grblHAL Teensy 4.1 Motion Controller Breakout Board
User Manual

Version 2.07

T41U5XBB – 5Axis, USB connected Breakout Board

T41E5XBB – Ethernet Connected Breakout Board
(note silkscreen says T41USB5XBB, both share a common PCB)

Features:

- 5 Axis control outputs – 5V compatible.
- Independent enables for each axis.
- 10 Opto-isolated inputs including standard grbl controls and limits switches for all axes.
- 7 Relay Outputs – Spindle, Mist Coolant, Flood Coolant, Dust Extraction and 3 auxiliary relays. Each output can control a relay coil directly or 5V TTL (SSR compatible) devices.
- Dust Extraction relay support. Activated by spindle enable.
- Separate control of Dust Collector 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.

- 4 Digital Inputs – EMI protected, 15.9KHz low pass filter, Schmitt Trigger.
- I2C header.
- EEPROM footprint for SOIC8 devices.
- LED indicators for 5V and 12V.
- USB interface.
- Ethernet interface.
- Serial I/O Header

Stepper Driver outputs.
> There are 5 sets of standard GRBL stepper driver outputs: X, Y, Z, A and B axes. Each has 3 pins: step, direction and enable. 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 5 limit inputs: X, Y, Z, A and B. All are opto-isolated and available via screw terminals.

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.

Probe Input
> Probe input is opto-isolated and available via screw terminals.

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. In addition, standard 0-10V output for spindle control is provided via a screw terminal.

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 the Spindle Enable output.
>
> 3 auxiliary relay outputs are supported via screw terminals and used via M62-M65 grblHAL pin control.
>
> All relay coil outputs are 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.
>
> 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.

Schmitt Triggered digital inputs:
> Four digital inputs are provided via a pin header. These have Shottky Diode protection and a low pass RC filter with an 15.9 KHz cutoff frequency. See the schematic for the specific circuit.

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 from the Teensy 4.1 pin 33 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.

Versions

There are two versions of this board. Currently, they share the same printed circuit board. However, in the future, that may change.

T41U5XBB – this is the USB interface version and is recognizable by the lack of the Ethernet connector. The controlling PC is connected to the T41U5XBB via the microUSB connector on the Teensy 4.1.

T41E5XBB – this is the Ethernet version. The controlling PC is connected the T41E5XBB via the Ethernet plug on the base PCB.

In both cases you need to load the appropriate version of grblHAL. A T41E5XBB may be used as a T41U5XBB by loading the USB version of grblHAL. See Loading Firmware section for details.

External Connections

Power

12V, Input
> Supply for relays and 0-10V output amplifier.

5V Input or Output
> Supply for 5V logic and Teensy 4.1 when not power via microUSB connector.
> Can supply upt to 150 mA to off board devices.

Stepper motor, Output
> 5V signals.

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

Limit Switches, Input
> One input for each axis. Opto-isolated, 5V.

Halt, Door, Cycle/Start and Feed/Hold, Input
> Opto-isolated, 5V.

Probe
> Opto-isolated, 5V.

Spindle Group, Output.
> PWM, Direction, Enable, Ground. This is a 5V group.
> 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 and powered relay modules.
Flood, Mist, Vac/Dust Collector, Aux0, Aux1, Aux2.
Note: Enable in the Spindle Group is capable of driver SSRs and powered relay modules.

Vac/DC trigger.
External Switch to activate a vacuum or dust collector.

Digital Input
4 input pins, 3.3V and Ground. Schmitt Triggered input, diode protected and low pass filtered. See schematic for more details.

Pin	Signal
St0	Schmitt Triggered, Low Pass Filtered (15.9KHz)
St1	Schmitt Triggered, Low Pass Filtered (15.9KHz)
St2	Schmitt Triggered, Low Pass Filtered (15.9KHz)
St3	Schmitt Triggered, Low Pass Filtered (15.9KHz)
3.3V	3.3VDC
Gnd	Ground

S0-S3 are 5V tolerant. Note that V2.05 is not 5V tolerant but V2.07 and later are.

I2C Header, Input/Output.

Pin	Signal
G	Ground
SC	I2C SCL
SD	I2C SDA
St	Strobe
+V	3.3VDC, source by Teensy 4.1
Hlt	Halt Signal. Connected to the Halt input Teensy 4.1 pin.

PCB Assembly

Not all components are required. See Optional Components section for more information.

Preparing the Teensy 4.1

Before installing components, you need to decide how you will connect the Teensy 4.1 to the breakout board. There are two approaches:
1. Directly solder the Teensy to the breakout board. This is the recommended approach. It makes for a much more secure connection. This is also easier than the socket approach.
2. Use sockets to mount the Teensy to the breakout board. This is more flexible but runs the risk of shaking loose in a moderate to high vibration environment.

Materials for directly soldering. See BOM section for ordering numbers.
- 2 24 pin 0.1” pin-header strips. These can be obtained from numerous sources.
- 1 2x3 2 mm pin-header for the Ethernet connection.

Materials for socketing. See BOM section for ordering numbers.
- 2 24 pin 0.1" pin-header strips. These can be obtained from numerous sources.
- 2 24 pin 0.1" sockets. <need specific info>
- 1 riser 2x3 2 mm pin header. <need specific info>
- 1 2x3 2 mm socket. <need specific info>

The T41E5XBB and T41U5XBB are provided with all standard surface mount components soldered in place. You are responsible for installing the through-hole components   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) and 5 Axis Headers (1x4). Use same technique as in 1).
3. Install 2X headers: TTL Relay Header (2x6) and Digital Input Header (2x3). Use same technique as in 1).
4. If you bought a Teensy 4.1 without headers, install pin headers. A solderless breadboard makes a great way to stabilize the pin headers while soldering the 0.1" header strips.
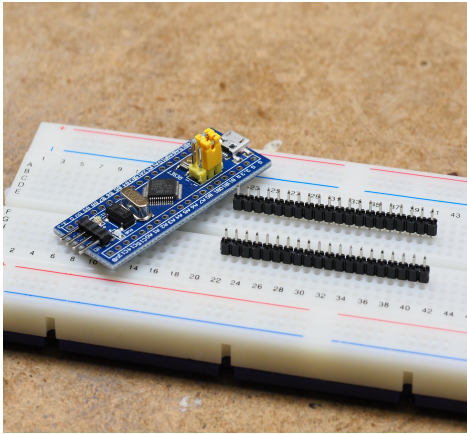
   If using Ethernet, solder the 2x3 2 mm header in place. Use tape to hold it in place, solder 1 pin and check for alignment. If misaligned, reheat the soldered pin and press the header into correct alignment. Then, solder the other pins.
5. Install R25. You can bend the leads to ensure it stays in place. But, also follow the the above approach of soldering 1 pin first, verifying alignment and then finishing. Note that a dual pinout footprint is used to allow several different types of trimmer potentiometer to be used. See BOM for more detail.
6. Install the Teensy 4.1. If using the sockets approach, place the sockets on the pin headers you just soldered onto the Teensy 4.1. Note, in the picture below, the 2x3 pin header on the Teensy 4.1 is for testing purposes and not needed for the USB version. The Ethernet version uses a different header that is attached to the underside.
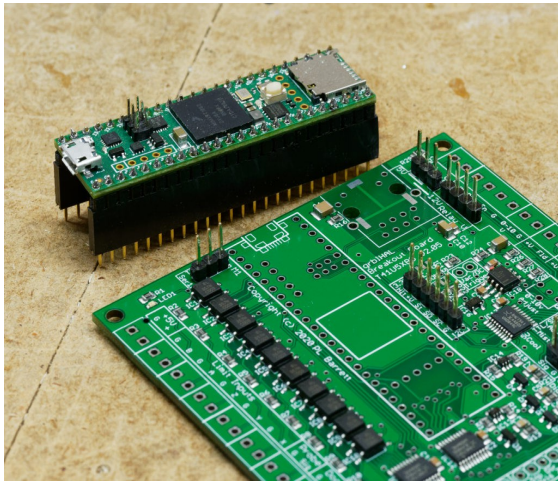
Now, gently inset the socketed Teensy 4.1 assembly into the indicated holes on the breakout board. Verify that all socket pins are correctly in place. Secure the entire assembly with tape on the component side of the board and then solder one pin on each of the different sockets and verify alignment. Once you are sure that the alignment is correct, solder the other pins, leaving the pins you initially soldered to last.

7. If using the direct solder approach, gently insert the Teensy 4.1 into the appropriate holes on the breakout board. Verify that all pins are correct and use tape on the component side to secure the Teensy 4.1 in place. The solder 1 pin on each header, verify alignment and correct if necessary. Once satisfied with the alignment, solder the other pins, leaving the pins you initially soldered to last.

8. 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

Optional Components.

Many components are optional. Refer to the following diagram.
Notes:

- Ser1 and I2C headers are optional. grblHAL will work correctly without either header installed. Specific options may need them.
- EEPROM is optional, Install if you need to use an external EEPROM. grblHAL will work correctly without it.
- 0-10V Spindle control is optional. Use if you are using a VFD controlled spindle. grblHAL will work correctly without it if you are manually controller your spindle. We recommend installing the screw terminals as they are difficult to add later.
- Relays are optional. The T41E5XBB and T41U5XBB is capable of driving relay coils directly. It is recommended that you install the screw terminals even if you don't initially plan on using them. Installing later can be difficult. See note on Vacuum/Dust Collector relay below. But, grblHAL will work correctly without any relays.
- A and/or B Axes are optional if you don't have them in your CNC machine.
- Safety Door alarm. Install if you have an enclosure for your CNC machine with a Safety Door sensor. grblHAL will work correctly without it but you will need to load the a version of grblHAL with it disabled. Alternatively, you can simply put a jumper in the Door terminal.
- Axis pin headers. There are 5 sets of pin headers, one for each Axis. Install these only if you intend on using a them to connect to your stepper drivers. For reliability, screw terminals are recommended over pin headers. If using pin headers, we recommend using hot glue to secure the connector in place.
- Ethernet MagJack. If you are not using Ethernet, there is no need to install this. Currently, both T41E5XBB and T41U5XBB boards have the footprint for the MagJack. Future versions of the T41U5XBB may not have this footprint.

- In general, we recommend that you install all screw terminals at the beginning. Adding them later can be difficult due to their interlocking nature.

Relay Voltage

Relay Coil Voltage source is selectable between 5V and 12V (or higher) provided via an external power supply. Use a "suitcase jumper" as indicated on the PCB to select the desired voltage.
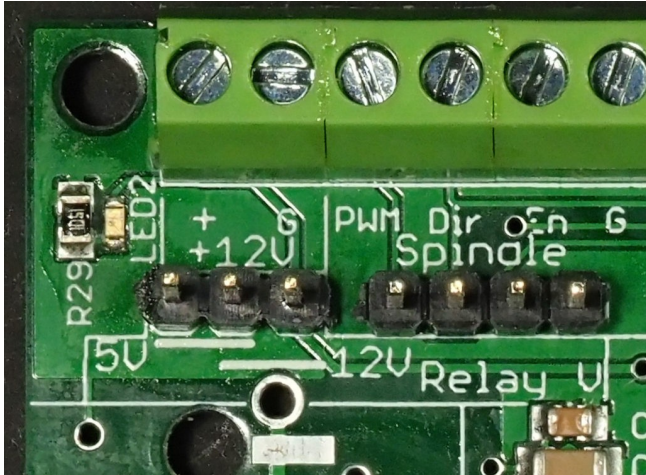
Note, we recommend you use an external 5V supply if you are driving 5V relay coils directly. To do so, you must disconnect the Teensy 4.1 +5V feed on the PCB. You will still need to power the Teensy 4.1 via the micro-USB connector. See Power Section for more information.

Relay coil voltage up to 24V is permissible and is applied at the input terminal labeled 12V. If using higher than 12V, we recommend changing resistor R29 to limit LED current to below 5 mA. For 24V, use 4.7K Ohm. The user is responsible for ensuring that all relays are rated for the voltage they provide.

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.

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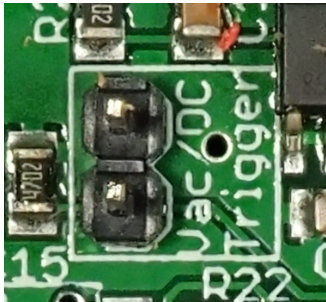
An additional driver is provided for a dust collector relay. It is activated whenever the spindle is turned on (M3). In addition, this relay output can be independently activated by a switch that connects to the pin header labeled Vac/DC Trigger. This makes it easy to do clean up with the same Vacuum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

Loading Firmware.

Prebuilt binaries are available on github. Check here for the lastest information - https://github.com/phil-barrett/grblHAL-teensy-4.x/blob/master/prebuilt.md. The names should be self descriptive but see below for more detail. The readme.txt file describes the process for loading the firmware on to the Teensy 4.1. Each folder includes the .hex file for loading as well as source files if you wish to make changes.

Folder Name	Features
3 axis usb no opts.	3 axis, USB interface, default grblHAL options
3 axis usb quad enc	3 axis, USB interface, Quadature encoder support: digital input pin assignements: QA – S1, QB – S2, Switch – S3.
5 axis usb no opts.	5 axis, USB interface, default grblHAL options
5 axis usb quad enc	5 axis, USB interface, Quadature encoder support: digital input pin assignements: QA – S1, QB – S2, Switch – S3.

More configurations may be added. Check the github site for changes.

You can also download the source code at https://github.com/terjeio/grblHAL, build and install it. A short guide is available here: https://github.com/phil-barrett/grbl-teensy-4/blob/master/grblHAL%20Build%20Guide.pdf.

Running grblHAL on your machine

Once you have finished assembly, your grblHAL Teensy 4.1 based Motion Controller is ready to be tried out. Attach it to a PC via a USB cable and run a compatible GRBL sender application on the PC. We recommend this one: https://github.com/terjeio/Grbl-GCode-Sender   Check for the most recent release. Next, you will need to set up GRBL to reflect your hardware. We will use the above G-Code Sender for our examples.. Actual grbl setting values are also shown. Follow these steps:

1. Hook up your control buttons: Feed Hold, Cycle Start and Rest/EStop.
2. Open the **Settings: Grbl** panel. You will see a list of parameters that control grblHAL.
3. Set the "Invert Step Enable" mask. Check all boxes. $4=7 for a 3 Axis machine. $4=15 for a 4 Axis machine and $4=31 for a 5 Axis machine
4. Set "Invert Control Pin" mask. Invert Feed Hold, Cycle Start, Reset and Safety Door. $14 = 15.
5. Save these parameter and return to the main tab (**Grbl** panel, you should see the DRO section).
6. Press the Red Reset button if and ALARM state is showing.
7. Open the **Jog** panel and click on any of the job buttons. The DRO should show movement. If you have motors hooked up, they should show movement.
8. If you have any control buttons attached, test them. It should show activity. Note the associated "LED" in the G Code Sender application when you press a button. If nothing happens, you should verify your connections.
9. Close the **Jog** panel, fill in 1000 in the Spindle RPM box and click on the CW "radio" button. The LED on the Teensy should light up. Click on off and the LED should go off.
10. If everything works to your satisfaction, you should now proceed to full testing of your machine.

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, 15 or 31	A 1 bit means invert. A 3 axis machine would have 7 as the value, a 4 axis machine would have 15, a 5 Axis - 31. Bit 0 is X, 1 is Y, 2 is Z, A is 3 and B is 4.
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 have xxx match this parameter (S1000, in the case of the default).
100, 101, 102, 103, 104	Steps/mm. One for each Axis. 100 – X, 101 – Y, and so on.	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 full rotation of the lead screw. Determine how many mm that axis will move with one full rotation of the lead screw. Divide the first number by the second to get the value you will use.

Note, if you don't attach any switches, the system may come up in the alarm state before you change any settings. This is normal. If you are not using the Safety Door Alarm, in the **Settings: Grbl** tab, **Invert control pins** section, check the **Safety Door** box. This makes the system see the (nonexistant) Safety Door as closed. Similarly, you can invert the Halt. However, we highly recommended that you do not disable the Halt function and that you install a dedicated Halt button in a prominent location on your CNC machine.

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. There are pre-built versions available, see the Loading Firmware section above.

Setting up the T41E5XBB, the Ethernet Version.

If you wish to use Ethernet to connect to your breakout board, you will need to solder the network interface connector in place. See the BoM section for the part number. Once you have soldered it on the PCB, you will need to load a build of grblHAL that has been configured to use networking. You will use the USB connection to do that.

You will next need to load an Ethernet build of the firmware. See the section on loading firmware for prebuilt binaries. Optionally, you can build a version from the source code at the grblHAL Github site (https://github.com/terjeio/grblHAL) and follow the instructions there.

Currently the only sender that works with networking is Grbl GCode Sender located at https://github.com/terjeio/Grbl-GCode-Sender. If you haven't gotten it yet, do so now. Download the zip file and and unpack to a directory where you will be using it.

Once you have loaded the networking version of grblHAL onto the Teensy 4.1, connect an ethernet cable as well as the USB cable. The ethernet cable should be connected to a switch or router that your PC is also connected to. Once the cable is plugged in, the LED on the MagJack should be blinking – this indicates that networking is active and connected to you local network. Start the Grbl GCode Sender (GCS, from here on) with the USB com port number you used to program the Teensy. You can find the port number in the Arduino IDE under Tools/Port, via the Teensy Loader in Help/Verbose Info or via the Windows Device Manager under Ports. If this is the first time you have run GCS, it will ask the for the port number. If you have already been using GCS, start it as you normally do.
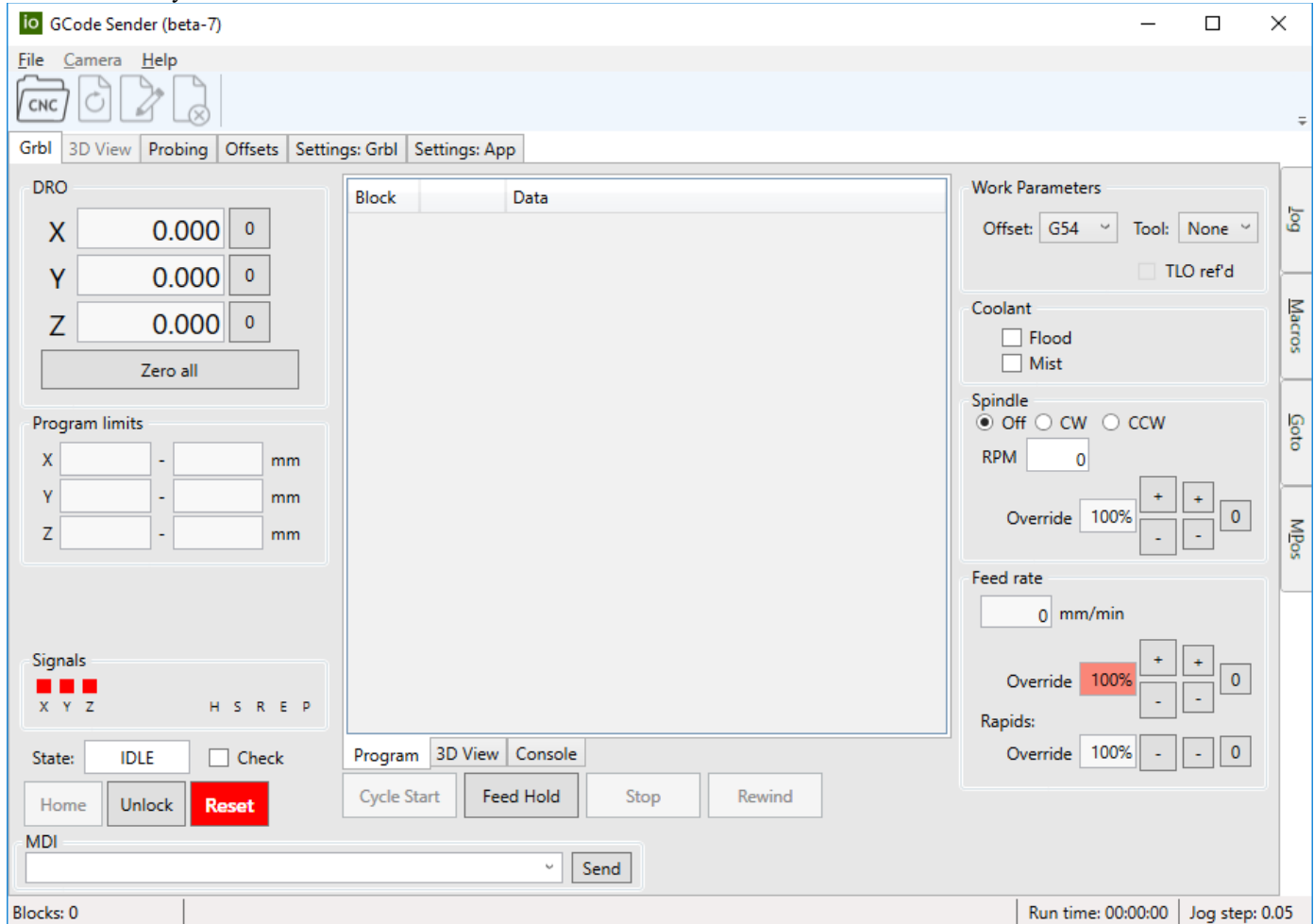
You can also start GCS via a command window. Hold the Windows key down and press R. A "run" box will open. Type cmd and enter. A command window will open up. Type

      "Gcode Sender.exe" -port <com port>:115200,N,8,1

See the example below. Your USB com port number will probably be different.
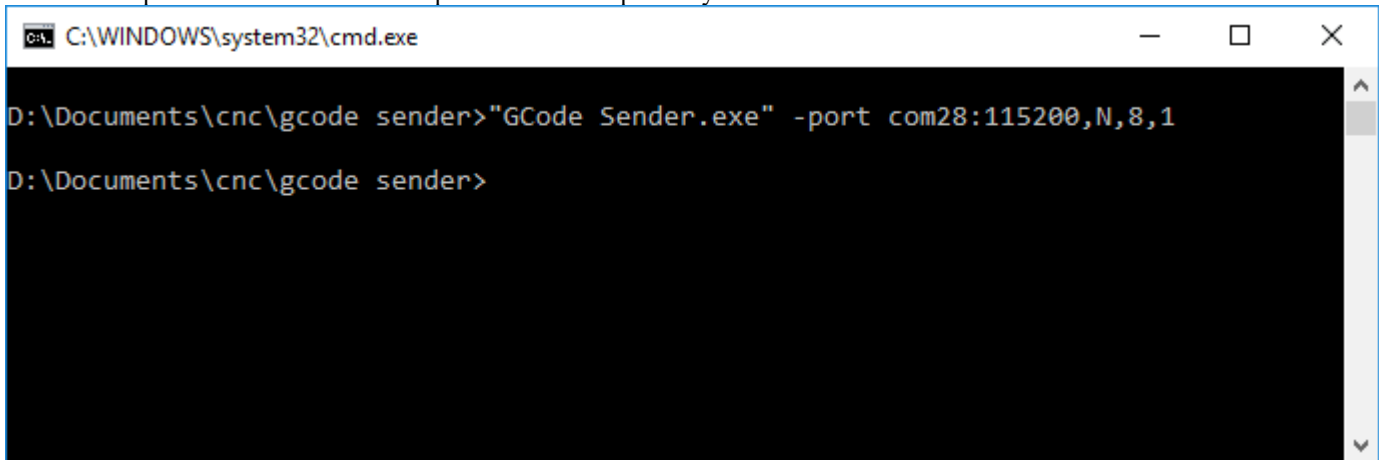
Once GCS runs you will see this:

Note that if the DRO entries for X, Y and Z are blank, you are not connected to the grblHAL board. Check to make see if you got the com port incorrect or had typos. You may need to power cycle the grblHAL board. Close the GCS and retry.

Click on the Console tab near the center bottom. You should see this:
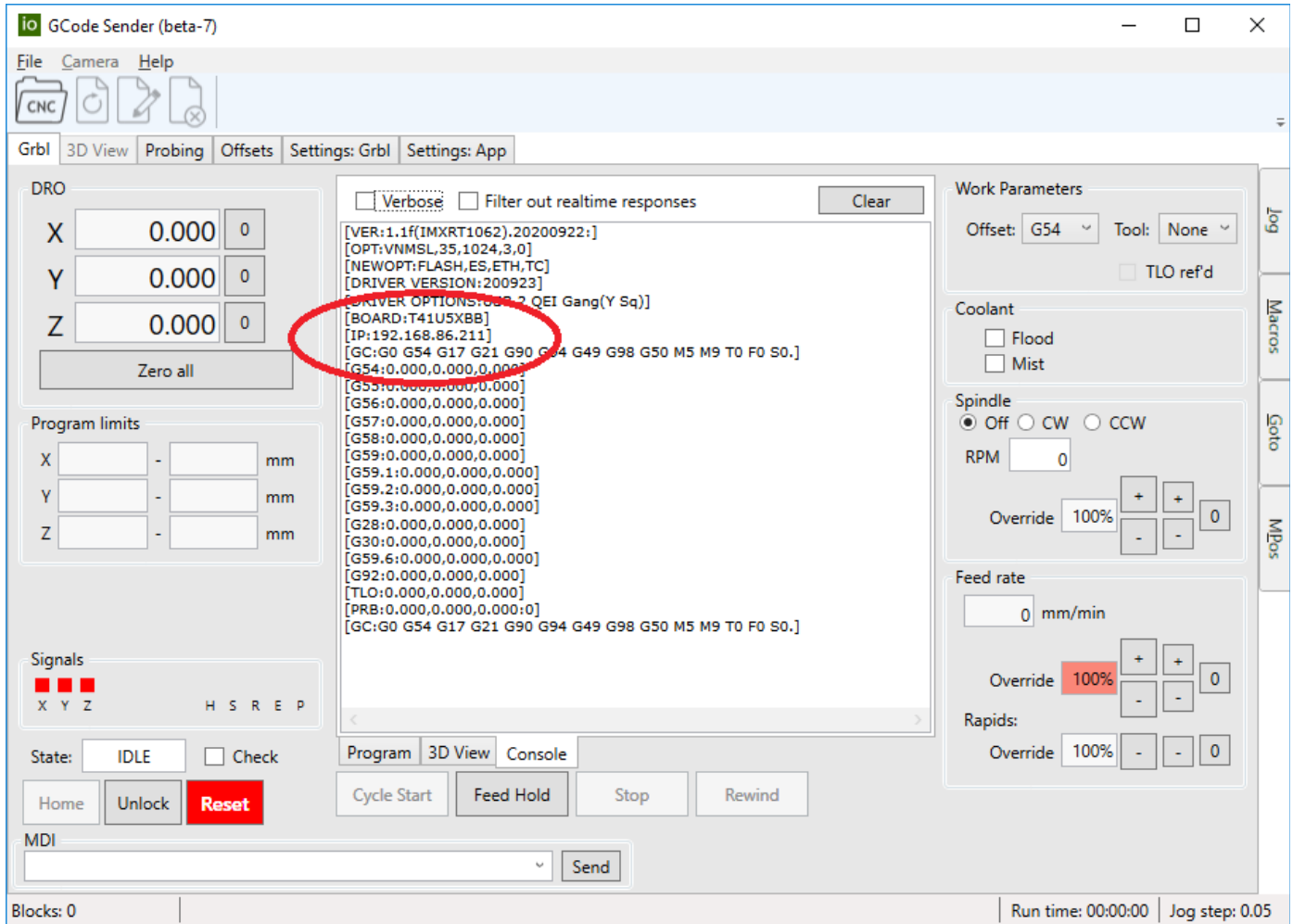
Note the [IP:xxx.xxx.xxx.xxx] line. Write the IP address down, you will need it next. Close the GCS.

We will now restart GCS with the IP address as the port. In the command window, enter
    "Gcode Sender.exe" -port xxx.xxx.xxx.xxx:23.
See the example below:
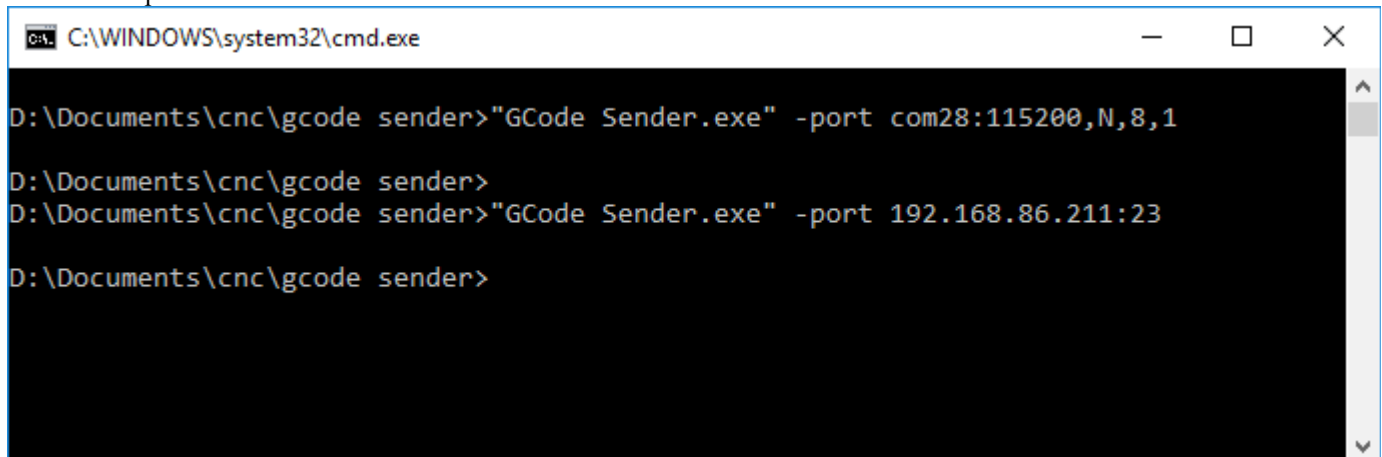
The GCS will start up again. Click on the Console tab and you should now see [NETCON: Telnet] indicating that GCS is now connected to the grblHAL board via Telnet.

Now, we will set up GCS to always use Telnet. Click on the Setting:App tab near the top of the window. You should see this:
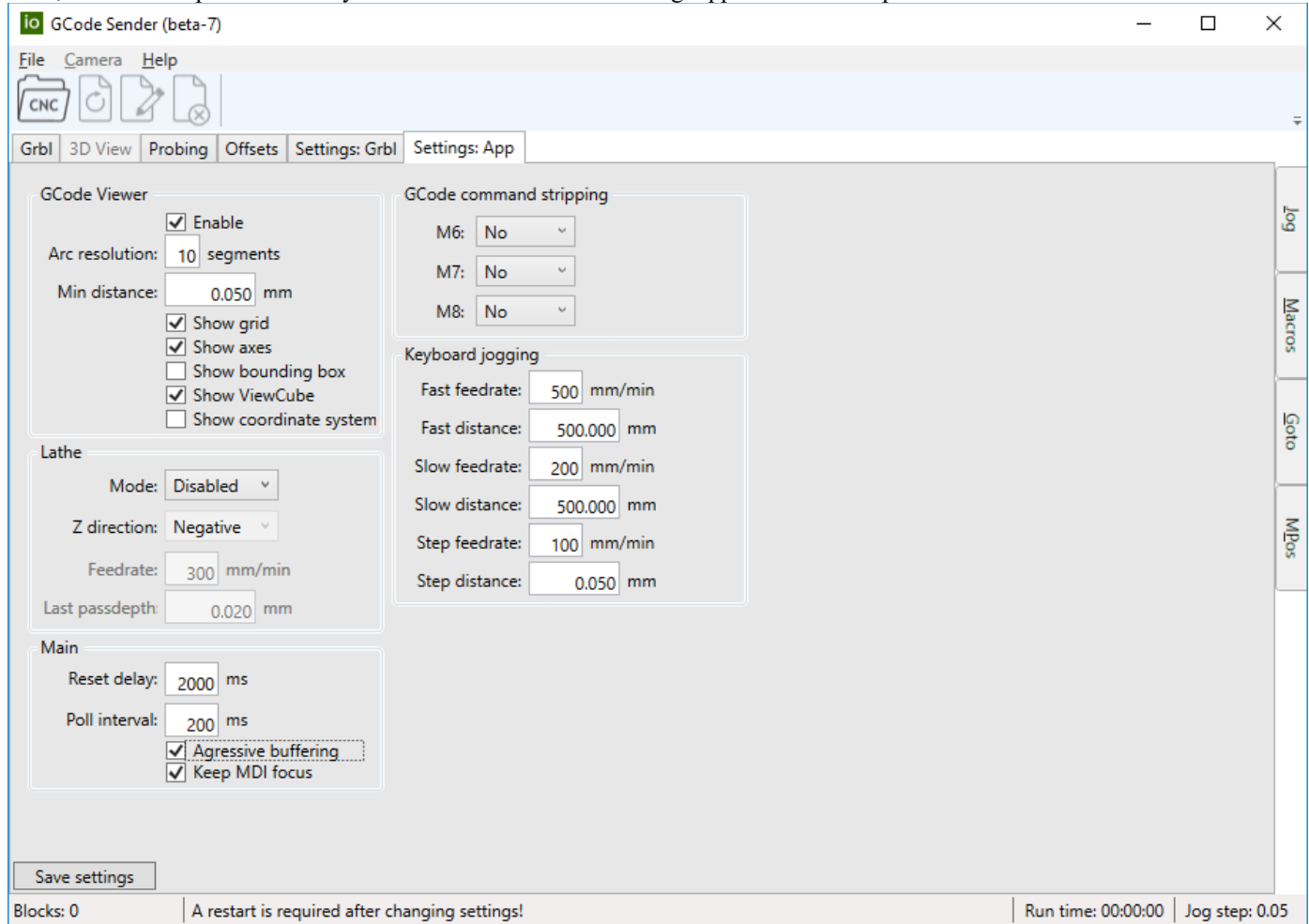
Click on the Save settings button in the lower left of the window. There will be no visible change but the network start up settings are saved to the GCS configuration file – app.config. You can directly edit app.config with a text editor if you wish.

We aren't quite done yet. The IP address that you are using was dynamically assigned by your local router. That means it could someday change and you would have to repeat the above process of connecting via USB, finding the new address and making that permanent. You will want to go into your router management web page or application and reserve that IP address for you machine. Consult your user manual. Most networking software uses the word "Reservation" in some way. Linksys and Dlink call it a DHCP Reservation, Google Mesh calls it DHCP IP Reservation. In general the process is quite simple.

Direct PC Connection via Ethernet

Many CNC users like to use a direct Ethernet connection between the PC and CNC machine. The advantage of this is the CNC machine is not visible from your network and is thus safe from intrusion and interference. Because grblHAL is not a secure system, this is the only way to network secure your CNC machine, The process is more technical and requires a fair amount of network manipulation. We won't give you a complete procedure but here are the general steps:
1. You will need 2 network interface connectors on you PC. Many PCs have them and you can get add-in network adaptors if yours does not.
2. Secure a cross-over Ethernet cable. It may be unnecessary but it won't hurt.
3. In Windows, you will need to configure your second network adaptor and give it an IP address, gateway and mask.

4. You will need to configure your grblHAL board to have a similar IP address, gateway and mask. When you run G Code Sender via USB, go into the Settings: Grbl tab and scroll down to find the settings starting at $300. Select static in $301 and enter the IP address, Mask and Gateway in the subsequent settings. The IP address should be one digit different in the last set of digits from you PC's second network IP address. If your PC's second IP address is 192.168.101.1, then your grblHAL IP address will need to be 192.168.101.2. Save your settings and exit GCS.
5. Network changes to your grblHAL board require a power cycle – unplug, count to 10 and replug the USB cable if powered via USB.
6. Follow the above procedure to start GCS with the the new IP Address.
7. Check the Console tab for the [NETCON:Telnet] line that indicates success.
8. In the Settings: App tab, press Save settings to make the new IP address permanent.

If you are unfamiliar with networking and still want to do this, we suggest you find some one knowledgeable to help you.

Note that modern network switches prevent most interference and are quite inexpensive.

0-10V 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 R25 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%. The LED on the Teensy 4.1 should light up.
- Measure the 0-10V output and G terminals.
- With a screwdriver, adjust the potentiometer 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.
- Reconnect your spindle or VFD and test.
- You may want to change the max spindle speed setting, $30, to something more appropriate for your machine.

You may want to repeat the above process with the spindle connected and running to fine tune the maximum speed.

PCB Level Configuration

A number of features can be configured via solder jumpers on the bottom of the PCB.

Notes:
1. To help seeing any trace you need to cut, carefully scrape the green solder mask off the area between the pads. The trace should show up as bright copper. This will also make a solder bridge easier to create.
2. When you cut a trace, be sure to clean out and inspect the cut to ensure no stray slivers of copper are causing a short.

Individual Stepper Enables

By default, all 5 Axis Stepper enable signals are tied together. This is a common CNC machine configuration. If your machine needs separate enables for all or specific axes, you can configure this in the Axis Enable Configuration block on the bottom of the PCB.
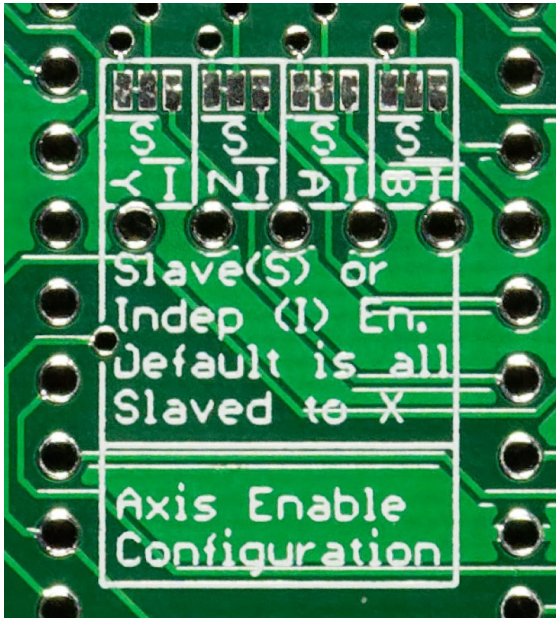

To make a given axis have an independent enable signal:
1. Locate the 2 way solder jumper associated with the axis you want to make independent. Note which side has the connection. It is marked with a horizontal line and an S.
2. Using a sharp knife, cut the trace between those two pads.
3. With a soldering iron, tin the center pad and the one one indicated with an I.
4. Then slowly add additional solder to the space between the I and center pads until there is a bead of solder that bridges between them.

If you wish to undo the configuration at a later date, use a soldering iron and wick to remove the solder bridge and then create a new one between the center and S pads.

External 5V Feed

The Teensy 4.1, when connected via USB, normally has enough power to support the 5V needs of the breakout board. You may wish to use external 5V in certain cases. We recommend you do this if using 5V relays. In that case, you will need to disconnect the base PCB from the Teensy 4.1's 5 volt supply. Note that there are 2 traces connecting the two pads. Disconnect 5V by cutting both traces between the pads in the external 5V block on the bottom of the PCB.
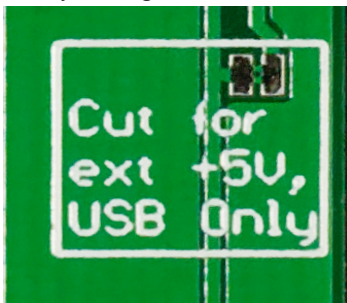
Using a sharp knife carefully cut the two traces. Use the tip of the knife to ensure there is no connection. Test it for continuity with a multi-meter. When powered up via USB only (i.e. no additional 5V source used), the LED next to the +5V screw terminal should not light up. If it does, you need to repeat the above process. You will need to separately supply power to the Teensy 4.1, via USB from a computer or charger.

This process may be reversed by bridging the two pads with solder as described the above section.

Vacuum/Dust Collector relay
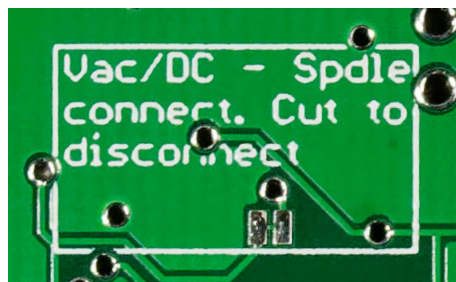
By default, the Vacuum/DC Relay is activated when the Spindle is enabled. You may disable this by cutting the trace between the two pads in the Vac/DC – Spindle Connect block on the bottom of the PCB.

This may be reversed by bridging the two pads with solder as described the above section.

Link A Axis to Y

This is for a dual motor Y axis configuration. The default configuration is A is not linked to Y. When jumpered to Y, both Y and A axis motors will run in tandem, both getting the same signals. Using a sharp knife, carefully cut fully between the pads marked A (right two pads) and use solder to short the pads marked Y (left two pads). You should verify that there is no continuity between the two A axis pads as that can cause board damage.

Note that the traces to be cut may not be exactly centered in the pads.

This process may be reversed by bridging the two pads with solder as described the above section.

Relay Coil Voltage

Similar to the pin header selection of the relay coil voltage, you may configure the relay voltage via solder jumpers.
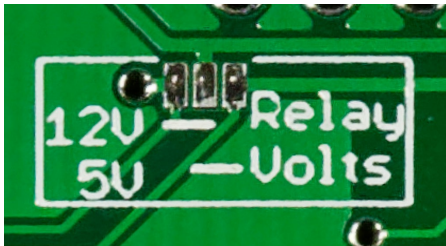
The default configuration has neither connected. Use the above solder jumper process to bridge the appropriate side of the two way jumper. You will need to short either the left pair of pins together for 12V or the right pair together for 5V.

WARNING. If you do this, it is highly recommended that you remove (or not install) the pin headers from the relay voltage selection section to prevent accidentally routing 12V into the 5V sections of the board. Failure to follow this precaution will cause you to destroy your breakout board and the Teensy 4.1 by inadvertently shorting 5V to 12V.

Power and EMI Considerations

Clean, EMI-free power is important for smooth operation of the grblHAL motion controller system. In designing the T41E5XBB and T41U5XBB, 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 interference later can be difficult – it is good practice to design your system with avoiding it in mind. General recommendations:

- Do not power 5V relay coils from the USB voltage supplied by the Teensy 4.1. 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 T41U5XBB or T41E5XBB PCB.
- Avoid routing wires near EMI sources such as a VFD, Stepper drivers, or power supplies. Avoid co-routing with wires that are connected to those devices as well.
- If you are connecting to the Teensy 4.1 via a USB cable, use one with a ferrite filter on it or add a clamp-on one close to the Teensy end of the cable.

If you are using Ethernet, and expect to not connect the Teensy 4.1 to a PC via USB, you will need to provide 5V for the Teensy. There are two ways to do this:
- Use a standard USB "charger" to power the Teensy 4.1 via the microUSB connector. We suggest a 1 Amp minimum capacity. This will work well if you aren't using 5V for relay coils.
- Provide 5V via the +5V screw terminal.

We recommend that all stranded wires have ferrules crimped on the end that goes into a screw terminal. This is a good practice in that it ensures the best possible contact and helps to avoid stray "cat whisker" strands of wire that could cause errors.

Using USB voltage for PWM control of VFDs

In some cases, the voltage supplied by USB may be lower than 5V. While the specification defines 4.75V as the minimum, some laptops computers USB ports output even lower voltage. This can cause lower than requested speeds when using the direct PWM signal to control a VFD/Spindle. This does not effect the 0-10V output. This problem can be solved 2 ways:
1. By using external +5V to power the board. Remember to follow the instructions in the above "External 5V Feed" section.
2. By using the 0-10V output signal connected to the 0-10V input of the VFD. This requires you provide 12V to the board.
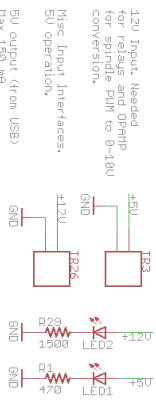
Errata:
1. V2.05 digital inputs ST0-ST3 are not 5V tolerant. They will work correctly at 3.3V. This is corrected in V2.07.
2. V2.05 silk screen labels the Flood connection as Cool. This is corrected in V2.07.
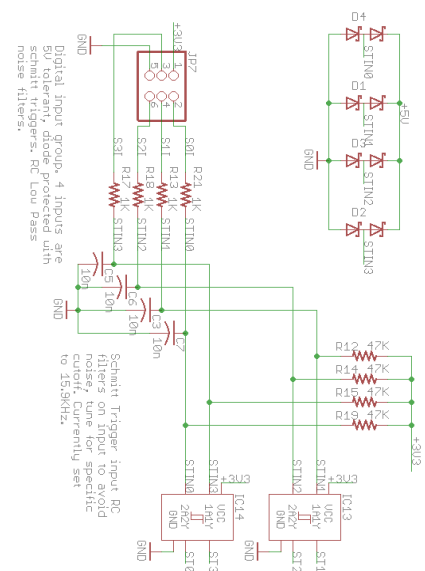
Schematics:

Board can be powered from external
5V or via USB power. To connect
via USB and use external +5V, cut
JP105. If connected via ethernet,
use external +5V, either from the
microUSB connector or the +5V
screw terminal.

5V output (from USB)
Max 150 mA.

Misc Input Interfaces,
5V operation.

12V Input. Needed
for relays and OPAMP
for spindle PWM to 0-10V
conversion.
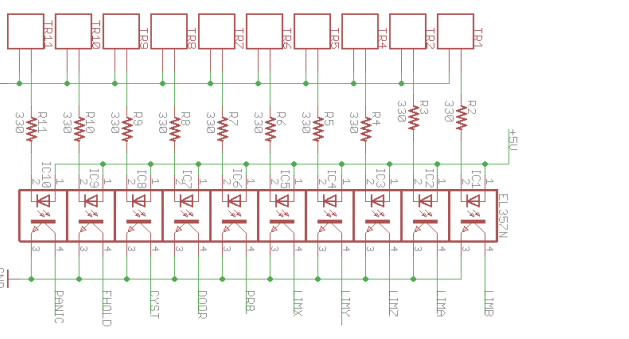
Limit and Probe Interfaces.
5V operation on LED side,
3.3V operation on photo
transistor side. LED It set to
slightly higher than 10 mA.

Digital input group, 4 inputs are
5V tolerant, diode protected with
schmitt triggers, RC Low Pass
noise filters.

Schmitt Trigger input RC
filters on input to avoid
noise, tune for specific
cutoff. Currently set
to 16.9KHz.
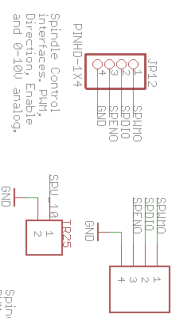
Spindle Control
interfaces, PWM,
Direction, Enable,
and 0-10V analog.

Spindle Control. Supports direct
PWM and/or HAL (via Spindle enable)
as well as 0-10V control, 10V output
is adjustable via trim Pot. Consider
replacing LM358 with smaller
opamp, single channel CJLC LT358
is Basic part and lowest cost Op
Amp.

Dual footprint
for alternative
trimpot
R25 2K

5V PWM to 0-10V.
2nd order filter,
Requires minimum 11.5V.

Ethernet Interface. Uses
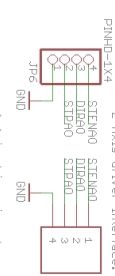MagJack. 1nF cap should
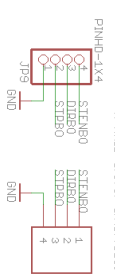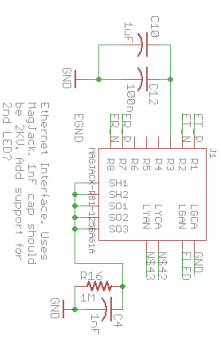be 2KV. Add support for
2nd LED?

B Axis driver interface.

A Axis driver interface.
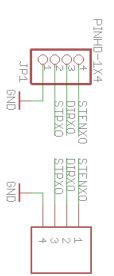
Z Axis driver interface.

Y Axis driver interface.

X Axis driver interface.

GRBL/HAL Teensy 4.1 Motion Controller
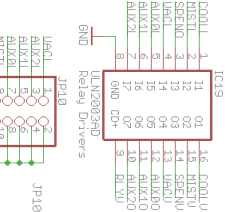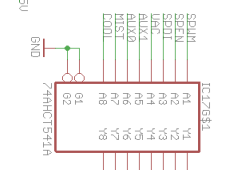T4.1U5XBB

Teensy 4.1 Section

3.3V internally connect on T4.1

Link Axis A to Y for dual Y motors.

External Opto Drivers
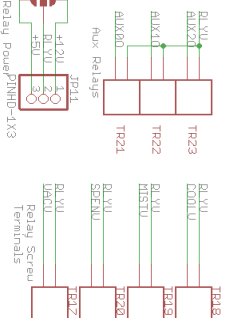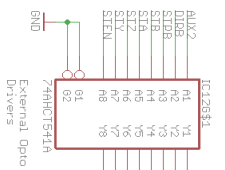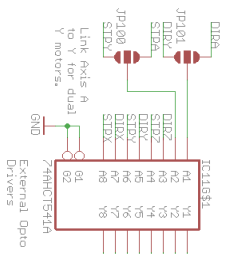
Digital output section. 3.3V inputs, 5V outputs. Use of AHCT logic allows this. Drive capability of 8mA.

74 logic bypass caps, necessary?

External Opto Drivers

USB HOST

Ethernet

Serial 1 from Teensy for external USB interface.

I2C Header

I2C interface tied to 3rd channel on Teensy 4.x. Strobe provided for signaling to minimize I2C traffic. Halt/Panic provided to grblHAL core, signaling to grblHAL core, to allow direct Halt/Panic provided to grblHAL core.

ULN2003HD Relay Drivers

Independent Control for Dust Extractor. A switch attached to the pin header can turn on the DE separately from the spindle. Can also detach the DE from spindle control. Default is attached.

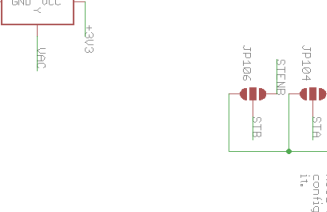Stepper Driver enable configuration. By default, all are set to the X Axis Enable. Can configure each to be connected to their individual enable signals. Note; need specific grblHAL configuration to support it.

EEPROM; Not necessary and unpopulated by default.

Relay section. Driver has 5V input which is also routed to pin headers. Relay coil voltage is configurable via jumpers 5V or 12V.

Relay Power Jumper

Aux Relays

Relay Screw Terminals

R23 100K
R22 2.2K
R20 2.2K
IC15 24LCxxx

JP100 STPX
JP101 DIRX
JP10 Relay Drivers
JP11
JP2
JP8
JP106 STB
JP104 STA
JP103 ST2
JP102 STY
JP107 SPEN
JP108

74AHCT541A
IC11 / IC12 / IC17

Board and mounting hole dimensions

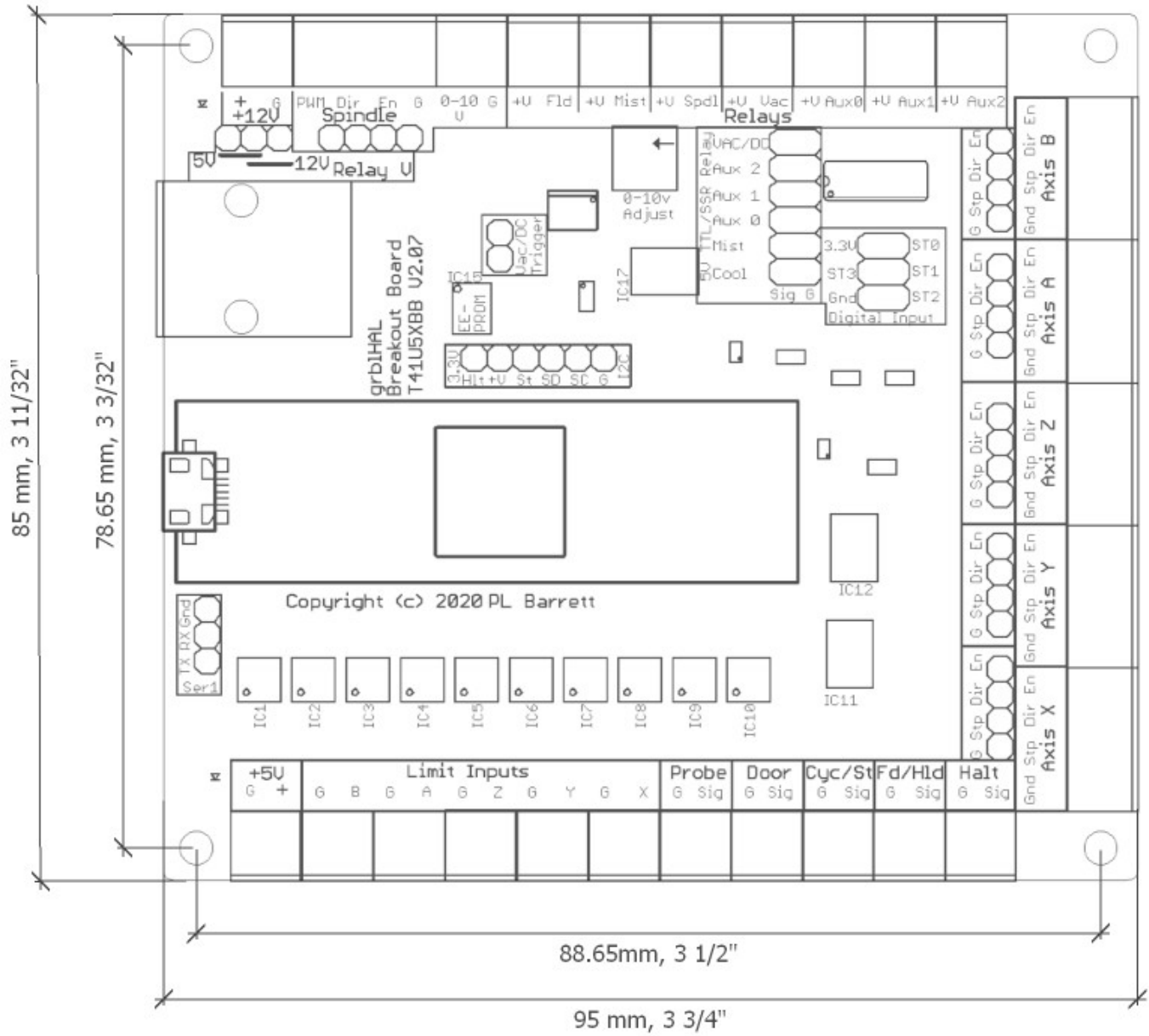# Bill of Materials for through hole components (for the "Unkit" version).

Item	Number	Source
2 pin 3.5 mm Screw terminal.	32	Readily available on ebay/amazon/aliexpress/...
1x2 2.54 mm pin header	1	Readily available on ebay/amazon/aliexpress/... Snap off of longer strips. [2]
1x3 2.54 mm pin header	2	Readily available on ebay/amazon/aliexpress/... Snap off of longer strips. [2]
1x4 2.54 mm pin header	6	Readily available on ebay/amazon/aliexpress/... Snap off of longer strips. [2]
1x6 2.54 mm pin header	1	Readily available on ebay/amazon/aliexpress/... Snap off of longer strips. [2]
2x3 2.54 mm pin header	1	Readily available on ebay/amazon/aliexpress/... Snap off of longer strips. [2]
2x6 2.54 mm pin header	1	Readily available on ebay/amazon/aliexpress/... Snap off of longer strips. [2]
1x24 2.54 mm pin header	2	For Teensy 4.1. If you purchase a Teensy with pins, omit these items. Readily available on ebay/amazon/aliexpress/... Snap off of longer strips. [2]
1x24 2.54 mm socket	2	Readily available on ebay/amazon/aliexpress/... [2][3] Higher Quality: Mouser – 437-80187014100001101, Digikey - 1212-1209-ND
Teensy 4.1	1	Available from pjrc.com.
R25, 10K Potentiometer	1	Numerous sources. Mouser: 652-3362P-1-103LF, Digikey: 3362P-103LF-ND [1]
T41E5XBB (Ethernet)		
MagJack	1	Whiznet RB1-125BAG1A Mouser: 950-RB1-125BAG1A Digikey:1278-1011-ND
2x3 2 mm Header	1	[4]
2.3 2 mm Socket	1	[4]

Notes:
1. The PCB has a dual footprint for the 10K trimmer potentiometer, R25. and will accept 2 different footprints: 3 pins in a row with 0.1"/2.54 mm pitch or a triangular layout with the middle pin offset by 2.54 mm. The first footprint is used by more expensive, higher quality multiturn trimmers and the second is very common and low cost. A multiturn trimmer will give a finer adjustment of the 0-10V output level. The BOM has the lower cost version. Also, you could use a 2K or 5K trimmer in place of the 10K one.
2. We recommend gold plated pin headers for reliability.
3. Single row sockets are also readily available from numerous sources though good quality ones are not that expensive. We recommend you use good quality, gold plated headers and sockets. Note: for using Ethernet with a socketed Teensy 4.1, care must be taken to select 2 mm and 2.54 mm headers and sockets that are similar in height. However, we recommend that you directly solder your Teensy 4.1 to the T41E5XBB PCB if using Ethernet.
4. Use if you decide to socket your Teensy 4.1. The 2 mm header and socket must be matched to the Teensy 4.1 socket and header height. If you solder your Teensy 4.1 in place, you will only need a 2x3 2 mm header but need to be sure it will be tall enough.

BOM for surface mount components.

Qty	Designator	Footprint	Comment
6	C1, C2, C8, C9, C11, C12	C0805	100NF 50V 0805 ROHS
2	C10, C13	C1206	1UF 50V 1206 ROHS
4	C3, C5, C6, C7	C0805	10NF 50V 0805 ROHS
1	C4	C1210	1NF ±10% 2KV X7R 1210
4	D1, D2, D3, D4	SOT-23-3	BAT54S
10	IC1, IC2, IC3, IC4, IC5, IC6, IC7, IC8, IC9, IC10	SOP-4_3.6x4.4x2.54P	EL357N(C)(TA)-G
3	IC11, IC12, IC17	TSSOP-20_4.4x6.5x0.65P	74AHCT541PW,118
2	IC13, IC14	SOT-363	74LVC2G17GW,125
1	IC16	SOT-753	SN74LVC1G32DBVR
1	IC18	SOIC-8_3.9x4.9x1.27P	LM358DR2G
1	IC19	SOIC-16_3.9x9.9x1.27P	ULN2003ADR
2	LED1, LED2	LED_0603	19-217/GHC-YR1S2/3T
1	R1	R0805	680OHMS ±1% 1/8W 0805 ROHS
4	R12, R14, R15, R19	R0805	47KOHMS ±1% 1/8W 0805 ROHS
1	R16	R0805	1MOHMS ±1% 1/8W 0805 ROHS
2	R20, R22, R29	R0805	2.2KOHMS ±1% 1/8W 0805 ROHS
1	R23	R0805	100KOHMS ±1% 1/8W 0805 ROHS
10	R2, R3, R4, R5, R6, R7, R8, R9, R10, R11	R0805	330OHMS ±1% 1/8W 0805 ROHS
4	R24, R26, R27, R28	R0805	10KOHMS ±1% 1/8W 0805 ROHS
1	R13, R17, R18, R21	R0805	1KOHMS ±1% 1/8W 0805 ROHS