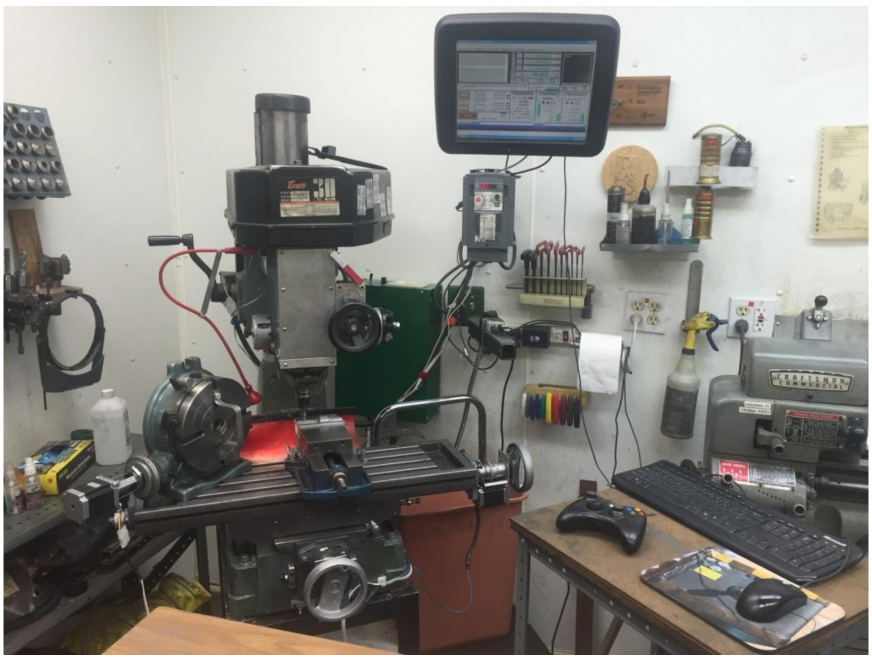
# Computer Numerical Control for my RF-30 Mill/Drill, version 2.2

## By R. G. Sparber





About 8 months ago, I bought a Computer Numerical Control (CNC) add on kit for my RF-30. It came with all of the parts necessary to interface between a PC with a parallel port and my mill's 3 axes. Recently I added a forth axis to rotate the part. After a few adjustments, it drove my machine just fine using Mach3 software.

Of course, this was just the starting point for me. I had circuits to add and wanted to repackage the existing parts into my own enclosure.

This article details what I did and why I did it. And yes, that is a roll of toilet paper to the right of my mill.

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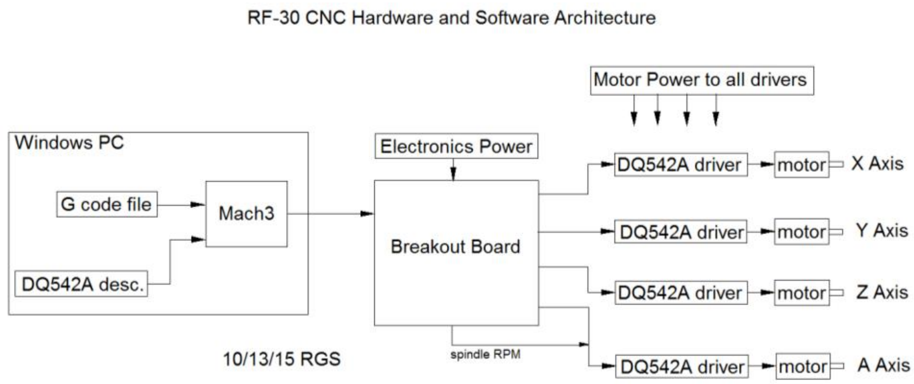
# System Overview



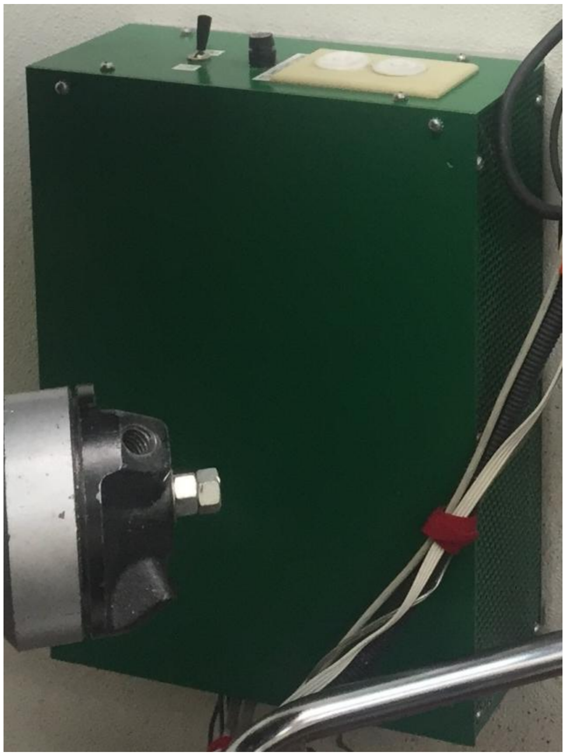

A Personal Computer running Windows XP® has a Computer Numerical Control program called Mach3 loaded on it. Mach3 receives set up information about the various motors plus a g-code file. The g-code file specifies how each axis is to move.

This PC is connected to a Break Out Board (BOB) which translates signals from Mach3 to signals that control the four motor drivers. The X, Y, and Z drive/motor paths are identical. The A driver/motor path receives signals from two places on the BOB.

Signals driving the X, Y, and Z axes move the cutter relative to the table specified distances. The A axis rotates the workpiece. When driven by the normal distance signal, it rotates a specified number of degrees either clockwise or counterclockwise. However, it can also be driven by the spindle RPM signal. This causes the A axis to rotate continuously. This simplifies the g-code.

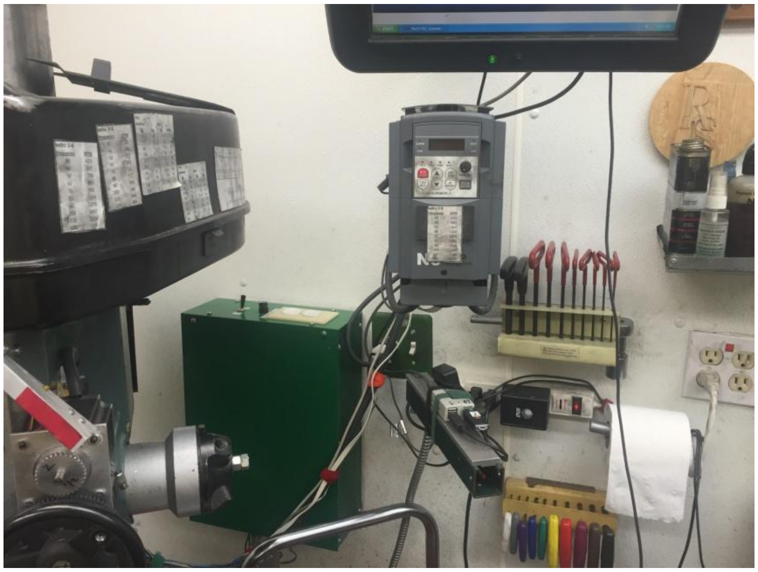
Not shown in this system block diagram are the few signals that go from the BOB back to the PC, the fault detection circuit, and spindle control.

## The Enclosure



The enclosure is hung on the wall and is wired to the axis motors and PC.

Originally I thought it would be useful to have a power outlet that was controlled by the box's power switch. Not only has this turned out not to be true, the exposed outlet has become a liability. I now keep plug covers in place to prevent swarf from entering.



The box hangs on the wall on two aluminum channels.

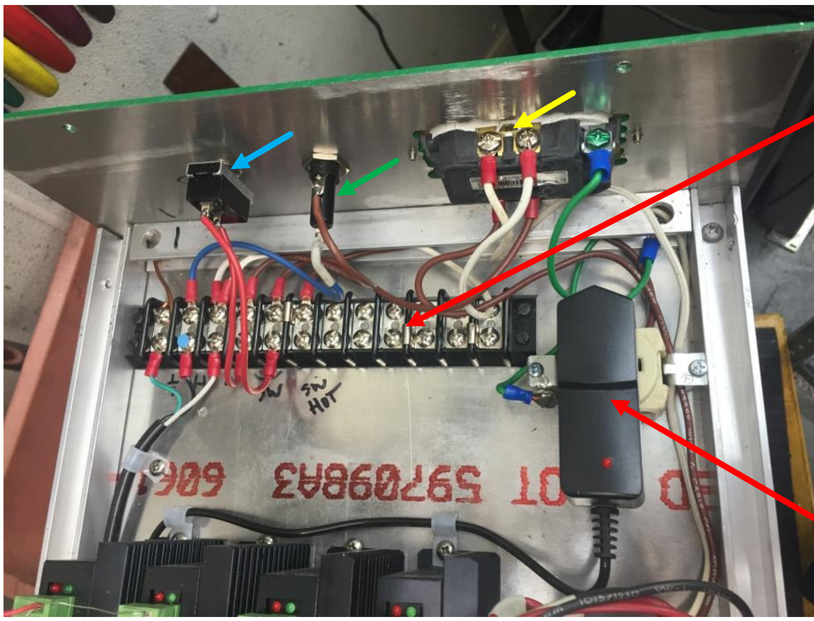
Access requires me to lift the box off of these channels, place it on the mill table, and remove 9 screws.

The cover then lifts off leaving all components supported by the back and top plates.

# A Tour of the Box

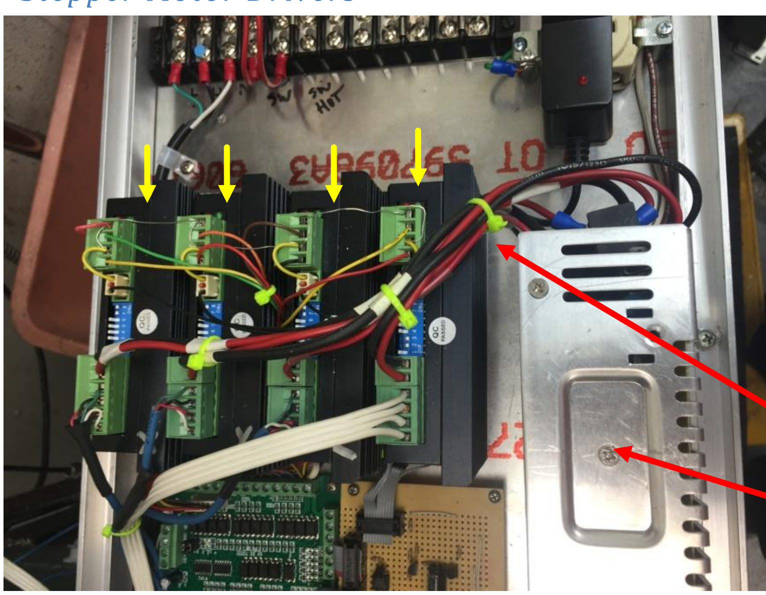
All components are bolted to a 0.1" thick aluminum plate. Not shown here is a second plate that bolts on the front. The left and right sides are perforated 20 gage sheet steel. I wanted plenty of air flow. The enclosure hangs on the wall behind the mill in an area that does not get pelted with swarf.

### *AC Power*



AC power is distributed via a large barrier strip at the top. It feeds a 10 amp fast blow fuse (green arrow), a power switch (blue arrow), and all AC loads. A duplex outlet (yellow arrow) is on the top. It feeds my touch screen PC. Below this outlet is a second outlet that feeds my 5V power supply.

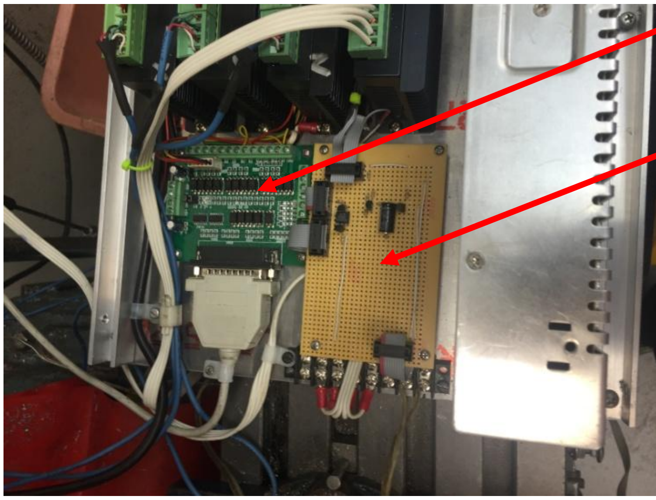
### *Stepper Motor Drivers*



My four DQ542MA Wantai stepper motor drives (yellow arrows) are side by side. Note that heat generated by these drivers rises and then exits the enclosure via the perforated side panels. Nothing except the barrier strip sits above them.

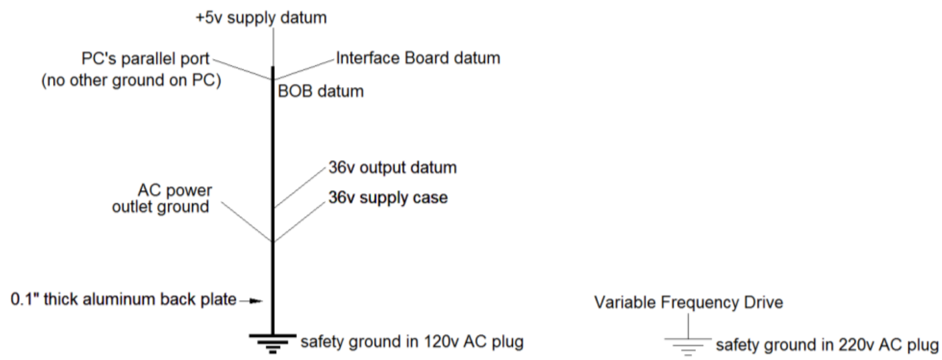
Each driver has its own wires to the output terminals of the 36v supply. This minimizes the voltage drop between the supply and any driver.

### *Break Out Board and Interface Board*



The Break Out Board (BOB), a DB25-1205,  sits below the drivers. It feeds both the drivers and an interface board. This interface board is fully connectorized and can be removed by unscrewing 4 screws and pulling 4 plugs. Most of this board is empty so there is plenty of room for growth.

# The Datum Tree

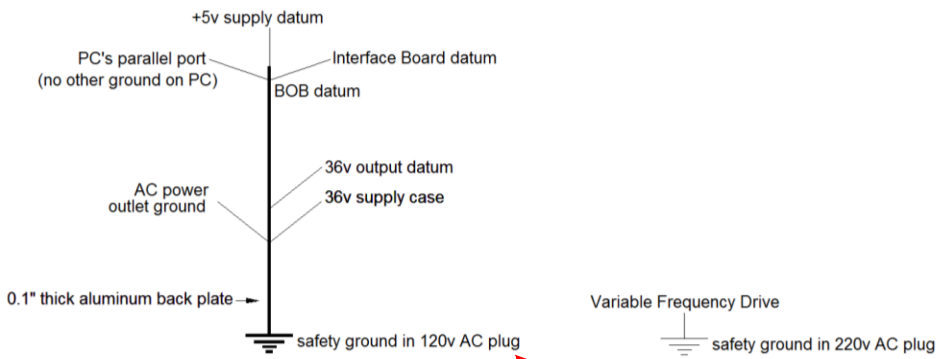


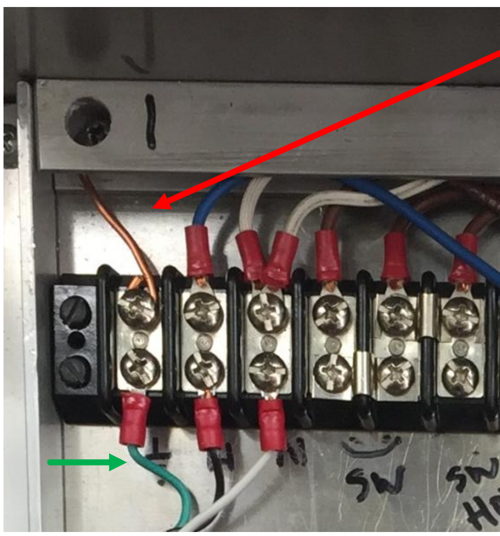

With all of these off the shelf parts, it was a challenge to ground them correctly. The goal was to prevent noise and fault currents from flowing into sensitive circuits and undersized conductors. Noise might just cause random errors during normal operation. Fault currents could cause damage to narrow trace on a circuit board or thin wires tied to ground.

Let me start by explaining the difference between ground and a datum. Any arbitrary point in a circuit can be defined as "ground". There can be only one ground in a circuit. All other points that connect to this ground are called datums. In my application here, ground is the 0.1 inch thick back plate. My ground wire from the 120V line cord bonds to it.

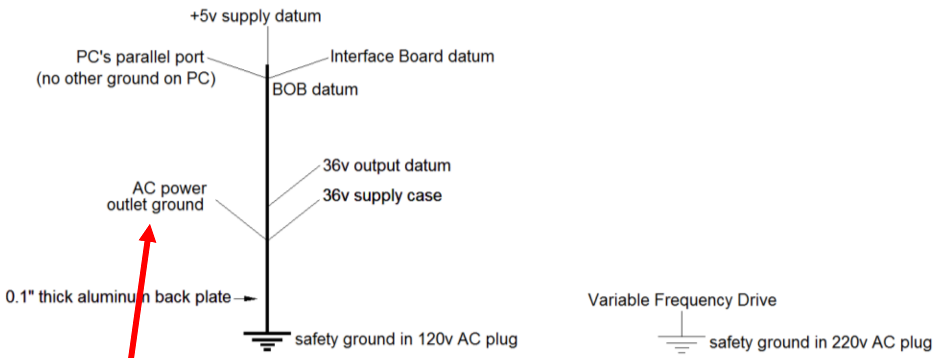
I am assuming that this plate has zero volts across it while it carries any non-fault, low frequency current. I furthermore assume that during a fault, the voltage drop across the plate will be harmless to all electronics that are exposed to it. Any fault current large enough to trip the 120V breaker should not cause a significant voltage drop across this plate. However, if this fault current passed through a circuit tied to the ground, it might fry conductors in that circuit. The goal is to minimize or eliminate such paths.

Starting at the bottom of my tree, you can see my two connections to safety ground. On the left is the green ground wire in the 120v AC power cable. It connects to everything in my enclosure. On the right is the green ground wire that connects to my Variable Frequency Drive.  There is no conductive path between the circuits in my enclosure and my VFD.

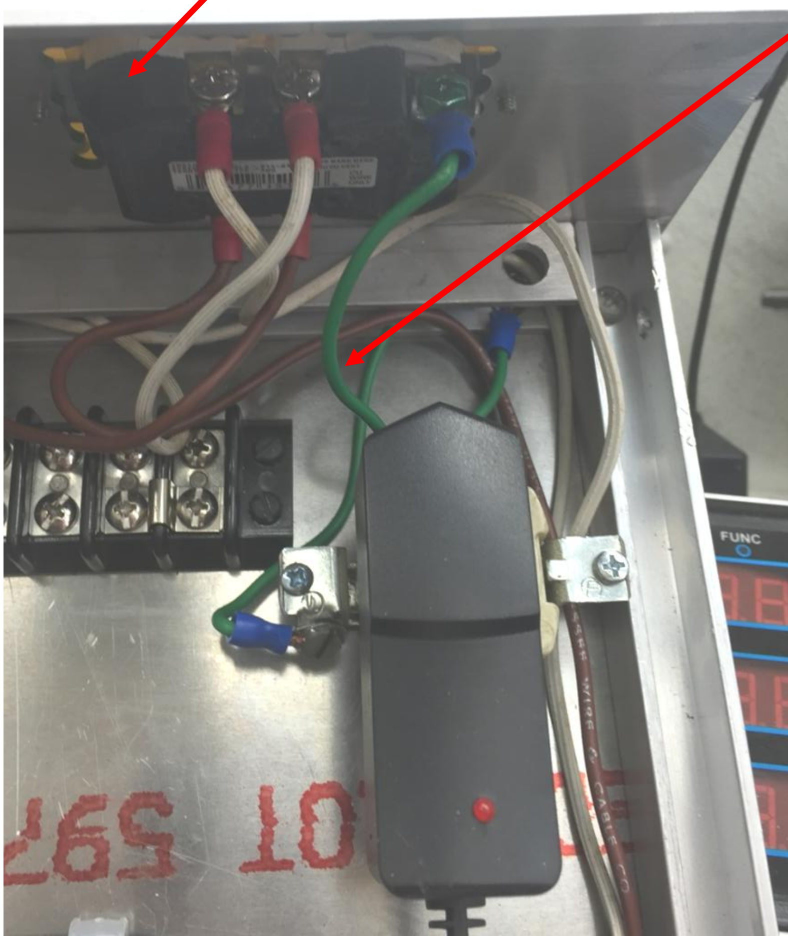


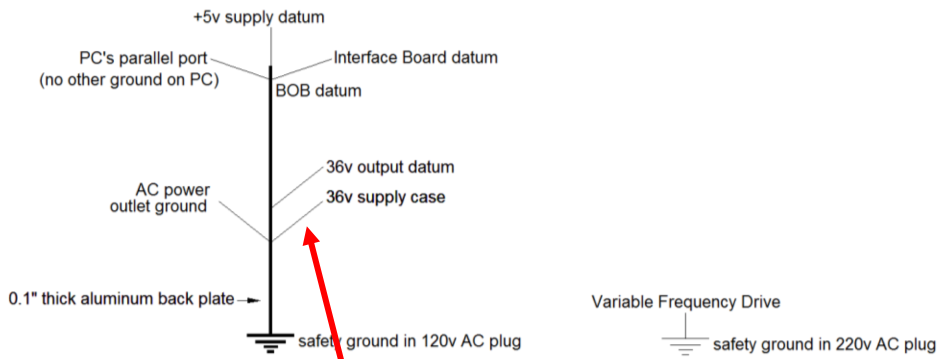



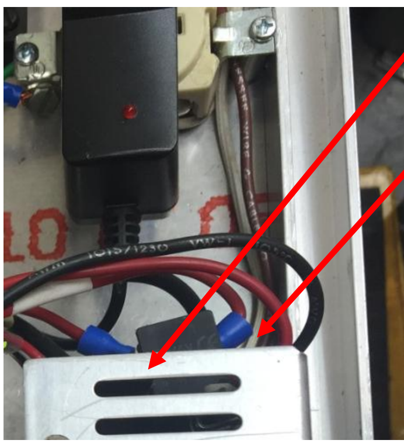
My first ground connection is from the green safety wire (green arrow) to my enclosure. A heavy copper wire is clamped in place with bolts. If AC power faults to the case, I want a solid path for the current to flow until the breaker trips. I do not want the enclosure to ever give me a shock.




My AC power outlet bolt to the case and picks up safety ground through a separate ground wire.

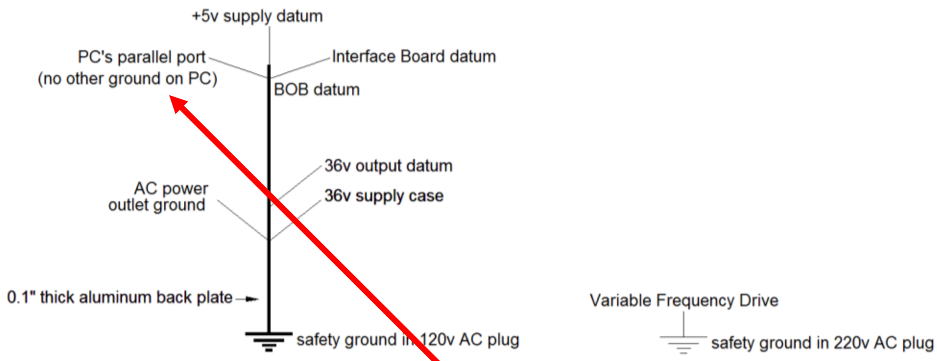


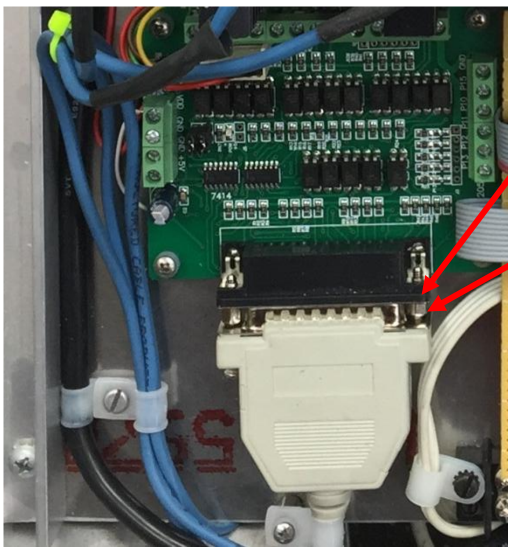


My 36v supply bolts to the enclosure and picks up safety ground.

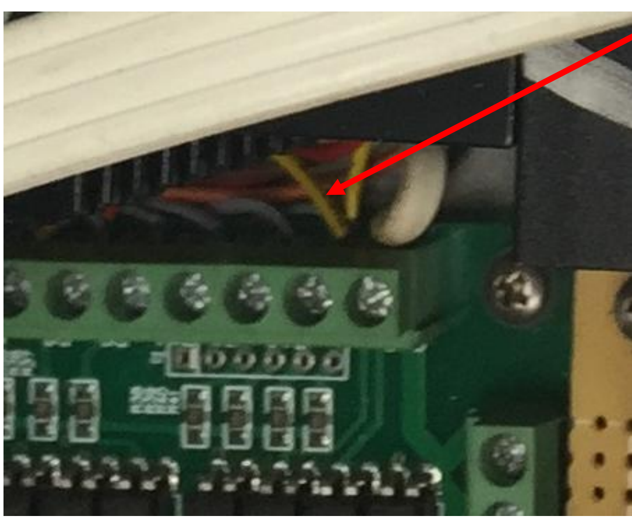
Grounding of the negative output (36v output datum) of this supply is via a wire on its barrier strip.



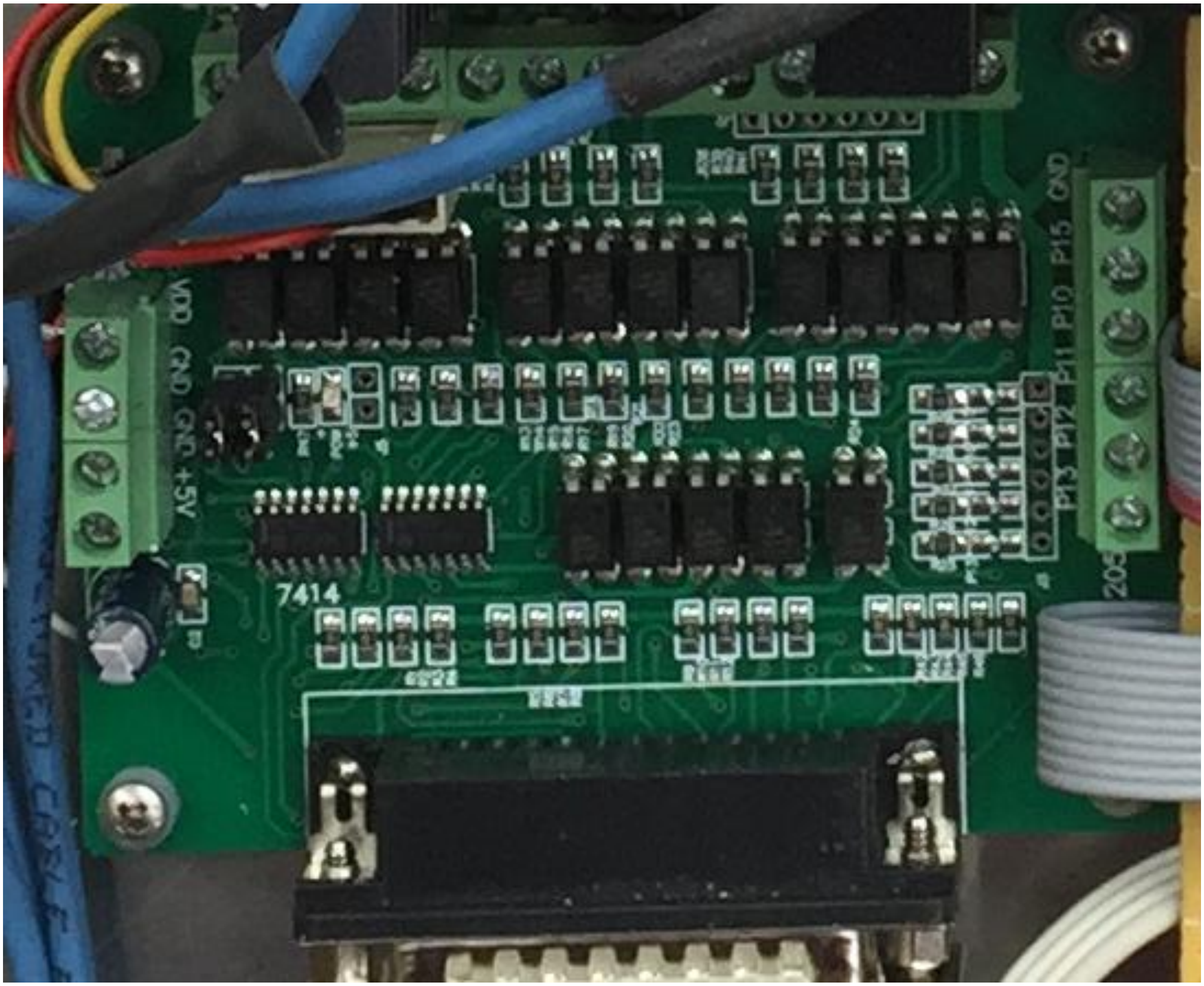
My PC is powered from a supply that does not have ground. This was very fortunate because I was then able to define ground via the PC's parallel port cable.

The parallel port connector is bonded to the BOB's datum.



The BOB is grounded to the case via a single wire.

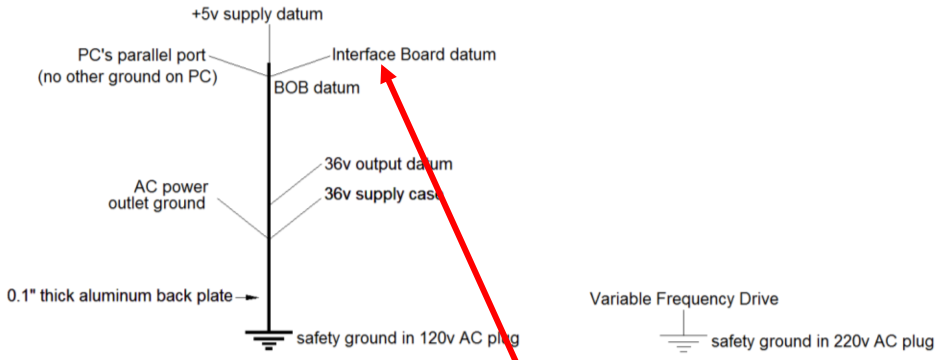
In the case where a circuit fault connects 120V to PC datum, the BOB would likely carry many tens of amps from the parallel port connector to this single ground wire. The BOB datum would then be at a voltage other than zero until the fault cleared. Circuits connected to the BOB use its datum so would not see this change. In no case should this fault current flow into these circuits.

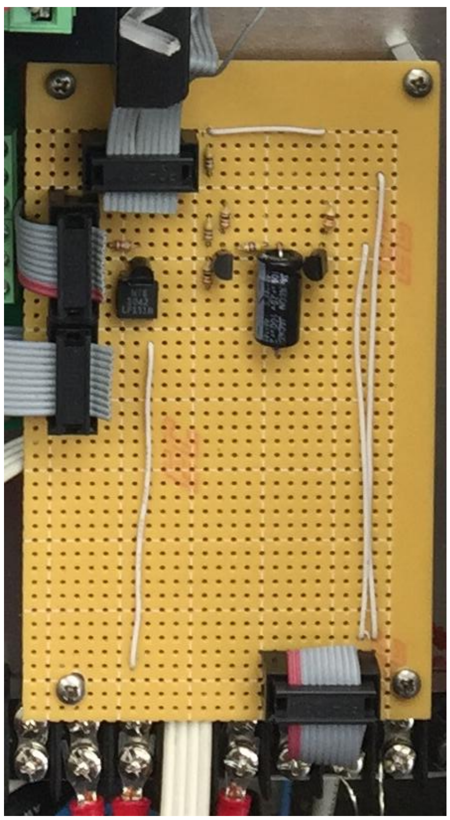



This DB25-1205 BOB must have been designed by someone that did not fully understand its function. Every signal path is blessed with an opto isolator which has the potential of providing excellent isolation between the parallel port and the CNC circuits. Too bad they connected all of the opto isolators to the same ground! They could have saved money and just installed NPN transistors.

This design error was not as serious as it might sound. The motor drivers have their own opto isolators. I did add isolation to the VFD interface but later realized this was not necessary.

5 volt power for the BOB has its return connected directly to the BOB ground.



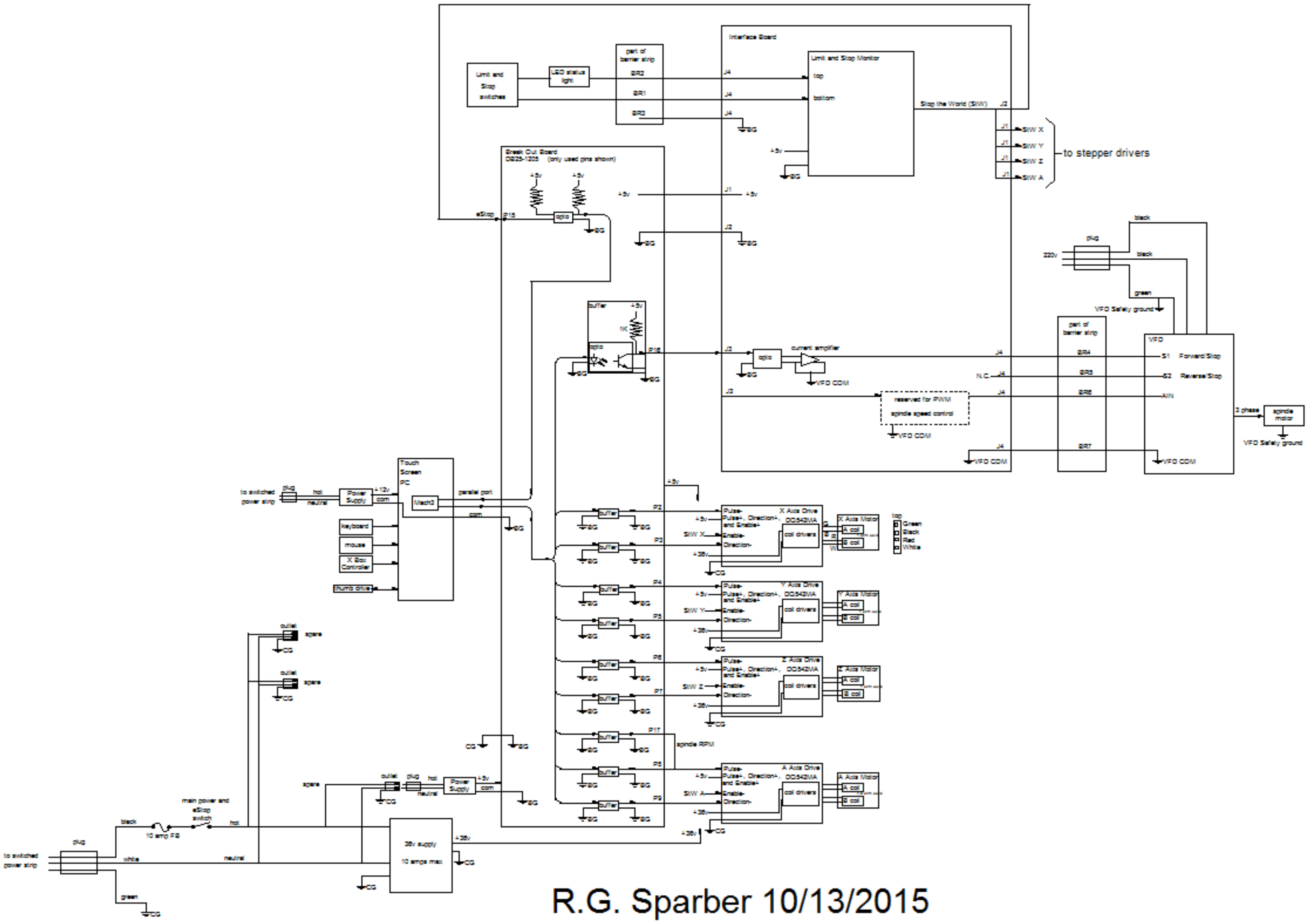
The Interface Board connects to the BOB datum.

By connecting the datums of the various elements in this way, we prevent unwanted ground currents from upsetting and possibly frying circuit.

There is one exception to proper grounding practices which will be explained in the Limit and Stop section.

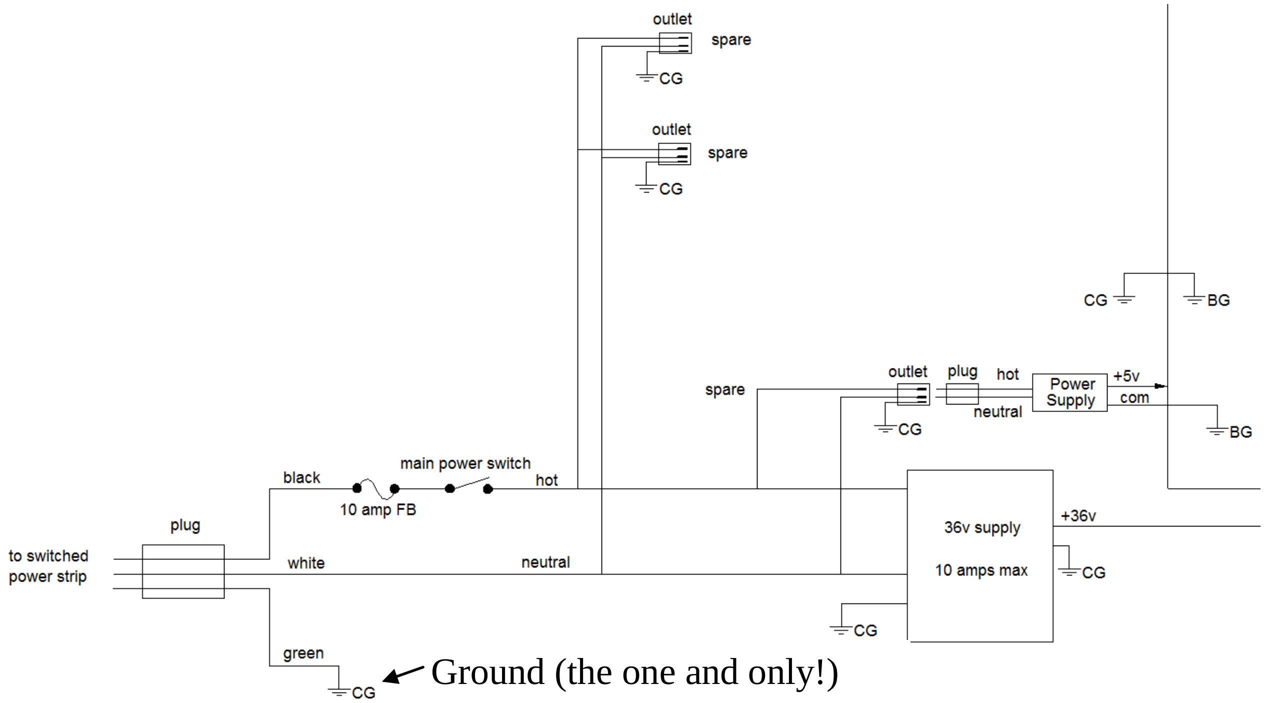
# CNC System Block Diagram

*Overview*




I do realize this diagram is impossible to read. I will zoom in on sections of it but you may want to refer back to this diagram for context.

## *Power*



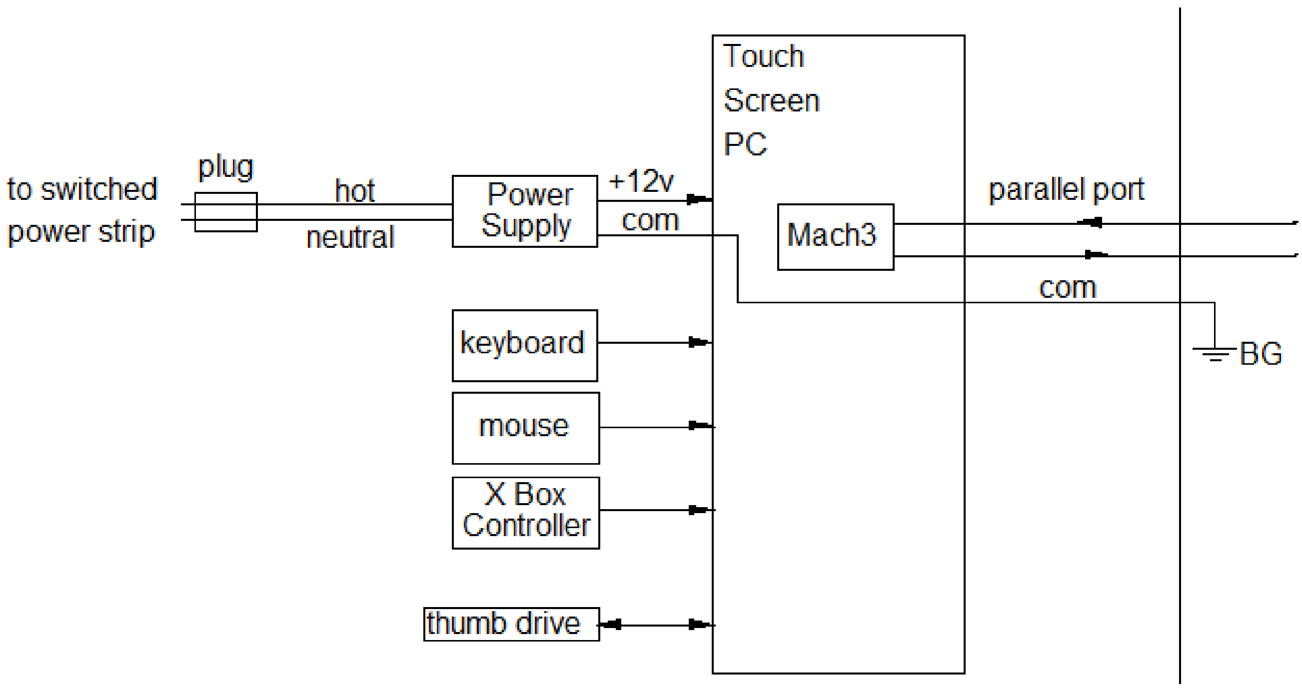

Starting in the lower left corner, we have the AC power cord. Power is first fed through a 10 amp fast blow fuse. A common misconception is that the fuse protects electronics. Fuses take many milliseconds to blow and electronics can be gone in microseconds. So fuses are around 1000 times too slow to protect electronics. Fuses protect wiring with the goal of reducing the chance of a fire while the breaker trips.

Note that the first component in the power chain is the fuse. The connection from black wire in the power cable and the fuse is the only unprotected node in the system. A ground fault there would cause excessive current to flow in the power cable. However, this cable is designed to withstand the surge.

Next comes the main power switch. The AC power feeds the 5v "wall wart" used to run the BOB and my 36v supply which feeds the drivers.

My touch screen PC gets power from an external power strip. This was done because the PC must be powered up and stable before the motors are turned on. Otherwise, random outputs from the PC at start up can cause unpredictable behavior.

*The Personal Computer*




The touch screen PC has no ground connection which lets me define its datum at the BOB Datum (BG).

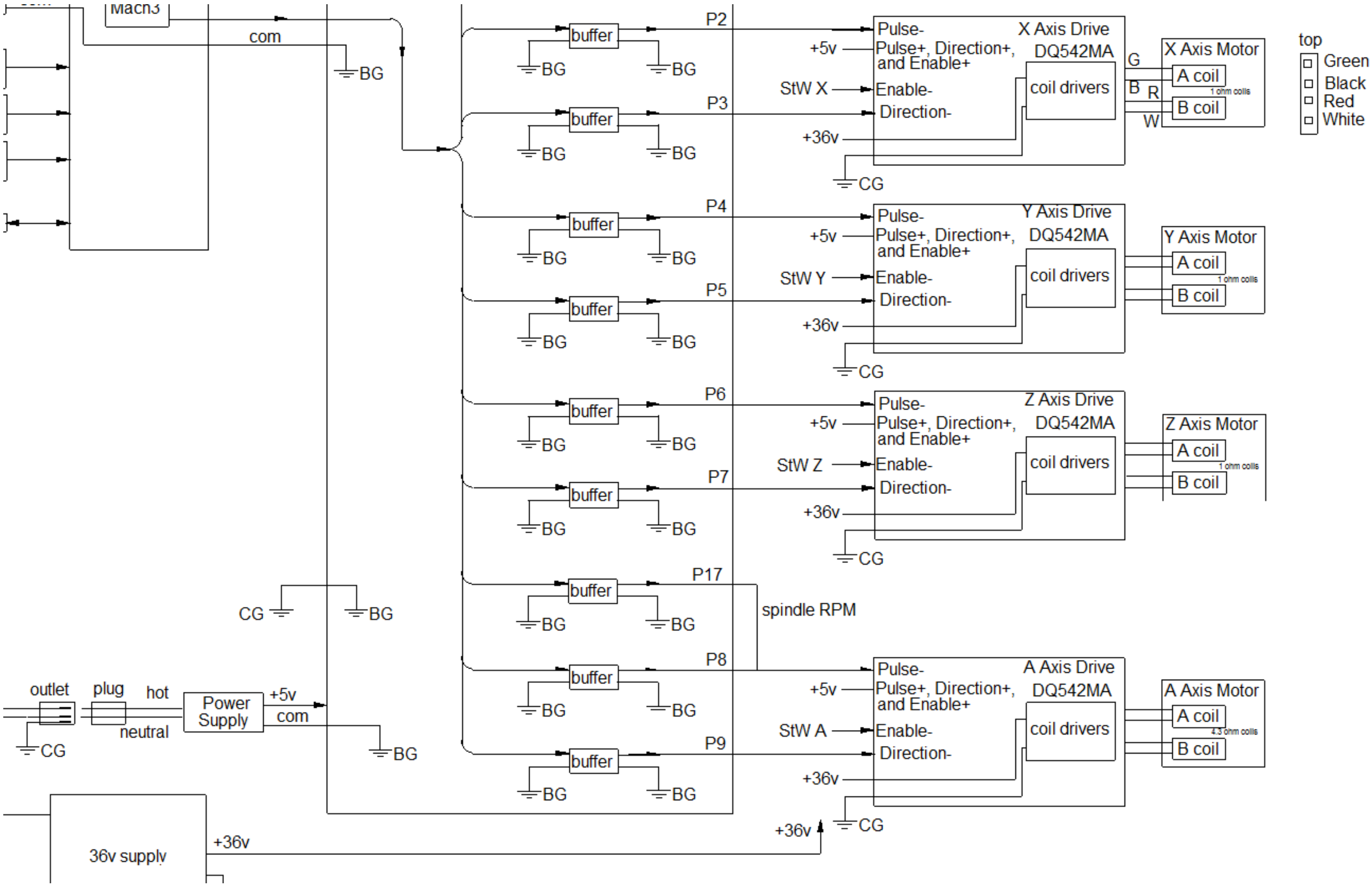
Signals from the PC flow through the parallel port and out to such circuits as the motor drivers. One signal flow from a circuit on the Interface Board, through the parallel port, and into the PC.

In the future I plan to add an electronic edge finder so a second signal will flow from the Interface Board to the PC.

I can control the PC with a keyboard, optical mouse, and an X Box Controller. This controller lets me move joy sticks to move all axes, set zero on the X, Y, or Z axes, plus control the spindle motor.

G-code programs are generated in my home PC and stored on a thumb drive. I then plug the thumb drive into the shop PC. This eliminates direct internet access to my shop PC.

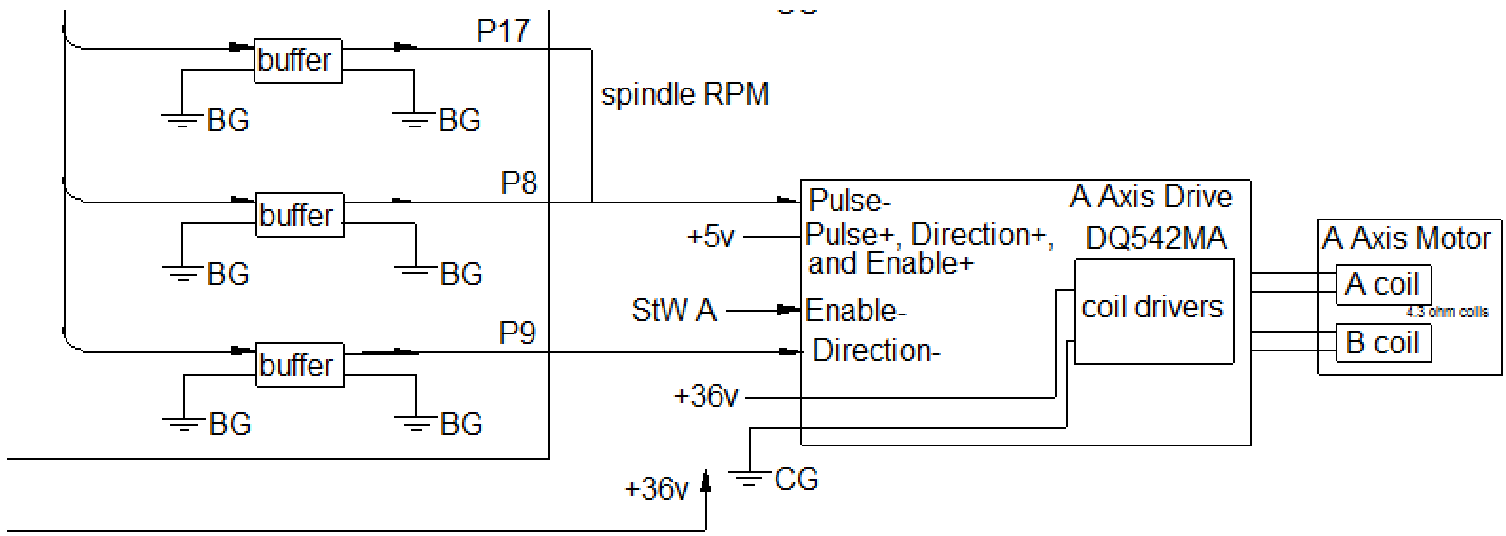
## X, Y, Z, and A Axis Signals




Here are the majority of the signals flowing from the PC. The label "P" followed by a number is the pin number within the parallel port on the BOB.

Each axis drive needs a pulse stream to set the RPM of the stepper motor and a direction signal. There is also an Enable signal which will turn off the driver when current flows through it. This signal comes from hardware and is not dependent on the sanity of the software. In this way I can kill all stepper motors even when the software goes insane.

These control signals are optically isolated from the coil driver circuit. This enables me to reference the control signals to BOB Ground and the coil power to Ground (CG).




The A axis is driven from two BOB outputs. P8 and P9 are similar to the other axes. They provide pulses and direction. But I have also wired P17, spindle RPM, to the pulse input of the drive.

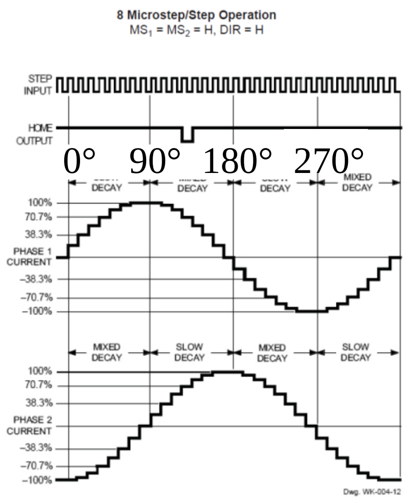
Using g-codes, I am able to both index the A axis and have it freely turning at a specified rate. After I issue a "S0" (S zero) command, I can specify an "Addd" command where ddd is the number of degrees to move. For example, if we start at zero, A156 rotates the A axis clockwise 156°. A-156 moves it back to the starting point.

When I want to turn the A axis continuously, I first set its direction with the A command. Then I specify the rotational speed with the S command. At the present time, S2336 gives me 1 RPM. I hope to change this so S10 gives me 1.0 RPM. The A axis starts to turn when the spindle's motor is turned on via the M3 command. Both turn off with the M5 command.

# DQ542MA Microstep Driver

The X, Y, and Z drivers are configured to output 2.84 amps peak and produce 1600 pulses per revolution. When the motor is not being turned, the current is lowered to 1.42 amps. (dip switch set to [SW1-SW8]  11000011)

Looking at the spec sheet, I see a maximum input current of less than 4 amps and an output current of 1 to about 4.2 amps. This tells me that the output current must be total current and not current per coil.




Looking at a typical pair of coil signals, I see that they are offset from each other by 90°.

At 0° the sum is 0 - I = -I where I is the current limit.

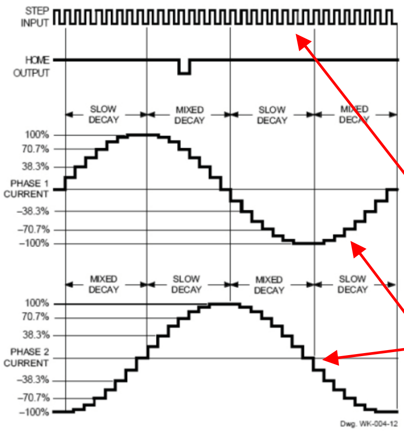
At 90° the sum is I + 0 = I. At 180° we are at 0 + I = I and at 270° we are at -I + 0 = -I. The magnitude of the current never exceeds I.

The A driver is configured to output 1.46 amps peak while turning the stepper.

When the motor is not being turned, the current is cut in half so is 0.73 amps. (dip switch set to [SW1-SW8]  01100011)

If all 4 axes moved at the same time, the peak current could be as large as 2.84 amps × 3 motors + 1.46 amps = 10 amps. However, only two axes move at the same time while the others are at idle. This gives us a peak current of 2.84 amps × 2 motors + 1.42 amps + 0.72 amps  = 7.8 amps. In either case, the 36 volt 10 amp power supply can handle the load.

# Stepper Motors

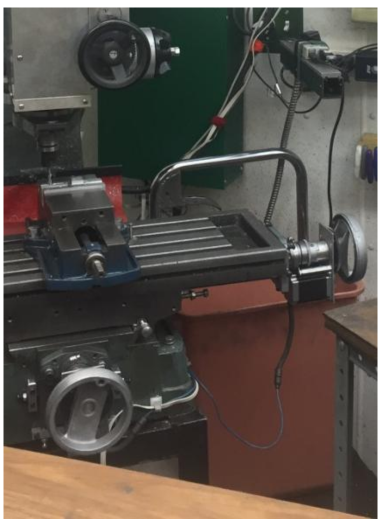



I found the explanation of stepper motors at https://en.wikipedia.org/wiki/Stepper_motor#cite_note-5 very helpful.

A very basic fact not so clear to me in this Wiki entry is that the faster you send pulses into the driver, the faster the stepper turns.

The signals into the two stepper coils do not change shape, they just take less time to repeat.

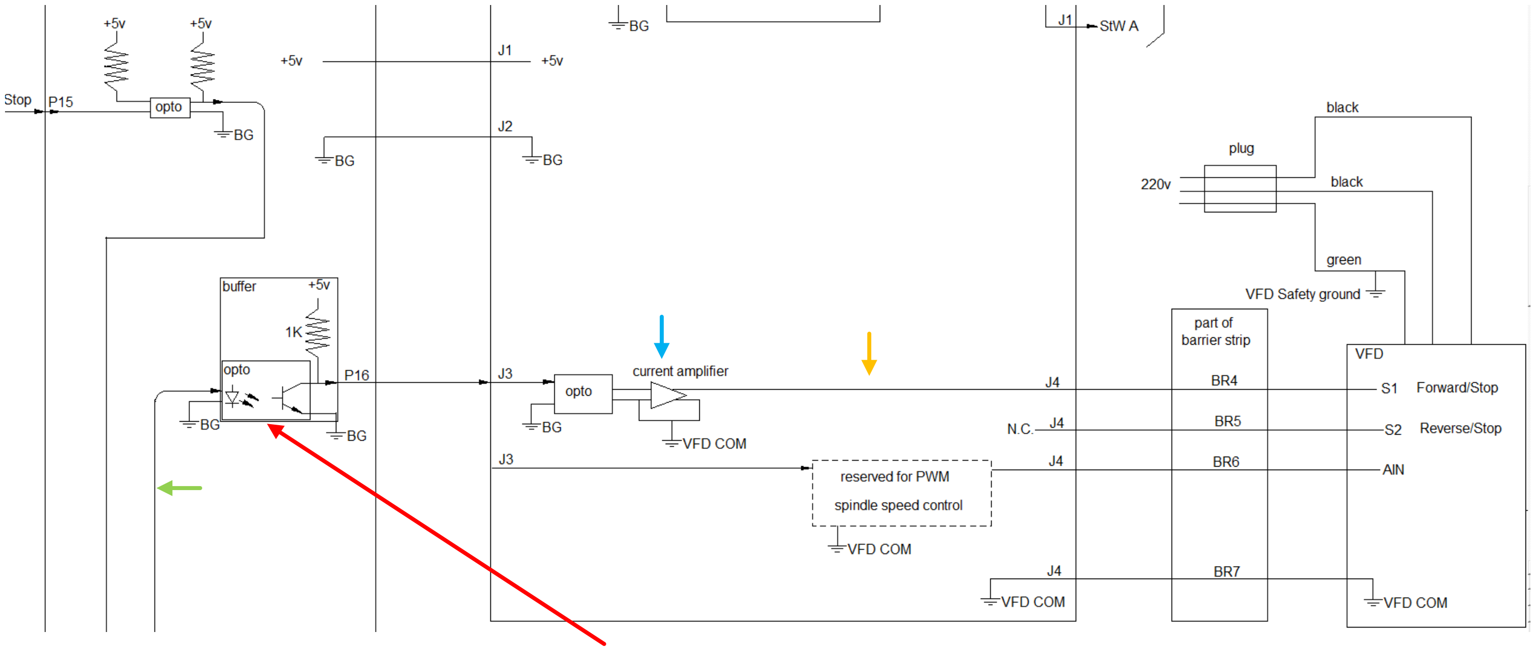
To see how stepper motors are incremented by a specified number of degrees, I recommend http://electronics.stackexchange.com/questions/70643/how-to-reverse-rotation-direction-of-stepper-motor



The X, Y, and Z stepper motors have a coil resistance of 1 ohm. Averaged over time, the output current is evenly split between the two coils. The driver is set to output a peak of 1.42 amps per coil. The power dissipation per coils is ***no more*** than $I^2R = (1.42)^2(1) = 2\, watts$. Since we have two coils, total dissipation is ***no more*** than 4 watts per motor. When at idle, total dissipation is about 0.5 watts.

The A stepper motor has a coil resistance of 4.3 ohms. Since the driver is set to output a peak of 1.46 amps, the current per coil is 0.73 amps. The power dissipation per coils is no more than $I^2R = (0.73)^2(4.3) = 2.3\, watts$. Since we have two coils, total dissipation is no more than 4.6 watts per motor. When at idle, total dissipation is no more than 1.1 watts.

## Spindle Motor Control




Note that I have labeled each opto isolator as a buffer. This was done to emphasis that there is no isolation in the BOB.


At the present time, there is one more output from the PC. It controls the Variable Frequency Drive (VFD) which powers my spindle motor. When an M3 g-code is encountered, an output (green arrow) of the PC goes to a logic high. That causes current to flow into an opto on the Interface Board. The output of this opto feeds a current amplifier (blue arrow). This amplifier pulls a control line on the VFD down from about +24v to about +1v (orange arrow). The VFD responds by driving the spindle motor in a clockwise direction.

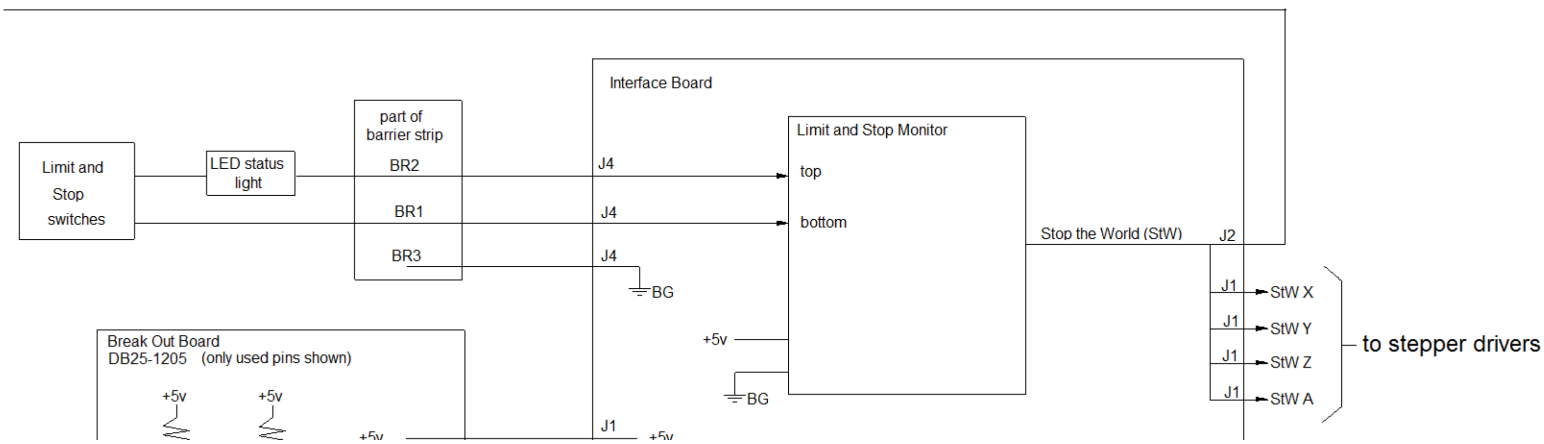
I have partially wired the ability to cause the VFD to drive the spindle motor in a counterclockwise direction (BR5) but do not have a need at this time. I could have added the ability to control the RPM of this motor via g-code (BR6). However, I have since stolen this signal to drive the A axis as explained on page 18.

Details of the current amplifier will be presented later.

When I designed this interface, I assumed that VFD COM was tied to VFD ground so used isolation to protect my circuits. I later measured the resistance between these two datum and discovered they are not connected so the isolation on the Interface Board is not needed.

# Limit and Stop

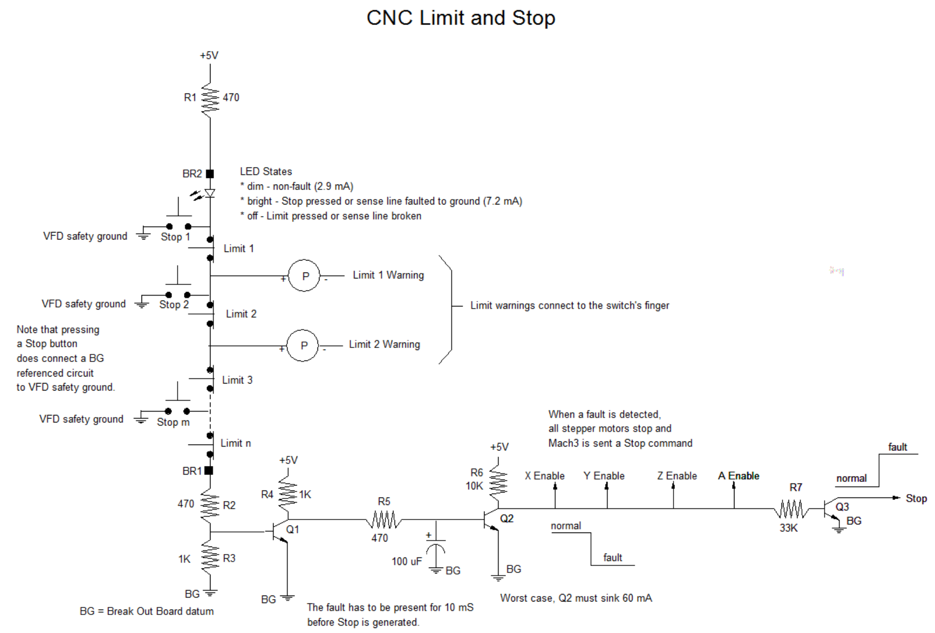
*Overview*




The one path from the hardware to the PC carries the Stop the World (StW) signal. I generate this signal in the Limit and Stop Monitor. More on this later.

Not shown is the eStop circuit. All AC power passes through this circuit. When the eStop button is pushed, all power except that to the PC is removed. eStop is only engaged when there is risk to either machine or people.

## *Circuit Description*




If any stop switch is toggled or a limit switch hit, all motors turn off and Mach3 is told to stop. The same thing happens if our alarm wire either breaks or is shorted to ground. Note that I do not involve the software in stopping the motors.

Lets walk thorough all known hardware and software fault conditions and how the circuit handles them:

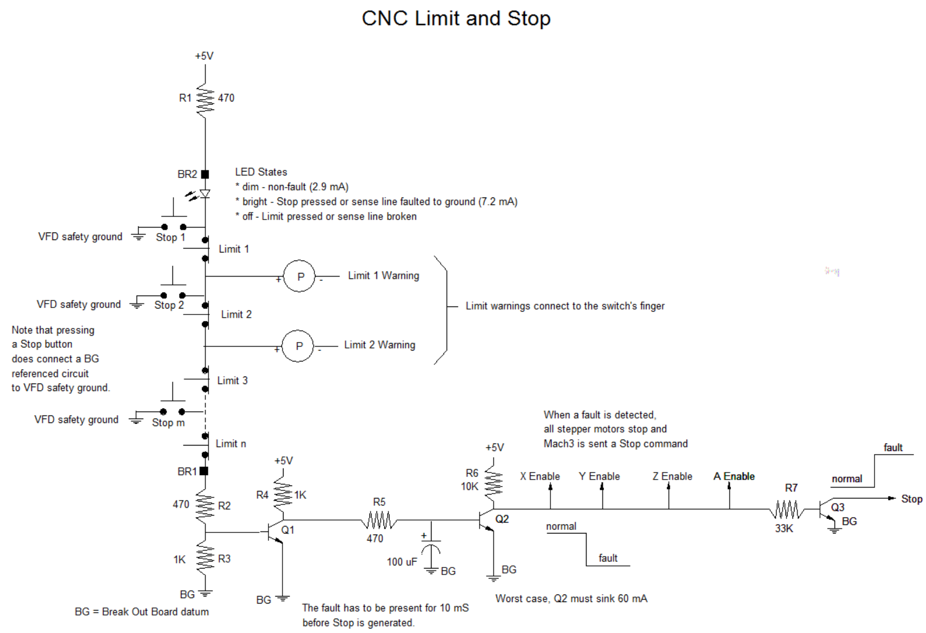
1. Hardware has no faults, software is sane, g-code is wrong: a drive hits a limit and all motors stop due to hardware only shut down of all motors.

2. Hardware has no faults, software goes insane: drive hits a limit and all stepper motors stop due to hardware only shut down of all motors. The spindle may keep turning.

3. Software is sane. Hardware has a fault that causes a drive to hit a limit: all stepper motors stop due to hardware only shut down of all motors. Mach3 turns off the spindle.

4. Hardware has a double fault that causes a drive to hit a limit but the limit switch does not detect the collision: on my machine the drive will miss steps; no guarantee that the spinning cutter won't cause damage. Since I will be sitting at the machine, I can minimize damage by turning off power to both the drives and spindle motor via the eSTOP button.

Next we will look at how the circuit works and how hardware faults are handled.

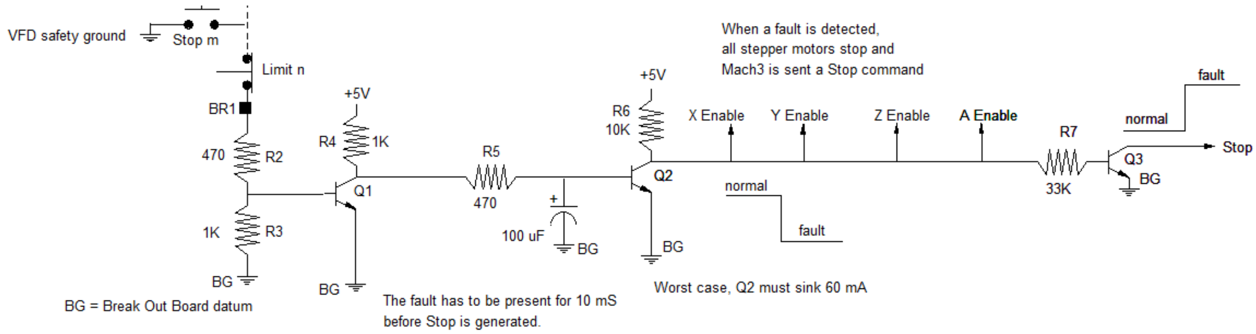



This circuit enables me to run a single wire through all limit and Stop switches. If any limit switch or Stop toggle switch is hit, all stepper motors turns off and the software is sent a Stop signal. This shutdown of the steppers does not depend on the software to be sane.

The circuit also detects physical faults to this single wire. If the wire breaks, all will be shut down. If the wire shorts to "ground", all will be shut down. The most likely "ground" that will contact the wire is the VFD Safety ground. This ground is bonded to the body of the mill/drill. An LED indicates if the alarm wire is OK, broken, or shorted.

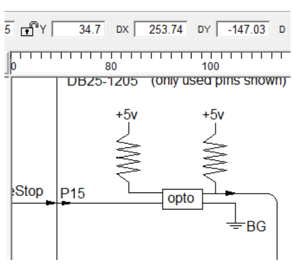
I chose to kill all axis motors if any limit switch is hit because I figure more damage could be done if the (possibly insane) software moved a remaining active axis when one hit a limit.

Optionally, I can attach piezoelectric beepers (circles with P inside) to the micro switch fingers. They will sound before the switch operates to give an early warning of being too close.




Note that I have individual wires from the collector of Q2 to each axis Enable. If I later decide I want to disable only one axis driver without killing the rest or causing a Stop signal to be sent to Mach3, I can add isolation diodes on the Interface Board. There are spare pins in its connectors.

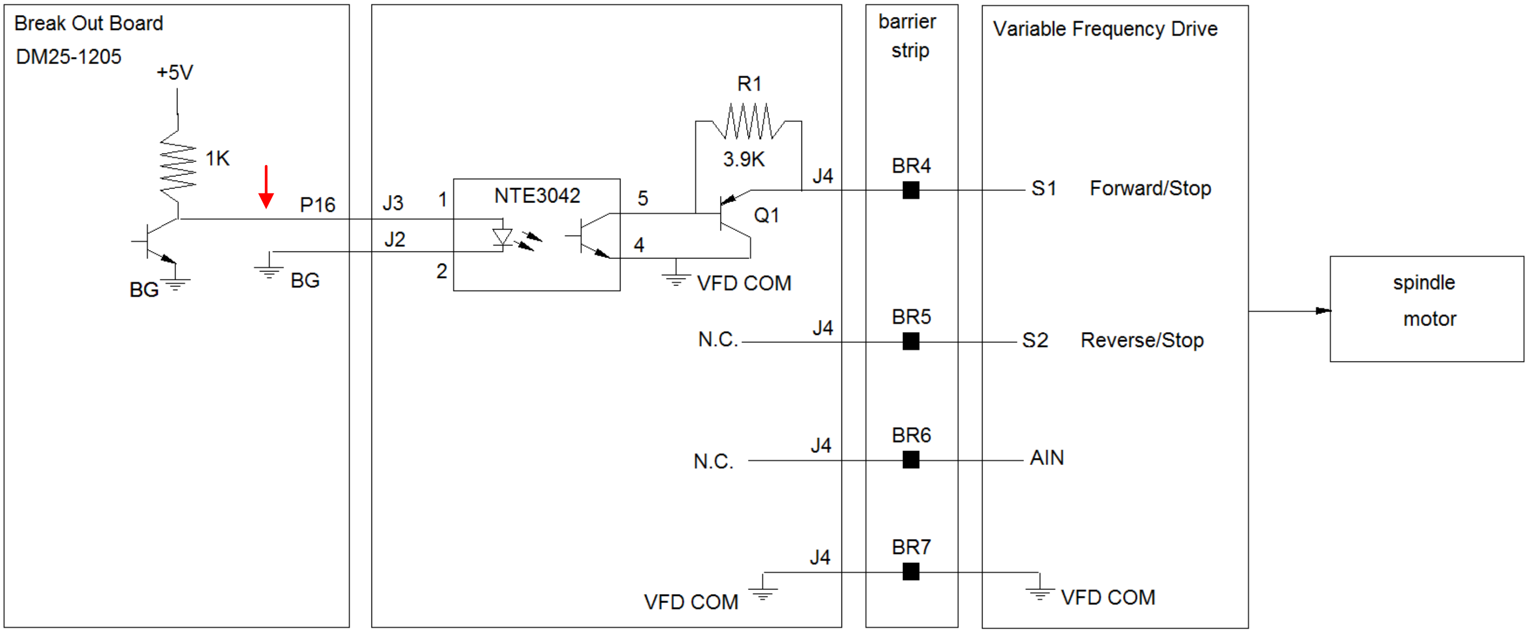
Resistors R4, R5, and the 100 u*f* capacitor provide noise immunity. Any limit or Stop signal less than about 10 milliseconds will be ignored. Experience will tell me if this is enough filtering.




Resistor R7 and Q3 invert the alarm signal so that under normal conditions we present a normally closed Stop signal to the BOB's P15. Originally I ran without this inverter so had normally open. Noise getting into the cable between the BOB and the PC ***could*** pull the line low and give a false stop signal. I never saw this situation but decided to be on the safe side. R7 was chosen to give plenty of drive to Q3 without causing any of the stepper motor drives to see a disable signal.

Note that this shut down circuit does not kill the spindle motor. At the present time only Mach3 and the eStop circuit can do that. Given a software failure, I figure that stopping all X,Y, Z, and A movement is enough. No need to automatically stop rotation. Time will tell if I am right.

# The VFD Interface Circuit




When the software in the PC processes an M3 g-code, pin 16 in the parallel port goes high. That causes P16 (red arrow) to rise relative to BG until the diode in the NTE3042 opto conducts. The resulting light from this diode shines on a phototransistor causing pin 5 to fall from about +24v down to about +0.2v. As current flows out of the VFD drive via barrier strip terminal BR4, a voltage is first developed across R1. When about $\frac{0.65v}{3.9K} = 0.2\ mA$ flows, Q1 turns on and pulls BR4 down to about +1v. That is good enough to cause a valid Forward command to appear at VFD pin S1. The spindle motor runs clockwise. Without this current amplifier, the opto was only able to pull S1 down to about +15v and that wasn't low enough to start the motor.

When the software processes an M5 g-code, pin 16 goes low. This turns off the NTE3042 opto which halts current flowing from S1. The VFD stops the spindle motor from turning.

If implemented, Reverse/Stop would work the same way using a second NTE3042 opto and PNP transistor.

The AIN (Analog IN) input is able to accept a DC voltage that can control the spindle motor's RPM. The software can generate a Pulse Width Modulated signal which would be fed through yet another NTE3042, be filtered by a yet to be added circuit, and present the proper DC voltage to the AIN pin.

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Thanks to "Druid Noibn" for seeing that my AC outlets were not grounded correctly. They are now.

Thanks to Dan Mauch for explaining to me that the 36v stepper motor power should be point to point and not daisy chained. Fixed now.

Thanks to Andy Wander to helping me to improve the Limit and Stop circuit. It isn't bullet proof yet but has certainly been improved.

Thanks to Brenden (from the UK) and Jeff Birt for helping me understand what was missing from the Limit and Stop circuit.

I welcome your comments and questions.

If you wish to be contacted each time I publish an article, email me with just "Article Alias" in the subject line.

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