pin on each of the two sockets and verify alignment. Once you are sure that the alignment is correct, solder the other pins,

leaving the pins you initially soldered to last.

7. Mount and solder screw terminals. Assemble a complete row before soldering. The terminals lock together but are sometimes hard to get completely aligned. If that is the case, place them upside down (with the pins pointing up) on a hard surface and press each terminal in place with a screwdriver or similar. When you are satisfied that the tops are flush, insert and solder an end pin. Then solder the pin at the other end, making sure the row is properly aligned. It is sometimes helpful to solder the pin of middle a middle terminal while moving the row into proper alignment. Then solder remaining terminals while ensuring that the row is straight. Be sure to include the 2 power terminals.

Relay Voltage

Relay Coil Voltage source is selectable between 5V and 12V. Use a “suitcase jumper” as indicated on the PCB to select the desired voltage.

The user is responsible for ensuring that all relays are rated for the voltage they select.

Note: it is recommended to not use the stepper motor supply for the relay supply. It could be a source of EMI and cause erratic operation of the system.

Dust Collector/Vacuum Control

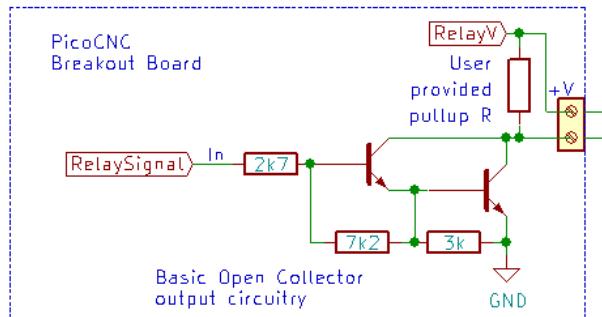
An additional driver is provided for a dust collector relay. It is activated whenever the spindle is turned on (M3). In addition, this relay output can be independently activated by a switch that connects to the pin header labeled Vac/DC Trigger. This makes it easy to do clean up with the same Vacuum or Dust Collector used for dust extraction while running your CNC machine.

Board Level Configuration Options

There are several options to modify the behavior of the PicoCNC board.

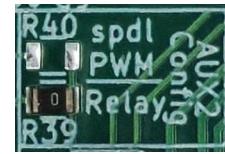
Open Collector Output Pull Up Resistor.

The relay outputs use an open collector to drive relay coils. Pads for pull up resistors are available if needed. They are located on the bottom of the PCB and are labeled for their associated output. Use an 805 SMD resistor. 10K ohms is a common pullup value but it is up to the user to determine the appropriate resistor value. Refer to the diagram to understand how the output works. Note that the attached device needs to share a common ground with the PicoCNC board.



12V Spindle PWM Output

Spindle PWM can be directed to Aux2 output. This controlled by R39 and R40. The default is to have Aux2 controlled by M62-M65 G Codes (technically, M Codes...). To have the Aux2 output controlled by the spindle PWM signal, you need to move the 0 ohm resistor on the R39 pad to the R40 pad. A small piece wire can be used if the 0R resistor is lost when desoldering. Note that a maximum PWM frequency of 50K is supported. Maximum current draw is 250 mA. Aux2 can not be used for M62-M65 control when configured for PWM.



I2C Pullup Resistors

If you are using an I2C device, you may need pullup resistors on the communication lines. There are pads on the bottom of the board to allow you to use 805 SMD resistors.

Firmware.

The [grblHAL Web Builder](#) site is used to create the proper firmware for your PicoCNC board.

Select PR2040 (Pi Pico and Pi Pico W) in the driver box and PicoCNC in the Board box.

In the General panel, select the Number of axes and the appropriate axis configurations for your CNC machine.

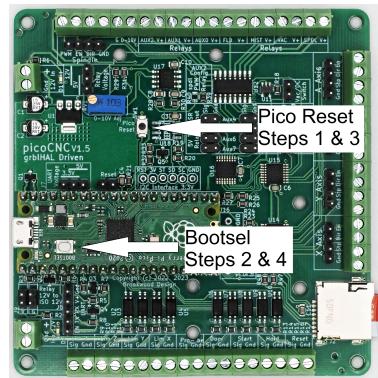
In the Plugins panel, select Enable or Ymoden in the SD card option.

If you have a Pico W, in the Network/WebUI panel select Networking WiFi and check Telnet, WebSocket and FTP.

Then press the Generate and Download button. Save the firmware file for use in the next section. Also, press the Save board button so that you will have the configuration if you need to later make changes.

Installing the firmware is very easy! Once you have a firmware file, connect a USB cable from your computer to the Pico installed on your PicoCNC board. Then:

1. Press and hold the Pico reset button on the PicoCNC board.
2. Press and hold the Bootsel button on the Pico board.
3. Release the Pico reset button on the PicoCNC board.
4. Release the Bootsel button on the Pico board.



Windows

A file explorer window will open. Drag and drop your firmware file onto the window. You will see a progress indicator as the firmware file is uploaded to the Pico. When done, you can start your GCode sender application and connect to the com port associated with the Pico. Use the Device Manager to determine what it is if you are having difficulty finding it.

Mac OS

A drive called RPI-RP2 will appear on your desktop. Double click on RPI-RP2 and a finder window will open. Drag and drop the firmware document onto the window. When done, you can start your GCode sender and connect to the Pico.

You can also download the grblHAL source code at <https://github.com/grblHAL>. Note that there are multiple libraries that you will need to download. A complete discussion of installing and building the source code is beyond the scope of this document.

Start with the core wiki to understand how to build grblHAL – <https://github.com/grblHAL/core/wiki/Compiling-grblHAL>.

Running grblHAL on your machine

Once you have finished assembly and installed the firmware, your grblHAL PicoCNC based Motion Controller is ready to be tested in your CNC machine. Attach it to a PC via a USB cable and run a compatible GCode sender application on the PC. We recommend this one: <https://github.com/terjeio/ioSender/releases/tag/2.0.42>. Check for the most recent release. Next, you will need to set up Grbl to reflect your hardware. We will use ioSender for our examples.. Actual Grbl setting values are also shown. Follow these steps:

1. Hook up your control buttons: Feed Hold, Cycle Start and EStop.
2. Open the **Settings: Grbl** panel. You will see a list of parameters that control grblHAL.
3. In the Spindle section, \$16, Invert spindle signals, check the PWM box.
4. In the Stepper section, \$4, Invert stepper enable pins (s), Check all boxes. \$4=7 for a 3 Axis machine. \$4=15 for a 4 Axis machine.
5. In the Control signals section, \$14, Invert control pins. Check Feed Hold, Cycle Start, EStop and Safety Door (if present). \$14 = 15.
6. Press the save button and return to the main tab (**Grbl** panel, you should see the DRO section).
7. Press the Red Reset button if an ALARM state is showing.
8. Open the **Jog** panel and click on any of the jog direction buttons. The DRO should show movement. If you have drivers and motors hooked up, they should show movement.
9. If you have any control buttons attached, test them. It should show activity. Note the associated “LED” in ioSender when you press a button. If nothing happens, you should verify your connections.
10. If everything works to your satisfaction, you should now proceed to full testing of your machine.

Note, if you have not connected 12V to the Iso 12V terminal (or installed jumpers on the 2x2 header next to the terminal), the input signals will not be active. You will also not see a lit LED near the Iso 12V screw terminal. This means that you won't see any of those signals in ioSender.

There is a lot more information in the grblHAL wiki at <https://github.com/grblHAL/core/wiki>. In particular, we recommend you check the First Run Grbl Settings section.

Some Initial Grbl Settings

Grbl settings are dependent on your hardware so you might have to experiment a bit. Here are some key settings that will help you get going faster.

\$ID	Name/meaning	Suggested Value	Comments
0	Step Pulse time in uS	5	Default is 10 but 3 or 5 should work ok. Using the default may cause problems for step rates above 80 kHz.
4	Step Enable bit mask, one per axis	7 (3 motors) or 15 (4 motors)	A 1 bit means invert. A 3 axis machine would have 7 as the value, a 4 axis machine would have 15. Bit 0 is X, 1 is Y, 2 is Z and A is 3.
14	Control pin inversion bit mask, one per pin.	30	A 1 bit means invert. Reset is bit 0, Feed Hold – 1, Cycle Start – 2, Safety Door – 3.
30	Max spindle speed in RPM	1000 or VFD max.	Default is 1000. If you have a VFD, you will need to set this to the spindle max. In G-Code, the Sxxx parameter controls speed and to get full speed, you will need to have xxx match this parameter (S1000, in the case of the default).
100, 101, 102,	Steps/mm. One for each Axis. 100 – X,	varies	Set these based on your hardware – lead screw/belt ratios, microstepping. The default is likely wrong for your machine but you will still get movement. On a per axis basis, determine the number of steps (including microsteps) it will take to make one

103, 104	101 – Y, and so on.	full rotation of the lead screw. Determine how many mm that axis will move with one full rotation of the lead screw, pinion gear or belt driver pulley. Divide the first number by the second to get the value you will use.
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You should spend some time studying all the Grbl settings. We suggest you start conservatively and tune your machine to higher performance one parameter at a time.

Compatible G-Code Senders

Most senders will work with grblHAL. If your preferred sender is having problems, it may need to use a version of grblHAL built with compatibility settings. Use the grblHAL Web Builder interface described in the Firmware section above. Compatibility Level is set in the Advanced features panel.

Setting up a Pico W.

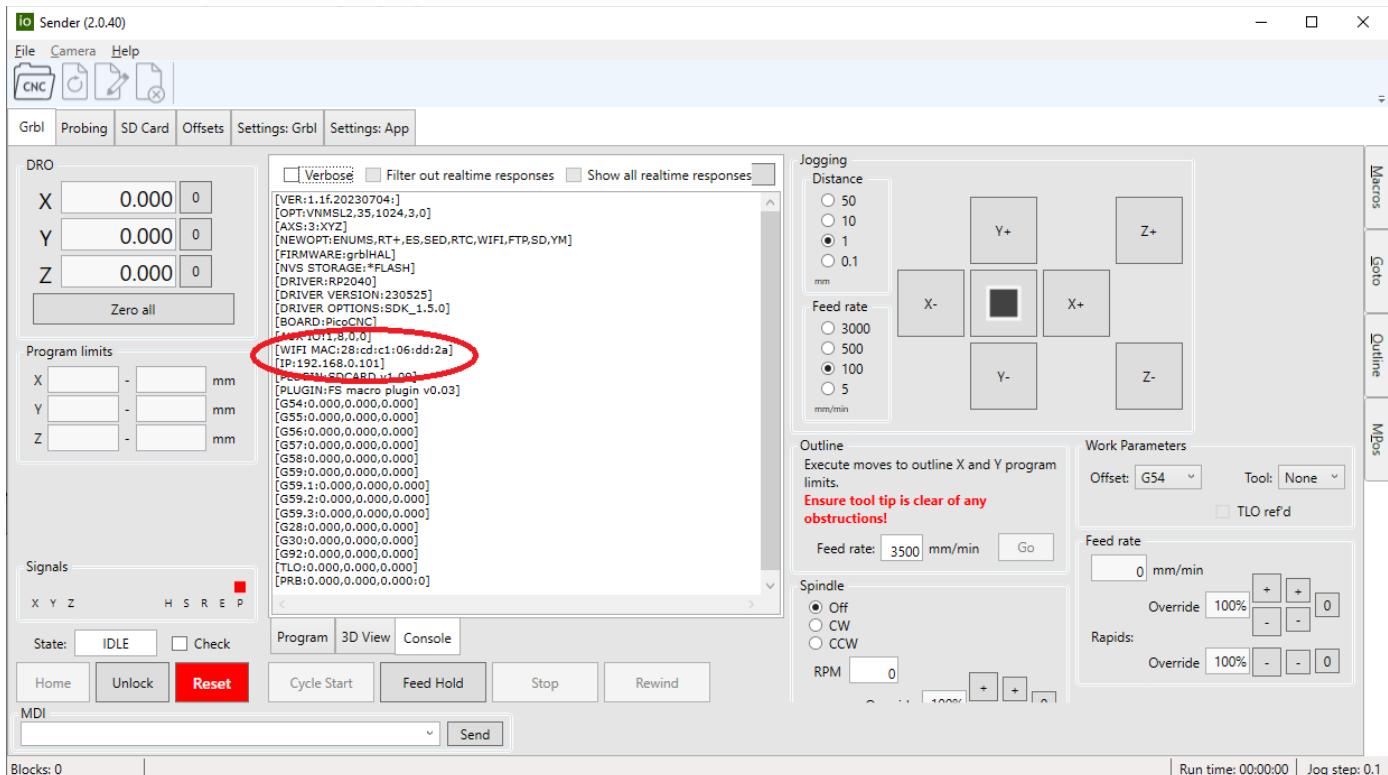
Follow all the above steps when setting up to use a Pico W. When building the firmware, be sure to select WiFi on the Network/WebUI panel, Networking box. Also check Telnet, WebSocket and FTP. Once you are able to connect to the PicoCNC board via USB, configure WiFi. In ioSender, open the Settings: Grbl panel.

1. Open the Networking section and click on the Network Services entry (\$70). Make sure that Telnet, Wensocket and FTP boxes are checked.
 2. Open the WiFi section and fill out the SSID (\$74, wifi network name) and password (\$75) for your WiFi network.
 3. Make sure that the Wifi Mode (\$73) is set to Station.
 4. Press the Save button, close ioSender and press the Pico Reset button on the PicoCNC board.

Wait a few seconds and then press and release the Pico Reset button on the PicoCNC board. Restart ioSender and click on the Console panel. Look for the following lines:

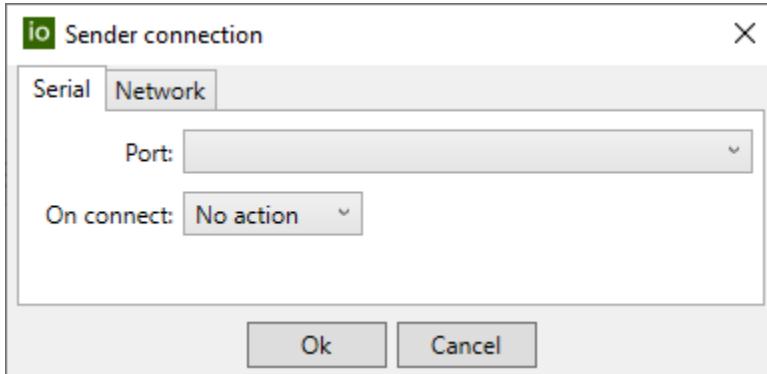
[WIFI MAC:xx:xx:xx:xx:xx:xx]
[IP:xxx.xxx.xxx.xxx]

Where xx or xxx are composed of the digits 0 through 9. If IP is 0.0.0.0, then you are not connected, otherwise the PicoCNC is now connected to your WiFi network. Write down the IP address numbers, you will use them shortly.



To set up communication via WiFi,

1. Close ioSender
2. Press and hold the Pico Reset button the PicoCNC board (alternatively, disconnect the USB cable from the Pico)
3. Restart ioSender. It will put up a dialog asking you to configure the connection.

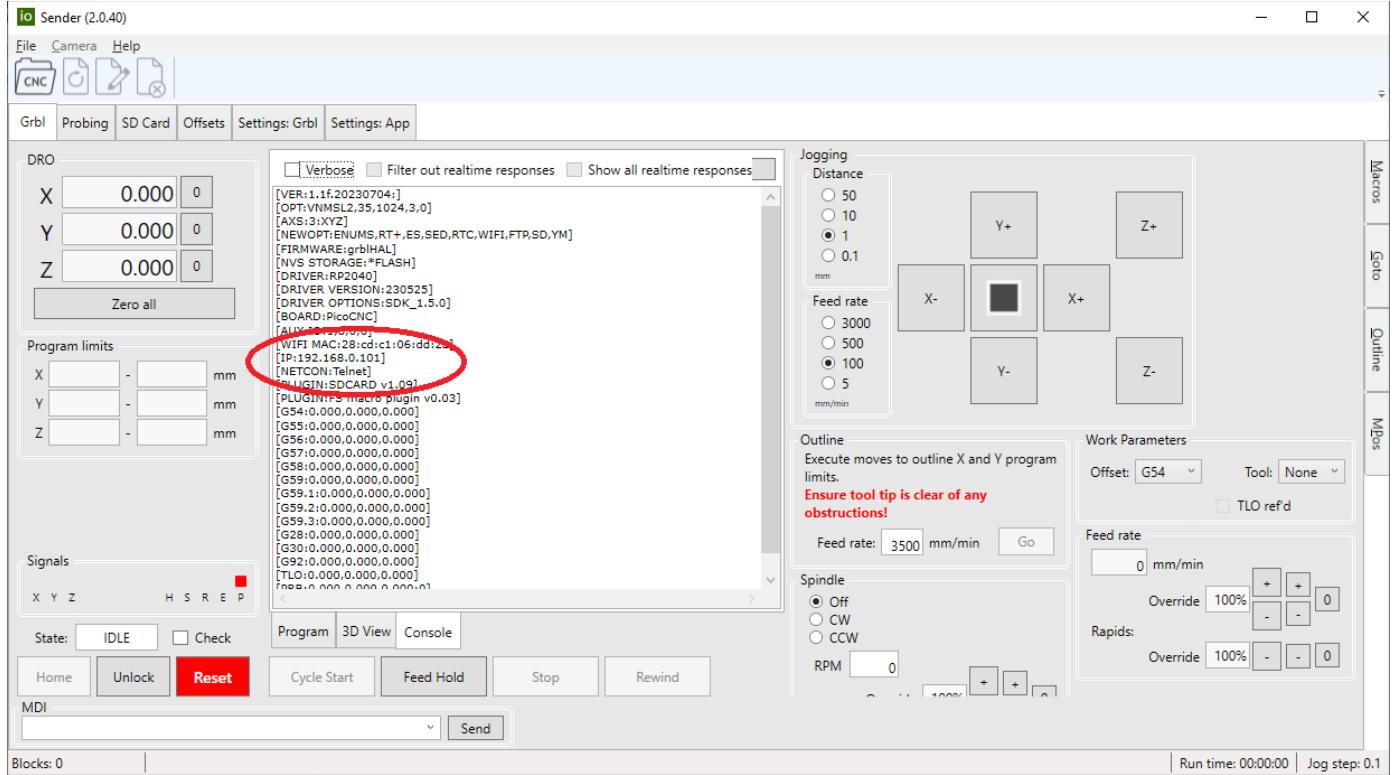


4. Release the Pico Reset button. (alternatively, plug the USB cable back into the Pico.)
5. Click on the Network tab.



6. Enter the IP address numbers in place of 192.168.5.1. Click on Ok and you should be rewarded with ioSender running and connected via WiFi to the PicoCNC.

To verify you are connected via WiFi, open the console panel and look for a line that reads [NETCON:Telnet].



0-10V Spindle output setup

The 0-10V circuit works by using an opamp to filter a 5V PWM signal and amplify it to 10V. As such it needs 12V or higher input which the user must provide via the 12V screw terminals. A second order filter with an aggressive low pass cut off frequency is used to provide a stable signal for the spindle controller.

Because source voltage level can vary, the amplifier must be adjusted. You can do this by turning on your spindle in GCode (via Sxxxx) to full speed and adjusting RV1 (the blue box with the screw) until the voltage on the 0-10V terminal reads 10V. Here is a step-by-step method you can use:

- Disconnect your spindle or VFD.
- In the **Settings: Grbl** tab, set \$30, **Maximum Spindle Speed**, to 1000.
- Send the following command to grblHAL: **M3 S1000**. This turns on the spindle and causes the speed to be set to 100%.
- With a digital multimeter, measure the voltage between the 0-10V output and G terminals.
- With a screwdriver, adjust the RV1, labeled “0-10V Adjust”, until the voltage is as close to 10V as you can get. Anything in the range 9.990V to 10.010V is acceptable.
- Send the following command to grblHAL: **M5**. This turns off the spindle and you should read 0V.
- Reconnect your spindle or VFD and test.
- Change the max spindle speed setting, \$30, to something more appropriate for your spindle.

You may want to repeat the above process with the spindle connected and running to fine tune the maximum speed. Most VFDs will show you the spindle speed.

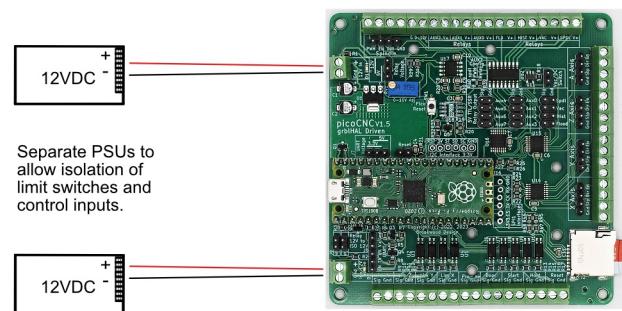
Power options for the PicoCNC.

The PicoCNC requires 12V input. It will draw approximately 500 mA though any directly driven relay coils or other devices will add to that.

There are 3 ways to power the PicoCNC board.

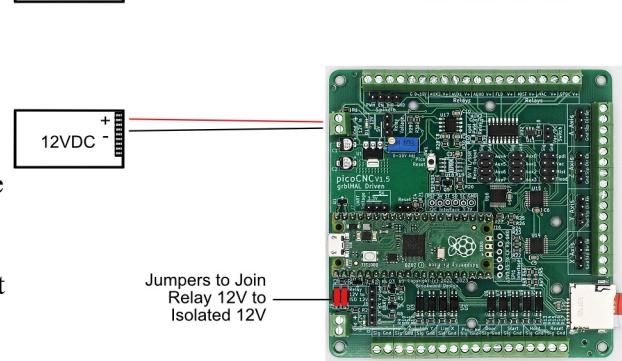
1) Dual PSUs

This provides separate power for the relay and spindle sections and isolated power for the limit sensors/switches. The digital section – the Pico board itself and all the digital logic on the PicoCNC board are power by an on-board 5V regulator fed from the 12V relay input. 1 Amp PSUs are acceptable for both supplies. If you have other 12V items to power, use the relay section PSU and size accordingly to the additional load.



2) Single PSU.

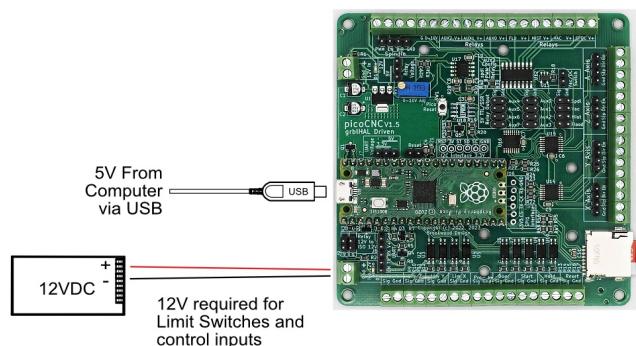
For budget conscious builders, there is the option to use a single PSU. The 2x2 pin header near the 12V Iso input can be jumpered to join the two 12V sections together and thus have one 12V PSU power the entire board. This does not provide true isolation for the limit, probe and control input section but may be acceptable, especially if good EMI practices are followed. The optoisolators provide some EMI protection



even without a fully isolated PSU. See “EMI Considerations” below.

3) Logic Powered from USB

The core digital section of the PicoCNC can be powered via USB power. This is acceptable if you do not power any relays or other devices. However, the Limit, Probe and Input section requires 12V power to function. If you do not supply 12V to the PicoCNC board, grblHAL may boot up in an error state. See the First Run Settings in the wiki for how to deal with that.



EMI Considerations

Electro Magnetic Interference can cause significant disruptions to your CNC machine. It is best to build your system using good practices. Often your wiring can act as antennas for EMI and conduct it back into your electronics box. In designing the PicoCNC, we used good practices to avoid EMI but further precautions are recommended. Power is often a source of EMI and you should take additional steps to ensure that these sources are managed. Finding the source of EMI later can be difficult – we recommend that you design your system with EMI avoidance it in mind.

These are general recommendations, you don't need to follow all of them but the more you do the better chance you stand of having EMI free operations.

- Do not power 5V relay coils from the USB voltage supplied by to the Pico. Relays can produce EMI and power fluctuations. Use external power (see above).
- Do not power relay coils directly from the Stepper Motor power supply. It can be a significant source of EMI.
- Use shielded wires for signals. Makes sure the shields are grounded in a star configuration at the controller box or other common ground.
- Use ferrite filters on all wires entering or exiting the PicoCNC.
- Avoid routing wires near EMI sources such as a VFD, Stepper drivers, or power supplies. Avoid co-routing with unshielded wires that are connected to those devices as well.
- If you are connecting to the PicoCNC via a USB cable, use one with a ferrite filter on it or add a clamp-on one close to the electronics box end of the cable.

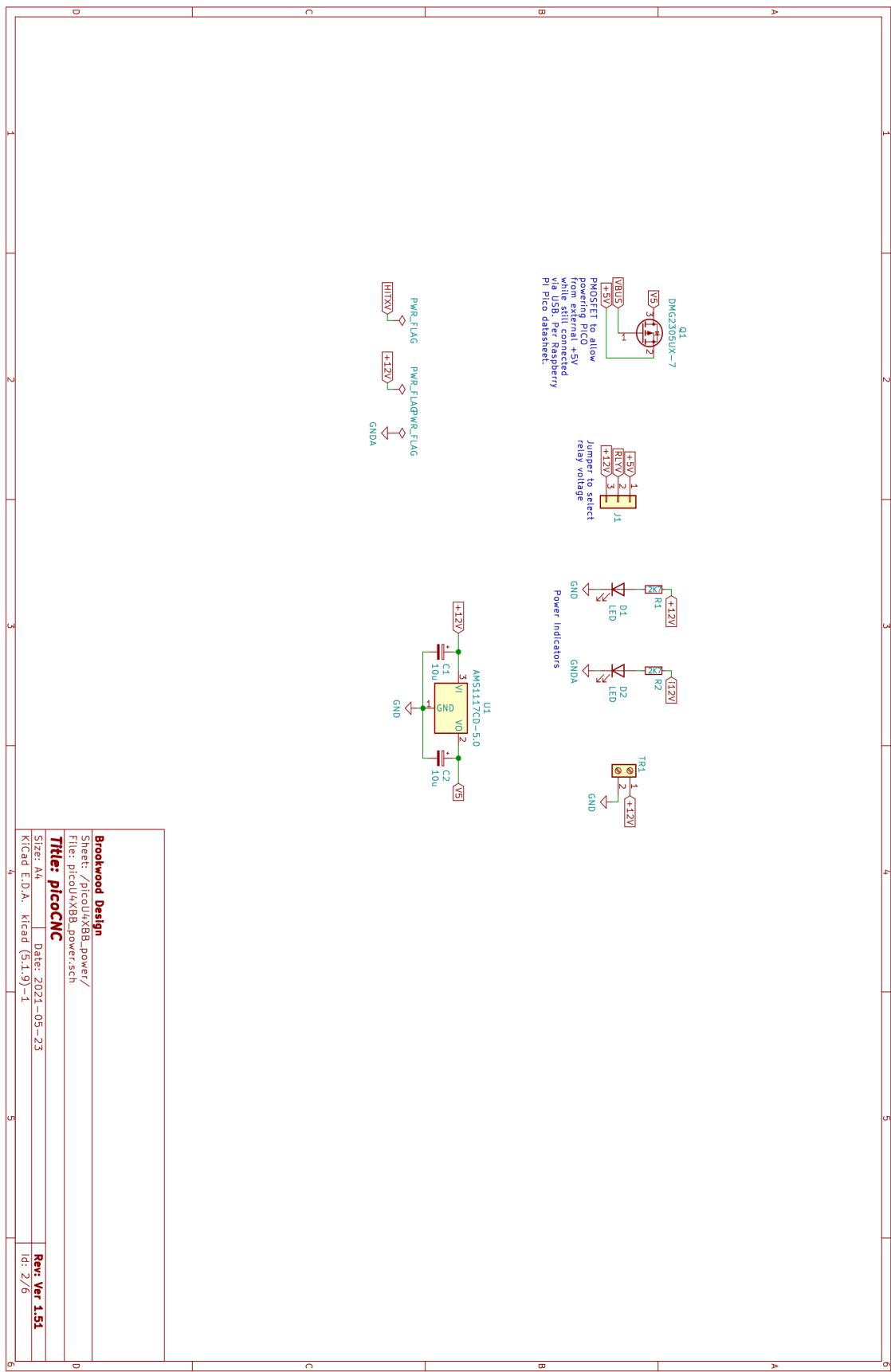
Ferrules

We recommend that all stranded wires have ferrules crimped on the end that goes into a screw terminal. This is a good practice. It ensures the best possible contact and helps to avoid stray “cat whisker” - strands of wire that could cause errors. Kits with ferrules and a crimper are available for \$20 to 30 USD. It is a worthwhile investment.

<insert photo of ferrules>

Schematics:



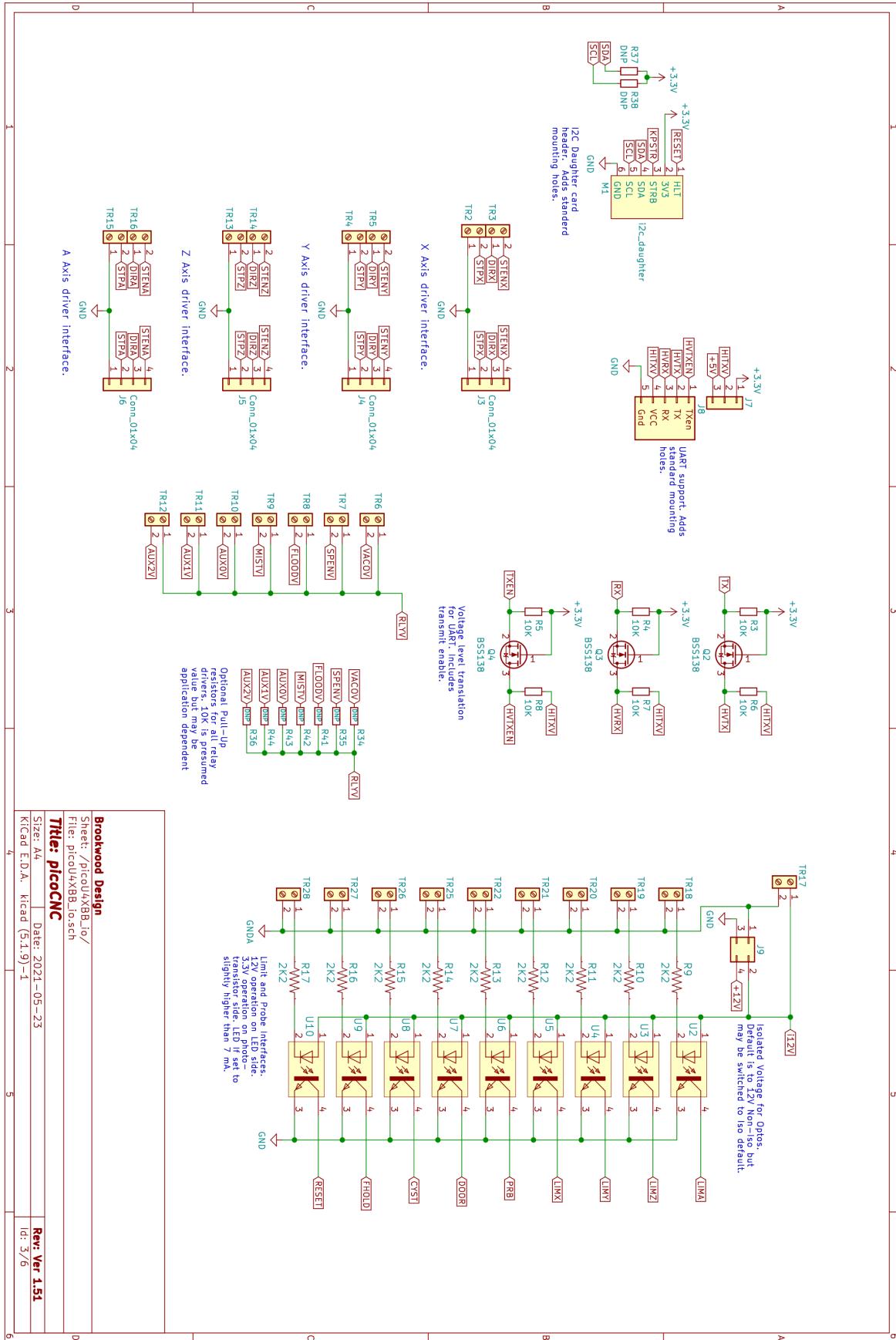


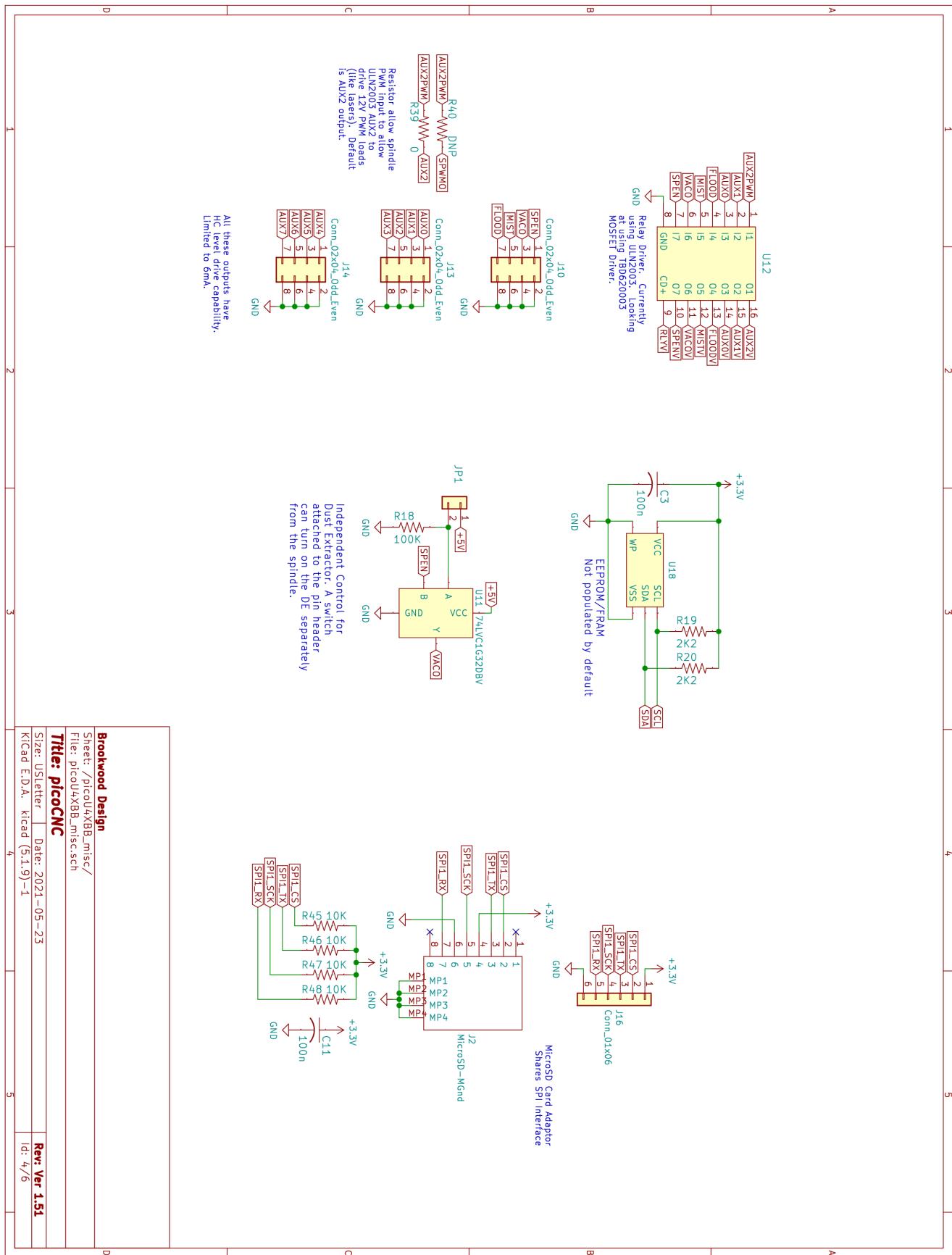
Brookwood Design
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File: picocNC.pcb

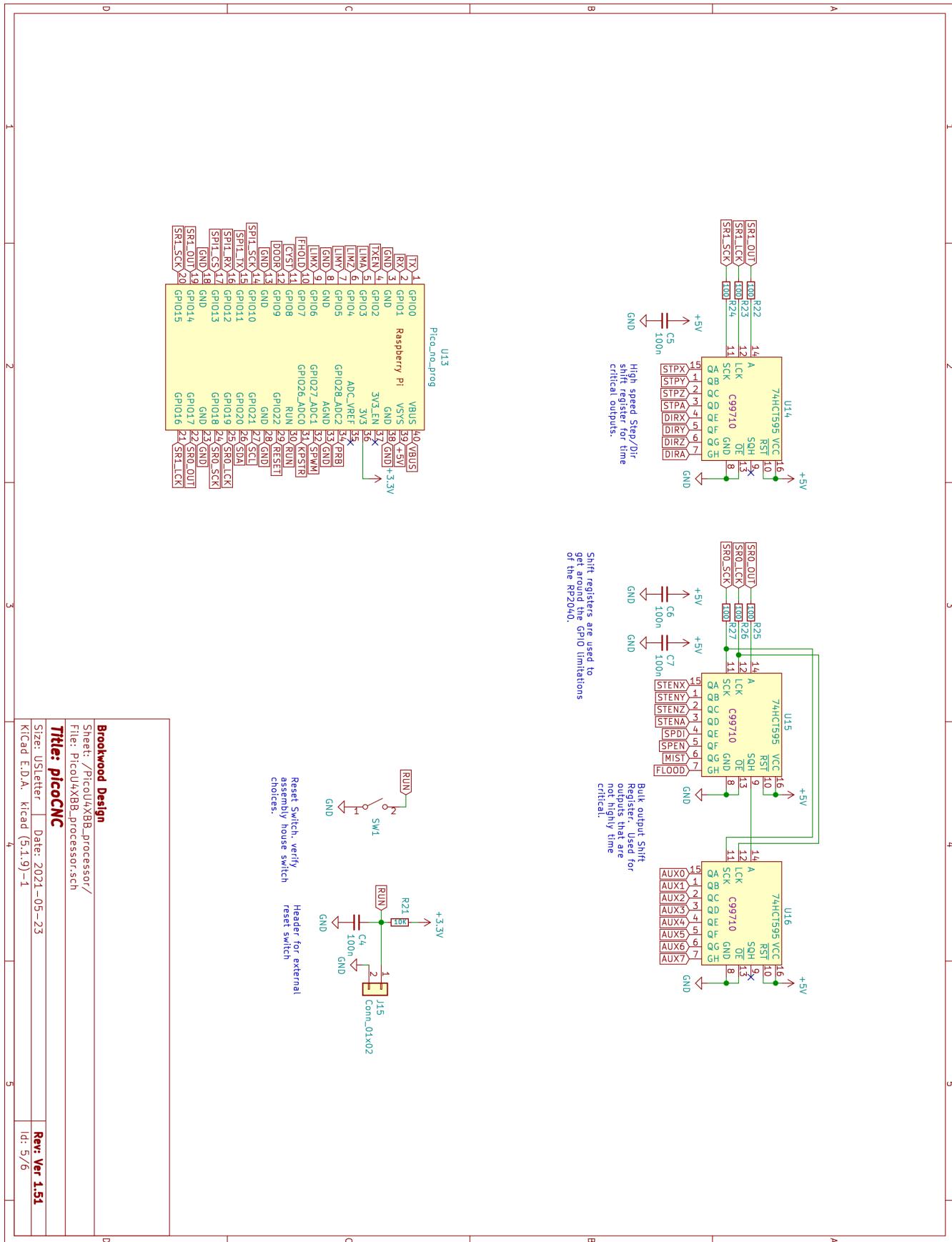
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Size: A4 Date: 2021-05-23 Rev: Ver 1.51

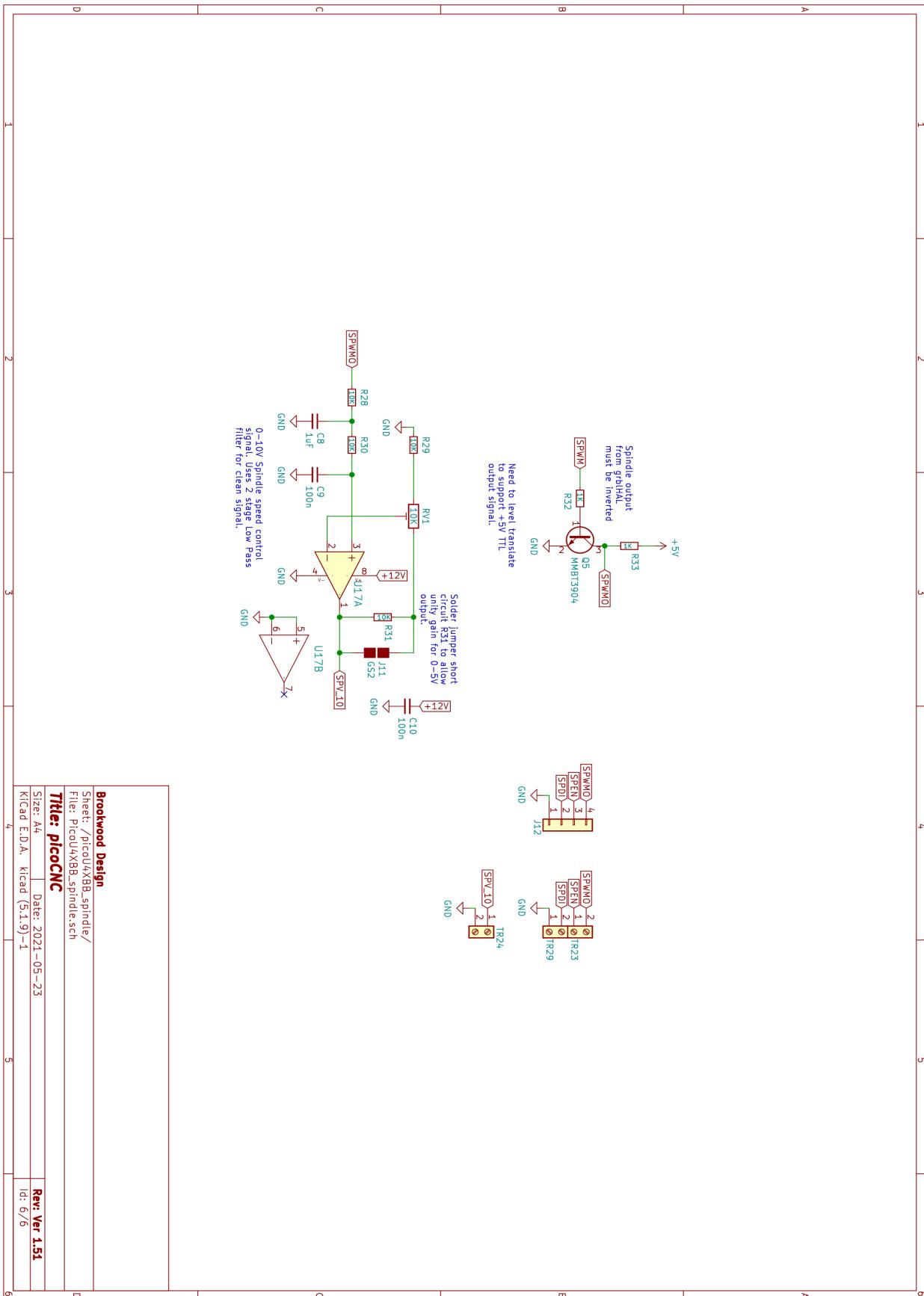
Kicad E.D.A. kicad (5.1.9)-1 Id: 276



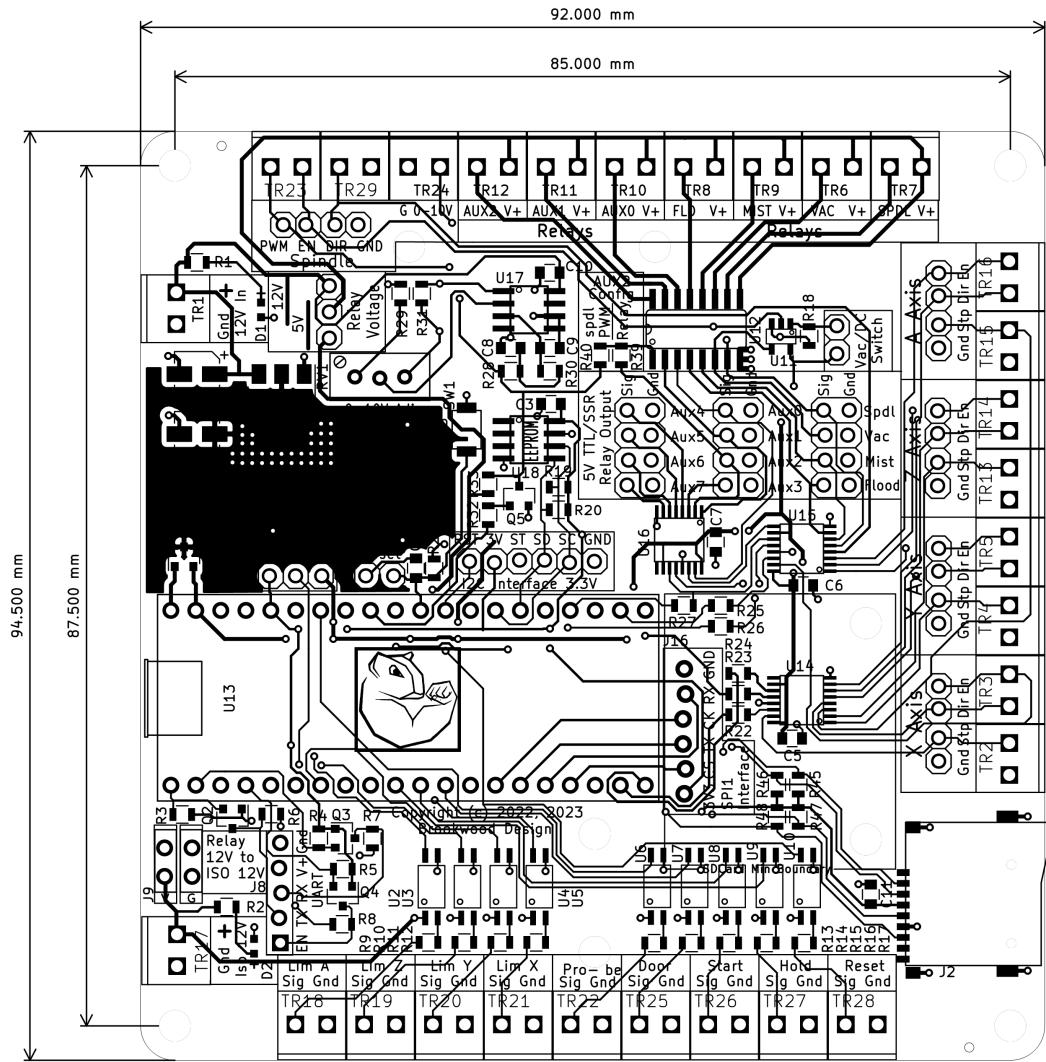




Brookwood Design	
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Title: picoCNC	
Size: USLetter	Date: 2021-05-23
Kicad E.D.A.	Rev: Ver 1.51
	Id: 5/6



Board and mounting hole dimensions



Assembly Kit Bill of Materials.

Item	Number	Descr	Part nums
Pico sockets	2	1x20 pin 2.54mm pitch socket	Various Suppliers. Mouser: 571-1-535541-8
Screw terminals	29	3.5mm pitch screw terminals	KF350-3.5-2P Various Suppliers. LCSC: C474892
2x4 pin header	3	2x4 2.54mm pitch header	Various suppliers.
1x40 pin header	1	1x40 2.54mm pitch header	Various suppliers.
2x2 pin header	1	2x2 2.54mm pin header	Various suppliers.
10K Trim Pot	1	10K trim potentiometer	Bochen 3296W-1-103, LCSC: C118954
Shorting Jumper	4	Shorting Jumper 2.54mm pitch.	Various suppliers. Mouser: 855-M7581-05

BOM for surface mount components.